THE UNIVERSITY OF CHICAGO
THE LAW SCHOOL
Abrams Environmental
Law Clinic

September 12, 2024

Via E-Filing

Ms. Lisa Felice
Executive Secretary
Michigan Public Service Commission
7109 West Saginaw Highway
Lansing, MI 48917

RE: MPSC Case No. U-21534

Dear Ms. Felice:

Please find enclosed the Official Exhibits DAO-264 to DAO-277 sponsored by Arjun Makhijani (Part 8 of 10) on Behalf of Soulardarity and We Want Green, Too, along with proof of service for electronic filing in the above-referenced matter. Please do not hesitate to contact me with any questions or comments.

Sincerely,

Mark N. Templeton, *pro hac vice*
6020 S. University Avenue
Chicago, IL 60637
Phone: (773) 702-9611
Email: templeton@uchicago.edu

xc: Parties to Case No. U-21534

UNITED STATES SECURITIES AND EXCHANGE COMMISSION

Washington, D.C. 20549

FORM 10-K

☒ ANNUAL REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934

For the Fiscal Year Ended December 31, 2023

Or

☐ TRANSITION REPORT PURSUANT TO SECTION 13 OR 15(d) OF THE SECURITIES EXCHANGE ACT OF 1934

For the transition period from _____ to _____



Commission File Number: 1-11607

DTE Energy Company

Michigan	**38-3217752**
(State or other jurisdiction of incorporation or organization)	(I.R.S Employer Identification No.)

Commission File Number: 1-2198

DTE Electric Company

Michigan	**38-0478650**
(State or other jurisdiction of incorporation or organization)	(I.R.S Employer Identification No.)

Registrants address of principal executive offices: One Energy Plaza, Detroit, Michigan 48226-1279

Registrants telephone number, including area code: (313) 235-4000

Securities registered pursuant to Section 12(b) of the Act:

Registrant	Title of Each Class	Trading Symbol(s)	Name of Exchange on which Registered
DTE Energy Company (DTE Energy)	Common stock, without par value	DTE	New York Stock Exchange
DTE Energy	2017 Series E 5.25% Junior Subordinated Debentures due 2077	DTW	New York Stock Exchange
DTE Energy	2020 Series G 4.375% Junior Subordinated Debentures due 2080	DTB	New York Stock Exchange
DTE Energy	2021 Series E 4.375% Junior Subordinated Debentures due 2081	DTG	New York Stock Exchange
DTE Electric Company (DTE Electric)	None		None

Securities registered pursuant to Section 12(g) of the Act:

DTE Energy **None** **DTE Electric** **None**

Indicate by check mark if the registrant is a well-known seasoned issuer, as defined in Rule 405 of the Securities Act.

DTE Energy **Yes** ☒ **No** ☐ **DTE Electric** **Yes** ☒ **No** ☐

Indicate by check mark if the registrant is not required to file reports pursuant to Section 13 or Section 15(d) of the Act.

DTE Energy **Yes** ☐ **No** ☒ **DTE Electric** **Yes** ☐ **No** ☒

Indicate by check mark whether the registrant (1) has filed all reports required to be filed by Section 13 or 15(d) of the Securities Exchange Act of 1934 during the preceding 12 months (or for such shorter period that the registrant was required to file such reports), and (2) has been subject to such filing requirements for the past 90 days.

DTE Energy **Yes** ☒ **No** ☐ **DTE Electric** **Yes** ☒ **No** ☐

Indicate by check mark whether the registrant has submitted electronically every Interactive Data File required to be submitted pursuant to Rule 405 of Regulation S-T during the preceding 12 months (or for such shorter period that the registrant was required to submit such files).

DTE Energy **Yes** ☒ **No** ☐ **DTE Electric** **Yes** ☒ **No** ☐

Indicate by check mark whether the registrant is a large accelerated filer, an accelerated filer, a non-accelerated filer, a smaller reporting company, or an emerging growth company. See the definitions of "large accelerated filer," "accelerated filer," "smaller reporting company," and "emerging growth company" in Rule 12b-2 of the Exchange Act.

	Large accelerated filer	Accelerated filer	Non-accelerated filer	Smaller reporting company	Emerging growth company
DTE Energy	☒	☐	☐	☐	☐
DTE Electric	☐	☐	☒	☐	☐

If an emerging growth company, indicate by check mark if the registrant has elected not to use the extended transition period for complying with any new or revised financial accounting standards provided pursuant to Section 13(a) of the Exchange Act. ☐

Indicate by check mark whether the registrant has filed a report on and attestation to its management's assessment of the effectiveness of its internal control over financial reporting under Section 404(b) of the Sarbanes-Oxley Act (15 U.S.C. 7262(b)) by the registered public accounting firm that prepared or issued its audit report.

DTE Energy **Yes** ☒ **No** ☐ **DTE Electric** **Yes** ☐ **No** ☒

If securities are registered pursuant to Section 12(b) of the Act, indicate by check mark whether the financial statements of the registrant included in the filing reflects the correction of an error to previously issued financial statements.

DTE Energy ☐ **DTE Electric** ☐

Indicate by check mark whether any of those error corrections are restatements that required a recovery analysis of incentive based compensation received by any of the registrants' executive officers during the relevant recovery period pursuant to §240.10D-1(b).

DTE Energy ☐ **DTE Electric** ☐

Indicate by check mark whether the registrant is a shell company (as defined in Rule 12b-2 of the Act).

DTE Energy **Yes** ☐ **No** ☒ **DTE Electric** **Yes** ☐ **No** ☒

On June 30, 2023, the aggregate market value of DTE Energy's voting and non voting common equity held by non-affiliates was approximately $22.6 billion (based on the New York Stock Exchange closing price on such date).

Number of shares of Common Stock outstanding at January 31, 2024:

Registrant	Description	Shares
DTE Energy	Common Stock, without par value	206,452,985
DTE Electric	Common Stock, $10 par value, indirectly-owned by DTE Energy	138,632,324

DOCUMENTS INCORPORATED BY REFERENCE

Certain information in DTE Energy's definitive Proxy Statement for its 2024 Annual Meeting of Common Shareholders to be held May 2, 2024, which will be filed with the Securities and Exchange Commission pursuant to Regulation 14A, not later than 120 days after the end of the Registrants' fiscal year covered by this report on Form 10-K, is incorporated herein by reference to Part III (Items 10, 11, 12, 13, and 14) of this Form 10-K.

This combined Form 10-K is filed separately by two registrants: DTE Energy and DTE Electric. Information contained herein relating to any individual registrant is filed by such registrant solely on its own behalf. DTE Electric makes no representation as to information relating exclusively to DTE Energy.

DTE Electric, an indirect wholly-owned subsidiary of DTE Energy, meets the conditions set forth in General Instructions I(1)(a) and (b) of Form 10-K and is therefore filing this form with the reduced disclosure format specified in General Instruction I(2) of Form 10-K.

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Part I

Items 1. and 2. ***Business and Properties***

General

In 1995, DTE Energy incorporated in the State of Michigan. DTE Energy's utility operations consist primarily of DTE Electric and DTE Gas. DTE Energy also has two other segments that are engaged in a variety of energy-related businesses.

DTE Electric is a Michigan corporation organized in 1903 and is an indirect wholly-owned subsidiary of DTE Energy. DTE Electric is a public utility engaged in the generation, purchase, distribution, and sale of electricity to approximately 2.3 million customers in southeastern Michigan.

DTE Gas is a Michigan corporation organized in 1898 and is an indirect wholly-owned subsidiary of DTE Energy. DTE Gas is a public utility engaged in the purchase, storage, transportation, distribution, and sale of natural gas to approximately 1.3 million customers throughout Michigan and the sale of storage and transportation capacity.

DTE Energy's other businesses include 1) DTE Vantage which is primarily involved in renewable natural gas projects and providing custom energy solutions to industrial, commercial, and institutional customers, and 2) energy marketing and trading operations.

DTE Electric and DTE Gas are regulated by the MPSC. Certain activities of DTE Electric and DTE Gas, as well as various other aspects of businesses under DTE Energy, are regulated by the FERC. In addition, the Registrants are regulated by other federal and state regulatory agencies including the NRC, the EPA, EGLE, and for DTE Energy, the CFTC and CARB.

The Registrants' annual reports on Form 10-K, quarterly reports on Form 10-Q, current reports on Form 8-K, proxy statements, and all amendments to such reports are available free of charge through the Investor Relations SEC Filings page of DTE Energy's website: *www.dteenergy.com*, as soon as reasonably practicable after they are filed with or furnished to the SEC.

The DTE Energy Code of Ethics and Standards of Behavior, Board of Directors' Mission and Guidelines, Board Committee Charters, and Categorical Standards for Director Independence are also posted on the DTE Energy website. The information on DTE Energy's website is not part of this report or any other report that DTE Energy files with, or furnishes to, the SEC.

Additionally, the public may read and copy any materials the Registrants file electronically with the SEC at *www.sec.gov*.

Corporate Structure

DTE Energy sets strategic goals, allocates resources, and evaluates performance based on the following structure. For financial information by segment for the last three years, see Note 22 to the Consolidated Financial Statements, "Segment and Related Information."

Electric

- The Electric segment consists principally of DTE Electric, which is engaged in the generation, purchase, distribution, and sale of electricity to approximately 2.3 million residential, commercial, and industrial customers in southeastern Michigan.

Gas

- The Gas segment consists principally of DTE Gas, which is engaged in the purchase, storage, transportation, distribution, and sale of natural gas to approximately 1.3 million residential, commercial, and industrial customers throughout Michigan and the sale of storage and transportation capacity.

Non-utility Operations

- DTE Vantage is comprised primarily of renewable energy projects that sell electricity and pipeline-quality gas and projects that deliver custom energy solutions to industrial, commercial, and institutional customers.
- Energy Trading consists of energy marketing and trading operations.

UNDERSTANDING EVICTION IN

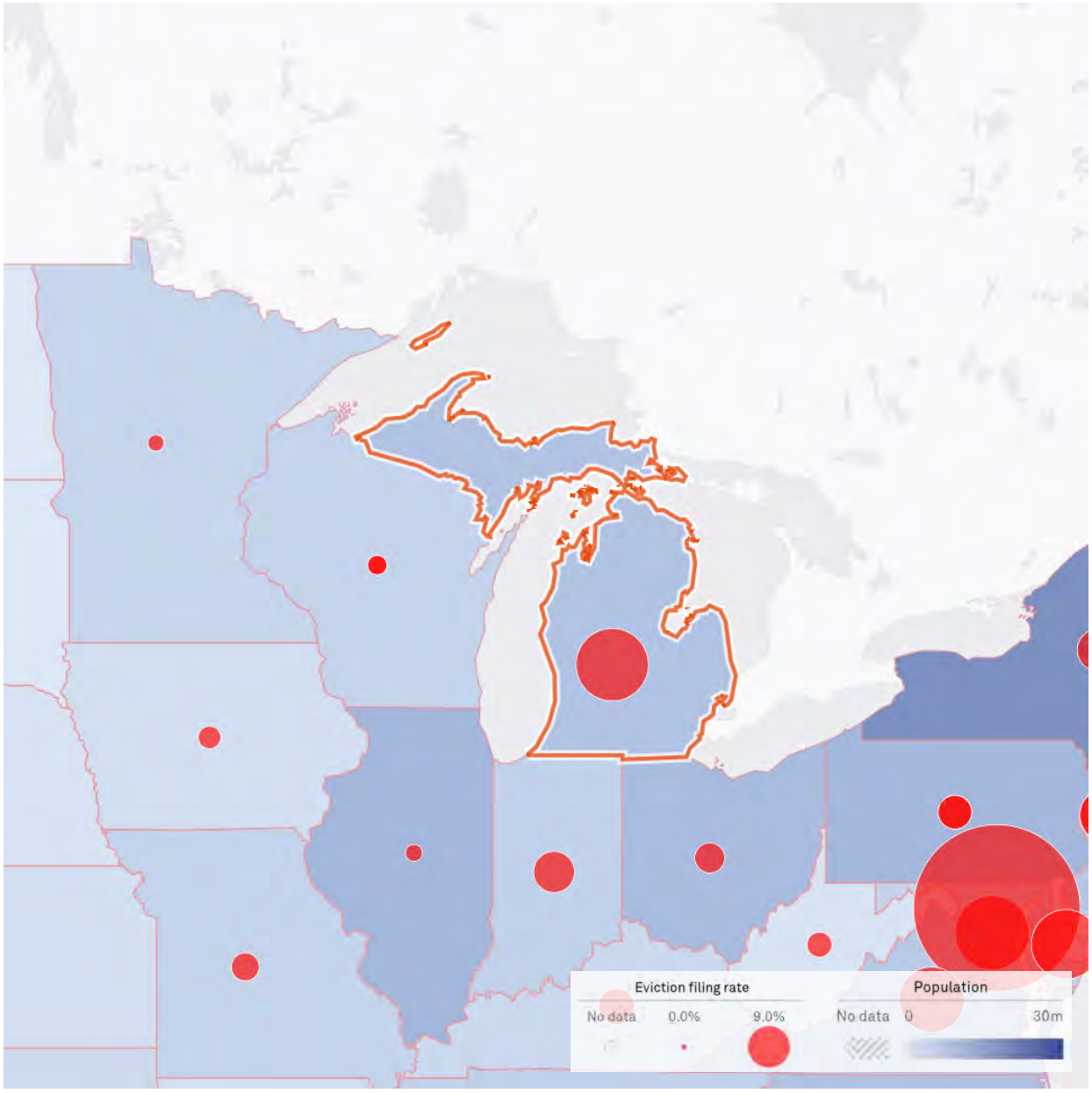
MICHIGAN

A presentation generated by The Eviction Lab at Princeton University

Data extracted on 2024-07-20

For further information, visit evictionlab.org

EVICTION LAB

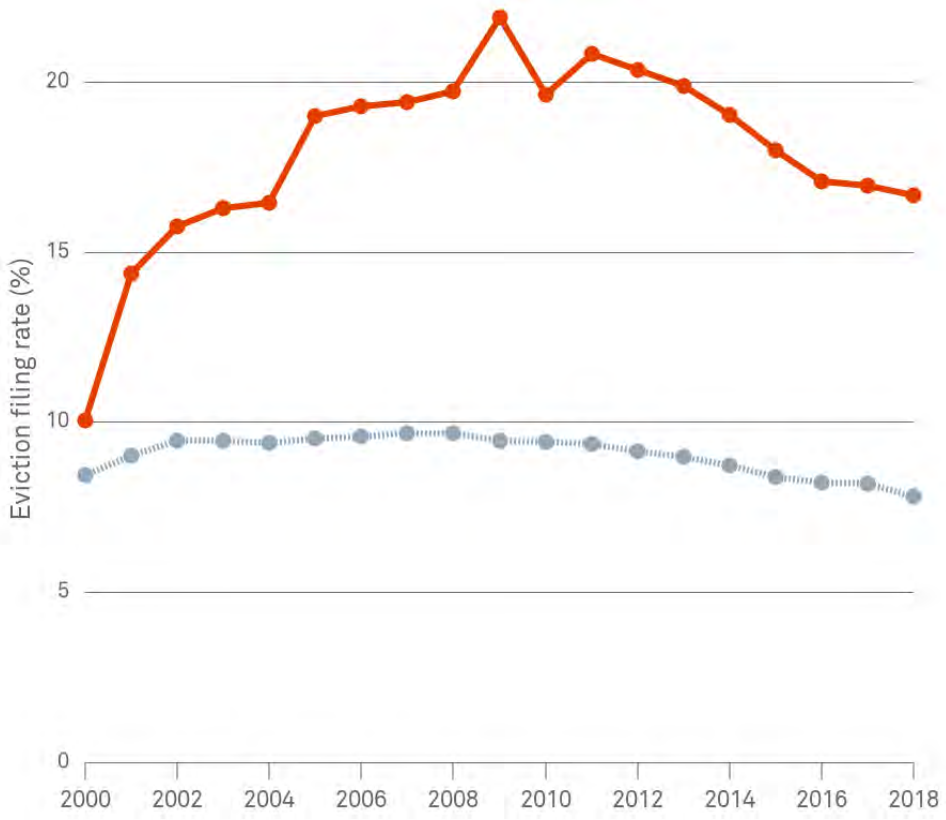


MICHIGAN HAD 191,957 EVICTION FILINGS IN 2018

- Eviction filings per day: **525.91**
- Eviction filing rate: **16.65%** (min: 16.45%, max: 16.86%)
- Households threatened rate: **12.61%** (min: 11.02%, max: 13.93%)
- Population: **9,957,488**

* The eviction filing rate is the number of eviction filings per 100 renter-occupied households.
* The households threatened rate is the number of unique households that received an eviction filing. This measure is the same regardless of how many evictions were filed in a year against the same household.
Please see our FAQ section to better understand these issues https://evictionlab.org/help-faq/

COMPARISON OF EVICTION FILING RATES OVER TIME



Michigan

2018

525.91	16.65% [1]
Filings per Day	Est. Filing Rate

Eviction Filings	191,957 [2]
Households Threatened	145,337 [3]
Households Threatened Rate	12.61% [4]

Census Demographics

Population	9,957,488
% Renter-Occupied Households	24.73%
Poverty Rate	10.37%
Median Gross Rent	$850
Median Household Income	$54,938
Median Property Value	$146,200
Rent Burden	29.8%
Black	13.66%
White	75.21%
Hispanic/Latinx	5%
Asian	3.04%
American Indian/Alaska Native	0.46%
Native Hawaiian/Pacific Islander	0.02%
Multiple Races	2.45%
Other Races	0.14%

[1] min: 16.45%, max: 16.86%
[2] min: 189,625, max: 194,339
[3] min: 126,997, max: 160,614
[4] min: 11.02%, max: 13.93%

UNDERSTANDING EVICTION IN

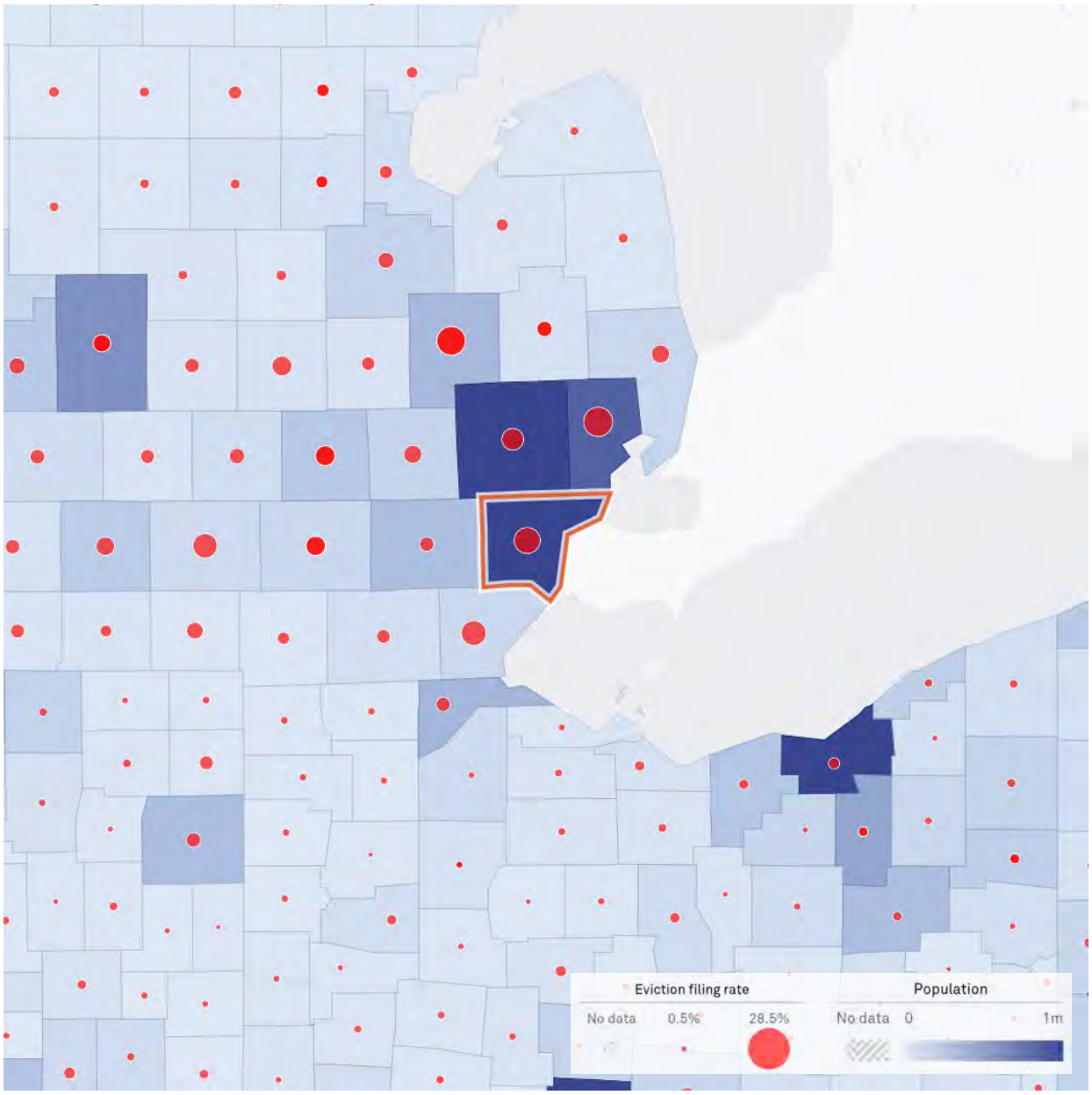
WAYNE COUNTY, MICHIGAN

A presentation generated by The Eviction Lab at Princeton University

Data extracted on 2024-07-20

For further information, visit evictionlab.org

EVICTION LAB

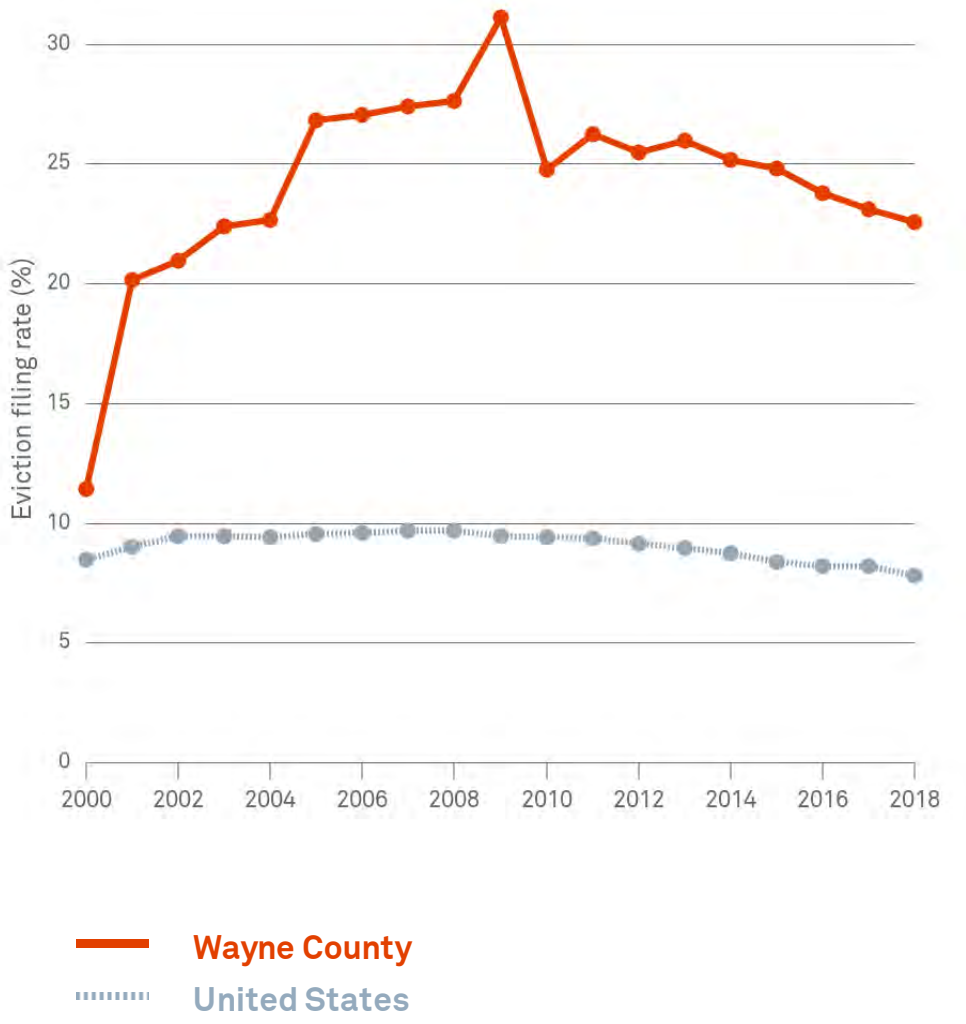


WAYNE COUNTY HAD 56,323 EVICTION FILINGS IN 2018

- Eviction filings per day: **154.31**
- Eviction filing rate: **22.55%** (min: 22.28%, max: 22.83%)
- Households threatened rate: **17.53%** (min: 14.94%, max: 19.64%)
- Population: **1,761,382**

* The eviction filing rate is the number of eviction filings per 100 renter-occupied households.
* The households threatened rate is the number of unique households that received an eviction filing. This measure is the same regardless of how many evictions were filed in a year against the same household.
Please see our FAQ section to better understand these issues https://evictionlab.org/help-faq/

COMPARISON OF EVICTION FILING RATES OVER TIME



Wayne County

2018

154.31	22.55% [1]
Filings per Day	Est. Filing Rate

Eviction Filings	56,323 [2]
Households Threatened	43,791 [3]
Households Threatened Rate	17.53% [4]

Census Demographics

Population	1,761,382
% Renter-Occupied Households	30.4%
Poverty Rate	17.84%
Median Gross Rent	$850
Median Household Income	$45,321
Median Property Value	$102,700
Rent Burden	33.1%
Black	38.71%
White	49.58%
Hispanic/Latinx	5.86%
Asian	3.24%
American Indian/Alaska Native	0.26%
Native Hawaiian/Pacific Islander	0.03%
Multiple Races	2.07%
Other Races	0.26%

[1] min: 22.28%, max: 22.83%
[2] min: 55,642, max: 57,019
[3] min: 37,307, max: 49,058
[4] min: 14.94%, max: 19.64%

Facts About Eviction

EVICTION LAB

What is an eviction?

An eviction happens when a landlord expels people from property they own. Evictions are landlord-initiated involuntary moves that happen to renters, whereas foreclosures are involuntary moves that happen to homeowners when a bank or other lending agency repossesses a home.

Why do people get evicted?

Most evictions happen because renters cannot or do not pay their rent. Landlords can evict renters for a number of other reasons, too, including taking on boarders, damaging property, causing a disturbance, or breaking the law. In most American cities and towns, landlords can evict renters even if they have not missed a rent payment or otherwise violated their lease agreement; these are called “no fault” evictions.

What is the relationship between the affordable housing crisis and the eviction epidemic?

Today, most poor renting families spend at least half of their income on housing costs, with one in four of those families spending over 70 percent of their income just on rent and utilities. Incomes for Americans of modest means have flatlined while housing costs have soared. Only one in four families who qualifies for affordable housing programs gets any kind of help. Under those conditions, it has become harder for low-income families to keep up with rent and utility costs, and a growing number are living one misstep or emergency away from eviction.

What is the eviction process like?

Landlords initiate the process, and renters are served notice to appear in court. Almost everywhere in the United States, evictions take place in civil court, where renters have no right to an attorney (with the exception of cities that have created right to counsel programs). For this reason and others, most renters do not appear in eviction court. When this happens, they receive a default eviction judgement, provided that the landlord or a representative is present. Renters who do appear in court may also receive an eviction judgement ordering them to vacate their home by a specific date. Eviction cases can be resolved in other ways as well. For one, the case may be dismissed or ruled in favor of defendants, allowing renter to remain in their home. In addition, a mediated agreement can be established between a landlord and a renter, often called a “settlement” or “stipulation,” which comes with certain terms. If renters meet the terms, the eviction is dismissed; if they do not, an eviction judgment can be rendered. In the event that evicted renters do not leave their home by the specified date, their landlord may file a “writ of restitution,” which permits law enforcement officers to forcibly remove a family and often their belongings.

Who is at most risk of eviction?

Low-income women, especially poor women of color, have a high risk of eviction. Research has shown domestic violence victims and families with children are also at particularly high risk for eviction.

How does an eviction affect someone's life?

Eviction causes a family to lose their home. They often are also expelled from their community and their children have to switch schools. Families regularly lose their possessions, too, which are piled on the sidewalk or placed in storage, only to be reclaimed after paying a fee. A legal eviction comes with a court record, which can prevent families from relocating to decent housing in a safe neighborhood, because many landlords screen for recent evictions. Studies also show that eviction causes job loss, as the stressful and drawn-out process of being forcibly expelled from a home causes people to make mistakes at work and lose their job. Eviction also has been shown to affect people's mental health: one study found that mothers who experienced eviction reported higher rates of depression two years after their move. The evidence strongly indicates that eviction is not just a condition of poverty, it is a cause of it.

What is the households threatened rate and how did you calculate it?

An eviction filing does not necessarily mean that the threatened household leaves its home. A common practice is what is known as "serial filing," where a landlord issues a series of eviction filings against a single household.

We created the households threatened rate so that we can clearly identify how many households annually receive at least one eviction filing. When calculating this rate, we looked at the number of households receiving an eviction filing per 100 renter households. The eviction filing rate (the number of filings per 100 renter households) is still available in our database, and this will measure the total of evictions filed, no matter how many happened to the same tenants.

We can use information in our case records to identify when a household receives multiple eviction filings in a given year. By counting the number of households who ever received a filing in a given year, we can calculate the households threatened rate. The eviction filing rate will always be higher than the households threatened rate.

About The Data

This report uses data from a variety of sources. While our primary eviction data were collected manually from courts across the country, we also collected proprietary data from private vendors. Because some areas are missing data over time in the courts and/or proprietary data, we used statistical models to “fill in the gaps” with modeled estimates. For more details on our data sources and modeled estimates, see our methodological report.

Homelessness and the Persistence of Deprivation: Income, Employment, and Safety Net Participation

Bruce D. Meyer
University of Chicago, NBER, and AEI

Angela Wyse
University of Chicago

Gillian Meyer
University of Pennsylvania

Alexa Grunwaldt
Yale University

Derek Wu
University of Virginia

February 2, 2024

Abstract

Homelessness is arguably the most extreme hardship associated with poverty in the United States, yet people experiencing homelessness are excluded from official poverty statistics and much of the extreme poverty literature. This paper provides the most detailed and accurate portrait to date of the level and persistence of material disadvantage faced by the U.S. homeless population, including the first national estimates of income, employment, and safety net participation based on administrative data. We link restricted-use microdata identifying those recorded as homeless during the 2010 Census to longitudinal tax records and administrative data on the Supplemental Nutrition Assistance Program (SNAP), Medicare, Medicaid, Disability Insurance (DI), Supplemental Security Income (SSI), veterans' benefits, housing assistance, and mortality. We find that nearly half of these adults had formal employment in the year they were observed as homeless, one-quarter received disability assistance, and more than 85 percent were reached by at least one safety net program, primarily SNAP. Incomes are persistently low for the decade surrounding an observed period of homelessness, suggesting that homelessness tends to arise in the context of long-term, severe deprivation rather than large and sudden losses of income. As our findings illustrate, most people appear to experience homelessness because they are very poor despite being connected to the labor market and safety net, with persistently low incomes leaving them vulnerable to loss of housing when met with even modest disruptions to life circumstances.

*Authors can be contacted at the following email addresses: Bruce D. Meyer (meyer1@uchicago.edu); Angela Wyse (awyse@uchicago.edu); Gillian Meyer (gplmeyer@wharton.upenn.edu), Alexa Grunwaldt (alexa.grunwaldt@yale.edu), Derek Wu (derek.wu@virginia.edu). This paper is released to inform interested parties of research and to encourage discussion. The Census Bureau has reviewed this data product for unauthorized disclosure of confidential information and has approved the disclosure avoidance practices applies to this release, authorization number CBDRB-FY2022-CES005-015. We thank the U.S. Census Bureau for their support, as well as John Abowd, Mark Asiala, George Carter, James Christy, Dennis Culhane, Kevin Deardorff, Conor Dougherty, Ingrid Gould Ellen, Anne Fletcher, Katie Genadek, Tatiana Homonoff, Kristin Kerns, William Koerber, Margot Kushel, Larry Locklear, Tim Marshall, Brian McKenzie, Brendan O'Flaherty, James Pugh, Trudi Renwick, Annette Riorday, Nan Roman, William Snow, Eddie Thomas, Matthew Turner, and John Voorheis for providing feedback and answering our questions. Ilina Logani and Mandana Vakil provided excellent research assistance. We appreciate the financial support of the Alfred P. Sloan Foundation, the Russell Sage Foundation, the Charles Koch Foundation, the Menard Family Foundation, and the American Enterprise Institute. Wyse thanks the National Institute on Aging for their support.

1. Introduction

Homelessness is an inordinately severe hardship. A long history of qualitative research and abundant anecdotal evidence suggests that people go to great lengths to avoid becoming homeless when confronted with an unfortunate turn of events like a job loss, health crisis, eviction, or relationship dispute, leaving only those with the fewest resources – those without savings or credit to afford temporary lodging, those without the possibility of emergency assistance from friends and family, those with mental health or substance abuse conditions that impair decision-making – to end up on the streets or in a homeless shelter. As Peter Rossi (1989) wrote in his seminal work *Down and Out in America: The Origins of Homelessness*, homelessness is "the most aggravated state of a more prevalent problem, extreme poverty."

Yet while the association between homelessness and severe economic disadvantage is apparent in a general sense, obtaining a detailed and accurate picture of the material circumstances of people who have experienced this hardship in the U.S. has proved challenging. Without a fixed address, such individuals are largely excluded from the household surveys that typically inform our understanding of poverty and well-being in the United States, and they have consequently been understudied in the extreme poverty literature. The most recent national survey to examine this population's income and program receipt, the National Survey of Homeless Assistance Providers and Clients (NSHAPC), dates back nearly three decades to 1996 (Burt 2001). Recent studies linking administrative homeless shelter and employment records have offered important insights but are limited to a handful of cities and a single income source, earnings (Metraux et al. 2018; Wachter, Schnorr, and Riesch 2020). Numerous ethnographic studies and geographically narrow surveys offer nuanced and detailed information on the material well-being of the individuals they represent, but their results may not generalize beyond those settings and they lack longitudinal information. These surveys also rely on self-reports that even when obtained from rigorously tested surveys of the housed have been shown to be substantially biased (Meyer, Mok, and Sullivan 2015).

Understanding the income and safety net participation of people who have experienced homelessness is crucial for the design and targeting of policy interventions. Such knowledge can, for example, indicate the degree of income-related deprivation that puts someone at risk of homelessness, which can in turn improve the targeting of prevention efforts, shed light on the size of the at-risk population, and inform the scale of interventions needed to significantly reduce

aggregate homelessness. Understanding the persistence or transience of deprivation can also direct policymakers towards the most appropriate prevention strategies, which might consist of measures aimed at raising permanent incomes, reducing housing costs, or mitigating income volatility.

This paper advances our understanding of the conditions in which homelessness arises by providing the most detailed and accurate portrait to date of income and safety net participation for the U.S. homeless population. Our sample consists of 140,000 adults recorded as sheltered and unsheltered homeless in the 2010 Census, by far the largest, most representative sample ever used to study these questions. We link these individuals to administrative tax and program records to provide the first national calculation of formal employment, income, and safety net participation for this population. We compare these outcomes to a demographically comparable sample of the housed poor and examine how pathways to homelessness appear to differ by sheltered status, race, gender, Hispanic ethnicity, and geography. We demonstrate the robustness of our findings to different linkage methods and alternative samples, including samples of the sheltered homeless population from the American Community Survey (ACS) and several cities' Homeless Management Information System (HMIS) shelter-use databases.

Our approach benefits not only from large samples that are designed to represent national homelessness patterns, but also from a wealth of accurate income and safety net information from administrative records. Using confidential personal identification keys, we link individuals experiencing homelessness to Internal Revenue Service (IRS) microdata on taxable income and employment from Forms 1040, W-2s, and 1099-Rs, as well as data on numerous state and federal safety net programs, including the Supplemental Nutrition Assistance Program (SNAP, formerly food stamps), Medicaid, Medicare, Temporary Assistance for Needy Families (TANF) and General Assistance (GA), Supplemental Security Income (SSI), Social Security Disability Insurance (DI), rental assistance from the Department of Housing and Urban Development (HUD), and service-connected disability payments from the Department of Veterans Affairs (VA). We account for mortality in our analyses using Social Security Administration (SSA) records of death dates.

We learn that the modern-day U.S. homeless population is surprisingly well-connected to formal employment and the safety net, in contrast to earlier years' depictions of individuals "unconnected to the world of work" with "no safety net of entitlements" (Rossi 1989). Nearly all sheltered homeless adults in our sample (97 percent) and the vast majority of unsheltered homeless adults (93 percent) were formally employed or enrolled in at least one safety net program in 2010,

the year they were observed as homeless. We also find that a substantial share of the homeless population is drawn from the ranks of the working poor: about half of those in shelters and 40 percent of those at unsheltered locations had formal employment in 2010. Their median annual earnings were about $8,300, however, suggesting low-wage, sporadic work. We find SNAP receipt to be especially high, reaching about 77 percent of all adults in our sample in 2010. Connections to work and the safety net coexist with deep poverty for this population, however. The median value of our most comprehensive resource measure, which adds to cash income the value of in-kind transfers from SNAP and HUD, was $7,500 for those in shelters and $5,500 for those experiencing unsheltered homelessness in 2010. In other words, people experience homelessness not because they are estranged from formal income and programs, but because they are very poor *despite* being highly connected to work and the safety net.

Turning to longitudinal patterns, our calculations reveal persistent, severe deprivation, with incomes remaining low for the decade surrounding an observed period of homelessness. Median annual income, including in-kind transfers, never exceeded $10,000 for the sheltered homeless and $8,000 for the unsheltered homeless in the decade surrounding 2010. We observe only a small dip in employment and earnings relative to the long-term trend preceding an observed period of homelessness, suggesting that employment and earnings shocks are not the predominant precipitating event for most spells of homelessness. Reliance on the safety net was also persistently high over the ten years of our study, although receipt of SNAP and TANF/GA – benefits typically understood to be temporary – peaked in the year observed as homeless, perhaps due in part to service providers' and homeless shelters' efforts to facilitate enrollment in these programs. We see a long-term pattern of declining employment that is accompanied by increasing enrollment in disability programs, with receipt of SSI or DI increasing from 19 to 34 percent for the sheltered homeless and 29 to 40 percent for the unsheltered homeless between 2010 and 2016. These longitudinal patterns suggest that homelessness tends to arise in the context of severe long-term deprivation, alongside steadily declining employment and increasing disability assistance receipt, rather than large shocks to income. Put differently, people experiencing homelessness are not just enduring an exceptionally difficult year – they are enduring an exceptionally difficult decade, and perhaps in many cases, an exceptionally difficult life.

Our analyses reveal a high degree of similarity between the material circumstances of people recorded in homeless shelters during the Census and poor housed individuals who share

their demographic profile. This poor housed comparison group consists of unmarried individuals who are predominantly male (70 percent), between the ages of 40 and 59 (69 percent), and disproportionately Black (39 percent) relative to the overall population. These individuals had a median income, including the value of in-kind transfers, of about $9,900 in 2010, only about $2,000 higher than the median of $7,500 among those who were in homeless shelters during the Census. By some measures, the housed poor appear to be somewhat *more* deprived than the sheltered homeless sample: they were slightly less likely to be employed in 2005 through 2010 and slightly *more* likely to receive SSI in 2010. These results underscore the dire economic circumstances faced by this segment of the housed poor population, a group that tends to be neglected in policy discussions on poverty relative to single mothers and children. In this way, our paper complements Meyer et al. (2021)'s work on extreme poverty in the U.S., which finds that after accounting for misreporting of income and program receipt in surveys, the only households who cannot be ruled out as being extremely poor are those consisting of a single, childless adults. Our findings suggest that this overlooked segment of the population, which appears to be exceptionally vulnerable to homelessness and likely other severe hardships as well, may merit more attention in national discussions of poverty alleviation.

Our findings help explain several patterns that have emerged in the recent literature on homelessness prevention. Prior work has emphasized the exceptional difficulty of identifying people who are most likely to become homeless and targeting prevention programs towards them, a finding that is consistent with our observation of substantial overlap between the economic circumstances of people in homeless shelters and the housed poor who share their demographic profile (O'Flaherty 2011; Shinn et al. 2013; Von Wachter et al. 2021). Even detailed and accurate information about someone's long-term trajectory of income and safety net participation are unlikely to yield useful predictors of homelessness.

At the same time, several experimental and quasi-experimental studies have found that providing small emergency payments to people at risk of losing housing, often on the order of one month's rent or less, can significantly reduce their probability of entering a shelter (Rolston et al. 2013; Evans, Sullivan, and Wallskog 2016; Phillips and Sullivan 2023). The effectiveness of such emergency assistance programs accords with our finding that homelessness tends to arise in the context of persistent, severe deprivation rather than major disruptions to income: just as a small loss of resources may be enough to trigger a spell of homelessness for those with the most

precarious circumstances, a small boost to income may be enough to prevent it. Yet our results also underscore the likely continued vulnerability to homelessness of those who receive small, one-time payments through emergency assistance programs. Indeed, these prior studies have found that the effect of emergency financial assistance on shelter entry attenuates over time, suggesting that some of the people for whom a spell of homelessness was initially averted eventually end up homeless – an outcome that is consistent with the persistent deprivation documented in this paper. A small-scale payment may be enough to prevent a singular instance of homelessness, but it is unlikely to make a dent in the long-term deprivation that leaves people vulnerable to the loss of housing.

These analyses shine new light on a highly disadvantaged segment of the U.S. population, those for whom extreme poverty can mean extreme vulnerability to homelessness when met with even modest disruptions to their life circumstances. The rest of the paper proceeds as follows. Section 2 discusses prior work on the income and safety net participation of homeless individuals. Section 3 describes our data, Section 4 describes our methodology, and Section 5 presents our main results, as well as analyses of heterogeneity by demographic characteristics and geography. Section 6 analyzes the robustness of our findings to alternative data sources, sample definitions, and linkage methods and presents extensions, including an analysis of demographic and income misreporting in household surveys. Section 7 compares our findings to prior work and Section 8 concludes.

2. Connections to Prior Work

Concerted efforts to learn about the income, employment, and safety net participation of people experiencing homelessness in the U.S. began in the 1980s, when an alarming and highly visible rise in homelessness drew renewed attention from researchers and the broader public. Rossi (1989) reviewed this early literature in his seminal ethnographic work, with an emphasis on his own surveys of Chicago's homeless population, which were innovative in their efforts to obtain representative samples. These early studies depicted an extremely deprived and disconnected population, heavily reliant on donations of meals and clothing and informal income from activities like panhandling and peddling. Rossi's surveys found that just one in four homeless Chicagoans received food stamps and that one in three had been employed in the previous month. Interviewees reported mean monthly income equivalent to about $375 in 2018 dollars, or $4,500 in a year.

The 1996 National Survey of Homeless Assistance Providers and Clients (NSHAPC) built on this early work to provide the first – and, until the present study, the only – estimates of the income, employment, and safety net participation using a sample designed to be representative of the entire U.S. homeless population (Burt, Martha R 1989; Burt et al. 1999). The NSHAPC, which was carried out by the Census Bureau on behalf of numerous federal agencies, collected detailed information from 4,200 users of homeless services around the country to learn about their characteristics, material well-being, health, and many other aspects of their life circumstances. This survey painted a picture of deprivation in the U.S. homeless population that was somewhat less grim than Rossi's but nevertheless dire. Survey respondents reported average monthly income of $590 in 2018 dollars, corresponding to annual income of $7,080, slightly less than half of the corresponding federal poverty threshold for a single individual from that year. Forty-four percent reported having worked in the previous month, and 37 percent said they received food stamps. NSHAPC also estimated the receipt of SSI (11 percent), Medicaid (30 percent), and General Assistance (GA) plus Aid to Dependent Families with Children (AFDC, the precursor to TANF) (19 percent). Taken together, about 40 percent of those experiencing homelessness received at least one benefit according to this survey.

While NSHAPC remains the most recent national survey of the U.S. homeless population, two studies have since revisited the question of employment among people experiencing homelessness using administrative data by linking individuals from Homeless Management Information System (HMIS) databases to data on employment and earnings (Metraux et al. 2018, Von Wachter et al. 2020). Linked administrative data permit longitudinal analyses and provide more accurate information on employment and earnings, which are frequently misreported in surveys and perhaps especially so for those experiencing homelessness, as we show in Section 5.

These two studies suggest somewhat lower employment than NSHAPC, although their estimates are at the annual and quarterly level and therefore not directly comparable to NSHAPC's monthly estimate. They also offer some evidence of disruptions to employment and earnings preceding homelessness. Metraux et al. (2018) find that about 42 percent of adults in New York City homeless shelters received wage income in the year they first enrolled in a shelter, a drop of about 6 percentage points relative to average employment over rates the preceding decade. They also observe an average $3,000 drop in mean earnings conditional on working relative to the preceding decade. Von Wachter et al. (2020) estimate that just 29 percent of Los Angeles shelter

users were employed in the year before shelter enrollment, although this share may be biased towards zero because it is based only on California state earnings records. They observe very little drop in employment in the year preceding the first shelter enrollment in the full sample, although mean earnings do fall among those who work. While these studies produced new insights into the level and longitudinal patterns of employment in this population, their findings are limited to homeless shelter users New York and Los Angeles and may not generalize nationally or to those experiencing unsheltered homelessness. Moreover, these studies examine just one income source (earnings) and therefore provide a limited view of individuals' financial resources.

In this paper, we advance this literature by providing the most comprehensive, accurate, and detailed calculation of the income, employment, and safety net participation for the U.S. homeless population to date. We build upon prior work by using national samples of the homeless population, including those residing outside of homeless shelters, and linking these individuals to administrative records that encompass a more comprehensive set of income sources. Administrative data allow us to obtain more detailed and accurate information on income and safety net receipt than in the NSHAPC and other surveys, including longitudinal patterns. In Section 7, we compare our results in detail to the studies described in this section and how these findings advance and revise our understanding of the level and persistence of deprivation faced by the U.S. homeless population relative to prior work.

3. Data

3.1 2010 Census Data on the U.S. Homeless Population

Our main sample of analysis consists of people who were recorded as experiencing sheltered and unsheltered homelessness during the 2010 Census. The Census collected information on this population through its Service-Based Enumeration (SBE) operation on March 29-31, 2010. SBE enumerators interviewed individuals in homeless shelters, users of soup kitchens and mobile food vans, and people spending the night at pre-identified outdoor locations known as targeted non-sheltered outdoor locations (TNSOLs), such as vehicle and tent encampments.[1] Because people using soup kitchens and food vans were only included in the homeless count if they did not indicate a valid residential or shelter address, we classify people enumerated at those locations as

[1] The SBE did not include people residing in domestic violence shelters. These individuals were included in the Census through a different counting operation and are not identified even in restricted-use data due to privacy concerns, so we do not include them in our study.

"unsheltered homeless" in our study. Our Census homeless sample therefore consists of a cross-section people who were experiencing literal homelessness in early 2010 – i.e., people residing in homeless shelters and those with a primary nighttime residence not meant for human habitation. In Section 4, we discuss the merits of this definition of homelessness relative to other definitions, for example those that include people who are "doubling up" or involuntarily sharing housing.

The Census built its list of service providers and outdoor locations for the SBE through a series of research and validation operations, including internet research, queries to local government officials, advocacy organization, and other local partners, and numerous advance visit and validation operations (Russell and Barrett 2013). Enumerators across the country received several days of uniform training that included a sensitivity component to teach them how to approach people experiencing homelessness and how to work with people suffering from psychological health concerns. At many locations, the Census engaged local "culture facilitators" to aid in interviewing people experiencing unsheltered homelessness. In principle, enumerators aimed to collect names and dates of birth from all interviewees. In practice, given the bustling nature of service locations and the fact that many individuals were sleeping during the outdoor counting operation, many individuals were enumerated by sight without providing this personal information. We discuss the implications of such nonresponse and our methods of accounting for the resulting non-linkage in Section 4.

Meyer, Wyse, and Corinth (2023)establish the broad coverage and reliability of the 2010 Census as a source of data on the U.S. homeless population, estimating that more than 90 percent of people residing in homeless shelters (as these facilities are defined by HUD) were included in its count. However, these individuals were at times classified as residing in housing or other types of congregate facilities due largely to ambiguities in the definition of a homeless shelter.[2] The completeness of the Census's unsheltered count is less certain, but the similarity of unsheltered estimates between the Census and HUD's point-in-time (PIT) count – despite substantial differences in the sources' methodologies – suggests that the Census covered this population reasonably well.

[2] We test the robustness of our findings to differences between the Census and PIT definitions of a homeless shelter in Section 6 by comparing results based on Census sheltered homeless in Los Angeles and Houston to those based on HMIS sheltered homeless samples in these cities, with the definition of a homeless shelter in these latter sources aligning closely with HUD's definition.

3.2 American Community Survey (ACS) Data on the Sheltered Homeless

We use additional data on the sheltered homeless population from the ACS to test the robustness of our findings to different samples, linkage methods, and years. The ACS interviews about 2,500 to 3,500 people in homeless shelters each year but excludes people experiencing unsheltered homelessness. Its shelter list is based on the most recent Census, with limited updates during the intercensal period. Unlike the Census, which collects only basic demographic characteristics, the ACS collects a wealth of information about shelter users' characteristics, geographic mobility, physical and cognitive difficulties, and self-reported income and program receipt. (B. D. Meyer, Wyse, et al. 2021)provide a detailed description of these outcomes for sheltered homeless individuals interviewed in the 2006-2018 ACS. Despite offering large, nationally representative samples of the sheltered homeless population, the ACS has been underused to study this population in the past because shelter users are not identified in public-use versions of the data.

3.3 Homeless Management Information System (HMIS) Data

In addition to the Census and ACS, we obtain administrative data on people experiencing sheltered homelessness from Homeless Management Information System (HMIS) databases from Los Angeles (2004-2014), Houston (2004-2015), and Chicago (2014-2019). These databases contain individual records of homeless shelter entries and exits covering a large share of these cities' sheltered homeless populations. All federally funded shelters are required to track clients' program use in HMIS and many others elect to do so.

Although HMIS data are limited geographically, they confer several advantages for examining heterogeneity and checking the robustness of results based on homeless samples from the Census and ACS. Unlike the Census and ACS, the HMIS data classify individuals into families and can thus be used to examine heterogeneity by family type that is often emphasized in the literature. Moreover, HMIS-recorded shelter entry and exit dates permit analyses of income and program receipt relative to individuals' first observed shelter enrollment. This allows us to compare results based on different temporal conceptions of the homeless population (e.g., those who were homeless at a point in time versus those with a first shelter enrollment during a period). Finally, because shelter administrators record the Social Security Numbers (SSNs) of clients in the HMIS, these data can be assigned linkage keys at higher rates than the Census and ACS, which rely only on name, date of birth, gender, and geographic location to assign linkage keys. We leverage these

high linkage rates to examine whether or not incomplete linkage leads to bias in the results based on Census and ACS samples (Section 6).

3.4 Administrative Records on Incomes and Program Receipt

We link homeless individuals from the Census, ACS, and HMIS to an extensive collection of administrative records on formal income, employment, and safety net participation from federal and state agencies. We obtain information on taxable sources of money income from Internal Revenue Service (IRS) Forms 1040s, W-2s, and 1099-Rs.[3] These records track the universe of formal employment (specifically wages) in the entire United States, with Form 1040 providing information for people who file taxes and Form W-2 adding wage amounts for those who do not. We have further information on retirement distributions from Form 1099-R. We obtain information on food assistance from five states' Supplemental Nutrition Assistance Program (SNAP) enrollment records and on cash assistance from New York State's Temporary Assistance for Needy Families (TANF)/General Assistance (GA) enrollment records.[4] We obtain national administrative data on housing assistance from the Department of Housing and Urban Development (HUD)'s Public and Indian Housing Information Center (PIC) and Tenant Rental Assistance Certification System (TRACS) files, which cover nearly all public and subsidized housing assistance programs under this agency's jurisdiction. We utilize Medicare and Medicaid enrollment records from the Centers for Medicare and Medicaid Services (CMS). We also obtain data on three sources of disability benefits: the Veterans Benefit Administration's USVETS data on service-connected disability compensation, a universe file on receipt of Supplemental Security Income (SSI), and an indicator for Disability Insurance (DI) receipt in Medicare records. Finally, we obtain birth and death dates from the Social Security Administration (SSA)'s Numident file to account for mortality when calculating income and program receipt.

These datasets cover most formal sources of income and the most important means-tested safety net programs in the United States. Formal income sources not covered by these data include DI amounts, Unemployment Insurance (UI) among people who do not file 1040s, and workers' compensation. We also emphasize that our data are limited to formal income and do not include income from informal employment or private transfers. Transfers from family, friends, and private

[3] IRS 1040 records are available for 2003-2015, W2s for 2005-2016, and 1099-Rs for 2003-2015.
[4] The states and years for which we have SNAP data are the following: Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016).

charity – which could consist of cash assistance or in-kind transfers via housing, food, clothing, or other goods – are undoubtedly important for many people experiencing homelessness but are outside the scope of the present analysis.

4. Methods

4.1 Defining Homelessness

The Census homeless population consists of people experiencing what HUD defines as "literal homelessness." People are literally homeless if they have "a primary nighttime residence that is a public or private place not designed for or ordinarily used as a regular sleeping accommodation for human beings" or if they are living in "a supervised publicly or privately operated shelter designated to provide temporary living arrangements" (HUD 2012).[5] As documented in Meyer, Wyse, and Corinth (2023), the Census definition of a homeless shelter differs in several straightforward ways from HUD's definition, with the latter including people in domestic violence shelters, those in hotel and motel beds funded by homeless service providers, and people sleeping in non-shelter facilities with temporary homeless accommodations. The Census also appears to have classified some HUD-designated shelters, particularly those where individuals can reside for extended periods of time, as housing units or other types of congregate facilities rather than homeless shelters. In Section 6, we test the robustness of our findings to HUD's broader definition of a homeless shelter by comparing results based on the Census's homeless population to those residing in HMIS shelters, which follow the HUD definition.

Literal homelessness does not include people residing in low-quality or shared housing or with tenuous attachment to their current residence. While such living arrangements reflect housing-related hardship in many cases and may indicate heightened risk of homelessness, we limit our attention in this paper to those experiencing literal homelessness for several reasons. First, literal homelessness typically indicates a degree of housing-related hardship that exceeds that associated with precarious or shared housing, as evidenced by individuals' revealed preference for such accommodations over literal homelessness. Moreover, it is not clear that shared housing reflects hardship in most cases, as is well-documented in the household formation literature (e.g.,

[5] For programmatic purposes, HUD also classifies among the "literally homeless" people exiting certain institutions, such as prisons and hospitals, where they have resided for 90 days if they were residing in a homeless shelter or at unsheltered locations immediately before entering the institution. Our definition does not include such individuals.

Browning, Chiappori, and Weiss 2014). The data requirements needed to identify those individuals for whom shared or low-quality housing represents hardship as extreme as literal homelessness also far exceed the information available in household surveys and administrative data. Meyer et al. (2023) provides further discussion of the merits and data limitations associated with different definitions of homelessness.

4.2 Constructing Homeless and Housed Comparison Samples

We limit our samples to people who were between the ages of 25 and 59 in 2010 and keep only those assigned an anonymized unique identifier by the Census Bureau's linkage software. Our primary homeless samples consist of 89,500 linked individuals who were residing in homeless shelters during the Census (the sheltered homeless) and 49,500 linked individuals who were counted at soup kitchens, food vans, or overnight at outdoor locations and indicated no valid usual address elsewhere (the unsheltered homeless). We also calculate key outcomes for two comparison groups of housed adults drawn from the first six months of the 2010 ACS. Our main comparison sample consists of 55,000 housed, unmarried individuals with self-reported incomes below the federal poverty threshold. To permit more direct comparisons, we reweight these individuals' demographic characteristics to align with those of the pooled sheltered and unsheltered homeless sample. We also calculate key outcomes for the 994,000-person ACS sample of housed individuals surveyed during the first six months of the 2010.

While most of our results are calculated for the entire U.S. population (excluding U.S. territories), our SNAP and TANF/General Assistance administrative records cover only a subset of the U.S. As a result, we impose geographic restrictions for analyses of these outcomes or measures that incorporate their values, such as the share of people receiving at least one benefit and the value of income including in-kind transfers. For such outcome measures, we restrict the sample in year *t* to people who in 2010 lived in a state for which we have data in year *t*. In Section 6, we estimate the magnitude of bias in longitudinal SNAP receipt patterns that arises due to migration between states for which we do and do not have administrative data.

4.3 Linking Across Datasets

We link datasets at the individual level using Protected Identification Keys (PIKs), unique anonymized identifiers assigned by the Census Bureau's Personal Identification Verification System (PVS). This software assigns linkage keys by matching the personal information provided to Census enumerators – including name, date of birth, and gender – against a reference file based

on Social Security Administration (SSA) records. In the restricted 2010 Census microdata, this software assigns a linkage key to 69 percent of people in homeless shelters, 42 percent of those counted at food vans and soup kitchens, and 17 percent of those counted at outdoor locations, or TNSOLs. According to the Census's evaluation report on the homeless counting operation, the main proximate reason for this non-linkage is that enumerators did not collect sufficient personal information from these individuals, either because the subjects were sleeping, deemed not "approachable," or because the bustling nature of many service locations prevented them from collecting complete information (Russell and Barrett 2013).

Incomplete linkage could create bias in our income and safety net calculations if the outcomes of unlinked individuals differ systematically from linked individuals. We address this concern by applying inverse probability weights to linked individuals, where these weights are obtained by estimating a probit model of linkage status on age, race, gender, Hispanic origin, state, and homeless location type. The key assumption is that non-linkage no longer biases analyses of outcomes conditional on these observed characteristics. Given low linkage rates and the limited characteristics available in the Census for our probability model, however, we test the robustness of our findings to alternate linkage methods using sheltered homeless samples from ACS and HMIS data. The ACS's rich set of covariates, which include self-reported measures of income and program receipt, allow us to estimate a more detailed inverse probability weighting model on these data and compare our findings to those based on the Census's more limited model. We also compare findings based on the Census homeless samples to those based on HMIS data, where linkage rates are about 90 percent across cities and years because most records contain SSNs.

Despite these robustness checks, we remain concerned that linkage may be non-random with respect to outcomes of interest in the population counted at TNSOLs, even conditional on the covariates in our probability model. The Census's SBE evaluation report indicates that nonresponse appeared to be "most serious" at these locations, where most residents were "asleep and/or covered up" during their overnight counting operation (Russell and Barrett 2013). We therefore exclude people counted at TNSOLs from our main analyses but include them in robustness checks in Section 6.

5. Results

This section contains our main results. We start by providing summary statistics of our homeless samples and comparison groups, before showing how employment, income, and program participation evolve in the years preceding and following an observed period of homelessness during the 2010 Census.[6] We next discuss comparisons in key outcomes between those who are homeless and the demographically comparable sample of the single housed poor population. The last set of results describe differences by gender and family status, race and ethnicity, and geography and discuss potential reasons for these differences.

5.1 Characteristics of the Homeless and Housed Comparisons Samples

Table 1 presents descriptive statistics for the Census homeless samples and ACS housed comparison groups used in our main analyses. Relative to housed adults (Column 4), sheltered (Column 1) and unsheltered (Column 2) homeless individuals are much more likely to be male (67 and 74 percent, respectively, compared to 49 percent of the overall housed) and much more likely to be Black (40 and 38 percent, compared to 13 percent). They are similarly likely to be Hispanic (14 and 15 percent, compared to 15 percent) and are slightly older (43.5 and 44.4 years old, on average, compared to 42.4), conditional on being between the ages of 25-59 in 2010.

As noted in Section 4, we reweight the single housed poor sample to match the distribution of demographic characteristics in the pooled sheltered and unsheltered homeless samples. The characteristics of the single housed poor indicated in Column 3 are therefore equal to a weighted average of the characteristics in Columns 1 and 2 by construction. This reweighting ensures that any subsequent comparisons are not confounded by demographic differences between those experiencing homelessness and single poor housed individuals. Such comparisons should be interpreted as between those experiencing homelessness and a demographically comparable segment of the single housed poor population, i.e., a segment that is more likely to be male, Black, and in their 40s and 50s than the typical single housed person living in poverty in the United States.

[6] We inflation-adjust all amounts to 2018 dollars using the Chained Consumer Price Index for All Urban Consumers (C-CPI-U) and report individual income and program receipt at the annual level. The notes on Appendix Tables A1-A7 contain detailed information about the definitions and methodology underlying income and program receipt measures.

5.2 Employment, Income, and Safety Net Participation in the Year Observed as Homeless

We begin by summarizing levels of employment, safety net participation, and material deprivation in the year individuals were observed as homeless, before turning to a discussion of longitudinal patterns of income, employment and earnings, disability program receipt, and receipt of other benefits in the years preceding and following an observed period of homelessness. Key results are indicated in Tables 2a and 2b.[7]

Connections to Formal Employment and the Safety Net

Figure 1a displays the share of the Census homeless population and single housed poor comparison group receiving various benefits and earnings in 2010. We find that homeless individuals are highly connected to formal employment and the safety net, with 97 percent of those in shelters and 93 percent of those at unsheltered locations receiving at least one government benefit and/or having been formally employed in 2010. The vast majority received at least one safety net benefit (89 percent of the sheltered and 80 percent of the unsheltered), and about 53 percent of sheltered homeless individuals and 40 percent of unsheltered homeless individuals had formal employment, albeit with low earnings (a median of $8,300 among workers) that suggest sporadic and/or part-time work at very low wages.[8]

Receipt of all non-disability benefits was higher among people experiencing sheltered rather than unsheltered homelessness, but this latter group was more likely to receive disability benefits from SSI or DI. About 83 percent of those in homeless shelters and 70 percent of those at unsheltered locations received SNAP in the year they were observed as homeless. Nearly half of this population was enrolled in Medicaid, and receipt of TANF and General Assistance was high (58 percent) among homeless shelter users in New York, where we have access to these data. A moderate share received disability benefits in 2010, with a respective 14 and 21 percent of the sheltered and unsheltered homeless receiving SSI, 9 and 14 percent receiving DI, and 3 and 2 percent receiving service-connected disability payments from the VA. A small share (10 percent of the sheltered and 9 percent of the unsheltered) received HUD housing assistance for at least some portion of 2010, although the mean months of receipt drop in 2010 relative to surrounding

[7] Detailed additional results are available in Appendix Tables A1-A7.
[8] For comparison, a full year of work at the federal minimum wage of $7.25 corresponds to about $15,000 of annual earnings.

years, suggesting disruptions in housing benefit receipt that are consistent with having been homeless for some portion of that year.

Income and the Value of In-Kind Transfers

We also calculate the median and 75th percentile of our most comprehensive resource measure, money income plus in-kind transfers, for our homeless and housed comparison samples in 2010 (Figure 1b). This income measure includes most sources of taxable income reported on 1040s or in W-2s and 1099-Rs, as well as (non-taxable) cash transfers from SSI and VA payments and the value of in-kind transfers from SNAP and HUD. Despite the high degree of connection to employment and the safety net indicated in Figure 1a, we find that people experiencing homelessness have extremely low incomes, indicating severe material deprivation. The median value of income including in-kind transfers was about $5,500 for the unsheltered homeless and $7,500 for the sheltered homeless in 2010. These annual incomes fall well below the official poverty threshold of about $12,000 for a single-person household, despite including the value of in-kind transfers that are not included when calculating official poverty status.[9]

At the same time, we note that material deprivation would be even more extreme in this population without certain safety net programs. For example, median income falls to about $750 for those in shelters and to $0 for the unsheltered homeless population when we deduct the value of transfers from SSI, SNAP, and housing assistance (Appendix Tables A3-A4). The safety net appears to provide crucial assistance to many people experiencing homelessness.

Comparisons to the Single Housed Poor

Figures 1a and 1b also allow us to compare the material circumstances of those experiencing homelessness and single housed poor individuals who share their demographic profile. We find that single housed poor individuals are *less* connected to formal employment and the safety net, with just 89 percent being employed and/or receiving at least one benefit in 2010, compared to 93 and 97 percent in the homeless samples. Among the single housed poor, the share with formal earnings (48 percent) falls between that of the sheltered homeless (52 percent) and unsheltered homeless samples (40 percent), with the median value of earnings conditional on

[9] We reference the 2018 federal poverty threshold because we measure incomes in 2018 dollars. Although we compare income to the poverty threshold for a single individual, we note that some people in our samples, particularly those recorded in homeless shelters in the Census, were likely accompanied by children and would hence be subject to even higher poverty thresholds.

working being about $12,200, compared to $8,300 among homeless individuals with formal employment. W-2 records offer suggestive evidence of slightly elevated employment instability in the homeless population, with sheltered and unsheltered homeless workers both having an average of 1.6 distinct jobs (as proxied for by the number of W-2 forms) in 2009, compared to 1.4 among the single housed poor (Appendix Tables A3-A5). The single housed poor are less likely to receive SNAP, TANF/GA, Medicaid, and VA disability benefits than those experiencing homelessness, but are more likely to receive housing assistance. They receive DI at similar rates to unsheltered homeless individuals, and their receipt of SSI falls (16 percent) falls between receipt rates for the sheltered homeless (14 percent) and unsheltered homeless samples (21 percent).

Turning to comparisons of the median and 75th percentiles of income including the value of in-kind transfers in Figure 1b, we observe a striking degree of similarity between those experiencing homelessness and single housed poor individuals who share their demographic profile. The median single housed poor individual had about $9,900 in income after in-kind transfers in 2010, only $2,400 higher than the median sheltered homeless individual. There is also a substantial amount of overlap between these samples' income distributions. At least one-quarter of those experiencing homelessness had *higher* incomes than most single housed poor adults: the 75th percentiles of income for the unsheltered and sheltered homeless were about $14,300 and $15,100, respectively, compared to the median value of $9,900 for the single housed poor. In other words, those experiencing homelessness, particularly sheltered homelessness, look very much like single housed poor adults who share their demographic profile in terms of their incomes, employment, and safety net participation.

5.3 Longitudinal Patterns of Employment, Income, and Safety Net Participation

Persistence of Deprivation

Moving beyond static levels of deprivation, Figure 2 examines longitudinal patterns in median income including the value of in-kind transfers from SNAP and HUD between 2005 and 2016. The solid lines indicate the value of income from all sources except SSI, which we only incorporate starting in 2010 (as reflected in the dashed lines) when administrative SSI records become available to us. This figure illustrates the stark persistence of material deprivation for this population, with incomes remaining very low over the four years prior to and six years after an observed period of homelessness. We find little evidence of major disruptions to income in the years leading up to 2010, a finding that contrasts with anecdotal narratives emphasizing major and

abrupt deteriorations in material circumstances preceding homelessness. This figure illustrates our key finding that people experiencing homelessness appear to be enduring not just a difficult year or two, but rather a decade or more of exceptional material hardship.

Longitudinal Patterns of Earnings and Employment

We next turn to longitudinal patterns of employment (Figure 3a) and median earnings among those who are employed (Figure 3b) to examine the magnitude of disruptions to these outcomes relative to their long-term trend in the years preceding and following an observed period of homelessness.[10] All homeless and housed comparison groups see a pattern of declining employment between 2005 and 2016, consistent with aging, but the proportional decline in employment is greatest for the unsheltered homeless (39 percent), followed by the sheltered homeless (30 percent), single housed poor (20 percent), and the overall housed population (7 percent).

Because we condition on being observed as homeless or poor in early 2010, we might expect any loss of earnings that led to homelessness or poverty to appear in 2009 tax records. Indeed, we observe a drop in employment and earnings in 2009 for the homeless and single housed poor groups relative to their long-term trends, but the magnitude of this drop is small. Conditional on working, the earnings of sheltered homeless workers are about $1,500 to $1,700 lower in 2009 relative to the two surrounding years, and for unsheltered homeless workers it is $500 to $1,000 lower. These disruptions are modest relative to the overall trend of declining employment between 2005 and 2016 and are similar in magnitude to the drop in earnings and employment observed among the single housed poor.

Longitudinal Patterns of Safety Net Participation

Looking longitudinally at enrollment in disability programs, we find that receipt of SSI (Figure 4a) and DI (Figure 4b) tends to be increasing for our homeless and housed poor samples in the years surrounding an observed period of homelessness or poverty, but the rate of increase differs across groups, increasing most quickly for the sheltered homeless, followed by the unsheltered, and then the single housed poor. SSI receipt in the sheltered homeless population surpasses that of the single housed poor in 2011 and continues to grow, while SSI receipt in the

[10] In addition to the single housed poor comparison group, this figure also includes a series for the overall housed population to help distinguish longitudinal patterns among the homeless and single housed poor from secular trends in employment for this age cohort during this period, which includes the Great Recession.

single housed poor population remains nearly level at around 16-17 percent. Accelerating disability program receipt for those experiencing homelessness could either indicate that the onset of disability is associated with the onset of homelessness or that the experience of homelessness causes new disabilities to arise. Alternatively, it could mean that people become connected to disability programs for which they already qualified while they are experiencing homelessness, perhaps due to concerted efforts by the Social Security Administration (SSA) to increase access to SSI and DI among eligible people experiencing homelessness.

Figures 5a and 5b display longitudinal patterns in the receipt of other safety net programs among sheltered and unsheltered homeless individuals, respectively, between 2003 and 2016. Patterns differ across benefits, with receipt of SNAP and TANF/GA – benefits typically understood to be temporary – peaking in the year observed as homeless relative to surrounding years. These peaks occur for both the sheltered and unsheltered homeless but are more pronounced in the sheltered homeless population.[11] Medicaid receipt increases steadily through 2013 for both groups, before increasing sharply in 2014 after many states expanded eligibility under the Affordable Care Act (ACA). Receipt of HUD housing benefits appears to dip slightly in 2009 for the sheltered homeless population before increasing through 2016, but the overall level of housing assistance receipt remains low (below 20 percent) for both groups over this entire period.

We find that people who were residing in homeless shelters during the 2010 Census have persistently higher rates of enrollment in non-disability safety net programs than those who were experiencing unsheltered homelessness, despite facing somewhat lower material deprivation overall, as indicated by their higher incomes.[12] This pattern appears to reflect, at least in part, differences in family structure between these groups, because adults with accompanying children are more likely to reside in shelters than at unsheltered locations and also to qualify for safety net programs. Different rates of program receipt could also reflect selection into sheltered or unsheltered status related to one's underlying propensity to use services, as we might expect that people who elect to use shelters – essentially a safety net service – will be more likely to take up other safety net programs, as well.

[11] Some of this peak could be due to migration between states for which we do and do not have SNAP data. We examine the potential for such bias in Section 6, with those analyses suggesting that migration is likely only a minimal source of bias.

[12] The unsheltered homeless are more likely than the sheltered homeless to be enrolled in Medicare, but this is largely because eligibility for DI entails Medicare eligibility (in most cases after a two-year qualifying period).

In addition to demographic heterogeneity and selection, sheltered homeless individuals may have higher program receipt because shelters facilitate the enrollment in and continued receipt of safety net benefits. We investigate this potential explanation for shelter users' higher program receipt using HMIS data, which unlike the Census indicate precise dates of shelter entry and exit. Figure 6 displays monthly SNAP enrollment among Chicago HMIS users relative to their first observed shelter entry.[13] SNAP enrollment remains steady at about 46 percent over the two years prior to shelter entry, before abruptly increasing to nearly 60 percent in the month of first observed shelter entry. Receipt peaks at 63 percent in the third month after shelter entry, before declining to about 51 percent after a year has passed. While not necessarily indicating a causal relationship, these results are highly suggestive that homeless shelters play a role in connecting their clients to the safety net. They also suggest that connections to the safety net deteriorate in the months following initial shelter entry, perhaps as people leave shelters and maintaining enrollment becomes more difficult.

5.4 Differences Across Demographic Groups and by Geography

Having discussed static and longitudinal patterns in economic conditions for the overall homeless population, we now turn to heterogeneity across policy-relevant sub-groups defined by gender and family status (i.e., the absence or presence of accompanying children), race and ethnicity, and geography (i.e., California, New York, and the rest of the U.S.).[14]

Family Status and Gender

We first examine heterogeneity in in longitudinal patterns of income and safety net participation by gender. In the year they were observed as homeless, women were more likely to be employed (Figure 7a) and had higher earnings conditional on working (Figure 7b) than men with the same sheltered status. Longitudinal patterns also differed by gender, with men experiencing larger and apparently more persistent disruptions to employment and earnings surrounding an observed period of homelessness. Sheltered homeless women also about 6 percentage points more likely to receive any benefit than sheltered homeless men in 2010, while unsheltered homeless women were 3 percentage points more likely to receive benefits than their unsheltered male counterparts.

[13] See Appendix Table A8.
[14] See Appendix Tables A9-A12.

Differences by gender are likely closely associated with differences in family status, a dimension of heterogeneity emphasized in much of the homelessness literature, including HUD's annual national reports on homelessness. Data from HUD's 2023 report that about 40 percent of sheltered homeless adult women had accompanying children, compared to just 10 percent of sheltered homeless adult men (HUD 2023).[15] Differences in income by gender could reflect higher cost of maintaining housing when children are present, leading women to be unable to afford housing even at higher levels of income. Similarly, higher benefit receipt among homeless women could reflect the greater ease of qualifying in households where children are present.

While Census and ACS data do not report household structure for those experiencing homelessness, we investigate heterogeneity by family status using cross-sections of individuals indicated as being enrolled in HMIS shelters in Los Angeles and Houston on March 30 of 2012 and 2013.[16] Adults in both types of households experience a drop in employment similar in magnitude to the drop among the Census homeless, but employment rates for those without children continue to decline after an observed period of homelessness, while employment among adults with accompanying children recovers almost to its initial level, consistent with gender-based differences described above (Figure 8).

In summary, our findings suggest that homeless women are more connected to employment and the safety net than men who share their sheltered status, and that homelessness appears to be associated with smaller disruptions to employment for women than for men. These patterns are mirrored in analyses of heterogeneity by family status, with women more likely to be in families with accompanying children.

Race and Hispanic Ethnicity

We next turn to analyzing differences across race (Figure 9a) and Hispanic ethnicity (Figure 9b). Compared to white individuals of the same sheltered status, Black individuals experiencing homelessness had higher rates of employment and benefit receipt, including disability benefits.

[15] The HUD reports do not contain separate cross-tabulation of gender and family status for adults and children, which are needed to estimate the share of women and men with accompanying children. The reports do, however, include cross-tabulations of gender and family status and age and family status. We assume that children are equally likely to be male and female and subtract these estimated counts from the overall cross-tabulations by gender and family status to obtain the necessary cross-tabulation of gender and family status among homeless adults.

[16] We use 2012 and 2013 reference years, rather than 2010, because we are more confident in the quality of HMIS shelter entry and exit date reporting in these years, for reasons explained in Meyer et al. (2023). We condition our sample on shelter enrollment on March 30 because this date aligns with the mid-point of the Census's homeless counting operation and hence ensures that our results are robust to any seasonal heterogeneity in shelter enrollment.

Hispanic homeless individuals had higher employment and lower disability program receipt than non-Hispanics with the same sheltered status. Overall benefit receipt was higher for sheltered homeless Hispanics than for sheltered homeless non-Hispanics, but the reverse was true among the unsheltered homeless, with Hispanics having lower overall benefit receipt than non-Hispanics.

Heterogeneity by race is of particular policy interest because people who are Black tend to be overrepresented among those who experience homelessness relative to their share in the broader population in poverty, raising concerns about equity. Meyer et al. (2021) find using the ACS that 47 percent of people in homeless shelters are Black, compared to 30 percent of single housed poor adults. Differences in income and program receipt by race may suggest differences in the predominant pathway to homelessness across groups. As suggested by gender-based differences, it is possible that homeless individuals who are Black appear to be somewhat less deprived than those who are white due to differences in the cost of maintaining housing. This cost could be higher, on average, for Black individuals due to housing market discrimination, racial disparities in the criminal justice system, or due to differences in the availability of resources in one's family and social network to help insure against homelessness.

California, New York, and Other States

Policy discussions on homelessness in the U.S. often center on two states: California, which is home to the largest unsheltered homeless population, and New York, which is home to the largest sheltered homeless population. We therefore examine income and safety net participation in these states separately and compare them to those experiencing homelessness in the rest of the country. As shown in Figure 10a, employment rates are lowest in California (47 percent among the sheltered, 35 percent among the unsheltered), followed by New York (50 percent among the sheltered, 37 percent among the unsheltered) and all other states (53 percent among the sheltered, 42 percent among the unsheltered). At the same time, Figure 10b demonstrates that median earnings among homeless workers in California and New York (about $10,000 to $11,000) are somewhat higher than those in other states (about $7,500), a difference that could once again reflect differential housing costs by state. We also observe slightly higher rates of disability program receipt in California and New York relative to other states (Figure 11c). In summary, although we find somewhat lower employment and higher disability program receipt in New York and California, these differences are relatively small and suggest a high degree of

similarity in the material circumstances of people experiencing homelessness across the United States as a whole.

6. Extensions and Robustness Checks

This section contains extensions of our main analyses and robustness checks. We begin by examining the accuracy of self-reported income and benefit measures and demographic characteristics among those surveyed in homeless shelters in the ACS and housed comparison groups. Our next sets of analyses check the robustness of key findings to alternative temporal conceptions of homelessness (i.e., we compare results based on samples of those with a first shelter enrollment in a year to samples of those enrolled in homeless shelters at a point in time) and to different data sources and years (i.e., we compare results based on those recorded as homeless in the Census to results based on those enrolled in HMIS shelters and those surveyed in homeless shelters in the ACS). Our final set of analyses test the robustness of our findings to alternative Census samples designed to address potential bias from non-linkage, misclassification, and the incomplete geographic coverage of our SNAP datasets.

6.1 Misreporting of Income, Benefit Receipt, and Characteristics in the ACS

Household surveys suffer from widespread underreporting of income and safety net benefit receipt, and self-reported measures may be especially inaccurate among those with very low and very high incomes (B. D. Meyer, Mok, and Sullivan 2015; Bollinger et al. 2019). Misreporting of income and program receipt among those experiencing homelessness is of particular interest because nearly all existing work on these outcomes relies on self-reported measures. This section examines the extent to which income, benefit receipt, and demographic characteristics are misreported in the ACS's sheltered homeless samples, as well as housed comparison groups. In doing so, we illustrate the importance of administrative data and provide estimates that may help researchers and service providers to interpret findings in surveys of this population.

We start by assessing the misreporting of date of birth, place of birth, gender, and citizenship status in the 2011-2018 ACS (Table 3a). We take characteristics indicated in Social Security Administration (SSA)'s Numident file to represent the truth and calculate the share of individuals reporting a different response in the survey. People experiencing homelessness are slightly more likely to misreport the exact day, month, or year of their birth, but only a small share (3.5 percent) report a date of birth that is three or more years away from the true date. These shares

are similar to the misreporting rate for this characteristic among the single housed poor (4 percent) and overall housed populations (3.7 percent). In addition, homeless individuals are slightly more likely to misreport their state or country of birth (7.4 percent) than the single housed poor (5.1 percent) and overall housed populations (4.9 percent), but they are less likely to misreport their gender. Citizenship misreporting rates are similar (3 to 3.7 percent) for all three groups. In summary, the demographic information provided by people experiencing homelessness appears to be generally quite reliable and only slightly less accurate than the information provided by housed individuals.

We next summarize the misreporting of wage and salary income, SNAP, Medicaid, and Medicare in the 2011-2016 ACS, where we take values from administrative datasets to be the truth (Table 3b).[17] Among those experiencing homelessness, 43.2 percent of wage earners fail to report any wages in the survey, which is higher than the corresponding false negative rates for the single housed poor (28 percent) and overall housed population (7.7 percent).[18] Among true SNAP recipients, individuals experiencing homelessness are slightly more likely to falsely report no receipt (20.5 percent) than the single housed poor (15.8 percent), but less likely to do so than the overall housed population (29 percent). On the other hand, false positive rates for SNAP receipt are substantially higher in the homeless sample than in the single housed poor and overall housed populations (30.7 percent, compared to 6.3 percent and 1.2 percent). The three groups have similar (and low) rates of false positives and false negatives for Medicare receipt. Finally, for Medicaid receipt, those experiencing homelessness have slightly lower false negative rates (16.5 percent, compared to 18.6 and 27.6 percent of the single housed poor and overall housed) but substantially higher false positive rates (20.4 percent, compared to 13.2 and 3.7 percent).

In summary, we find that people experiencing homelessness are slightly more likely than the housed population to underreport certain sources of income and benefits (e.g., wage and salary income, SNAP) but may be less likely to underreport receipt of other benefits (e.g., Medicaid). At the same time, the overreporting of program receipt (e.g., SNAP and Medicaid) appears to be a

[17] We limit the sample to ACS data through 2016 for income and safety net misreporting analyses because these are the years for which we have access to administrative data.
[18] We note that our administrative earnings data indicate only formal wage and salary income, so false negative rates should be interpreted as false negatives for formal wage and salary income. Because people may report informal income in the survey that would not be recorded in the tax data, false positive rates should be interpreted with more caution.

greater concern for this population, perhaps reflecting misunderstanding about these programs vis-a-vis other types of food and medical assistance that they may receive.

6.2 Income and Program Receipt Relative to First Shelter Enrollment

One limitation of the Census and ACS homeless data is that they do not indicate the start and end dates for spells of homelessness. Assuming these dates are uniformly distributed throughout the year, cross-sectional samples of the homeless population like those in the Census and ACS should, on average, include individuals midway through their spells, but we cannot identify the date of homelessness onset, nor can we examine heterogeneity in income and program receipt by the length of time spent homeless. Knowing the exact date of homelessness onset could help differentiate disruptions to income, employment, and safety net receipt that precede homelessness and those that occur after one becomes homeless. Prior work has also emphasized differences in the life circumstances of people displaying patterns of chronic homelessness (remaining homeless for extended periods of time, typically while struggling with behavioral health or substance abuse conditions), episodic homelessness (frequently cycling in and out of homelessness), and transitional homelessness (having just one or a few short spells) (Kuhn and Culhane 1998). We therefore wish to learn whether income and program receipt in a cross-sectional sample of the homeless population differs from that of samples of people who were ever homeless during a period of time. The former sample will contain a larger share of people who are homeless for extended periods of time than the latter.

Specifically, we leverage shelter entry and exit dates in HMIS data to compare income and program receipt in a cross-section of the homeless population and a sample of people with first shelter enrollments in a year. The first sample, which aligns with the Census's temporal conception of homelessness, consists of people who were enrolled in Los Angeles and Houston shelters on March 30 of 2012 or 2013.[19] The second consists of people with a first observed shelter enrollment in 2012 or 2013 and aligns with HMIS-based samples used in key prior studies, thereby facilitating comparisons with prior work (e.g., Metraux et al. 2018, Von Wachter et al. 2020).

In Los Angeles, both the level and longitudinal patterns of employment (Figure 11a) and disability program receipt (Figure 11b) were similar across the two temporal conceptions of the

[19] We use 2012 and 2013 for these analyses, rather than the Census year of 2010, to ensure that we have several years of preceding high-quality HMIS data, which in turn increases our likelihood of having identified an individual's first shelter enrollment. See Meyer et al. (2023) for a discussion of HMIS data quality improvements over time.

homeless population, differing by only about 0 to 4 percentage points across years. In Houston, people in the cross-sectional sample had higher employment rates (by about 3 to 9 percentage points) and lower disability program receipt (by about 5 to 8 percentage points) than those with a first enrollment in the same year. These patterns may be related to gender and family status, which differ substantially across samples: the latter sample has a larger share of women (50 versus 39 percent) and adults with accompanying children (19 versus 14 percent). As in Los Angeles, however, longitudinal patterns in employment and disability program receipt appear similar for the two samples in Houston.

Our findings suggest that using a sample of people with first shelter enrollments in a year rather than a cross-section of those experiencing homelessness at a point in time makes little difference for interpreting longitudinal patterns of income and program receipt, although levels of these outcomes may vary, particularly when characteristics differ substantially between the two temporal conceptions of the homeless population.

6.3 Comparing Census, HMIS, and ACS Sheltered Homeless Samples

We next compare income and program receipt for the Census sheltered homeless samples in Los Angeles and Houston to samples drawn from HMIS records in those cities. Meyer et al. (2023) highlight ambiguities in the definition of a homeless shelter that lead the Census to classify some HMIS facilities as conventional housing or other types of group quarters rather than homeless shelters. For example, the Census appears to have classified many transitional shelters, where people experiencing homelessness can reside for up to two years under a formal tenancy agreement, as conventional housing rather than homelessness shelters. Given these definitional differences, and because HMIS data form the basis for HUD's widely cited point-in-time estimates and are often used in the literature, we compare results based on otherwise comparable samples of the sheltered homeless population drawn from Census and HMIS datasets. These analyses also serve as a check on our methods to account for non-linkage because the majority of HMIS records contain Social Security numbers, leading to much higher linkage rates (about 90 percent in most years in Los Angeles and 96 percent in most years in Houston) than in the Census.[20]

[20] Following Meyer et al. (2023), we exclude from the Los Angeles sample people whose HMIS-recorded exit dates appear to be erroneous, i.e., those with exit dates of March 31, 2010 (the date of an apparent administrative closure of numerous spells with missing exit dates), as well as those who still had open spells on March 30 despite being enrolled in Los Angeles's Winter Shelter Program, which ended on March 15.

Figures 12a and 12b illustrate employment and disability benefit receipt for the Census sheltered homeless from Los Angeles and Houston and for HMIS shelter users with entry and exit dates indicating enrollment during the Census's homeless counting operation in those cities. In Los Angeles, both the levels and longitudinal patterns of employment and disability program receipt were similar for the two samples, with employment differing by at most 4 percentage points and disability program receipt differing by at most 3 percentage points across years. In Houston, the HMIS sample had notably higher employment (by about 7 to 10 percentage points) and lower disability program receipt (by about 9 to 13 percentage points) than the Census sample, although the longitudinal patterns were similar in the two samples.

The prevalence of transitional housing offers one proxy for the degree of misalignment between the Census and HMIS shelter definitions and may help explain the similarity of Census- and HMIS-based results in Los Angeles and their differences in Houston. In Los Angeles, only one-quarter of the HMIS sample was enrolled in transitional housing, compared to about two-thirds of the Houston sample. In other words, the levels of income and program receipt appear to be sensitive to ambiguities in the definition of a homeless shelter, but longitudinal patterns appear robust to these differences. Nationally, the share of all homeless shelter beds that are in transitional housing falls between the shares in Los Angeles and Houston, at about 50 percent in 2010 (U.S. Department of Housing and Urban Development 2010). We might therefore expect our national estimates based on the Census sheltered homeless samples to indicate levels of income and program receipt that are slightly lower than one might obtain if using national HMIS data. Our findings suggest, however, that the Census definition of a homeless shelter identifies a somewhat more deprived segment of the population than the HMIS definition.

6.4 Robustness to Alternative ACS and Census Samples

We describe further checks on our findings' robustness to alternative samples, linkage methods, and years in detail in Appendix A. Our main findings are robust to the use of sheltered homeless samples from the 2010-2014 ACS, suggesting that the patterns we observe generalize beyond those who were homeless in 2010. Comparisons between Census and ACS samples also support the validity of our use of inverse probability weights to adjust for non-linkage in the Census because the ACS has higher linkage rates due to more complete personal information and because the ACS's inverse probability weighting model includes a wealth of additional predictors relative to the Census, including self-reported income and benefit receipt. We also find that key results are

robust to the inclusion of those counted during the Census's overnight enumeration at unsheltered locations (a group we excluded from main analyses due to their exceptionally low linkage rate of 17 percent) and to the exclusion of people who were counted at both homeless locations and in housing during the Census (a group which might be thought to include individuals who were misclassified as homeless when they were in fact housed). Finally, we address concerns over potential bias in longitudinal SNAP receipt arising from migration by calculating longitudinal SNAP receipt using a subset of the Census homeless population that we consider less likely to have moved states in the years surrounding 2010. The peak in SNAP receipt in 2010 from our main analyses is somewhat attenuated in this migration-adjusted sample, but remains notable, suggesting that only a small share of this peak reflects bias due to migration between states for which we do and do not have SNAP enrollment data.

7. Comparisons to Past Work

We compare our findings to three key prior studies on the income, employment, and safety net participation of the U.S. homeless population: the NSHAPC survey, Metraux et al. (2018), and Von Wachter et al. (2020). The NSHAPC survey interviewed a random sample of 4,200 users of homeless services in 1996, including people who were homeless at the time of the interview and some who had recently been homeless (Burt et al. 2001). Its advantages lie in its nationally representative nature and detailed measures of self-reported income and program receipt, but three decades have passed since this survey was conducted. More recently, Metraux et al. (2018) base their analyses on a sample of 161,000 New York shelter users with first observed HMIS enrollments in 1990-2002 and Von Wachter et al. (2020)'s sample consists of 137,000 Los Angeles shelter users with first observed HMIS enrollments in 2010-2018. Metraux et al. (2018) link their sample to Social Security Administration (SSA) earnings data and Von Wachter et al. (2020) link their sample to California Unemployment Insurance (UI) wage records. These studies benefit from large samples and accurate earnings data but are limited to a single income source (earnings – and only in-state wages in the latter study), do not include people who are unsheltered homeless, and may not generalize outside of the cities in which they were conducted.

Table 4 summarizes the main findings from these studies alongside the most comparable estimates available in our study. They include estimates for the pooled Census sheltered and unsheltered in Column (1) to facilitate comparisons with NSHAPC and estimates for the sheltered

homeless only in Column (3) to facilitate comparisons with Metraux et al. (2018) and Von Wachter et al. (2020). We also indicate employment rates and Medicaid receipt for single adults and those in families (from our pooled Los Angeles and Houston HMIS samples) to compare differences by family status to the results in prior work. We report all dollar amounts in 2018 dollars. While we have so far emphasized percentiles of income in this study, in this section we report mean income amounts to align estimates based on the Census homeless with prior studies' results.

Our estimates of formal income and earnings in the year observed as homeless exceed the estimates in prior studies. Mean pre-tax cash income for the pooled Census sheltered and unsheltered homeless, including the value of SSI payments, is about $10,900, nearly $4,000 greater than the $7,100 average income reported in NSHAPC.[21] We also calculate mean annual earnings among workers to be nearly $6,000 higher than in Metraux et al. (2018) and $3,500 higher than in Von Wachter et al. (2020), differences that could reflect the studies' different timeframes, geographic coverage, or sample selection. We also find higher rates of employment in the sheltered homeless population than those suggested by Metraux et al. (2018) and Von Wachter et al. (2020). Fifty-two percent of the Census sheltered homeless were employed in the year observed as homeless, compared to just 42 percent of shelter users in Metraux et al. (2018) and 29 percent of those in Von Wachter et al. (2020). Low employment rates in this latter study may in part reflect the incomplete coverage of their earnings data, which consist of Unemployment Insurance (UI) wage records exclusively from California.

Comparisons with prior work also suggest a reversal in employment rates between single homeless adults and homeless adults with partners or children over the past three decades. Both NSHAPC and Metraux et al. (2018), studies that relied primarily on homeless samples from the 1990s, found substantially higher employment among unaccompanied adults than those with partners or children, with the first group being predominantly male and the latter group consisting primarily of single mothers. In contrast, our estimates based on 2012-2013 HMIS data from Los Angeles and Houston and Von Wachter et al. (2020)'s estimates based on Los Angeles HMIS data from 2010-2018 indicate substantially higher employment for adults in families than for unaccompanied adults. The reversal in employment rates by family status between the 1990s and

[21] In New York, where we have access to TANF/GA data, we estimate mean pre-tax cash income including these cash benefits to be about $12,700. We note, however, that New York's cash assistance programs tend to be more generous than in other states.

2010s may reflect well-established patterns of increasing labor supply among single mothers since the 1990s. Prior studies have shown that this trend in the broader low-income population appears to be driven primarily by the Earned Income Tax Credit (EITC) and other tax changes, but also in part by cuts to welfare benefits and similar programs (Meyer and Rosenbaum 2001, Grogger 2003).

Finally, we compare safety net participation in our study to that reported in the NSHAPC.[22] Pooling the sheltered and unsheltered Census samples, we estimate that about 86 percent of those experiencing homelessness in 2010 received at least one benefit that year, including about 77 percent of people who received SNAP. In NSHAPC, just 40 percent of those experiencing homelessness reported receiving at least one benefit, including 37 percent receiving SNAP. We find higher receipt rates for all benefits: 24 percent were enrolled in SSI (compared to 11 percent in NSHAPC), 46 percent were enrolled in Medicaid (compared to 30 percent in NSHAPC), and 48 percent were enrolled in in TANF or GA in New York (compared to 19 percent of the U.S. homeless population enrolled in in AFDC in NSHAPC). Some of these differences may be driven by the underreporting of benefit receipt in the survey, but our findings in Section 5 suggest that such misreporting – while undoubtedly present – is unlikely to be of sufficient magnitude to explain such large differences. Furthermore, our annual measures of benefit receipt are higher by construction than NSHAPC's contemporaneous receipt measures, but such timeframe misalignment is unlikely to explain all of the differences we observe. Higher program receipt in the 2010 Census homeless population appears to reflect, at least in part, a true increase in connections to the safety net for this population since the 1990s.

In summary, our analyses are qualitatively consistent with past studies in demonstrating the dire economic circumstances of people experiencing homelessness. At the same time, we show that these individuals have somewhat greater incomes, employment, and connections to the safety net than previously understood. Differences between our estimates and those in prior work likely reflect some combination of true changes over time – including an apparent rise in employment among homeless mothers and increasing program receipt in recent decades – as well as the improvements to accuracy that come from using administrative data rather than self-reported outcomes, as has been well-established in the broader literature on poverty measurement (e.g.,

[22] A caveat is that the NSHAPC reports contemporaneous program receipt at the time of interview, while our estimates indicate program receipt at any point in the calendar year.

Meyer, Mok, and Sullivan 2015). At the same time, we caution that these findings do not necessarily mean that this population is less deprived than previously thought. Homelessness itself is an unambiguous indicator of severe deprivation, so there can be no doubt that people experiencing homelessness are severely deprived. Rather, these comparisons further underscore that people experience homelessness because they are very poor despite being connected to formal work and the safety net, not because they are disconnected from these sources of income.

8. Conclusions

This paper provides the most detailed and accurate description to date of the level and persistence of material deprivation among people experiencing homelessness in the United States, including the first-ever national estimates of income, employment, and safety net participation based on administrative data. We find that this population is highly connected to work and the safety net, with nearly all sheltered homeless adults (97 percent) and the vast majority of unsheltered homeless adults (93 percent) having received at least one benefit or been formally employed in the year they were observed as homeless. Pooling together the sheltered and unsheltered samples, we find that half of these individuals (46 percent) had formal employment in the year they were observed as homeless, more than three-quarters received food assistance from SNAP (77 percent), and many were enrolled in Medicaid (43 percent) or received disability assistance through SSI or DI (24 percent). At the same time, formal incomes were very low: the median annual value of our most comprehensive resource measure – cash income plus the value of in-kind transfers from SNAP and HUD – was just $7,500 for the sheltered homeless and $5,500 for the unsheltered homeless in 2010. As these findings illustrate, people with very low incomes remain vulnerable to homelessness even when they are connected to formal labor markets and the social safety net. Conversely, connecting people to formal employment and these social safety net programs are unlikely to be sufficient policies for preventing or reducing homelessness.

Our longitudinal analyses suggest that deprivation is highly persistent in this population, with little change in median incomes over the four years prior to and six years after an individual is observed as homeless in 2010. Employment declines steadily between 2005 and 2016, with only a small and transitory drop relative to this long-term trend in the years preceding an observed period of homelessness in 2010. Long-term declines in employment are accompanied by increasing disability program receipt, with enrollment in SSI or DI increasing from 24 to 37 percent

between 2010 and 2016. Taken together, these results suggest that homelessness tends to arise in the context of long-term, severe deprivation, including declining employment and increasing disability program receipt, rather than large and sudden losses of employment or benefit income. Put differently, our results suggest that extremely low permanent incomes translate into heightened vulnerability to homelessness, leaving individuals with few resources to buffer against the loss of housing when met with even a relatively modest disruption to their income or life circumstances.

Perhaps surprisingly, we observe a high degree of similarity in the material circumstances of people experiencing sheltered homelessness and unmarried poor individuals who are housed but share their demographic profile (i.e., disproportionately male, Black, and in their 40s and 50s). Both groups have persistently very low incomes and high benefit receipt. Although median annual incomes are higher among the housed poor, there is substantial overlap between these groups' income distributions, with at least a quarter of sheltered homeless adults having incomes that exceed the median income in the housed poor comparison group. Adults in our sheltered homeless sample even had slightly *higher* rates of employment than the single housed poor in the years leading up to 2010. These analyses highlight the severe income-related deprivation faced by this segment of the housed population, a group that tends to receive less attention in academic and policy discussions about poverty alleviation than single mothers and children.

At the same time, substantial overlap in the economic circumstances of sheltered homeless and housed poor individuals raises the question of what factors, unobserved in our data, cause some individuals to become homeless while others remain housed. With only about 600,000 people experiencing literal homelessness in the U.S. at a point in time (Meyer et al. 2023), homelessness remains a rare event even among those who are very poor. Differences in permanent incomes and connections to formal work and the safety net do not appear to be the predominant factors distinguishing those who experience homelessness from the single housed poor. Alternative explanations may center on the role of behavioral health conditions and substance abuse disorders, the strength of social ties and affluence of one's social network, and the bad luck of experiencing non-income shocks to life circumstances. Understanding what non-income factors raise or lower an individual's probability of becoming homeless can shed light on the most effective prevention measures and inform the targeting of such interventions. Extreme poverty appears to be just one part of the broader puzzle of what put someone at risk of homelessness.

An important caveat on our longitudinal analyses is that we describe patterns in the central tendencies of income, employment, and safety net participation in the U.S. homeless population over time, but we do not examine individual dynamics in these outcomes. This approach yields useful summary measures of the level of deprivation in this population and how this level changes on average across years, but it does not allow us to describe individual-level variability in these outcomes. In future work, we plan to examine individual income dynamics surrounding an observed period of homelessness to characterize the extent of income volatility associated with homelessness and to understand heterogeneity in dynamic patterns. These analyses will shed light on whether policies aimed at increasing permanent incomes (or, equivalently, lowering housing costs) or policies aimed at reducing the volatility of income (or, equivalently, reducing the volatility of housing costs) will be more effective prevention measures.

Another limitation of our study is that we do not observe the duration of spells of homelessness for those in our Census samples. HUD's best estimates, which are based on surveys of likely uneven quality conducted by local service providers, suggest that only about one-quarter of people who are literally homeless at a point in time face extended or repeated long-term spells of homelessness (U.S. Department of Housing and Urban Development 2022). In other words, we expect most people in our Census sample to have been housed for much of the decade surrounding 2010. Yet our findings do not suggest that 2010 was major aberration in these individuals' long-term economic trajectories; they face similar levels of material deprivation even in years where we expect most of them to have been housed. Moreover, our analyses using HMIS data demonstrate the remarkable robustness of key findings to the use of samples designed to include a smaller share of those with longer or more frequent spells of homelessness. Literal homelessness is a severe hardship that rightly draws widespread concern, but the context of persistent, extreme poverty within which homelessness arises – poverty that is less visible than literal homelessness, and hence less likely to capture the attention of policymakers – may be just as alarming and deserving of humanitarian concern.

This paper adds to an emerging portrait of the life circumstances of people who experience homelessness in the United States based on large, national samples linked to administrative data. Recent work has documented the substantially elevated mortality risk associated with homelessness (Meyer, Wyse, and Logani 2023), and ongoing analyses seek to understand homeless individuals' patterns of housing status transitions, migration histories, and the effects of safety net

programs on health and wellbeing. These pathbreaking analyses are informing efforts to understand the causes and consequences of homelessness and to identify the most effective strategies for improving the lives of this exceptionally deprived and ill-understood segment of the U.S. population.

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10. Tables

Table 1: Characteristics of Census Homeless and Housed Comparison Groups (Ages 25-59 in 2010)

	Sheltered Homeless (1)	Unsheltered Homeless (2)	Single Housed Poor (3)	Overall Housed (4)
Age (mean)	43.48	44.43	43.85	42.35
Age 25-29	0.11	0.09	0.10	0.14
Age 30-39	0.22	0.20	0.21	0.27
Age 40-49	0.34	0.36	0.35	0.30
Age 50-59	0.33	0.35	0.34	0.29
Male	0.67	0.74	0.70	0.49
White	0.49	0.52	0.50	0.76
Black	0.40	0.38	0.39	0.13
Other race	0.04	0.04	0.10	0.11
Hispanic	0.14	0.15	0.15	0.15
Sample Size	89,500	49,500	55,000	994,000
Population	128,400	118,200	4,846,000	72,270,000
Share Assigned Linkage Key (PIK)	0.69	0.42	0.86	0.91

Sources: 2010 Census, 2010 ACS

Notes: Homeless and housed samples as defined in the text.

Table 2a: Income and Earnings (Homeless and Single Housed Poor, Ages 25-59)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
50th Percentile of Income Including the Value of In-Kind Transfers from SNAP and HUD (No SSI)												
Sheltered Homeless	$5,634	$5,029	$4,564	$3,177	$2,835	$3,948	$4,414	$3,906	$3,947	$3,527	$4,041	$4,347
Unsheltered Homeless	$2,399	$2,484	$3,619	$2,264	$2,664	$2,710	$2,630	$2,579	$2,525	$2,389	$2,439	$2,417
Single Housed Poor	$7,158	$6,786	$9,937	$7,012	$6,169	$7,026	$7,356	$7,491	$7,545	$7,411	$7,532	$8,350
50th Percentile of Income Including the Value of In-Kind Transfers from SNAP and HUD (Including SSI)												
Sheltered Homeless						$7,461	$9,149	$9,289	$9,441	$9,325		$9,518
Unsheltered Homeless						$5,479	$5,950	$6,101	$6,419	$6,303		$7,571
Single Housed Poor						$9,886	$10,140	$10,450	$10,660	$10,500		$11,030
Employment												
Sheltered Homeless	0.622	0.620	0.605	0.579	0.501	0.518	0.496	0.462	0.454	0.438	0.435	0.437
Unsheltered Homeless	0.559	0.546	0.527	0.493	0.418	0.403	0.389	0.359	0.357	0.339	0.339	0.341
Single Housed Poor	0.611	0.596	0.582	0.553	0.484	0.483	0.498	0.493	0.489	0.488	0.489	0.487
Earnings (Conditional on Employed)												
Sheltered Homeless	$9,493	$9,534	$9,327	$8,039	$6,590	$8,328	$10,870	$11,170	$11,380	$11,820	$12,860	$13,470
Unsheltered Homeless	$8,377	$8,483	$8,514	$7,847	$7,373	$8,298	$10,120	$10,310	$10,620	$11,020	$12,020	$12,320
Single Housed Poor	$14,510	$14,920	$14,230	$12,790	$10,690	$12,240	$13,890	$14,930	$15,830	$16,460	$17,650	$18,560
Sample Size												
Sheltered Homeless	89,500	89,500	89,500	89,500	89,500	89,500	89,000	88,000	86,500	85,500	84,500	83,000
Unsheltered Homeless	49,500	49,500	49,500	49,500	49,500	49,500	49,000	48,500	48,000	47,000	46,500	45,500
Single Housed Poor	55,000	55,000	55,000	55,000	55,000	55,000	54,500	54,000	54,000	53,500	53,000	52,500
Population												
Sheltered Homeless	128,400	128,400	128,400	128,400	128,400	128,400	127,500	126,000	124,400	122,800	121,100	119,100
Unsheltered Homeless	118,200	118,200	118,200	118,200	118,200	118,200	117,300	115,900	114,400	112,700	110,900	108,900
Single Housed Poor (1000s)	4,846	4,846	4,846	4,846	4,846	4,846	4,814	4,770	4,718	4,672	4,616	4,560

Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: See notes on Tables A1-A6 for full definition of each outcome measure. Samples include PIKed adults with a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Homeless and housed samples as defined in text. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table 2b: Benefit Receipt (Homeless and Single Housed Poor, Ages 25-59)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
SSI Receipt														
Sheltered Homeless								0.137	0.176	0.201	0.210	0.213		0.225
Unshelt. Homeless								0.210	0.234	0.255	0.260	0.260		0.270
Single Housed Poor								0.157	0.166	0.174	0.176	0.173		0.174
DI Receipt														
Sheltered Homeless				0.058	0.063	0.069	0.074	0.089	0.112	0.136	0.153	0.164	0.166	0.167
Unshelt. Homeless				0.105	0.114	0.122	0.129	0.145	0.160	0.174	0.187	0.196	0.194	0.191
Single Housed Poor				0.095	0.104	0.114	0.122	0.142	0.157	0.169	0.178	0.183	0.179	0.177
HUD Housing Assistance														
Sheltered Homeless	0.083	0.083	0.082	0.078	0.074	0.071	0.068	0.101	0.126	0.143	0.146	0.154	0.161	0.165
Unshelt. Homeless	0.082	0.084	0.083	0.081	0.081	0.082	0.083	0.094	0.104	0.111	0.116	0.122	0.128	0.132
Single Housed Poor	0.113	0.116	0.119	0.123	0.131	0.140	0.152	0.160	0.158	0.154	0.149	0.148	0.144	0.141
VA Service-Connected Disability Receipt														
Sheltered Homeless					0.015	0.017	0.023	0.026	0.029	0.031	0.033	0.034	0.035	0.036
Unshelt. Homeless					0.014	0.014	0.017	0.018	0.020	0.021	0.022	0.023	0.024	0.025
Single Housed Poor					0.011	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021
SNAP Receipt														
Sheltered Homeless			0.358	0.382	0.538	0.600	0.738	0.826	0.786	0.737	0.707	0.681	0.652	0.628
Unshelt. Homeless			0.413	0.428	0.503	0.560	0.636	0.695	0.683	0.666	0.658	0.647	0.631	0.610
Single Housed Poor			0.374	0.408	0.437	0.473	0.548	0.595	0.594	0.575	0.558	0.549	0.528	0.507
Medicaid Receipt														
Sheltered Homeless					0.315	0.333	0.376	0.445	0.473	0.488	0.492	0.612	0.661	
Unshelt. Homeless					0.328	0.348	0.374	0.414	0.446	0.470	0.476	0.614	0.683	
Single Housed Poor					0.322	0.338	0.371	0.398	0.414	0.420	0.421	0.503	0.540	
TANF and GA Receipt (New York Only)														
Sheltered Homeless					0.333	0.361	0.469	0.584	0.486	0.396	0.343	0.303	0.289	0.275
Unshelt. Homeless					0.219	0.264	0.285	0.302	0.267	0.251	0.239	0.228	0.213	0.199
Single Housed Poor					0.183	0.182	0.186	0.191	0.162	0.145	0.122	0.113	0.109	0.103
Sample Size														
Sheltered Homeless	89,500	89,500	89,500	89,500	89,500	89,500	89,500	89,500	89,000	88,000	86,500	85,500	84,500	83,000
Unsheltered Homeless	49,500	49,500	49,500	49,500	49,500	49,500	49,500	49,500	49,000	48,500	48,000	47,000	46,500	45,500
Single Housed Poor	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	54,500	54,000	54,000	53,500	53,000	52,500
Population														
Sheltered Homeless	128,400	128,400	128,400	128,400	128,400	128,400	128,400	128,400	127,500	126,000	124,400	122,800	121,100	119,100
Unsheltered Homeless	118,200	118,200	118,200	118,200	118,200	118,200	118,200	118,200	117,300	115,900	114,400	112,700	110,900	108,900
Single Housed Poor (1000s)	4,846	4,846	4,846	4,846	4,846	4,846	4,846	4,846	4,814	4,770	4,718	4,672	4,616	4,560

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: See notes on Tables A1-A6 for full definition of each outcome measure. Samples include PIKed adults with a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Homeless and housed samples as defined in text. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table 3a: Share of Individuals Misreporting Date of Birth, Place of Birth, Gender, and Citizenship Status: 2011-2018 ACS

	Homeless 2011-2018			Single Housed Poor 2011-2018			Overall Housed 2011-2018		
	Share	(SE)	Obs.	Share	(SE)	Obs.	Share	(SE)	Obs.
Date of Birth									
MM/DD/YYYY is misreported	11.7%	0.004	18,000	10.2%	0.000	2,403,000	9.2%	0.000	34,600,000
MM/YYYY is misreported	10.6%	0.004	18,000	8.0%	0.000	2,403,000	7.1%	0.000	34,600,000
YYYY is misreported	10.0%	0.004	18,000	6.8%	0.000	2,403,000	6.0%	0.000	34,600,000
YYYY is misreported by 3 or more years	3.5%	0.002	18,000	4.0%	0.000	2,403,000	3.7%	0.000	34,600,000
Age									
Age is misreported	10.6%	0.004	18,500	8.1%	0.000	2,484,000	7.3%	0.000	35,660,000
Age is misreported by 3 or more years	3.5%	0.002	18,500	4.4%	0.000	2,484,000	4.1%	0.000	35,660,000
Mean age misreport (in years)	-0.01	0.011	18,500	-0.02	0.003	2,484,000	0.00	0.001	35,660,000
Mean absolute age misreport (in years)	0.25	0.011	18,500	0.58	0.003	2,484,000	0.55	0.001	35,660,000
Place of Birth									
State or country of birth is misreported	7.4%	0.003	17,500	5.1%	0.000	2,398,000	4.9%	0.000	33,990,000
Gender									
Gender is misreported	0.5%	0.001	20,000	3.0%	0.000	2,624,000	2.7%	0.000	37,030,000
Gender is misreported [Sample: Women in Numident]	0.6%	0.001	8,000	2.4%	0.000	1,577,000	2.7%	0.000	19,130,000
Gender is misreported [Sample: Men in Numident]	0.5%	0.001	12,000	3.7%	0.000	1,047,000	2.7%	0.000	17,900,000
Citizenship									
Citizenship is misreported	3.4%	0.002	19,500	3.0%	0.000	2,505,000	3.7%	0.000	35,410,000
False positive [Sample: Non-citizens in Numident]	22.9%	0.016	1,000	25.9%	0.001	118,200	35.5%	0.000	2,021,000
False negative [Sample: Citizens in Numident]	1.6%	0.002	18,500	1.1%	0.000	2,386,000	0.9%	0.000	33,390,000

Sources: 2006-2018 ACS, 2019 Social Security Administration Numident

Notes: Sample consists of PIKed individuals in the 2006-2018 ACS who link to the Social Security Administration's Numident file. Sample is further limited to observations in which the variable in question is non-blank in the Numident (e.g. for analyses of date of birth misreporting, the sample is limited to only observations for which the Numident contains date of birth data). We exclude observations in which the variable in question is hot-deck imputed in the ACS data and observations for which an alternative or edited version of the variable exists in the Numident.

Table 3b: Share of Individuals Misreporting Income and Receipt: 2011-2018 ACS

		Wage and Salary Income			SNAP		
		Homeless	Single Housed Poor	Overall Housed	Homeless	Single Housed Poor	Overall Housed
		2011-2016**	2011-2016	2011-2016	2011-2016**	2011-2016	2011-2016
Outcome	Sample	Mean or Rate	Mean or Rate	Mean or Rate	Mean or Rate	Mean or Rate	Mean or Rate
Survey>0, Administrative=0	Full population	0.044	0.050	0.048	0.049	0.024	0.010
		(0.006)	(0.001)	(0.000)	(0.006)	(0.000)	(0.000)
Survey=0, Administrative>0	Full population	0.177	0.123	0.055	0.172	0.097	0.054
		(0.013)	(0.001)	(0.000)	(0.009)	(0.001)	(0.000)
Survey>0, Administrative>0	Full population	0.234	0.317	0.664	0.668	0.516	0.131
		(0.013)	(0.001)	(0.000)	(0.012)	(0.002)	(0.000)
Survey=0, Administrative=0	Full population	0.545	0.510	0.233	0.111	0.363	0.805
		(0.016)	(0.002)	(0.000)	(0.008)	(0.001)	(0.000)
False Negative Rate	Administrative>0	0.432	0.280	0.077	0.205	0.158	0.290
		(0.025)	(0.002)	(0.000)	(0.011)	(0.002)	(0.001)
False Positive Rate	Administrative=0	0.075	0.089	0.172	0.307	0.063	0.012
		(0.010)	(0.001)	(0.001)	(0.031)	(0.001)	(0.000)
Administrative Receipt Rate	Full population	0.411	0.440	0.719	0.840	0.613	0.185
		(0.016)	(0.002)	(0.000)	(0.010)	(0.001)	(0.000)
Survey Receipt Rate	Full population	0.278	0.367	0.712	0.717	0.541	0.141
		(0.014)	(0.002)	(0.000)	(0.011)	(0.002)	(0.000)
Mean Reported ($)	Survey>0	$9,235	$8,414	$50,250			
		($519)	($31)	($52)			
Mean True ($)	Administrative>0	$7,980	$11,120	$48,250			
		($1,059)	($105)	($108)			
Mean True ($)	Survey>0, Administrative>0	$7,929	$11,550	$50,880			
		($524)	($87)	($113)			
Mean Absolute Misreport ($)	Survey>0, Administrative>0	$5,598	$5,316	$12,190			
		($468)	($79)	($98)			
Observations		1,900	173,000	2,833,000	3,300	181,000	1,933,000

		Medicaid			Medicare		
		Homeless	Single Housed Poor	Overall Housed	Homeless	Single Housed Poor	Overall Housed
Outcome	Sample	2011-2016**	2011-2016	2011-2016	2011-2016**	2011-2016	2011-2016
		Mean or Rate	Mean or Rate	Mean or Rate	Mean or Rate	Mean or Rate	Mean or Rate
Survey>0, Administrative=0	Full population	0.096	0.072	0.033	0.022	0.018	0.007
		(0.005)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)
Survey=0, Administrative>0	Full population	0.087	0.085	0.032	0.033	0.034	0.015
		(0.004)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)
Survey>0, Administrative>0	Full population	0.440	0.372	0.084	0.045	0.072	0.031
		(0.008)	(0.001)	(0.000)	(0.003)	(0.000)	(0.000)
Survey=0, Administrative=0	Full population	0.377	0.472	0.851	0.901	0.875	0.947
		(0.008)	(0.001)	(0.000)	(0.004)	(0.000)	(0.000)
False Negative Rate	Administrative>0	0.165	0.186	0.276	0.424	0.320	0.330
		(0.008)	(0.001)	(0.001)	(0.022)	(0.002)	(0.001)
False Positive Rate	Administrative=0	0.204	0.132	0.037	0.023	0.021	0.007
		(0.009)	(0.001)	(0.000)	(0.002)	(0.000)	(0.000)
Administrative Receipt Rate	Full population	0.527	0.456	0.117	0.078	0.107	0.047
		(0.008)	(0.001)	(0.000)	(0.003)	(0.000)	(0.000)
Survey Receipt Rate	Full population	0.536	0.443	0.117	0.066	0.091	0.038
		(0.008)	(0.001)	(0.000)	(0.003)	(0.000)	(0.000)
Observations		8,200	708,000	10,660,000	12,500	1,015,000	15,840,000

Sources: 2006-2017 ACS, 2006-2016 IRS 1040 Datasets, 2006-2016 IRS W-2 Datasets, Illinois 2009-2016 SNAP Datasets, Indiana 2005-2016 SNAP Datasets, New Jersey 2007-2016 SNAP Datasets, New York 2007-2016 SNAP Datasets, Tennessee 2005-2016 SNAP Datasets, various states' Medicaid data, CMS Medicare 2008-2016 Datasets

Notes: Sample is PIKed ACS respondents ages 18-64. Sample is limited to those who respondeded to the ACS survey in January or December, and imputed whole person observations are not included. Observations are weighted by the product of IPW weights and ACS person weights, and observations where wage and salary income are allocated are excluded. Wage and salary income is calculated from administrative datasets as the sum of wage and salary income (both taxable and deferred) across W-2s. Those with negative survey values for wage and salary income are assumed to have reported a wage and salary income of $0. Mean wage and dollar misreport amounts are reported in January 1, 2018 dollars. Standard errors are robust.

* Reference period: 2005-2010

** Reference period: 2010-2016

Table 4: Comparisons to Key Prior Studies: Income, Employment, and Safety Net Participation

	(1) Present study - pooled homeless	(2) NSHAPC (Burt et al. 2001)	(3) Present study - sheltered homeless	(4) Metraux et al. (2018)	(5) Von Wachter et al. (2020)
Sample Definition					
Homeless sample	Census sheltered and unsheltered homeless (pooled)	Service users (current and recent homeless)	Census sheltered homeless	People with first HMIS enrollment in year	People with first HMIS enrollment in year
Geographic coverage	National	National	National	New York	Los Angeles
Age range	25-59	17+	25-59	18+	18+
Year(s) observed as homeless	2010	1996	2010	1990-2002	2010-2018
Resource data source	Various administrative	Self-reported	Various administrative	SSA earnings data	UI records (California)
Characteristics					
Male	0.70	0.68	0.67	0.50	0.61
White[1]	0.50	0.41	0.49	0.08	0.24
Black	0.39	0.40	0.40	0.56	0.46
Other Race	0.11	0.19	0.04	0.36	0.30
Mean Income, Share Employed, and Mean Earnings in Year Observed as Homeless (2018 Dollars)					
Pre-tax cash income (sources not specified)	-	$7,080	-	-	-
Pre-tax cash income (no SSI or TANF/GA)	$9,196	-	$8,069	-	-
Pre-tax cash income (with SSI, no TANF/GA)[2]	$10,912	-	$9,811	-	-
Pre-tax cash income (with SSI and TANF/GA; NY only)	$12,709	-	$12,175	-	-
Employment Timeframe	*Calendar year*	*Last month*	*Calendar year*	*Year of enrollment*	*Past year*
Employment in month/year (All Adults)	0.46	0.44	0.52	0.42	0.29
Employment (Adults in Families)[3]	-	0.29	0.68	0.38	0.44
Employment (Adults not in Families)	-	0.46	0.43	0.45	0.25
Earnings (conditional on working)	$14,674		$13,510	$7,700	$9,970
Program Receipt in Year Observed as Homeless					
Any benefit	0.86	0.40	0.89	-	-
SSI	0.24	0.11	0.14	-	-
Food stamps	0.77	0.37	0.83	-	-
Medicaid (All Adults)	0.46	0.30	0.45	-	-
Medicaid (Adults in Families)	-	0.60	0.69	-	-
Medicaid (Adults not in Families)	-	0.25	0.26	-	-
AFDC/TANF or GA (NY only in Census samples)	0.48	0.19	0.58	-	-
Sample Size	139,000	4,200	89,500	160,525	136,726

Sources: Burt et al. (2001), Metraux et al. (2018), Von Wachter et al. (2020), present study

Notes: We inflation-adjust all dollar amounts to 2018 dollars using the Chained CPI for Urban Consumers (C-CPI-U).

[1]Metraux et al. (2018) and Von Wachter et al. (2020) indicate non-Hispanic white shares, while the Census and NSHAPC indicate Hispanic and non-Hispanic whites.

[2]Pre-tax cash income amounts reported in main tables do not include the value of SSI or TANF/GA from New York. We calculate pre-tax cash income with these benefits by adding the share receiving these benefits times the mean benefit amount conditional on receipt.

[3]Employment for adults in families/adults not in families for the present study is calculated by pooling the Los Angeles and Houston HMIS samples.

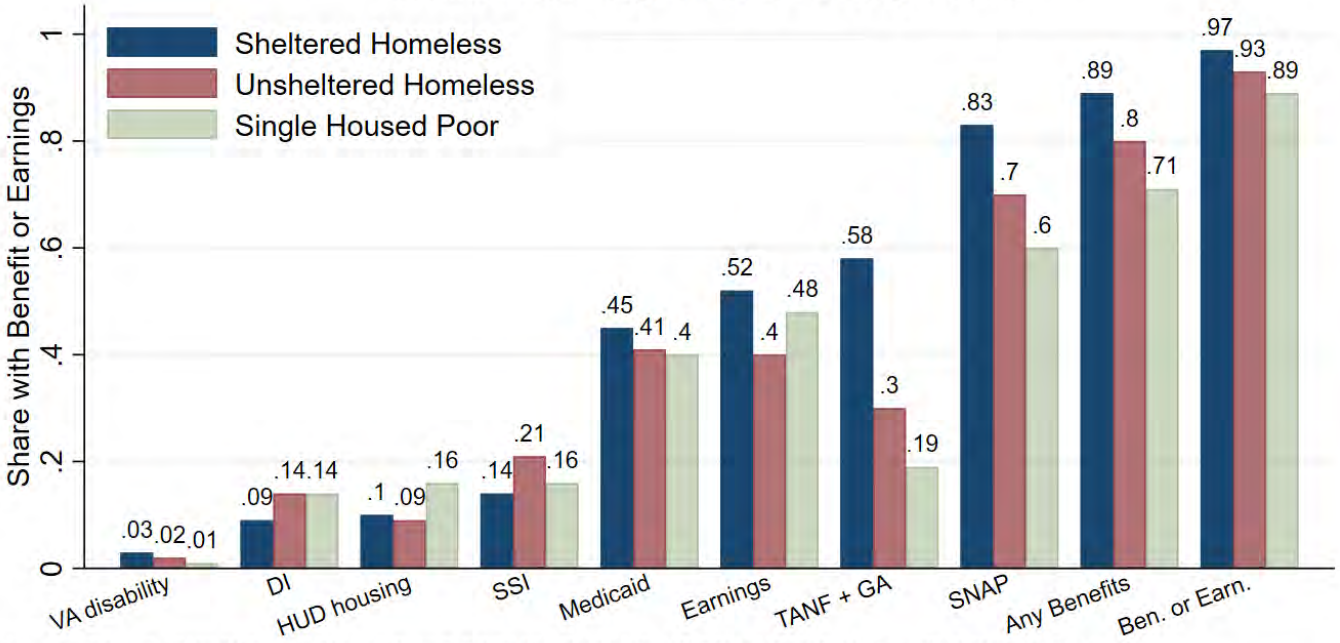
[4]We omit 2009 from the pre-period because we count people as homeless in the beginning of 2010, meaning that many individuals in our sample may have become homeless in 2009 rather than 2010.

[5]Von Wachter et al. (2020) do not report the share employed in the year after shelter entry. They only report earnings in the year after shelter entry. We report the change in employment as the share employed in the year prior to shelter entry minus the share employed in the year of shelter entry.

11. Figures

Figure 1a: Benefit Receipt and Earnings in 2010

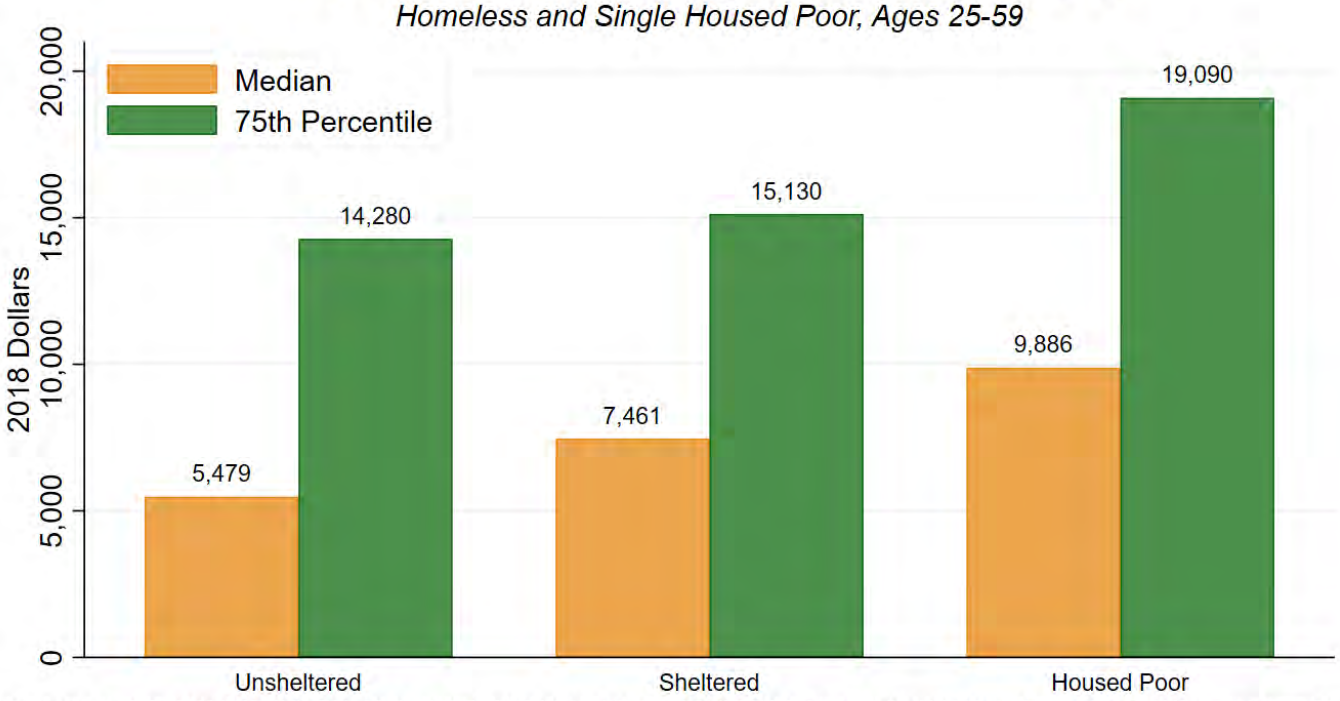
Homeless and Single Housed Poor, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), HUD PIC/TRACS (2003-2016), USVETS (2007-2015), Medicare (2006-2014), Medicaid (2007-2015), SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 1b: Income Including In-Kind Transfers in 2010

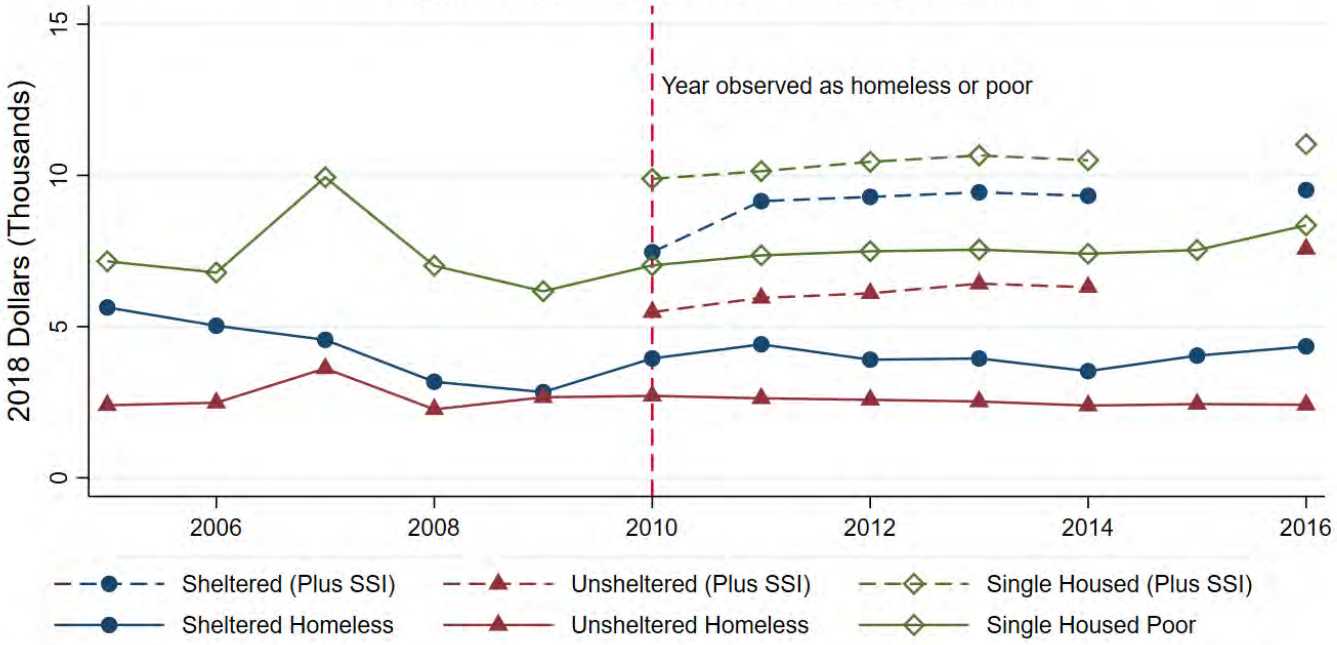
Homeless and Single Housed Poor, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 1099-Rs (2003-2015), HUD PIC/TRACS (2003-2016), USVETS (2007-2015) SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. In-kind transfers from SNAP and HUD.

Figure 2: Median Income Including In-Kind Transfers in 2005-2016

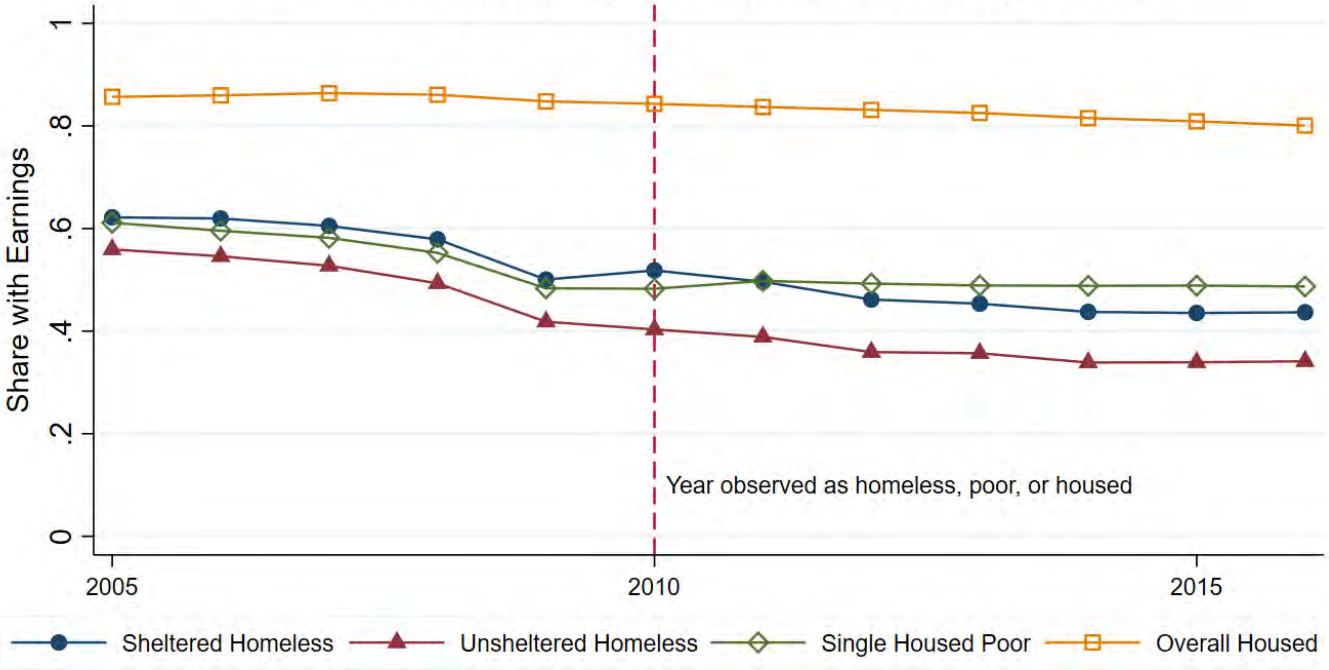
Homeless and Single Housed Poor, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), and 1099-Rs (2003-2015), HUD PIC/TRACS (2003-2016), USVETS (2007-2015), SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), SSI (2010-2014, 2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 3a: Share with Earnings, 2005-2016

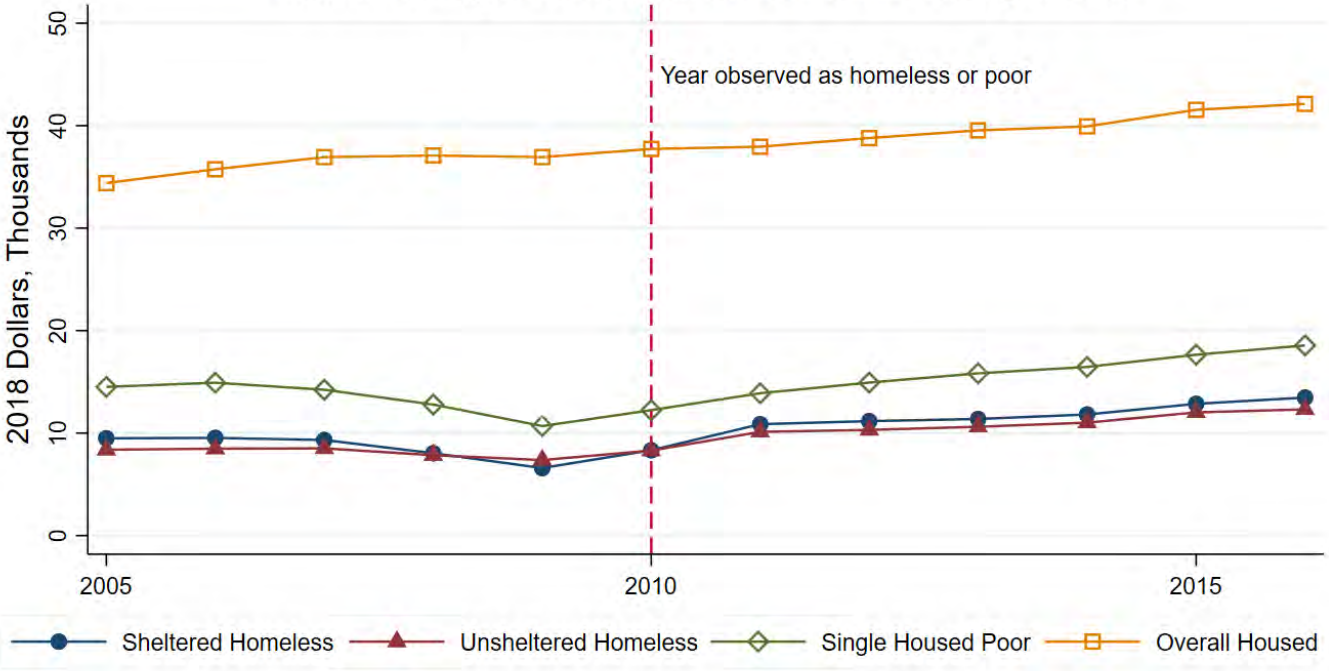
Homeless, Single Housed Poor, and Overall Housed, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 3b: Median Earnings (Conditional on Working), 2005-2016

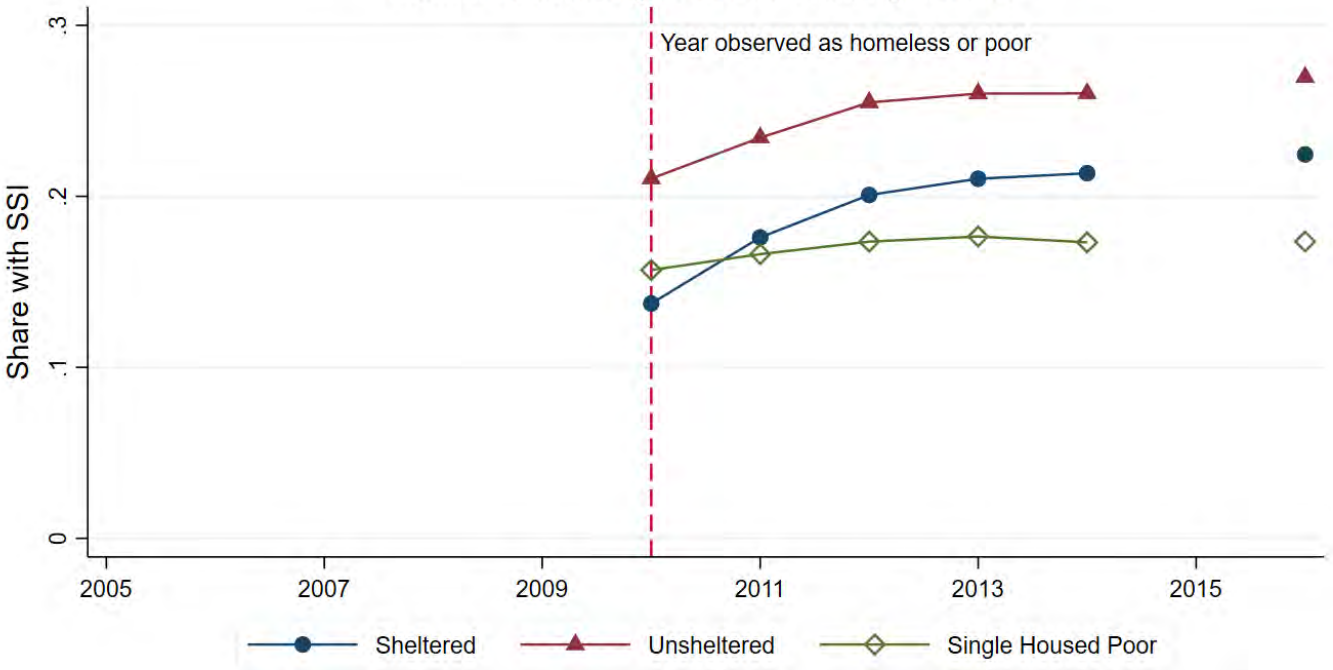
Homeless, Single Housed Poor, and Overall Housed, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 4a: SSI Receipt, 2010-2016

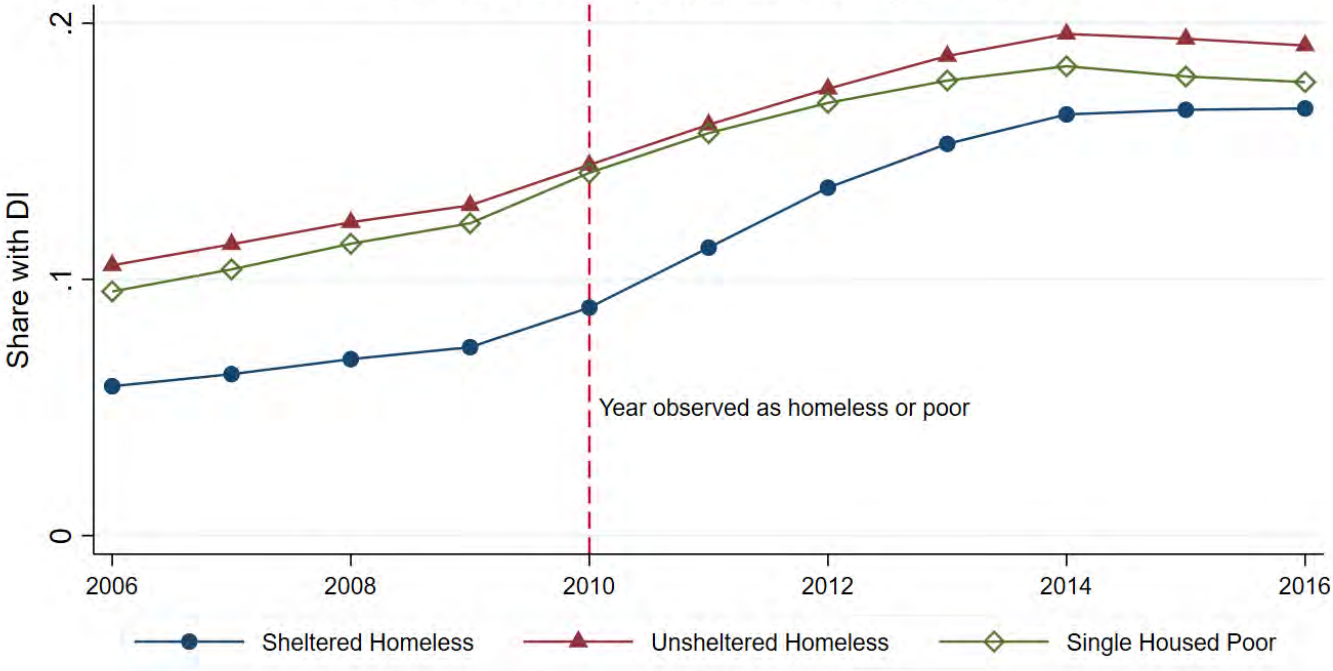
Homeless and Single Housed Poor, Ages 25-59



Sources: SSI Datasets (2010-2014, 2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 4b: DI Receipt (According to Medicare Records), 2006-2016

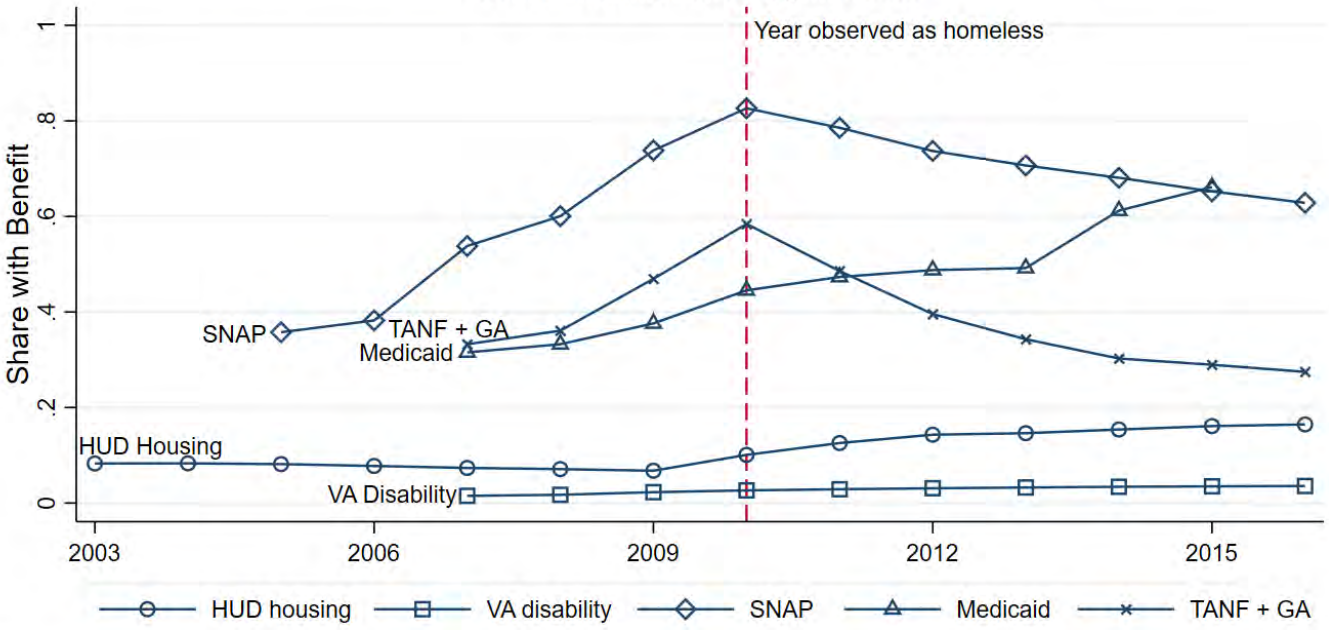
Homeless and Single Housed Poor, Ages 25-59



Sources: 2006-2016 Medicare Datasets, 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 5a: Program Receipt of Sheltered Homeless, 2003-2016

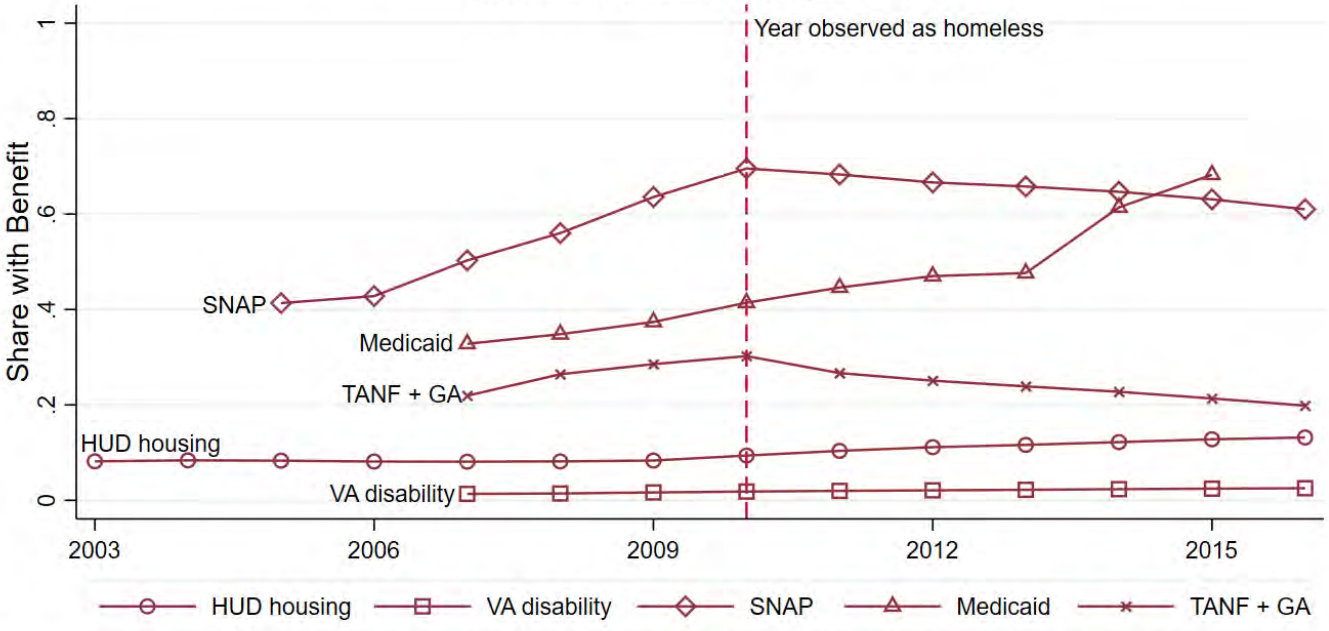
Sheltered Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), and 1099-Rs (2003-2015), HUD PIC/TRACS (2003-2016), USVETS (2007-2015), Medicare (2006-2014), Medicaid (2007-2015), SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 5b: Program Receipt of Sheltered Homeless, 2003-2016

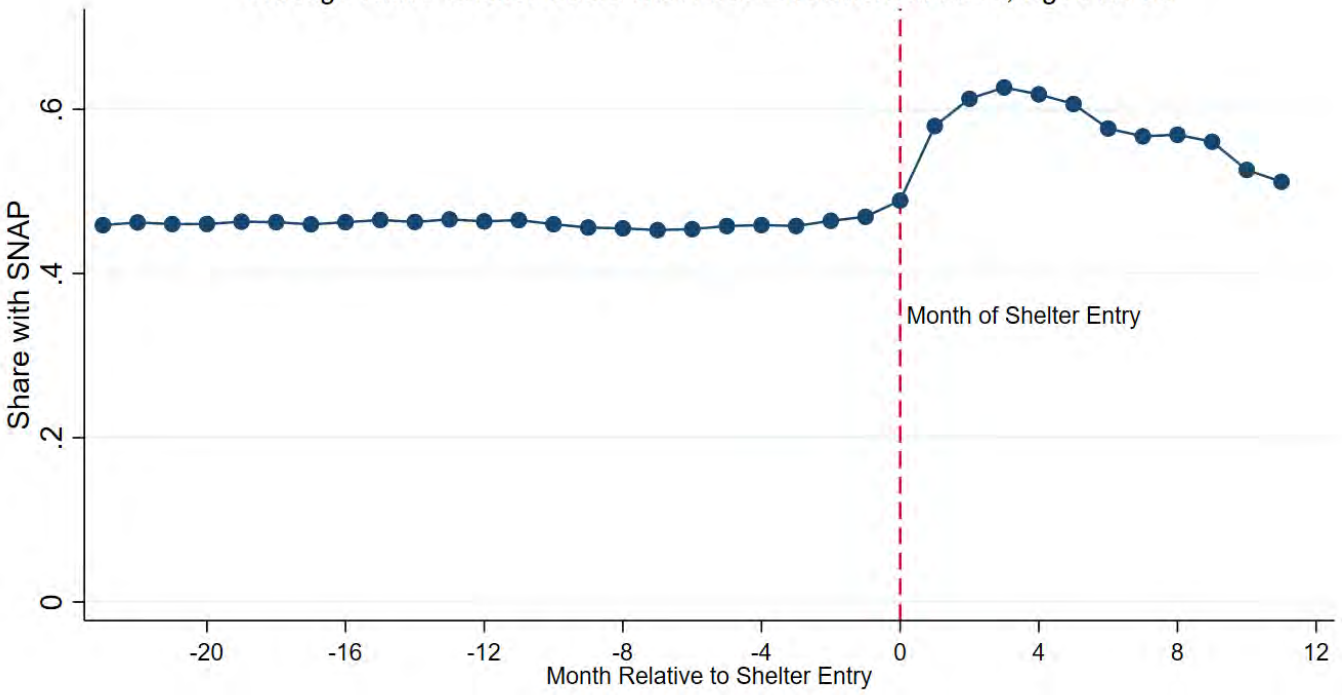
Unsheltered Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), and 1099-Rs (2003-2015), HUD PIC/TRACS (2003-2016), USVETS (2007-2015), Medicare (2006-2014), Medicaid (2007-2015), SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 6: Monthy SNAP Receipt in Chicago HMIS Data

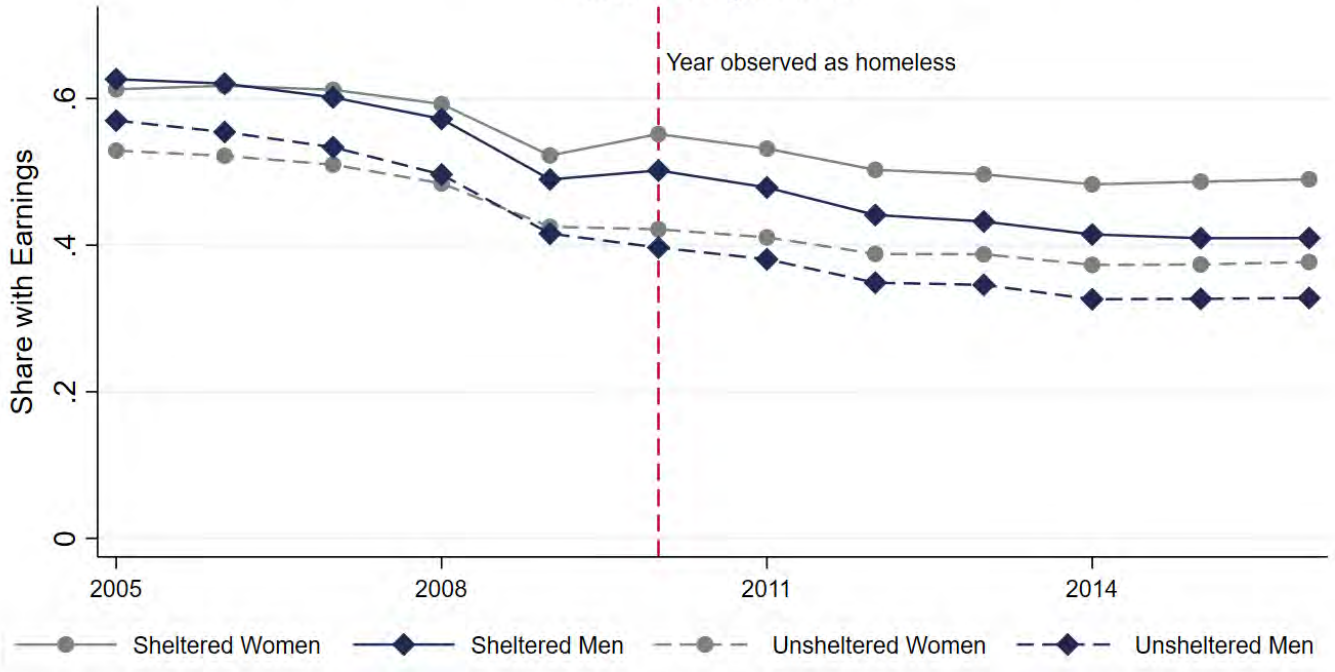
Chicago HMIS Shelter Users with First Enrollment in 2016, Ages 25-59



Sources: Chicago (2014-2019) HMIS dataset, Illinois SNAP dataset (2009-2016).
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 7a: Share with Earnings by Gender, 2005-2016

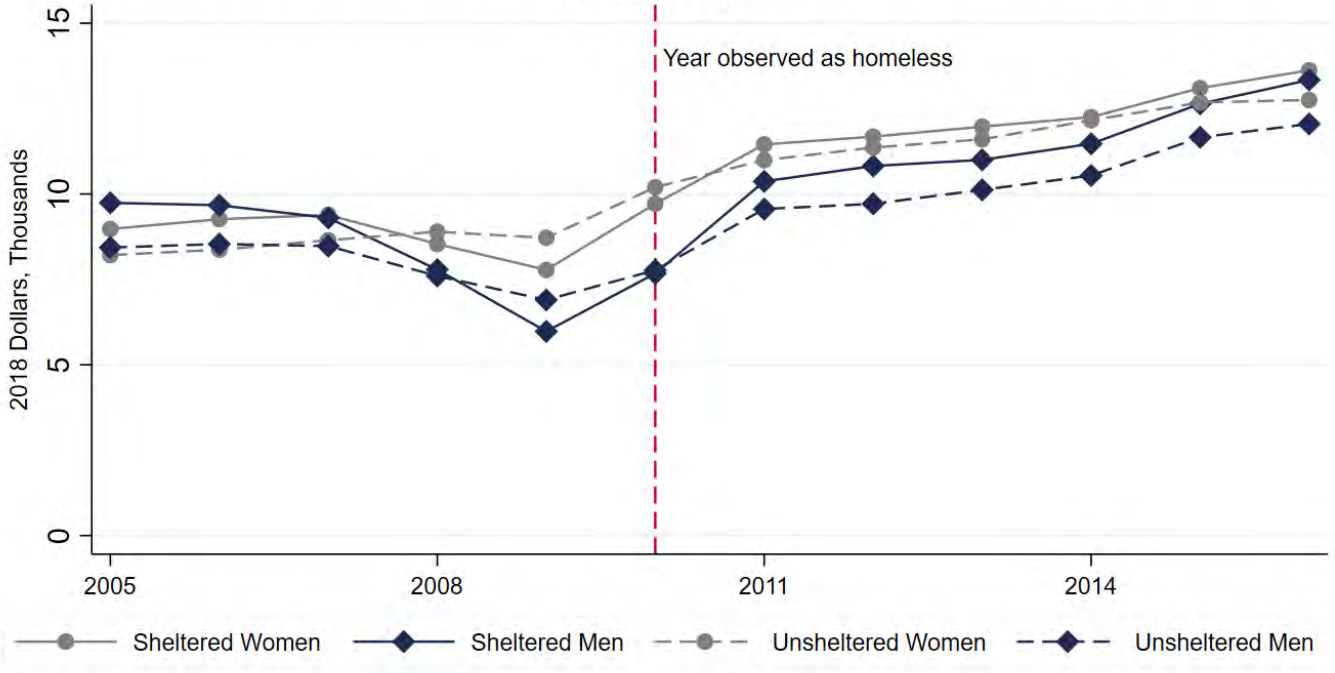
Homeless Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 7b: Median Earnings by Gender (Conditional on Working), 2005-2016

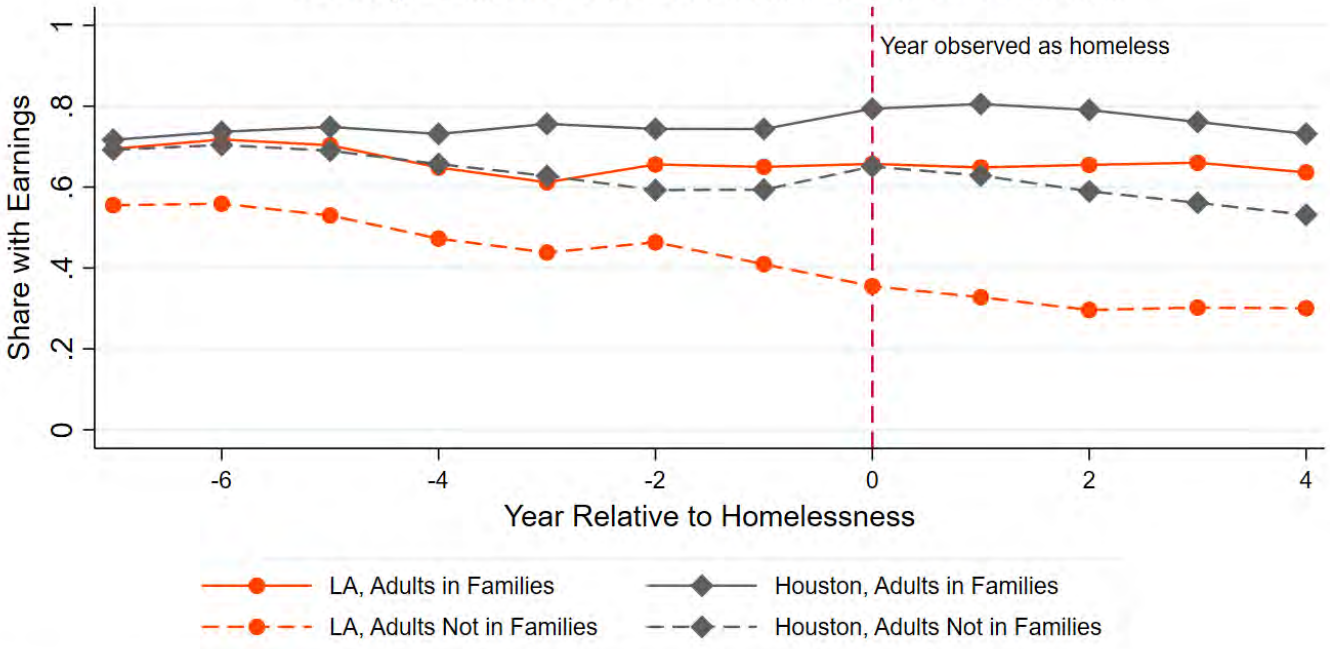
Homeless Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census, 2010 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 8: Share with Earnings by Family Status

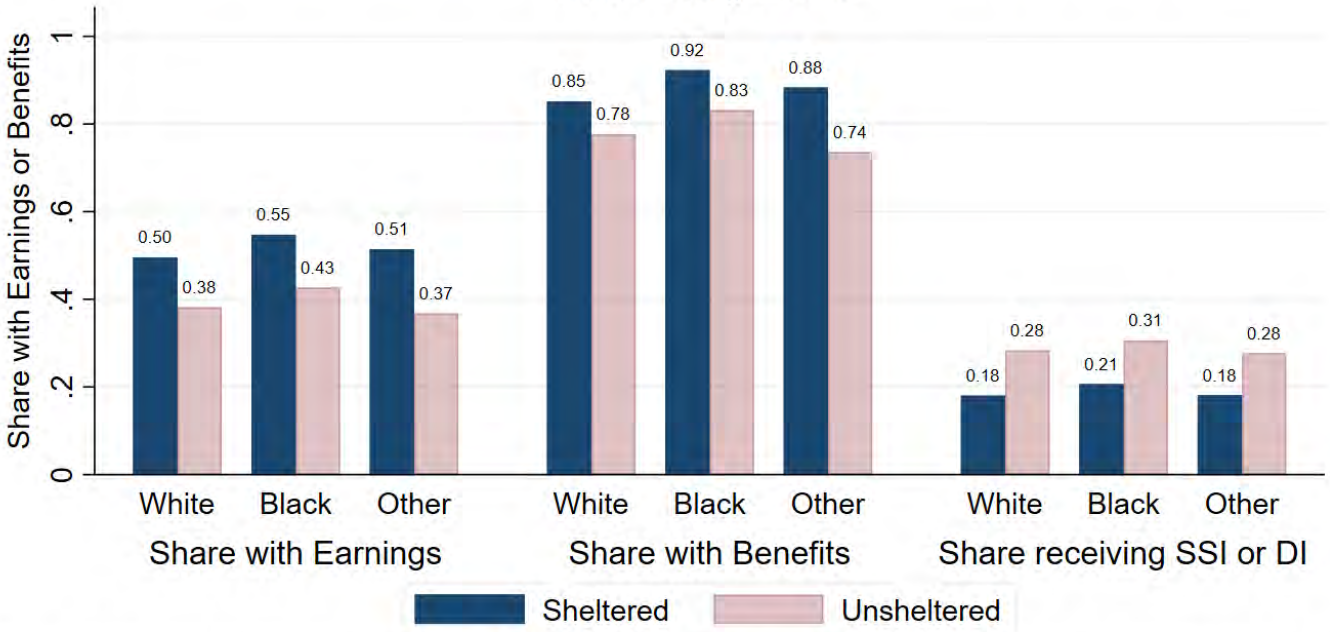
Los Angeles and Houston HMIS Shelter Users, 2012 and 2013



Sources: IRS 1040s (2003-2015), W2s (2005-2016), Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. Sample contains those enrolled in HMIS shelters on March 30, 2012 or 2013.

Figure 9a: Share with Earnings, Benefits, and Disability by Race, 2010

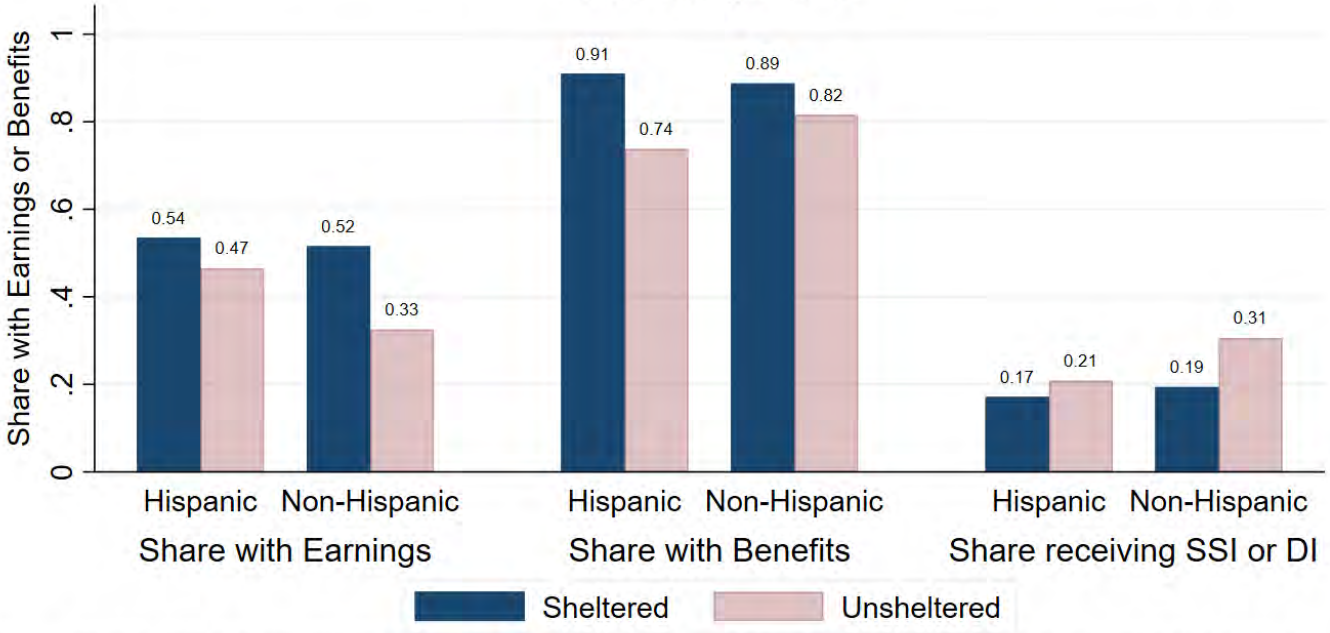
Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), and 1099-Rs (2003-2015), HUD PIC/TRACS (2003-2016), USVETS (2007-2015), Medicare (2006-2014), Medicaid (2007-2015), SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 9b: Share with Earnings, Benefits, and Disability by Ethnicity, 2010

Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), and 1099-Rs (2003-2015), HUD PIC/TRACS (2003-2016), USVETS (2007-2015), Medicare (2006-2014), Medicaid (2007-2015), SNAP for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 10a: Share with Earnings by State, 2010

Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 10b: Median Earnings (Conditional on Positive) by State, 2010

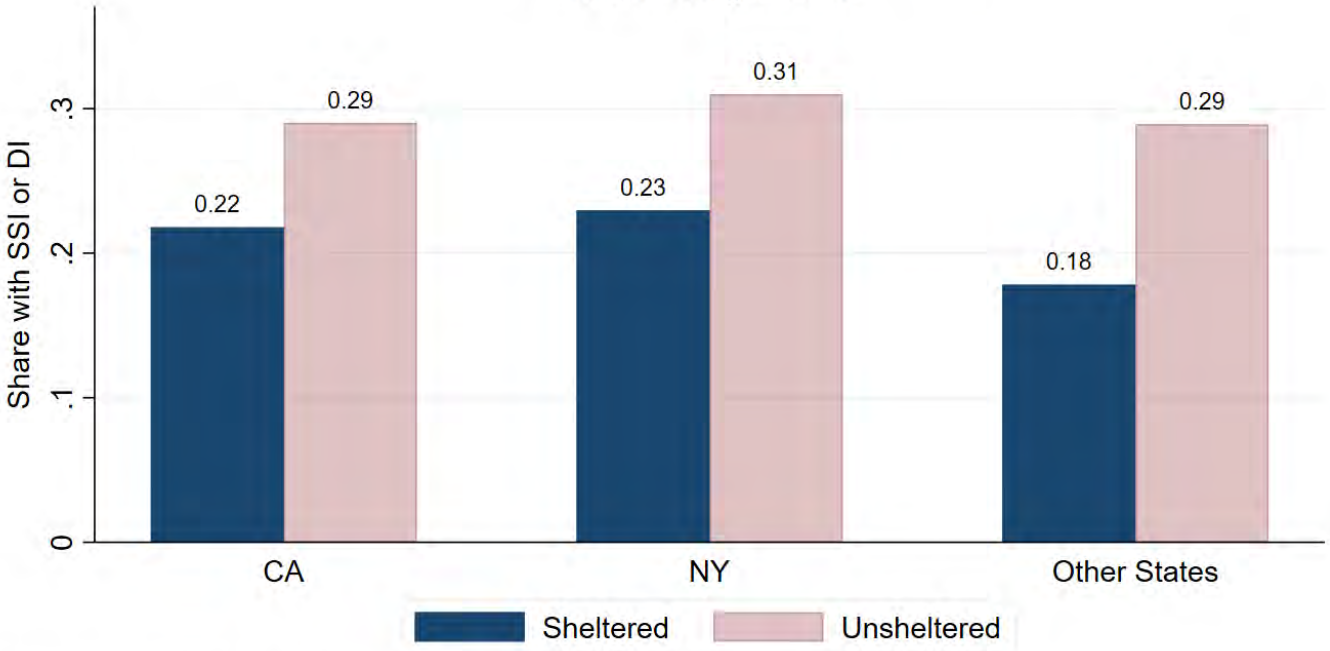
Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 10c: Share with SSI or DI by State, 2010

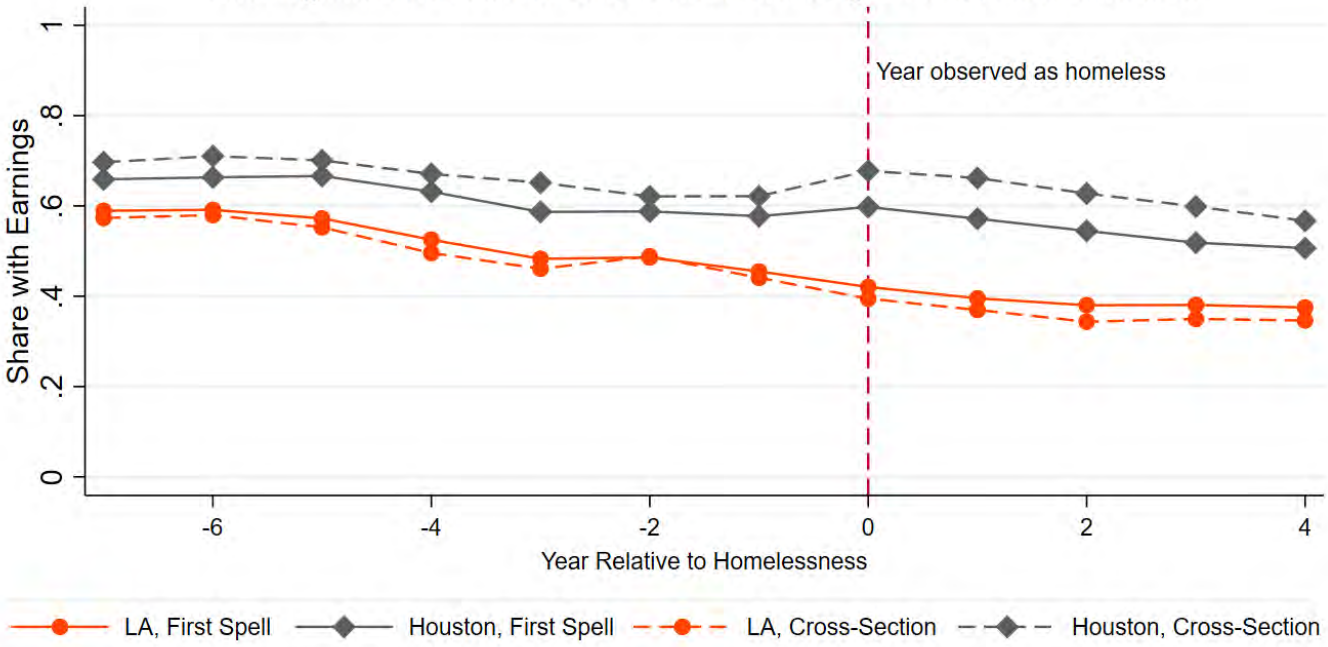
Homeless, Ages 25-59



Sources: Medicare (2006-2014), Medicaid (2007-2015), SSI (2010-2014, 2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure 11a: Share with Earnings in HMIS Data, Comparison of Sample Time-Frames

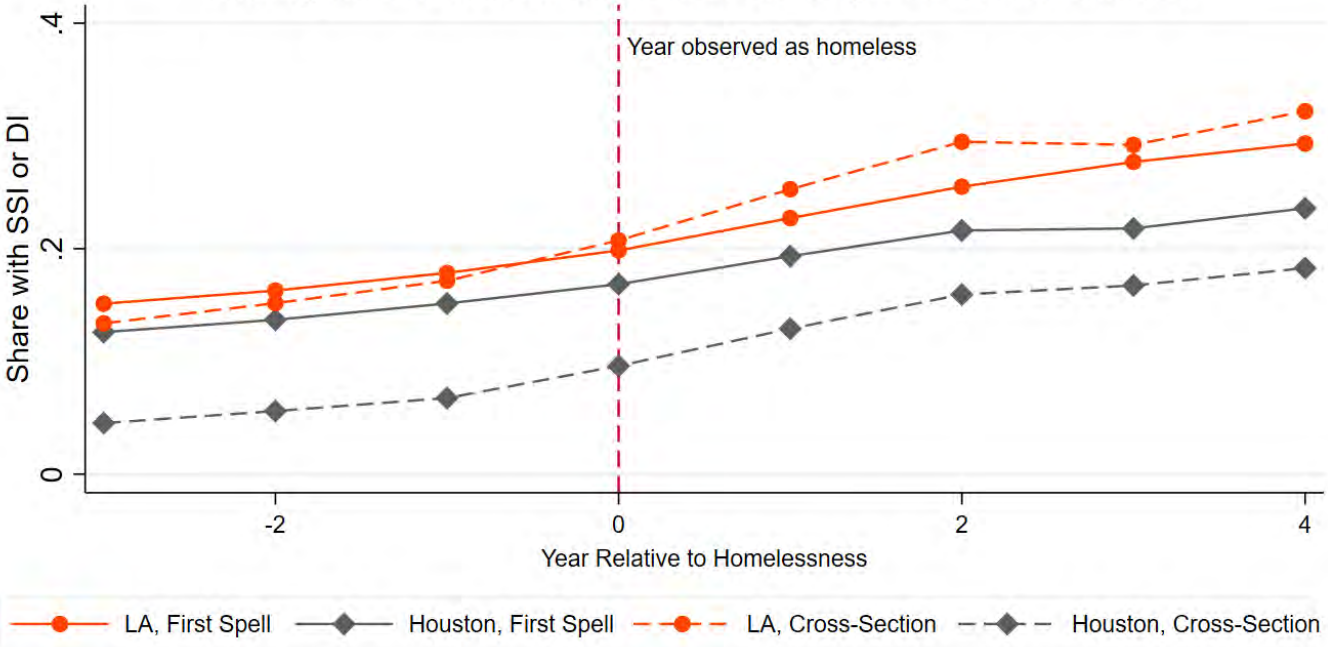
Los Angeles and Houston HMIS Shelter Users Ages 25-59, 2012 and 2013



Sources: Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, 2003-2016 IRS 1040 Datasets, 2005-2016 W2 Datasets.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. "First spell" sample consists of those with first observed HMIS enrollment in 2012 or 2013. "Cross section" includes those enrolled on March 30, 2012 or March 30, 2013.

Figure 11b: Share with SSI or DI in HMIS Data, Comparison of Sample Time-Frames

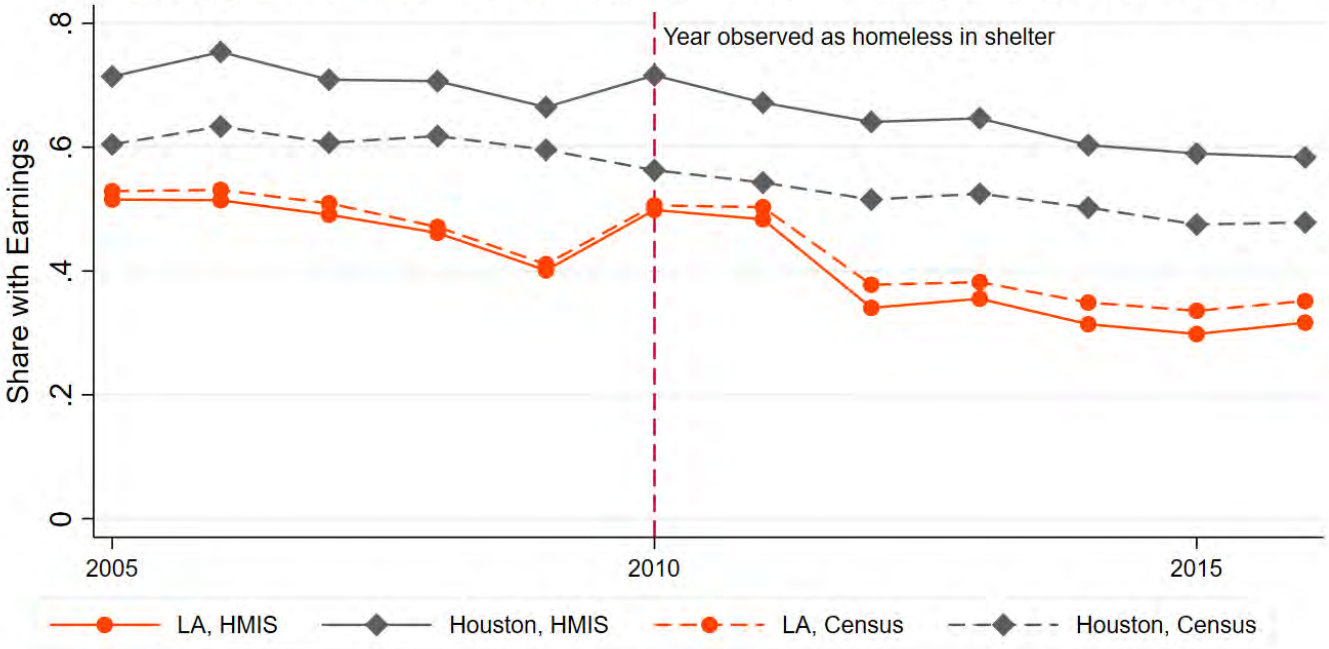
Los Angeles and Houston HMIS Shelter Users Ages 25-59, 2012 and 2013



Sources: Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, SSI Datasets (2010-2014, 2016), 2006-2016 Medicare Datasets.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. "First spell" sample consists of those with first observed HMIS enrollment in 2012 or 2013. "Cross section" includes those enrolled on March 30, 2012 or March 30, 2013.

Figure 12a: Share with Earnings, Comparison of HMIS and Census Samples

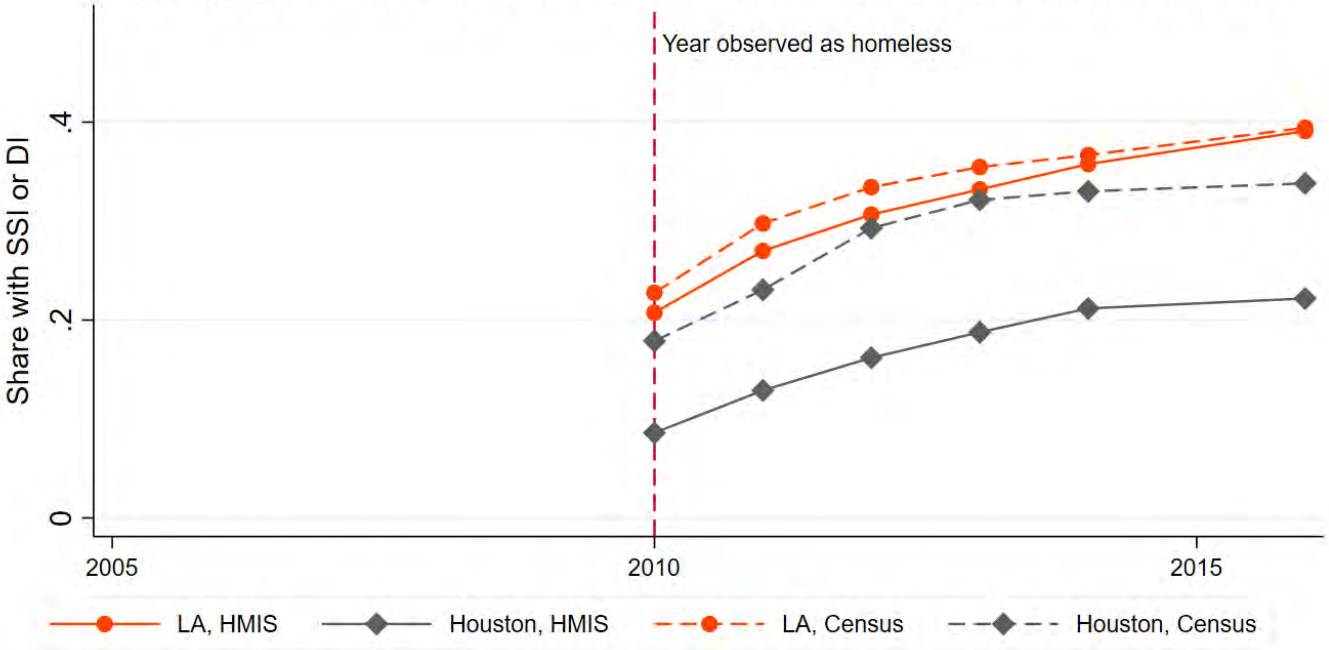
Los Angeles and Houston Census and HMIS Shelter Users Ages 25-59, 2012 and 2013



Sources: Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, 2010 Census, 2003-2016 IRS 1040 Datasets, 2005-2016 W2 Datasets.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. Census sample consists of sheltered homeless counted in Los Angeles or Houston. HMIS sample consists of those enrolled in HMIS shelters in Los Angeles or Houston on March 30, 2010.

Figure 12b: Share with SSI or DI, Comparison of HMIS and Census Samples

Los Angeles and Houston Census and HMIS Shelter Users Ages 25-59, 2012 and 2013



Sources: 2010 Census, Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, SSI Datasets (2010-2014, 2016), 2006-2016 Medicare Datasets.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. Census sample consists of sheltered homeless counted in Los Angeles or Houston. HMIS sample consists of those enrolled in HMIS shelters in Los Angeles or Houston on March 30, 2010.

A. Appendix: Additional Robustness Checks

This section contains additional analyses to test the robustness of our findings to alternative samples, linkage methods, and years through a series of additional analyses using alternative Census and ACS homeless samples.

A.1 Income and Program Receipt using the ACS Sheltered Homeless Sample

We first calculate longitudinal employment and disability program receipt for sheltered homeless samples drawn from the 2010-2014 ACS and compare these results to the 2010 Census homeless. These analyses allow us to see whether homeless samples from years other than 2010 exhibit the same patterns. They also provide an additional check on whether our inverse probably weighting procedure in the Census leads to a representative sample, because the ACS permits us to estimate the probability of linkage using a wealth of additional predictors beyond the limited demographic characteristics available in the Census, including self-reported income and benefit measures that are highly correlated with our administrative outcomes of interest. Figures A1 and A2 (Table A15) show that our findings are robust to the use of ACS sheltered homeless samples. Both the levels and longitudinal patterns of employment and disability program receipt track closely in the two samples, bolstering the generality of our results beyond 2010 and supporting the validity of our approach to adjusting for non-linkage in the Census.

A.2 Robustness to Alternative Samples of the Census Homeless

We also calculate employment and benefit receipt for a version of the Census unsheltered homeless sample that includes those counted at outdoor locations (TNSOLs) and also for a version of the sheltered and unsheltered homeless Census samples that excludes people who were recorded in housing units as well as being counted as homeless in the 2010 Census. The first analysis serves as a check on our decision to omit this group from our main results due to low linkage rates and concerns about non-randomness of linkage conditional on observed characteristics. The second analysis accounts for the finding in Meyer et al. (2023) that about 40 percent of the unsheltered population and 20 percent of those in shelters were also counted as housed in the Census, raising concerns about misclassification of housed people as homeless. Figures A3-A6 (Tables A16 and A17) contain these results.

Our findings are robust to these alternative sample choices. Despite concerns about low linkage rates for people at TNSOLs, the decision to exclude these individuals appears to have little

effect on our results. We also note that people who were double counted during the Census appear slightly more likely to be employed and slightly less likely receive benefits, differences which may reflect a small degree of misclassification but which could alternatively reflect heterogeneity in these outcomes between people with more or fewer connections to housed friends or family.

A.3 Potential Bias in Longitudinal SNAP Receipt from Migration

Our final robustness check examines possible downward bias in SNAP receipt that may arise due to migration between states for which we do and do not have SNAP records. People residing in SNAP states in 2010 who resided in other states for which we do not have these records would necessarily be indicated as non-recipients in those other years in our analyses. To explore this possibility, we link the 2010 Census homeless population to the 2000 Census to identify individuals who lived in the same states in both years, a subset that we consider less likely to have migrated than the typical homeless person. Figure A7 (Table A18) displays the results from this analysis. As expected, the peak in SNAP receipt surrounding 2010 is mitigated somewhat in the migration-adjusted sample, but the qualitative pattern of sharply increasing SNAP receipt preceding 2010 and somewhat decreasing SNAP receipt after 2010 remains intact. Our findings are similar when we examine migration-adjusted SNAP receipt in the unsheltered homeless and single housed poor samples, suggesting that the peak in SNAP receipt in the year observed as homeless is a real phenomenon, not the result of bias due to incomplete coverage of SNAP datasets.

Appendix Tables

Table A1a: Summary of Connections to Formal Work, Safety Net, and Disability Programs, Ages 25-59 in 2010, 2005-2016

Sheltered and Unsheltered Homeless

Sheltered Homeless												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share employed[1]	0.622	0.620	0.605	0.579	0.501	0.518	0.496	0.462	0.454	0.438	0.435	0.437
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Share receiving any safety net benefits[2]			0.683	0.729	0.823	0.892	0.876	0.851	0.837	0.838	0.837	
			(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.004)	
Share receiving disability benefits (SSI or DI)						0.191	0.245	0.288	0.312	0.327		0.343
						(0.002)	(0.002)	(0.002)	(0.002)	(0.002)		(0.002)
Share with benefits or earnings			0.888	0.899	0.929	0.966	0.960	0.951	0.947	0.947	0.945	
			(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	
Share with disability benefits or earnings						0.657	0.679	0.694	0.709	0.714		
						(0.002)	(0.002)	(0.002)	(0.002)	(0.002)		
Sample Size	89,500	89,500	89,500	89,500	89,500	89,500	89,000	88,000	86,500	85,500	84,500	83,000
Population	128,400	128,400	128,400	128,400	128,400	128,400	127,500	126,000	124,400	122,800	121,100	119,100
Unsheltered Homeless												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share employed[1]	0.559	0.546	0.528	0.493	0.418	0.403	0.389	0.359	0.357	0.339	0.339	0.341
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Share receiving any safety net benefits[2]			0.647	0.699	0.753	0.800	0.800	0.792	0.797	0.806	0.829	
			(0.012)	(0.008)	(0.006)	(0.005)	(0.005)	(0.006)	(0.005)	(0.005)	(0.007)	
Share receiving disability benefits (SSI or DI)						0.291	0.327	0.359	0.376	0.385		0.396
						(0.005)	(0.005)	(0.005)	(0.005)	(0.005)		(0.005)
Share with benefits or earnings			0.881	0.892	0.899	0.926	0.928	0.921	0.927	0.930	0.936	
			(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	
Share with disability benefits or earnings						0.623	0.642	0.653	0.667	0.667		0.678
						0.004	0.004	0.004	0.004	0.004		0.005
Sample Size	49,500	49,500	49,500	49,500	49,500	49,500	49,000	48,500	48,000	47,000	46,500	45,500
Population	118,200	118,200	118,200	118,200	118,200	118,200	117,300	115,900	114,400	112,700	110,900	108,900

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults from the 2010 Decennial Census and 2009-2010 ACS who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

[1] Earnings row reports the share of individuals with positive estimated earnings across IRS 1040 and W2 datasets, as defined in Tables 4-6.

[2] Any benefits includes SNAP, HUD, VA, Medicare, and Medicaid benefits, as well as SSI benefits, when indicated.

Table A1b: Summary of Connections to Formal Work, Safety Net, and Disability Programs, Ages 25-59 in 2010, 2005-2016

Single Housed Poor and Overall Housed

Single Housed Poor												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share employed[1]	0.611	0.596	0.582	0.553	0.484	0.483	0.498	0.493	0.489	0.488	0.489	0.487
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Share receiving any safety net benefits[2]			0.577	0.608	0.662	0.707	0.717	0.707	0.698	0.717	0.716	
			(0.011)	(0.010)	(0.009)	(0.007)	(0.008)	(0.007)	(0.008)	(0.007)	(0.012)	
Share receiving disability benefits (SSI or DI)						0.251	0.274	0.292	0.305	0.308		0.307
						(0.005)	(0.004)	(0.005)	(0.004)	(0.005)		(0.005)
Share with benefits or earnings			0.860	0.868	0.861	0.892	0.903	0.909	0.907	0.919	0.928	
			(0.008)	(0.007)	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)	(0.005)	(0.007)	
Share with disability benefits or earnings						0.691	0.726	0.740	0.748	0.753		0.750
						0.004	0.003	0.003	0.003	0.003		0.004
Sample Size	55,000	55,000	55,000	55,000	55,000	55,000	54,500	54,000	54,000	53,500	53,000	52,500
Population (100,000s)	48.46	48.46	48.46	48.46	48.46	48.46	48.14	47.70	47.18	46.72	46.16	45.60
Overall Housed												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share employed[1]	0.857	0.860	0.864	0.861	0.848	0.843	0.837	0.831	0.825	0.815	0.809	0.801
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share receiving any safety net benefits[2]			0.185	0.192	0.201	0.217	0.225	0.228	0.229	0.247	0.261	
			(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	
Share receiving disability benefits (SSI or DI)						0.059	0.064	0.068	0.073	0.077		0.078
						(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
Share with benefits or earnings						0.931	0.928	0.927	0.925	0.924		
						(0.001)	(0.001)	(0.001)	(0.001)	(0.001)		
Share with disability benefits or earnings						0.884	0.882	0.880	0.878	0.873		0.859
						0.000	0.000	0.000	0.000	0.000		0.000
Sample Size	994,000	994,000	994,000	994,000	994,000	994,000	992,000	989,000	986,000	983,000	979,000	975,000
Population (100,000s)	722.70	722.70	722.70	722.70	722.70	722.70	722.70	722.70	721.30	719.10	716.80	714.40

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults from the 2010 Decennial Census and 2009-2010 ACS who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

[1] Earnings row reports the share of individuals with positive estimated earnings across IRS 1040 and W2 datasets, as defined in Tables A3-A6.

[2] Any benefits includes SNAP, HUD, VA, Medicare, and Medicaid benefits, as well as SSI benefits, when indicated.

Table A2: Income and Benefit Receipt among All Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2005-2016*

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Employment and Earnings												
Share employed[1]	0.622	0.620	0.605	0.579	0.501	0.518	0.496	0.462	0.454	0.438	0.435	0.437
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
50th percentile (cond. on +)	$9,493	$9,534	$9,327	$8,039	$6,590	$8,328	$10,870	$11,170	$11,380	$11,820	$12,860	$13,470
	($69)	($71)	($68)	($68)	($68)	($63)	($63)	($71)	($77)	($89)	($102)	($103)
75th percentile (cond. on +)	$20,290	$19,780	$18,700	$16,780	$14,950	$16,570	$20,060	$20,450	$20,980	$21,780	$23,850	$24,850
	($120)	($108)	($103)	($94)	($99)	($98)	($121)	($116)	($131)	($141)	($156)	($156)
Pretax Cash Income, Plus In-Kind Transfers (no SSI)[3]												
50th percentile	$5,634	$5,029	$4,564	$3,177	$2,835	$3,948	$4,414	$3,906	$3,947	$3,527	$4,041	$4,347
	($247)	($218)	($135)	($87)	($33)	($100)	($139)	($126)	($131)	($127)	($151)	($158)
75th percentile	$14,920	$14,380	$14,370	$12,930	$11,950	$13,940	$15,690	$15,490	$15,560	$15,220	$16,220	$16,670
	($423)	($382)	($153)	($152)	($126)	($118)	($145)	($145)	($144)	($154)	($168)	($170)
Safety Net Program Receipt												
Share receiving any safety net benefits[2]			0.669	0.717	0.795	0.856	0.846	0.827	0.821	0.825	0.834	
			(0.005)	(0.004)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)	
Share receiving SNAP	0.384	0.404	0.524	0.584	0.697	0.774	0.745	0.709	0.687	0.667	0.644	0.621
	(0.007)	(0.007)	(0.005)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Share enrolled in Medicaid			0.321	0.340	0.375	0.430	0.460	0.479	0.484	0.613	0.672	
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	
Share receiving disability benefits (SSI or DI)						0.239	0.284	0.322	0.343	0.355		0.368
						(0.003)	(0.003)	(0.003)	(0.003)	(0.003)		(0.003)
Sample Size	139,000	139,000	139,000	139,000	139,000	139,000	138,000	136,500	134,500	132,500	131,000	128,500
Population	246,600	246,600	246,600	246,600	246,600	246,600	244,800	241,900	238,800	235,500	232,000	228,000

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults from the 2010 Decennial Census and 2009-2010 ACS who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

[1] Earnings row reports the share of individuals with positive estimated earnings across IRS 1040 and W2 datasets, as defined in Tables A3-A6.

[2] Any benefits includes SNAP, HUD, VA, Medicare, and Medicaid benefits, as well as SSI benefits, when indicated.

Table A3a: Income and Benefit Receipt among Sheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2005-2016*

Income and Earnings	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Employment and Earnings[1]												
Share with earnings	0.622	0.620	0.605	0.579	0.501	0.518	0.496	0.462	0.454	0.438	0.435	0.437
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Mean (cond. on +)	$14,810	$14,620	$14,040	$12,810	$11,610	$13,510	$15,780	$15,890	$16,330	$16,620	$17,890	$18,480
	($83)	($82)	($78)	($84)	($86)	($103)	($103)	($108)	($111)	($116)	($121)	($120)
Std Deviation (cond. on +)	$19,020	$19,080	$17,940	$18,740	$17,570	$21,610	$21,090	$21,690	$21,730	$21,820	$22,580	$22,620
25th percentile (cond. on +)	$2,943	$2,958	$3,014	$2,435	$1,738	$2,452	$3,659	$3,662	$3,941	$4,061	$4,413	$4,656
	($38)	($38)	($40)	($34)	($26)	($38)	($58)	($58)	($68)	($70)	($78)	($79)
50th percentile (cond. on +)	$9,493	$9,534	$9,327	$8,039	$6,590	$8,328	$10,870	$11,170	$11,380	$11,820	$12,860	$13,470
	($69)	($71)	($68)	($68)	($68)	($63)	($63)	($71)	($77)	($89)	($102)	($103)
75th percentile (cond. on +)	$20,290	$19,780	$18,700	$16,780	$14,950	$16,570	$20,060	$20,450	$20,980	$21,780	$23,850	$24,850
	($120)	($108)	($103)	($94)	($99)	($98)	($121)	($116)	($131)	($141)	($156)	($156)
Pretax Cash Income[2]												
Mean	$9,519	$9,475	$9,432	$8,055	$6,520	$8,069	$9,050	$8,393	$8,337	$8,245	$8,835	$9,192
	($65)	($63)	($60)	($62)	($52)	($61)	($62)	($63)	($64)	($66)	($70)	($71)
Std Deviation	$18,760	$18,560	$17,600	$18,380	$15,200	$17,870	$18,110	$18,460	$18,760	$19,170	$20,200	$20,210
25th percentile	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)
50th percentile	$2,230	$2,250	$3,520	$1,450	$238	$758	$681	$12	$0	$0	$0	$0
	($50)	($50)	($60)	($39)	($17)	($35)	($43)	($13)	($6)	($0)	($0)	($0)
75th percentile	$13,430	$13,600	$13,360	$11,230	$8,346	$10,980	$13,070	$12,220	$12,020	$11,850	$12,950	$13,360
	($96)	($97)	($76)	($79)	($84)	($69)	($77)	($98)	($103)	($107)	($94)	($98)
Pretax Cash Income, Plus In-Kind Transfers (no SSI)[3]												
Mean	$10,270	$9,666	$10,120	$9,121	$8,543	$10,040	$10,970	$10,680	$10,710	$10,430	$11,120	$11,540
	($235)	($222)	($112)	($106)	($96)	($99)	($107)	($107)	($111)	($111)	($117)	($128)
Std Deviation	$13,700	$12,970	$15,400	$14,590	$14,270	$14,870	$15,870	$15,800	$16,290	$16,210	$16,960	$18,440
25th percentile	$754	$754	$902	$833	$1,277	$1,994	$1,790	$1,565	$1,469	$1,210	$1,159	$1,041
	($91)	($85)	($33)	($29)	($23)	($22)	($27)	($28)	($29)	($30)	($34)	($39)
50th percentile	$5,634	$5,029	$4,564	$3,177	$2,835	$3,948	$4,414	$3,906	$3,947	$3,527	$4,041	$4,347
	($247)	($218)	($135)	($87)	($33)	($100)	($139)	($126)	($131)	($127)	($151)	($158)
75th percentile	$14,920	$14,380	$14,370	$12,930	$11,950	$13,940	$15,690	$15,490	$15,560	$15,220	$16,220	$16,670
	($423)	($382)	($153)	($152)	($126)	($118)	($145)	($145)	($144)	($154)	($168)	($170)
Pretax Cash Income, Plus In-Kind Transfers (with SSI)												
Mean						$11,280	$12,550	$12,460	$12,600	$12,280		$13,150
						($100)	($111)	($110)	($113)	($112)		($126)
Std Deviation						$14,980	$16,450	$16,240	$16,640	$16,340		$18,140
25th percentile						$2,413	$2,411	$2,330	$2,285	$2,083		$2,132
						($16)	($25)	($29)	($33)	($33)		($44)
50th percentile						$7,461	$9,149	$9,289	$9,441	$9,325		$9,518
						($142)	($115)	($106)	($102)	($96)		($73)
75th percentile						$15,130	$17,090	$17,190	$17,310	$17,040		$18,260
						($132)	($133)	($130)	($125)	($136)		($156)
Sample Size	89,500	89,500	89,500	89,500	89,500	89,500	89,000	88,000	86,500	85,500	84,500	83,000
Population	128,400	128,400	128,400	128,400	128,400	128,400	127,500	126,000	124,400	122,800	121,100	119,100

*Sources and notes after Table A6.

Table A3b: Income and Benefit Receipt among Sheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2003-2016*

Connections to Employment and Formal Income	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1040 Filing Status														
Share filing 1040	0.390	0.381	0.374	0.376	0.447	0.372	0.330	0.381	0.399	0.341	0.332	0.308	0.306	0.299
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
1040 cofiling rate (cond. on filing)	0.204	0.200	0.193	0.180	0.153	0.158	0.149	0.131	0.131	0.171	0.177	0.187	0.194	0.204
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
Share with dependents (cond. on filing)	0.415	0.419	0.421	0.417	0.354	0.375	0.365	0.367	0.358	0.412	0.425	0.447	0.441	0.437
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Mean dependents (cond. on +)	1.753	1.756	1.742	1.736	1.726	1.756	1.770	1.790	1.805	1.821	1.846	1.857	1.875	1.890
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)
Income Sources on 1040s														
Share filing 1040 with positive total money income	0.388	0.378	0.359	0.360	0.430	0.356	0.315	0.367	0.376	0.330	0.321	0.298	0.296	0.290
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Median total money income (cond. on +)	$16,760	$16,400	$14,040	$14,180	$12,300	$12,150	$11,290	$12,730	$14,790	$15,020	$15,190	$15,600	$16,590	$17,440
	($108)	($103)	($94)	($92)	($65)	($78)	($64)	($80)	($79)	($80)	($77)	($77)	($92)	($110)
Share filing 1040 with self-employment income (+ or -)	0.038	0.040	0.040	0.043	0.047	0.047	0.049	0.053	0.056	0.054	0.054	0.051	0.048	0.047
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Median self-employment income (cond. on +)	$7,283	$7,170	$6,953	$7,914	$7,863	$8,444	$9,897	$10,030	$10,060	$10,070	$9,755	$9,437	$9,188	$8,352
	($261)	($245)	($239)	($230)	($220)	($184)	($151)	($136)	($134)	($135)	($175)	($189)	($222)	($257)
Share filing 1040 with social security income	0.003	0.003	0.004	0.007	0.054	0.013	0.010	0.016	0.020	0.020	0.021	0.021	0.025	0.027
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Median social security income (cond. on +)	$11,360	$11,280	$10,750	$10,240	$9,945	$10,370	$11,170	$12,950	$12,830	$12,330	$11,050	$11,280	$11,390	$11,630
	($460)	($478)	($348)	($215)	($60)	($175)	($233)	($226)	($124)	($173)	($151)	($158)	($131)	($138)
Share filing 1040 with wage and salary income	0.372	0.362	0.354	0.352	0.375	0.336	0.285	0.325	0.329	0.296	0.292	0.274	0.274	0.270
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Median 1040 wage and salary income (cond. on +)	$16,000	$15,880	$13,240	$13,160	$11,820	$10,800	$9,466	$10,810	$13,140	$13,560	$13,930	$14,530	$15,730	$16,600
	($123)	($116)	($104)	($108)	($88)	($88)	($88)	($76)	($108)	($107)	($120)	($122)	($132)	($139)
IRS Information Returns (W2s and 1099Rs)														
Share receiving W2			0.602	0.597	0.583	0.548	0.454	0.448	0.423	0.406	0.402	0.403	0.406	0.411
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Median W2 wage and tips (cond. on +)			$9,073	$8,973	$8,690	$7,231	$5,021	$5,759	$8,176	$9,456	$10,260	$11,210	$12,580	$13,230
			($72)	($74)	($69)	($65)	($54)	($57)	($87)	($95)	($102)	($104)	($114)	($113)
Mean W2s received (cond. on +)			2.073	2.101	2.099	1.940	1.647	1.650	1.611	1.623	1.646	1.700	1.764	1.802
			(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.008)
Share receiving 1099R	0.040	0.041	0.039	0.041	0.042	0.042	0.039	0.030	0.028	0.033	0.034	0.038	0.041	0.044
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Sample Size	89,500	89,500	89,500	89,500	89,500	89,500	89,500	89,500	89,000	88,000	86,500	85,500	84,500	83,000
Population	128,400	128,400	128,400	128,400	128,400	128,400	128,400	128,400	127,500	126,000	124,400	122,800	121,100	119,100

*Sources and notes after Table A6.

Table A3c: Income and Benefit Receipt among Sheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2003-2016*

Safety Net Program Receipt														
	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Housing Benefits (HUD)														
Share with housing benefits	0.083	0.083	0.082	0.078	0.074	0.071	0.068	0.101	0.126	0.143	0.146	0.154	0.161	0.165
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mean housing benefit amount (equivalized) (cond. on +)[4]	$4,904	$5,043	$4,972	$4,860	$4,858	$4,790	$4,906	$4,291	$5,455	$5,684	$6,067	$5,983	$6,094	$6,267
	($41)	($41)	($41)	($42)	($42)	($43)	($46)	($35)	($33)	($33)	($33)	($32)	($32)	($32)
Mean assistance unit size (cond. on +)	2.839	2.791	2.668	2.585	2.454	2.267	2.012	1.829	1.819	1.844	1.841	1.849	1.849	1.836
	(0.022)	(0.022)	(0.022)	(0.023)	(0.023)	(0.023)	(0.022)	(0.016)	(0.015)	(0.014)	(0.013)	(0.013)	(0.013)	(0.013)
Share with child in assistance unit (cond. on +)	0.611	0.585	0.544	0.507	0.456	0.392	0.298	0.256	0.257	0.262	0.263	0.262	0.258	0.254
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Mean months of housing benefit receipt (cond. on +)	10.300	10.360	10.200	9.992	9.892	9.607	9.245	7.829	9.755	10.080	10.630	10.550	10.640	10.730
	(0.046)	(0.044)	(0.045)	(0.045)	(0.046)	(0.047)	(0.049)	(0.042)	(0.034)	(0.032)	(0.028)	(0.028)	(0.026)	(0.025)
Veterans' Benefits (VA)														
Share with VA service-connected disability					0.015	0.017	0.023	0.027	0.029	0.031	0.033	0.034	0.035	0.036
					(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Supplemental Nutrition Assistance Program (SNAP)[5]														
Share with SNAP receipt			0.358	0.382	0.538	0.601	0.738	0.826	0.786	0.737	0.707	0.681	0.652	0.628
			(0.008)	(0.008)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Mean SNAP benefit amount (equivalized) (cond. on +)			$1,224	$1,203	$1,278	$1,364	$1,736	$1,886	$1,812	$1,795	$1,748	$1,581	$1,589	$1,564
			($24)	($22)	($8)	($8)	($8)	($6)	($7)	($8)	($8)	($8)	($8)	($9)
Mean months of SNAP receipt (cond. on +)			7.327	7.401	8.905	9.108	9.189	10.200	10.100	10.160	10.360	10.300	10.410	10.380
			(0.110)	(0.104)	(0.036)	(0.034)	(0.028)	(0.020)	(0.023)	(0.024)	(0.024)	(0.025)	(0.025)	(0.026)
Mean assistance unit size (cond. on +)			1.965	1.918	2.029	2.000	1.938	1.941	1.947	1.939	1.941	1.930	1.926	1.922
			(0.043)	(0.041)	(0.017)	(0.016)	(0.012)	(0.011)	(0.012)	(0.012)	(0.013)	(0.013)	(0.014)	(0.014)
Share with child in assistance unit (cond. on +)			0.332	0.308	0.338	0.319	0.298	0.291	0.287	0.279	0.273	0.264	0.256	0.249
			(0.013)	(0.013)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.000)
Medicaid and Medicare														
Share enrolled in Medicaid					0.315	0.333	0.376	0.445	0.473	0.488	0.492	0.612	0.662	
					(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	
Share enrolled in Medicare Part A or B				0.059	0.064	0.069	0.074	0.090	0.113	0.137	0.154	0.166	0.181	0.198
				(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Disability programs (DI and SSI)														
Share receiving DI as indicated by Medicare records				0.058	0.063	0.069	0.074	0.089	0.112	0.136	0.153	0.164	0.166	0.167
				(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share receiving SSI								0.137	0.176	0.201	0.210	0.214		0.225
								(0.001)	(0.001)	(0.002)	(0.002)	(0.002)		(0.002)
Mean SSI amount (cond. on +)								$8,885	$9,898	$9,797	$9,183	$8,691		$8,000
								($87)	($116)	($117)	($89)	($72)		($53)
Share receiving SSI or DI according to Medicare								0.191	0.245	0.288	0.312	0.327		0.343
								(0.002)	(0.002)	(0.002)	(0.002)	(0.002)		(0.002)
Share living in SNAP state in 2010			0.038	0.038	0.206	0.206	0.242	0.242	0.242	0.243	0.243	0.244	0.244	0.245
Share living in Medicaid state in 2010					0.946	0.946	0.946	0.946	0.946	0.947	0.946	0.806	0.368	
Sample Size	89,500	89,500	89,500	89,500	89,500	89,500	89,500	89,500	89,000	88,000	86,500	85,500	84,500	83,000
Population	128,400	128,400	128,400	128,400	128,400	128,400	128,400	128,400	127,500	126,000	124,400	122,800	121,100	119,100

*Sources and notes after Table A6.

Table A4a: Income and Benefit Receipt among Unsheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2005-2016*

Employment and Income

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Employment and Earnings[1]												
Share with earnings	0.559	0.546	0.528	0.493	0.418	0.403	0.389	0.359	0.357	0.339	0.339	0.341
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Mean (cond. on +)	$15,210	$15,410	$15,450	$14,800	$14,700	$16,300	$17,890	$18,310	$18,660	$19,100	$20,300	$21,010
	($173)	($179)	($215)	($169)	($186)	($203)	($231)	($257)	($263)	($255)	($268)	($296)
Std Deviation (cond. on +)	$23,320	$25,140	$24,140	$24,590	$24,740	$26,280	$27,870	$30,860	$30,610	$30,440	$31,300	$34,140
25th percentile (cond. on +)	$2,100	$2,245	$2,359	$2,014	$1,607	$2,066	$2,902	$2,642	$2,920	$3,048	$3,403	$3,479
	($62)	($70)	($83)	($56)	($59)	($66)	($125)	($102)	($121)	($99)	($116)	($120)
50th percentile (cond. on +)	$8,377	$8,483	$8,514	$7,847	$7,373	$8,298	$10,120	$10,310	$10,620	$11,020	$12,020	$12,320
	($155)	($147)	($187)	($126)	($166)	($143)	($188)	($172)	($172)	($175)	($185)	($197)
75th percentile (cond. on +)	$19,820	$19,860	$19,740	$18,510	$17,730	$19,750	$21,920	$21,810	$22,520	$23,440	$25,410	$26,370
	($281)	($257)	($333)	($224)	($302)	($307)	($385)	($303)	($343)	($324)	($359)	($337)
Pretax Cash Income[2]												
Mean	$8,931	$9,002	$9,692	$8,104	$7,070	$7,926	$8,361	$7,753	$7,788	$7,659	$8,205	$8,453
	($109)	($117)	($136)	($109)	($102)	($107)	($111)	($118)	($125)	($125)	($133)	($136)
Std Deviation	$20,910	$23,010	$21,560	$21,420	$20,040	$21,070	$21,860	$23,560	$24,580	$24,750	$26,110	$25,950
25th percentile	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)
50th percentile	$610	$475	$2,205	$114	$0	$0	$0	$0	$0	$0	$0	$0
	($62)	($58)	($122)	($29)	($0)	($0)	($0)	($0)	($0)	($0)	($0)	($0)
75th percentile	$10,900	$10,800	$12,340	$9,595	$7,261	$8,174	$9,080	$7,238	$7,212	$6,489	$7,402	$7,844
	($228)	($218)	($171)	($207)	($234)	($223)	($242)	($289)	($304)	($326)	($359)	($352)
Pretax Cash Income, Plus In-Kind Transfers (no SSI)[3]												
Mean	$9,252	$9,270	$11,030	$10,070	$9,514	$10,420	$10,830	$10,400	$10,740	$10,070	$11,120	$11,110
	($364)	($385)	($296)	($282)	($248)	($259)	($276)	($261)	($307)	($267)	($302)	($319)
Std Deviation	$15,960	$16,870	$19,530	$19,580	$20,120	$20,720	$21,580	$20,620	$23,440	$21,010	$23,570	$24,200
25th percentile	$170	$162	$420	$453	$817	$1,350	$1,161	$992	$880	$703	$616	$507
	($54)	($51)	($72)	($72)	($79)	($68)	($67)	($77)	($80)	($76)	($93)	($86)
50th percentile	$2,399	$2,484	$3,619	$2,264	$2,664	$2,710	$2,630	$2,579	$2,525	$2,389	$2,439	$2,417
	($184)	($175)	($353)	($112)	($22)	($32)	($37)	($20)	($42)	($1)	($17)	($36)
75th percentile	$11,940	$11,500	$14,300	$12,790	$11,350	$12,530	$13,070	$12,650	$12,580	$11,970	$13,130	$13,280
	($704)	($569)	($492)	($543)	($459)	($482)	($502)	($501)	($470)	($499)	($519)	($521)
Pretax Cash Income, Plus In-Kind Transfers (with SSI)												
Mean						$11,920	$12,480	$12,210	$12,640	$11,960		$12,900
						($268)	($288)	($273)	($316)	($277)		($329)
Std Deviation						$20,610	$21,600	$20,570	$23,360	$20,830		$23,940
25th percentile						$1,870	$1,534	$1,594	$1,653	$1,461		$1,407
						($67)	($71)	($102)	($107)	($114)		($100)
50th percentile						$5,479	$5,950	$6,101	$6,419	$6,303		$7,571
						($384)	($418)	($434)	($431)	($436)		($402)
75th percentile						$14,280	$15,230	$15,030	$14,990	$14,640		$15,520
						($373)	($506)	($458)	($471)	($458)		($511)
Sample Size	49,500	49,500	49,500	49,500	49,500	49,500	49,000	48,500	48,000	47,000	46,500	45,500
Population	118,200	118,200	118,200	118,200	118,200	118,200	117,300	115,900	114,400	112,700	110,900	108,900

*Sources and notes after Table A6.

Table A4b: Income and Benefit Receipt among Unsheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2003-2016

Connections to Employment and Formal Income														
	2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
1040 Filing Status														
Share filing 1040	0.348	0.338	0.327	0.327	0.432	0.326	0.291	0.311	0.325	0.270	0.262	0.244	0.241	0.239
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
1040 cofiling rate (cond. on filing)	0.257	0.267	0.255	0.243	0.202	0.229	0.236	0.218	0.208	0.276	0.278	0.293	0.303	0.308
	(0.004)	(0.007)	(0.004)	(0.004)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)
Share with dependents (cond. on filing)	0.407	0.405	0.407	0.394	0.306	0.362	0.362	0.345	0.327	0.382	0.392	0.405	0.398	0.383
	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Mean dependents (cond. on +)	1.801	1.793	1.779	1.779	1.756	1.775	1.832	1.822	1.804	1.811	1.811	1.830	1.834	1.844
	(0.012)	(0.012)	(0.010)	(0.011)	(0.011)	(0.015)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.014)	(0.014)	(0.015)
Income Sources on 1040s														
Share filing 1040 with positive total money income	0.346	0.335	0.313	0.311	0.415	0.309	0.275	0.297	0.303	0.259	0.252	0.234	0.231	0.231
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
Median total money income (cond. on +)	$17,100	$17,450	$14,520	$14,750	$12,150	$13,640	$13,890	$14,810	$15,510	$15,790	$15,920	$16,810	$18,110	$18,570
	($204)	($273)	($181)	($170)	($137)	($172)	($228)	($160)	($211)	($187)	($171)	($181)	($180)	($202)
Share filing 1040 with self-employment income (+ or -)	0.033	0.034	0.035	0.035	0.039	0.040	0.045	0.044	0.044	0.042	0.042	0.040	0.038	0.036
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Median self-employment income (cond. on +)	$5,637	$5,854	$6,071	$6,373	$6,153	$6,701	$8,296	$8,188	$7,285	$6,651	$6,830	$6,783	$6,063	$5,792
	($340)	($315)	($351)	($356)	($314)	($319)	($1046)	($317)	($344)	($353)	($395)	($373)	($389)	($426)
Share filing 1040 with social security income	0.006	0.006	0.007	0.013	0.098	0.024	0.020	0.023	0.027	0.026	0.027	0.027	0.029	0.032
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Median social security income (cond. on +)	$10,850	$11,300	$10,610	$10,790	$9,808	$10,580	$11,540	$13,090	$12,840	$12,520	$11,740	$12,200	$12,330	$12,370
	($448)	($423)	($331)	($220)	($66)	($157)	($195)	($212)	($154)	($216)	($220)	($208)	($254)	($205)
Share filing 1040 with wage and salary income	0.332	0.322	0.311	0.305	0.327	0.291	0.248	0.260	0.264	0.233	0.229	0.216	0.213	0.212
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)
Median 1040 wage and salary income (cond. on +)	$16,320	$16,700	$13,600	$13,710	$12,550	$11,830	$11,500	$12,200	$13,490	$14,000	$14,320	$15,210	$16,570	$17,110
	($223)	($287)	($197)	($206)	($249)	($198)	($187)	($206)	($295)	($243)	($237)	($222)	($223)	($237)
IRS Information Returns (W2s and 1099Rs)														
Share receiving W2			0.538	0.526	0.507	0.464	0.371	0.331	0.312	0.310	0.310	0.309	0.315	0.319
			(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Median W2 wage and tips (cond. on +)			$8,371	$8,419	$7,939	$7,170	$5,533	$5,290	$7,407	$8,625	$9,808	$10,720	$11,760	$12,330
			($155)	($169)	($163)	($130)	($130)	($135)	($173)	($203)	($240)	($218)	($209)	($218)
Mean W2s received (cond. on +)			1.993	2.019	1.989	1.841	1.575	1.536	1.532	1.539	1.572	1.619	1.668	1.685
			(0.012)	(0.015)	(0.015)	(0.012)	(0.024)	(0.009)	(0.011)	(0.009)	(0.010)	(0.012)	(0.012)	(0.011)
Share receiving 1099R	0.034	0.035	0.031	0.032	0.034	0.035	0.036	0.031	0.030	0.032	0.032	0.036	0.039	0.041
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Sample Size	49,500	49,500	49,500	49,500	49,500	49,500	49,500	49,500	49,000	48,500	48,000	47,000	46,500	45,500
Population	118,200	118,200	118,200	118,200	118,200	118,200	118,200	118,200	117,300	115,900	114,400	112,700	110,900	108,900

*Sources and notes after Table A6.

Table A4c: Income and Benefit Receipt among Unsheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, 2003-2016

Safety Net Program Receipt	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Housing Benefits (HUD)														
Share with housing benefits	0.082	0.084	0.083	0.081	0.081	0.082	0.083	0.094	0.104	0.111	0.116	0.122	0.128	0.132
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Mean housing benefit amount (equivalized) (cond. on +)[4]	$4,875	$4,926	$4,905	$4,835	$4,927	$4,957	$5,161	$5,138	$5,463	$5,510	$5,628	$5,676	$5,850	$6,002
	($60)	($64)	($63)	($84)	($56)	($55)	($76)	($60)	($52)	($63)	($57)	($63)	($56)	($62)
Mean assistance unit size (cond. on +)	2.404	2.405	2.361	2.282	2.182	2.113	2.052	1.913	1.821	1.755	1.710	1.651	1.623	1.616
	(0.027)	(0.055)	(0.056)	(0.058)	(0.060)	(0.060)	(0.079)	(0.072)	(0.053)	(0.050)	(0.049)	(0.048)	(0.047)	(0.046)
Share with child in assistance unit (cond. on +)	0.445	0.425	0.405	0.385	0.349	0.321	0.283	0.243	0.219	0.201	0.186	0.168	0.160	0.155
	(0.010)	(0.014)	(0.014)	(0.015)	(0.015)	(0.015)	(0.016)	(0.014)	(0.013)	(0.013)	(0.012)	(0.012)	(0.012)	(0.012)
Mean months of housing benefit receipt (cond. on +)	10.450	10.550	10.580	10.370	10.380	10.430	10.360	9.969	10.410	10.490	10.570	10.550	10.660	10.780
	(0.064)	(0.068)	(0.066)	(0.115)	(0.066)	(0.063)	(0.091)	(0.068)	(0.056)	(0.049)	(0.050)	(0.075)	(0.045)	(0.041)
Veterans' Benefits (VA)														
Share with VA service-connected disability					0.014	0.014	0.017	0.018	0.020	0.021	0.022	0.023	0.024	0.025
					(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Supplemental Nutrition Assistance Program (SNAP)[5]														
Share with SNAP receipt			0.413	0.428	0.503	0.560	0.636	0.695	0.683	0.666	0.658	0.647	0.631	0.610
			(0.011)	(0.011)	(0.010)	(0.009)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
Mean SNAP benefit amount (equivalized) (cond. on +)			$1,136	$1,101	$1,141	$1,197	$1,644	$1,790	$1,713	$1,687	$1,681	$1,515	$1,513	$1,445
			($28)	($27)	($14)	($15)	($16)	($14)	($14)	($18)	($40)	($23)	($25)	($16)
Mean months of SNAP receipt (cond. on +)			8.127	8.081	9.222	9.301	9.712	10.190	10.260	10.450	10.650	10.700	10.750	10.620
			(0.141)	(0.135)	(0.063)	(0.138)	(0.049)	(0.045)	(0.077)	(0.041)	(0.051)	(0.048)	(0.048)	(0.057)
Mean assistance unit size (cond. on +)			1.910	1.816	1.809	1.793	1.707	1.658	1.662	1.653	1.659	1.662	1.657	1.647
			(0.052)	(0.048)	(0.037)	(0.040)	(0.030)	(0.027)	(0.025)	(0.025)	(0.029)	(0.030)	(0.031)	(0.032)
Share with child in assistance unit (cond. on +)			0.278	0.238	0.195	0.170	0.149	0.134	0.134	0.132	0.127	0.124	0.118	0.111
			(0.016)	(0.015)	(0.007)	(0.008)	(0.006)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.000)
Medicaid and Medicare														
Share enrolled in Medicaid					0.328	0.348	0.374	0.414	0.446	0.470	0.476	0.614	0.683	
					(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	
Share enrolled in Medicare Part A or B				0.106	0.114	0.123	0.130	0.146	0.161	0.175	0.188	0.197	0.209	0.227
				(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
Disability programs (DI and SSI)														
Share receiving DI as indicated by Medicare records				0.106	0.114	0.122	0.129	0.145	0.160	0.174	0.187	0.196	0.194	0.191
				(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Share receiving SSI								0.210	0.234	0.255	0.260	0.260		0.270
								(0.004)	(0.004)	(0.004)	(0.004)	(0.003)		(0.004)
Mean SSI amount (cond. on +)								$8,018	$8,525	$8,511	$8,513	$8,388		$7,834
								($79)	($100)	($104)	($101)	($193)		($79)
Share receiving SSI or DI according to Medicare								0.291	0.327	0.359	0.376	0.385		0.396
								(0.005)	(0.005)	(0.005)	(0.005)	(0.005)		(0.005)
Share living in SNAP state in 2010			0.036	0.036	0.148	0.148	0.175	0.175	0.175	0.175	0.175	0.176	0.176	0.176
Share living in Medicaid state in 2010					0.953	0.953	0.953	0.953	0.953	0.953	0.953	0.839	0.415	
Sample Size	49,500	49,500	49,500	49,500	49,500	49,500	49,500	49,500	49,000	48,500	48,000	47,000	46,500	45,500
Population	118,200	118,200	118,200	118,200	118,200	118,200	118,200	118,200	117,300	115,900	114,400	112,700	110,900	108,900

*Sources and notes after Table A6.

Table A5a: Income and Benefit Receipt among Single Housed Poor Adults, Ages 25-59 in 2010 Decennial Census, 2005-2016*

A: Employment and Income												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Employment and Earnings[1]												
Share with earnings	0.611	0.596	0.582	0.553	0.484	0.483	0.498	0.493	0.489	0.488	0.489	0.487
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
50th percentile (cond. on +)	$14,510	$14,920	$14,230	$12,790	$10,690	$12,240	$13,890	$14,930	$15,830	$16,460	$17,650	$18,560
	($180)	($168)	($155)	($153)	($122)	($147)	($157)	($158)	($156)	($171)	($213)	($235)
75th percentile (cond. on +)	$28,010	$28,090	$26,420	$23,500	$18,510	$21,160	$23,930	$26,120	$27,810	$29,910	$31,830	$33,460
	($288)	($308)	($301)	($263)	($206)	($243)	($260)	($290)	($315)	($332)	($360)	($365)
Pretax Cash Income, Plus In-Kind Transfers (no SSI)[3]												
50th percentile	$7,158	$6,786	$9,937	$7,012	$6,169	$7,026	$7,356	$7,491	$7,545	$7,411	$7,532	$8,350
	($642)	($588)	($344)	($375)	($334)	($314)	($328)	($358)	($357)	($380)	($426)	($434)
75th percentile	$20,890	$19,640	$20,480	$18,630	$16,160	$17,560	$18,930	$19,200	$19,710	$20,160	$21,890	$23,200
	($899)	($1018)	($554)	($560)	($400)	($406)	($465)	($496)	($537)	($577)	($574)	($627)
Pretax Cash Income, Plus In-Kind Transfers (with SSI)												
50th percentile						$9,886	$10,140	$10,450	$10,660	$10,500		$11,030
						($249)	($253)	($245)	($240)	($259)		($254)
75th percentile						$19,090	$20,070	$20,460	$21,100	$21,600		$23,890
						($396)	($411)	($428)	($436)	($527)		($551)
Sample Size	55,000	55,000	55,000	55,000	55,000	55,000	54,500	54,000	54,000	53,500	53,000	52,500
Population (100,000s)	48.46	48.46	48.46	48.46	48.46	48.46	48.14	47.70	47.18	46.72	46.16	45.60

*Sources and notes after Table A6.

Table A5b: Income and Benefit Receipt among Single Housed Poor Adults, Ages 25-59 in 2010 Decennial Census, 2005-2016*

B: Connections to Employment and Formal Income

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share filing 1040	0.518	0.515	0.509	0.512	0.612	0.499	0.466	0.468	0.480	0.457	0.451	0.446	0.442	0.433
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)
1040 cofiling rate (cond. on filing)	0.225	0.215	0.201	0.185	0.147	0.152	0.138	0.138	0.147	0.179	0.193	0.204	0.218	0.233
	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Share filing 1040 with dependents (cond. on filing)	0.510	0.514	0.517	0.512	0.436	0.501	0.497	0.511	0.497	0.518	0.522	0.524	0.514	0.505
	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.005)	(0.006)
Mean number of dependents (cond. on filing with dependents)	1.816	1.802	1.801	1.793	1.780	1.798	1.835	1.846	1.844	1.874	1.870	1.865	1.852	1.852
	(0.012)	(0.013)	(0.013)	(0.012)	(0.012)	(0.013)	(0.013)	(0.011)	(0.012)	(0.011)	(0.012)	(0.011)	(0.011)	(0.013)
Share filing 1040 with positive total money income	0.511	0.508	0.488	0.485	0.587	0.475	0.439	0.447	0.456	0.437	0.431	0.426	0.424	0.416
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)
Share filing 1040 with self-employment income, positive or negative	0.085	0.089	0.090	0.095	0.101	0.101	0.104	0.105	0.105	0.101	0.101	0.101	0.101	0.097
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Share filing 1040 with positive social security income	0.007	0.007	0.006	0.014	0.106	0.027	0.025	0.025	0.030	0.030	0.032	0.037	0.041	0.044
	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share filing 1040 with positive wage and salary income	0.471	0.464	0.455	0.448	0.456	0.416	0.359	0.359	0.375	0.372	0.372	0.368	0.366	0.361
	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.004)
Share receiving W2			0.557	0.539	0.521	0.485	0.407	0.394	0.411	0.415	0.415	0.421	0.425	0.427
			(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Mean number of W2s received (cond. on +)			1.679	1.690	1.684	1.588	1.442	1.485	1.483	1.480	1.502	1.541	1.562	1.565
			(0.011)	(0.010)	(0.011)	(0.009)	(0.010)	(0.009)	(0.011)	(0.010)	(0.010)	(0.011)	(0.011)	(0.011)
Share receiving 1099R	0.050	0.049	0.047	0.053	0.063	0.067	0.073	0.064	0.058	0.059	0.061	0.068	0.070	0.074
	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Sample Size	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	54,500	54,000	54,000	53,500	53,000	52,500
Population (100,000s)	48.46	48.46	48.46	48.46	48.46	48.46	48.46	48.46	48.14	47.70	47.18	46.72	46.16	45.60

*Sources and notes after Table A6.

Table A5c: Income and Benefit Receipt among Single Housed Poor Adults, Ages 25-59 in 2010 Decennial Census, 2005-2016*

C: Safety Net Program Receipt

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Housing Benefits (HUD)														
Share with housing benefits	0.113	0.117	0.120	0.123	0.131	0.140	0.152	0.160	0.158	0.155	0.149	0.148	0.144	0.141
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Mean housing benefit amount (equivalized) (cond. on +)[4]	$5,045	$5,211	$5,237	$5,228	$5,186	$5,281	$5,680	$5,833	$5,719	$5,672	$5,773	$5,704	$5,867	$5,975
	($73)	($79)	($73)	($72)	($67)	($73)	($69)	($66)	($65)	($68)	($74)	($76)	($81)	($85)
Mean assistance unit size (cond. on +)	2.736	2.707	2.672	2.589	2.553	2.445	2.359	2.346	2.355	2.298	2.236	2.193	2.155	2.109
	(0.033)	(0.035)	(0.035)	(0.036)	(0.034)	(0.030)	(0.027)	(0.029)	(0.029)	(0.030)	(0.030)	(0.029)	(0.028)	(0.030)
Share with child in assistance unit (cond. on +)	0.570	0.545	0.535	0.514	0.498	0.469	0.438	0.421	0.413	0.397	0.381	0.359	0.339	0.320
	(0.011)	(0.010)	(0.010)	(0.010)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Mean months of housing benefit receipt (cond. on +)	11.140	11.190	11.210	11.170	11.100	11.070	11.240	11.390	11.320	11.240	11.340	11.230	11.280	11.250
	(0.071)	(0.066)	(0.063)	(0.066)	(0.061)	(0.056)	(0.051)	(0.053)	(0.040)	(0.048)	(0.048)	(0.063)	(0.060)	(0.043)
Veterans' Benefits (VA)														
Share with VA service-connected disability					0.011	0.013	0.014	0.015	0.016	0.017	0.018	0.019	0.020	0.021
					(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Supplemental Nutrition Assistance Program (SNAP)[5]														
Share with SNAP receipt			0.374	0.408	0.437	0.473	0.548	0.595	0.594	0.575	0.558	0.549	0.528	0.507
			(0.016)	(0.018)	(0.011)	(0.010)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.008)
Mean SNAP benefit amount (equivalized) (cond. on +)			$1,377	$1,403	$1,385	$1,479	$1,911	$1,992	$1,890	$1,810	$1,759	$1,582	$1,570	$1,505
			($43)	($46)	($25)	($25)	($29)	($26)	($23)	($23)	($24)	($21)	($23)	($22)
Mean months of SNAP receipt (cond. on +)			8.604	8.884	9.611	9.938	9.999	10.380	10.360	10.450	10.700	10.510	10.550	10.450
			(0.175)	(0.196)	(0.103)	(0.089)	(0.093)	(0.085)	(0.069)	(0.074)	(0.065)	(0.070)	(0.073)	(0.074)
Mean assistance unit size (cond. on +)			2.516	2.396	2.333	2.302	2.192	2.194	2.166	2.145	2.091	2.039	2.029	2.003
			(0.075)	(0.078)	(0.053)	(0.049)	(0.039)	(0.035)	(0.035)	(0.035)	(0.037)	(0.035)	(0.037)	(0.031)
Share with child in assistance unit (cond. on +)			0.510	0.484	0.426	0.408	0.373	0.367	0.346	0.331	0.308	0.289	0.279	0.269
			(0.023)	(0.026)	(0.016)	(0.014)	(0.012)	(0.011)	(0.010)	(0.010)	(0.010)	(0.008)	(0.009)	(0.000)
Medicaid and Medicare														
Share enrolled in Medicaid					0.322	0.338	0.371	0.398	0.414	0.420	0.421	0.503	0.540	
					(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.006)	
Share enrolled in Medicare Part A or B				0.097	0.105	0.115	0.123	0.143	0.158	0.170	0.179	0.185	0.197	0.216
				(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Disability programs (DI and SSI)														
Share receiving DI as indicated by Medicare records				0.095	0.104	0.114	0.122	0.142	0.157	0.169	0.178	0.183	0.179	0.177
				(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Share receiving SSI								0.157	0.166	0.174	0.177	0.173		0.174
								(0.003)	(0.003)	(0.003)	(0.003)	(0.003)		(0.003)
Mean SSI amount (cond. on +)								$7,540	$8,050	$7,785	$7,800	$7,608		$7,410
								($101)	($171)	($155)	($95)	($94)		($147)
Share receiving SSI or DI according to Medicare								0.251	0.274	0.292	0.305	0.308		0.307
								(0.005)	(0.004)	(0.005)	(0.004)	(0.005)		(0.005)
Share living in SNAP state in 2010			0.048	0.048	0.131	0.131	0.174	0.174	0.174	0.174	0.174	0.173	0.174	0.173
Share living in Medicaid state in 2010					0.949	0.949	0.949	0.949	0.949	0.949	0.949	0.786	0.391	
Sample Size	55,000	55,000	55,000	55,000	55,000	55,000	55,000	55,000	54,500	54,000	54,000	53,500	53,000	52,500
Population (100,000s)	48.46	48.46	48.46	48.46	48.46	48.46	48.46	48.46	48.14	47.70	47.18	46.72	46.16	45.60

*Sources and notes after Table A6.

Table A6a: Income and Benefit Receipt among All Housed Adults, Ages 25-59 in 2010 Decennial Census, 2005-2016

Employment and Income	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Earnings												
Share with earnings	0.857	0.860	0.864	0.861	0.848	0.843	0.837	0.831	0.825	0.815	0.809	0.801
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
50th percentile (cond. on +)	$34,400	$35,750	$36,930	$37,090	$36,930	$37,730	$37,950	$38,790	$39,540	$39,930	$41,550	$42,130
	($53)	($53)	($53)	($54)	($56)	($58)	($58)	($59)	($61)	($61)	($64)	($64)
75th percentile (cond. on +)	$60,360	$62,080	$63,830	$64,140	$64,610	$66,480	$67,160	$68,560	$70,080	$70,390	$73,510	$74,490
	($84)	($87)	($90)	($89)	($91)	($96)	($99)	($103)	($109)	($109)	($114)	($117)
Pretax Cash Income, Plus In-Kind Transfers (no SSI)												
50th percentile	$28,490	$29,510	$34,650	$34,920	$35,280	$36,210	$35,960	$36,560	$37,200	$37,510	$39,000	$39,740
	($217)	($228)	($162)	($159)	($140)	($143)	($149)	($152)	($153)	($153)	($159)	($160)
75th percentile	$52,370	$53,680	$66,390	$66,660	$67,240	$69,620	$70,290	$71,760	$73,320	$74,080	$77,380	$78,790
	($346)	($350)	($274)	($275)	($235)	($248)	($254)	($263)	($275)	($272)	($287)	($299)
Pretax Cash Income, Plus In-Kind Transfers (with SSI)												
50th percentile						$36,230	$36,000	$36,590	$37,220	$37,550		$39,770
						($142)	($149)	($151)	($152)	($152)		($161)
75th percentile						$69,650	$70,320	$71,800	$73,350	$74,100		$78,840
						($249)	($254)	($264)	($274)	($271)		($300)
Sample Size	994,000	994,000	994,000	994,000	994,000	994,000	992,000	989,000	986,000	983,000	979,000	975,000
Population (100,000s)	722.70	722.70	722.70	722.70	722.70	722.70	722.70	722.70	721.30	719.10	716.80	714.40

*Sources and notes after Table A6.

Table A6b: Income and Benefit Receipt among All Housed Adults, Ages 25-59 in 2010 Decennial Census, 2005-2016

Connections to Employment and Formal Income	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share filing 1040	0.827	0.835	0.840	0.848	0.886	0.866	0.863	0.860	0.857	0.847	0.841	0.835	0.831	0.821
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
1040 cofiling rate (cond. on filing)	0.545	0.554	0.565	0.572	0.569	0.588	0.598	0.603	0.606	0.616	0.622	0.626	0.632	0.637
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Share filing 1040 with dependents (cond. on +)	0.538	0.542	0.545	0.545	0.531	0.543	0.546	0.533	0.525	0.521	0.513	0.524	0.513	0.501
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mean number of dependents (cond. on +)	1.876	1.869	1.864	1.859	1.855	1.868	1.882	1.875	1.876	1.876	1.873	1.871	1.868	1.864
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Share receiving W2			0.781	0.783	0.783	0.778	0.758	0.747	0.741	0.736	0.729	0.723	0.717	0.709
			(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mean number of W2s received (cond. on +)			1.478	1.469	1.445	1.397	1.322	1.322	1.322	1.325	1.327	1.339	1.346	1.339
			(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Sample Size	994,000	994,000	994,000	994,000	994,000	994,000	994,000	994,000	992,000	989,000	986,000	983,000	979,000	975,000
Population (100,000s)	722.70	722.70	722.70	722.70	722.70	722.70	722.70	722.70	721.30	719.10	716.80	714.40	711.70	708.80

*Sources and notes after Table A6.

Table A6c: Income and Benefit Receipt among All Housed Adults, Ages 25-59 in 2010 Decennial Census, 2005-2016

Safety Net Program Receipt

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Housing Benefits (HUD)														
Share with housing benefits	0.027	0.027	0.026	0.025	0.025	0.025	0.026	0.026	0.026	0.026	0.025	0.025	0.024	0.024
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mean housing benefit amount (equiv'd) (cond. on +)	10.890	10.940	10.900	10.910	10.920	11.020	11.150	11.220	11.230	11.190	11.190	11.130	11.110	11.120
	(0.029)	(0.030)	(0.030)	(0.030)	(0.026)	(0.028)	(0.027)	(0.026)	(0.024)	(0.024)	(0.025)	(0.024)	(0.025)	(0.023)
Veterans' Benefits (VA)														
Share with VA service-connected disability					0.009	0.010	0.011	0.012	0.012	0.013	0.014	0.015	0.016	0.017
					(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Food Assistance (SNAP)														
Share with SNAP receipt			0.124	0.122	0.098	0.108	0.123	0.137	0.144	0.144	0.144	0.142	0.138	0.132
			(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mean SNAP benefit amount (equiv'd) (cond. on +)			8.017	8.280	9.176	9.175	9.220	9.467	9.468	9.810	10.090	10.030	10.130	10.060
			(0.085)	(0.074)	(0.051)	(0.047)	(0.035)	(0.035)	(0.030)	(0.035)	(0.030)	(0.028)	(0.031)	(0.032)
Medicaid and Medicare														
Share enrolled in Medicaid					0.095	0.095	0.103	0.109	0.114	0.115	0.116	0.153	0.174	
					(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	
Share enrolled in Medicare Part A or B				0.027	0.030	0.033	0.036	0.042	0.046	0.050	0.055	0.060	0.076	0.100
				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Disability programs (DI and SSI)														
Share receiving DI as indicated by Medicare records				0.027	0.030	0.033	0.036	0.042	0.046	0.050	0.055	0.059	0.059	0.060
				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Share receiving SSI								0.026	0.027	0.028	0.028	0.027		0.027
								(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
Share receiving SSI or DI according to Medicare								0.059	0.064	0.068	0.073	0.077		0.078
								(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		(0.000)
Share living in SNAP state in 2010			0.042	0.042	0.134	0.134	0.177	0.177	0.177	0.177	0.177	0.177	0.177	0.177
Share living in Medicaid state in 2010					0.949	0.949	0.949	0.949	0.949	0.949	0.949	0.786	0.402	
Sample Size	994,000	994,000	994,000	994,000	994,000	994,000	994,000	994,000	992,000	989,000	986,000	983,000	979,000	975,000
Population (100,000s)	722.70	722.70	722.70	722.70	722.70	722.70	722.70	722.70	721.30	719.10	716.80	714.40	711.70	708.80

*Sources and notes after Table A6.

Table A7: TANF and General Assistance Receipt among Homeless and Comparison Groups, Ages 25-59 in 2010 Decennial Census, New York, 2007-2016

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share receiving TANF - Sheltered	0.333	0.361	0.469	0.584	0.486	0.396	0.343	0.303	0.290	0.275
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Mean TANF amount (cond on +)	$4,330	$4,602	$3,725	$4,047	$5,411	$4,871	$5,382	$5,476	$5,625	$5,771
	($92)	($98)	($77)	($71)	($87)	($82)	($98)	($103)	($102)	($104)
Share receiving TANF - Unsheltered	0.219	0.264	0.286	0.302	0.267	0.251	0.239	0.228	0.214	0.199
	(0.010)	(0.023)	(0.022)	(0.022)	(0.023)	(0.024)	(0.024)	(0.025)	(0.025)	(0.026)
Mean TANF amount (cond on +)	$3,550	$3,582	$3,696	$3,912	$4,077	$4,022	$4,601	$4,278	$4,504	$4,540
	($188)	($387)	($284)	($215)	($436)	($376)	($226)	($416)	($401)	($403)
Share receiving TANF - Single Housed Poor	0.183	0.182	0.186	0.191	0.162	0.145	0.122	0.113	0.109	0.103
	(0.011)	(0.011)	(0.011)	(0.012)	(0.011)	(0.011)	(0.009)	(0.009)	(0.009)	(0.009)
Mean TANF amount (cond on +)	$4,226	$4,569	$4,872	$4,742	$5,162	$5,014	$5,605	$5,471	$5,311	$5,287
	($497)	($447)	($488)	($506)	($491)	($510)	($575)	($477)	($481)	($532)
Share receiving TANF - Overall Housed	0.028	0.027	0.028	0.028	0.027	0.025	0.023	0.022	0.020	0.019
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mean TANF amount (cond on +)	$3,913	$4,140	$4,397	$4,453	$4,646	$4,531	$4,809	$4,623	$4,906	$4,883
	($235)	($212)	($225)	($222)	($210)	($185)	($192)	($176)	($191)	($196)
Sample Size - Sheltered	13,000	13,000	13,000	13,000	13,000	12,500	12,500	12,500	12,500	12,000
Population - Sheltered	17,820	17,820	17,820	17,820	17,690	17,550	17,370	17,200	17,030	16,810
Sample Size - Unsheltered	3,500	3,500	3,500	3,500	3,400	3,400	3,400	3,300	3,300	3,200
Population - Unsheltered	9,694	9,694	9,694	9,694	9,635	9,544	9,437	9,341	9,195	9,037
Sample - Single Housed Poor	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,100	3,100
Population - Single Housed Poor	304,600	304,600	304,600	304,600	303,300	299,100	295,300	291,000	288,800	285,200
Sample Size - Overall Housed	60,500	60,500	60,500	60,500	60,500	60,500	60,000	60,000	60,000	59,500
Population - Overall Housed	4,563,000	4,563,000	4,563,000	4,563,000	4,556,000	4,545,000	4,533,000	4,519,000	4,507,000	4,494,000

Sources: 2010 Decennial Census, 2019 Numident, 2007-2016 New York TANF dataset

Notes: Sample includes PIKed homeless adults from the 2010 Decennial Census, PIKed single adults in poverty, and PIKed housed adults who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010 and lived in New York stat in that year. Table displays the weighted means and shares. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A8: Monthly SNAP receipt among Chicago HMIS Shelter Users Ages 25-59

Month relative to shelter enrollment:	1	2	3	4	5	6	7	8	9	10	11	12
24-13 months prior	0.459	0.462	0.460	0.460	0.463	0.463	0.460	0.463	0.465	0.463	0.466	0.464
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Sample Size	5737	5737	5737	5737	5737	5737	5737	5737	5737	5737	5737	5737
12-0 months prior	0.465	0.460	0.456	0.455	0.453	0.454	0.458	0.459	0.458	0.464	0.469	0.489
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Sample Size	5737	5737	5737	5737	5737	5737	5737	5737	5737	5737	5737	5737
1-12 months after	0.580	0.613	0.627	0.618	0.606	0.577	0.567	0.569	0.561	0.526	0.512	
	(0.007)	(0.007)	(0.007)	(0.008)	(0.008)	(0.009)	(0.010)	(0.011)	(0.013)	(0.016)	(0.022)	
Sample Size	5300	4900	4400	3900	3400	3000	2500	2100	1500	1000	550	

Source: Chicago (2014-2019) HMIS dataset, various states' SNAP datasets

Notes: Sample consists of people with first observed homeless spell in 2016.

Table A9a: Share of Sheltered Homeless with Income and Benefit Receipt by Gender, Ages 25-59 in 2010 Census

Panel A: Income and Benefit Receipt among Sheltered Homeless Women Ages 25-59 in 2010 Decennial Census, 2003-2016

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share with earnings	0.613	0.618	0.612	0.593	0.523	0.552	0.532	0.503	0.497	0.483	0.487	0.490
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
50th percentile earnings (cond. on +)	$8,975	$9,262	$9,388	$8,536	$7,777	$9,715	$11,450	$11,680	$11,970	$12,250	$13,100	$13,620
	($108)	($115)	($108)	($110)	($119)	($106)	($92)	($103)	($117)	($130)	($135)	($135)
75th percentile earnings (cond. on +)	$18,140	$18,280	$17,620	$16,160	$15,380	$16,390	$18,770	$18,970	$19,450	$19,840	$21,650	$22,910
	($172)	($149)	($159)	($131)	($129)	($119)	($138)	($147)	($163)	($186)	($215)	($214)
50th percentile pre-tax income + in-kind transfers	$5,983	$5,454	$6,666	$5,376	$4,252	$6,906	$8,072	$7,569	$7,769	$7,250	$8,012	$8,284
	($366)	($360)	($209)	($196)	($152)	($237)	($271)	($275)	($267)	($273)	($271)	($260)
75th percentile pre-tax income + in-kind transfers	$13,680	$13,760	$15,360	$14,700	$13,900	$15,920	$17,170	$17,040	$17,250	$16,910	$18,070	$18,420
	($652)	($587)	($224)	($212)	($173)	($175)	($177)	($192)	($192)	($202)	($194)	($216)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)			0.791	0.821	0.890	0.930	0.919	0.903	0.891	0.893	0.874	
			(0.005)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.007)	
Share receiving SNAP	0.491	0.506	0.628	0.683	0.806	0.869	0.840	0.797	0.767	0.741	0.709	0.681
	(0.015)	(0.015)	(0.006)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Share with child in assistance unit (cond on +)	0.584	0.559	0.562	0.545	0.538	0.532	0.521	0.504	0.492	0.473	0.457	0.445
	(0.019)	(0.018)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Share enrolled in Medicaid			0.502	0.514	0.561	0.619	0.636	0.640	0.637	0.732	0.757	
			(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	
Share receiving SSI or DI (according to Medicare records)						0.200	0.253	0.293	0.315	0.331		0.344
						(0.003)	(0.004)	(0.004)	(0.004)	(0.004)		(0.004)

Panel B: Income and Benefit Receipt among Sheltered Homeless Men Ages 25-59 in 2010 Decennial Census, 2003-2016

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share with earnings	0.627	0.621	0.602	0.572	0.490	0.502	0.479	0.441	0.432	0.415	0.410	0.410
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
50th percentile earnings (cond. on +)	$9,741	$9,672	$9,300	$7,786	$5,977	$7,674	$10,370	$10,820	$11,000	$11,470	$12,640	$13,340
	($90)	($92)	($86)	($84)	($77)	($70)	($99)	($106)	($111)	($130)	($150)	($148)
75th percentile earnings (cond. on +)	$21,260	$20,610	$19,280	$17,110	$14,660	$16,720	$20,900	$21,450	$22,040	$22,990	$25,180	$26,120
	($148)	($145)	($135)	($128)	($139)	($150)	($161)	($163)	($173)	($188)	($211)	($205)
50th percentile pre-tax income + in-kind transfers	$5,446	$4,816	$3,268	$2,264	$2,666	$2,896	$3,103	$2,794	$2,618	$2,389	$2,452	$2,635
	($318)	($264)	($139)	($46)	($11)	($56)	($89)	($65)	($63)	($53)	($72)	($89)
75th percentile pre-tax income + in-kind transfers	$15,700	$14,700	$13,530	$11,400	$10,140	$12,370	$14,220	$14,070	$14,150	$13,770	$14,460	$14,990
	($555)	($537)	($211)	($193)	($191)	($153)	($189)	($190)	($199)	($201)	($222)	($229)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)			0.611	0.667	0.780	0.869	0.848	0.817	0.803	0.802	0.821	
			(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	
Share receiving SNAP	0.300	0.329	0.478	0.545	0.695	0.799	0.751	0.698	0.668	0.642	0.615	0.594
	(0.010)	(0.010)	(0.005)	(0.005)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Share with child in assistance unit (cond on +)	0.158	0.140	0.141	0.125	0.120	0.119	0.117	0.109	0.106	0.099	0.095	0.091
	(0.014)	(0.010)	(0.005)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
Share enrolled in Medicaid			0.223	0.242	0.284	0.359	0.392	0.411	0.419	0.551	0.616	
			(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	
Share receiving SSI or DI (according to Medicare records)						0.186	0.241	0.286	0.310	0.325		0.342
						(0.002)	(0.003)	(0.003)	(0.003)	(0.003)		(0.003)

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Note: Sample includes PIKed adults enumerated in emergency and transitional shelters in the 2010 Decennial Census who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A9b: Share of Unsheltered Homeless with Income and Benefit Receipt by Gender, Ages 25-59 in 2010 Census

Panel A: Income and Benefit Receipt among Unsheltered Homeless Women Ages 25-59 in 2010 Decennial Census, 2003-2016

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share with earnings	0.529	0.522	0.510	0.484	0.425	0.422	0.411	0.388	0.388	0.373	0.374	0.377
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
50th percentile earnings (cond. on +)	$8,210	$8,371	$8,646	$8,897	$8,715	$10,200	$10,990	$11,360	$11,600	$12,160	$12,680	$12,750
	($206)	($204)	($208)	($217)	($226)	($216)	($223)	($211)	($216)	($235)	($257)	($276)
75th percentile earnings (cond. on +)	$18,770	$19,330	$19,420	$19,250	$18,850	$20,020	$21,020	$21,070	$21,490	$22,560	$24,140	$24,920
	($322)	($355)	($325)	($327)	($359)	($404)	($401)	($396)	($421)	($461)	($494)	($497)
50th percentile pre-tax income + in-kind transfers	$2,474	$2,380	$5,719	$3,789	$3,233	$3,933	$3,992	$3,738	$3,863	$3,275	$3,579	$4,560
	($294)	($310)	($408)	($313)	($206)	($305)	($327)	($305)	($342)	($307)	($334)	($408)
75th percentile pre-tax income + in-kind transfers	$10,000	$10,030	$16,090	$15,150	$13,940	$15,470	$16,170	$15,870	$16,130	$15,810	$17,030	$17,110
	($1132)	($1050)	($577)	($675)	($609)	($547)	($571)	($543)	($510)	($545)	($622)	($689)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)			0.728	0.745	0.783	0.820	0.831	0.823	0.823	0.832	0.850	
			(0.010)	(0.010)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.012)	
Share receiving SNAP	0.547	0.555	0.578	0.605	0.662	0.715	0.718	0.702	0.691	0.687	0.670	0.652
	(0.021)	(0.021)	(0.011)	(0.011)	(0.010)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Share with child in assistance unit (cond on +)	0.485	0.430	0.419	0.401	0.362	0.335	0.322	0.315	0.299	0.290	0.276	0.258
	(0.026)	(0.026)	(0.015)	(0.014)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Share enrolled in Medicaid			0.490	0.498	0.516	0.548	0.571	0.588	0.595	0.708	0.759	
			(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.006)	
Share receiving SSI or DI (according to Medicare records)						0.335	0.362	0.395	0.414	0.422		0.432
						(0.006)	(0.006)	(0.006)	(0.006)	(0.006)		(0.007)

Panel B: Income and Benefit Receipt among Unsheltered Homeless Men Ages 25-59 in 2010 Decennial Census, 2003-2016

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share with earnings	0.570	0.555	0.534	0.497	0.416	0.397	0.381	0.349	0.346	0.326	0.327	0.328
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
50th percentile earnings (cond. on +)	$8,434	$8,535	$8,477	$7,599	$6,899	$7,769	$9,560	$9,713	$10,120	$10,540	$11,660	$12,050
	($193)	($183)	($237)	($151)	($215)	($152)	($247)	($228)	($239)	($230)	($240)	($260)
75th percentile earnings (cond. on +)	$20,180	$20,010	$19,790	$18,210	$17,270	$19,620	$22,250	$22,110	$22,760	$24,010	$25,950	$27,020
	($360)	($324)	($437)	($288)	($401)	($408)	($510)	($409)	($459)	($426)	($449)	($424)
50th percentile pre-tax income + in-kind transfers	$2,349	$2,569	$2,952	$2,222	$2,538	$2,710	$2,630	$2,579	$2,525	$2,389	$2,439	$2,417
	($254)	($223)	($356)	($103)	($53)	($24)	($22)	($28)	($15)	($22)	($16)	($41)
75th percentile pre-tax income + in-kind transfers	$12,500	$11,960	$13,670	$11,880	$10,190	$11,050	$11,710	$11,290	$10,960	$10,260	$11,520	$11,760
	($833)	($659)	($621)	($704)	($631)	($631)	($635)	($637)	($651)	($693)	($689)	($687)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)	0.380	0.457	0.617	0.682	0.742	0.793	0.789	0.781	0.787	0.796	0.822	
	(0.013)	(0.014)	(0.015)	(0.010)	(0.008)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)	
Share receiving SNAP	0.363	0.381	0.475	0.544	0.626	0.688	0.670	0.653	0.645	0.631	0.616	0.594
	(0.013)	(0.013)	(0.013)	(0.013)	(0.010)	(0.009)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)	(0.011)
Share with child in assistance unit (cond on +)	0.159	0.125	0.095	0.078	0.065	0.059	0.064	0.061	0.058	0.057	0.054	0.050
	(0.015)	(0.013)	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Share enrolled in Medicaid			0.270	0.295	0.323	0.367	0.402	0.428	0.434	0.579	0.653	
			(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.007)	
Share receiving SSI or DI (according to Medicare records)						0.276	0.314	0.346	0.363	0.372		0.383
						(0.007)	(0.007)	(0.007)	(0.006)	(0.006)		(0.007)

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Note: Sample includes PIKed adults enumerated in unsheltered locations in the 2010 Decennial Census who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A10: Income and Benefit Receipt among HMIS Shelter Users Ages 25-59 by Family Status (Point-in-Time Samples, 2012-2013)

	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4
Panel A1: Los Angeles - Adults in Families												
Share with earnings	0.695	0.718	0.704	0.649	0.612	0.656	0.650	0.657	0.649	0.655	0.660	0.636
	(0.015)	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.016)	(0.022)
50th percentile earnings (cond. on +)	$10,490	$11,230	$11,700	$11,790	$12,290	$12,270	$11,270	$11,760	$14,290	$15,150	$15,630	$15,560
	($651)	($650)	($592)	($595)	($588)	($482)	($482)	($456)	($436)	($408)	($491)	($779)
Share enrolled in Medicaid			0.560	0.587	0.639	0.698	0.779	0.853	0.853	0.838		
			(0.016)	(0.016)	(0.016)	(0.015)	(0.014)	(0.012)	(0.012)	(0.012)		
Share receiving SSI or DI (according to Medicare records)						0.051	0.056	0.069	0.081	0.098	0.083	0.103
						(0.006)	(0.006)	(0.006)	(0.008)	(0.012)	(0.008)	(0.008)
Sample Size	950	950	950	950	950	950	950	950	950	950	900	500
Panel A2: Los Angeles - Adults Not in Families												
	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4
Share with earnings	0.555	0.559	0.530	0.473	0.438	0.463	0.410	0.355	0.328	0.296	0.302	0.301
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.008)
50th percentile earnings (cond. on +)	$10,120	$10,170	$9,461	$9,309	$9,280	$10,740	$8,242	$6,737	$7,590	$8,921	$10,180	$10,740
	($303)	($306)	($320)	($315)	($293)	($370)	($298)	($247)	($286)	($394)	($406)	($654)
Share enrolled in Medicaid			0.223	0.228	0.239	0.250	0.268	0.309	0.580	0.821		
			(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.005)		
Share receiving SSI or DI (according to Medicare records)					0.147	0.167	0.189	0.228	0.279	0.325	0.324	0.356
					(0.006)	(0.004)	(0.004)	(0.004)	(0.005)	(0.008)	(0.005)	(0.006)
Sample Size	6,200	6,200	6,200	6,200	6,200	6,200	6,200	6,200	6,200	6,100	6,100	3,100
Panel B1: Houston - Adults in Families												
	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4
Share with earnings	0.717	0.737	0.749	0.731	0.756	0.744	0.744	0.794	0.806	0.791	0.761	0.732
	(0.022)	(0.022)	(0.022)	(0.022)	(0.021)	(0.022)	(0.022)	(0.020)	(0.020)	(0.020)	(0.021)	(0.033)
50th percentile earnings (cond. on +)	$8,611	$10,250	$10,690	$11,130	$10,760	$11,320	$10,410	$10,550	$14,120	$15,040	$15,560	$14,270
	($658)	($810)	($816)	($872)	($711)	($523)	($546)	($767)	($601)	($590)	($685)	($1196)
Share enrolled in Medicaid			0.450	0.428	0.477	0.512	0.561	0.638	0.529	0.434		
			(0.025)	(0.025)	(0.025)	(0.025)	(0.025)	(0.024)	(0.025)	(0.036)		
Share receiving SSI or DI (according to Medicare records)												
Sample Size	400	400	400	400	400	400	400	400	400	400	400	200
Panel B2: Houston - Adults Not in Families												
	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t	t+1	t+2	t+3	t+4
Share with earnings	0.692	0.704	0.690	0.657	0.628	0.593	0.594	0.651	0.629	0.590	0.561	0.532
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.012)	(0.011)	(0.012)	(0.012)	(0.012)	(0.017)
50th percentile earnings (cond. on +)	$10,350	$11,180	$10,520	$9,421	$9,107	$8,401	$5,826	$7,186	$10,040	$11,370	$11,450	$11,990
	($520)	($453)	($419)	($432)	($320)	($395)	($285)	($334)	($431)	($582)	($582)	($1024)
Share enrolled in Medicaid			0.114	0.116	0.109	0.126	0.141	0.179	0.185	0.202		
			(0.008)	(0.008)	(0.007)	(0.008)	(0.008)	(0.009)	(0.009)	(0.014)		
Share receiving SSI or DI (according to Medicare records)					0.049	0.060	0.075	0.110	0.145	0.175	0.190	0.201
					(0.006)	(0.005)	(0.005)	(0.006)	(0.007)	(0.010)	(0.006)	(0.007)
Sample Size	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,800	1,700	1,700	850

Source: Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, various administrative datasets

Notes: Point-in-time samples consists of those who were in an HMIS shelter on March 30 of 2012 and 2013.

Table A11: 2010 Income and Benefit Receipt among Sheltered and Unsheltered Homeless Individuals Ages 25-59 in the 2010 Census, by Race and Ethnicity

	Sheltered				
	White	**Black**	**Other Race**	**Hispanic**	**Non-Hispanic**
Share with earnings	0.496	0.547	0.514	0.535	0.516
	(0.002)	(0.003)	(0.005)	(0.005)	(0.002)
50th percentile earnings (cond. on +)	$7,126	$9,567	$9,961	$10,510	$7,965
	($82)	($103)	($228)	($183)	($62)
75th percentile earnings (cond. on +)	$15,210	$17,100	$19,580	$19,190	$16,080
	($138)	($155)	($378)	($321)	($99)
50th percentile pre-tax income + in-kind transfers	$2,982	$4,996	$4,634	$4,617	$3,795
	($74)	($178)	($353)	($310)	($102)
75th percentile pre-tax income + in-kind transfers	$11,910	$14,710	$15,920	$15,420	$13,520
	($208)	($168)	($380)	($289)	($134)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)	0.852	0.923	0.883	0.910	0.888
	(0.004)	(0.003)	(0.006)	(0.004)	(0.002)
Share receiving SNAP	0.776	0.867	0.802	0.850	0.820
	(0.005)	(0.003)	(0.007)	(0.005)	(0.003)
Share enrolled in Medicaid	0.395	0.486	0.506	0.541	0.429
	(0.002)	(0.003)	(0.005)	(0.005)	(0.002)
Share receiving SSI or DI (according to Medicare records)	0.180	0.207	0.181	0.172	0.194
	(0.003)	(0.003)	(0.006)	(0.005)	(0.002)
Share living in SNAP state in 2010	0.178	0.315	0.260	0.365	0.222
	Unsheltered				
	White	**Black**	**Other Race**	**Hispanic**	**Non-Hispanic**
Share with earnings	0.383	0.427	0.368	0.465	0.326
	(0.004)	(0.006)	(0.011)	(0.013)	(0.003)
50th percentile earnings (cond. on +)	$7,474	$8,946	$10,030	$12,300	$7,744
	($143)	($270)	($514)	($364)	($131)
75th percentile earnings (cond. on +)	$19,000	$19,160	$25,150	$27,630	$18,050
	($337)	($525)	($1261)	($717)	($328)
50th percentile pre-tax income + in-kind transfers	$2,694	$2,710	$3,495	$3,017	$2,710
	($70)	($58)	($520)	($980)	($17)
75th percentile pre-tax income + in-kind transfers	$10,690	$12,520	$17,520	$17,410	$11,310
	($1228)	($375)	($1262)	($2129)	($331)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)	0.777	0.832	0.736	0.739	0.816
	(0.011)	(0.006)	(0.016)	(0.021)	(0.005)
Share receiving SNAP	0.671	0.733	0.608	0.661	0.704
	(0.015)	(0.007)	(0.019)	(0.026)	(0.006)
Share enrolled in Medicaid	0.404	0.428	0.416	0.397	0.417
	(0.006)	(0.006)	(0.015)	(0.017)	(0.004)
Share receiving SSI or DI (according to Medicare records)	0.284	0.306	0.277	0.209	0.306
	(0.006)	(0.008)	(0.025)	(0.010)	(0.006)
Share living in SNAP state in 2010	0.130	0.240	0.162	0.231	0.165

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults in the 2010 Decennial Census who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A12: 2010 Income and Benefit Receipt among Sheltered and Unsheltered Homeless Individuals Ages 25-59 in the 2010 Census, by State

	Sheltered			Unsheltered		
	California	**New York**	**Other States**	**California**	**New York**	**Other States**
Share with earnings	0.471	0.497	0.531	0.347	0.368	0.422
	(0.005)	(0.004)	(0.002)	(0.008)	(0.014)	(0.004)
50th percentile earnings (cond. on +)	$10,330	$9,989	$7,534	$9,957	$11,310	$7,770
	($260)	($116)	($64)	($338)	($637)	($148)
75th percentile earnings (cond. on +)	$22,280	$16,000	$15,540	$24,840	$24,830	$18,030
	($485)	($248)	($106)	($825)	($1008)	($325)
50th percentile pre-tax income + in-kind transfers		$4,049	$3,426		$2,400	$2,699
		($180)	($103)		($103)	($54)
75th percentile pre-tax income + in-kind transfers		$40,000	$12,400		$36,780	$11,470
		($171)	($169)		($955)	($376)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)		0.932	0.839		0.814	0.788
		(0.002)	(0.004)		(0.009)	(0.006)
Share receiving SNAP		0.862	0.779		0.694	0.697
		(0.003)	(0.004)		(0.012)	(0.007)
Share enrolled in Medicaid	0.375	0.896	0.367	0.379	0.722	0.387
	(0.005)	(0.003)	(0.002)	(0.013)	(0.011)	(0.004)
Share receiving SSI or DI (according to Medicare records)	0.218	0.230	0.178	0.290	0.310	0.289
	(0.006)	(0.006)	(0.002)	(0.016)	(0.018)	(0.005)
Share living in SNAP state in 2010			0.143			0.128

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults in the 2010 Decennial Census who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A13: Income and Benefit Receipt among HMIS Shelter Users Ages 25-59 - Point-in-Time and Interval-Based Results

	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t-0	t+1	t+2	t+3	t+4
Panel A1: Los Angeles Sample of First Spells in Year (2012-2013)												
Share with earnings	0.589	0.591	0.573	0.525	0.483	0.486	0.455	0.421	0.395	0.380	0.381	0.375
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.006)
50th percentile earnings (cond. on +)	$9,975	$10,590	$10,750	$10,870	$10,780	$10,720	$9,704	$6,831	$9,013	$10,380	$11,350	$11,760
	($190)	($190)	($192)	($201)	($185)	($170)	($194)	($162)	($205)	($187)	($223)	($331)
Share enrolled in Medicaid		0.139	0.301	0.310	0.325	0.338	0.357	0.393	0.599	0.798	0.781	
		(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.005)	
Share receiving SSI or DI (according to Medicare records)					0.151	0.163	0.179	0.198	0.227	0.255	0.277	0.293
					(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.005)
Sample Size	14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,500	14,000	7,600
Panel A2: Los Angeles Point-in-Time Sample (2012-2013)												
	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t-0	t+1	t+2	t+3	t+4
Share with earnings	0.574	0.580	0.553	0.496	0.461	0.489	0.441	0.395	0.370	0.344	0.350	0.346
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.008)
50th percentile earnings (cond. on +)	$10,170	$10,360	$10,010	$9,948	$10,140	$11,110	$9,124	$7,865	$9,726	$10,940	$11,780	$12,080
	($274)	($278)	($286)	($280)	($285)	($314)	($255)	($263)	($288)	($356)	($353)	($502)
Share enrolled in Medicaid		0.124	0.267	0.275	0.291	0.309	0.335	0.380	0.616	0.823	0.821	
		(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.005)		
Share receiving SSI or DI (according to Medicare records)					0.134	0.152	0.172	0.207	0.253	0.295	0.292	0.322
					(0.005)	(0.004)	(0.004)	(0.003)	(0.005)	(0.007)	(0.005)	(0.005)
Sample Size	7,200	7,200	7,200	7,200	7,200	7,200	7,200	7,200	7,100	7,100	7,000	3,600
Panel B1: Houston Sample of First Spells in Year (2012-2013)												
	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t-0	t+1	t+2	t+3	t+4
Share with earnings	0.659	0.663	0.666	0.632	0.587	0.588	0.578	0.598	0.572	0.545	0.519	0.507
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.008)
50th percentile earnings (cond. on +)	$8,610	$9,330	$10,020	$10,020	$10,660	$10,300	$8,911	$6,023	$8,436	$9,945	$10,330	$10,630
	($197)	($182)	($209)	($202)	($189)	($188)	($187)	($157)	($211)	($220)	($242)	($346)
Share enrolled in Medicaid		0.110	0.221	0.226	0.234	0.255	0.278	0.301	0.311	0.310		
		(0.003)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)		
Share receiving SSI or DI (according to Medicare records)					0.126	0.137	0.151	0.169	0.193	0.216	0.218	0.236
					(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)	(0.005)	(0.005)
Sample Size	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	8,900	8,800	4,500
Panel B2: Houston Point-in-Time Sample (2012-2013)												
	t-7	t-6	t-5	t-4	t-3	t-2	t-1	t-0	t+1	t+2	t+3	t+4
Share with earnings	0.697	0.710	0.701	0.671	0.652	0.621	0.622	0.678	0.662	0.628	0.599	0.567
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.011)	(0.015)
50th percentile earnings (cond. on +)	$9,891	$10,890	$10,600	$9,783	$9,495	$9,234	$6,796	$7,970	$10,790	$12,300	$12,470	$12,670
	($421)	($399)	($367)	($395)	($297)	($327)	($291)	($320)	($403)	($426)	($466)	($754)
Share enrolled in Medicaid		0.089	0.177	0.174	0.178	0.198	0.219	0.265	0.249	0.243		
		(0.006)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.013)		
Share receiving SSI or DI (according to Medicare records)					0.045	0.056	0.068	0.096	0.129	0.159	0.167	0.183
					(0.005)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.003)
Sample Size	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,100	2,100	1,000

Source: Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, various administrative datasets

Notes: Interval-based sample consists of people who had a first homeless spell in 2012 or 2013. Point-in-time sample consists of those who were in an HMIS shelter on March 30 of 2012 and 20

Table A14: Income and Benefit Receipt among HMIS Shelter Users Ages 25-59 and Census Homeless in Los Angeles and Houston

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Panel A1: Los Angeles HMIS Sample												
Share with earnings	0.515	0.514	0.491	0.462	0.401	0.499	0.484	0.341	0.355	0.314	0.298	0.317
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.009)	(0.008)	(0.008)	(0.009)
50th percentile earnings (cond. on +)	$10,250	$10,650	$9,751	$9,119	$8,320	$12,750	$15,700	$12,890	$12,310	$13,770	$15,580	$16,140
	($419)	($405)	($439)	($430)	($433)	($501)	($572)	($503)	($527)	($568)	($612)	($683)
Share enrolled in Medicaid			0.308	0.318	0.347	0.391	0.426	0.449	0.465	0.752	0.768	
			(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	(0.008)	
Share receiving SSI or DI (according to Medicare records)						0.208	0.270	0.307	0.332	0.358		0.391
						(0.007)	(0.007)	(0.008)	(0.008)	(0.008)		(0.008)
Sample Size	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,100	3,100	3,000
Panel A2: Los Angeles Census Sample												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share with earnings	0.529	0.531	0.509	0.471	0.411	0.506	0.503	0.378	0.382	0.349	0.336	0.351
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
50th percentile earnings (cond. on +)	$10,400	$10,950	$9,514	$9,173	$8,208	$12,850	$15,740	$12,970	$12,370	$13,500	$15,440	$16,240
	($419)	($405)	($439)	($430)	($433)	($501)	($572)	($503)	($527)	($568)	($612)	($683)
Share enrolled in Medicaid			0.271	0.283	0.306	0.358	0.389	0.423	0.444	0.720	0.764	
			(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	(0.008)	
Share receiving SSI or DI (according to Medicare records)						0.228	0.298	0.334	0.355	0.367		0.394
						(0.007)	(0.007)	(0.008)	(0.008)	(0.008)		(0.008)
Sample Size	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,500	3,400	3,400	3,300	3,300
Panel B1: Houston HMIS Sample												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share with earnings	0.714	0.754	0.709	0.707	0.665	0.716	0.672	0.641	0.647	0.603	0.590	0.584
	(0.016)	(0.015)	(0.016)	(0.016)	(0.017)	(0.016)	(0.017)	(0.017)	(0.017)	(0.018)	(0.018)	(0.018)
50th percentile earnings (cond. on +)	$8,716	$9,333	$9,097	$7,505	$6,855	$8,147	$11,850	$11,800	$10,840	$11,820	$12,590	$12,900
	($536)	($534)	($684)	($514)	($461)	($477)	($536)	($556)	($753)	($726)	($745)	($702)
Share enrolled in Medicaid			0.211	0.208	0.211	0.273	0.286	0.314	0.310	0.305		
			(0.014)	(0.014)	(0.014)	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)		
Share receiving SSI or DI (according to Medicare records)						0.086	0.129	0.162	0.188	0.212		0.222
						(0.008)	(0.010)	(0.010)	(0.011)	(0.011)		(0.011)
Sample Size	800	800	800	800	800	800	800	800	800	800	750	750
Panel B2: Houston Census Sample												
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share with earnings	0.605	0.633	0.607	0.618	0.596	0.563	0.543	0.515	0.525	0.503	0.475	0.479
	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.016)	(0.016)
50th percentile earnings (cond. on +)	$9,293	$8,484	$8,961	$8,661	$7,364	$8,098	$10,950	$11,770	$11,270	$12,370	$13,620	$13,050
	($624)	($569)	($625)	($540)	($388)	($443)	($675)	($658)	($674)	($773)	($925)	($907)
Share enrolled in Medicaid			0.138	0.153	0.175	0.223	0.266	0.300	0.307			
			(0.010)	(0.011)	(0.011)	(0.012)	(0.014)	(0.014)	(0.014)			
Share receiving SSI or DI (according to Medicare records)						0.179	0.231	0.293	0.321	0.330		0.338
						(0.017)	(0.019)	(0.021)	(0.021)	(0.021)		(0.022)
Sample Size	1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,100	1,100	1,100	1,100	1,100

Source: Los Angeles (2004-2014) and Houston (2004-2015) HMIS datasets, various administrative datasets

Notes: Interval-based sample consists of people who had a first homeless spell in 2012 or 2013. Point-in-time sample consists of those who were in an HMIS shelter on March 30 of 2012 and 2013.

Table A15: Income and Benefit Receipt Two Years Before and After Observed As Homeless, 2010-2014 ACS Sheltered Homeless Ages 25-59

	t-2	*t*-1	*t*	*t*+1	*t*+2
Share with earnings	0.5336	0.4908	0.5065	0.4627	0.4613
	(0.0181)	(0.0194)	(0.0221)	(0.0200)	(0.0205)
Mean earnings (cond. on receipt)	$12,940	$11,510	$11,260	$12,830	$13,430
	($629)	($594)	($528)	($610)	($555)
Median earnings (cond. on receipt)	$9,514	$7,350	$7,779	$10,140	$11,380
	($458)	($443)	($413)	($425)	($491)
75th percentile earnings (cond. on receipt)	$16,880	$14,400	$15,010	$17,730	$19,200
	($622)	($493)	($466)	($563)	($685)
Share receiving disability (SSI or DI)	0.1354	0.1397	0.1686	0.2095	0.2391
	0.0123	0.0112	0.0116	0.0145	0.0133
Share receiving any benefits, excl. SSI (SNAP, Medicaid, HUD, VA, or Medicare)	0.7872	0.8777	0.9386	0.9245	0.9077
	(0.0251)	(0.0211)	(0.0141)	(0.0166)	(0.0189)
Share receiving any benefits, incl. SSI (SNAP, Medicaid, HUD, VA, Medicare, or SSI	0.8713	0.9218	0.9575	0.9321	0.9239
	(0.0217)	(0.0188)	(0.0135)	(0.0212)	(0.0269)
Mean cash income (pretax)	$7,801	$6,453	$6,451	$6,661	$6,834
	($450)	($458)	($431)	($469)	($460)
Median cash income	$1,150	$553	$600	$333	$136
	($243)	($141)	($151)	($86)	($92)
75th percentile cash income	$11,790	$9,667	$9,996	$11,440	$12,370
	($468)	($467)	($503)	($518)	($534)
Mean cash income + in-kind transfers, excl. SSI (SNAP, HUD, and VA)	$9,652	$9,009	$9,025	$9,169	$9,789
	($828)	($771)	($705)	($830)	($960)
Median cash income + in-kind transfers, excl. SSI	$3,911	$3,580	$3,661	$3,722	$5,012
	($697)	($642)	($665)	($664)	($800)
75th percentile cash income + in-kind transfers, excl. SSI	$14,430	$13,080	$13,260	$14,880	$16,120
	($804)	($694)	($849)	($739)	($817)
Mean cash income + in-kind transfers, incl. SSI (SNAP, HUD, VA, and SSI)	$10,280	$9,832	$9,941	$9,956	$10,710
	($641)	($765)	($650)	($706)	($958)
Median cash income + in-kind transfers, incl. SSI	$6,788	$6,676	$7,526	$7,328	$8,546
	($952)	($881)	($816)	($1009)	($1009)
75th percentile cash income + in-kind transfers, incl. SSI	$15,230	$14,000	$13,830	$15,340	$16,580
	($850)	($715)	($763)	($742)	($960)
Sample Size	4200	4200	4200	4100	4100

Sources: 2010-2014 ACS, various administrative datasets

Note: Sample includes sheltered homeless individuals ages 25-59 at the time of survey.

Table A16: Income and Benefit Receipt among Unsheltered Homeless Individuals Ages 25-59 in 2010 Decennial Census, including TNSOLs, 2003-2016

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Share with earnings	0.549	0.535	0.522	0.485	0.412	0.397	0.399	0.361	0.358	0.342	0.342	0.341
	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.007)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
50th percentile earnings (cond. on +)	$8,799	$8,926	$8,719	$8,096	$7,509	$8,589	$10,480	$10,650	$11,000	$11,250	$12,310	$12,670
	($146)	($143)	($228)	($123)	($162)	($150)	($473)	($258)	($268)	($301)	($319)	($206)
75th percentile earnings (cond. on +)	$20,610	$20,540	$20,070	$18,930	$18,370	$20,310	$22,580	$22,430	$23,250	$24,280	$26,190	$27,000
	($267)	($242)	($411)	($232)	($324)	($307)	($958)	($385)	($430)	($555)	($584)	($344)
50th percentile pre-tax income + in-kind transfers	$2,409	$2,472	$4,030	$2,264	$2,666	$2,710	$2,630	$2,579	$2,525	$2,389	$2,439	$2,417
	($176)	($163)	($324)	($98)	($22)	($25)	($29)	($17)	($31)	($4)	($9)	($26)
75th percentile pre-tax income + in-kind transfers	$12,330	$11,550	$14,580	$12,980	$11,490	$12,750	$13,120	$12,800	$12,640	$12,110	$13,230	$13,360
	($699)	($615)	($461)	($513)	($448)	($486)	($476)	($485)	($453)	($487)	($503)	($503)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)			0.643	0.691	0.745	0.791	0.790	0.781	0.788	0.796	0.817	0.000
			(0.011)	(0.007)	(0.006)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.007)	
Share receiving SSI or DI (according to Medicare records)						0.270	0.303	0.334	0.351	0.361		0.373
						(0.006)	(0.006)	(0.007)	(0.007)	(0.007)		(0.007)
Sample Size	54,000	54,000	54,000	54,000	54,000	54,000	53,500	52,500	52,000	51,000	50,500	49,500

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults enumerated at unsheltered locations in the 2010 Decennial Census who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. We include individuals who were counted in TNSOLs. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A17: Income and Benefit Receipt among Sheltered Homeless Ages Individuals 25-59 in 2010 Decennial Census, excluding individuals counted in multiple housing statuses in the Census, 2003-2016

	Sheltered Homeless											
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share with earnings	0.619	0.616	0.600	0.573	0.490	0.509	0.486	0.449	0.441	0.423	0.422	0.423
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
50th percentile earnings (cond. on +)	$9,135	$9,146	$8,896	$7,541	$5,938	$7,775	$10,440	$10,690	$10,880	$11,150	$12,190	$12,700
	($73)	($77)	($72)	($70)	($67)	($60)	($72)	($78)	($80)	($88)	($105)	($110)
75th percentile earnings (cond. on +)	$19,260	$18,910	$17,790	$15,690	$13,600	$15,380	$18,910	$19,260	$19,680	$20,360	$22,310	$23,410
	($128)	($106)	($104)	($93)	($103)	($86)	($113)	($110)	($128)	($139)	($163)	($156)
50th percentile pre-tax income + in-kind transfers	$5,607	$4,937	$3,841	$2,797	$2,666	$3,388	$3,748	$3,383	$3,348	$3,085	$3,391	$3,564
	($265)	($237)	($134)	($75)	($17)	($82)	($122)	($105)	($113)	($111)	($132)	($139)
75th percentile pre-tax income + in-kind transfers	$14,450	$14,210	$13,550	$12,210	$10,940	$13,270	$14,960	$14,700	$14,750	$14,350	$15,260	$15,720
	($453)	($414)	($164)	($157)	($150)	($118)	($149)	($151)	($153)	($149)	($172)	($174)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)			0.687	0.734	0.834	0.906	0.890	0.862	0.848	0.849	0.851	
			(0.004)	(0.004)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.005)	
Share receiving SSI or DI (according to Medicare records)						0.181	0.238	0.283	0.309	0.326		0.343
						(0.002)	(0.002)	(0.002)	(0.003)	(0.003)		(0.003)
Sample Size	74,500	74,500	74,500	74,500	74,500	74,500	74,000	73,000	72,000	71,500	70,000	69,000
	Unsheltered Homeless											
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Share with earnings	0.555	0.542	0.519	0.480	0.395	0.377	0.361	0.324	0.322	0.299	0.301	0.303
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
50th percentile earnings (cond. on +)	$7,088	$7,108	$7,136	$6,324	$5,507	$7,128	$8,230	$8,177	$8,476	$8,844	$9,912	$10,100
	($181)	($183)	($210)	($141)	($217)	($138)	($217)	($209)	($220)	($193)	($198)	($198)
75th percentile earnings (cond. on +)	$16,910	$16,670	$16,450	$14,940	$14,470	$15,600	$18,030	$17,840	$18,120	$18,990	$20,260	$21,180
	($291)	($312)	($338)	($212)	($315)	($300)	($458)	($317)	($359)	($300)	($323)	($324)
50th percentile pre-tax income + in-kind transfers	$2,057	$2,223	$2,224	$1,962	$2,284	$2,505	$2,578	$2,443	$2,441	$2,255	$2,346	$2,370
	($213)	($228)	($102)	($58)	($53)	($30)	($28)	($34)	($29)	($34)	($34)	($31)
75th percentile pre-tax income + in-kind transfers	$10,120	$10,030	$10,840	$8,806	$6,809	$8,426	$9,600	$8,819	$8,370	$8,229	$9,200	$9,961
	($843)	($694)	($345)	($444)	($419)	($424)	($422)	($417)	($425)	($417)	($454)	($427)
Share with benefits (SNAP, HUD, Medicaid, Medicare, or VA benefits)			0.653	0.695	0.757	0.819	0.814	0.805	0.811	0.823	0.846	
			(0.008)	(0.008)	(0.007)	(0.006)	(0.006)	(0.007)	(0.006)	(0.006)	(0.009)	
Share receiving SSI or DI (according to Medicare records)						0.236	0.277	0.312	0.332	0.344		0.363
						(0.007)	(0.008)	(0.008)	(0.007)	(0.007)		(0.007)
Sample Size	29,500	29,500	29,500	29,500	29,500	29,500	29,500	29,000	28,500	28,000	27,500	27,000

Sources: 2010 Decennial Census, 2019 Numident, 2003-2016 IRS 1040 Datasets, 2006-2016 W2 Datasets, 2004-2016 IRS 1099R Datasets, 2004-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2014 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016)

Notes: Sample includes PIKed adults enumerated as homeless in the 2010 Decennial Census who have a non-missing birthdate in the 2019 Numident who were between the ages of 25 and 59 (inclusive) as of March 30, 2010. We exclude individuals who were counted in a housed or other group quarters status in addition to being counted as homeless in the Census. Table displays the weighted means, percentiles, and shares for individuals who link to income and benefits datasets from 2003-2016. For disclosure purposes, percentiles are calculated as the average of the twelve observations above and the twelve observations below the weighted percentile. Sample sizes are rounded to comply with Census Bureau requirements. Dollars are expressed as Chained CPI-U-adjusted 2018 dollars.

Table A18: Migration-Adjusted SNAP Receipt

Panel A: Migration Adjustment Approach #1

Baseline consists of all those who lived in SNAP state in 2010. Migration-adjusted sample consists of those who lived in the same SNAP state in 2000 and 2010.

		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sheltered	Baseline												
Homeless	Migration Adjusted	0.4366	0.4498	0.5852	0.6432	0.7668	0.8435	0.8090	0.7604	0.7363	0.7123	0.6846	0.6519
	SE	0.0138	0.0139	0.0060	0.0059	0.0047	0.0040	0.0044	0.0048	0.0050	0.0051	0.0053	0.0055
Sample size	Baseline												
	Migration Adjusted	1,300	1,300	6,800	6,800	8,100	8,100	8,100	8,000	7,900	7,800	7,700	7,600
Unsheltered	Baseline												
Homeless	Migration Adjusted	0.5004	0.4959	0.5364	0.5704	0.6445	0.7024	0.6941	0.6902	0.6739	0.6658	0.6492	0.6275
	SE	0.0183	0.0183	0.0103	0.0102	0.0089	0.0086	0.0086	0.0087	0.0089	0.0090	0.0092	0.0094
Sample size	Baseline												
	Migration Adjusted	750	750	2,400	2,400	3,000	3,000	3,000	2,900	2,900	2,800	2,800	2,700
Single Housed	Baseline												
Poor	Migration Adjusted	0.4082	0.4496	0.4428	0.4689	0.5417	0.5873	0.5951	0.5818	0.5647	0.5500	0.5342	0.5137
	SE	0.0202	0.0212	0.0131	0.0131	0.0112	0.0110	0.0110	0.0110	0.0111	0.0113	0.0114	0.0114
Sample size	Baseline												
	Migration Adjusted	1,800	1,800	4,300	4,300	5,800	5,800	5,800	5,800	5,700	5,700	5,600	5,600

Panel B: Migration Adjustment Approach #2

Baseline consist of 2010 Medicaid recipients in SNAP state in 2010. Migration-adjusted sample consists of Medicaid recipients in SNAP state in pre- and post-2010 window.

		2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Sheltered	Baseline			0.6097	0.6810	0.8409	0.9174	0.8689	0.8113	0.7734	0.7429	0.7082	0.6848
Homeless	SE			0.0043	0.0041	0.0031	0.0023	0.0028	0.0033	0.0036	0.0037	0.0039	0.0040
	Migration Adjusted			0.6872	0.7580	0.8786	0.9197	0.8992	0.8574	0.8222	0.7914	0.7537	0.7284
	SE			0.0039	0.0036	0.0025	0.0019	0.0018	0.0025	0.0029	0.0030	0.0030	0.0025
Sample size	Baseline			13,500	13,500	14,500	14,500	14,500	14,500	14,000	14,000	14,000	13,500
	Migration Adjusted			11,500	11,500	12,500	12,500	12,500	12,000	12,000	12,000	12,000	11,500
Unsheltered	Baseline			0.6410	0.7165	0.8046	0.8558	0.8288	0.8008	0.7844	0.7688	0.7509	0.7319
Homeless	SE			0.0207	0.0115	0.0084	0.0069	0.0079	0.0086	0.0090	0.0095	0.0101	0.0108
	Migration Adjusted			0.6869	0.7603	0.8236	0.8527	0.8464	0.8304	0.8197	0.8030	0.7841	0.7696
	SE			0.0266	0.0078	0.0046	0.0044	0.0040	0.0052	0.0049	0.0055	0.0056	0.0050
Sample size	Baseline			3,600	3,600	4,000	4,000	4,000	4,000	3,900	3,800	3,800	3,700
	Migration Adjusted			3,300	3,300	3,700	3,700	3,700	3,700	3,600	3,600	3,500	3,400
Single Housed	Baseline			0.6473	0.6930	0.7959	0.8432	0.8205	0.7911	0.7574	0.7459	0.7151	0.6951
Poor	SE			0.0130	0.0127	0.0097	0.0086	0.0093	0.0097	0.0102	0.0103	0.0107	0.0110
	Migration Adjusted			0.6932	0.7304	0.8081	0.8446	0.8474	0.8304	0.8041	0.7895	0.7573	0.7317
Sample size	SE			0.0111	0.0096	0.0051	0.0049	0.0044	0.0046	0.0063	0.0065	0.0074	0.0078
	Baseline			3,900	3,900	5,100	5,100	5,100	5,100	5,000	5,000	4,900	4,900
	Migration Adjusted			3,600	3,600	4,800	4,800	4,800	4,700	4,700	4,600	4,600	4,500

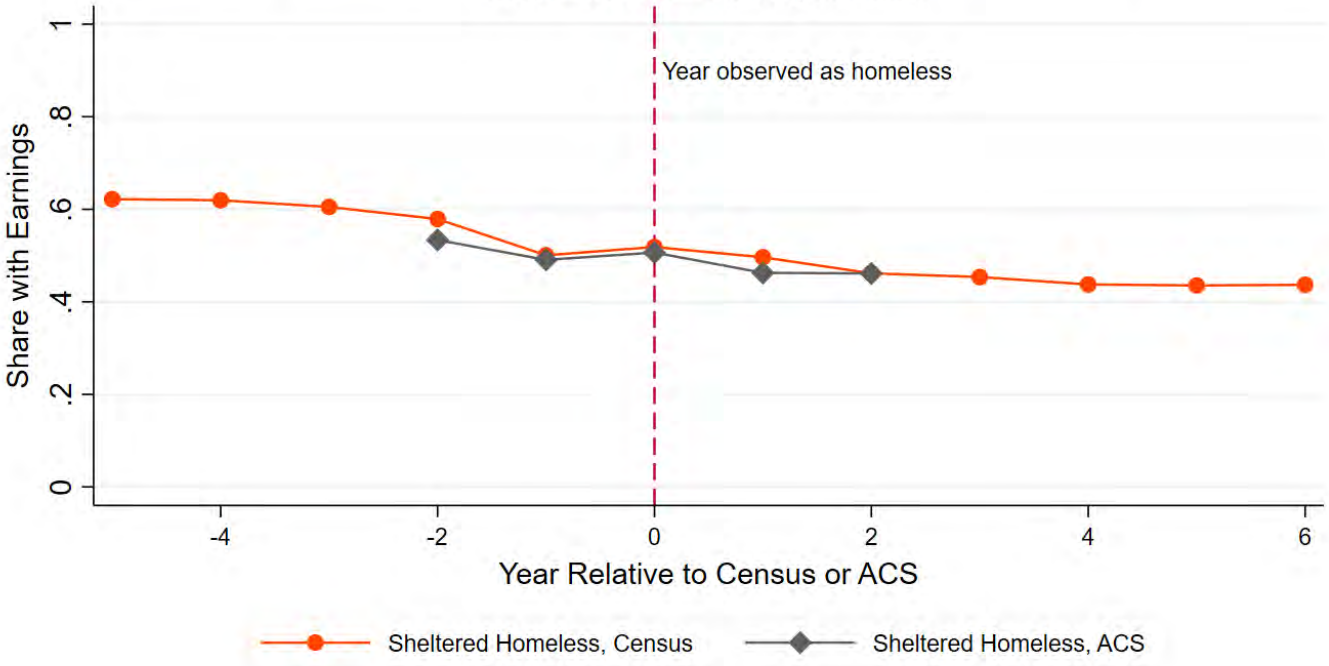
Sources: 2000 and 2010 Census, 2010 ACS, various states' SNAP datasets, various states' Medicaid datasets

Notes: Sample for Approach 1 consists of people who lived in a SNAP state in 2010 and in the same state in 2000 according to that year's Census. Sample for Approach 2 consists of people who received Medicaid in a SNAP state in a three-year window before 2010 and a three-year window after 2010; baseline consists of those who received Medicaid in a SNAP state in 2010.

Appendix Figures

Figure A1: Share with Earnings, Comparison of Census and ACS Homeless

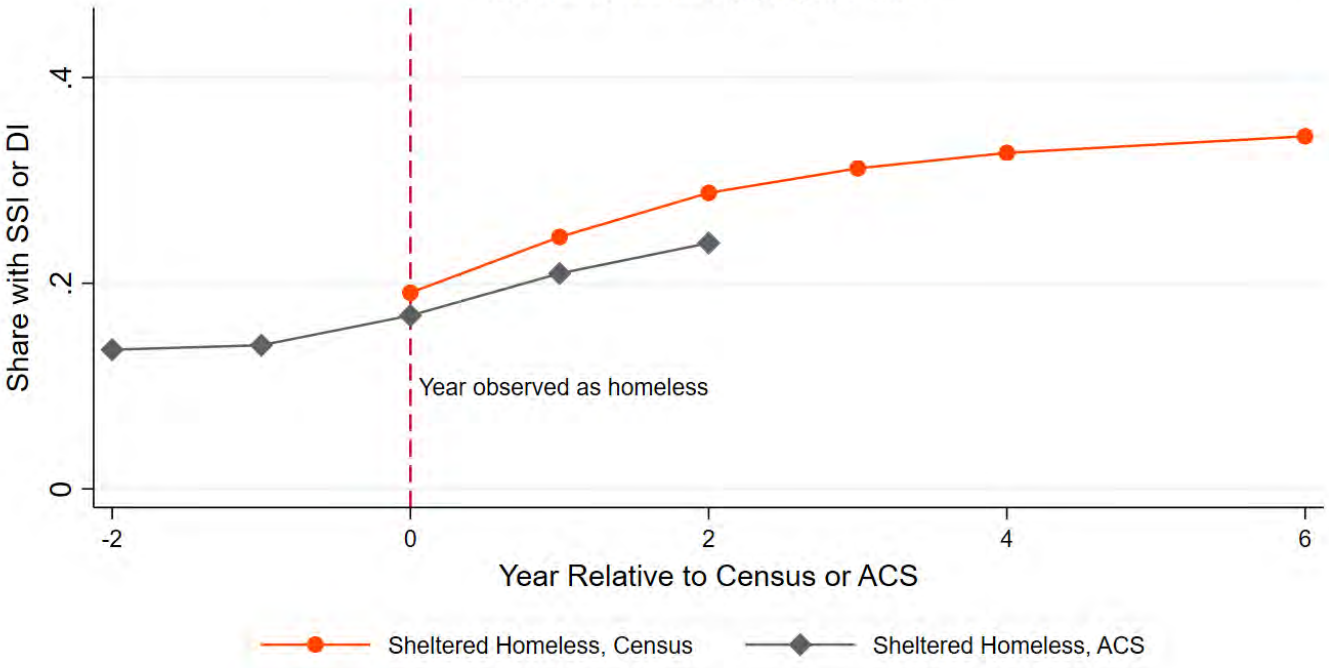
Sheltered Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census, 2010-2014 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure A2: Share with SSI or DI, Comparison of Census and ACS Homeless

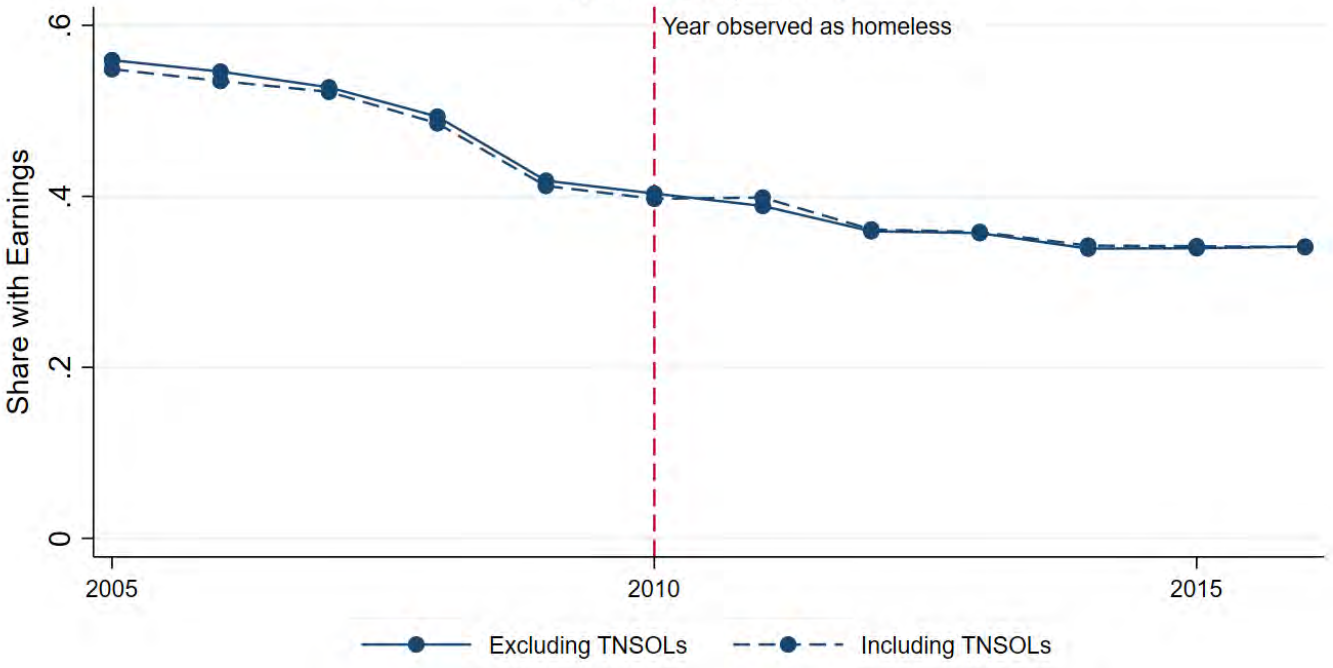
Sheltered Homeless, Ages 25-59



Sources: SSI Datasets (2010-2014, 2016), 2006-2016 Medicare Datasets, 2010 Census, 2010-2014 ACS.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure A3: Share with Earnings, Including and Excluding TNSOLs, 2005-2016

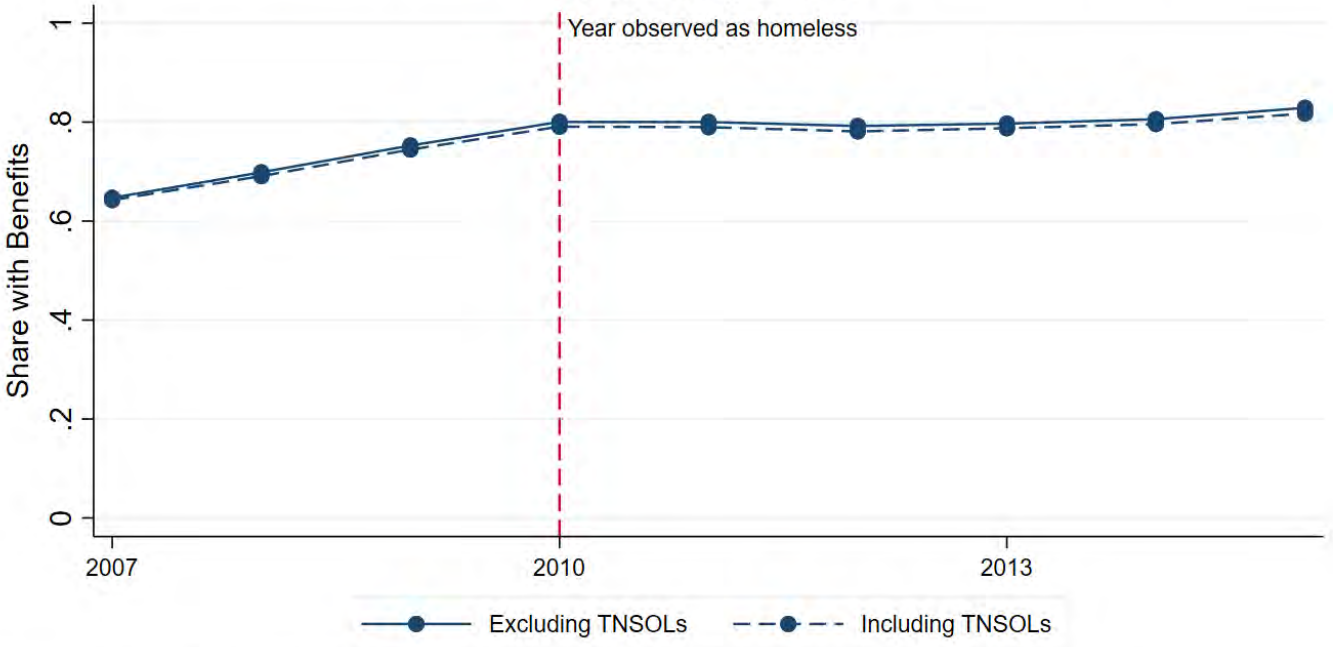
Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure A4: Share with Benefits, Including and Excluding TNSOLs, 2005-2016

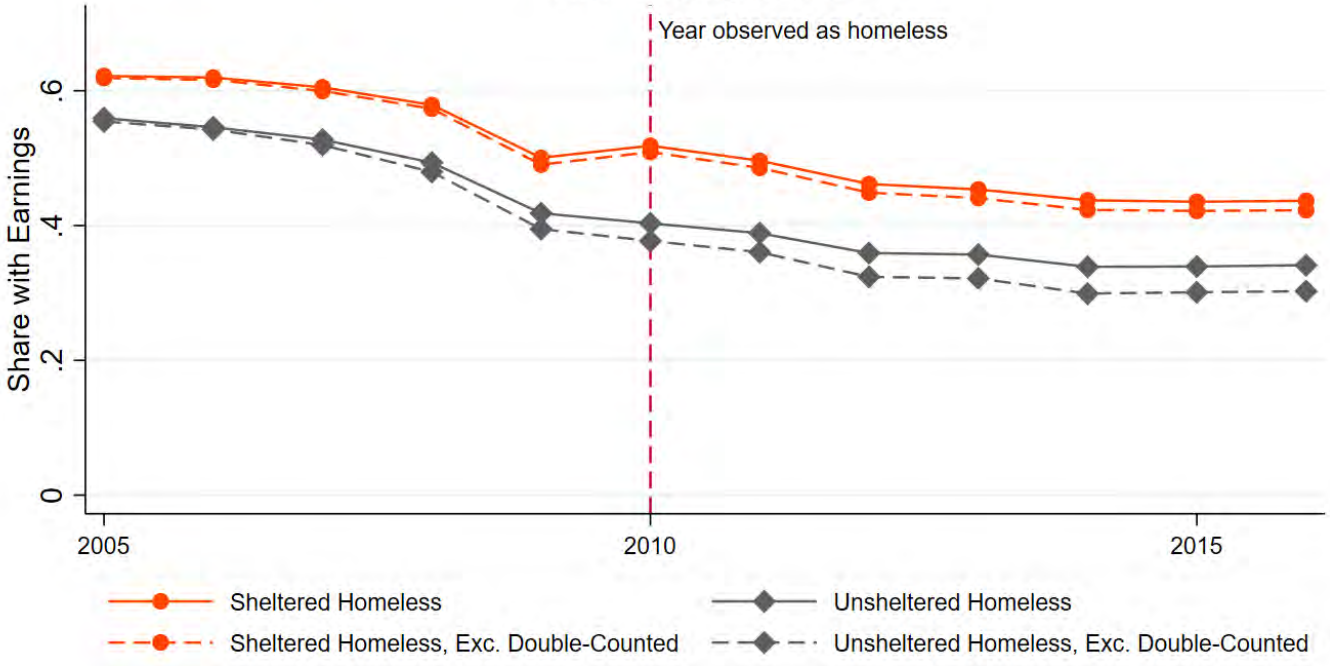
Homeless, Ages 25-59



Sources: 2010 Census, 2003-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2016 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016).
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure A5: Share with Earnings, Including and Excluding Double-Counted, 2005-2016

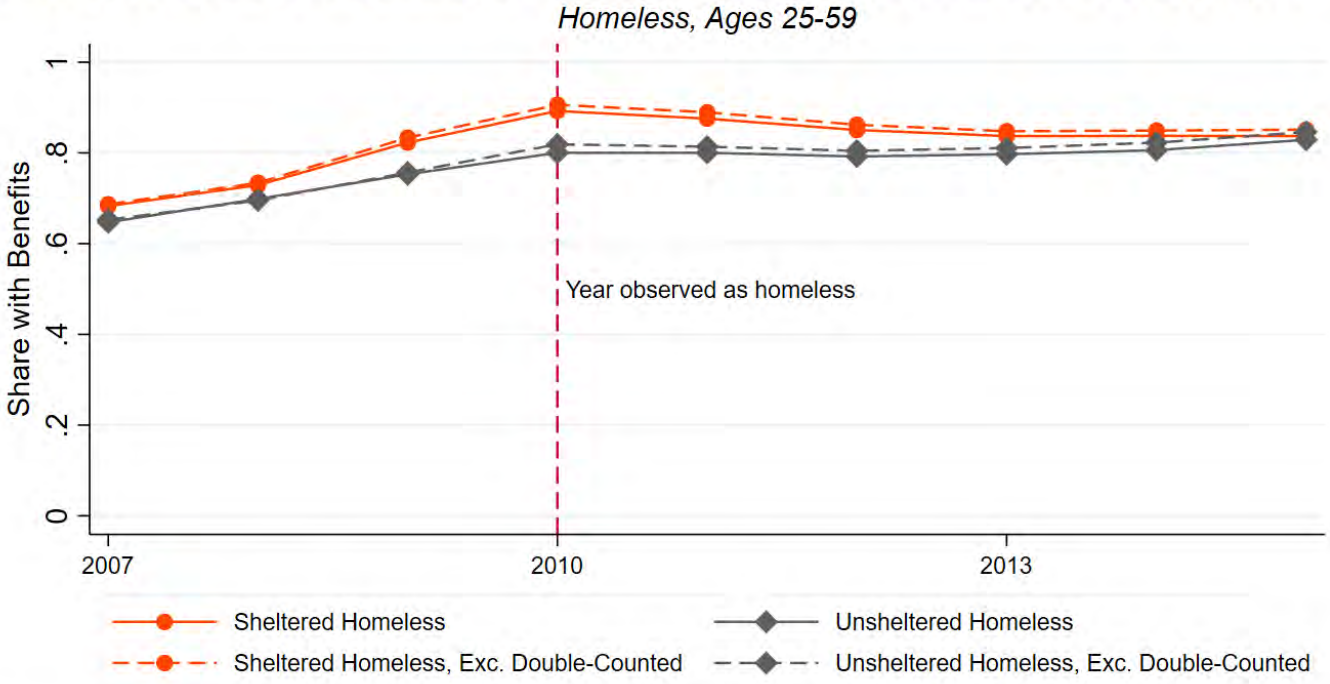
Homeless, Ages 25-59



Sources: IRS 1040s (2003-2015), W2s (2005-2016), 2010 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

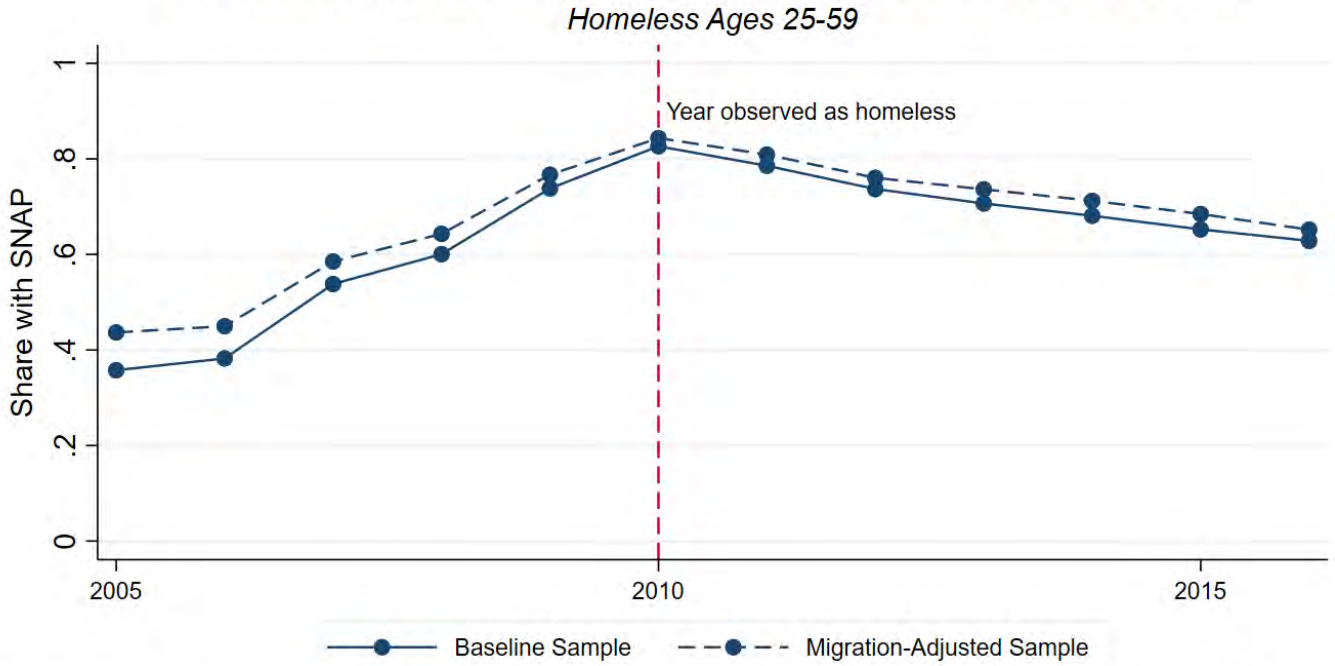
Figure A6: Share with Benefits, Including and Excluding Double-Counted, 2005-2016

Homeless, Ages 25-59



Sources: 2010 Census, 2003-2016 HUD PIC & TRACS, 2007-2015 Administrative VA Dataset, 2006-2016 Medicare Datasets, 2007-2015 Medicaid dataset, SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016).
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015.

Figure A7: Baseline and Migration-Adjusted SNAP Receipt, 2005-2016



Sources: SNAP datasets for Illinois (2009-2016), Indiana (2004-2016), New York (2007-2016), New Jersey (2007-2016), and Tennessee (2004-2016), TANF/GA for New York (2007-2015), SSI (2010-2014, 2016), 2010 Census, 2000 Census.
Notes: Approved for release by the Census Bureau's Disclosure Review Board, authorization number CBDRB-FY2022-CES005-015. Baseline sample consists of homeless residing in SNAP states in 2010. Migration-adjusted sample consists of homeless residing in SNAP states in both 2010 and 2000.

Glossary of Terms to Affordable Housing

Administrative Processes & Streamlining: Contains procedures by which developers receive permission to develop affordable housing. It includes the process for obtaining zoning changes, building permits, and occupancy permits. The topic also refers to receiving approvals from each government agency involved in the development process, as well as any required public hearings or citizen meetings. It includes both the pre-construction planning activities and the review activities that occur during construction.

Reference: www.huduser.org/rbc/categories.html

Affordable Housing: Affordable housing is generally defined as housing on which the occupant is paying no more than 30 percent of gross income for housing costs, including utilities.

Reference: www.hud.gov

Building and Housing Codes: State and local ordinances that prescribe certain minimum standards for construction, rehabilitation, or occupancy of affordable housing. It also relates to the acceptance or rejection of new building designs, materials, or technology intended to reduce the cost of affordable housing.

Reference: www.huduser.org/rbc/categories.html

Fair Housing and Neighborhood Deconcentration: This category refers to state and local laws that prohibit discrimination based on race, color, religion, sex, handicap, familial status, and national origin. It also refers to actions taken by state and local governments to enforce or evade these laws.

Reference: www.huduser.org/rbc/categories.html

Fees and Dedications: This category contains state and local requirements for the payment of fees, dedication of property, or installation of infrastructure to meet the increased demand on public services that result from a particular development.

Reference: www.huduser.org/rbc/categories.html

Housing Authority: Housing authorities are public corporations with boards appointed by the local government. Their mission is to provide affordable housing to low- and moderate-income people. In addition to public housing, housing authorities also provide other types of subsidized housing.

Reference: http://www.phada.org/ha_list.php

Impact Fees: Impact fees are imposed to charge the owners of newly developed properties for the "impact" the new development will have on the community. Fees can be used for such things as transportation improvements, new parks, and expansion of schools. Impact fees are not used to maintain existing facilities, but instead are used to create new facilities in proportion to the number of new developments in the area.

Reference: www.answers.com

Inclusionary Zoning: Usually practiced in urban areas, is planning communities and developments that will provide housing to all income brackets. Inclusionary zoning ordinances often require any new housing construction to include a set percentage of affordable housing units.

The positive aspects of Inclusionary zoning include the production of affordable housing at little cost to local government, the creation of income-integrated communities, and the lessening of sprawl. Negative aspects of inclusionary zoning may include shifting the cost of providing affordable housing, segmenting the upwardly mobile poor, and inducing growth.

Reference: www.answers.com

Land Trusts: A trust created to effectuate a real estate ownership arrangement in which the trustee holds legal and equitable title to the property subject to the provisions of a trust agreement setting out the rights of the beneficiaries whose interests in the trust are declared to be personal property.

Reference: www.answers.com

Low income Housing Tax Credit: Many for-profit and nonprofit-developed rental properties use these federal income tax credits. The Washington State Housing Finance Commission allocates these credits to developers to build or fix up low-income housing. Large corporations, institutions, pension funds, and insurance companies invest in the housing as a method to gain the tax credits and reduce their income tax obligations. These apartments serve residents below 60% of median income and must accept Section 8 vouchers.

Reference: www.phada.org/ha_list.php

Market Rate Rent: The prevailing monthly cost for rental housing. It is set by the landlord without restrictions.

Reference: www.phada.org/ha_list.php

Median Income: This is a statistical number set at the level where half of all households have income above it and half below it. The U.S. Department of Housing and Urban Development Regional Economist calculates and publishes this median income data annually in the Federal Register.

Reference: www.phada.org/ha_list.php

Nonprofit Housing: Nonprofit housing is developed by nonprofit corporations with a community board of directors and mission. Most housing developed by nonprofit housing developers is affordable with rents or prices below market-rate. Income generated from the housing is put back into the mission of the organization, rather than being distributed to stockholders or individual investors as would be the case in for-profit housing.

Reference: www.phada.org/ha_list.php

Nonprofit Housing Developer: A nonprofit organization with a mission that involves the creation, preservation, renovation, operation or maintenance of affordable housing.

Reference: www.phada.org/ha_list.php

Operating Subsidy: This is a type of subsidy going to property owners to reduce the management, maintenance and utility costs of housing. It is needed for projects housing extremely low-income residents who can't afford rents covering the actual costs of housing.

Reference: www.phada.org/ha_list.php

Planning & Growth Restrictions: This refers to barriers and solutions included relate to the process of developing a comprehensive land use plan and the restrictions placed on future development based on a map of the community. The topic also covers activities such as smart growth programs, sewer and building permit moratoriums, or requirements for fiscal impact studies.

Reference: www.huduser.org/rbc/categories.html

Rent Controls: Defined as state and local government actions that restrict rent increases or service fee charges to tenants.

Reference: www.huduser.org/rbc/categories.html

Redevelopment/ Infill: This refers to the rules under which abandoned or underused property is redeveloped. This topic includes inner city redevelopment, single lot infill, and brownfields redevelopment, as well as the process for obtaining the state and local government authorization to proceed with such work.

Reference: www.huduser.org/rbc/categories.html

Section 8 Housing: Many Section 8 contracts have expired or will expire soon, and the property owners must now decide whether to renew their contract or leave the program ("opt out"). Most of these contracts are now renewed on a one-year basis. Projects with high risk of opting out typically have rents set by the Section 8 contract below the prevailing market rents for comparable units. Owners thus have an incentive to leave the program and convert their property to private market rentals.

Reference: www.huduser.org/rbc/categories.html **Section 8 Vouchers**: This federal program is administered by the local housing authority. Eligible tenants receive vouchers they can use to help them pay for apartments in the private market.

Reference: www.huduser.org/rbc/categories.html

State and Local Tax Policies: Barriers and solutions which impact housing affordability, and include laws related to property taxes, tax assessments, transfer taxes, and sales taxes on building materials. It also refers to tax abatements or concessions and homestead exemptions.

Reference: www.huduser.org/rbc/categories.html

Subsidized Housing: A generic term covering all federal, state or local government programs that reduce the cost of housing for low- and moderate-income residents. Housing can be subsidized in numerous ways—giving tenants a rent voucher, helping homebuyers with downpayment assistance, reducing the interest on a mortgage, providing deferred loans to help developers acquire and develop property, giving tax credits to encourage investment in low- and moderate-income housing, authorizing tax-exempt bond authority to finance the housing, providing ongoing assistance to reduce the operating costs of housing and others. Public housing, project-based Section 8, Section 8 vouchers, tax credits, the State Housing Trust Fund, and Seattle Housing Levy programs are all examples of subsidized housing. Subsidized housing can range from apartments for families to senior housing high-rises. Subsidized simply means that rents are reduced because of a particular government program. It has nothing to do with the quality, location or type of housing. In fact, a number of Seattle's subsidized housing developments have received local and national design awards.

Reference: http://www.phada.org/ha_list.php

Zoning, Land Development, Construction and Subdivision Regulations: Rules and regulations that affect the use of land. It also contains rules and regulations that permit an owner to divide his land into smaller tracts. These activities include barriers, such as exclusionary zoning, as well as solutions, such as bonus density zoning. It also includes private restrictions on the use of property, such as deed restrictions.

Reference: www.huduser.org/rbc/categories.html

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insisted it was the Regal. "I ain't trying to pull nobody over in *the Daytona*," he'd say, feigning offense. Quentin was well manicured, built but not muscular, with curly hair and lots of jewelry—a thick chain, a thicker bracelet, rings. Sherrena thought he looked like a dope dealer but gave him her real number anyway. Quentin called Sherrena for three months before she agreed to let him take her out for ice cream. It took him another six years to marry her.

When Quentin pulled Sherrena over, she was a fourth-grade teacher. She talked like a teacher, calling strangers "honey" and offering motherly advice or chiding. "You know I'm fixing to fuss at you," she would say. If she sensed your attention starting to drift, she would touch your elbow or thigh to pull you back in.

Four years after meeting Quentin, Sherrena was happy with their relationship but bored at work. After eight years in the classroom, she quit and opened a day care. But "they shut it down on a tiny technicality," she remembered. So she went back to teaching. After her son from an earlier relationship started acting out, she began homeschooling him and tried her hand at real estate. When people asked, "Why real estate?" Sherrena would reply with some talk about "long-term residuals" or "property being the best investment out there." But there was more to it. Sherrena shared something with other landlords: an unbending confidence that she could make it on her own without a school or a company to fall back on, without a contract or a pension or a union. She had an understanding with the universe that she could strike out into nothing and through her own gumption and intelligence come back with a good living.

Sherrena had bought a home in 1999, when prices were low. Riding the housing boom a few years later, she refinanced and pulled out $21,000 in equity. Six months later, she refinanced again, this time pulling $12,000. She used the cash to buy her first rental property: a two-unit duplex in the inner city, where housing was cheapest. Rental profits, refinancing, and private real-estate investors offering high-interest loans helped her buy more.

She learned that the rental population comprised some upper- and middle-class households who rent out of preference or circumstance, some young and transient people, and most of the city's poor, who were excluded both from homeownership and public housing.[1] Landlords operated in different neighborhoods, typically clustering their properties in a concentrated area. In the segregated city, this meant that landlords focused on housing certain kinds of people: white ones or black ones, poor families or college students.[2] Sherrena decided to specialize in renting to the black poor.

Four years later, she owned thirty-six units, all in the inner city, and took to carrying a pair of cell phones with backup batteries, reading *Forbes*, renting office space, and accepting appointments from nine a.m. to nine p.m. Quentin quit his job and started working as Sherrena's property manager and buying buildings of his own. Sherrena started a credit-repair business and an investment business. She purchased two fifteen-passenger vans and started Prisoner Connections LLC, which for $25 to $50 a seat transported girlfriends and mothers and children to visit their incarcerated loved ones upstate. Sherrena had found her calling: inner-city entrepreneur.

SHERRENA PARKED IN front of Lamar's place and reached for a pair of eviction notices. The property sat just off Wright Street, with empty lots and a couple of street memorials for murder victims: teddy bears, Black & Mild cigars, and scribbled notes lashed to tree trunks. It was a four-family property consisting of two detached two-story buildings, one directly behind the other. The houses were longer than they were wide, with rough-wood balconies painted blue-gray like the trim and vinyl siding that was the brownish-white of leftover milk in a cereal bowl. The house facing the street had two doors, for the upper and lower units, and a pair of wooden steps leading to each, one old with peeling paint, the other new and unvarnished.

Lamar lived in the lower unit of the back house, which abutted the alley. When Sherrena pulled up, he was outside, being pushed in

a wheelchair by Patrice, whose name was on the other eviction notice. He had snapped on his plastic prosthetic legs. An older black man, Lamar was wiry and youthful from the waist up, with skin the color of wet sand. He had a shaved head and a thin mustache, flecked with gray. He wore a yellow sports jersey with his keys around his neck.

"Oh, I got two at the same time," Sherrena tried to say lightly. She handed Lamar and Patrice their eviction notices.

"You almost been late," Patrice said. She wore a headwrap, pajama pants, and a white tank top that showed off her tattoo on her right arm: a cross and a ribbon with the names of her three children. At twenty-four, Patrice was half Lamar's age, but her eyes looked older. She and her children lived in the upper unit of the front house. Her mother, Doreen Hinkston, and her three younger siblings lived below her, in the bottom-floor unit. Patrice creased her eviction notice and jammed it into a pocket.

"I'm fixin' to go to practice," Lamar said from his seat.

"What practice?" Sherrena asked.

"My kids' football practice." He looked at the paper in his hand. "You know, we fixin' to do the basement. I'm already started."

"He didn't tell me about that," Sherrena replied, "he" being Quentin. Sometimes tenants worked off the rent by doing odd jobs for landlords, like cleaning out basements. "You better call *me*. Don't forget who the boss is," Sherrena joked. Lamar smiled back at her.

As Patrice began pushing Lamar down the street, Sherrena went over a checklist in her head. There were so many things to deal with—repairs, collections, moves, advertisements, inspectors, social workers, cops. The swirl of work, a million little things regularly interrupted by some big thing, had been encroaching on her Sunday soul food dinners with her mom. Just a month earlier, someone had been shot in one of her properties. A tenant's new boyfriend had taken three pumps to the chest, and blood had run down him like a full-on faucet. After police officers had asked their questions and balled up the yellow tape,

Sherrena and Quentin were stuck with the cleanup. Quentin set on it with a couple guys, rubber gloves, and a Shop-Vac. "Here you come with a boyfriend that I don't know anything about?" Sherrena asked the tenant. Quentin dealt with messes; Sherrena dealt with people. That was the arrangement.

Then, a few days after the shooting, another tenant phoned Sherrena to say that her house was being shut down. Sherrena didn't believe it until she pulled up and spotted white men in hard hats screwing green boards over her windows. The tenants had been caught stealing electricity, so the We Energies men had disconnected service at the pole and placed a call to the Department of Neighborhood Services (DNS). The tenants had to be out that day.[3]

In Milwaukee and across the nation, most renters were responsible for keeping the lights and heat on, but that had become increasingly difficult to do. Since 2000, the cost of fuels and utilities had risen by more than 50 percent, thanks to increasing global demand and the expiration of price caps. In a typical year, almost 1 in 5 poor renting families nationwide missed payments and received a disconnection notice from their utility company.[4] Families who couldn't both make rent and keep current with the utility company sometimes paid a cousin or neighbor to reroute the meter. As much as $6 billion worth of power was pirated across America every year. Only cars and credit cards got stolen more.[5] Stealing gas was much more difficult and rare. It was also unnecessary in the wintertime, when the city put a moratorium on disconnections. On that April day when the moratorium lifted, gas operators returned to poor neighborhoods with their stacks of disconnection notices and toolboxes. We Energies disconnected roughly 50,000 households each year for nonpayment. Many tenants who in the winter stayed current on their rent at the expense of their heating bill tried in the summer to climb back in the black with the utility company by shorting their landlord. Come the following winter, they had to be connected to benefit from the

moratorium on disconnection. So every year in Milwaukee evictions spiked in the summer and early fall and dipped again in November, when the moratorium began.[6]

Sherrena watched the DNS hard hats march around her property. There were few things that frustrated landlords more than clipboard-in-hand building inspectors. When they were not shutting down a property, they were scrutinizing apartments for code violations. Upon request, DNS would send a building inspector to any property. The service was designed to protect the city's most vulnerable renters from negligent landlords, but to Sherrena and other property owners, tenants called for small, cosmetic things—and often because they were trying to stop an eviction or retaliate against landlords. Sherrena thought about the money she had just lost: a few thousand dollars for electrical work and unpaid rent. She remembered taking a chance on this family, feeling sorry for the mother who had told Sherrena she was trying to leave her abusive boyfriend. Sherrena had decided to rent to her and her children even though the woman had been evicted three times in the past two years. "There's me having a heart again," she thought.

SHERRENA DROVE OFF Wright Street and headed north. Since she was in this part of town, she decided to make one more stop: her duplex on Thirteenth and Keefe. Sherrena had let a new tenant move in the previous month with a partial rent and security deposit payment.

The tenant was sitting on her stoop in a long-sleeved flannel shirt, hushing a colicky baby and talking with her mother, who was leaning against a car. Seeing Sherrena, the young woman wasted no time. "My son is sick because my house is cold," she said. Her voice was tired. "The window have a hole in it, and I've been waiting patiently. I mean, I'm ready to move."

Sherrena tilted her head, confused. The window had a hole, not a crater, and it was warm enough outside that children were still swimming in Lake Michigan. How could the house be cold?

"I done called the city," the mother added, peeling herself off the car. She was slender and tall, her hair frizzed by the late-summer humidity.

Sherrena took a breath. There were worse houses on the block, but Sherrena knew her place on Thirteenth Street wasn't up to code. She would say almost no house in the city was, a commentary on the mismatch between Milwaukee's worn-out housing stock and its exacting building code. Thanks to the tenant's mother, an inspector would arrive in a few days. He would jiggle the stair banister, photograph the hole in the window, shimmy the unhinged front door. Every code violation would cost Sherrena money.

"That wasn't right for you to do that," Sherrena said, "because I was working with her."

"Then fix the window," the mother replied.

"We will! But if she don't call us to let us know—"

"She don't have no phone, that's why I called!" the mother interrupted.

As the conversation grew louder, a crowd gathered. "Who's she?" a young boy asked. "Landlord," came a reply.

"I didn't know you were going to call the building inspector, Momma," the tenant said, nervously.

"It's too late now. The damage is done," Sherrena said. She shook her head and, hands on her hips, looked at the young woman with the baby. "It's always the ones that I try to help that I have the problems out of. And I'm not saying that you a problem, but it's just that, somebody else is involved, and you the one living here. So it puts you in a spot."

"Well, let me ask you something." The tenant's mother stepped closer and the crowd with her. "If this was your daughter and these were your grandkids, what would you do?"

Sherrena didn't step back. She looked up at the mother, noticing her gold front tooth, and answered, "I would have definitely made a connection with the landlord and not called the city."

Sherrena pushed past the crowd and stepped briskly to her car. When she got home, she opened the door and yelled, "Quentin, we done walked straight into some bullshit!"

Sherrena sat down in her paper-cluttered home office. The office was one of five bedrooms in Sherrena and Quentin's home, which sat in a quiet middle-class black neighborhood off Capitol Drive. The house had a finished basement with an inset Jacuzzi tub. Sherrena and Quentin had furnished it with beige leather furniture, large brass and crystal light fixtures, and gold-colored curtains. The kitchen was spacious and unused, since they ate out most days. Typically the only things in the refrigerator were restaurant doggie bags.

"Huh?" Quentin called back, coming down the stairs.

"The girl downstairs at Thirteenth Street? Her momma done called the building inspector. . . . Her mother was outside talking *shit*!"

Quentin listened to the story and said, "Put her out."

Sherrena thought about it for a moment, then agreed. She reached in a drawer and began filling out a five-day eviction notice. The law forbade landlords from retaliating against tenants who contacted DNS. But landlords could at any time evict tenants for being behind on rent or for other violations.

By the time Quentin and Sherrena pulled the Suburban onto Thirteenth Street, night had fallen. The apartment door was open. Sherrena walked right through it without knocking and handed the young tenant an eviction notice, saying, "Here. I hope you get some assistance."

A man followed Sherrena out the door and stood on the unlit porch. "Excuse me," he called out as Sherrena met Quentin in the street. "You're *evicting* her?"

"She told me she wanted to move, so that let me know she wasn't going to pay anything else," Sherrena answered.

"She told you she wanted the windows fixed."

Quentin interjected, looking at Sherrena, "He ain't got nothin' to do with it."

"I got *everything* to do with it, blood. This my stepdaughter here!"

"You don't even stay here though, man!" Quentin yelled back.

"Ain't nobody want to live like that. . . . Fuck you mean, I don't have nothing to do with it?"

Quentin opened the Suburban's door and pulled out his security belt, equipped with handcuffs, a small baton, and a canister of Mace the size of a small fire extinguisher. Quentin had been here before. There was the tenant who told him he was going to take his security deposit out of Quentin's pocket. There was the one who said he was going to shoot him in the face.

The tenant's mother joined the stepfather on the dark porch. "Are you evicting her?" she asked.

"She didn't pay her rent," Sherrena said. "Do *y'all* have her rent to pay?"

"I don't give a shit, man," the stepfather was saying almost to himself. What he didn't give a shit about wasn't the eviction but whatever was going to transpire there, at that very moment, on that dark street.

"I don't either!" Quentin shot back.

"I'll whip that motherfuckin' ass, nigga. . . . Don't say I ain't got nothin' to do with it."

"*You don't!*" Sherrena yelled as Quentin tugged her back to the Suburban. "You don't!"

Days after the tenant left, Sherrena took a call from a caseworker at Wraparound, a local social services agency. The caseworker had a client who needed a place to live with her two boys. Wraparound would pay her security deposit and first month's rent, which sounded good to Sherrena. The new tenant's name was Arleen Belle.

SCIENCE ADVANCES | RESEARCH ARTICLE

PUBLIC HEALTH

Nitrogen dioxide exposure, health outcomes, and associated demographic disparities due to gas and propane combustion by U.S. stoves

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Gas and propane stoves emit nitrogen dioxide (NO_2) pollution indoors, but the exposures of different U.S. demographic groups are unknown. We estimate NO_2 exposure and health consequences using emissions and concentration measurements from >100 homes, a room-specific indoor air quality model, epidemiological risk parameters, and statistical sampling of housing characteristics and occupant behavior. Gas and propane stoves increase long-term NO_2 exposure 4.0 parts per billion volume on average across the United States, 75% of the World Health Organization's exposure guideline. This increased exposure likely causes ~50,000 cases of current pediatric asthma from long-term NO_2 exposure alone. Short-term NO_2 exposure from typical gas stove use frequently exceeds both World Health Organization and U.S. Environmental Protection Agency benchmarks. People living in residences <800 ft^2 in size incur four times more long-term NO_2 exposure than people in residences >3000 ft^2 in size; American Indian/Alaska Native and Black and Hispanic/Latino households incur 60 and 20% more NO_2 exposure, respectively, than the national average.

INTRODUCTION

Gas stoves are used in approximately 50 million U.S. homes (*1*) and millions more worldwide (*2*, *3*). Gas and propane combustion in stoves emits hazardous air pollutants, including nitrogen dioxide (NO_2), benzene (C_6H_6), carbon monoxide (CO), formaldehyde (H_2CO), and ultrafine particles (*4*–*12*). Nitrogen dioxide and benzene emissions are of particular concern, as typical gas stove use can elevate indoor concentrations of these pollutants above health benchmarks (*5*, *6*, *8*, *10*, *11*). Long-term exposure (averaged over a year) to NO_2 has been linked to increased incidence and exacerbation of pediatric asthma (*13*–*16*), incidence and mortality from chronic obstructive pulmonary disease (COPD) (*17*–*19*), and incidences of lung cancer, preterm birth, and diabetes mellitus (*20*). Given the abundance of gas and propane stoves and the dangers of additional NO_2 exposure generally, quantifying the burden of NO_2 exposures and health outcomes from gas and propane combustion by stoves is needed for assessing public safety.

Previous studies estimating disease burdens attributable to combustion by gas stoves have limitations that reduce their abilities to assess exposure as a function of different behaviors or across different socioeconomic, racial, or ethnic groups. First, constraining estimates of indoor NO_2 exposure from direct measurements of indoor concentrations is challenging because the data are sparse and because observed concentrations can fluctuate with ventilation and stove use (*21*, *22*). Second, studies that correlate health outcomes with the presence or absence of a gas stove (rather than with direct pollutant exposure) typically do not capture large differences in housing size and layout, ventilation, or behavior that may substantively affect exposure across groups (*23*–*25*), hindering investigations of health disparities mediated through such factors. Existing meta-analyses calculating odds ratios (ORs) of specific health outcomes associated with gas stoves have relied either on correlations between measured indoor NO_2 concentrations and health outcomes, as opposed to directly quantifying NO_2 exposure, or have used the presence of gas stoves as a proxy for NO_2 exposure (*16*, *26*).

Gaps in current epidemiological knowledge can be addressed using detailed assessments of the population-wide distribution of long-term (year-averaged) and short-term (hour-averaged) NO_2 exposure attributable to combustion by natural gas (which is composed of >90% methane) and propane stoves. Previous studies have quantified NO_2 emission rates from gas stoves (*6*, *10*, *27*) but not, to our knowledge, from propane stoves. Previous studies (*5*, *8*, *10*, *28*–*31*) have also measured the resulting indoor NO_2 concentrations in a handful of residences representing a single building type or a local geography. Models have focused either on individual buildings (*32*–*34*) or on a specific, local geography (*35*) or, if encompassing a broader geography, have omitted variation in cooking and occupancy patterns (*36*). The two previous studies that assessed exposure in multiple building types relied on models that treat residences as open boxes that lacked interior walls rather than as homes with discrete rooms and hallways (*35*, *36*); hence, these single-zone models do not capture higher short-term exposures while people are cooking or spending additional time in the kitchen.

We constructed a population-level model of NO_2 exposure from combustion by gas and propane stoves using the National Institute of Standards and Technology's (NIST's) CONTAM multizone indoor air quality model (*37*) and our field measurements of NO_2 emission rates from gas and propane stoves. We ran the model on more than 31,100 combinations of input variables whose distributions and weights we obtained from our field measurements combined with published datasets for the U.S. housing stock and relevant behaviors of the U.S. population (see Materials and Methods). This model allowed us to estimate NO_2 exposure attributable to gas and

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propane stoves stratified by various environmental, behavioral, and demographic parameters, including residence size and layout, time spent with windows open, frequency of range hood use, range hood capture efficiency, and time spent in the kitchen and other rooms. We also updated previously published (*10*) NO_2 emission rates from gas stoves with field measurements of 50 additional homes (over 70 total homes when including measurements of propane and electric stoves), bedroom NO_2 concentrations in six houses for 8 hours during and following stove use, and NO_2 emission rates from propane stoves. We validated the CONTAM model by comparing our modeled and measured NO_2 concentrations in a set of 18 test houses of various sizes and floorplans, in each case directly measuring NO_2 concentrations in multiple rooms before, during, and––for several hours, at least––after gas and propane stove use ended.

Using the validated CONTAM model, we estimated long- and short-term NO_2 exposure attributable to combustion by gas and propane stoves for the U.S. population overall and in subpopulations, including various income levels and racial/ethnic groups (see Materials and Methods). We then used well-established epidemiological relationships (*26*, *38*) for NO_2 exposure to estimate the excess cases of pediatric asthma and adult mortality attributable to long-term NO_2 exposure from gas and propane stoves. We compare our results against estimates of pediatric asthma burden attributable to gas stoves overall (*16*).

RESULTS

Agreement between the CONTAM model and measured NO_2 concentrations

We assessed the performance of our indoor air model by comparing its outputs against NO_2 measurements in 18 test residences before, during, and after gas stove use. These residences ranged in size from 280 to 1650 ft^2 (25 to 150 m^2). They included both apartments and single- and multistory detached homes in the following locations: San Francisco Bay Area, CA; Los Angeles, CA; Bakersfield, CA; Denver, CO; Houston, TX; New York City, NY; and Washington, DC. We included scenarios with windows open and closed and with an outside-venting range hood both on and off. We observed close agreement between modeled and actual NO_2 concentrations ($r^2 = 0.64$, slope = 0.89, SE of slope = 0.11, $P \ll 0.01$; see Fig. 1 for plots of the largest and smallest test residences; see fig. S1A for a regression of modeled versus actual concentrations and fig. S1B for boxplots summarizing all measured residences). The model results showed no evidence of systematic bias relative to measurements as assessed statistically (fig. S1 and table S1). Without an outside-venting range hood on and with either one burner or one burner and one oven on, concentrations in over half of the kitchens, living rooms, and bedrooms tested exceeded the Environmental Protection Agency's (EPA's) 1-hour ambient exposure benchmark of 100 parts per billion volume (ppbv) (*39*) and the World Health Organization's (WHO's) 1-hour (i.e., short-term) exposure guideline of 200 $\mu g/m^3$ (~100 ppbv) (*40*). Surveys show that range hoods are used only 15 to 39% of the time (*41*, *42*).

Nitrogen dioxide emission factors from propane stoves and updated emission factors for gas stoves

Nitrogen dioxide emissions occurred only with fossil fuel use and scaled linearly with the amount of fuel burned, as assessed by CO_2 emissions, across 10 propane and 50 natural gas stoves (Fig. 2 and fig. S3A; $r^2 = 0.61$ for gas and 0.70 for propane; $P \ll 0.01$ for each). In contrast to the results for fossil fuel combustion, all 7 induction and 12 electric coil and radiant stoves that we measured had zero NO_2 emissions (i.e., emissions were statistically indistinguishable from zero; see Fig. 2 and table S3).

NO_2 emissions from propane and gas combustion were statistically identical when normalized per joule of fuel burned (table S2). Because NO_2 forms in flames as a function of temperature (*43*) and the adiabatic flame temperatures of methane and propane differ by less than 1% (*44*), it is unsurprising that gas and propane burners emitted the same amount of NO_2 per joule of fuel burned.

Estimates of NO_2 emission factors calculated from the 50 gas stoves measured newly in this work were statistically identical to the emission factors measured previously for 32 gas stoves by Lebel *et al.* (*10*). Combining data from this work with the data from Lebel *et al.*, we calculated median NO_2 emission factors for gas stoves to be 8.7 [95% confidence interval (CI): 8.2, 9.3] ng J^{-1} for gas burners on high and 8.2 [95% CI: 7.5, 9.2] ng J^{-1} for burners on low. See fig. S3B and table S3 for emission rates and emission factors per joule for all burner and oven types measured. We used results from the pooled set of 82 burners in our modeling.

NO_2 concentrations in bedrooms and with range hoods on

Bedroom NO_2 concentrations tested during oven use, with interior doors open and the range hood off exceeded the U.S. EPA's 1-hour ambient benchmark (*39*) and the WHO's 1-hour exposure guideline (*40*) within 25 min in half the homes we tested (three of six homes). In two test cases, bedroom NO_2 levels remained above health-based guidelines for 2 to 3 hours after the oven was turned off (houses 1 and 2; Fig. 3A). We found that an outside-venting range hood reduced peak NO_2 concentrations in some cases (Fig. 3B) but that some outside-venting range hoods are ineffective at reducing NO_2 concentrations (Fig. 3C). Across a subset of five randomly selected homes, we found that outside-venting hoods reduced hour-averaged kitchen NO_2 concentrations by between 10 and 70% (mean reduction in concentration = 35%, $n = 5$; fig. S15). This result is consistent with prior work assessing the efficacy of installed range hoods, which found that most hoods operating in homes have capture efficiencies well below 70% (*45*, *46*). Our measurements both with and without hoods on further support our model's finding that gas and propane stove use increases long- and short-term NO_2 exposures (see below).

Modeled long- and short-term NO_2 exposure

We estimated long- and short-term NO_2 exposure attributable to gas and propane stoves by combining our measured NO_2 emissions data with published housing characteristics and with published statistical distributions of resident use patterns. These variables included how much time a person spent cooking, how much gas was burned (i.e., how many burners/ovens were used plus cooking duration), time spent with windows open, percentage of cooking time with the range hood on, and capture efficiency of the range hood used—all applied in a multizone indoor air quality model (see Materials and Methods). We calculated CIs using a Monte Carlo method (see Materials and Methods). See the "Definitions" section for more details on how we calculated long-term (year-averaged) and short-term (hour-averaged) exposures.

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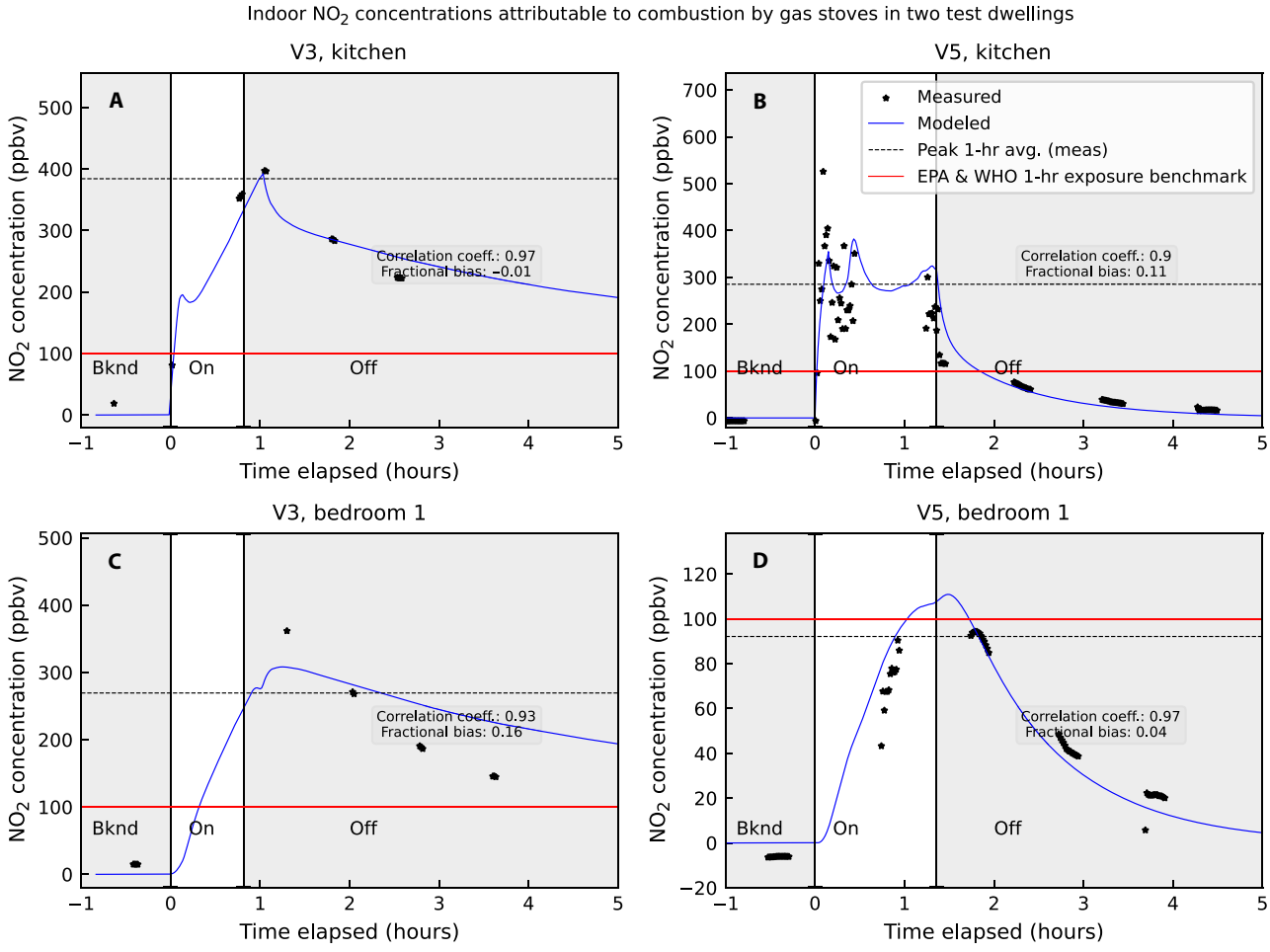


Fig. 1. Measured and modeled NO_2 concentrations in two test residences. ("V3" on the left and "V5" on the right). NO_2 concentrations measured (black points) and modeled (blue lines) in the (**A**) kitchen and (**C**) bedroom (farthest from the kitchen) of a 900-ft^2 (85-m^2) house, "V3," and in the (**B**) kitchen and (**D**) bedroom of a 1500-ft^2 (140-m^2) house, "V5" (see table S2 for metrics for each house). "Background" ("Bknd") represents NO_2 concentrations in a given room before lighting the stove, "On" represents concentrations with one stove burner on high and the oven set to 350°F (175°C), and "Off" represents concentrations after turning off the stove burner and oven. "Time elapsed" represents hours since lighting the burner and oven. The white background demarcates the interval in which the burner and oven were in use. The horizontal black line represents the highest concentrations measured in each room, time-averaged over 1 hour. The solid horizontal red line represents the U.S. Environmental Protection Agency's (EPA's) 1-hour ambient exposure benchmark of 100 ppbv (*39*) and the World Health Organization's (WHO's) 1-hour exposure guideline of 200 μg/m^3 (~100 ppbv) (*40*). A range hood was not used in the tests shown here, though we tested the CONTAM model with a range hood on and window open. See fig. S2 for analogous plots and fig. S1 for summary plots of all tests including tests with range hoods on and windows open. The correlation coefficients (*r*) and fractional biases of the modeled concentrations are reported for each room and for all rooms together (see table S1).

Based on our results, gas and propane stoves in the United States elevate long- and short-term NO_2 exposure substantially. We estimate that U.S. median gas and propane stove use increases long-term NO_2 exposure by 4.0 [95% CI: 2.4, 6.1] ppbv. Maximum daily hour-averaged exposure to NO_2 from median gas and propane stove use in the United States exceeds 200 μg/m^3 (~100 ppbv), the WHO's 1-hour indoor exposure guideline (*40*), on 12 [95% CI: 4, 24] days of the year (3.3% of days), averaged across the population. Home cooks who are in the 95th percentile of stove use encounter ~110 days per year exceeding 200 μg/m^2 (see below).

These long- and short-term stove-attributable exposures are large relative to common health benchmarks. For instance, the 4.0 ppbv of stove-attributable long-term exposure comprises 75% of the WHO's annual NO_2 exposure guideline (*47*) (Fig. 4) and 50% of the U.S.-averaged outdoor NO_2 concentration (*48*) in 2021. In addition to exceeding the WHO 1-hour exposure guideline, stove-attributable exposures would also exceed the U.S. EPA's outdoor standard of no more than 2% of days with maximum NO_2 concentrations exceeding 100 ppbv (*39*) if this standard were applied indoors (fig. S5). Although the U.S. EPA does not currently regulate indoor air pollution (*39*), Canada does—its hour-averaged indoor NO_2 standard is 170 μg/m^3 [~90-ppbv NO_2], slightly lower than the WHO standard (*40*, *49*).

Long- and short-term exposure burdens from combustion by gas and propane stoves are unequally distributed across the U.S. population. Gas and propane stoves increase the long-term

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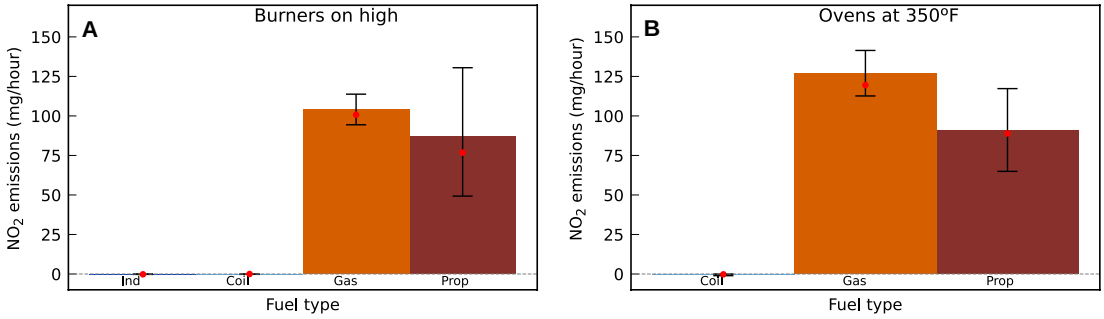


Fig. 2. Mean and median NO_2 emissions by fuel type. Emissions reported in milligrams of NO_2 per hour by fuel type (electric induction, electric coil/radiant, gas, and propane) for burners on high (**A**) and for ovens set to 350°F (175°C) (**B**). The red points are median values, the bar heights are mean values, and the black error bars are the 95% CIs of the mean (calculated using a bootstrap method as described in the methods).

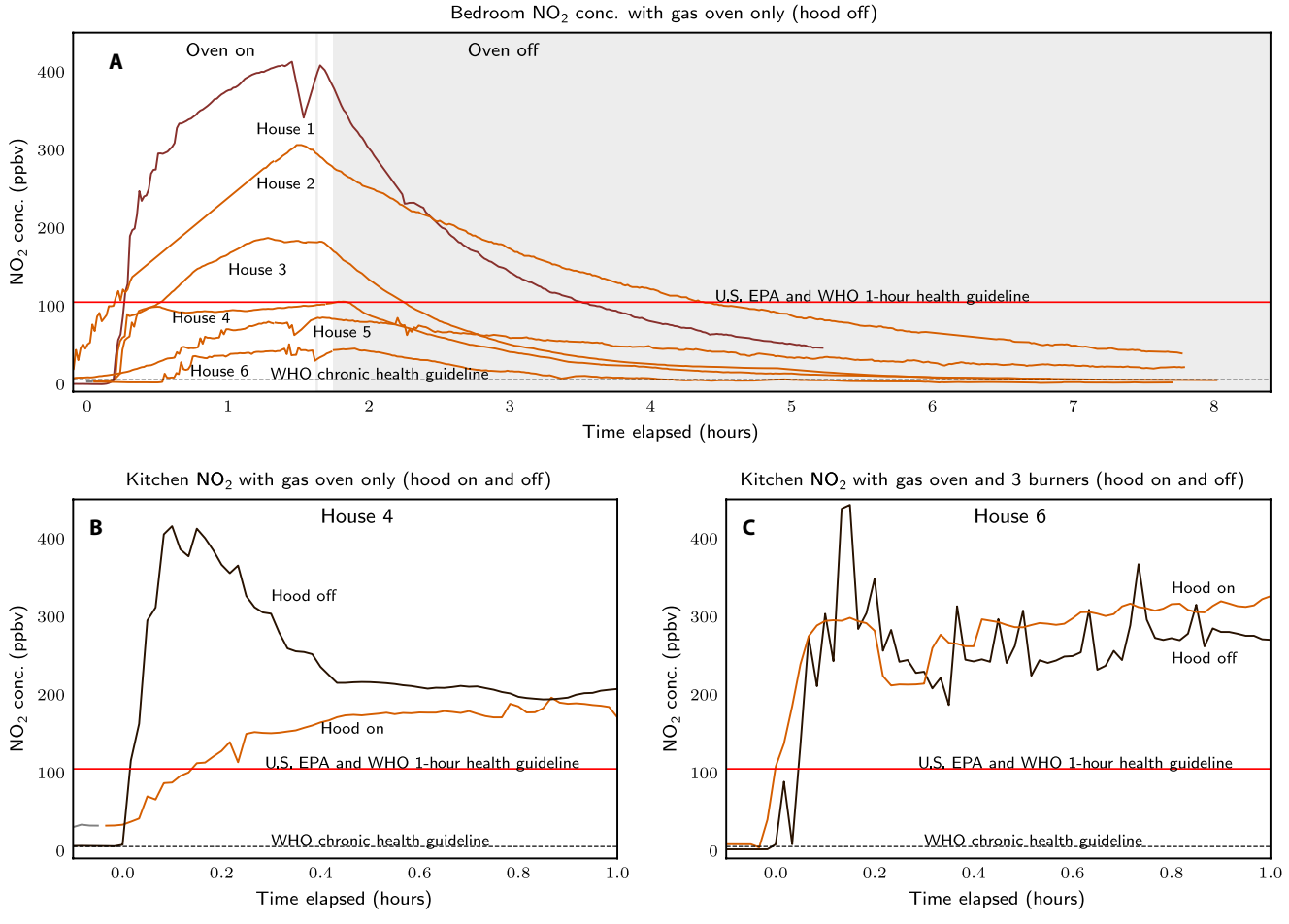


Fig. 3. Timecourses of NO_2 concentrations in bedrooms during and after oven use. (**A**) NO_2 concentrations (parts per billion volume) measured in bedrooms furthest from kitchens with the oven set to 475°F (245°C) for 1.5 hours and then turned off for 3.5 to 6.5 hours to mimic a common "bread-baking" scenario. Air-sampling hoses in houses 2, 3, 4, 5, and 6 were placed in the farthest bedrooms ~8 m down the hall from the kitchen; the sampling hose in house 1 was also in the farthest bedroom, but it was only ~4 m from the kitchen. (**B**) NO_2 concentrations measured in the kitchen of house 4 with the oven set to 475°F for 1 hour with the house's outside-venting hood off (dark brown) and on (orange), and (**C**) NO_2 concentrations measured in the kitchen of house 6 with three burners on high and the oven set to 350°F (175°C), corresponding with a higher-use scenario in the RECS database, for 1 hour with the house's outside-venting hood on (orange) and, for comparison, off (dark brown). The red horizontal line represents the U.S. EPA's 1-hour ambient concentration benchmark of 100 ppbv (*39*) and the WHO's 1-hour exposure guideline of 200 μg/m^3 (~100 ppbv) (*40*); the horizontal dashed line near the bottom of the plot represents the WHO's long-term exposure guideline of 10 μg/m^3 (*60*).

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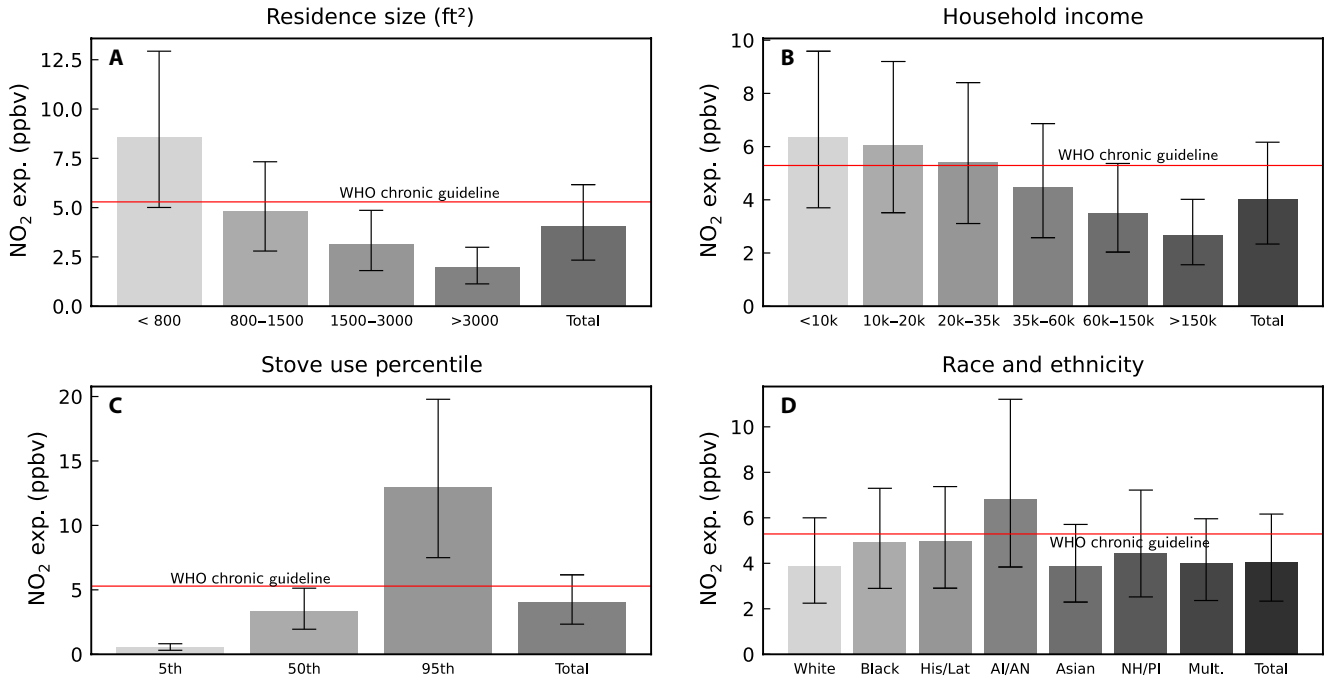


Fig. 4. Additional long-term NO_2 exposure attributable to combustion by gas and propane stoves in the United States. NO_2 exposure stratified by: (**A**) Home size (ft^2). 800 ft^2, 75 m^2; 800–1500 ft^2, 75–140 m^2; 1500–3000 ft^2, 140–280 m^2; >3000 ft^2, >280 m^2. (**B**) RECS respondent household income (US$ per year; k, $1000). (**C**) Amount of gas or propane stove use as a percentile in the population as measured by burner minutes and oven minutes (proportional to total enthalpy of gas or propane burned; see Materials and Methods). (**D**) Race/ethnicity self-reported to RECS. The racial and ethnic categories identified by RECS include (*1*): His/Lat, Hispanic or Latino; AI/AN, American Indian or Alaska Native; NH/PI, Native Hawaiian or Pacific Islander; Mult., multiracial. In each panel, "Total" refers to the average across the U.S. population. The red horizontal line in each plot is the WHO's annual NO_2 guideline (*47*). Error bars represent 95% CIs calculated using a Monte Carlo method (see Materials and Methods).

NO_2 burden of people living in residences <800 ft^2 (75 m^2) in size by 8.6 [95% CI: 5.1, 13] ppbv, more than four times the exposure of people living in residences >3000 ft^2 (280 m^2) in size (2.0 [95% CI: 1.2, 3.0] ppbv; Fig. 4A). Short-term exposures are also substantially higher for people living in smaller residences; people living in residences <800 ft^2 experience more than nine times as many days with 100-ppbv exceedances as people living in residences >3000 ft^2 in size (fig. S5A).

The relationship between increased exposure and smaller residence size also drives disparities in exposure burden borne by different U.S. subpopulations. For instance, people in households making <$10,000 per year, as recorded by the Residential Energy Consumption Survey (RECS) (*1*), are exposed to 6.3 [95% CI: 3.7, 9.5]–ppbv long-term NO_2 from gas and propane stoves. This additional exposure is more than twice that of people in households making >$150,000 per year (Fig. 4B). Short-term exposures follow the same pattern of increased risk for poorer residents; people in households making <$10,000 per year are exposed to three times as many days with 100-ppbv exceedances as people in households making >$150,000 per year (fig. S5B).

Racial and ethnic disparities arise in exposures attributable to gas and propane combustion from stoves, as well. Using RECS' racial/ethnic categories, we found that people in households with American Indian/Alaska Native respondents experience the highest stove-attributable long-term NO_2 exposure (6.8 [95% CI: 4.0, 10.0] ppbv), followed by Hispanic/Latino and Black households (5.0 [95% CI: 2.9, 7.3] and 4.9 [95% CI: 2.9, 7.2] ppbv, respectively). These exposure levels represent 60, 20, and 20% more than the average U.S. stove-attributable exposure, respectively, and, for all three groups, exceed WHO's total annual exposure benchmark just from using a gas stove—before including any contribution from outdoor air pollution (*47*). Households with white (3.9 [95% CI: 2.3, 5.9] ppbv) and Asian (3.9 [95% CI: 2.3, 5.7] ppbv) respondents experienced the lowest stove-attributable long-term NO_2 exposures of all racial/ethnic groups identified in the RECS database (Fig. 4C; $P < 0.01$ for pairwise group comparison of white and Asian exposures versus Black, Hispanic/Latino, and American Indian/Alaska Native exposures). Short-term exposures follow the same outcomes as long-term exposures; people in households with Hispanic/Latino, Black, and American Indian/Alaska Native respondents experience between 40 and 100% more days with 100-ppbv exceedances than the national average (fig. S5C). The racial and ethnic disparities we observed are primarily influenced by differences in average residence sizes: 29, 23, and 23% of American Indian/Alaska Native, Hispanic/Latino, and Black respondents, respectively, live in residences <800 ft^2 in size, whereas only 12 and 20% of white and Asian respondents do, respectively (*1*).

Both long- and short-term NO_2 stove-attributable exposures are strongly affected by behavioral factors, including the duration and intensity of stove use (i.e., how much gas is burned), range hood use and window opening, and time spent in the kitchen. The dominant factor predicting NO_2 exposure in our analysis was the total amount

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of gas or propane burned. People in residences in the 95th percentile of duration of burner and oven use (corresponding with two burners on medium for 30 min daily in the morning, and four on medium for 30 min and the oven set to 350°F (175°C) for roughly 2.25 hours in the evening) (*41*) were exposed to 3 times more than the average long-term stove-attributable NO_2 and 25 times more than people in households in the 5th percentile of burner and oven use (i.e., one burner on medium for 5 min daily in the morning and two on for 5 min in the evening with no oven used; Fig. 4D). Short-term exposures follow the same trend: People in houses in the 95th percentile of duration of burner and oven use experience 110 [95% CI: 50, 170] days per year with a 100-ppbv exceedance while people in the 5th percentile typically experience zero (fig. S5D). See data S1 for numerical values and Materials and Methods for a more detailed description of the distribution of burner and oven use.

Model sensitivity

We assessed the sensitivity of the CONTAM model combined with our exposure calculations by altering parameters systematically and estimating the effects of parameter changes on long- and short-term NO_2 exposure risk. We varied the levels of each input parameter from the 5th to 95th percentiles (or minimum to maximum values, if distribution statistics were unavailable), holding all other parameters constant at their default values (see table S7). Our analysis showed that long-term NO_2 exposure was most sensitive to duration and intensity of gas stove use (as measured by total burner minutes and oven minutes, which are proportional to enthalpy of gas or propane burned; see Materials and Methods).

The next-most important behavioral factors in determining exposure (after the amount of fuel burned) were mechanical and natural ventilation and time spent in the kitchen. People who lack an outside-venting hood or who do not use their hoods are exposed to 25% more long-term stove-attributable NO_2 than average. Meanwhile, people with a 75% capture efficiency outside-venting hood who use it every time they cook are exposed to 70% less long-term stove-attributable NO_2 than average. The effect on long-term stove-attributable NO_2 of opening and closing windows (one window modeled in the kitchen and at least three additional windows, opened or closed all at once; see Materials and Methods) was comparable to the average benefit of using a range hood (Fig. 5).

However, opening a window was far less helpful in reducing short-term exposures, measured by days per year with a 1-hour averaged NO_2 exposure >100 ppbv. Whereas people who leave their windows closed are exposed to nine times more long-term NO_2 than people who leave their windows open, people who leave their windows closed are exposed to only 1.5 times more days per year with a 100-ppbv exceedance (compare the relative sizes of the burnt orange bars in Fig. 5, A and B).

Prevalence and economic burden of stove-attributable adverse health outcomes

Combining data from the 2020 RECS (*1*) with the 2024 meta-analysis of Puzzolo *et al.* (*26*) of the association between pediatric asthma and gas stoves, we estimate that gas and propane stoves in the United States are responsible for 200 [95% CI: −20, 410] thousand current cases of pediatric asthma. Our central estimate represents roughly 10% the number of pediatric asthma cases attributable to pollution from all road traffic (*50*). Following the calculation of Nurmagambetov *et al.* (*51*), applying the EPA's value of a statistical life (VSL) to asthma-induced deaths and combining this cost with asthma-related medical costs yields an annual societal cost of gas and propane stoves of $1 (0, 2) billion. Our estimate of pediatric asthma population-attributable fraction (PAF) (see Table 1) is smaller than but statistically indistinguishable from that reported by Gruenwald *et al.* (*24*), who relied on an older meta-analysis (*16*).

Our estimate of long-term NO_2 exposure attributable to gas stoves allows us to address what portion of pediatric asthma attributed to gas stoves overall may be due specifically to long-term NO_2 exposure. Our central estimate for pediatric asthma attributable to long-term NO_2 exposure from stoves (Table 1) is ~25% of the estimate for stoves overall. This discrepancy may be due to several potential factors. These may include (i) that the majority of stove-attributable pediatric

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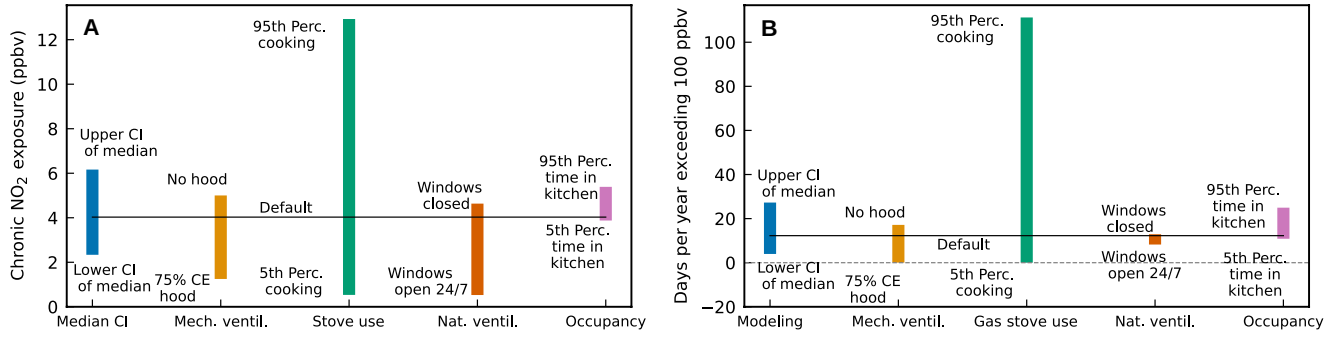


Fig. 5. Sensitivity analysis of exposure estimates. Modeled increase in (**A**) long-term NO_2 exposure (parts per billion volume) and (**B**) days with 1-hour 100-ppbv exceedances attributable to gas and propane stoves at median values of model input parameters and at high and low ends of the observed distributions. The black horizontal line in each panel indicates the modeled exposure (A) and exceedances (B) assuming default input values of all parameters (see table S7). The blue vertical range at the left of each panel spans the 90% CI of the median (from 5th to 95th percentiles; see Materials and Methods). Light orange ranges span central estimates of exposure corresponding with maximum and minimum reasonable use cases for mechanical ventilation (based on surveys and direct measurements; see Materials and Methods). Green ranges span central estimates of exposure corresponding with values modeled between the 5th and 95th percentiles of joules of gas or propane burned. Burnt orange ranges span central estimates of exposures corresponding with the maximum and minimum reasonable use cases for window opening (based on surveys, see Materials and Methods). Lilac ranges to the right span values modeled for 5th to 95th percentiles of kitchen occupancy. "CI" and "CE" stand for confidence interval and capture efficiency, respectively.

Table 1. Pediatric asthma outcomes attributable to long-term exposure to NO_2 pollution from gas and propane stoves. Modeled population attributable fraction (PAF) and annual burden attributable to the presence of gas and propane stoves (i.e., as a function of having a gas stove independent of any exposure estimate) and to long-term NO_2 exposure from gas and propane stoves in the United States. The right-most column reports the odds ratio (OR) used to calculate the asthma burden attributable to gas stoves overall (*26*) and the relative risk (RR) per 15-ppb increase in annual indoor NO_2 exposure used to calculate the asthma burden attributable to NO_2 exposure (*16*). Parenthetical numbers indicate 95% CIs calculated using a Monte Carlo method (see Materials and Methods) or, for OR and RRs, come from values reported in the literature (*16*, *26*). See data S2 and S3 and fig. S6 for a breakdown by individual U.S. states and for gas and propane stove prevalence by state (*1*).

Attribution	Pediatric asthma PAF	Modeled current pediatric asthma burden (thousand cases)	Pediatric asthma OR or RR
Presence or absence of gas stove	3.8 [0.0, 8.0] %	180 [−20, 380]	1.09 [0.99, 1.19] (OR)
Presence or absence of propane stove	0.36 [0.00, 0.75] %	17 [−2, 36]	1.09 [0.99, 1.19] (OR)
Long-term NO_2 from gas stoves	0.91 [−1.33, 3.0] %	43 [−63, 142]	1.09 [0.91, 1.31] (RR per 15 ppb)
Long-term NO_2 from propane stoves	0.09 [−0.13, 0.0.29] %	4 [−6, 14]	1.09 [0.91, 1.31] (RR per 15 ppb)

asthma cases are due to additional factors such as short-term NO_2 exposure and other gas stove pollutants; (ii) that estimates of pediatric asthma attributable to stoves do not fully account for confounding variables and could be too high; and (iii) that our model underestimated the true long-term NO_2 exposure attributable to gas and propane stoves (see limitations discussed in our conclusion and in our methods).

Exposure to NO_2 outdoors has been associated with statistically significant increases in all-cause adult mortality, though quantifying its direct effect is challenging because of potential confounding with exposure to co-occurring outdoor pollutants such as particulate matter in automobile exhaust and other combustion sources (*38*, *52*, *53*). Assuming that meta-analyses of outdoor NO_2 and all-cause adult mortality may be applied to long-term exposure to indoor NO_2, our analysis suggests that long-term NO_2 exposure from gas and propane stoves in the United States may be responsible for up to 19,000 [95% CI: 8500, 34,000] deaths annually—0.67 (0.29, 1.2)% of total U.S. adult deaths—or roughly 40% the number of deaths attributable to secondhand smoke (*54*). Applying the U.S. EPA's VSL (*55*) to each death yields an annual societal cost of gas and propane stoves of $250 (75, 480) billion (data S2), or approximately $4500 per year per U.S. household with a gas or propane stove, based on 2020 RECS data (*1*). These estimates likely overestimate the health and cost burdens attributable to NO_2 because of additional pollutants found in traffic-related air pollution. However, they also underestimate health and cost burdens because our estimates account for only long-term NO_2 exposures and not short-term exposures to high concentrations, which routinely exceeded 100 ppbv in our measurements (see Figs. 1 and 3). Better disambiguation between the effects of NO_2 and $PM_{2.5}$ as well as more studies on short-term NO_2 effects are needed to constrain NO_2 mortality estimates.

DISCUSSION

Gas stoves are common globally and in U.S. homes. Emissions from gas and propane stove combustion degrade indoor air quality (*3*, *10*, *40*, *56*, *57*) and are associated with adverse health outcomes that include pediatric asthma and hospitalizations (*23*–*25*, *52*, *58*, *59*). We report updated field estimates of NO_2 emission rates for gas stoves and previously unreported emission rates of NO_2 from propane stoves. We combined our emissions measurements with the NIST's CONTAM indoor air model and other published datasets; in doing so, we produced a population-level estimate of the distribution of NO_2 exposure and health outcomes attributable to gas and propane stoves as a function of specific behaviors and for different income and race and ethnicity groups (see Materials and Methods).

Consistent with previous research (*10*, *24*, *25*), we find that combustion from gas and propane stoves represents a major source of long- and short-term NO_2 exposure that can exceed U.S. and WHO guidelines just by using a stove, independent of any outdoor NO_2 exposures. Demographic detail provided by the RECS (*1*) and the precision afforded by the multizone CONTAM model (*37*) allowed us to extend previous research to the entire United States and to exposures in specific rooms, estimating both short- and long-term exposure as a function of behavioral and demographic variables such as gas and propane stove use, time spent in the kitchen and other rooms, and the income and race of occupants. Our findings also quantified the importance of gas and propane stove use (i.e., joules burned) compared with ventilation and occupancy in determining indoor NO_2 exposure. We also found that housing size greatly influences exposure. Differences in housing size partly drive income-based and racial disparities in stove-attributable NO_2 exposure, though there are other potentially relevant factors not captured by our model, such as social differences in cooking and ventilation behavior and differences in the time spent indoors and outdoors.

Our estimated health consequences of gas and propane stove use are large. We found that gas and propane stoves may contribute up to 19,000 adult deaths annually in the United States. We also estimated that long-term NO_2 exposure from gas and propane stoves is responsible for approximately 50,000 current cases of pediatric asthma. In addition, the total number of current pediatric asthma cases attributable to pollution from gas and propane stoves is likely closer to 200,000. That number of cases is approximately 10% of pediatric asthma attributable to pollution from road traffic and corresponds with a societal cost of roughly $1 billion annually.

Additional research could enhance future estimates of adverse health outcomes associated with gas and propane stoves. First, we assessed only one pollutant, NO_2, in this exposure assessment. Because gas stoves also emit carbon monoxide (CO), benzene, formaldehyde, and ultrafine particles (*7*, *9*–*11*), which are linked to adverse health outcomes beyond asthma (*40*), our estimates of disease burden and societal cost almost certainly underestimate the full health consequences of combustion from gas and propane stoves. Second, the granularity of our modeling was limited by the availability of

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data on burner and range hood use for different geographies and demographic groups. Gathering and incorporating these data into an exposure model may produce a more precise estimate of socioeconomic and racial disparities in gas stove-attributable NO_2 exposure. Third, our study's quantification of all-cause mortality was limited by potential confounding of NO_2 with other coproduced pollutants outdoors. Future work focusing on the effect of indoor NO_2 on mortality, COPD, or other adverse health outcomes would enable modeling of the stove-attributable component of these diseases. Fourth, our study did not estimate the health effects of our measured short-term exposure to high NO_2 concentrations. High-quality epidemiological studies assessing the health effects of short-term NO_2 exposure would allow the results of this study and future work to be used to model adverse health outcomes associated with short-term stove-attributable NO_2. Fifth, our study relied on data for the United States only; incorporating behavioral and housing stock data from outside the United States would expand the scope of exposure estimates to other countries and continents. To address this shortcoming, we are undertaking indoor pollution measurements associated with gas stoves in countries that include Australia, the United Kingdom, the Netherlands, Italy, and China.

Although successful policies have reduced sources of air pollutants such as NO_2 in the United States (*48*), indoor air quality remains largely unmeasured and unregulated (*39*). Our research shows that pollution from gas and propane stoves disproportionately affects lower-income people and racial and ethnic minorities and that gas and propane stoves are responsible for substantial pediatric asthma and adult mortality. Our results also highlight the importance of including indoor sources of air pollution in future policies designed to protect people from pollutants such as NO_2, benzene, and carbon monoxide.

MATERIALS AND METHODS

Definitions

We defined a "cooktop" as a flat surface with two to six individual cooking elements and "burners" as cooking elements using a gas or propane flame. We defined gas, propane, and electric ovens as enclosed spaces heated by gas, propane, or electricity, respectively. We defined a "stove" (also called a "range") as a freestanding unit that contains both a cooktop and an oven. We defined an "outside-venting range hood" as an exhaust fan located directly above a stove, cooktop, or oven that sends kitchen air outdoors. We defined a "recirculating range hood" as a range hood that returns exhaust air to the kitchen rather than venting it outside.

Throughout the paper we used the term "concentration" for its accessibility in place of the more strictly correct term "molar mixing ratios." We assumed a temperature of 25°C and a pressure of 1 atm when converting between true concentrations and molar mixing ratios, which yields the conversion 1-ppbv $NO_2 = 1.89\ \mu g\ m^{-3}\ NO_2$. We also used a conversion of 1-ppbv $NO_2 = 1.89\ \mu g\ m^{-3}$ to convert relative risks (RR) reported in units of micrograms per cubic meter to units of parts per billion volume.

We used CONTAM, a multizone indoor air model developed by the NIST, to model indoor NO_2 concentrations (*37*). We validated the model by comparing its predictions against measured NO_2 concentrations in a set of 18 test residences referred to as "validation residences" or "validation homes." We then used the validated model to estimate NO_2 concentrations in a set of other residence footprints (detached houses, duplexes and multiplexes, mobile homes, and apartments) for which we lacked measured NO_2 data. We refer to these as the "model residences" or "model homes."

We define "long-term" exposures in terms of parts per billion volume of NO_2 exposure averaged over a year and "short-term" exposures in terms of the number of days per year on which daily maximum hour-averaged NO_2 exposure exceeds 200 $\mu g/m^3$ (~100 ppbv), the WHO hour-averaged NO_2 standard (*60*).

We used commonly accepted definitions of epidemiological terms: (*38*, *61*) "population attributable fraction" (PAF) is the fraction of cases of a health outcome in a population attributable to an exposure; "odds ratio" (OR) is the ratio of the odds that a health outcome will occur given an exposure to the odds that the same health outcome will occur without the exposure; "relative risk" (RR) is the ratio of the probability of a health outcome in the exposed population divided by the probability in the unexposed population; "incidence" is the number of new cases of a disease per time interval (1 year, unless stated otherwise); "prevalence" is the total number of active cases of the disease in the population at a given time; and "burden" is the number of health outcomes (either at a given time or per unit time) attributable to an exposure.

Instrumentation

We measured NO_2 concentrations using a Teledyne T200P analyzer. We measured CO_2 and N_2O concentrations using an Aeris carbon dioxide/nitrous oxide MIRA Ultra Mobile LDS analyzer and measured CH_4 and C_2H_6 using an Aeris methane/ethane MIRA Ultra Mobile LDS analyzer. The calibrations of the analyzers were checked weekly and whenever transported.

Site selection

We measured NO_2 emission rates from 50 gas, 11 propane, and 14 electric stoves in 20 counties in California, Colorado, Texas, New York, and Washington, D.C. between January 2022 and July 2023 (fig. S7). Our measurements included 24 gas, 9 propane, and 14 electric stoves for which we previously reported benzene emission factors (*11*) (see table S4 for a summary of the characteristics of stoves we sampled and table S3 for a comparison against other published emission rates). Our set of sample residences also included a range of kitchen sizes (15 to 150 m^3) in private houses, apartments, and several Airbnb rentals, where we could measure longer uninterrupted time courses. We selected residences through online participant sign-up pages and neighborhood and community associations. We performed CONTAM validations tests (see below) on an 18-home subset of our sample, whose open floor area (excluding closed-off rooms and garages) varied in size from 250 to 1650 ft^2 and included 10 detached houses and eight apartments in three U.S. states (table S3).

Emission rate calculations and statistics

We calculated NO_2 and CO_2 emission rates from gas and propane combustion by measuring the increase in NO_2 concentration through time in sealed kitchens of known volumes, an approach analogous to that used in our previous work to measure NO_x, methane, and benzene emission factors from stoves (*10*, *11*). We converted measured concentrations into emission rates using Eq. 1

$$f = \frac{V_k}{t - t_0}(C_t - C_o + \Sigma_{i=1}^{n}(C_{t_i} - C_{bkg})(e^{-\lambda(t_i - t_{(i-1)})} - 1) \quad (1)$$

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where t_i is the timestamp of the ith datapoint, t_0 is the initial time, f is the mean gas emission rate over the course of a measurement (in volume per time), V_k is the kitchen volume, λ is the kitchen chamber's air exchange constant (in reciprocal time), n is the number of gas concentration datapoints (typically 12) collected in a given measurement period, C_{ti} is the gas concentration at time t_i (in parts per billion volume), and C_0 is the concentration inside the chamber at the start of the measurement, and C_{bkg} is the background gas concentration outside the kitchen chamber (see the "Correction for air exchange" section, below). We assume that C_b is equal to the gas concentration we measure inside the kitchen immediately after airing it out with fresh outdoor air. We converted volumetric emission rates into gravimetric emission rates using the temperature measured in the kitchen.

We measured the energy output from gas burners and ovens using the flow rate of CO_2 and the enthalpy of combustion of methane to calculate the joules (J) of energy emitted per unit time.

We calculated the kitchen volume (V_k) and air exchange constant (λ) using 300- to 500-ml injections of a known volume of either ethane (C_2H_6) or nitrous oxide (N_2O) as a dilution tracer, using fans to mix the kitchen air, a method validated by Lebel *et al.* (the slope of laser-measured versus tracer gas–measured room volume is 1.1 [95% CI: 0.9, 1.3]; adjusted $r^2 = 0.91$) (*10*). The estimated kitchen volume is the injected tracer gas volume divided by the peak tracer gas concentration immediately following injection, and the air exchange constant is the tracer gas's decay constant through time after the peak concentration (see the "Correction for air exchange" section, below).

We calculated mean and median 95% CIs of emission rates from a 25,000 replicate bootstrap sample set (*62*, *63*) using a method described by Lebel *et al.* and by Kashtan *et al.* (*10*, *11*): We generated each replicate sample in the bootstrap by randomly sampling with replacement the set of emission factors in question to form a random sample of equal size to the set of emission factors in question. For instance, the bootstrap gas burners on high consisted of 25,000 replicates of size 50, generated by randomly sampling (with replacement) the set of 50 emission rates for gas burners on high. We then calculated 95% CIs for the means and medians of these bootstraps (*62*, *63*). We calculated statistical significance between gas and propane stove emissions using the two-sided Mann-Whitney U test (also known as the Wilcoxon rank sum test).

Our method for measuring NO_2 emission factors was the same as that used in Kashtan *et al.* to measure benzene, and similar to that used by Lebel *et al.*, to measure methane and NO_2. We sampled kitchen air approximately 1.5 m off the ground using a 7 liter min^{-1} pump drawing air through a polytetrafluoroethylene (PTFE) hose attached to our analyzers outside the sampling area. Where necessary to estimate emissions factors (but never when measuring concentrations), we created enclosed kitchen partitions by closing the kitchen's doors and windows, closing off open spaces with plastic, and placing fans in each kitchen to mix the air (being careful not to disturb the flame). We measured NO_2 concentration in the closed chamber for at least 15 min before igniting the stove to verify that no other sources or sinks were present (see fig. S8A).

The 5- to 8-hour time course NO_2 concentrations reported in the "NO_2 concentrations in bedrooms and with range hoods on" section were measured using no plastic partitions anywhere and with all interior doors open in six different houses. To avoid mixing the air, we did not use fans or other means of active air circulation during these concentration-based time courses. In all six houses for which we did the 8-hour time courses, we set the oven to 475°F (245°C), a temperature commonly used to bake bread, for 1.5 hours with the hood off. We continued monitoring NO_2 concentrations for 3.5 to 6.5 additional hours in the farthest bedroom from the kitchen after turning the oven off.

Correction for air exchange

Because it is impossible to seal kitchens perfectly, we corrected for air exchange between the chamber and the air outside the chamber. We calculated the air exchange constant for each kitchen by injecting 300- to 500-ml volumes of ethane or nitrous oxide and measuring changes in concentration through time as described in Materials and Methods and in Lebel *et al.* (*10*).

Kitchen volume is calculated using Eq. 2

$$V_k = \frac{V_i}{C_{tracer_peak}} \tag{2}$$

where V_k is the kitchen volume, V_i is the volume of injected tracer (ethane or nitrous oxide), and C_{tracer_peak} is the peak ethane concentration following injection.

The concentration of the tracer, ethane or nitrous oxide, after injection follows an exponential decay attributable to air exchange and is described by Eq. 3

$$C_{tracer,t} - C_{tracer,b} = C_{tracer,0}e^{-\lambda t} \tag{3}$$

where $C_{tracer,t}$ is the concentration of the tracer at time t, $C_{tracer,b}$ is the background concentration of the tracer, $C_{tracer,0}$ is the concentration of the tracer in the kitchen before injection (typically very close to background), t is time, and λ is the air exchange constant.

Rearranging, we can calculate the air exchange constant λ using Eq. 4

$$\lambda = \frac{\ln\left(\frac{C_{tracer,0}}{C_{tracer,t} - C_{tracer,b}}\right)}{t} \tag{4}$$

Then, the corrected gas concentration $\hat{C}_{g,t}$ for the ith datapoint collected is given by Eq. 5

$$\hat{C}_{t_i} = C_{t_i} + \Sigma_{i=1}^{n}(C_{t_i} - C_{bkg})(e^{-\lambda(t_i - t_{(i-1)})} - 1) \tag{5}$$

where t_i is the time of the ith datapoint, $\hat{C}_{t_i}$ is the corrected gas concentration at time t_i, C_{bkg} is the background gas concentration outside the kitchen chamber, C_{t_i} is the true gas concentration at time t_i, and C_0 is the initial gas concentration in the chamber (usually almost the same as C_{bkg}).

The flow rate of the gas can then by calculated using the linear model given by Eq. 6

$$f = \frac{V_k(\hat{C}_t - C_0)}{t - t_0} = \frac{V_k}{t - t_0}(C_t - C_0 + \Sigma_{i=1}^{n}(C_{t_i} - C_{bkg})(e^{-\lambda(t_i - t_{(i-1)})} - 1) \tag{6}$$

where f is the gas flow rate (expressed as volume per time) and t_0 is the initial time.

We used Eq. 6 to calculate flow rates for CH_4, and CO_2. This method is the same as that used by Lebel *et al.* (*10*).

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Modeling population-level exposures and health risks

We used CONTAM to model indoor NO_2 concentrations resulting from gas and propane stove use under different conditions. All quantities not measured, such as wall and door leakage areas and wind pressure profiles, used the default values in the ASHRAE Handbook-Fundamentals based on a house's age and height (*64*). We assumed a previously reported (*32*) NO_2 decay rate of -2.4×10^{-4} s^{-1}.

Validation of the CONTAM multizone model

We validated our CONTAM model by comparing measured and modeled NO_2 concentrations in 18 test houses. In each test house, we measured the NO_2 emission rate of a specific combination of burners and oven on known settings using the methods described above (see table S2). After fully airing out the house, we then measured the NO_2 concentrations in one to four different rooms (including at least the kitchen and another room or, in studio-style apartments, a single zone representing a combined kitchen/living space) for 40 min to an hour with the given burner/oven combination on and for another 1 to 3 hours with all burners and oven off. Note that the 18 1-hour–and–40-min– to 4-hour CONTAM validation measurements are distinct from the 6 8-hour bedroom measurements.

For validation measurements, all internal doors in residences were left open. In several instances, we measured both with windows open and closed and with an outside-venting range hood on or off. Because we had only one Teledyne NO_2 analyzer, we sampled sequentially from each room in question using a valve system to cycle between rooms so as not to disturb the sampling hoses or to have to enter the rooms (see fig. S8B).

After obtaining time-resolved concentration measurements, we modeled NO_2 concentrations in each residence using CONTAM. We constructed each residence in CONTAM based on laser distance measurements (see table S2 for a summary of home sizes and characteristics). We modeled each room as a single zone, except for hallways which we represented using two to four zones, depending on length. In each validation house, we inputted into CONTAM the NO_2 emission rate we measured from the burner/oven combination being tested. We also inputted into CONTAM weather profiles [obtained from OpenWeather Marketplace; (*65*)], corresponding with the address and time-period of each validation measurement.

Because interior airflow is strongly influenced by temperature gradients, time-resolved temperature gradients in multiple zones of each residence were required to accurately model NO_2 concentrations attributable to stoves. We measured temperature profiles of each room in 11 of the 18 validation homes (see fig. S9 for CONTAM floorplans of each of the 11 homes) and observed strong overall agreement between modeled and measured NO_2 concentrations in the 11 houses for which we have temperature data (see Results).

We could not scale such a time-resolved model to the entire U.S. housing stock because internal temperature profiles are variable and we thus could not use house-specific time-resolved temperature gradients as inputs in our nationwide model. To extend our model, we also verified that we could replace airflow due to temperature variation with a fixed-bidirectional airflow at each open door and still accurately predict kitchen, living room, and bedroom NO_2 concentrations averaged across several residences.

We considered a range of different bidirectional flow values between 300 and 1300 m^3/hour and found empirically that setting bidirectional flow to 1000 m^3/hour [590 cfm; within the range of turbulent flow rates observed in real interior doorways; (*66*)] minimized the error between averaged measured and modeled hour-averaged and day-averaged concentrations (see table S5; figs. S4 and S10 show results for different bidirectional flow rates; day-averaged concentrations extrapolated from measured and modeled values at the end of the measurement period using a decay rate of -2.4×10^{-4} s^{-1}). We calculated error as $100\,\% \times \frac{\text{Measured} - \text{Modeled}}{\text{Measured}}$.

NO_2 exposure calculations using CONTAM

We used CONTAM to model time-resolved NO_2 concentrations under different scenarios in each of the 7632 residences with gas, propane, and mixed-fuel stoves included in the United States Energy Information Administration's 2020 RECS. The 2020 RECS is a survey of 18,500 households in all 50 states and the District of Columbia that reports information on participants' energy use, housing characteristics, and demographics, and which assigns each participating household a representation weight such that results may be extrapolated to the entire U.S. population (*1*).

We combined our CONTAM modeling with the RECS data by assigning each RECS household to 1 of 24 distinct CONTAM floorplans that most resembled the RECS household in question based on housing type, floor area, number of stories, presence or absence of a forced air system, and home age. We selected the 24 floorplans from a pool of 209 residences constructed in CONTAM by Persily *et al.* (*67*) to represent the U.S. housing stock. The 24 floor plans represent diverse yet common types of homes that encompass the characteristics of the 7632 RECS residences (see fig. S11 for an assignment flowchart and table S6 for a summary of the 24 floorplans). We represented with a single floorplan homes that only differed from one another in factors out of the scope of this study (e.g., foundation type and room types). We assigned RECS residences to our set of floorplans according to, in order of decreasing prioritization, type of home, floor area, number of stories, presence or absence of a forced air system, and home age.

We left each model floorplan unchanged except for the following: because windows were not included in the default floorplans in CONTAM, we added one National Fenestration Research Council standard window (1.2 m × 1.5 m or 4 ft × 5 ft) to an exterior wall in every bedroom, living room, and kitchen (*68*); as discussed above, to simulate indoor air transport we replaced each modeled open door with bidirectional flow at a rate of 1000 m^3/hour (590 cfm); because we adjust the modeled NO_2 emission rate to account for outside-venting range hoods (for instance, we model a 50% capture efficiency outside-venting hood by reducing the emission rate by 50%), we removed modeled range hoods in floorplans that had them so as not to double-count range hoods. We left central forced-air systems unchanged and assigned their schedule on the basis of modeled ambient temperature (see table S7).

We captured a range of behaviors and environments by assigning a weighted distribution of scenarios to each RECS household. We used prior surveys and direct measurement studies to select three or four distinct values for each of six parameters: range hood use, stove use, window use, ambient temperature, windspeed, and occupancy, for a total of $4 \times 3 \times 3 \times 4 \times 3 \times 3 = 1296$ combined scenarios for each floorplan. We modeled each scenario for each of the 24 CONTAM floorplans and then calculated peak 1-hour–averaged and day-averaged NO_2 concentrations associated with each scenario. On the basis of existing data on each parameter and on the number of heating degree days and cooling degree days expected for the specific

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location of each RECS residence, we assigned relative weights for each of the 1296 modeled scenarios for each RECS residence. The weights of each value are presented in table S7. We also performed a sensitivity analysis on all six parameters (see Results).

We calculated the distribution of national long-term NO_2 exposure burden by iterating through all 7632 RECS representative residences with gas or propane stoves and for each residence calculating the weighted mean of the 1296 modeled day-averaged NO_2 exposures. We then multiplied this mean by the residence's weight in the RECS database and normalized for total number of residences represented in the RECS database. We calculated the distribution of the percentage of days with 1-hour–averaged NO_2 exposure exceeding 100 ppbv in an analogous fashion: for each RECS residence, we calculated the percentage of modeled exposure days with a 100-ppbv exceedance, then multiplied the value by the given residence's weight and normalized for total number of residences represented by RECS.

Estimation of pediatric asthma attributable to gas and propane stoves overall and to NO_2 exposure from gas and propane stoves

We estimated the PAF of asthma incidence attributable to the use of gas and propane stoves compared with the use of electric stoves using ORs reported by Puzzolo *et al.* (*26*), who conducted a meta-analysis featuring multiyear, multicohort, geographically diverse studies. Because Puzzolo *et al.* did not report ORs or RRs per unit of indoor NO_2, we estimated the PAF of asthma incidence due to long-term NO_2 exposure from gas and propane stoves using Lin *et al.*'s 2013 estimate (*16*), which also featured multiyear, multicohort, geographically diverse studies focusing exclusively on indoor NO_2. Following Gruenwald *et al.* (*24*), we used ORs in place of RRs, as pediatric asthma affects less than 10% of the U.S. child population (*69*).

To our knowledge, there are no meta-analyses assessing the effect of indoor NO_2 on mortality. To estimate the PAF of deaths attributable to long-term NO_2 exposure from gas and propane stoves, we thus used the RRs reported by a meta-analysis featuring multiyear, multicohort, geographically diverse studies of ambient NO_2 (*38*). Potential confounding with other coproduced ambient pollutants, such as particulate matter, increases the uncertainty of our mortality calculations. While Buonocore *et al.* used the RR for all-cause mortality associated with NO_2 reported by Faustini *et al.*'s 2014 meta-analysis (*70*), we instead opted for an RR reported in a newer meta-analysis by Atkinson *et al.* (*38*), which exclusively incorporated cohort studies (1.02 [95% CI: 1.01, 1.03] per 10 μg/m^3 increment in long-term NO_2 concentration, smaller than Faustini *et al.*'s value of 1.04 [95% CI: 1.02, 1.06] per 10 μg/m^3).

Consistent with prior epidemiological work assessing the influence of long-term NO_2 exposure on respiratory diseases (*15*, *71*, *72*), we assumed a log-linear concentration-response function and calculated health outcome burdens as

$$\text{Burden} = Inc_g \Sigma_n P_n \times W_n \times (1 - e^{-\beta \Delta c_n}) \quad (7)$$

where values are summed over all $n = 7632$ RECS residence types with gas or propane ranges or cooktops in the RECS database, Burden is the number of adverse health outcomes (death or pediatric asthma) attributable to NO_2 from stoves, Inc_g is the current incidence rate of the adverse health outcome in question in the geography in question, P_n is the number of people living in the nth household, W_n is the number of households the nth RECS household represents in the U.S. housing stock, β is the concentration response factor (calculated as $\frac{\ln(RR)}{\Delta c}$), which is assumed to be constant, and Δc_n is the median year-averaged gas-stove-attributable NO_2 exposure in the nth residence. We calculated burden separately for pediatric asthma and adult mortality using the appropriate P_n, based on child and adult occupancy of RECS houses.

We calculated pediatric asthma burden using a U.S. pediatric asthma incidence rate averaged between 2006 and 2008 (12.5 cases per 1000 children) (*69*) multiplied by the current U.S. population under 18. We used state-by-state incidence of pediatric asthma from the U.S. Centers for Disease Control and Prevention from 2021 (*73*), the most recent date for which data stratified by state were available. We calculated state-stratified asthma rates only in states for which the incidence rate was reported.

Because the total population covered by the RECs database (62 million children, 239 million adults) is slightly lower than today's U.S. population (258 million adults and 73 million children) (*74*), likely because of occupancy data that is older than the most recent U.S. census, we proportionally adjusted our calculated burdens to match the current U.S. adult and child population

$$\text{Burden}_{adj} = \text{Burden}_{orig} \times \frac{Pop_{current}}{Pop_{RECS}} \quad (8)$$

Following Mansournia (*75*), we calculated PAFs from calculated burdens and baseline incidence of deaths and pediatric asthma as

$$\text{PAF} = \frac{\text{Burden}}{\text{Incidence}} \quad (9)$$

where Incidence is the number of new deaths or pediatric asthma cases per year in the geography in question. When calculating PAFs for individual states, we used state-specific incidence estimates, and when calculating national PAFs, we used national incidence estimates.

Because the uncertainty in RRs may be correlated with uncertainty in exposure, we conservatively assumed a wide uncertainty in PAFs. Rather than add fractional errors of RR and Δc_n in quadrature, we calculated our lower uncertainty bound using the lower bound of each reported RR and of each Δc_n estimate we calculated. We performed the analogous calculation for upper bounds.

Following Buonocore *et al.* (*61*), we calculated the valuation of excess deaths using the VSL from the EPA's BenMAP (*55*), $13.1 ($7.9, $18.5) million per death when adjusted to U.S. $ 2023, and the valuation of asthma incidence from an analysis by Nurmagambetov *et al.* (*51*), $5300 ($4120, $6490) per year per pediatric asthma case. We assumed that uncertainties in health outcome burdens and valuations were independent.

Uncertainty

We calculated uncertainty in exposure and health outcomes using a Monte Carlo method. To calculate uncertainty in exposure, we computed a Monte Carlo distribution resulting from the combination of three input distributions representing three key elements of the model: (i) measured NO_2 emission factors, (ii) estimated burner intensities used, and (iii) the distribution of NO_2 exposures modeled in different CONTAM scenarios, normalized to amount of gas burned and weighted according to the prevalence of each scenario, according to Eq. 10A and 10B

$$MC_{mean} = \text{mean}(EF * BI * CE * WE) \quad (10A)$$

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$$MC_{\text{median}} = \text{median}(EF * BI * CE * WE) \quad (10B)$$

where *EF*, *BI*, and *CE* are randomly sampled (with replacement) values from the distributions of emission factors, burner intensities, and ratios of CONTAM-modeled exposures (normalized to gas burned), respectively, and *WE* is the weight corresponding to the particular CONTAM-modeled exposure *CE* selected. Because we have sparse data on the frequency with which people cook with burners on low, medium, and high (*41*), we assumed a normal distribution for burner intensity expressed as a fraction of emissions on high (mean = 0.5; SD = 0.1). See the "Limitations" section for further discussion.

Each sample *EF* and *CE* contained a number of elements equal to the minimum number of elements in each of the included distributions. For gas, this was 390 (number of gas emission factors) and for propane it was 20. Because *BI* was drawn from a known normal distribution, each sample *BI* contained only one element. MC_{mean} and MC_{median} are the mean and median, respectively, of the product of a single set of *X*-element input samples, where $X = 390$ for gas and 20 for propane. We calculated MC_{mean} and MC_{median} over 10,000 iterations to form a Monte Carlo distribution of the mean and median and calculated 95% CIs for mean and median exposure based on the Monte Carlo distributions.

We calculated central-estimate, lower-bound, and upper-bound long-term exposure for each floorplan as the average of the central estimate, lower bound, and upper bound of modeled day exposures, respectively. We calculated short-term exposure exceedances as the fraction of modeled days with a maximum 1-hour average exposure exceeding 100 ppb and converted the fraction to days per year by multiplying by 365. We used the central estimate, lower bound, and upper bound of modeled day exposures to calculate our CI in an analogous fashion to long-term exposures.

We used the same method to calculate uncertainties in our estimates of health outcomes and costs associated with exposure to NO_2. This time, we combined the distribution of concentrations calculated by Eq. 10A with a normal distribution of RRs reported for asthma (*16*) or mortality (*38*), according to Eq. 11

$$MC_{\text{health}_{\text{mean}}} = \text{mean}(1 - e^{\frac{\ln(RR)}{\Delta c} \times MC_{\text{conc}}}) \quad (11)$$

where $MC_{\text{healthmean}}$ is the mean of a single result in the Monte Carlo distribution of health outcome risks (pediatric asthma or adult mortality), *RR* is a relative risk value randomly sampled (with replacement) from a normal distribution, according to 95% CIs provided by Lin *et al.* and Atkinson *et al.* (*16*, *38*) for asthma and mortality, respectively, and MC_{conc} is a long-term exposure value randomly sampled (with replacement) from the 10,000-element normal distribution produced by running Eq. 10A 10,000 times. We then calculated the 95% CI of this Monte Carlo distribution. We calculated uncertainties in costs using the same method, this time drawing values from our calculated distribution of predicted health outcome burdens and from a distribution of per-case costs derived from uncertainties provided in the literature (see above).

We performed an analysis of the sensitivity of our calculated adverse health outcome burdens to the choice of concentration-response model. We did so by calculating the estimated burden of pediatric asthma and adult all-cause mortality attributable to long-term NO_2 from stoves using a log-linear model, a linear model, and a log-linear model with a 2-ppbv no-effect threshold, three models mentioned in recent long-term NO_2 literature (*13*, *15*, *71*, *72*). In each case, we calculated 95% CIs using a Monte Carlo method analogous to that described above for the calculation of log-linear adverse health outcome burden. The observed differences between models were modest and statistically indistinguishable (fig. S13).

Limitations

Our study assessed only one pollutant from gas stoves, NO_2. Because gas stoves also emit CO, benzene, formaldehyde, and ultrafine particulate matter (*7*, *9*–*12*, *76*), our estimates of disease burden and societal cost almost certainly underestimate the full health consequences of gas and propane stoves.

Results are based on measurements and assumptions throughout the modeling chain. We can partition the modeling chain, and associated uncertainties and limitations, as follows:

1) NO_2 emission rates of gas and propane burners and ovens.

To our knowledge, before Lebel *et al.*, NO_2 emission rates from gas stoves were last systematically quantified in 1985, but summary statistics were not reported. Other researchers have since reported emission factors per joule but not emission rates per time (see table S3 for a comparison of our results and previously reported emission rates and emission factors). Our modeling thus used emission rates measured in this work and by Lebel *et al.* (*10*). Our work and results from Lebel *et al.* (*10*) have constrained median NO_2 emission rates from gas burners on high and ovens to ±15% (see table S3). Larger uncertainties (up to ±50% for burners on high) remain for propane burner and propane oven emissions (see table S3). Moreover, our independent estimates in this paper for NO_2 emissions were statistically indistinguishable from those in Lebel *et al.* (see fig. S4 and table S3 for emission rates and table S8 for a summary of uncertainties).

2) Modeled indoor NO_2 concentrations from CONTAM, given a set of known input parameters.

We constrained uncertainties in modeled concentrations at ±18% (with positive values indicating an underestimate; see table S5). Our set of validation measurements included 18 homes and spanned a range of characteristics and measurement conditions. However, given time constraints it was impossible to validate the model on every combination of input parameters.

3) The population-wide distribution of burner minutes and oven minutes used per day, range hood use and capture efficiency, window opening schedules, outdoor temperatures, and outdoor windspeeds (the input parameters in step 2).

As demonstrated in our sensitivity analyses, there is a broad range in how frequently people use their stoves and their range hoods (and range hoods' efficacy) and open their windows, and these input parameters can alter estimated exposure (see Fig. 4). Of these inputs, stove use (i.e., length of time and number and intensity of burner and oven usage) had the largest spread and effect on exposure estimates. To our knowledge, no U.S.-wide study of burner and oven use exists, so we relied on a direct-measurement study by Zhao *et al.* (*41*) of stove use in 54 single family houses and 17 low-income apartments in California.

4) Other behavioral assumptions.

Apart from the behaviors listed above, there were other behaviors for which we lacked information. Two such behaviors that affect exposure are burner intensity and interior door opening. We inferred burner intensity based on reported cooking behaviors (see table S7), but because we lack measured data, our assumption that "on" burners are set to 50% of "high" may be an over- or underestimate of NO_2 emissions. We attempted to account for this uncertainty by adding

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a ± 10% normally distributed uncertainty to our exposure and health outcome estimates. We assumed that all interior doors of houses remain open. Compared with an assumption of more closed doors, our open-door assumption results in lower exposure to people in and near the kitchen and higher exposure to others in the house. While this should not substantively affect our population-averaged estimates of long-term exposure, it may lead us to underestimate exposure for primary cooks in a given household and to overestimate exposure for people who spend little time in the kitchen. This issue applies to both long-term and short-term exposure estimates but is more relevant to short-term exposures.

5) Assignment of each residence in the RECS database to a specific floorplan in CONTAM.

We assigned each residence in the RECS database to 1 of 24 floorplans and thus were unable to perfectly match each RECS residence to a given floorplan. For example, we split apartments into >1000 ft^2 (>90 m^2) and <1000 ft^2, representing the 65th percentile of floorspace for apartments with gas or propane stoves [the median is 900 ft^2 (80 m^2)] (*1*). This assignment (and analogous assignments for other variables) thus result in the floorspace of roughly equal numbers of RECS residences being over- and underestimated and thus should not substantively affect our population-averaged exposure estimates. However, it may underestimate differences in exposure due to housing size and other characteristics.

6) Conversion of exposure estimates to estimates of disease burden.

We relied on RR values from recent meta-analyses to calculate stove-attributable pediatric asthma and mortality (*16*, *26*, *38*). For pediatric asthma, we relied on meta-analysis assessing indoor NO_2 only (*16*). Because no meta-analysis has assessed indoor NO_2 and mortality, to our knowledge, we calculated mortality using a meta-analysis on outdoor NO_2. Our estimate of mortality is thus limited in its precision by potential confounding pollutants that co-occur with outdoor NO_2, such as particulate matter, and by the variability in RRs reported by different studies. We applied a mortality RR of 1.02 (1.01, 1.03)) per 10 $\mu g/m^3$ of long-term NO_2 exposure derived from meta-analysis by Atkinson *et al.* (*38*) that included only long-term, cohort studies. Other meta-analyses (*70*, *77*) have estimated higher RRs than what we used. For instance, a 2014 meta-analysis (*70*) on NO_2 exposure and mortality used by Buonocore *et al.* to calculate premature deaths from upstream oil and gas production (*61*) calculated $RR = 1.04$ (1.02, 1.06) per 10 $\mu g/m^3$ increase in long-term NO_2. We propagated uncertainty bounds provided by Atkinson *et al.* but recognize that there is additional uncertainty and that choosing meta-analyses with broader inclusion criteria than used by Atkinson *et al.* may have resulted in higher mortality estimates than those we calculated.

Supplementary Materials

This PDF file includes:
Figs. S1 to S15
Tables S1 to S8
Legends for data S1 to S3
References

Other Supplementary Material for this manuscript includes the following:
Data S1 to S3

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Utility Characteristics									RESIDENTIAL		
									Revenues	Sales	Customers
Data Year	Utility Number	Utility Name	Part	Service Type	Data Type O = Observed I = Imputed	State	Ownership	BA Code	Thousand Dollars	Megawatthours	Count
2022	5109	DTE Electric Company	A	Bundled	O	MI	Investor Owned	MISO	2,910,745.9	15,844,478	2,047,944
2022	5109	DTE Electric Company	C	Delivery	O	MI	Investor Owned	MISO	24.1	305	16

COMMERCIAL			INDUSTRIAL			TRANSPORTATION			TOTAL		
Revenues	Sales	Customers	Revenues	Sales	Customers	Revenues	Sales	Customers	Revenues	Sales	Customers
Thousand Dollars	Megawatthours	Count	Thousand Dollars	Megawatthours	Count	Thousand Dollars	Megawatthours	Count	Thousand Dollars	Megawatthours	Count
2,019,207.0	16,500,656	208,758	658,926.5	8,548,188	711	533.7	4,320	2	5,589,413.1	40,897,642	2,257,415
71,743.6	2,811,992	4,347	13,888.6	1,673,198	124	.	.	.	85,656.3	4,485,495	4,487

Utility Characteristics								RESIDENTIAL			
								Revenues	Sales	Customers	Revenues
Data Year	Utility Number	Utility Name	Part	Service Type	Data Type O = Observed I = Imputed	State	Ownership	BA Code	Thousand Dollars	Megawatthours	Count	Thousand Dollars
2022	15497	Puerto Rico Electric Pwr Authority	A	Bundled	O	PR	State	NA	1,823,195.0	6,419,574	1,370,811	2,332,860.0
2022	19879	Virgin Islands Water & Power Authority	A	Bundled	O	VI	State	NA	87,199.4	258,812	45,850	43,788.2
2022	40428	Guam Power Authority	A	Bundled	O	GU	State	NA	167,563.9	555,558	45,271	305,996.8
2022	40429	American Samoa Power Authority	A	Bundled	O	AS	State	NA	25,372.6	56,424	10,893	31,667.8
2022	57105	Commonwealth Utility Corporation	A	Bundled	O	MP	State	NA	25,079.1	94,566	12,770	37,702.1
2022	57313	Tesla Inc.	A	Bundled	O	PR	Behind the Meter	NA	0.0	0	0	201.0
2022	59579	Sunnova	A	Bundled	O	GU	Behind the Meter	NA	5,059.2	18,734	1,413	0.0
2022	59579	Sunnova	A	Bundled	O	PR	Behind the Meter	NA	68,257.0	276,245	33,822	0.0
2022	59647	Sunrun Inc.	A	Bundled	O	PR	Behind the Meter	NA	10,419.2	27,380	3,770	0.0
2022	60981	TerraForm US Energy Services, LLC	A	Bundled	O	PR	Behind the Meter	NA	0.0	0	0	118.0
2022	61098	Longroad Energy	A	Bundled	O	PR	Behind the Meter	NA	.	.	.	17.1
2022	99999	Adjustment 2022	A	Bundled	I	GU		NA	0.0	0	-1,413	0.0
2022	99999	Adjustment 2022	A	Bundled	I	PR		NA	0.0	0	-37,592	1,768.0

To calculate a state or the US total, sum Parts (A,B,C & D) for Revenue, but only Parts (A,B & D) for Sales and Customers.
To avoid double counting of customers, the aggregated customer counts for the states and US do not include the customer count for respondents with ownership code 'Behind the Meter'.
This group consists of Third Party Owners of rooftop solar systems.

COMMERCIAL		INDUSTRIAL			TRANSPORTATION			TOTAL		
Sales	Customers	Revenues	Sales	Customers	Revenues	Sales	Customers	Revenues	Sales	Customers
Megawatthours	Count	Thousand Dollars	Megawatthours	Count	Thousand Dollars	Megawatthours	Count	Thousand Dollars	Megawatthours	Count
7,495,422	127,739	505,081.0	1,768,396	589	0.0	0	0	4,661,136.0	15,683,392	1,499,139
101,485	7,524	95,359.1	261,772	2,292	.	.	.	226,346.7	622,069	55,666
984,602	7,602	.	.	.	.	.	.	473,560.7	1,540,160	52,873
70,418	1,575	10,834.7	24,745	4	.	.	.	67,875.1	151,587	12,472
163,706	4,195	0.0	0	0	0.0	0	0	62,781.2	258,272	16,965
4,834	12	0.0	0	0	0.0	0	0	201.0	4,834	12
0	0	0.0	0	0	0.0	0	0	5,059.2	18,734	1,413
0	0	0.0	0	0	0.0	0	0	68,257.0	276,245	33,822
0	0	0.0	0	0	0.0	0	0	10,419.2	27,380	3,770
731	5	0.0	0	0	0.0	0	0	118.0	731	5
101	2	.	.	.	.	.	.	17.1	101	2
0	0	0.0	0	0	0.0	0	0	0.0	0	-1,413
10,390	-17	0.0	0	0	0.0	0	0	1,768.0	10,390	-37,609

Utility Characteristics						Decoupled				Revenue Adjustment Method			
Data Year	Utility Number	Utility Name	Ownership	State	BA-Code	Residential	Commercial	Industrial	Transportation	Residential	Commercial	Industrial	Transportation
2022	604	City of Andalusia	Municipal	AL	SOCO	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	963	Atlantic City Electric Co	Investor Owned	NJ	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	1167	Baltimore Gas & Electric Co	Investor Owned	MD	PJM	Yes	Yes	No	No	Automatic	Automatic		
2022	1179	Versant Power	Investor Owned	ME	ISNE	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	1179	Versant Power	Investor Owned	ME	NBSO	Yes	Yes	Yes	No	Automatic	Automatic	Automatic	
2022	1764	Black Diamond Power Co	Investor Owned	WV	PJM	Yes	Yes			Automatic	Automatic		
2022	2651	Butler Rural Electric Coop Inc - (OH)	Cooperative	OH	PJM	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	2812	City of Calhoun - (GA)	Municipal	GA	SOCO	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	3240	Central Electric Coop Inc - (OR)	Cooperative	OR	BPAT	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	Proceeding
2022	3249	Central Hudson Gas & Elec Corp	Investor Owned	NY	NYIS	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	3542	Duke Energy Ohio Inc	Investor Owned	OH	PJM	Yes	No	No	No	Proceeding			
2022	3989	City of Colorado Springs - (CO)	Municipal	CO	WACM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	4003	City of Colton - (CA)	Municipal	CA	CISO	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	4110	Commonwealth Edison Co	Investor Owned	IL	PJM	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	4176	Connecticut Light & Power Co	Investor Owned	CT	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	4226	Consolidated Edison Co-NY Inc	Investor Owned	NY	NYIS	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	4296	Cookson Hills Elec Coop, Inc	Cooperative	OK	AECI	Yes	Yes	Yes	No	Automatic	Automatic	Automatic	
2022	5027	Delmarva Power	Investor Owned	MD	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	5325	City of Douglas	Municipal	GA	SOCO	Yes	Yes			Automatic	Automatic		
2022	5336	City of Dover - (OH)	Municipal	OH	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	6374	Fitchburg Gas & Elec Light Co	Investor Owned	MA	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	7294	City of Glendale - (CA)	Municipal	CA	LDWP	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	7563	Grand Valley Power	Cooperative	CO	PSCO	Yes	Yes	Yes	No	Automatic	Automatic	Automatic	
2022	8287	Hawaii Electric Light Co Inc	Investor Owned	HI	NA	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	9191	Idaho Power Co	Investor Owned	ID	IPCO	Yes	Yes	No	No	Proceeding	Proceeding		
2022	9246	Indian Electric Coop, Inc	Cooperative	OK	SWPP	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	10451	Kotzebue Electric Assn Inc	Cooperative	AK	NA	Yes	Yes			Automatic	Automatic		
2022	10668	Licking Rural Electric Inc	Cooperative	OH	PJM	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	10879	Lehi City Corporation	Municipal	UT	PACE	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	11171	Long Island Power Authority	State	NY	NYIS	Yes	Yes	No	Yes	Automatic	Automatic		Automatic
2022	11200	Lorain-Medina R E C, Inc	Cooperative	OH	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	11586	Town of Mansfield - (MA)	Municipal	MA	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	11804	Massachusetts Electric Co	Investor Owned	MA	ISNE	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	11843	Maui Electric Co Ltd	Investor Owned	HI	NA	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	12268	Medina Electric Coop, Inc	Cooperative	TX	ERCO	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	12351	City of Mesa - (AZ)	Municipal	AZ	WALC	Yes	Yes			Automatic	Automatic		
2022	12515	Midwest Electric, Inc	Cooperative	OH	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	12539	Midwest Electric Member Corp	Cooperative	NE	WACM	No	No	Yes	No			Automatic	
2022	13206	Nantucket Electric Co	Investor Owned	MA	ISNE	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	13214	The Narragansett Electric Co	Investor Owned	RI	ISNE	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	13314	Navajo Tribal Utility Authority	State	AZ	PACE	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	13314	Navajo Tribal Utility Authority	State	UT	PACE	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	13314	Navajo Tribal Utility Authority	State	NM	PACE	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	13511	New York State Elec & Gas Corp	Investor Owned	NY	NYIS	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	13573	Niagara Mohawk Power Corp.	Investor Owned	NY	NYIS	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	Proceeding
2022	13640	Northern Virginia Elec Coop	Cooperative	VA	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	13679	Town of North Attleborough - (MA)	Municipal	MA	ISNE	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	13693	North Central Elec Coop, Inc	Cooperative	OH	PJM	Yes	Yes	Yes	No	Automatic	Automatic	Automatic	
2022	13762	Northern Neck Elec Coop, Inc	Cooperative	VA	PJM	Yes	Yes			Proceeding	Proceeding		
2022	13781	Northern States Power Co - Minnesota	Investor Owned	MN	MISO	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	14328	Pacific Gas & Electric Co.	Investor Owned	CA	CISO	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	14354	PacifiCorp	Investor Owned	WA	PACW	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	14401	City of Palo Alto - (CA)	Municipal	CA	CISO	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	14534	City of Pasadena - (CA)	Municipal	CA	CISO	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	14537	Pascoag Utility District	Municipal	RI	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	14626	Pedernales Electric Coop, Inc	Cooperative	TX	ERCO	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	14839	City of Peru - (IN)	Municipal	IN	MISO	Yes	Yes	Yes		Proceeding	Proceeding	Proceeding	
2022	15248	Portland General Electric Co	Investor Owned	OR	PGE	Yes	Yes	No	No	Automatic	Automatic		

Utility Characteristics						Decoupled				Revenue Adjustment Method			
Data Year	Utility Number	Utility Name	Ownership	State	BA-Code	Residential	Commercial	Industrial	Transportation	Residential	Commercial	Industrial	Transportation
2022	15270	Potomac Electric Power Co	Investor Owned	MD	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	15270	Potomac Electric Power Co	Investor Owned	DC	PJM	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	15410	Prince George Electric Coop	Cooperative	VA	PJM	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	15466	Public Service Co of Colorado	Investor Owned	CO	PSCO	Yes	Yes	Yes	No	Proceeding	Proceeding	Proceeding	
2022	15477	Public Service Elec & Gas Co	Investor Owned	NJ	PJM	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	15500	Puget Sound Energy Inc	Investor Owned	WA	PSEI	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	16183	Rochester Gas & Electric Corp	Investor Owned	NY	NYIS	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	16572	Salt River Project	Political Subdivision	AZ	SRP	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	16609	San Diego Gas & Electric Co	Investor Owned	CA	CISO	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	17609	Southern California Edison Co	Investor Owned	CA	CISO	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	17612	Bear Valley Electric Service	Investor Owned	CA	CISO	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	17637	Southern Maryland Elec Coop Inc	Cooperative	MD	PJM	Yes	Yes	No	No	Automatic	Automatic		
2022	19497	United Illuminating Co	Investor Owned	CT	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	19501	Union Rural Electric Coop, Inc	Cooperative	OH	PJM	No	No	Yes	No			Automatic	
2022	19547	Hawaiian Electric Co Inc	Investor Owned	HI	HECO	Yes	Yes	Yes	No	Automatic	Automatic	Automatic	
2022	19603	USBIA-Mission Valley Power	Federal	MT	NWMT	Yes	Yes	Yes	No	Automatic	Automatic	Automatic	
2022	19896	City of Volga - (SD)	Municipal	SD	SWPP	Yes	Yes	Yes		Automatic	Automatic	Automatic	
2022	20169	Avista Corp	Investor Owned	WA	AVA	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	20169	Avista Corp	Investor Owned	MT	AVA	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	20169	Avista Corp	Investor Owned	ID	AVA	Yes	Yes	Yes	Yes	Automatic	Automatic	Automatic	Automatic
2022	24590	Unitil Energy Systems	Investor Owned	NH	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	26510	Liberty Utilities (Granite State Electri	Investor Owned	NH	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	38084	Great Lakes Energy Coop	Cooperative	MI	MISO	No	Yes	Yes			Automatic	Automatic	
2022	54913	NSTAR Electric Company	Investor Owned	MA	ISNE	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	56697	Ameren Illinois Company	Investor Owned	IL	MISO	Yes	Yes	Yes	Yes	Proceeding	Proceeding	Proceeding	Proceeding
2022	57483	Liberty Utilities	Investor Owned	CA	CISO	Yes	Yes	No	No	Proceeding	Proceeding		





North Carolina

Climate Risk Assessment and Resilience Plan

Impacts, Vulnerability, Risks, and Preliminary Actions

A Comprehensive Strategy for Reducing North Carolina's Vulnerability to Climate Change

June 2020





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North Carolina

Climate Risk Assessment and Resilience Plan

Impacts, Vulnerability, Risks, and Preliminary Actions

A Comprehensive Strategy for Reducing North Carolina's Vulnerability to Climate Change

June 2020


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Message from Governor Cooper



From the mountains to the coast, North Carolina is a place of hardworking, resilient people and great natural beauty. In recent years we've faced unprecedented challenges, from hurricanes and flooding to a global pandemic and economic downturn. Climate change is also testing our mettle and affecting everyday life.

We're still recovering from the damage and loss of life inflicted by two 500-year storms—Hurricane Florence and Hurricane Matthew— that hit our state within 23 months of each other. The last ten years are the warmest on record for North Carolina, and 2019 was the single hottest year. Severe storms, flooding, high temperatures, drought, and other climate stressors impact our health, safety, economy and quality of life. They contribute to crop and livestock loss, destroy endangered species and critical habitats, damage government buildings and land, disrupt business operations and economic activity and threaten our state's transportation infrastructure, cultural resources, and energy and water utilities.

As we continue to discover the many ways climate change threatens daily life for North Carolinians, we must take actions that reduce air pollution and increase resilience. Those actions can also create good paying jobs. That is why North Carolina is investing in rural and urban communities, advancing clean energy, transitioning to zero-emission vehicles, and strengthening natural infrastructure. It's also why we are supporting local governments, updating state assets, and investing in a resilient business environment. A resilient North Carolina is a strong and competitive North Carolina.

The latest climate science underscores what we already know firsthand. There will be increased temperatures, continued sea level rise, more precipitation, more intense hurricanes, more severe thunderstorms, and more storm surge flooding.

The good news is that we know the key cause of climate change—greenhouse gas emissions from human activities—and we can help control our own fate while boosting the economy. We can reduce greenhouse gas emissions and reduce our vulnerability to negative climate change impacts. In response to the Climate Crisis, I issued Executive Order No. 80 to call for a 40% drop in statewide greenhouse gas emissions by 2025, establish the North Carolina Climate Change Interagency Council, and direct state agencies to take actions that reduce emissions and strengthen our state. One of those actions is the development of this North Carolina Climate Change Risk Assessment and Resilience Plan.

This plan helps us better understand our vulnerability to climate change and how we can become more resilient to future impacts. It builds upon North Carolina's ongoing work in this area and establishes the North Carolina Resilience Strategy, which includes four elements: (1) the *North Carolina Climate Science Report*, (2) State Agency Resilience Strategies, (3) Statewide Vulnerability Assessment and Resilience Strategies, and (4) the North Carolina Enhanced Hazard Mitigation Plan.

This *Risk Assessment and Resilience Plan* is the culmination of more than a year's worth of work by state agencies and stakeholders, and I thank all who contributed to its thoughtful development. This strategic document reflects the commitment we share in creating a North Carolina where folks are healthier, better educated, and have more money in their pockets so they have opportunities to live more abundant and purposeful lives.

Governor Roy Cooper



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Executive Summary

From the world-famous Outer Banks and the majestic Blue Ridge Mountains to the 18 million acres of forest and abundant agricultural resources, North Carolina is famous for its natural beauty and diversity. We are also known for our strong communities and our resilient people. These attributes make North Carolina one of the most visited tourism destinations and one of the top five states for people looking for a new place to call home.

While we enjoy all that North Carolina has to offer, our communities, economy, environment, and natural resources are increasingly at risk from the impacts of climate change. Our state has suffered from multiple natural disasters in recent years. Storms are becoming stronger and more intense, creating an enormous toll on human life, health and our economy. Hurricane Dorian in 2019 was the third significant hurricane to impact the state following Hurricanes Matthew (2016) and Florence (2018). These storms have cost lives, along with billions of dollars in damage and inflicted psychological stress on those whose lives and livelihood have been disrupted many times over.

> ***A resilient North Carolina is a state where our communities, economies, and ecosystems are better able to rebound, positively adapt to, and thrive amid changing conditions and challenges, including disasters and climate change; to maintain quality of life, healthy growth, and durable systems; and to conserve resources for present and future generations***

To make North Carolina more resilient to both climate and non-climate related stressors, Governor Roy Cooper signed Executive Order 80 (EO80) on October 29, 2018, calling for integration of climate adaptation and resilience planning into cabinet agency policies, programs, and operations. The order directed the Department of Environmental Quality (DEQ), with support of other agencies and stakeholders, to prepare the North Carolina Climate Risk Assessment and Resilience Plan (2020 Resilience Plan) and for the Climate Change Interagency Council to submit to the Governor in March 2020. EO80 called for agencies to develop resilience strategies that support communities and sectors of the economy most vulnerable to the effects of climate change and to enhance the state government's ability to protect human life and health, property, natural and built infrastructure, cultural resources, and other public and private assets of value to North Carolinians.

In response to the order, DEQ enlisted assistance from the North Carolina Institute for Climate Studies at North Carolina State University to provide the current state of climate science and change. Representatives from many major higher education institutions in the state and other subject matter experts with national recognition contributed to the development of the North Carolina Climate Science Report (NCCSR). One key finding of the NCCSR is that, "*our scientific understanding of the climate system strongly supports the conclusion that large changes in North Carolina's climate, much larger than at any time in the state's history, are very likely (90–100% probability of outcome) by the end of this century...".* State agencies developing the 2020 Resilience Plan referenced the key findings and executive summary from the NCCSR (contained in Chapter 3) to understand the historical and projected climate trends and how they will impact state assets, programs, and services.

DEQ also enlisted the assistance of federal partners, state universities, local governments, community planners, non-governmental organizations, climate justice leaders, stakeholders interested in nature-based solutions (NBS), and other interested partners to help cabinet agencies develop the 2020 Resilience Plan.



The National Oceanic and Atmospheric Administration's (NOAA) Climate Program Office and UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) supported the agencies in applying the U.S. Climate Resilience Toolkit. Following 11 months of collaborative work, this document lays out the groundwork for focusing the state's attention on climate resilience actions both within government and together with business, academic, nonprofit, and community partners. It recognizes that climate change adaptation and the concept of resilience to improve our ability to adapt and recover from future disasters are extremely complex processes.

As detailed in the sector-based analysis, there is no single means of response. Adaptation and resilience planning needs to be highly integrated processes that occur on a continuum, across all levels of government, and involving many internal and external partners and individual actions. It also calls for collaborative work with policy makers to make informed decisions and secure financial resources to implement long-range strategies that protect people and property.

This 2020 Resilience Plan establishes the North Carolina Resilience Strategy, which is a compilation of documents organized into four elements: (1) The North Carolina Science Report, (2) State Agency Resilience Strategies, (3) Statewide Vulnerability Assessment and Resilience Strategies, and (4) the state of North Carolina Enhanced Hazard Mitigation (EHMP). This plan provides updates to elements one through three, as explained further in Chapter 7.

This plan provides the following important output: (1) our best understanding of the projected change in the climate; (2) climate justice considerations; (3) state infrastructure, assets, programs and services within 11 critical sectors that are vulnerable and at risk to climate and non-climate stressors; (4) preliminary actions currently underway or which could be taken to reduce the risk for at least three example vulnerability areas; and (5) recommendations for nature-based solutions to enhance ecosystem resiliency and sequester carbon in the state's natural and working lands (NWL). The process has led to many lessons learned, particularly the importance of increased collaboration between state agencies and statewide partners to facilitate goal setting and building internal capacity to develop long-range strategic actions.

The 2020 Resilience Plan concludes by describing next steps for implementing and updating the North Carolina Resilience Plan as well as strategic cross-cutting resilience initiatives. The Resilience Team in the North Carolina Office of Recovery and Resiliency (NCORR) will lead and coordinate state resilience planning and implementation, with support from state agencies, local governments, businesses, and community stakeholders. Elements to be addressed in future updates include: (1) incorporating new decision relevant science information, (2) state agencies expanding and implementing strategies for the 11 sectors studied, (3) developing an action plan for cross-cutting challenges, and (4) incorporating the action plan into the EHMP, which is submitted every five (5) years to the Federal Emergency Management Agency (FEMA). Supporting this ambitious path will require adequate staff, funding, expertise, time and support. Each agency will then be able to develop resilience priorities and actions that are implemented equitably and inclusively across North Carolina.

This plan is intended as a framework to guide state action, engage policy-makers and stakeholders, and facilitate collaboration among many partners to protect the state against high-impact, low frequency weather events. It serves to address underlying stressors such as the changing climate, aging infrastructure, socio-economic disparities, and competing development priorities. Strategies to advance adaptation, resiliency, and mitigation are necessary key steps.



The 2020 Resilience Plan moves North Carolina to become more resilient to the impacts of climate change, even as we work to limit the magnitude of that change by reducing greenhouse gas emissions and transitioning to clean energy. By setting clear goals, taking action, and evaluating progress on a regular basis, North Carolina can make certain that our resilient state thrives amid changing conditions and challenges.

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Chapter 1

Key Findings and Recommendations

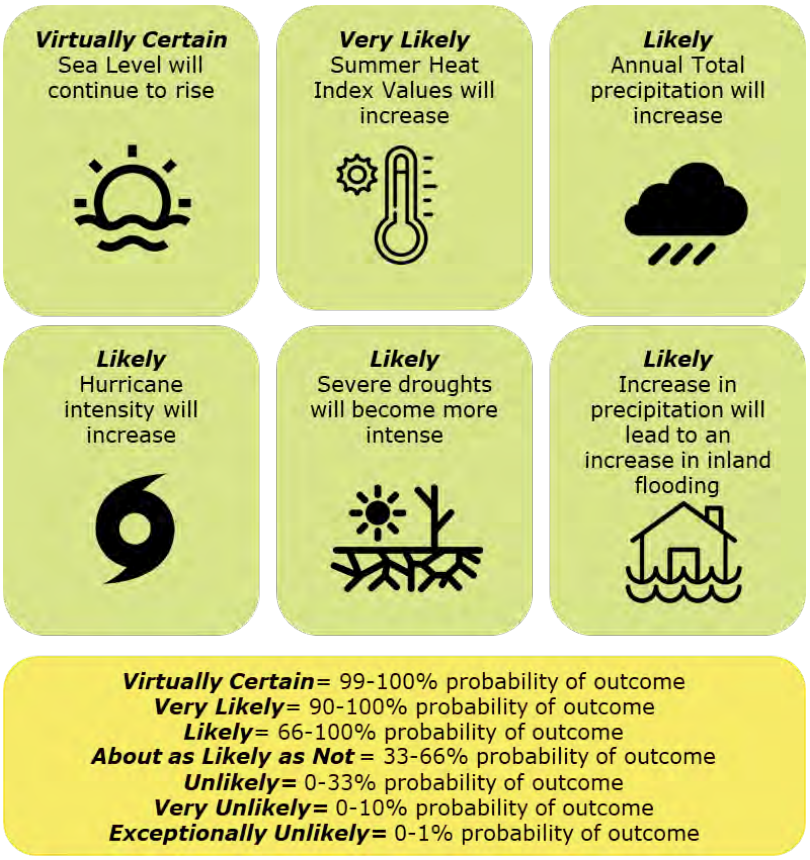
1. Key Findings and Recommendations

The 2020 Resilience Plan is organized as shown in Figure 1-1 below. The discussion in this chapter highlights key findings, messages, recommendations, and next steps to taking further action.

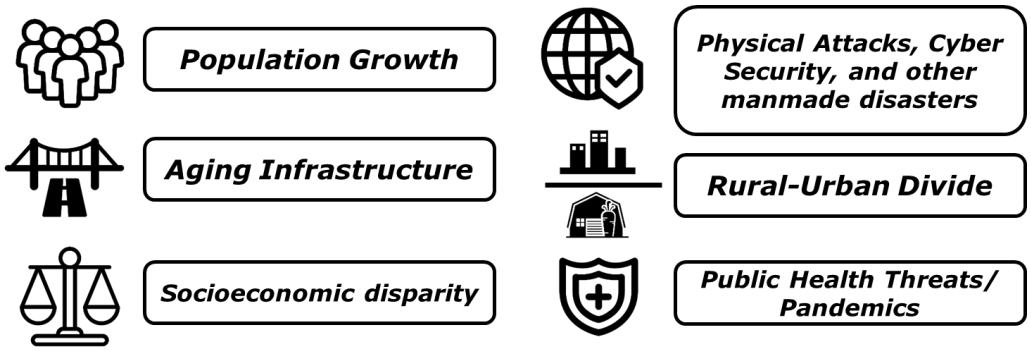


Figure 1-1: Document layout

A. Climate Change Projections in North Carolina[1]



B. Non-Climate Stressors facing North Carolina



[1] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K.D. Dello, J. P. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: *North Carolina Climate Science Report*. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr



C. Climate Hazards Facing North Carolina[2]

Average and Extreme Temperatures

- Although regional changes in temperature can vary from global changes, it is ***very likely*** that North Carolina temperatures will also increase substantially in all seasons. Annual average temperature increases relative to the recent climate (1996–2015) for North Carolina are projected to be on the order of 2°–5°F under the current emissions scenario and 2°–4°F under a lower emissions scenario by the middle of this century.
- It is ***likely*** that the number of hot and very hot days will increase and the number of cold days (daytime maximum temperatures of 32°F or lower) will decrease.
- Warmer nights will ***very likely*** increase, reducing relief from the heat of the day and increasing heat-related stress on public health; households and people who lack access to sufficient cooling will be most vulnerable.
- Health-related problems due to heat stress such as respiratory issues will increase, young people, people of low socioeconomic status, and the elderly are especially vulnerable.
- Extreme heat events will become more frequent, longer lasting, and more intense, exacerbating demands for water.
- Plants and animals that rely on cooler temperatures may not be able to thrive in warmer temperatures and may migrate to cooler areas, and/or be out-competed for by other more heat-tolerant species.
- Warmer nights will put more stress on agricultural crops that depend on nighttime cooling.

Drought

- More intense droughts in the future due to climate change are ***likely***. This will put further stress on agriculture, forestry and municipal and agricultural water resources, causing widespread economic damage.
- Water shortages due to drought increase the risk of catastrophic wildfires, and temporarily reduce the availability of suitable habitat for wetland and aquatic animal populations.
- It is ***likely*** that future severe droughts in North Carolina will be more intense due to higher temperatures leading to more heat stress for public health, especially people who work outdoors.
- It is ***likely*** that future severe droughts in their multiple forms in North Carolina will be more **frequent** and intense due to higher temperatures leading to increased evaporation. As a result, it is ***likely*** that the frequency of climate conditions conducive to wildfires in North Carolina will increase.

Heavy Precipitation and Storms:

- Heavy precipitation accompanying hurricanes and other weather systems is ***likely*** to increase, thus increasing the potential for flooding in inland and coastal areas.
- Energy infrastructure located along inland watersheds and coastal areas will be further subject to changes in river discharge and flooding from heavy precipitation events.
- Heavy precipitation from more intense and frequent storms can cause significant damage to public and private structures such as homes, roads, utility services, etc.

[2] For a complete assessment of historical and projected climate trends in North Carolina under increased greenhouse gas concentrations, see summary of the North Carolina Climate Science Report in Chapter 3: NC Climate Science, or the full North Carolina Science Report in Appendix A.



- Vulnerable populations are most at risk of flooding and may have difficulty evacuating when necessary.

Wildfires

- Higher average temperatures and more severe droughts will lead to an increased likelihood of conditions conducive to wildfires.
- Increases in wildfires will pose a major risk for human health and emergency services, putting more lives at risk of fire related injuries, fatalities, and losses.
- Conditions more conducive to wildfires leave residents, businesses, infrastructure, forestry, and agricultural assets more at risk of related economic damages.
- Increases in population will amplify the public safety risks associated an increase in the wildfire urban interface, which increases the potential for more economic and public damage.
- More intense wildfires due to climate change will negatively impact air quality because of more fine particles in the air, exacerbating health issues such as asthma.

Coastal Flooding and Coastal Erosion

- It is ***virtually certain*** that sea level along the North Carolina coast will continue to rise due to expansion of ocean water from warming and melting of ice on land.
- It is ***virtually certain*** that rising sea level and increasing intensity of coastal storms will lead to an increase in storm surge flooding in coastal North Carolina.
- High tide flooding will a near daily occurrence at some points along the coast in the future.
- Cultural resources in fixed locations are inherently sensitive to flooding and it is difficult to reduce sites' exposures to flooding.
- Sea level rise and flooding will limit available land that is in high demand for both human (economic) and ecosystem services.
- More frequent coastal flooding will impact coastal habitats, fisheries, and the protective services that natural areas provide to local communities.
- Increased storm surges will erode shorelines and kill vegetation in maritime grasslands, tidal marshes, estuaries, lower reaches of coastal plain rivers, and low-lying wetlands near estuaries.
- Coastal erosion will reduce habitat for freshwater tidal wetlands, maritime uplands, and maritime wetlands.
- Endangered and threatened species that are vulnerable to storm surge and erosion on beaches are likely to decline.
- Coastal erosion will leave properties further at risk of flooding and storm damage, due to land or natural buffers being lost.

Hurricanes

- Intensity of the strongest hurricanes is ***likely*** to increase with warming of the oceans and atmosphere, leading to greater damage to people, communities, our economy and natural resources from more intense hurricanes and accompanying flooding and precipitation.
- More intense hurricanes will further damage wetlands and natural barriers which help to protect infrastructure and communities from storm surge, increasing the vulnerability to subsequent storms.
- Stronger hurricanes will destroy or damage public and private buildings and property.



- Vulnerable communities will be most at risk of flooding occurrences due to hurricanes; with hurricanes happening in short succession, vulnerable communities will struggle to recover between hurricanes.

Inland Flooding

- Increases in extreme precipitation is ***likely*** to increase inland flooding in North Carolina.
- Inland communities across the state are at risk from flooding due to extreme precipitation and outdated and/or undersized storm drainage infrastructure.
- Increased inland flooding caused by extreme precipitation events will further increase economic and agricultural losses after a flooding event.
- More frequent flooding will impact inland habitats, fisheries, and the protective services that natural areas provide to local communities.
- Flooding will continue to damage archaeological and historic sites on floodplains across all three physiographic regions and within every river basin in the state.
- Increased or more frequent flooding may inundate and potentially destroy more cultural resources.

Ecosystems and Habitat Loss

- Harmful algal blooms may increase due to warmer temperatures.
- Loss of organisms that rely on calcium-based shells such as oysters and clams, and organisms dependent upon them for food or habitat will be harmed by ocean acidification.
- Loss of wetlands due to sea level rise will result in habitat losses that will impact both commercial and recreational fisheries, decrease buffering capacity, adversely impacting water quality, and reducing the resilience of coastal communities.

Saltwater Intrusion

- Higher water levels due to sea level rise threaten otherwise productive land, leading to agricultural and economic losses.
- Increased saltwater intrusion due to sea level rise is expected to change the salinity of estuarine communities and to convert lower coastal floodplains from swamp forest to wetlands.
- Saltwater intrusion due to climate change will make drinking water from both groundwater and surface waters more vulnerable to contamination and/or expensive to treat and secure.
- Intrusion in freshwater sources can cause crop yields to decline and farmland to be unsuitable for growing crops due to high salinity and less available freshwater, leading to a loss of revenue in agriculture.

Public Health

- Cumulative hazards from heat and flooding are harming human health through poor air quality, flooding injuries, heat-related illness, decreased mental health, and increased infectious diseases.
- Existing inequities in environmental health exposures are exacerbated by climate change; older adults, children, low-income earners, communities of color, and veterans are disproportionately harmed.
- Changing climate can increase the areas where disease-carrying vectors such as mosquitos are present.
- Extreme weather events will put more stress on emergency management, public services, and institutions, and will require more resources to address the impacts. It will also further increase the frequency, magnitude, duration, or scale of the responses to hazards in North Carolina.



Population Growth and Other Hazards

- North Carolina's population is expected to increase, leading to more urban heat island effects and creating more heat and water related stress on people.
- Development due to population growth will lead to loss of habitat, species and natural buffers that protect communities from extreme precipitation.
- More severe climate disasters will further interrupt business activities for North Carolina's economy.
- An increase in impermeable surfaces causes more water to get funneled downstream, leading to more flooding of farmland, forested lands, and rural communities.

D. Key Observations and Recommendations: State Agency Assessment[3]

1. Agriculture and Forestry

Key Observations

- Agriculture, forestry, and endangered native plants are tied to climate due to biological, physiological, and ecological constraints. Elevated night-time temperatures will have outsized negative impacts due to disruptions in plant physiology.
- The agriculture and forestry industries must attract and retain experienced personnel as well as maintain equipment to meet a growing set of hazards.

Critical Impacts and Resilience Strategies

- Inland flooding is the greatest climate-related hazard to North Carolina Department of Agriculture and Consumer Services (NCDA&CS) assets (research stations, state forests, and nurseries) and to private farms and forests. Must focus on adaptive capacity (e.g., levees) to protect crop and pasture lands statewide.
- Research and development are needed on adaptive varieties and species for crops, livestock, and poultry to more resistant to extreme heat.
- Education of stakeholders can provide adaptive capacity for drought and wildfire. This is personnel-intensive and personnel are currently directed toward response.
- Protecting North Carolina's endemic and nearly endemic species, species that exist only in our state or a handful of places is a unique responsibility of the state.
- Regenerative practices that sequester carbon.

[3] With guidance and facilitation from National Oceanic and Atmospheric Administration's (NOAA) Climate Program Office, UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) and North Carolina Institute for Climate Studies (NCICS), State agencies used the U.S. Climate Resilience Toolkit to qualitatively assess the exposure, vulnerability, and risk of agency assets, programs and services to climate-related hazards. Out of 744 impact pairs identified, agencies undertook an abbreviated assessment for a subset of potential impacts and conducted risk assessments for 48 impact pairs. The key observations and recommendations presented here explore state agency vulnerability and provides resilience strategies to take action for this subset.



2. Coastal Resources and Infrastructure

Key Observations

- Flooding from storms and extreme tides, magnified by sea level rise, is severely affecting land use, public infrastructure, and natural resources along the coast of North Carolina
- The intensity of recent storms and flooding have challenged the state's response and recovery plans. We should plan for greater extremes in the future.
- Climate hazards intensify existing social inequalities and lack of ability to adapt in economically challenged counties in the coastal region.

Critical Impacts and Resilience Strategies

- Climate change is impacting coastal habitats, fisheries, and the ecosystem services provided in coastal communities. State monitoring, research, and education can enhance understanding of impacts and potential adaptation strategies.
- Immediate focus must be on developing strategic priorities for public and natural infrastructure improvements as well as actions that integrate climate resiliency into agency operations, local disaster recovery programs, and long-term planning.
- Future climate conditions and resiliency should be integrated into current public investment decisions in local and regional water and transportation infrastructure improvements and other critical assets.
- State leadership should model adaptive behavior and incentivize local resiliency efforts that balance protection of life, property, and the environment. Inter-agency coordination can help build local capacity and action through funding and technical assistance.

3. Commerce and Business

Key Observations

- The greatest impact of recent climate hazards was business interruption. Getting people back to work and transitioning to a more resilient economy are critical.

Critical Impacts and Resilience Strategies

- Supporting rural economies with education, training and additional resources.
- Public/private partnerships help leverage risk. Government can help build resilience into infrastructure, which helps lower risks for small businesses.
- Include resilience training in North Carolina Main Street and Rural Planning programs for small towns and Main Street communities along with the businesses they support.
- The business sector needs to drive continual improvement of resource optimization.

4. Cultural Resources

Key Observations

- Cultural resources such as state and local historic sites and museums are irreplaceable, making them inherently sensitive to sea level rise and the increasing frequency and severity of heavy precipitation and flooding.
- The North Carolina Department of Natural and Cultural Resources (DNCR) is active across all 100 counties, so resources are limited. The threat of the hazard is growing.
- DNCR has regulatory authority over destruction of any public records managed on a local level.
- Much of the technical and constituent services for cultural assets are provided in a collaborative



environment with federal, state, local, and private interests all having a stake in the solutions.

Critical Impacts and Resilience Strategies

- There is no single solution to protect cultural assets from "water where it doesn't belong".
- The focus for now, and in the near-term, should be building resilience into assets owned and managed by the state, such as state museums, historic sites and parks.
- DNCR must provide greater services such as technical assistance to locally-owned cultural resources
- Develop and enhance federal, state, local, and private partnerships to build cross-boundary resiliency capacity for cultural assets.

5. Ecosystems

Key Observations

- The North Carolina Natural Heritage Program assessed ecosystem vulnerability in 2010 and updated the assessment in 2019.
- Ecosystems in all 100 counties are affected by climate change and numerous land use changes that have occurred in recent decades.
- The ecosystems with the highest risk support a high concentration of rare species and have a low tolerance of environmental variation.
- Ecosystems are shaped by climate. Human impacts reduce ecosystems' natural resilience to disturbance and change.
- Conserving and managing land for key ecosystems yields benefits to other sectors, including water resources, tourism and commerce, and public health.
- Minimizing non-climate stressors will reduce the overall stress on ecosystems and help avoid catastrophic change and loss.
- Need multi-agency understanding of the financial value of ecosystem services.

Critical Impacts and Resilience Strategies

- To improve overall landscape resilience, create nature preserves as large as possible and maintain habitat connectivity across the landscape.
- Preserve and restore wetlands and natural areas alongside rivers and streams.
- Manage land for natural processes, such as prescribed fire and restoration of natural stream flows.
- Establish natural recreation areas such as parks, trails, and greenways that will improve resilience and public health, and become valued community assets that improve quality of life.
- Increase public awareness of the importance of land conservation, planning for resilience, and the value to people of ecosystem function and services.
- Business must adopt biomimicry practices to provide holistic regenerative economic value.

6. Health and Human Services

Key Observations

- The health of the environment impacts the health of all people.
- Cumulative hazards from heat and flooding are diminishing health.
- Existing inequities in environmental health exposures are exacerbated by climate change.

Critical Impacts and Resilience Strategies

- Ongoing medical and public health services to residents are impacted.
- Increased staffing needs during hurricanes, especially for NC Emergency Operations Center, emergency shelters, coordinating emergency services, and seeking administrative waivers for benefits.



- Need additional support for North Carolina Department of Health and Human Services (DHHS) programs: Building Resilience Against Climate Effects program, Back@Home program, mold and moisture education, and infectious disease tracking.
- Strategies for creating resilience should address existing toxic exposures, such as hazardous waste and lead in water or homes, in low-income communities and communities of color.

7. Housing, Buildings, and Support Services

Key Observations

- Critical infrastructure and cross-agency assets make this sector important but difficult to prioritize.
- Need to have detailed, quantified risk assessments at a local level.

Critical Impacts and Resilience Strategies

- Flooding is the biggest hazard.
- Aging infrastructure is vulnerable, so many solutions will be costly and take time to implement.
- State-managed recovery is an immediate and growing need which shows that building resilience is important to reduce recurring impacts.
- Meet the growing demand of housing for veterans. Promote building resilience strategies for vulnerable VA hospitals.
- Waste management and its planning are important prior to and after any damage caused by environmental impacts.

8. Public Safety

Key Observations

- A permanently funded resiliency office, requiring personnel and budget, is needed.
- Public Safety is the largest state government cabinet agency with over 25,000 employees. It manages response and recovery for climate hazards and the growing number strains resources. North Carolina is viewed as a nationwide leader for these services.
- Resilience services will require greater interagency support and resources. Operational, logistical, maintenance, and resiliency challenges are synergistic in nature. All must be simultaneously addressed.
- Correctional facilities will require substantial upgrades. North Carolina is responsible for the custodial care of more than 35,000 inmates and 200 juveniles, vulnerable groups with higher exposure and low adaptive capacity.

Critical Impacts and Resilience Strategies

- Building resilience into critical infrastructure that supports response and quality of life must be an immediate priority.
- Working with local governments to build resilience is critical but will require time to build trust, institute new policies and regulations, and properly allocate resources.
- Long-term master planning is needed to determine the most cost-effective means to address, maintain, and operate resiliency plans through their life cycles.
- New and more strategically located facilities may serve well during a natural disaster.
- Training, tabletop exercises and continuity of Operation Plans for each of our divisions need to occur on an annual basis.

9. Transportation

Key Observations



- The core of North Carolina Department of Transportation (NCDOT)'s is to connect people, products and places safely and efficiently is heavily impacted by a growing number of climate-related hazards.
- NCDOT directly owns and maintains a large and diverse number of assets statewide. Storm-related damages are threatening public safety, creating economic disruptions, and causing budgetary shortfalls that require a strategic refocusing.

Critical Impacts and Resilience Strategies

- Maintaining critical connections and access must be the immediate near-term priority, whether along the coast during major storms, in the piedmont during heavy precipitation, or in the mountains due to landslides.
- All modes of transportation must be assessed for resilience to build adaptive capacity and redundancy moving forward.
- NCDOT is committed to collaborating and partnering with communities and businesses to build the resilient infrastructure they require.
- NCDOT will develop and apply resilience policies in three main areas: (1) long range transportation planning; (2) individual project planning and design; and (3) operations and maintenance.

10. Water and Land Resources

Key Observations

- Reliable, clean supplies of freshwater and land resources are essential to human and ecological health.
- Water availability affects all sectors and is vulnerable to climate change and increased demands from a growing population.
- The Water and Land Resources sector has directly managed assets and provides a number of services that require a uniquely trained and experienced workforce.
- Water infrastructure funding programs cannot meet existing demand to help communities meet their water infrastructure needs without considering additional needs due to climate change.

Critical Impacts and Resilience Strategies

- Dam and water infrastructure impacts from flooding are a big concern.
- Landslides are increasing due to extreme rainfall events.
- Water quality impacts to our drinking water and ecosystems as a result of polluted runoff are a continuing issue. Sediment is the largest pollutant by volume of our surface waters and carries excess nutrients and many other pollutants with it.
- Stormwater requirements and design specifications including rainfall intensity statistics should be assessed for future needs and revised as needed.

11. Energy

Key Observations

- Energy drives commerce, transportation, environmental controls, emergency response, agriculture, housing, and many other parts of our economy and therefore solutions must be integrated across these sectors.
- Energy resources, regulations, technology innovation, consumer demand, carbon reduction goals, and market pressures are rapidly changing the industry. This creates an opportunity to build resilience through the modernization of the energy supply and delivery infrastructure.
- North Carolina utilities, regulators, policy makers, energy planners, and emergency response planners should develop resiliency metrics to quantify human and economic costs of power



outages and apply a risk-based framework to accelerate decision making related to energy infrastructure planning and operations.

Critical Impacts and Resilience Strategies

- Disruptions to the electric power grid from increased storm intensity can be mitigated by securing a diverse source of utility scale and distributed generation assets such as microgrids equipped with renewable energy and battery storage devices, hardening the grid/transmission infrastructure, reducing demand for power, and modernizing existing grid assets with smart meters, controllers, automation, and analytics to manage a diverse source of power supply, transmission, and distribution system components.
- Stress on thermoelectric power plant cooling due to drought can be addressed with non-traditional water and energy sources, water capture and dry cooling to protect water quantity and quality, and demand side management programs.
- Fuel supply chains disruption from increased storm intensity may benefit from alternative fuel infrastructure and hardening existing pipelines, terminals, and fuel stations to facilitate evacuation routes and protect critical infrastructure.
- The North Carolina Disaster Recovery Framework, led by NC Emergency Management, should expand to focus on how to integrate resiliency planning for both storm-related outages and cyberattacks into its disaster recovery planning. The effort should evaluate how new and existing infrastructure can best be deployed to reduce recovery efforts.



E. Climate Justice Recommendations

To address the climate justice issues described in this chapter, the following recommendations are put forth by the authors of this chapter. These recommendations should be implemented with sufficient funding, staff or contracting support, as well as interagency cooperation to ensure effective action. Table 1-1 lists recommendations for cabinet agencies, Table 1-2 lists recommendations for the entire state government, and Table 1-3 lists research related recommendations.

Table 1-1: Climate Justice Recommendations for Cabinet Agencies

Entity Responsible	Recommendation
Interagency Climate Council	Develop an equitable public participation framework for all climate change mitigation and resilience efforts. For use by state agencies as well as boards and commissions.
	Design an interagency process to survey and educate staff on unified definitions of equity, vulnerability, climate risk, resilience, and other terms needed to demonstrate state's understanding and to ensure common ground within resilience work.
	Release a North Carolina Climate Justice Report as part of future North Carolina Resilience Plans with opportunities for public involvement.
North Carolina Emergency Management	Increase emphasis on communication with non-English speakers, older adults, rural communities, etc. Explore new risk communication methodologies.
	Continue to update existing state hazard mitigation, emergency preparedness, and response plans with increased emphasis on protecting, communicating with, and serving low-income populations, communities of color, older adults and people with disabilities during and after emergencies.
	Continue to support development of local hazard mitigation plans.
	Provide recommendations and guidance to local governments on maximizing the quality and effectiveness of local or regional hazard mitigation plans, especially in rural areas.
	Provide recommendations and guidance on stakeholder engagement in development and implementation of meaningful hazard mitigation plans and the inclusion of equity, diversity, and inclusion in local plans.
North Carolina Office of Recovery and Resiliency	Increase communication and interaction with all communities, including (especially) vulnerable and historically marginalized communities.
	Develop university partnerships to address gaps in research on climate resilience, especially issues that affect populations differently, and to offer capacity in the state to smaller and more rural communities to do effective and equitable resilience work.
	Develop a strategic plan for resilience-focused capacity building within socially vulnerable communities.



Entity Responsible	Recommendation
	Assist local governments in identifying additional resources to aid in advancing resilience.
	Seek funding that would be distributed to fund community-based resilience projects.
	Create a Local Government Climate Resiliency Toolkit.
	Create and strengthen working relationships among state agency advisory boards that focus on equity and inclusion, such as the DEQ Environmental Justice and Equity Advisory Board.
NC Department of Commerce	Set aside clear, numerical percentages for the number of newly established jobs/contracts/projects that should go to vulnerable communities & for which historically marginalized business receive priority bidding.
	Partner with the DOA Office of Historically Underutilized Businesses, NC Institute of Minority Economic Development, and other entities to increase outreach efforts of bidding and contracting opportunities for marginalized communities.
	Increase outreach efforts in impacted communities.
	Leverage Disaster Recovery Funds and other sources of capital to promote equitable job creation and inclusive business development in communities most vulnerable to climate change.
NC Department of Environmental Quality	Provide updated mapping when detailed climate projections come out, including overlap with socially vulnerable communities using 2020 Census and other up-to-date data.
	Continue enhanced engagement strategies for potentially underserved communities and translation and interpretation services for non-English speakers (as laid out in the DEQ's Public Participation and LEP Language Access Plans).
	Pursue continuation and expansion of Weatherization Assistance Program (WAP).
NC Department of Health and Human Services	Support the Building Resilience Against Climate Effects (BRACE) program and expand the tracking of epidemiological health impacts of climate change in North Carolina.
	Support increasing Back@Home initiative funding (post Hurricane housing initiative) to $16 million.
All Agencies Administering Disaster Recovery Funds	Increase outreach efforts in impacted communities. Implement a coordinated, strategic approach to increase communication and interaction, with an emphasis on vulnerable and historically marginalized communities.
	Offer adequate social services support to North Carolinians navigating the multitude of government processes during recovery.



Entity Responsible	Recommendation
	Increase the ability of community groups to communicate with state agencies on disaster recovery needs and the effectiveness of disaster recovery efforts
	Publish clear percentages of newly established jobs or contracts that should go to vulnerable communities and for which historically marginalized businesses receive priority bidding. Increase outreach efforts for hiring in communities where work will be completed.
	Continue to partner with the DOA Office of Historically Underutilized Businesses, NC Institute of Minority Economic Development, and other entities to increase outreach efforts of bidding and contracting opportunities for underserved communities.
	Leverage disaster recovery funds and other sources of capital to promote equitable job creation and inclusive business development in communities most vulnerable to climate change. Other sources of capital to explore include: Opportunity Funds, Donor Advised Funds, New Markets Tax Credits, Low Income Housing Tax Credits, activities of Community Development Financial Institutions, Small Business Investment Companies, Rural Business Investment Companies, and investments required by the Community Reinvestment Act.



Table 1-2: Climate Justice Recommendations for State Government

Recommendation Type	Recommendation
State Policy Changes	Adopt the targeted universalism approach for resilience, in which policies and programs begin by addressing the needs of those who are most vulnerable to climate change, and seek to improve the resilience of the entire state.
	Develop metrics to determine progress of equity and resilience initiatives.
	Adopt incentive or funding programs that encourage best practices for equitable resilience within state government and quasi-governmental organizations and among local governments, businesses, and non-profit organizations. For example, competitive funding programs within the state might include a resilience component in their scoring rubric.
	Advocate for funding from the General Assembly for climate science specific to North Carolina and for resiliency programs, policies, and interventions that support our shared efforts to prosper into the twenty-first century and beyond.
	Work with agency Human Resource offices to set goals and strategies for diversifying staff and leadership in recovery and resilience, and for hiring disaster survivors into recovery and resilience positions.
	With agency communications offices, set goals and strategies to increase interaction with communities that have historically frayed relationships with government and government officials.
	Reduce substandard housing and increase access to adequate cooling and other climate risk reduction measures.
	Advocate for funding for new or continuing weatherization programs that target low-income homeowners.
State Role in Building Local Sources of Resilience	Build capacity and leadership within communities most vulnerable to climate change impacts by promoting, supporting, and leveraging community-specific strategies, projects, and events. This recommendation could be accomplished through the North Carolina Resilient Communities program detailed in Chapter 7. These initiatives could be led by local governments or by community or faith-based organizations.
	Identify and communicate resilience resources, including educational and funding opportunities, already available to local governments and communities.
	Fund a grant program to support community or regionally-based resilience projects. This program could be sponsored by public and private funds.



Recommendation Type	Recommendation
	Engage community and faith-based organizations that work on disaster response to incorporate other elements of resilience into their programming.
	Explore opportunities to provide financial resources for climate preparation efforts to culturally specific organizations.
	Improve local resilience by ensuring that recovery programs, plans, and investments leave the community with additional capacity to cope with the next event. For example, a recovery program might include formal capacity building activities, a recovery fund might facilitate regional gatherings for grantees to share lessons learned, and planning efforts might identify clear, realistic implementation steps for after the plan is complete.
Information Needs	Improve the accessibility of hazard and climate change data to non-experts through web portals, infographics, classroom education modules, or other communication channels.
	Provide resources for community and K-12 education on climate change and resiliency.



Table 1-3: Climate Justice Research Recommendations

Research Recommendations
Examine the distribution of climate hazard exposure and impact, adaptive capacity, and benefits and burdens of resilience interventions among different groups of socially vulnerable populations.
Identify opportunities for citizen science and community observations to add value to research used by the state. For example, analyze ways for risk assessment to include qualitative methods and local knowledge.
Evaluate the effectiveness of methods for engaging different underrepresented groups in climate resilience plans, programs, and policies.
Investigate under-recognized sources of community resilience by learning more about the support systems local communities have created to 'fill in gaps' of disaster response.
Continue to map climate risks and social vulnerabilities together. Re-visit this mapping based on 2020 Census data. Use geospatial and other analyses to understand the distinction among different regions of the state and in urban, suburban, and rural areas. Extend this research to identify "hotspot" areas where climate justice issues are likely to be most severe.
Determine the best ways to measure and capture compounding vulnerabilities, or climate impacts that are experienced in the context of inequalities across health, housing, and economy.
Analyze the business and workforce development opportunities in risk and resilience fields. The results of such a study should inform programmatic decisions in the state's workforce development systems and organizations.
Analyze insurance coverage among socially vulnerable populations, especially in light of changing insurance markets and new developments with the National Flood Insurance Programs. Recommend strategies to improve insurance coverage among low-income households, including renters, in high-risk areas. Analyze insurance coverage of public assets in all communities, especially those with smaller budgets where insurance may have fallen to the wayside.



F. Key Observations and Recommendations: Nature-Based Solutions

The Natural and Working Lands (NWL) stakeholders developed 25 nature-based solutions (NBS) to build climate change resilience in communities and ecosystems and sequester carbon while also meeting other economic, ecologic and societal goals that are detailed in Appendix B: North Carolina Natural and Working Lands Action Plan.

Key Observations

- NWL stakeholders recommend that the state of North Carolina act quickly to protect, restore, and manage sufficient land area as "green-infrastructure" to provide community and ecosystem resilience.
- State agencies can build resilience using the NBS presented in the North Carolina NWL Action Plan.
- Voluntary landowner participation in carbon offset markets could be used to finance specific NBS that sequester significant amounts of atmospheric carbon and build community and ecosystem resilience.
- Important actions the state can take in building community and ecosystem resilience and sequestering carbon include:

    1. Sustainable management and financial support of the 14 million acres of privately-owned forests through new policies and economic opportunities.
    2. Protection and restoration of critical portions of the 13 million acres of floodplains and wetlands to mitigate floods as shown in the map given below.
    3. Protection, restoration and proper management of North Carolina's pocosins and coastal estuaries to build coastal resilience, sequester significant amounts of carbon, and mitigate the risk of wildfires and floods.[4]

Mapping Opportunities for Nature-Based Solutions to Build Resilience

The map presented in Figure 1-2 shows that increasing forested land area and reforesting both marginal forests and woody wetlands builds community resilience by reducing flood risks. The areas marked by the two purple colors represent land protection and reforestation opportunities to reduce flood risks. The areas marked in pink and magenta colors represent opportunities to both reduce flood risk and improve water quality. The map shows these opportunities primarily lie in the Coastal Plains, especially along major rivers. Protecting and restoring forests also sequesters carbon by removing carbon dioxide from the atmosphere and storing it in trees and soil.

[4] Peatland pocosins are saturated wetlands of Coastal Plain flats, swales, and Carolina bays, with organic matter accumulation, and with distinctive vegetation characterized by Pond Pine (Pinus serotina) and a suite of dense evergreen shrub species, which sequester and store a high volume of carbon per acre above and below ground.

Source: Nicholas Institute for Environmental Policy Solutions at Duke University

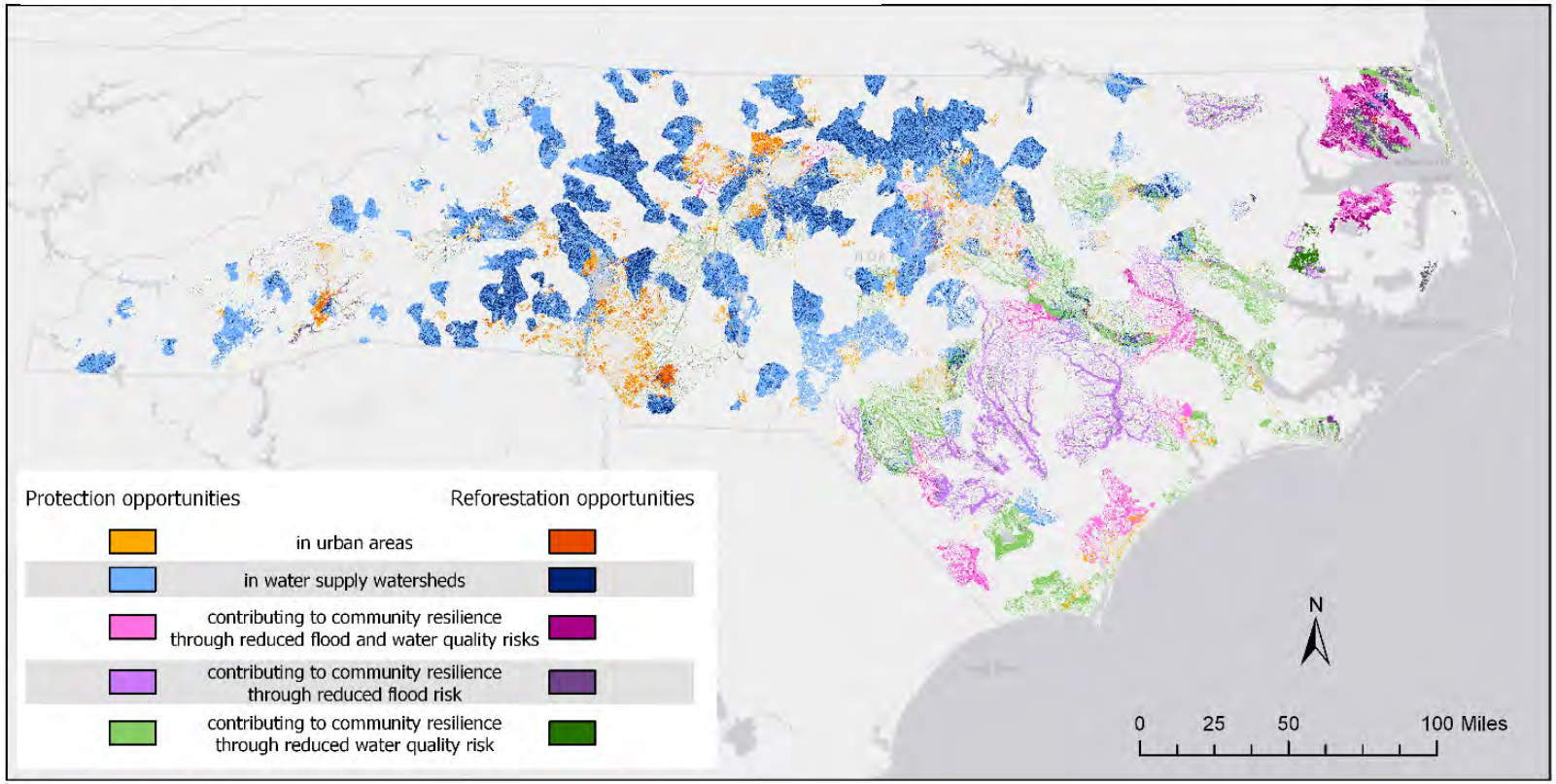


Figure 1-2: Protection and reforestation opportunities with community resilience benefit



Table 1-4 lists all the priority recommendations developed for North Carolina's Natural and Working Lands (NWL)Action Plan.

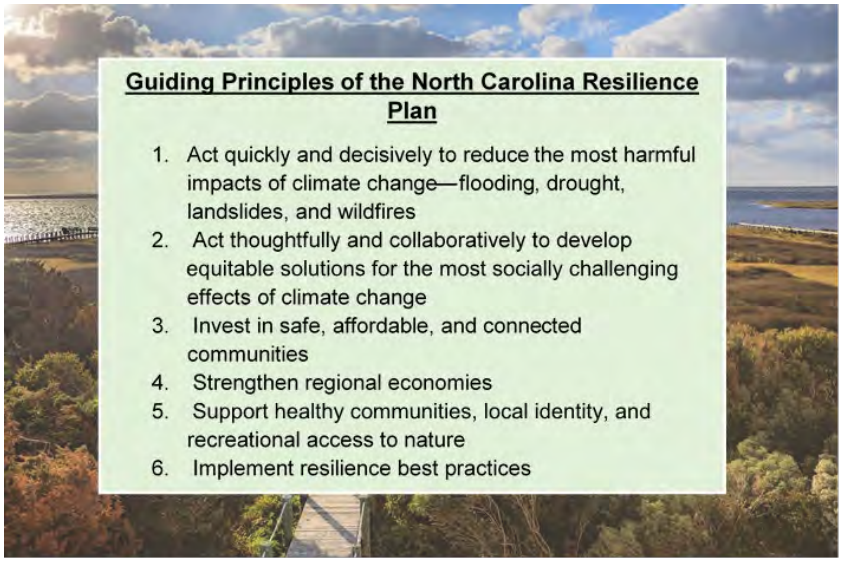
Table 1-4: Natural and Working Lands (NWL) Recommendations

Recommendation Type	Strategy
Transformative	1. Protect and restore forests and wetlands within flood prone areas.
	2. Facilitate voluntary landowner participation in carbon offset and ecosystem services markets.
	3. Build a multi-state NWL solutions toolbox.
	4. Integrate climate adaptation and resiliency strategies into local government comprehensive plans.
Protect Forest Lands	5. Conserve forest lands through easements and acquisition.
	6. Modernize forest policy and tax incentives.
Restore Forest Land	7. Expand restoration efforts on publicly owned lands.
	8. Encourage restoration and reforestation on private lands.
Enhance Forest Lands	9. Increase landowner access to forest management technical and financial assistance.
	10. Support the wood products markets.
Protect and Restore Floodplains and Wetlands	11. Coordinate the state's floodplain buyout and restoration program to increase resilience.
Restore Pocosins	12. Rewet hydrologically altered peatlands to prevent soil loss and catastrophic fire.
	13. Reforest peatlands with Atlantic White Cedar.
Enhance Pocosins	14. Enhance soil health and retention on working peatlands via best management practices and drainage management.
	15. Implement targeted interventions to protect peatlands from sea level rise and saltwater intrusion guided by scenario-based modeling.
Protect Coastal Habitats	16. Provide incentives to stakeholders for coastal habitat protection.
	17. Facilitate migration of coastal habitats through protection of migration corridors.
Restore Coastal Habitats	18. Prioritize climate change and sea level rise in coastal habitat restoration planning.
Protect and Restore Urban Lands	19. Promote urban forests through statewide programs to foster the retention of urban trees and their proper management.
	20. Protect and restore forested lands in water supply watersheds.
Enhance Urban Lands	21. Improve site preparation and soil amendment during land development.
	22. Research urban forestry climate adaptation and canopy baseline needs.
Enhance Agriculture	23. Encourage adoption of high mitigation agricultural conservation practices on croplands and pasturelands.
	24. Improve manure management on farms.
	25. Encourage food system efficiency through reduced food loss and waste.

G. Path Forward

The Path Forward is a vision for building a resilient North Carolina where our communities, economies, and ecosystems are better able to rebound, adapt, and thrive amid changing conditions and challenges, including natural hazards and climate change. Developing a shared vision of resilience will enable us to maintain and improve quality of life, nurture healthy growth, and ensure long lasting and sustainable social, economic, and environmental systems. A resilient North Carolina will also safeguard our ability to conserve resources for present and future generations.

The Path Forward first lays out guiding Principles that frame the state's action on climate resilience. It is based on the analysis and recommendations of this plan's authors and contributors, recommendations from local and community partners, and the progress that the state has made to date. The guiding principles (shown to the right) are both values and goals. The threat of climate change requires effective and decisive action, made with a clear-eyed understanding of the very real challenges we face in our state and in our world. These principles light the path.



1. Statewide Climate Vulnerability Assessment and Resilience Strategy

To guide the Path Forward, the state will maintain and update the North Carolina Resilience Plan. The North Carolina Resilience Plan is a compilation of documents organized into four elements: (1) The North Carolina Science Report; (2) State Agency Resilience Strategies; (3) Statewide Vulnerability Assessment and Resilience Strategies; and (4) the North Carolina Enhanced State Hazard Mitigation Plan (EHMP). Detailed discussion of these elements is provided in Chapter 7.



Table 1-5: North Carolina Resilience Strategy Elements

North Carolina Resilience Plan Element	Current Components	Earlier Versions	Update Cycle
1. Science Report	2020 North Carolina Climate Science Report	Chapter 2 ("Climate Trends") of 2012 Climate Ready NC	As needed to incorporate new decision-relevant information
2. State Agency Resilience Strategies	Chapter 5 ("Climate Impacts, Risks and Vulnerabilities") of 2020 Resilience Plan		March 2021, and annually thereafter.
3. Statewide Climate Vulnerability Assessment with Goals and Action Steps	Chapter 4 ("Climate Justice"), Chapter 6 ("Nature-Based Solutions"), Chapter 7 ("Path Forward")	Chapter 3 ("Impacts, Risks and Vulnerabilities for North Carolina"); Appendices B through E; Chapter 4 ("Cross-Sector Strategies"), 2012 Climate Ready NC	• Priority 1: 2022 and every 4 years thereafter • Priority 2: 2024 and every 4 years thereafter
4. State Hazard Mitigation Plan	2018 North Carolina State Hazard Mitigation Plan	2013, 2010, 2007, 2004 SHMP	Current FEMA mandate: every 5 years



Table 1-6: Elements of the North Carolina Resilience Plan Going Forward

PLAN ELEMENTS	NEXT STEPS	PARTICIPATION	RESOURCE NEEDS
1. North Carolina Climate Science Report	• Update 2020 Climate Science Report as deemed necessary • Synthesize decision-relevant studies and contracted analysis from Elements 2, 3	• Universities • Federal agencies • State agencies • External contractors	• U.S. National Climate Assessment updates • Contracting funds for scientific expertise • State agency staff participation
2. State Agency Resilience Strategies	• Develop Agency strategies based on 2020 Resilience Plan Chapter 5 ("Climate Impacts, Risks, and Vulnerabilities") • Agencies seek advisory capacity on strategies from NCORR State Disaster Recovery Task Force Recovery Support Function teams (RSFs) as needed • Agencies publish Agency Resilience Strategy	• State agency resilience lead staff • NCORR resilience staff (general guidance; administration of SDRTF RSFs) • Universities • External contractors • Local governments • Stakeholders representing agency priority areas	• Funding for state agency resilience leads (1 new FTE per agency) • Each agency will have different resource needs for implementing resilience in its programs, which may include: o Contracting funds for agency-specific quantitative and qualitative risk and vulnerability assessments o Contracting funds for facilitating prioritization discussions and strategy development • NCORR guidance
3. Statewide Climate Vulnerability Assessment and Resilience Strategy	Identify, perform supporting vulnerability assessment, and develop Resilience Action Plan for Cross-Cutting Challenges: • Priority 1 Challenges: extreme events and actions potentially eligible for federal funding, such as Enhanced Hazard Mitigation Plan funding • Priority 2 Challenges: long-term issues not addressed through Priority 1.	• Statewide Strategy development process established by NCORR, with advisory input from Interagency Resilience Team and SDRTF RSFs	• Contracting funds for facilitating prioritization discussions and strategy development to gather input and prioritize actions
4. State Enhanced Hazard Mitigation Plan	• Incorporate climate science data into FEMA required Risk and Vulnerability Assessment process • Incorporate Element 3 Priority 1 Cross-Cutting Resilience Action Plan items into FEMA required Hazard Mitigation Strategy	• NCEM Hazard Mitigation, with advisory input from NCORR resilience staff (Resilience Strategy support and SDRTF administration)	• Contracting funds for quantitative and qualitative risk and vulnerability assessments • Contracting funds for facilitating prioritization discussions and strategy development to gather input and prioritize actions across levels of government



Priority Resilience Initiatives

Certain priority resilience initiatives are recommended first steps in providing opportunities for education and collaboration across stakeholder groups and sectors. Some recommended initiatives require additional dedicated funding to be successful. If this funding is not secured, these programs will not be able to move forward or will need revisions in proposed scale and scope.

The first initiative to prioritize is to **manage and coordinate statewide resilience**. The North Carolina Office of Resiliency and Recovery (NCORR) team will lead the state's resilience efforts. This involves supporting coordination among state agencies and maintaining productive relationships and partnerships between state, tribal, local, and regional governments; business and non-profit partners; and community stakeholders. Collaboration and interaction among partners inside and outside of state government helps all entities leverage expertise throughout the state to build a more resilient North Carolina.

The NCORR team provides resilience expertise to state government across the executive and legislative branches and all state agencies. The CRO also facilitates strategic planning and supports state agencies and offices as they continuously expand their capacity for and attention to resilience. Among other responsibilities, the NCORR team issue guidance to state agencies as they develop and annually update their Agency Resilience Strategies.

Additional priority resilience initiatives are discussed in full detail in Chapter 7 and listed below:

- Convene a dedicated Interagency Resilience Team
- Continue resilience efforts through the North Carolina Climate Change Interagency Council
- Establish the North Carolina Resilient Communities Program

Cross-Cutting Resilience Strategies

Various cross-cutting resilience strategies would advance resilience planning and implementation across agencies, sectors, and communities statewide. These recommended strategies include the following:

- Consider resilience criteria in making state investments
- Update plans, standards, and design values
- Increase resilience capacity in state agencies
- Identify sustainable funding sources for resilience
- Increase communication and outreach on climate change

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Chapter 2

Resilience Plan Development Process

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2. Plan Development Process

A. Introduction

Since its founding, North Carolina has grown to become a state known for its diverse population, economy, and culture. The state is divided into 100 counties with a population of over 10.4 million with a median income of $52,797 and with over 60% of residents making up its labor force.[1] North Carolina's rich history is rooted in agriculture and over the years, the population has shifted from an agricultural state with a manufacturing base in tobacco, textiles, and furniture to an advanced economy with strengths in finance, biotechnology, advanced manufacturing, and the knowledge economy more broadly.[2] The population is also experiencing a growing divide between rural and urban areas as North Carolina has metropolitan areas such as Raleigh and Charlotte, which account for over 33% of the state's population growth, as well as less dense rural cities such as Pembroke and Hickory.

North Carolina is comprised of 3 distinct physiographic provinces. The Coastal Plain, along the east coast, is well known for the profitable agriculture, fisheries, and tourism industries and diverse rural communities. The Piedmont region in the central part of the state is the heart of North Carolina's growth, encompassing the cities of Charlotte, Raleigh, Durham, and Greensboro. These cities are flourishing with expansions in the finance and research sectors, leading to an abundance of specialized job creation in areas such as the Research Triangle. The Blue Ridge Mountains along the state's western border are known for beautiful mountain peaks such as Grandfather Mountain, and lush forests, such as Pisgah National Forest. North Carolina's robust economy and rich history has provided opportunity and resources for longtime residents, tribal communities, and tourists alike.

Our geographic diversity means North Carolina has experienced devastating effects of almost every type of severe weather events and disasters. The latest science shows that these impacts will become more severe and will be endured across the state by all residents, especially those in socially vulnerable communities. These impacts have highlighted the need for action oriented state-wide resilience planning to reduce future risk.

It is important to recognize and address the threat that the changing climate poses to our state's economy, people, and culture. North Carolina is taking responsibility for the leadership and action needed to build resilience, adapt to climate hazards and risks, and reduce vulnerability to valued assets, services, and operations.

B. Executive Order 80

Governor Roy Cooper has answered the call for climate leadership by joining the U.S. Climate Alliance[3], a group of 25 bipartisan Governors whose states represent over 55 percent of the U.S. population and an economy larger than all countries except the U.S. and China. Each state has committed to implement policies that advance the goals of the 2015 Paris Agreement to reduce greenhouse gas emissions (GHGs) by at least 26-28 percent below 2005 levels by 2025 and accelerate new and existing policies to reduce carbon pollution and promote clean energy deployment at the state and federal level.

[1] North Carolina Department of Commerce. 2019. North Carolina Annual Economic Report Retrieved from https://www.nccommerce.com/blog/2019/11/04/nc-annual-economic-report-gross-domestic-product
[2] North Carolina Department of Commerce. 2019. North Carolina Annual Economic Report. Retrieved: https://www.nccommerce.com/blog/2019/11/04/nc-annual-economic-report-gross-domestic-product
[3] http://www.usclimatealliance.org/



Through Executive Order 80 (EO80), Governor Cooper calls for North Carolina to address the impact of climate change through GHG mitigation strategies and statewide adaptation and resiliency planning. The landmark order calls for the state to strive for the following climate goals for North Carolina to achieve by the year 2025:

- Reduce statewide GHG emissions to 40% below 2005 levels.
- Increase the number of registered, zero-emission vehicles (ZEVs) to at least 80,000.
- Reduce energy consumption per square foot in state-owned buildings by at least 40% from fiscal year 2002-2003 levels.

EO80 created the **Climate Change Interagency Council** (Council), comprised of representatives of each cabinet agency and chaired by the Secretary of the Department of Environmental Quality (DEQ). EO80 directed the Council to finalize strategic plans in key action areas to mitigate the impacts of climate change by transitioning the state to clean energy and transportation sources as described below.

2019 saw the development of the **North Carolina Clean Energy Plan: Transitioning to a 21st Century Electricity System** by DEQ under EO 80.[4] The Clean Energy Plan is a stakeholder driven product that conveys a collective vision for transitioning North Carolina's electricity system to accommodate clean energy technology trends and public needs. The Plan contains recommendations and actions to achieve goals related to decarbonization of the power sector; energy affordability, price stability, and equity; and economic development opportunities for both rural and urban areas of the state.

That same year, the Department of Transportation developed the **ZEVs Plan,** also called for by EO80.[5] The plan recommends a number of strategies for increasing the number of ZEVs on North Carolina roads. These strategies are organized into four action areas: education, convenience, affordability, and policy.

To address the use of ZEVs by state government, the Department of Administration developed the **2019 Motor Fleet Zero Emission Vehicles Plan** under the EO 80 directive.[6] The plan identified 572 traditional vehicles for replacement with ZEVs, finding that doing so would save taxpayers an estimated $3.8 million and reduce emissions by over 22,000 metric tons over the lifetime of the vehicles.

Governor Cooper's EO 80 also required the Department of Commerce issue a **Clean Energy and Clean Transportation in North Carolina: A Workforce Assessment**[7], which it did in the fall of 2019. This assessment evaluates the clean energy and clean transportation sectors in North Carolina, assesses the skills and education needed in these sectors, and recommends actions for supporting such a workforce in North Carolina.

In 2019, DEQ published the **North Carolina GHG Inventory (1990-2030)**, a detailed account of GHGs emitted or stored from 1990 to 2017, as well as a projection of North Carolina's anticipated GHG emissions from 2018-2030.[8] The inventory concluded that the state is on track to meet and exceed the

[4] North Carolina Clean Energy Plan, NC Department of Environmental Quality – State Energy Office, October 2019, accessed at. https://files.nc.gov/governor/documents/files/NC_Clean_Energy_Plan_OCT_2019_.pdf
[5] North Carolina Zero Emission Vehicle Plan, NC Department of Transportation, October 2019, accessed at. https://files.nc.gov/governor/documents/files/NC_Clean_Energy_Plan_OCT_2019_.pdf
[6] North Carolina Motor Fleet Zero Emission Vehicle Plan, NC Department of Administration, October 2019, accessed at https://files.nc.gov/ncdeq/climate-change/interagency-council/EO-80-DOA-MF-ZEV-PLan--Final-.pdf
[7] North Carolina Clean Energy and Clean Transportation Workforce Assessment, NC Department of Commerce, October 2019, accessed at https://files.nc.gov/ncdeq/climate-change/interagency-council/Clean-Energy---Clean-Transportation-in-NC-A-Workforce-Assessment-2019.pdf
[8] NC Greenhouse Gas Inventory (1990-2030), NC Department of Environmental Quality - Division of Air Quality, January 2019, accessed at https://deq.nc.gov/energy-climate/climate-change/greenhousegas-inventory.

Paris emission reduction goals before 2020. The process resulted in a tracking system to monitor progress of future emission reduction activities through local and state government actions and private sector initiatives.

EO80 also directed DEQ, with the support of cabinet agencies and informed by stakeholder engagement, to prepare a **North Carolina Climate Risk Assessment and Resiliency Plan** for the Council to submit to the Governor by March 1, 2020. In preparing this 2020 Resilience Plan, agencies are required to evaluate the impacts of climate change on their programs and operations, and integrate climate change adaptation and resiliency planning into their missions and services. The directive also called for agencies to help local governments and communities vulnerable to climate change impacts develop community-level adaptation and resilience plans.

This 2020 Resilience Plan is a collective response to qualitatively analyze the vulnerability of state assets, services, and programs to climate hazards and impacts. This plan also explores examples of state agency vulnerability and provides potential resilience strategies. The purpose of this plan is to build state government capacity to understand and incorporate the impact of climate change into future decision-making. State agencies analyzed the vulnerabilities and risks associated with two to three climate stressors, such as flooding, drought, and extreme heat events. By this effort, agencies were able to better understand the climate stressors that affect them, and the impacts of those stressors, while increasing institutional understanding of climate change and interagency collaboration to address those threats. The sectors shown in Figure 2-1 are evaluated by the state agencies:



Figure 2-1: Sectors Evaluated in Chapter 5: Vulnerability, Risk, and Resilience Strategies for Addressing Climate Related Hazards



C. Historical Climate Change Adaptation and Resilience Accomplishments

In 2012, the **North Carolina Interagency Leadership Team** issued the **Climate Ready North Carolina: Building a Resilient Future**[9] report, which identified climate trends and risks associated with those trends, and recommended overarching cross-sector strategies. This 2012 Report established critical information and analysis for this 2020 Resilience Plan.

The 2012 Climate Ready North Carolina report ("2012 Report") conducted a statewide, multi-sector resilience analysis. Chapter 4 of that document ("Cross-Sector Strategies") identifies six cross-sector strategies for a resilient North Carolina, which remain applicable today. This section reiterates each strategy and summarizes the implementation status of each.

The following list is not comprehensive, but highlights some of the milestones in state government. Communities, universities, businesses, and non-profits have provided invaluable leadership and expertise during this period to increase North Carolina's resilience, and those efforts are gratefully acknowledged.

Appendices B through E of the 2012 report identify sector-specific adaptive response strategies for broad categories based upon common issues that are of concern to North Carolinians: our people, our economy, our built environment, and our natural environment. Those sector-specific impacts and strategies and progress made since 2012 are highlighted below, along with activities under way.

1. Promote comprehensive adaptation planning among state agencies

The 2012 Report recommends the following sub strategies:

- Encourage agencies to incorporate climate adaptation into existing planning programs, designs and policies, and integrate consideration of changing climate conditions into relevant decisions with long planning horizons.
- Facilitate linkages between climate adaptation, pre-disaster planning, natural hazard mitigation planning, and long-term disaster recovery planning.
- Prioritize "no-regrets" adaptation actions that yield mutual benefits with other efforts.
- Establish an ongoing process that ensures state agencies are collaboratively planning for adaptation.

North Carolina has or will implement this strategy through the following actions.

- Section 2 of EO80 required the following: "Cabinet agencies shall evaluate the impacts of climate change on their programs and operations, and integrate climate change mitigation and adaptation practices into their programs and operations."
- To provide leadership to this work, North Carolina established the North Carolina Climate Change Interagency Council and a Chief Resilience Officer.
- The General Assembly prioritized resilience in state disaster recovery through creating the North Carolina Office of Recovery and Resilience (NCORR).
- The North Carolina Climate and Health Program in DHHS is part of a national public health effort to anticipate and prepare for human health effects related to global and local climate

[9] http://www.climatechange.nc.gov/Climate_Ready_North_Carolina_Building_a_Resilient_Future.pdf



change. The program is supported by the Centers for Disease Control and Prevention's Climate and Health program.

- DHHS implemented the Building Resilience Against Climate Effects (BRACE) Framework to identify likely climate impacts, potential health effects associated with these impacts on the most vulnerable populations in the state. This funding initiative led to the development of the Climate and Health Profile Report[10], which determined the health impacts of heat-related illness and wildfire smoke as the greatest concerns in North Carolina.
- DHHS continues to track public health effects of climate change, to provide services in response to increasing extreme weather and wildfires, and to accommodate disruptions from climate-related conditions to the daily services DHHS provides.
- As described in Chapter 7 of this 2020 Resilience Plan, the state will establish an Interagency Resilience Team and each state agency will generate its own resilience strategy to be updated annually.
- North Carolina Department of Emergency Management will integrate long-term resilience practices and climate data, where appropriate, into the State Hazard Mitigation Plan starting in 2023.

2. Facilitate Communication and Education to Support Local, Regional, and State Adaptation Planning Efforts

The 2012 Report recommends the following sub strategies:

- Work to enable decision makers, stakeholders and the general public to be well informed of potential climate impacts and vulnerabilities, as well as the state's efforts to address these concerns.
- Collaborate on communication planning and outreach with partners such as universities, extension agencies, federal agencies, local governments, Councils of Governments, and nongovernmental organizations.
- Include local or state-wide concerns with specific climate adaptation options as part of outreach and education efforts.

North Carolina has or will implement this strategy through the following actions:

- The NCORR issued Natural Hazards Resilience: A Quick Start Guide for North Carolina Communities.
- The active Recovery Support Functions of the State Disaster Recovery Task Force include resilience in their mission, which is to advise on state disaster recovery efforts and build capacity to prepare for future disaster recoveries.

[10] North Carolina Department of Health and Human Services Division of Public Health, North Carolina Climate and Health Profile - Building Resilience Against Climate Effects North Carolina Climate Ready Program, March 2015. accessed https://epi.dph.ncdhhs.gov/oee/climate/ClimateAndHealthProfile.pdf



3. Collaborate with Partners to Provide Relevant Information for Decision-Making

The 2012 Report recommends the following sub strategies:

- Collaborate with partners to access climate-related information that informs decisions.
- Develop a North Carolina clearinghouse for climate adaptation with links to relevant localized and state climate information and a toolbox with adaptive response options.
- Improve understanding of various climate-related risks and systems vulnerabilities.

North Carolina has or will implement this strategy through the following actions:

- Division of Coastal Management (DCM) developed a series of webpages on Coastal Adaptation, which includes data, policy and planning tools, and success stories. It is available on the division's website.
- The North Carolina Institute for Climate Studies, in collaboration with the Office of the State Climatologist at NC State University, contributed a rigorous science assessment for the 2020 North Carolina Climate Science Report.
- The Albemarle-Pamlico National Estuary Partnership conducted a study: Climate Ready Estuaries: A Blueprint for Change with Duke University in 2010 to assess the needs of coastal communities.
- The Albemarle-Pamlico National Estuary Partnership and the NC Commission on Indian Affairs will work with tribal communities to further resiliency planning.

4. Encourage broad collaboration and partnership to leverage resources

The 2012 Report recommends the following sub strategies:

- Partner with organizations, private industry, professional associations and institutions to reduce duplication of effort and leverage resources
- Encourage partnerships at a regional level to ensure coordination

North Carolina has or will implement this strategy through the following actions:

- State and local staff continue to participate in regional partnerships that bring together resilience practitioners across the Southeast, such as the Southeast and Caribbean Climate Community of Practice and the Southeast and Caribbean Disaster Recovery Partnership.
- State and local staff continue to partner with and benefit from the expertise of numerous federally funded climate science and adaptation partnerships housed in or with significant staffing located in North Carolina, including those partially funded by the National Oceanic and Atmospheric Administration - NOAA (the National Centers for Environmental Information, North Carolina Cooperative Institute for Climate and Satellites, the Southeast Regional Climate Center, the Carolinas Integrated Sciences and Assessments Program, North Carolina Sea Grant, North Carolina National Estuarine Research Reserves), the United States Environmental Protection Agency (Albemarle-Pamlico National Estuary Partnership), the United States Geological Survey (Southeast Climate Adaptation Science Center), USDA (Southeast Regional Climate Hub), U.S. Fish and Wildlife Service (Southeast Landscape Conservation Cooperative), and the Department of Defense (Southeast Regional Partnership for Planning and Sustainability).



- State and local staff also benefit from university-based programs devoted to climate science and adaption support, including but not limited to the State Climate Office of North Carolina at NC State University and the National Environmental Modeling and Analysis Center (NEMAC) at UNC-Asheville. Researchers at public and private universities throughout the state regularly reach out to state and local governments for ideas on research that meets resilience decision needs. Since June 2019, 3 faculty teams have received notification that they will receive federal funding for proposals developed with input on resilience needs and letters of support from the NCORR and from DCM.
- State staff continue to participate in national cross-state partnerships for resilience, such as the U.S. Climate Alliance and non-profit and foundation-led efforts to bring together state-level resilience leaders.
- Six local governments in the Triangle J Council of Governments collaboratively funded the Triangle Regional Resilience Partnership, which generated a regional geospatial analysis of stressors, assets and threats and prioritized recommendations for the geographic area. The results of this effort can be accessed at: https://www.tjcog.org.

5. Partner with Communities to facilitate local climate adaptation efforts

The 2012 Report recommends the following sub strategies:

- Provide technical assistance and information for interested communities to ensure their success in working toward climate adaptation goals.
- Build local capacity to develop solutions that manage risk from extreme weather and other climate change impacts in order to reduce losses.

North Carolina has or will implement this strategy through the following actions:

- In 2016-2018, the DEQ DCM conducted the Resilience Evaluation and Needs Assessment pilot program in five communities to better understand local experiences with coastal hazards and to identify areas where state and local staff can focus resources to mitigate future impacts from flooding, winds, and other damaging events.
- To inform the pilot program, the DCM conducted a coast-wide coastal hazards needs assessment survey in February 2017.
- The Albemarle-Pamlico National Estuary Partnership conducted a Climate Resilience Evaluation and Awareness Tool exercise with the towns of Manteo and Columbia to assess vulnerabilities in water infrastructure in 2013.
- DHHS has implemented community pilot projects for adapting to increases in temperature and air quality impacts of wildfire.
- EO80 calls for the Council to "support communities that are interested in assessing risks and vulnerabilities to natural and built infrastructure and in developing community-level adaptation and resiliency plans"
- As described in Chapter 7 of this 2020 Resilience Plan, the state will establish the North Carolina Resilient Communities Program to provide resources so local governments can stand up their own resilience efforts



6. Refine Adaptation Strategies as Information Becomes Available and Tools Improve

The 2012 Report recommends the following sub strategies:

- Use the best available science to inform flexible strategies, which will evolve over time.
- Monitor, evaluate, and adjust to support adaptive management of resources.
- Ensure that expert advice and stakeholder input are a continued part of the long-term ongoing process of climate adaptation.

North Carolina has or will implement this strategy through the following actions:

- The NC Climate Science Report includes state-of-the-art climate science, provided by the North Carolina Institute for Climate Studies.
- DCM and the Coastal Resources Commission's Science Advisory Panel remain committed to updating the state of the knowledge on sea level rise every 5 years, as required by Session Law 2012-202.
- Prioritize natural infrastructure and land use strategies.
- Fund investments in resilience of existing infrastructure and housing that has a reasonable outlook for survival under climate change and non-climate stressors.



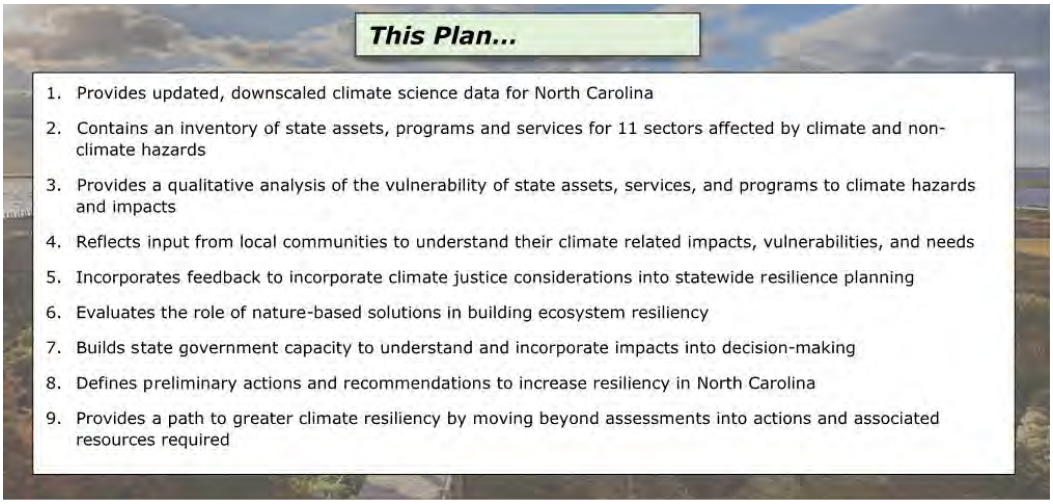
D. 2020 Resilience Plan Development Process

1. Scope of the 2020 Resilience Plan

The 2020 Resilience Plan is developed in partnership with all cabinet agencies, the Department of Agriculture and Forestry, North Carolina Institute for Climate Studies (NCICS), NOAA Climate Program Office, NEMAC, Natural and Working Lands Stakeholder Group, the NC Climate Office, and many others. It is a collective response to qualitatively analyze the vulnerability of state assets, services, and programs to climate hazards and impacts. This plan also explores examples of state agency vulnerability and provides potential resilience strategies. The purpose of this plan is to build state government capacity to understand and incorporate the impact of climate change into future decision-making.

The 2020 Resilience Plan builds upon the 2012 **Climate Ready North Carolina: Building a Resilient Future**[11] report and the resilience work conducted in North Carolina over the past decade. It also builds on our most current knowledge of climate science and applies accepted methods to evaluate vulnerabilities, risk, and additional action strategies. It adds new components into resiliency planning by considering impacts faced by North Carolina communities and accounting for climate justice issues. It recognizes the significant role nature-based solutions can play to enhance resiliency through the state's vast natural and working lands. It is meant to inform the governing bodies and decision-makers within state government of the climate impacts which affect the people, culture, environment, and other valuable assets within the state.

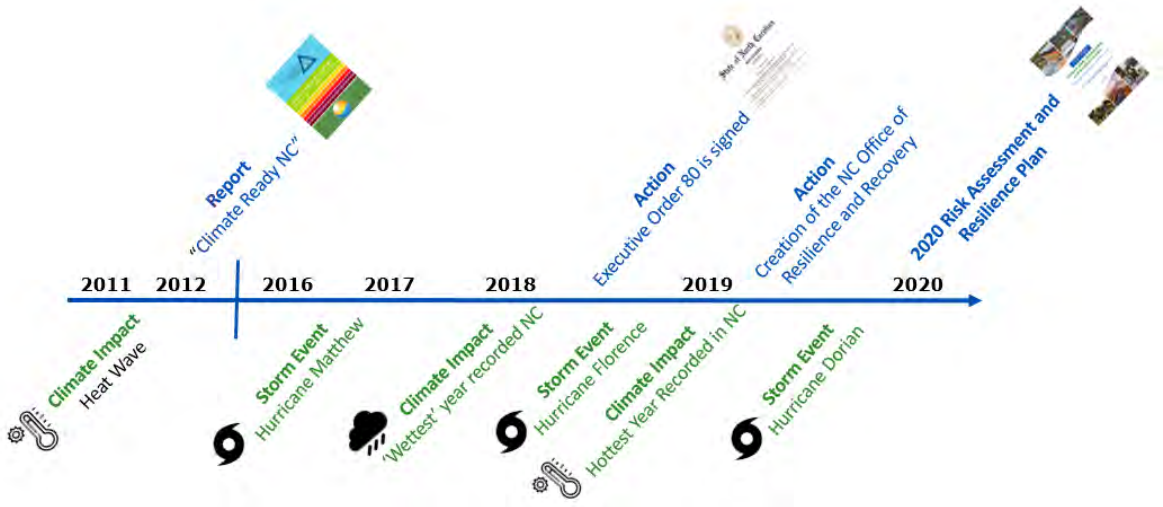
This 2020 Resilience Plan establishes the North Carolina Resilience Strategy, which is a compilation of documents organized into four elements: (1) The North Carolina Science Report, (2) State Agency Resilience Strategies, (3) Statewide Vulnerability Assessment and Resilience Strategies, and (4) the State of North Carolina Enhanced Hazard Mitigation (EHMP). This plan provides updates to elements one through three, as explained further in Chapter 7.



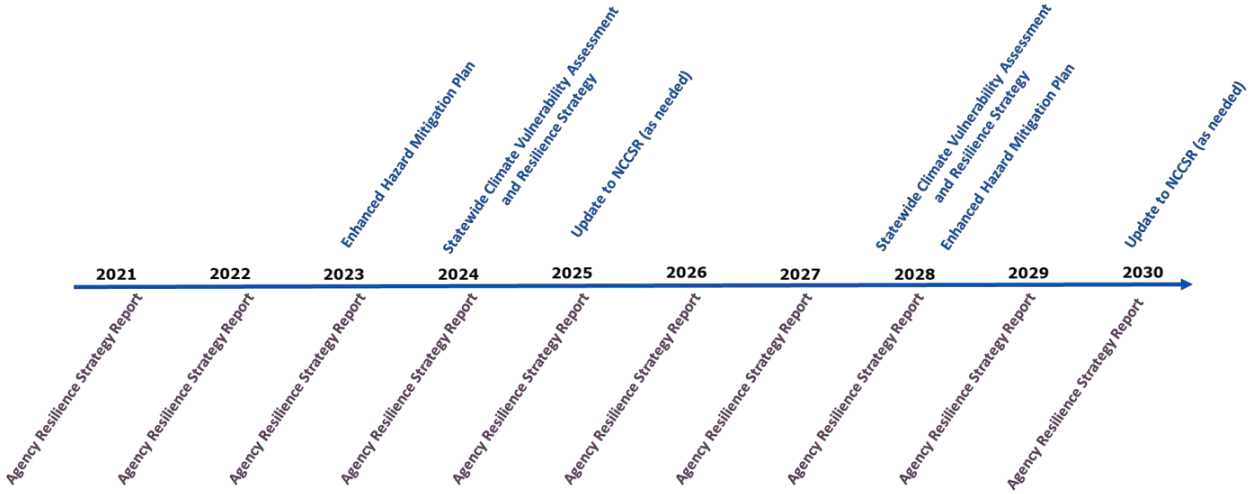
[11] http://www.climatechange.nc.gov/Climate_Ready_North_Carolina_Building_a_Resilient_Future.pdf

2. Timeline

Historic



Planned





3. North Carolina Climate Science Report

In support of EO80 Section 9 and the North Carolina Climate Risk Assessment and Resilience Plan, DEQ engaged with the leading climate experts at NCICS to develop an independent peer-reviewed scientific report describing the state of the knowledge of climate change in NC. With this collaboration, NCICS, along with an expert Climate Science Advisory Panel, have produced the NC Climate Science Report (NCCSR).[12]

This scientific report provides an overview of the physical science of climate change, detailed information on observed and projected changes in temperature and precipitation averages and extremes, hurricanes and other storms, sea level, and other relevant climate topics identified as needs. The NCICS team received input from DEQ, the NC Climate Change Interagency Council and its designees on the type of information needed such as temperature and precipitation averages and extremes, hurricanes and other storms, sea level, and other relevant climate metrics, geographic focus areas, and time horizon. Although the state agencies requested the information to evaluate its effects on their programs, the NCCSR remains an independent document that has gone through an expert review process.

The Climate Science Advisory Panel (CSAP) consists of the top climate scientists from universities across the state and was convened to serve as expert contributors and reviewers for the report. Authors of the report included the following:

Authors

Kenneth E. Kunkel, North Carolina Institute for Climate Studies, North Carolina State University
David R. Easterling, NOAA National Centers for Environmental Information
Andrew Ballinger, The University of Edinburgh
Solomon Bililign, North Carolina A&T State University
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[12] For More Information, see Appendix A: NC Climate Science Report and Chapter 3: NC Climate Science Report

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This independent resource was developed to inform state agencies, local governments, the general public and related stakeholders of the latest climate science information for the State of North Carolina. Please refer to Chapter 3 of this report for the key findings and executive summary from the report and Appendix A for the full *North Carolina Climate Science Report*.

4. Community Level Input through Regional Resilience Workshops

In an effort to engage the local community in the state resilience planning process, DEQ, with help from regional Council of Governments, other state agencies, and public, private, and non-profit partners, planned and hosted seven Regional Resilience Workshops across the state (see Figure 2-2). These workshops were attended by over 300 stakeholders representing 82 of the North Carolina's 100 counties. Stakeholders from over 100 local governments, community organizations, local planners, business owners, tribal communities, and others joined in facilitated discussions led by cabinet agency representatives to identify regional climate impacts, and developed recommendations that could be implemented at the state level.[13]

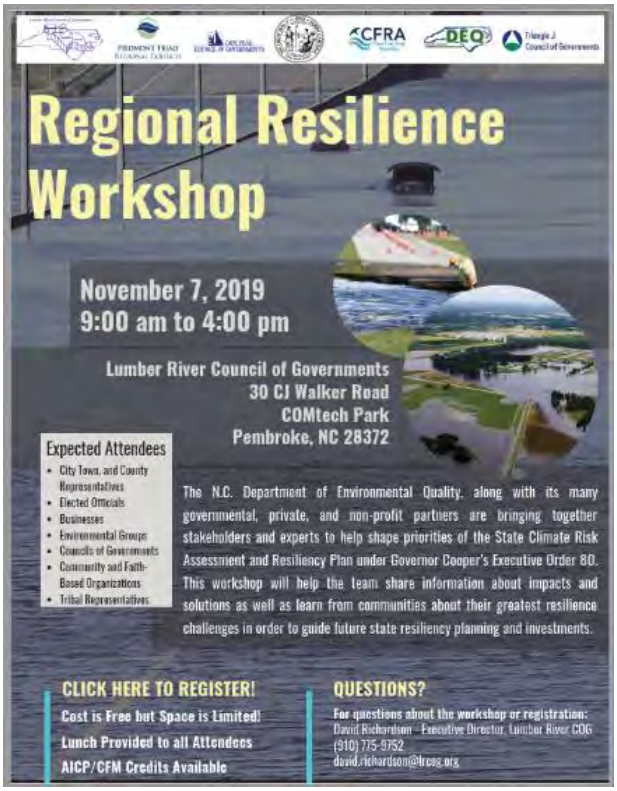


Figure 2-2: Example announcement for a regional resilience workshop

[13] For More Information about the NC Regional Resilience Workshops, See Appendix C: NC Mountain and Piedmont Regional Resilience Workshops Report and Appendix D: NC Coastal Resilience Workshops Report.



The objectives of these workshops were to convene stakeholders to:

- Present some of the latest climate science available for the state,
- Share regional climate change and resiliency challenges,
- Generate strategies that could be implemented at the local level,
- Generate recommendations that could be implemented at the state level, and
- Prioritize regional vulnerabilities to be addressed in the North Carolina Climate Risk and Resiliency Plan.

The Mountain and Piedmont Regional Resiliency Workshops were designed following the completion of two workshops in the Coastal region (see Figure 2-3). Workshops were hosted by partnering organizations on the dates shown in Table 2-2.

Table 2-2: Regional Resilience Workshops

Workshop Location	Workshop Date	Host Organization
Elizabeth City, NC	May 2, 2019	
Wilmington, NC	May 14, 2019	
Havelock, NC	June 11-12 (Coastal summit)	
Sylva, NC	October 15, 2019	Southwestern Community College
Hickory, NC	October 16, 2019	Western Piedmont COG
Kernersville, NC	November 4, 2019	Piedmont Triad Regional COG
Pembroke, NC	November 7, 2019	Lumber River COG
Wilson, NC	November 12, 2019	Upper Coastal Plain COG



Figure 2-3: Stakeholder representation at the NC Regional Resilience Workshops

In Technical Session I of the Mountain and Piedmont workshops, the agencies invited climate scientist and members of the climate science community to (1) provide an overview of historic, present, and



projected regional climate patterns, and (2) help participants to understand global, state, and regional climate trends and stressors.

In Technical Session II, a panel of local government officials, state regional office staff, university partners, business owners, and non-government organization staff provided varied local perspectives on local hazards, impacts and challenges and share approaches to managing short- and long-term environmental, economic and societal changes by answering the following questions:

1. *What are the top two climate hazards and impacts to your region/community?*
2. *How are these impacts affecting the different sectors of the community?*
3. *How are local governments preparing for and responding to these impacts?*
4. *What are some knowledge gaps that you find as you engage with community members?*
5. *What strategy has been the most effective in community-level resilience planning?*

During the facilitated discussion portion of the workshop, participants were separated into six focus area groups based on interest and area of expertise. The following focus groups were facilitated by representatives from corresponding cabinet agencies:

Workshop Focus Groups
• Agriculture, Business, and Commerce
• Local Planning
• Environment and Natural Resources
• People and Community
• Transportation
• Public Health

The participants were asked to respond to the following questions in the context of their focus groups:

1. *How has your community been affected by natural hazards and long-term stressors?*
2. *What steps have you already taken to reduce future climate hazards and risks? What actions would you like to take and what are the barriers you face?*
3. *How can the state better support communities in addressing climate hazard risks and impacts?*

Stakeholder Feedback

Stakeholders prioritized actions that can be taken at the local level, and generated recommendations for state agencies to take in order to increase local capacity for resilience. Recommendations for state agencies fell within the following categories:

- Data and Research
- Technical Assistance
- Staff Resources and Connections
- Regulation and Policy Changes
- Funding
- Education, Training, and Outreach

Across the state, local stakeholders expressed similar concerns with the following overarching themes:

- Lack of local climate resilience knowledge and capacity

- Need for improved floodplain and watershed mapping and management tools
- Need for technical assistance with local hazard mitigation planning
- Lost revenue for small businesses, agricultural operations, and outdoor employees during climate events
- Lack of emergency access to rural communities during and after a disaster
- Need for comprehensive technical assistance with the federal recovery grant process
- Lack of reliable broadband access in rural communities during disasters

Additional feedback given by the stakeholders is provided in Appendix C: NC Mountain and Piedmont Regional Resilience Workshops Report and Appendix D: NC Coastal Resilience Workshops Report.

5. Climate Justice Considerations

In order to ensure the equity and inclusion of vulnerable, under-represented communities into statewide resilience planning, the members of DEQ Secretary's Environmental Justice and Equity Advisory Board: Subcommittee on Climate Change and Extreme Weather Resilience provided feedback and recommendations to identify key content and themes for inclusion in the Climate and Environmental Justice Chapter.

The Board itself is comprised of 16 members appointed by the Secretary of DEQ, who represent academic institutions, environmental and community organizations, and Native American Indian Tribes. The scope of the Environmental Justice and Equity Advisory Board is to assist the Department in achieving and maintaining the fair and equal treatment and meaningful involvement of North Carolinians regardless of where they live, their race, religion or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Feedback from the NC Regional Resiliency Workshops (discussed earlier) was used to identify recurring themes related to climate change and equity concerns described by local stakeholders and was distilled into a detailed outline provided to the Subcommittee members for their feedback. Members of the Subcommittee responded with detailed suggestions and comprehensive recommendations which were incorporated into Chapter 4: Climate and Environmental Justice.

6. Impact, Vulnerability, and Risk Assessment for Sectors Evaluated[14]

DEQ partnered with the NOAA and the authors of U.S. Climate Resilience Toolkit team (CRT team) to develop a collaborative work plan to lead state agencies to qualitatively asses the exposure, vulnerability, and risk of state agency assets and services to climate-related hazards. Additional facilitation and technical support were provided by UNC NEMAC and NCICS. Together, the Lead team guided participating state agency staff through a series of three workshops designed to (a) develop a clear understanding of state assets and climate-related hazards; (b) establish a process for assessing climate-related risks to those assets; and (c) agree on a framework and process for authoring a statewide resiliency plan.

U.S. Federal agencies have focused since the 1991 Global Change Research Act upon documenting sources and impacts of climate variability and change on local and national assets and populations. Thus, there is increasing awareness at local and regional levels about the need to improve resilience to climate-related hazards. The National Research Council has recommended that U.S. Federal agencies provide

[14] Gardiner E. P., Herring D. H., and Fox. 2019. The U.S. Climate Resilience Toolkit: evidence of progress. Climatic Change 153(4): 477-490. Also see https://toolkit.climate.gov/#steps

climate adaptation decision support.[15] They further suggested focusing first and foremost on end-user needs and investing in processes and relationships between those users and information providers.

During the risk assessment and resilience planning process, we qualitatively assessed the exposure, vulnerability, and risk of agency assets and services to climate-related hazards. Through a series of knowledge building workshops and a writing process, teams from throughout North Carolina's state government learned a set of terminology and documented their exposure to climate-related hazards (see Chapter 5 of this report). That qualitative process has established a shared understanding across departments and agencies, making it possible to quantify climate-related vulnerability and risk in a future stage of work.

The 2020 Resilience Plan development team adopted the Steps to Resilience Framework (Figure 2-4) to facilitate the required learning and documentation. Team members have gained an appreciation of the different outcomes and valuation systems that must be reconciled in future engagements across the North Carolina state government. The first step in the framework requires that teams coalesce around shared goals that address exposure to climate-related hazards. This report focuses attention on that shared understanding.



Figure 2-4 The U.S. Climate Resilience Toolkit's 'Steps to Resilience'

Sectors analyzed in this 2020 Resilience Plan were developed based on the sectors identified in the 2012 Report discussed earlier[16] and expanded to incorporate the needs and vulnerabilities identified by state agencies and local communities (see Table 2-3). These sectors cover the natural, built, economic, and social systems affected by climate hazards in the state. A complete risk assessment and determination of adaptation options was not possible given the large number of potential impacts, so agencies undertook an abbreviated assessment for a subset of those potential impacts. Out of 744 impact pairs identified, agencies conducted risk assessments for 48 impact pairs.

[15] National Research Council. 2009. Informing Decisions in a Changing Climate. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
[16] http://www.climatechange.nc.gov/Climate_Ready_North_Carolina_Building_a_Resilient_Future.pdf

Table 2-3: Sectors Evaluated in the 2020 Resilience Plan

Sector	Contributing Department(s)	Examples of Assets, Services, Programs
Agriculture and Forestry	Department of Agriculture and Consumer Services	Endangered native plant species, agricultural sector, crop and pasture lands, forest-land, wildlife, livestock and poultry
Coastal Resources and Structures	Department of Environmental Quality	Natural buffers – wetlands and barrier islands, Public and private property, marine and estuarine habitats, Beach nourishment/channel dredging
Commerce and Business	Department of Commerce	Economic vitality, businesses
Cultural Resources	Department of Natural and Cultural Resources	State museums; state archives and records; state historic sites; historic structures; districts and landscapes; national register of historic places, properties, and districts
Ecosystems	Department of Natural and Cultural Resources, Department of Environmental Quality	Biodiversity, habitats, ecosystems, wildlife resources, inland and marine fisheries, threatened and endangered plants and animals
Housing, Buildings and Support Services	Department of Public Safety, Department of Military and Veterans Affairs, Department of Administration, Department of Environmental Quality	Infrastructure - homes/buildings, residential properties, commercial properties, critical infrastructure
Health and Human Services	Department of Health and Human Services, Department of Environmental Quality	Insect and water borne diseases, heat stress, air quality
Public Safety	Department of Public Safety	Emergency management, law enforcement, state-managed shelters, prison system, flood risk management
Transportation	Department of Transportation	Roads, bridges, railroads, ports, airports, infrastructure, maintenance, project development, planning and programming
Water and Land Resources	Department of Environmental Quality	Public water supply, industrial water supply, agricultural water use, water quality, wastewater
Energy	Department of Environmental Quality	Energy generating sources, transmission and distribution lines, power grid components, thermoelectric plant cooling systems, fuel pipelines, terminals and service stations



7. Natural and Working Lands Action Plan Process

Nature-based solutions (NBS) refer to reshaping the structure, management and use of North Carolina's NWL to tackle socio-environmental challenges, such as climate change, by leveraging the unique properties of these resources. They can be used to address infrastructure needs such as storm water retention, protect from climate impacts such as storm surge, and act as hazard mitigation strategies that contribute to increasing drought and flood tolerance. These solutions have been used successfully for many decades, most notably for stormwater management and watershed protection. Now, they are being recognized for their true economic potential to protect our ecosystems and citizens from the devastating impacts of climate change.

The NWL Action Plan took shape in the summer of 2018. The North Carolina Department of Environmental Quality (DEQ) was in the process of building a statewide GHG inventory that included the NWL sector. The inventory indicated that the NWL sector was sequestering significant amounts of carbon. The inventory indicated that the NWL sector was sequestering significant amounts of carbon. It was estimated that almost 25% of annual gross CO_2 equivalent emissions were removed from the atmosphere by forests and other lands.

In addition to this work, representatives from the state of North Carolina attended the U.S. Climate Alliance and American Forests' 3-day Learning Lab in Washington DC. The Alliance convened representatives from various states, who participated in a to learn about NWL and develop a framework for ongoing NWL stakeholder engagement in their home states.

The NWL Action Plan is a cornerstone of EO80 because it addresses both mitigation of GHG emissions and building community and ecosystem resilience. Chapter 6 discusses how state agencies and local governments can use the NWL Action Plan to build adaptive capacity and resilience to climate change-related weather events and stressors.

To explore opportunities in the NWL sector, DEQ convened a stakeholder group in October and December of 2018, to discuss potential carbon sequestration opportunities. The stakeholders represented the following entities:

- Public/private landowners and managers.
- Scientists.
- Policymakers
- State and local government planners.
- Universities.
- Consulting firms.
- Non-profit organizations.

Close to 100 people participated in the NWL Stakeholders Group's six subcommittees developing and vetting 25 priority recommendations for the NWL Action Plan over an 18-month period. The purpose of NWL Action Plan is to create opportunities and implement projects on North Carolina's NWL that achieve the following goals shared by the plan's stakeholders:

1. Enhance the ability of NWL to sequester carbon and mitigate GHG emissions.
2. Build resilience in ecosystems and communities.
3. Provide public health and ecosystem co-benefits.
4. Create economic opportunities for agribusiness, recreation, and tourism.
5. Ensure implementation of any action is a socially equitable process.

After the December Stakeholder Group meeting, attendees formed subcommittees that would focus on a particular land sector.[17] The land sectors focused on by the subcommittees are listed in Figure 2-5:[18]

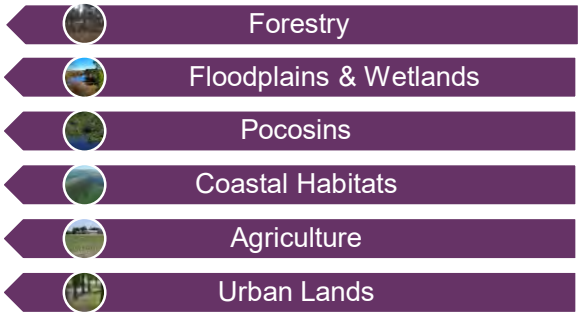


Figure 2-5: Natural and Working Land Subcommittees

The subcommittees met numerous times in 2019 to develop a set of actionable recommendations. The DEQ acted as a facilitator for the group, creating a work plan and assisting with documentation. A steering committee was also formed consisting of the subcommittee leaders, facilitators from DEQ and other lead, and key members of the 2020 Resilience Plan team. The steering committee guided the process and deliverables for the NWL Action Plan.

Over a two-day period in October of 2019, stakeholders prioritized the list of recommendations that would be included in the NWL Action Plan. An evaluation criterion was set prior to the meeting that was created by the steering committee. The recommendations that met the criteria and obtained a majority consensus as a priority are included in the plan. Figure 2-6 shows the process for developing the NWL Action Plan.

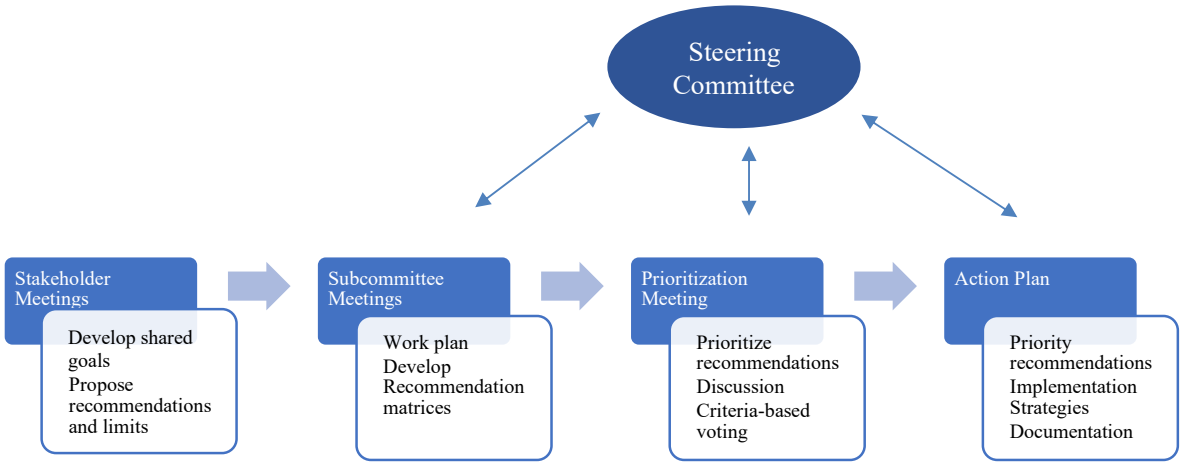


Figure 2-6: Process Flow for Development of the Natural and Working Land Action Plan

[17] For a full list of subcommittee participants, see the full report in Appendix B.
[18] Pocosins are naturally-occurring freshwater evergreen shrub-dominated wetlands of the Coastal Plains with deep, acidic, peat soils.



The resulting 25 recommendations included in the NWL Action Plan are those that were prioritized by the majority of NWL stakeholders and did not require full consensus of all stakeholders. The stakeholders summarized the recommendations into four main categories:

- ***Transformative*** – cross-cutting actions that will result in large amounts of carbon sequestration and resilience.
- ***Protect Land*** – acquisition of land or conservation agreements to conserve additional natural areas.
- ***Restore Land*** – restoration of the ecological function to natural systems to increase carbon sequestration and resilience.
- ***Enhance Land*** – improved use and management of existing lands to increase carbon sequestration and resilience.

The stakeholders recognize that the state needs to act quickly to acquire and develop sufficient land area as "green-infrastructure" for mitigating climate change impacts and sequestering carbon. The NWL Action Plan recommendations, along with the expertise of the stakeholders who developed it, should be a first resource for building long-lasting resilience in North Carolina. A summary of each of the 25 priority recommendations is provided in Chapter 6: NBS for Resiliency. These recommendations are actionable by both state/local governments and impact partners such as universities and conservation organizations. Several subcommittees have formed teams working on their design and implementation. The full NWL Action Plan is included in Appendix B.

E. Future Updates to the Plan through the North Carolina Office of Recovery and Resiliency

In 2018, following the devastation of Hurricane Florence amidst the ongoing recovery from Hurricane Matthew in 2016, the NCORR was established to administer funds received by the state through the U.S. Department of Housing and Urban Development's Community Development Block Grants for Disaster Recovery Program. Working closely with North Carolina Emergency Management, the NCORR provides disaster recovery coordination with services that include oversight of recovery funding, processing of program applications, construction and vendor management, and public outreach and education, among other responsibilities.

In 2019, Governor Cooper appointed a state Chief Resilience Officer (CRO) to lead NCORR's resilience staff and direct the state's initiative to help storm-impacted communities rebuild smarter and stronger in the face of future natural disasters and long-term climate change. The NCORR's resilience staff works to improve collaboration between governments, non-profits, the private sector and academia, with a goal of developing solutions that enhance the resilience of communities and the natural environment while creating safe and affordable housing solutions. As part of that work, NCORR coordinates the State Disaster Recovery Task Force (SDRTF) and its subcommittees, the Recovery Support Functions (RSFs), which bring together experts in the field of recovery and resiliency, both within state government as well as federal and local government, industry and nonprofit organizations. Each RSF provides and promotes recommendations through NCORR and North Carolina Emergency Management (NCEM) to state government and the General Assembly on ongoing disaster recovery efforts and future resilience-building.



NCORR has been tasked with leading the state's future resilience efforts. This involves supporting coordination among state agencies and maintaining productive relationships and partnerships between state and local and regional governments, business and non-profit partners, and community stakeholders. Collaboration and interaction among partners inside and outside of state government helps all entities leverage expertise throughout the state to build a more resilient North Carolina.

The NCORR and key state agency staff have prepared a path forward strategy for the state to maintain and update a unified North Carolina Resilience Plan. The NC Resilience Plan is a living document, updated regularly, with four primary elements:

1. A Climate Science Report.
2. State agency-specific resilience strategies.
3. A statewide vulnerability assessment and resilience strategy with goals and action steps.
4. The North Carolina Enhanced State Hazard Mitigation Plan.

The path forward identifies priority initiatives and offers recommendations for state government to build resilience capacity and enhance the ability of residents, businesses, and communities to cope with climate change. The principles, plans, proposed initiatives, and strategies outlined in Chapter 7 implement recommendations and best practices on climate assessment and resilience planning.

F. Document Organization

Chapter 3 provides key findings and executive summary from the NCCSR.[19]

Chapter 4 describes the disproportionate burden that climate impacts have on socially vulnerable communities and provides a variety of recommendations to ensure equity in climate adaptation planning.

Chapter 5 is an assessment of critical vulnerabilities in each identified sector and provides potential actions which demonstrate how agencies, working both independently and cooperatively, may address the impacts of climate variability and change on citizens, infrastructure, and assets throughout the state.

Chapter 6 identifies opportunities to sequester carbon, provide ecosystem benefits, and enhance resiliency through project implementation within natural ecosystems.[20]

Chapter 7 outlines the next steps to advance climate resiliency throughout the state and provides a framework for the future of climate resilience and adaptation in North Carolina.

Appendix A presents the NC Climate Science Report.

Appendix B presents the Natural and Working Land Action Plan.

Appendix C and D presents Regional Workshop Reports for the Mountain and Piedmont region and the Coastal region, respectively.

Appendix E contains a glossary of key words and terminologies.

Appendix F contains a list of acronyms used in the report.

[19] For more information, refer to Appendix A: NC Climate Science Report
[20] For more information, refer to Appendix B: NC Natural and Working Lands Action Plan

Chapter 3

NC Climate Science Report



3. NC Climate Science Report

A. Overview

1. What is this Report?

The North Carolina Climate Science Report (NCCSR) is a scientific assessment of historical climate trends and potential future climate change in North Carolina under increased greenhouse gas (GHG) concentrations. It provides an overview of the physical science of climate change, detailed information on observed and projected changes in temperature and precipitation averages and extremes, hurricanes and other storms, sea level, and other relevant climate metrics.

Findings are presented for both the state as a whole and for each of three regions in the state: the Coastal Plain, the Piedmont, and the Western Mountains. The report also includes chapters on sea level rise, trends involving interactions of multiple aspects of the climate system (including inland flooding, wildfire, forest ecosystem changes, urban heat island effects, and air pollution), and findings relevant to engineering design standards.

2. Background

Governor Cooper's Executive Order 80 (EO80), "North Carolina's Commitment to Address Climate Change and Transition to a Clean Energy Economy," directed all cabinet agencies to integrate climate adaptation and resiliency planning into their policies, programs, and operations. The order specifies a number of emissions-reduction and clean-energy goals, establishes an interagency council on climate change, and calls for a range of other specific actions across the state government.

One provision of EO80 directed the North Carolina Department of Environmental Quality (DEQ) to develop a "North Carolina Climate Risk and Resilience Plan." The DEQ and other agencies recognized the need for an objective and credible climate science analysis to support the E080 activities and the development of the resiliency plan.

In response to this need and request, the North Carolina Institute for Climate Studies (NCICS), an inter-institutional research institute of the University of North Carolina system administered by NC State University, led the development of the NCCSR. This Report is intended to serve as an independent peer-reviewed scientific contribution to the E080 activities and the 2020 Resilience Plan and to inform the citizens of North Carolina about the state of knowledge on climate change in North Carolina

3. Report Authorship and Development

The report was prepared independently by North Carolina-based climate experts. While some authors (including those from NCICS) are employed by state universities, and state agency needs informed the selection of report topics, the authors based their analysis of the science on their own climate expertise informed by (a) the scientific consensus on climate change represented in the Fourth United States National Climate Assessment and the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; (b) the latest research published in credible scientific journals; and (c) information in the North Carolina State Climate Summary.

Under the direction of Kenneth Kunkel, NCICS Lead Scientist for Assessments and NC State Research Professor, NCICS assembled an author team to write the report and an advisory panel to provide scientific oversight and expert reviews. The advisory panel ("Climate Science Advisory Panel") consisted of North Carolina university and federal research scientists with national and international reputations in their specialty areas of climate science. The author team comprised NCICS scientists and several members of the advisory panel.



The report leverages the expertise of NOAA's Assessments Technical Support Unit (TSU), which is staffed primarily by NCICS, and applies the methodologies and processes developed for the U.S. National Climate Assessment.

The report underwent several rounds of review and revision, including an anonymous peer review organized by NOAA's National Centers for Environmental Information (NCEI).

Please refer to the NCCSR full report for list of authors, advisory panel members, and other contributors who supported the technical analysis, report management and production.

4. Report Contents and Availability

The sections below provide the NCCSR Report Findings, the overarching key findings and conclusions of the NCCSR, and the NCCSR Executive Summary, which is a more detailed discussion of the key conclusions and report findings.

The full report is available via the NCICS website: www.ncics.org/nccsr.

B. NCCSR Report Findings

These findings present key conclusions of this report about observed and projected changes in the climate of the state of North Carolina. They are based on analyses using well-established and carefully evaluated observational and modeling datasets, national and international climate assessments, and an assessment of the latest peer-reviewed scientific literature, complemented by other sources where appropriate. All of these sources were determined to meet the standards of the federal Information Quality Act.

Climate projections for the NC Climate Science Report are determined using Representative Concentration Pathways (RCPs). RCPs are a set of hypothetical future scenarios used in climate model simulations to examine how Earth's climate would respond to differing levels of GHG concentrations. Most of the projections referenced in this report are based on two of the RCPs: a higher scenario (RCP8.5), in which GHGs continue to increase through the end of the century, and a lower scenario (RCP4.5), in which emissions increase at a slower rate, peak around the middle of the century, and then begin to decrease (Figure 3-1). Note, although annual emissions declined slightly in 2019 and the potential effects of coronavirus on emissions have not been fully quantified, recent evidence has shown that global emissions have been tracking close to the highest emission scenario – RCP 8.5.

Future increases in temperature are dependent on greenhouse gas emissions, with higher emissions resulting in greater warming. Qualitative projections are based on expert judgment and assessment of the relevant scientific literature and draw on multiple lines of scientific evidence as well as model simulations.

Global average temperature has increased about 1.8°F since 1895. Scientists have ***very high confidence*** that this warming is largely due to human activities that have significantly increased atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases. It is ***virtually certain*** that global warming will continue, assuming greenhouse gas concentrations continue to increase. By the end of this century (2080–2099), global average temperature is projected to increase by about 4°–8°F compared to the recent climate (1996–2015) under the higher scenario (RCP8.5) and by about 1°–4°F under the lower scenario (RCP4.5).

Global average sea level has increased by about 7–8 inches since 1900, with almost half of this increase occurring since 1993. It is ***virtually certain*** that global sea level will continue to rise due to expansion of ocean water from warming and melting of ice on land, such as the Greenland and Antarctic ice sheets.

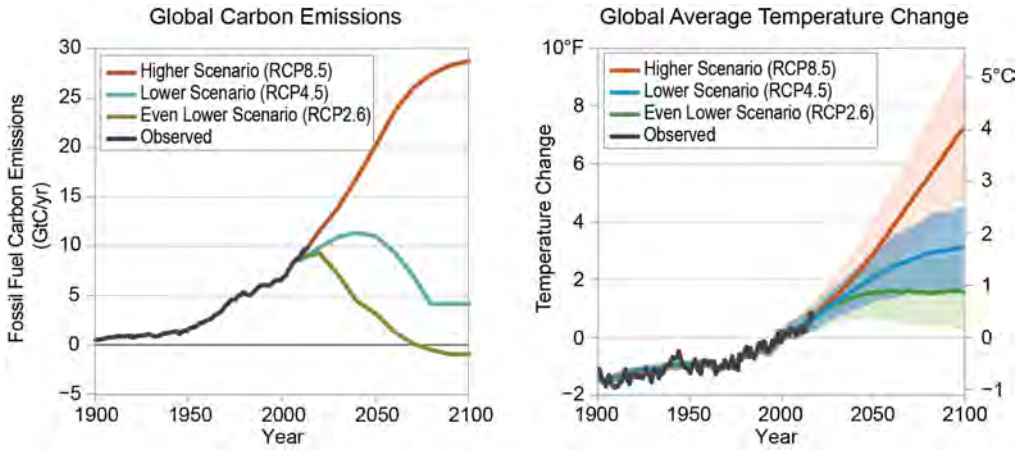


Figure 3-1: (left) Observed and projected global carbon emissions. The black line shows observed carbon emissions (1900–2016) resulting from human activities. Under the higher scenario used in this report (RCP8.5, burnt orange line), emissions continue to increase through the end of the century. Under the lower scenario used in this report (RCP4.5, blue line), emissions increase at a slower rate, peak around midcentury, and then decline in response to climate change mitigation policies. Also shown is an even lower scenario (RCP2.6, green line), which assumes rapid emissions reductions and eventually net negative emissions. (right) Observed temperatures and the projected future temperature changes associated with the three RCP scenarios shown in the left panel. Temperature changes are shown relative to the 1986–2015 global average. Source: Hayhoe et al. 2018.

1. Observed and Projected Changes for North Carolina

Except where noted, statements about future changes refer to projections through the end of this century. The following definitions apply:

Virtually Certain= 99-100% probability of outcome
Very Likely= 90-100% probability of outcome
Likely= 66-100% probability of outcome
About as Likely as Not = 33-66% probability of outcome
Unlikely= 0-33% probability of outcome
Very Unlikely= 0-10% probability of outcome
Exceptionally Unlikely= 0-1% probability of outcome

Our scientific understanding of the climate system strongly supports the conclusion that large changes in North Carolina's climate, much larger than at any time in the state's history, are ***very likely*** by the end of this century under both the lower and higher scenarios.

Temperature

- North Carolina annual average temperature has increased by about 1.0°F since 1895, somewhat less than the global average. The most recent 10 years (2009–2018), however, represent the warmest 10-year period on record in North Carolina, averaging about 0.6°F warmer than the warmest decade in the 20th century (1930–1939). Recently released data indicate that 2019 was the warmest year on record for North Carolina.



- Although regional changes in temperature can vary from global changes, it is ***very likely*** that North Carolina temperatures will also increase substantially in all seasons. Annual average temperature increases relative to the recent climate (1996–2015) for North Carolina are projected to be on the order of 2°–5°F under a higher scenario (RCP8.5) and 2°–4°F under a lower scenario (RCP4.5) by the middle of this century.
- By the end of this century, annual average temperature increases relative to the recent climate (1996–2015) for North Carolina are projected to be on the order of 6°–10°F under a higher scenario (RCP8.5) and 2°–6°F under a lower scenario (RCP4.5).
- North Carolina has not experienced an increase in the number of hot (daytime maximum temperatures of 90°F or higher) and very hot (daytime maximum temperatures of 95°F or higher) summer days since 1900. However, it has seen an increase in the number of warm (nighttime minimum temperatures of 70°F or higher) and very warm nights (nighttime minimum temperatures of 75°F or higher).
- It is ***very likely*** that the number of warm and very warm nights will increase.
- It is ***very likely*** that summer heat index values will increase because of increases in absolute humidity.
- It is ***likely*** that the number of hot and very hot days will increase.
- It is ***likely*** that the number of cold days (daytime maximum temperatures of 32°F or lower) will decrease.

Precipitation

- There is no long-term trend in annual total precipitation averaged across the state. However, there is an upward trend in the number of heavy rainfall events (3 inches or more in a day), with the last four years (2015–2018) having seen the greatest number of events since 1900.
- It is ***likely*** that annual total precipitation for North Carolina will increase.
- It is ***very likely*** that extreme precipitation frequency and intensity in North Carolina will increase due to increases in atmospheric water vapor content.

Sea Level

- Sea level along the northeastern coast of North Carolina has risen about twice as fast as along the southeastern coast, averaging 1.8 inches per decade since 1978 at Duck, NC, and 0.9 inches per decade since 1935 at Wilmington, NC.
- It is ***virtually certain*** that sea level along the North Carolina coast will continue to rise due to expansion of ocean water from warming and melting of ice on land, such as the Greenland and Antarctic ice sheets. Under a higher scenario (RCP8.5), storm-driven water levels that have a 1% chance of occurring each year in the beginning of the 21st century may have as much as a 30%–100% chance of occurring each year in the latter part of the century. High tide flooding, defined as water levels of 1.6–2.1 feet (0.5–0.65 m) above Mean Higher High Water, is projected to become a nearly daily occurrence by 2100 under both the lower and higher scenarios.

Hurricanes

- On a global scale, the intensity of the strongest hurricanes is ***likely*** to increase with warming. The confidence in this outcome is ***high***. For individual regions such as North Carolina, the confidence in this outcome is medium. While confidence for North Carolina is lower than for the entire globe, there is no known reason that North Carolina would be protected from stronger hurricanes and this potential risk should be considered in risk assessments.
- Heavy precipitation accompanying hurricanes that pass near or over North Carolina is ***very likely*** to increase, which would in turn increase the potential for freshwater flooding in the state.
- There is ***low confidence*** concerning future changes in the number of landfalling hurricanes in North Carolina.



Storms

- It is ***likely*** that the frequency of severe thunderstorms in North Carolina will increase.
- It is ***likely*** that total snowfall and the number of heavy snowstorms in North Carolina will decrease due to increasing winter temperatures.
- There is ***low confidence*** concerning future changes in the number of winter coastal storms.
- There is ***low confidence*** concerning future changes in the number of ice storms in North Carolina.

Floods, Droughts, and Wildfire

- It is ***virtually certain*** that rising sea level and increasing intensity of coastal storms, especially hurricanes, will lead to an increase in storm surge flooding in coastal North Carolina.
- It is ***likely*** that increases in extreme precipitation will lead to increases in inland flooding in North Carolina.
- It is ***likely*** that future severe droughts **in their multiple forms** in North Carolina will be **more frequent** and intense due to higher temperatures leading to increased evaporation. As a result, it is ***likely*** that the frequency of climate conditions conducive to wildfires in North Carolina will increase.

Other Compound Events

- It is ***likely*** that future urban growth will increase the magnitude of the urban heat island effect, with stronger warming in North Carolina urban centers.
- There is ***low confidence*** concerning future changes in conditions favorable for near-surface ozone formation in North Carolina because of counteracting influences from increases in both temperature and water vapor.

Engineering Design Standards

- It is ***very likely*** that some current climate design standards for North Carolina buildings and other infrastructure will change by the middle of the 21st century. This includes increases in design values for precipitation, temperature, and humidity. Several professional societies, however, are actively working on methods to incorporate climate change into national standards, and updated standards appropriate for use in a changing climate may be available in the near future.

C. NCCSR - Executive Summary

Our scientific understanding of the climate system strongly supports the conclusion that North Carolina's climate has changed in recent decades and the expectation that large changes—much larger than at any time in the state's history—will occur if current trends in greenhouse gas concentrations continue. Even under a scenario where emissions peak around 2050 and decline thereafter, North Carolina will experience substantial changes in climate. The projected changes with the highest level of scientific confidence include increases in temperature, increases in summer absolute humidity, increases in sea level, and increases in extreme precipitation. It is also ***likely*** that there will be increases in the intensity of the strongest hurricanes.

A full appreciation for past and future changes in North Carolina's climate requires a global perspective. Earth's climate has warmed substantially since the late 19th century, with most of that warming occurring in the last 50 years. This warming trend is clear from global temperature records and many other indicators, including rising global sea levels and rapid decreases in arctic sea ice cover. Scientists have ***very high confidence*** that this warming is largely due to human activities that have significantly increased atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases. Extensive research has examined other potential causes of this warming, and the increase in greenhouse gas concentrations is the only plausible cause that is consistent with the observed data and the physics that governs the climate system.



1. Observed Changes

In North Carolina, annual average temperature has increased about 1°F since 1895, compared to the global average increase of about 1.8°F during that period. Annual average temperatures have been consistently above normal since the 1990s, with the most recent 10 years (2009–2018) representing the warmest 10-year period on record— about 0.6°F warmer than the warmest decade of the 1900s (1930–1939). Data for 2019, which were released during the review of this report, indicate that 2019 was the warmest year on record for North Carolina.

Most other temperature indicators also show warming. Average temperatures have increased in all four seasons. There has been an increase in the number of very warm nights. The length of the growing season has increased and is now about 1.5 weeks longer than the long-term average. There is an upward trend in the number of cooling degree days (a temperature indicator related to air conditioning demand) and a downward trend in the number of heating degree days (an indicator of heating demand)—both changes are consistent with a warming climate. However, a few indicators that would be expected to change with warmer conditions have not. For example, the number of very hot days has not increased, and there is no overall trend in the number of cold days and cold nights.

There is no long-term trend in annual total precipitation averaged across the state; however, 2018 was the wettest year on record, in part due to the torrential rainfall from Hurricane Florence. There has been an upward trend in the number of heavy rainfall events (days with more than 3 inches of rain), indicating that a larger portion of the annual total precipitation is occurring in heavy events. Temperature and precipitation trends in the three regions of the state (Coastal Plain, Piedmont, and Western Mountains) are generally similar to statewide trends.

Most observing stations outside of the mountains have experienced a downward trend in snowfall. In the Western Mountains, there is no century-long trend in snowfall, although stations in the southern mountains have seen decreasing trends over the last 50 years. Conditions favorable for snow-cover maintenance and snowmaking in the Western Mountains have been highly variable since 1981, but recent years have seen below average percentages of time when conditions are favorable.

Global average sea level has increased by about 7–8 inches since 1900, with almost half of this increase occurring since 1993—a rate of about 1.2 inches per decade. Sea level along the northeastern coast of North Carolina is rising about twice as fast as along the southeastern coast, averaging 1.8 inches per decade since 1978 at Duck, NC, and 0.9 inches per decade at Wilmington, NC, mainly due to different rates of land subsidence.

2. Projected Changes

The projections of North Carolina climate conditions presented in this report are based on the ***virtual certainty*** that greenhouse gas concentrations, particularly CO_2, will continue to rise. It may take decades for non-carbon-based sources of energy to replace most of the production based on fossil fuels. The basic principles of physics dictate that increases in greenhouse gas concentrations will have a warming effect, with ***virtual certainty***, due to the increase in atmospheric absorption of infrared energy.

Quantitative projections for temperature, precipitation, and sea level rise are provided for two future scenarios: a higher scenario (RCP8.5), in which greenhouse gas emissions continue to increase through the end of this century, and a lower scenario (RCP4.5), in which emissions increase at a slower rate, peak around the middle of this century, and then begin to decrease. RCP8.5 and RCP4.5 are Representative Concentration Pathways—scenarios used in climate model simulations to examine how Earth's climate would respond to differing levels of greenhouse gas concentrations. The numbers 8.5 and 4.5 refer to the magnitude of the energy imbalance in the climate system (in units of watts per square meter) that would result in the year 2100 from the increases in greenhouse gas concentrations specified by the respective



scenarios. By comparison, the increase in concentrations since the initiation of the Industrial Revolution has resulted in an imbalance of approximately 2.3 watts per square meter.

A very low scenario (RCP2.6) is also used occasionally in this report, but this scenario is very unlikely because there has been no slowdown in the annual growth rate of CO_2. Qualitative projections are based on expert judgment and assessment of the relevant scientific literature and draw on multiple lines of scientific evidence as well as model simulations. Except where noted, statements below about future changes refer to projections through the end of this century.

By the end of this century (2080–2099), global average temperature is projected to increase by about 4°–8°F compared to the current climate (1996–2015) under the higher scenario (RCP8.5) and by about 1°–4°F under the lower scenario (RCP4.5). The warming is projected to be greater in the middle and high latitudes and less at tropical latitudes.

Regional changes in temperature can differ from global changes, at least temporarily, as shown by the historical lower rate of warming in North Carolina compared to the global average. Seasonal and annual average temperatures, however, have been rising in North Carolina in recent decades, and it is ***very likely*** that North Carolina temperatures will continue to increase substantially in all seasons.

- By the middle of this century, annual average temperature increases relative to the current climate (1996–2015) for North Carolina are projected to be on the order of 2°–5°F under the higher scenario (RCP8.5) and 2°–4°F under the lower scenario (RCP4.5).
- By the end of this century, annual average temperature increases relative to the current climate (1996–2015) for North Carolina are projected to be on the order of 6°–10°F under the higher scenario (RCP8.5) and 2°–6°F under the lower scenario (RCP4.5).

Temperature extremes are also projected to change:

- It is ***very likely*** that the number of very warm nights will increase, continuing recent trends.
- It is ***likely*** that the number of very hot days will increase, although the level of confidence is lower than for very warm nights because of the lack of recent trends.
- It is ***likely*** that the number of cold days and very cold nights will decrease, but again the level of confidence is lower than for very warm nights because of the lack of recent trends.

Several additional climate features directly tied to temperature are also projected to change, with a high level of certainty:

- It is ***very likely*** that extreme precipitation frequency and intensity will increase because global ocean surface temperatures will continue to increase gradually. In turn, near-surface air temperature and absolute humidity will increase over the oceans because maximum water vapor content is strongly related to temperature, increasing by about 3.5% per °F.
- It is ***virtually certain*** that global sea level will continue to rise due to both the expansion of ocean water from warming and from the melting of ice on land, including the Greenland and Antarctic ice sheets. It is ***virtually certain*** that sea level along the North Carolina coast will also continue to rise. Under the higher scenario (RCP8.5), storm-driven water levels having a 1% chance of occurring each year in the beginning of the 21st century may have as much as a 30%–100% chance of occurring each year in the latter part of the century. High tide flooding is projected to become nearly a daily occurrence by 2100 under both the lower and higher scenarios.
- It is ***very likely*** that summer heat index values will increase because of increases in absolute humidity.
- It is ***likely*** that the probability of snowfall and snow cover will decrease nearly everywhere in North Carolina because of warmer temperatures.



For climate variables where the temperature dependence is more complex, projected changes are less certain:

- Inland flooding depends not only on extreme precipitation but also on characteristics of the land surface, including land use, land cover, and soil moisture conditions. It also depends on whether deliberate adaptive measures are implemented proactively. It is ***likely*** that the frequency and severity of inland flooding will increase because of increases in the frequency and intensity of extreme precipitation. This lower level of certainty compared to projections for changes in extreme precipitation stems from the additional factors that determine flooding.
- It is ***likely*** that annual total precipitation in the state will increase, but there is less certainty for annual total precipitation than for projected increases in extreme precipitation because total precipitation is a function of both atmospheric water vapor and the frequency and intensity of weather systems that cause precipitation. Future changes in the intensity and frequency of such weather systems are more uncertain.

Hurricanes have some of the most important impacts on the state, often catastrophic (storm surge, wind, and flooding damage) but sometimes beneficial (rainfall recharging soil moisture and groundwater aquifers). An understanding of future changes in hurricanes has been the subject of extensive research by climate scientists. While that understanding continues to evolve, a recent assessment of the science leads to the conclusion that the intensity of the strongest hurricanes is ***likely*** to increase with warming, and this could result in stronger hurricanes impacting North Carolina. Confidence in this result is ***high*** for tropical cyclone changes on a global scale. For individual regions such as North Carolina, the confidence in this outcome is medium. While confidence for North Carolina is lower than for the entire globe, there is no known reason that North Carolina would be protected from stronger hurricanes and this potential risk should be considered in risk assessments.

It is ***virtually certain*** that rising sea level and increasing intensity of coastal storms, especially hurricanes, will lead to increases in storm surge flooding in coastal North Carolina. There is ***low confidence*** concerning future changes in the total number of hurricanes. The total number of hurricanes depends on a variety of meteorological factors, such as vertical wind shear (changes in wind speed or direction with height in the atmosphere), and not just ocean surface temperatures, and there is considerable uncertainty about changes in these other factors. Heavy precipitation accompanying hurricanes is ***very likely*** to increase, increasing the potential for freshwater floods.

Severe thunderstorms (hail, tornadoes, and strong winds) are a regular occurrence in North Carolina, particularly in the spring. Severe thunderstorms require two primary atmospheric conditions: an unstable atmosphere and high vertical wind shear. It is ***very likely*** that vertical instability will increase, but it is also ***likely*** that vertical wind shear will decrease. These may counteract one another. Recent research suggests that the increases in atmospheric instability will dominate. While this remains an active area of research, it is ***likely*** that there will be increases in the frequency of severe thunderstorms.

Other important weather systems include snowstorms, winter coastal storms, and ice storms. There is considerable uncertainty about future changes in the number and severity of extratropical cyclones—the weather phenomenon that causes each of these winter storm types. In the case of snow, temperature is an important factor, and it is ***likely*** that total snowfall and the number of heavy snowstorms will decrease because of increasing temperatures. There is ***low confidence*** concerning future changes in the number of ice storms and winter coastal storms.

Drought can have major impacts on the state, including agricultural production, water availability in rivers, lakes, and aquifers, and wildfires. The impacts on these different sectors and systems varies depending on the duration and spatial scale of the precipitation deficits. Although overall precipitation is projected to increase, this is principally a result of larger amounts during heavy rain events. Intervening dry periods are projected to become more frequent and higher temperatures during those dry periods will

more rapidly deplete soil moisture. Thus, it is ***likely*** that major droughts in their multiple forms will become more frequent and severe because of higher temperatures that will increase evaporation rates. As a result, it is ***likely*** that the climate conditions conducive to wildfires in North Carolina will increase in the future.

The major urban areas of the state have expanded substantially over the past few decades, and this trend shows no signs of abating. The urban heat island effect results from the conversion of vegetated surfaces (such as forests and farmland) to urban and suburban landscapes with substantial percentages of impervious, non-vegetated surfaces, reducing the amount of natural cooling from evapotranspiration (the combination of evaporation of water from the surface and transpiration of water vapor from vegetation) and increasing the amount of heat retained in darker, paved surfaces as compared to natural land cover. It is ***likely*** that future warming in urban areas will be enhanced by future growth of those areas.

Near-surface ozone is a major component of air pollution, and harmful levels of near-surface ozone result from a combination of climate conditions and human-caused emissions of compounds necessary for the formation of ozone, including nitrogen oxides, carbon monoxide, and volatile organic compounds (referred to as ozone precursor compounds). Near-surface ozone concentrations tend to increase with temperature. However, changes in other climate conditions, such as increased precipitation, can counteract the temperature effect. Overall, it is uncertain what the net effect will be. Thus, there is ***low confidence*** concerning future changes in the conditions favorable for near-surface ozone concentrations.

Climate design values, which provide information on the average and extreme climate conditions experienced in a given location, are important for planning and designing many types of infrastructure. Many climate design values are projected to change because of warming. Because of the high level of confidence in increased temperature and extreme precipitation, it is ***very likely*** that some current climate design standards for building and other infrastructure will change by the middle of this century. This includes increases in design values for precipitation, temperature, and humidity. In fact, current design values are based on historical data and do not incorporate recent trends; thus, some standards may already be out of date. Several professional societies, however, are actively working on methods to incorporate climate change into national standards, and updated standards appropriate for use in a changing climate may be available in the near future.

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Chapter 4

Climate and Environmental Justice

4. Climate and Environmental Justice

The state of North Carolina gratefully acknowledges significant input from the DEQ's Secretary's Environmental Justice and Equity Advisory Board's Climate Change and Extreme Weather Resilience Subcommittee to this chapter.

A. What Is Climate Justice?

Climate change does not affect all people equally. Some people live in places that are more vulnerable to climatic stressors. Others, by nature of their race, wealth, income, age, or other characteristic, are made more vulnerable to climate hazards. These demographic, economic, and social attributes are collectively described as **social vulnerability**. According to scholars, social vulnerability is "the characteristics of a person or their group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard."[1]

Different levels of social vulnerability reflect – and may magnify – historic, social, and economic inequalities. The impacts of natural disasters are often disproportionately felt in low-income communities and communities of color, who may face additional burdens like poor political representation, housing instability, or discrimination.[2] For example, the average black worker in New Orleans was seven times more likely to lose their job after Hurricane Katrina than the average white worker.[3]

The intersection of social inequality with environmental issues is not unique to climate change; it exists in many arenas of environmental decision-making and impact. **Environmental justice**[4] is defined by the U.S. EPA as "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies." So-called "fenceline" communities, which are those located closest to existing environmental hazards, may also be "front-line" communities, or those that experience negative impacts of climate change first and worst.

Climate justice refers to a social and political movement that acknowledges the deep inequities posed by climate change impacts and identifies opportunities to focus greenhouse gas mitigation and climate change adaptation efforts on the needs of those who are most vulnerable.[5] These inequities function at all geographic scales – from disparities among neighborhoods in one town to differences among the Global North and Global South. Climate justice efforts around the world focus on many topics. Often, climate justice advocacy aims at equity in greenhouse gas reduction schemes or in efforts to shift economic systems away from environmentally-unsustainable practices. Other climate justice work focuses on inequalities in climate outcomes. This chapter examines the inequalities in climate change impacts in North Carolina and actions that can achieve equitable resiliency. The 2019 North Carolina Clean Energy

[1] Davis, I., Blaikie, P.M., Wisner, B., Cannon, T. (2003). *At Risk: Natural Hazards, People's Vulnerability and Disasters*. Routledge.
[2] Elliott, J.R., & Pais, J. (2006). "Race, class, and Hurricane Katrina: Social differences in human responses to disaster." *Social science research* 35(2): 295-321.
[3] Elliott, J.R., and Pais, J. (2006). "Race, class, and Hurricane Katrina: Social differences in human responses to disaster." *Social science research* 35.2: 295-321.
[4] North Carolina is often cited as the birthplace of the Environmental Justice movement. Large protest against citing a toxic waste landfill in Warren County, North Carolina, shined a spotlight on the concentration of waste facilities and other contaminants in communities of color. Learn more about North Carolina Department of Environmental Quality's Environmental Justice Program at https://deq.nc.gov/outreach-education/environmental-justice. Since the First National People of Color Environmental Leadership Summit, the *17 Principles of Environmental Justice* have served to define the foundation of the EJ movement.
[5] Lee, C. (2014 April 24). *Climate Justice.* Retrieved from https://blog.epa.gov/2014/04/24/climate-justice/.



Plan provides more information about social equity in the reduction of greenhouse gases in North Carolina.[6]

North Carolina faces serious challenges to adapt to climate change, but an equitable and just resilience strategy has the potential to bring about positive change in many arenas. To achieve climate justice, climate solutions must be shared equitably. Climate resilience requires that all of our state's residents have access to opportunities and capabilities that enable healthy, secure lives. Once we achieve this level of wellbeing for all residents, communities will have greater abilities to cope with a flood, wildfire, or extreme heat. By marrying goals of social equity and climate resilience, we commit to the health and safety of all residents, the expansion of economic opportunities across the state, the sustainability of our natural resources, and the vibrancy of our state's heritage and many cultures. The resilience of our state depends on these conditions.

North Carolina is on the front line of climate change. Our state and people will experience countless effects from the changing climate in the coming years, decades, and centuries. It is no longer a question of whether North Carolina will experience these effects, arguably, the state has already indeed experienced varying impacts of the changing climate. Rather, the question becomes, how will the state equitably[7] address the challenges posed by climate change and seize the opportunities to mitigate risks and best adapt our communities to a climate-altered future? The vision for a climate-just North Carolina is one for a state that recognizes the inequities of both the past and of the present, in order to create a more equitable future for all. A state that prioritizes communities most vulnerable to the risks of climate change and strengthens North Carolina's resilience and adaptive capacity, while providing opportunities for meaningful involvement to everyone at every stage. Working together with communities, organizations, Tribes, and government agencies at all levels, we can improve outcomes for the future. When race can no longer be used as an indicator to predict life outcomes and outcomes for all people are improved, we will have achieved climate justice.

B. Inequity in Climate Vulnerability and Resilience

Different populations within the state experience varying exposures to and impacts from climate change, especially climate-related hazards. **Exposure** refers solely to the condition of living, working, recreating, or learning in a place that could be adversely affected by a hazard, while **impacts** are characterized by the actual effects that result from these hazards. Evaluating both exposure and impact is critical to assessing vulnerability, or the likelihood of adverse impact from hazards, because impacts may differ among different areas or populations that are exposed to the same hazard.

In this section, we start by discussing examples of socially vulnerable populations and reasons for their elevated vulnerability to climate change. Next, we consider major climate risks and discuss geographic disparities in exposure to climate hazards for socially vulnerable populations. For each climate hazard, we overview issues related to inequalities in impact and adaptive capacity. The following section examines how existing conditions of health, housing, and economic inequalities reinforce climate injustices.

[6] State of North Carolina (2019). *North Carolina Clean Energy Plan: Transitioning to a 21st Century Electricity System*. Retrieved from https://files.nc.gov/ncdeq/climate-change/clean-energy-plan/NC_Clean_Energy_Plan_OCT_2019_.pdf

[7] The authors intentionally use the terms "equity" and "equality" throughout this Chapter, noting the distinction, as the Government Alliance on Race and Equity defines "equity is about fairness, while equality is about sameness." For example, equally distributing a resource (example: food) means giving the same amount to every individual regardless of need. Equitably distributing that resource means giving more food to some people who need additional amounts of that resource (food), such as underweight or famished individuals.

Finally, we consider how existing tools for improving resilience serve some communities and populations more effectively than others.

1. Socially Vulnerable Populations

There are a variety of individuals and groups that systematically face disparate impacts from climate change and barriers to adaptation in North Carolina. For example, minority populations are more likely to experience the damaging and destabilizing effects of climate change and are less likely to be able to recover from a climate hazard.[8] This difficult truth about the racial disparity in climate change impacts is in large part attributed to centuries of structural racism. According to researchers, **structural racism:**

"[i]nvolves interconnected institutions, whose linkages are historically rooted and culturally reinforced. It refers to the totality of ways in which societies foster racial discrimination, through mutually reinforcing inequitable systems (in housing, education, employment, earnings, benefits, credit, media, health care, criminal justice, and so on) that in turn reinforce discriminatory beliefs, values, and distribution of resources, which together affect the risk of adverse … outcomes."[9]

Structural racism is different from intentional, interpersonal discrimination. These types of discrimination matter, but structural racism is a more powerful driver of racial inequality, working even in the absence of intentional, interpersonal discrimination. The result of centuries of structural racism is visible across the state and apparent in unequal **compounding vulnerabilities,** or climate burdens piled on top of environmental, social, economic, or health burdens, that many minority communities experience today.

Different minority populations may be vulnerable to climate change for different reasons. For example, historic Native American settlements often are located near water in coastal or riverine floodplains, increasing their exposure to flooding.[10] In addition, a diversity of Native American communities have strong cultural and/or economic relationships with land or specific sites, which makes them particularly sensitive to the effects of climate change.[11] North Carolina has more Native Americans than any state east

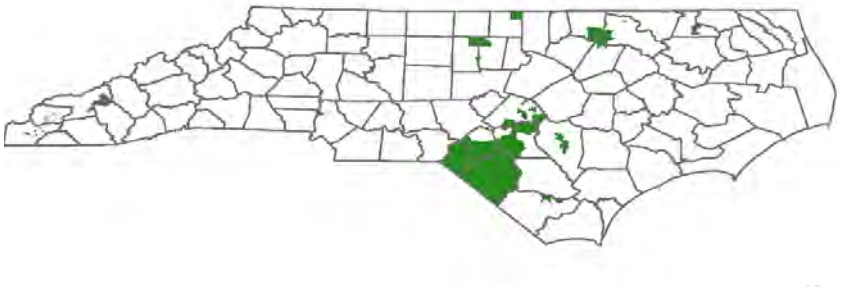


Figure 4-1: State Designated Tribal Statistical Areas in North Carolina

[8] Thomas, K., Hardy, R. D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., … Winthrop, R. (2019). Explaining differential vulnerability to climate change: A social science review. *Wiley interdisciplinary reviews. Climate change*, *10*(2), e565. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6472565/

[9] Bailey, Z. D., Krieger, N., Agénor, M., Graves, J., Linos, N. & Bassett, M. T. (2017). America: Equity and Equality in Health 3, Structural racism and health inequities in the USA: evidence and interventions. *The Lancet, 389,* 1453. Retrieved from: https://www.rootcausecoalition.org/wp-content/uploads/2017/04/Structural-racism-and-health-inequities-in-the-USA-evidence-and-interventions.pdf

[10] National Congress of American Indians. (n.d.) *Climate Change.* Retrieved from http://www.ncai.org/policy-issues/land-natural-resources/climate-change

[11] Wildcat, D.R. (2014). "Introduction: climate change and indigenous peoples of the USA." *Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions.* Springer.



of the Mississippi, and their diversity is partially reflected in the wide distribution of state designated tribal statistical areas, mapped in Figure 4-1.

Immigrants are at particular risk for climate change in North Carolina as well. According to the U.S. Census, nearly half a million North Carolina residents speak English less than "very well." Individuals with limited English proficiency encounter barriers to receiving information critical to their health and safety. For many immigrant communities where both documented and undocumented immigrants may live, risk of deportation and a historical mistrust of government officials in their home countries may lead to a lack of trust in government officials in the United States, which in turn may limit access to emergency services, recovery programs, and resilience resources.

Race, ethnicity, nationality and language are not the only drivers of unequal vulnerability. Income, age, disability, and location within the state also underlie inequities. Low-income households, including many seniors on fixed incomes, have few financial resources necessary to fix damage from hazards, afford increasing energy bills, or to absorb fluctuations in the cost of food. Homeless populations face exposure to the elements, limited access to medical and mental health services, and lack the financial resources to address impacts of climate change. Rural populations have a greater share of adults who work in weather-dependent environments like agriculture and forestry, where climate change may affect one's ability to earn a living.

Populations with elevated health stressors are also more susceptible to impacts of climate change. Many health stressors like diabetes and respiratory issues are themselves tied to the social and economic conditions of people's lives and the places they inhabit.[12,13,14] These conditions are often referred to as social determinants of health (SDOH) and they include economic stability, neighborhood conditions, access to healthcare, education, and other kinds of community context.[15] SDOH help us understand the compounding ways that social stressors like racial inequality and poverty increase the impact of climate change. These socioeconomic conditions shape our exposure to climate hazards, access to resources to cope with impacts, and sensitivity to health effects.

For example, poor households, already at increased risk for respiratory problems, are more likely to lack central air conditioning, which makes them more likely to suffer mold and poor indoor air quality after a flood. Low-income and minority neighborhoods experience elevated levels of diabetes and are more likely to be located in "food deserts," or areas without access to fresh food.[16] When climate stressors interrupt agriculture, food prices increase, exacerbating the affordability and availability of fresh food,[17] which worsens diabetes outcomes. These are examples of compounding vulnerabilities. While these examples comprise major dimensions of climate inequity in North Carolina, they are far from the only demographic, social or economic attributes that systematically elevate risk and lower resilience.

[12] Garcia, J. G., & Sznajder, J. I. (2013). Healthcare disparities in patients with acute respiratory distress syndrome. Toward equity.
[13] Peek, M. E., Cargill, A., & Huang, E. S. (2007). Diabetes health disparities. *Medical Care Research and Review*, *64*(5_suppl), 101S-156S.
[14] Garcia, J. G., & Sznajder, J. I. (2013). Healthcare disparities in patients with acute respiratory distress syndrome. Toward equity.
[15] Centers for Disease Control and Prevention. (n.d.) *Social Determinants of Health: Know What Affects* Health. Retrieved from https://www.cdc.gov/socialdeterminants/index.htm
[16] [46] Walker, R. E., Keane, C. R., & Burke, J. G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & place*, *16*(5), 876-884.
[17] https://www.cdc.gov/climateandhealth/effects/default.htm

2. Unequal Exposure, Unequal Impact

Maps can help illustrate where socially vulnerable populations may have elevated exposure to climate hazards in North Carolina. To achieve this objective, this chapter uses the Department of Environmental Quality's environmental justice mapping protocol. Using standard environmental justice guidelines from the U.S. EPA and the National Environmental Policy Act (NEPA) guidance, the DEQ protocol identifies Census block groups as *potentially underserved* if their populations are disproportionately nonwhite and disproportionately experiencing poverty. Specifically, potentially underserved populations meet the following criteria for both race and poverty:

Racial composition:

- Share of nonwhites is over fifty percent OR
- Share of nonwhites is at least ten percent higher than county or state share

Poverty rate:

- Share of population experiencing poverty is over twenty percent AND
- Share of households in poverty is at least five percent higher than the county or state share

The concept and definition of *potentially underserved communities* is just one way to illustrate inequality in climate exposure. In this chapter's recommendations, we suggest experimenting with a diversity of mapping methodologies and data sources to better understand the distribution of climate exposure. One caveat related to the use of maps is that some factors that influence how a community or household is impacted by a climate hazard, like political influence or social capital, may never be particularly well captured by quantitative or spatial data. The maps in this chapter distinguish between a higher share of minorities or an elevated level of poverty compared to the county and the state. Comparing at a county level allows identification of potentially underserved areas within a specific county. This scale provides a localized understanding of underserved areas and may assist local officials in targeting specific areas in their county for enhanced engagement, mitigation, or services. Comparison with the state allows for a state level analysis of potentially underserved areas, which similarly may assist state officials in targeting areas that may be underserved on the state level.

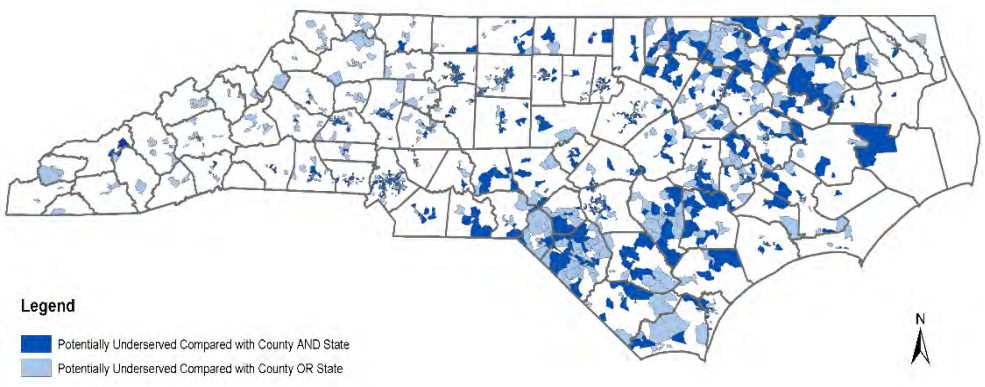


Figure 4-2: Potentially Underserved Populations in North Carolina[18]

[18] Data are derived from the *American Community Survey* (U.S. Census Bureau) 2017 Five-year estimates, using the following tables: *B03002- Hispanic or Latino Origin by Race* and *C17002- Ratio of Income to Poverty Level*.

Relying on data from the U.S. Census Bureau *American Community Survey* 2017 Five-year estimates, Figure 4-2 illustrates the distribution of potentially underserved populations across the state. Note that Census block groups are determined by population, not land area, so potentially underserved populations in rural areas display more prominently on a statewide map than those in dense, urban areas.

This chapter uses historical climate data to visualize the presence of potentially underserved populations in areas of elevated risk for five climate-driven hazards in North Carolina: wildfires, inland flooding, excessive heat, coastal flooding, and landslides. In the future, we recommend the development of maps that use projected climate data, when it is available at the statewide level, and updated U.S. Census data to further understand inequalities in climate exposure. In addition to mapping unequal exposure to the selected climate-driven hazards, we include a brief consideration of inequalities in impacts of exposure.

Wildfires

Climate conditions conducive to wildfire are likely to increase in North Carolina[19], as they will in many parts of the country and the globe.[20] As shown in Figure 4-3, wildfire risk is greatest among potentially underserved communities in the southern and western regions of the state. Some of the most affected counties include Robeson, Hoke, Brunswick, and Bladen in the southern region of the state, and Henderson, Buncombe, Cleveland, Burke, Catawba and Iredell counties in the western region of the state.

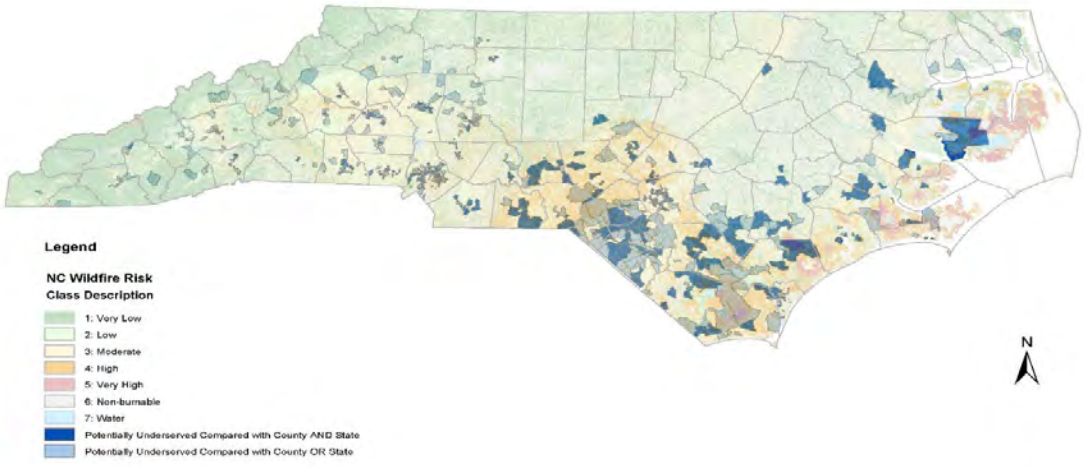


Figure 4-3: Potentially Underserved Populations and Current Wildfire Risk[21]

Wildfire poses many risks to the health and well-being of North Carolina residents. The North Carolina Department of Health and Human Services *Climate and Health Profile* indicates that air quality and respiratory diseases are the most significant public health impact of climate change in the state.[22] Wildfire causes deterioration in air quality, triggering respiratory and cardiac health problems. During the wildfires in Dare County in 2008, hospital emergency departments experienced an estimated 42 to 66 percent

[19] For more information, see Chapter 3: NC Climate Science Report
[20] Liu, Y., Stanturf, J., & Goodrick, S. (2010). Trends in global wildfire potential in a changing climate. *Forest ecology and management*, *259*(4), 685-697. Retrieved from https://www.srs.fs.usda.gov/pubs/36444
[21] Data from: USDA Forest Service. (2018). *Wildfire Hazard Potential (WHP)*. Retrieved from https://www.firelab.org/project/wildfire-hazard-potential
[22] North Carolina Department of Health and Human Services. (n.d.). *North Carolina Climate and Health Profile.* Retrieved from https://epi.dph.ncdhhs.gov/oee/climate/ClimateAndHealthProfile.pdf

increase in visits for respiratory and cardiovascular problems.[23,24] Socio-economic variables affect the number of wildfires, their extent, and their impact. Wildfires that start in high-poverty communities are less likely to be extinguished quickly due to lack of resources.[25] Health impacts of wildfire smoke also have greater impact across social and demographic differences, like greater mortality among senior citizens.[26] Wildfire also has economic impacts on North Carolina. The ecological damage resulting from wildfires harms communities that derive economic activity and employment from scorched areas,[27] which could include Christmas tree farming operations, logging, or tourism. Workers in these industries are disproportionately at risk from economic burdens of wildfire, in addition to other elevated economic and health risks of outdoor work due to climate change.

Inland Flooding

Inland flooding is one of the most common natural hazards experienced in North Carolina, and climate change is projected to increase the frequency of extreme precipitation events that cause inland flooding.[28] Inland flooding is magnified by non-climate-related factors such as floodplain development, urbanization,

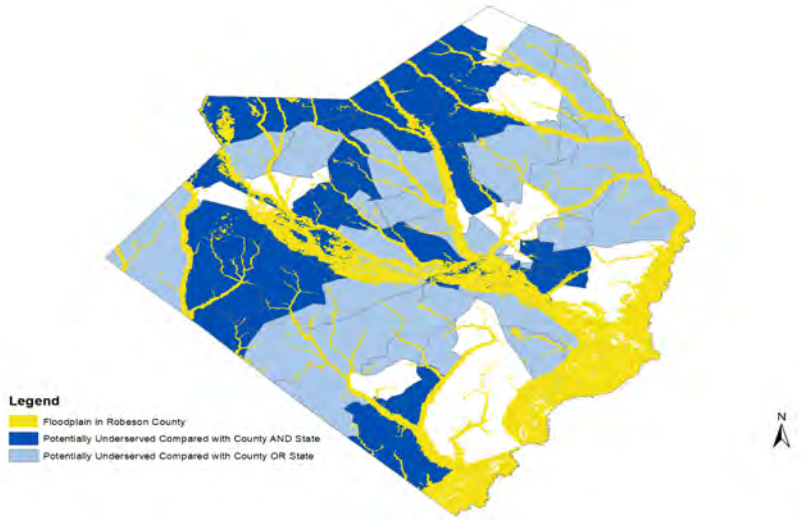


Figure 4-4: Potentially Underserved Populations and Floodplain in Robeson County, North Carolina[29]

[23] Rappold, A.G., Stone, S.L., Cascio, W.E., Neas, L.M., Kilaru, V.J., Carraway, M.S., …Devlin, R.B. Peat bog wildfire smoke exposure in rural North Carolina is associated with cardiopulmonary emergency department visits assessed through syndromic surveillance. (2011). *Environmental Health Perspectives*. 119:1415-20. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/21705297

[24] Tinling MA. Emergency Department Diagnoses in Eastern North Carolina Associated with Smoke Exposure from the 2011 Pains Bay Wildfire. 2012. Master's thesis. Cited in North Carolina Department of Health and Human Services. (n.d.). *North Carolina Climate and Health Profile.* Retrieved from https://epi.dph.ncdhhs.gov/oee/climate/ClimateAndHealthProfile.pdf

[25] Mercer, D. E., & Prestemon, J. P. (2005). Comparing production function models for wildfire risk analysis in the wildland–urban interface. *Forest policy and economics*, *7*(5), 782-795. Retrieved from https://www.fs.usda.gov/treesearch/pubs/21080

[26] Kochi, I., Champ, P. A., Loomis, J. B., & Donovan, G. H. (2012). Valuing mortality impacts of smoke exposure from major southern California wildfires. *Journal of forest economics*, *18*(1), 61-75. Retrieved from https://www.fs.fed.us/rm/pubs_other/rmrs_2012_kochi_i001.pdf

[27] Butry DT, Mercer DE, Prestemon JP, Pye JM, Holmes TP. (2001). *What is the price of catastrophic wildfire?* Retrieved from https://www.srs.fs.usda.gov/pubs/ja/ja_butry001.pdf

[28] United States Environmental Protection Agency. (2015). *Climate Action Benefits Report: Inland Flooding.* Retrieved from https://www.epa.gov/cira/climate-action-benefits-inland-flooding#findings. For more information, see Chapter 3: NC Climate Science Report

[29] Data from: EnviroAtlas. (2018). *Estimated floodplain map for the Conterminous United States.* Retrieved from https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7B4c37f02a-0c91-49b2-b7df-82ea4a6b9750%7D

and land-use changes.[30] It is one of the most widespread risks in the state, even as acute impacts are very localized. Inland flooding affects people of all socioeconomic backgrounds, but mapping demonstrates that exposure is often concentrated in areas of social vulnerability. An example from Robeson County in Figure 4-4 demonstrates the risk of inland flooding on potentially underserved communities in the county. Future maps should be downscaled further to better understand the location of housing and development in socially vulnerable areas with respect to flood risk. Regulatory floodplains have not proven consistent predictors of the location of flooding in recent storms, so improved modeling for inland flood risk would also improve the accuracy of exposure maps.

Socially vulnerable communities may be concentrated in areas exposed to inland flooding for many reasons. Land values are typically lower in a floodplain, making homes more affordable to build, sell, or rent. Historic patterns of racial housing discrimination have resulted in concentrations of communities of color, especially African Americans, living in flood prone areas. In addition, the impact of inland flooding disproportionately disrupts the lives of socially vulnerable populations. Low-income households, seniors, people with disabilities, and people with chronic illnesses may have less access to transportation, making evacuation or mobility difficult during a flood.[31] Individuals with low incomes have less ability to pay for hotels in the event they are evacuated or less disposable income to replace spoiled food in case of a power outage. Because of differences in the quality of housing and insurance coverage, wealthier communities often recovery more quickly from inland flooding.

Extreme Heat

Most areas of North Carolina have warmed in the last century, and this warming is projected to continue. Within 70 years, it is estimated that most of the state will experience between 20 and 40 days a year of temperatures above 95° F, defined as "extreme heat."[32] The Climate Science Report, summarized in Chapter III, projects that by the end of the century, annual average temperature will increase 5° to 10°F under a higher, "business as usual" emissions scenario (RCP8.5) and 2° to 6°F under a lower emissions scenario (RCP4.5).

Figure 4-5 illustrates that areas with elevated extreme heat days are largely concentrated in the Eastern part of the state, creating a band from Northampton and Hertford counties south to Robeson, Columbus, and Brunswick counties. Several counties, including Robeson, Sampson, Duplin, Wayne, Bertie, and Halifax have both high percentages of potentially underserved populations and elevated extreme heat days. High heat in urban areas is magnified by the urban heat-island effect. According to NASA, "an urban heat island occurs when a city experiences much warmer temperatures than nearby rural areas. The difference in temperature …has to do with how well the surfaces in each environment absorb and hold heat."[33] The heat island effect also triggers increases in energy consumption for air conditioning, which increases adverse public health impacts due to emissions from energy production and consumption.[34] Many households in potentially underserved areas are located in urban areas, including the cities of Charlotte, Raleigh, Durham, Fayetteville, Greenville, and Wilmington, which already experience an elevated number of extreme heat days.

[30] United States Environmental Protection Agency. (2015). *Climate Action Benefits Report: Inland Flooding.* Retrieved from https://www.epa.gov/cira/climate-action-benefits-inland-flooding#findings.
[31] Ibid.
[32] Data from: EnviroAtlas. (2018). *Estimated floodplain map for the Conterminous United States.* Retrieved from https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7B4c37f02a-0c91-49b2-b7df-82ea4a6b9750%7D
[33] NASA (n.d.). *What is an Urban Heat Island?* Retrieved from https://climatekids.nasa.gov/heat-islands/
[34] United States Environmental Protection Agency. (2019) *Heat Island Impacts.* Retrieved from https://www.epa.gov/heat-islands/heat-island-impacts

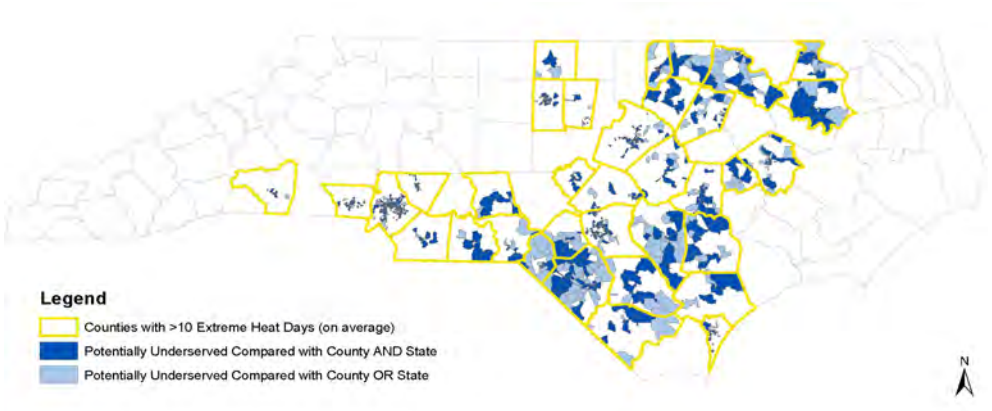


Figure 4-5: Potentially Underserved Populations in Counties with > 10 Average Extreme Heat Days Annually[35]

Individuals exposed to extreme heat are vulnerable to heat-related illness, and research shows that social characteristics exacerbate that risk. For example, in urban environments, poverty and low educational attainment are associated with increases in emergency department visits for heat-related illness.[36] In rural areas, the number of mobile homes and the labor intensity of agriculture are likewise associated with increased heat-related illness.[37]

Storm Surge

According to the 2020 North Carolina Climate Science Report (NCCSR), summarized in Chapter 3, it is "virtually certain" that rising sea level and increasing intensity of coastal storms will drive increases in storm surge flooding. This climate hazard will certainly impact high-value, ocean-facing properties, but communities on the Inner Banks or otherwise near coastal waters face significant risk too, like New Bern or the Down East villages of Carteret County. Many of these communities have unique, historic cultures and heritage, the continuity of which is threatened by climate change. In figure 4-6, potentially underserved communities at risk of storm surge exposure from a Category 5 hurricane are identified in blue against the storm surge areas in yellow. Clusters of potentially underserved communities exposed to storm surge exist along the entire North Carolina coastline and throughout the sounds, including Shallotte, Wilmington, South Jacksonville, New Bern, East Greenville, Edenton, and Elizabeth City. Differential impacts of storm surge are similar to those of inland flooding. Homes in higher poverty areas are less likely to be elevated, the burden of evacuating is greater for poor households and people with disabilities, and navigating insurance and government recovery programs favors people with more education.

[35] Data from: xmACIS2. (2019). *Temperature data 1996-2016.* https://xmacis.rcc-acis.org/
[36] Kovach, M. M., Konrad II, C. E., & Fuhrmann, C. M. (2015). Area-level risk factors for heat-related illness in rural and urban locations across North Carolina, USA. *Applied Geography*, *60*, 175-183. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0143622815000788
[37] Kovach, M. M., Konrad II, C. E., & Fuhrmann, C. M. (2015). Area-level risk factors for heat-related illness in rural and urban locations across North Carolina, USA. *Applied Geography*, *60*, 175-183. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0143622815000788

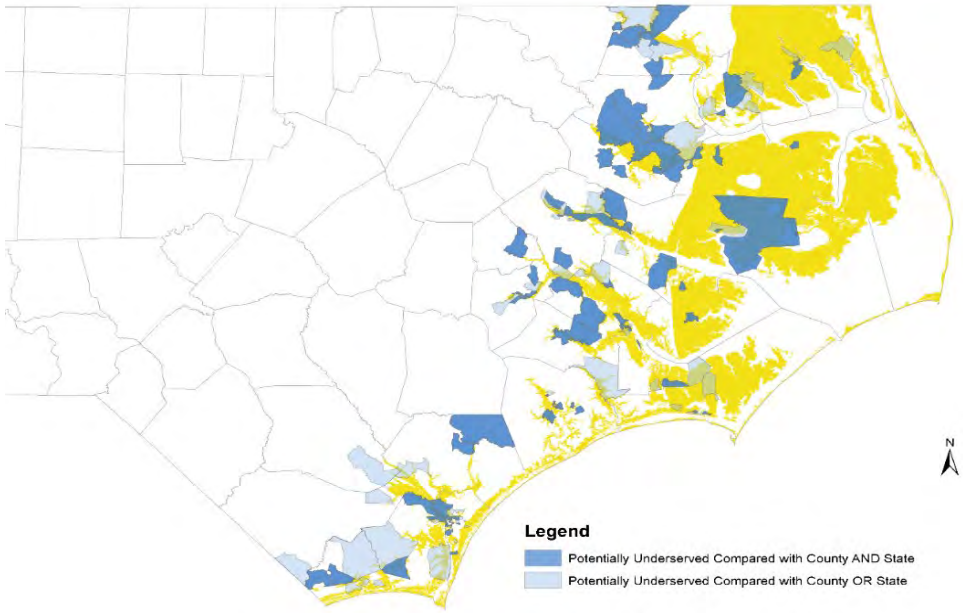


Figure 4-6: Potentially Underserved Populations in Storm Surge Areas[38]

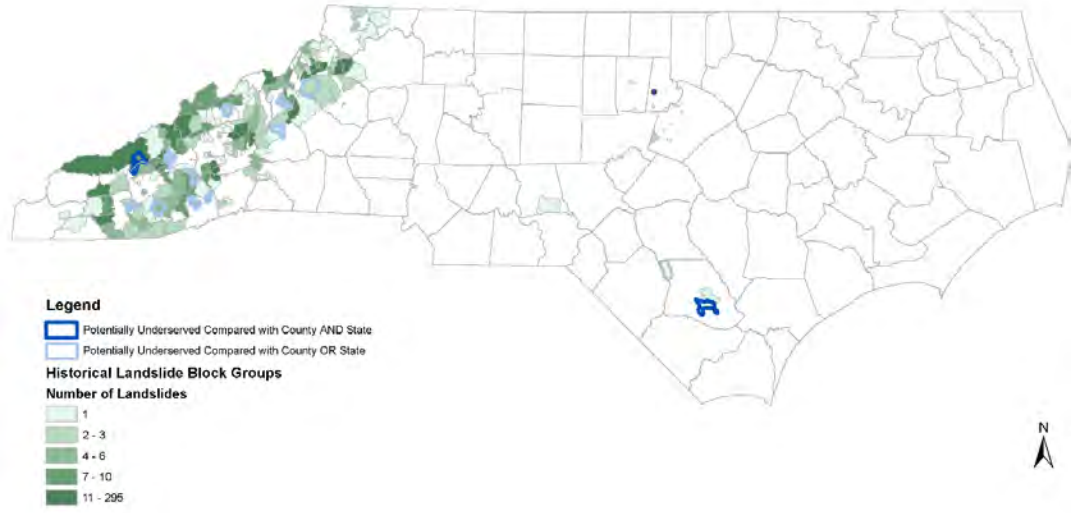


Figure 4-7: Potentially Underserved Populations in Historic Landslide Areas[39]

[38] Data from: NOAA. (2018). *National Storm Surge Hazard Maps- Version 2 (Category 5).* Retrieved from https://www.nhc.noaa.gov/nationalsurge/

[39] Data from: NC Geological Survey. (2019). *North Carolina slope movement-slope movement deposit database (NCSM-SMD database).* Retrieved from: https://www.nconemap.gov/datasets/landslides

Landslides

A changing climate can increase landslide risk via multiple pathways, including an increase in air temperatures, higher intensity and more frequent rain events, and drought (particularly in the summer).[40,41] As shown in Figure 4-7, the overwhelming majority of landslides occur in the western region of the state, with just a few occurring in central North Carolina. There are approximately twenty Census block groups classified as potentially underserved communities located in areas with a history of landslides. These areas are primarily located in the West but also present in other areas of the state.

Landslides often occur without warning. Populations with a limited ability to flee the impacted area due to the lack of vehicle access, older age, or limited mobility, are disproportionately more likely to experience adverse health and safety effects. Landslides also cause significant damage to private property and infrastructure. For households, recovery from this damage requires financial resources. Landslides tend to be localized, so they are unlikely to trigger a Presidential disaster declaration. Without federal recovery resources, state and local governments with infrastructure damage will need to spend their own funds on repair. Both of these realities favor landslide recovery in wealthier areas.

3. Physical Infrastructure and Housing Disparities

Housing and neighborhood conditions in North Carolina predispose socially vulnerable communities to greater impacts of climate change. The lack of affordable housing strains household resources at every income level, but especially for those who are very low-income. As a result, very low-income individuals are more likely to experience long-term displacement and homelessness as a result of climatic events.

The inability to remain in secure housing can affect a person's ability to attend and perform well in school or in a job. Housing security in the context of climate hazards is tenuous for socially vulnerable populations. Housing and infrastructure in low-income and minority neighborhoods tends to be older and less weatherized to cope with climate hazards.[42] Neighborhoods with greater shares of minorities, low-income households, and renters tend to have less vegetation like street trees, which would decrease heat health impacts.[43,44] Not even considering the worsening of some neighborhood conditions around housing due to climate change impacts, racial disparities of health outcomes may already be linked with past racial segregation in housing.[45] These underlying housing and neighborhood conditions reflect social inequalities and magnify climate injustices.

Despite longstanding inequalities in health, housing and economic wellbeing, there are examples of resilience that are present and sometimes concentrated in socially vulnerable communities. For example,

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[40] Crozier, M. J. (2010). Deciphering the effect of climate change on landslide activity: A review. *Geomorphology*, *124*(3-4), 260-267.Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0169555X10001881

[41] Borgatti, L., Soldati, M. (2010). *Landslides and Climatic Change.* Retrieved from https://books.google.com/books?hl=en&lr=&id=YlIwBQAAQBAJ&oi=fnd&pg=PA87&dq=Borgatti,+L.,+Soldati,+M.+(2010).+&ots=pi3y7GGkEX&sig=QZGtsJ0c01Tx16135FnmYwkbTB8#v=onepage&q=Borgatti%2C%20L.%2C%20Soldati%2C%20M.%20(2010).&f=false

[42] Tonn, B., Schmoyer, R., & Wagner, S. (2003). Weatherizing the homes of low-income home energy assistance program clients: a programmatic assessment. *Energy Policy*, *31*(8), 735-744.

[43] Landry, S. M., & Chakraborty, J. (2009). Street Trees and Equity: Evaluating the Spatial Distribution of an Urban Amenity. *Environment and Planning A: Economy and Space*, 41(11), 2651–2670.

[44] Reid, C.E., O'Neill, M.S., Gronlund, C.J., Brines, S.J., Brown, D.G., Diez-Roux, A.V., & Schwartz, J. (2009). Mapping Community Determinants of Heat Vulnerability. *Environmental Health Perspectives.* 117(11). Retrieved from https://ehp.niehs.nih.gov/doi/10.1289/ehp.0900683

[45] Williams, D., & Collins, C. (2001). Racial Residential Segregation: A Fundamental Cause of Racial Disparities in Health. *Public Health Reports*, 116, 404-416.



bonding social capital plays an outsized role in coping with natural hazards or climatic impacts.[46] Bonding social capital describes connections and relationships within a group or community that draws on similar demographic characteristics, attitudes, beliefs, and resources.[47]

Many socially vulnerable communities have strong family, ethnic, faith-based, cultural, and community ties. Day-to-day social connections can support communication, shared responsibility, and strong personal relationships that form the basis for communal and household recovery and resilience. In these instances, bonding social capital is particularly critical because vulnerable communities may lack easy access to government aid and external assistance. Instead, social groups provide avenues to recovery. On the other hand, displacement and disruption caused by climate change can physically dismantle the social ties that comprise these sources of support. Therefore, it is essential to integrate an understanding of bonding social capital assets in planning for disasters and climate change.[48]

The state of North Carolina recognizes the role of underlying inequalities in many of its recovery and resilience programs. For example, to address housing inequalities, Office of Recovery and Resiliency (NCORR) will be dispersing hundreds of millions of dollars in Community Development Block Grants (CDBG) across many sectors (housing, water infrastructure, recovery, etc.) to support recovery primarily among low- to moderate- income (LMI) households or to benefit neighborhoods where LMI households reside. NCORR also works with the Historically Underutilized Businesses program in the Department of Administration to conduct outreach to firms interested in contracting for recovery work. Contractors with NCORR programs are required to substantially employ low- and very low-income persons to the greatest extent feasible. These are examples of ways in which the state's recovery programs have sought to support recovery in ways that acknowledge and address pre-existing disparities.

4. Inequalities in Climate Adaptation Interventions

In addition to uneven exposure to climate hazards and inequitable distribution of the impacts of those risks, some resilience interventions serve households and communities unequally. These disparities are present on different geographic scales.

Climate Adaptation Development

As in most places around the world, the majority of policy changes that support resilience in North Carolina have taken place at the local level. On one hand, local governments are well positioned to improve resilience through best practices like land use provisions and to cater their strategies to the resilience needs of their own communities. On the other hand, the delegated nature of resilience efforts favors local governments with the staff and resources to dedicate toward this purpose. Stakeholders from across the state who participated in the 2019 Regional resiliency workshops talked about the difficulty that smaller cities and towns face in addressing resiliency without more resources from higher levels of government. They told state staff that many communities that most need resiliency thinking, where infrastructure is already failing, for example, have the least capacity to dedicate staff or financial resources toward solutions. The state is addressing this disparity in many ways, through state-level action like Executive Order 80, the 2020 Resilience Plan, and the unified North Carolina Resilience Plan detailed in Chapter 7, and through providing resources to local governments through the North Carolina Resilient Communities Program, also detailed in Chapter 7.

[46] Aldrich, D. P., & Meyer, M. A. (2015). Social Capital and Community Resilience. *American Behavioral Scientist*, *59*(2), 254–269. Retrieved from https://doi.org/10.1177/0002764214550299
[47] Lin, N., Cook, K.S. & Burt, R.S. (2001*). Social Capital: Theory and Research*. New York: Aldine de Gruyter
[48] Aldrich, D. P., & Meyer, M. A. (2015). Social Capital and Community Resilience. *American Behavioral Scientist*, *59*(2), 254–269. Retrieved from https://doi.org/10.1177/0002764214550299

Another way in which resilience initiatives tend to exclude socially vulnerable communities is through their governance and approach. Historically, resilience efforts have not engaged organizations that interface most frequently with socially vulnerable populations, such as public schools, social service and healthcare providers, houses of worship, faith-based organizations, and public transit systems. These kinds of organizations could be the basis of very successful resilience efforts in the future. Some aspects of resilience efforts rely heavily on science to the exclusion of local community knowledge and lived experiences. For example, official modeling for established flood zones may be dissimilar from areas where people actually experience regular flooding, which complicates insurance policies and eligibility for recovery programs. Social science may favor one type of resilience solution, but local residents may understand that the solution is likely to fail in that place for local reasons. Moving forward, resilience initiatives could enrich their fact base by soliciting local knowledge.

There are also systemic reasons why socially vulnerable populations may not be well represented in all public policy, including resilience policy and planning. Citizen involvement and participation in public policy requires volunteering one's time to attend public hearings and meetings, which is difficult for individuals who care for children or the elderly, or for people who either work more than one job or do not have flexibility in their working hours. The language and process of public policy is virtually inaccessible to individuals with less education. Segregation and other factors of some socially vulnerable populations limit connections to and representation in government and other institutions of influences, which researchers call "bridging social capital."[49] Further, as participants in the regional resilience workshops expressed, a general sense of mistrust in government and government programs by socially vulnerable populations and leaders hinders the creation of beneficial partnerships.

Climate Adaptation Implementation

At the household scale, many resilience measures target property owners, leaving renters vulnerable to climate change impacts and related risks. For example, many of the state's programs for home elevations or property buyouts prioritize owner-occupied homes, which leaves renters more exposed to flooding. Other federal and state recovery programs are designed to help both homeowners and renters, but because homeowners own more valuable assets, i.e. their houses, more recovery aid goes to homeowners. Even among homeowners, those who can afford insurance or have access to personal financial resources are better situated to rebuild faster and more effectively than those who must wait for government assistance. This leads to obvious inequalities in disaster recovery.

Another structural inequality in resilience interventions relates to real estate values. For example, to build levees or other flood protection infrastructure, a benefit-cost analysis is required. The benefit of the potential investment is typically based on the value of real property that the infrastructure would protect. Naturally, this methodology favors investments in areas with high property values. On the other hand, buyouts or managed retreat strategies of last resort are more likely to occur in areas with lower property values because each additional buyout costs less than an equivalent buyout where property values are higher.[50] Governments may use a variety of tools to encourage buyouts, like construction moratoria, condemnation, and "substantially damaged" declarations.[51] These tools are often more effective in low-income neighborhoods because these individuals often rely on outside public or insurance assistance for recovery. The role of real estate values in public policy decisions increases the likelihood of in-place solutions for areas with higher values and increases the likelihood of buyout in areas with lower property

[49] Lin, N., Cook, K.S. & Burt, R.S. (2001*). Social Capital: Theory and Research*. New York: Aldine de Gruyter
[50] Siders, A. R. (2019). *Social Justice Implications of US Managed Retreat Buyout Programs*. Retrieved from https://doi.org/10.1007/s10584-018-2272-5.
[51] "Substantially damaged" refers to the finding that the home is over 50% damaged, which requires the home to be brought to current code, even if it had been built at an earlier point under lower code standards. De Vries, Daniel H., and James C. Fraser. (2017). *Historical Waterscape Trajectories That Need Care: The Unwanted Refurbished Flood Homes of Kinston's Devolved Disaster Mitigation Program.* Retrieved from https://doi.org/10.2458/v24i1.20976.

values. While most researchers agree that buyouts are a more secure solution to flood vulnerability, buyouts also have significant social costs like breaking apart neighborhoods and the impact of vacant lots on the neighborhood.

Leveraging Social Capital

Despite longstanding inequalities in physical infrastructure, health, and economic wellbeing, there are examples of resilience that are present and can be stronger in socially vulnerable communities. For example, bonding social capital plays an outsized role in coping with natural hazards or climatic impacts.[52] Bonding social capital describes connections and relationships within a group or community that draws on similar demographic characteristics, attitudes, beliefs, and resources.[53]

Many socially vulnerable communities have strong family, ethnic, faith-based, cultural, and community ties. Day-to-day social connections can support communication, shared responsibility, and strong personal relationships that form the basis for community and household recovery and resilience. In these instances, bonding social capital is particularly critical because vulnerable communities may lack easy access to government aid and external assistance. Instead, social groups provide avenues to recovery. On the other hand, displacement and disruption caused by climate change can physically dismantle the social ties that comprise these sources of support. Therefore, it is essential to integrate an understanding of bonding social capital assets in planning for disasters and climate change.[54]

C. Climate Justice Spotlight Issues

This section examines climate and environmental issues which have drawn significant concern in North Carolina, including:

- energy cost burden and higher heat;
- workers, small businesses, and family businesses in vulnerable industries;
- African American property ownership; and
- insurance inequalities.

These issues have been highlighted by the DEQ's Secretary's Environmental Justice and Equity Advisory Board's Climate Change and Extreme Weather Resilience Subcommittee as well as the state Disaster Recovery Task Force's Recovery Support Functions. Additionally, the effect of changing climate on outdoor workers and small businesses was identified as a major consequence in the NC Regional Resilience Workshops.[55]

1. Energy Burden and Higher Heat

Home energy cost is a significant financial strain for many individuals and families in North Carolina. As the state experiences progressively more days of extreme heat, energy burden, or the percentage of household income spent on home energy bills, will also increase. Fuel poverty, or the inability of

[52] Aldrich, D. P., & Meyer, M. A. (2015). Social Capital and Community Resilience. *American Behavioral Scientist*, *59*(2), 254–269. Retrieved from https://doi.org/10.1177/0002764214550299
[53] Lin, N., Cook, K.S. & Burt, R.S. (2001*). Social Capital: Theory and Research*. New York: Aldine de Gruyter
[54] Aldrich, D. P., & Meyer, M. A. (2015). Social Capital and Community Resilience. *American Behavioral Scientist*, *59*(2), 254–269. Retrieved from https://doi.org/10.1177/0002764214550299
[55] For more information, see Appendix C: NC Mountain and Piedmont Regional Resilience Workshops Report

households to afford adequate energy services, already exists in the state of North Carolina.[56] The U.S Department of Health and Human Services classifies an energy burden of above six percent of household income as unaffordable.[57] In North Carolina, many low-income homeowners and renters face an energy burden higher than 6%, with some county averages reaching 25% (shown in Figures 4-8 and 4-9). Higher rates of fuel poverty for low-income and minority households is a combined result of lower incomes and living in homes that are older and less fuel efficient, increasing the amount of energy required to maintain a healthy indoor temperature.[58,59] Renters are particularly vulnerable to energy cost burdens because landlords do not have a financial incentive to improve the efficiency of properties where tenants pay the utility bills.

Fuel poverty is particularly concerning in a warming North Carolina. Elevated levels of fuel poverty are present in all parts of the state. Figure 4-8 illustrates the geographic distribution of fuel poverty among homeowners overlaid with data on extreme heat and Figure 4-9 illustrates the same distribution among renters. Counties with the highest energy burden experience an elevated number of high heat days as compared to the rest of the state, include: Warren, Halifax, Northampton, Hertford, Bertie, Nash, Pitt, Sampson, Duplin, Bladen, Columbus, Anson, Richmond, and Caswell.

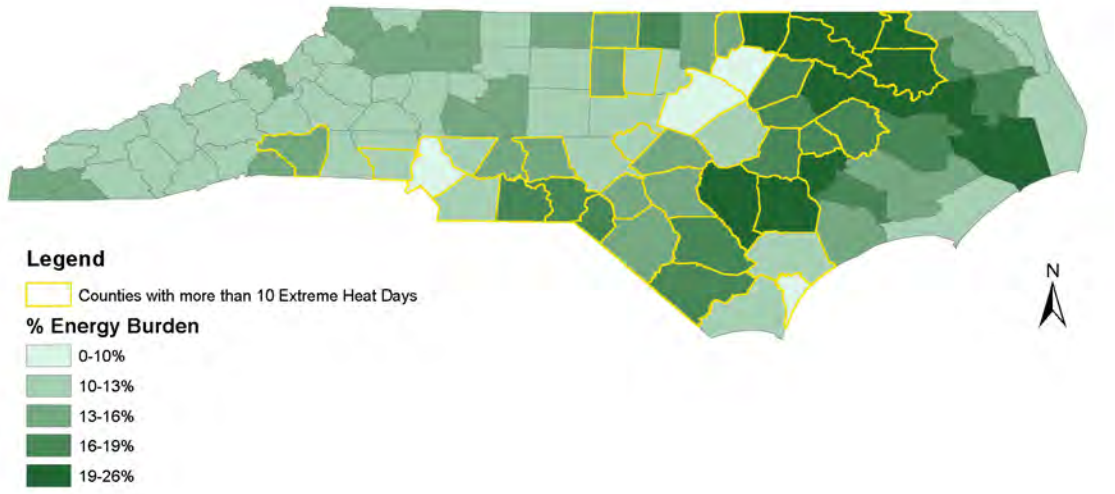


Figure 4-8: Energy Burden of Low-Income Homeowners by County[60] *Note that Figures 4-8 and 4-9 use different scales for rate of fuel poverty and therefore should not be compared on the basis of color gradient alone.*

[56] Moore, R. (2012). Definitions of fuel poverty: Implications for policy. *Energy policy*, *49*, 19-26. Retrieved from https://www.sciencedirect.com/science/article/pii/S0301421512000833
[57] North Carolina Housing Coalition. (2018). *Housing Matters: Mapping Energy Burden.* Retrieved from https://nchousing.org/housing-matters-mapping-energy-burden/
[58] Nevin, R. (2010). Energy-efficient housing stimulus that pays for itself. *Energy Policy*, *38*(1), 4-11. Retrieved from https://www.sciencedirect.com/science/article/pii/S030142150900696X
[59] Lewis, J., Hernández, D., & Geronimus, A. T. (2019). Energy efficiency as energy justice: addressing racial inequities through investments in people and places. *Energy Efficiency*, 1-14. Retrieved from https://link.springer.com/article/10.1007%2Fs12053-019-09820-z
[60] Map data from: North Carolina Housing Coalition. (2019). *2019 County Data.* Retrieved from https://nchousing.org/county-fact-sheets/

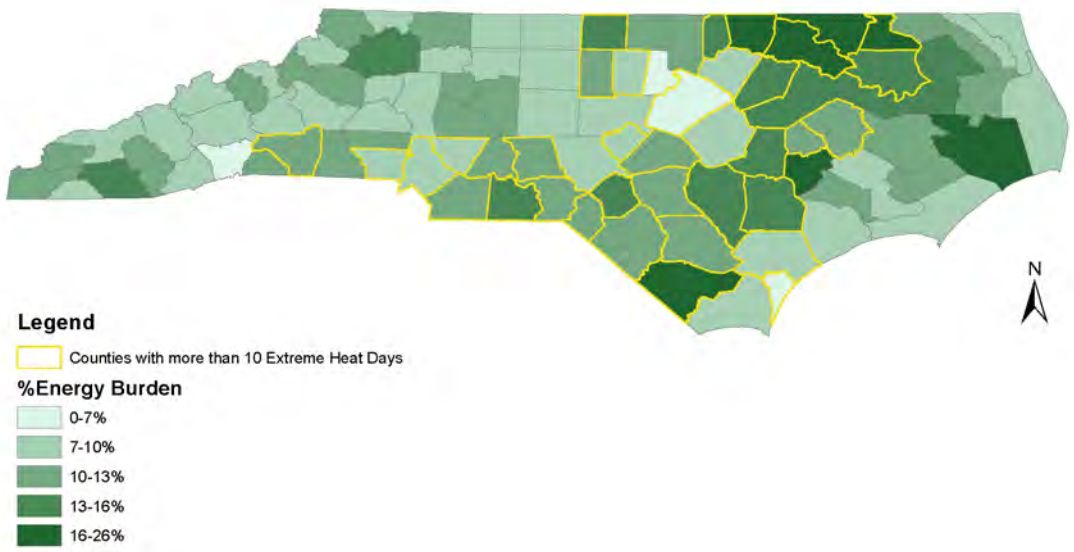


Figure 4-9: Energy Burden of Low-Income Renters by County[61] *Note that Figures 4-8 and 4-9 use different scales for rate of fuel poverty and therefore should not be compared on the basis of color gradient alone.*

Many low-income households and vulnerable populations face the "heat or eat" dilemma, in which they must choose to either pay for food or to pay for the energy to heat (or cool) their home.[62] As the number of high heat days is projected to increase, these households are at particular risk of being unable to afford to adequately cool their homes. Poor climate control is associated with adverse health outcomes and increased risk of death for seniors.[63] Higher temperatures and humidity can exacerbate poor indoor air quality and result in excess moisture, dampness, and mold in a home. These conditions can trigger respiratory illnesses, like asthma and increase susceptibility to heat-related illnesses.[64]

Energy efficiency and weatherization programs, such as North Carolina's Weatherization Assistance Program, attempt to address the problems exacerbated by fuel poverty. Weatherization programs also reduce greenhouse gas emissions that drive climate change in the first place. These programs, which often target those households most at risk for increased energy burden in the face of climate change, should be continued and expanded.

2. Workers, Small Businesses, and Family Businesses in Vulnerable Industries

Climate change will affect jobs, small businesses, and family-owned businesses, especially in traditional agricultural industries and tourism. Climate change may force growers to switch crops, or switch out of traditional lines of work all together. For example, Christmas trees are a major cash crop in Western

[61] Ibid.
[62] Bhattacharya, J., DeLeire, T., Haider, S., & Currie, J. (2003). Heat or eat? Cold-weather shocks and nutrition in poor American families. *American Journal of Public Health*, *93*(7), 1149-1154. Retrieved from https://ajph.aphapublications.org/doi/full/10.2105/AJPH.93.7.1149
[63] Klinenberg, E. (2015). *Heat wave: A social autopsy of disaster in Chicago*. University of Chicago Press. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12584383
[64] Clark, N. M., Ammann, H. M., Brunekreef, B., Eggleston, P., Fisk, W., Fullilove, R., ... & Von Essen, S. G. (2004). Damp indoor spaces and health. *Washington, DC*.

North Carolina, but increasing rain and warmer temperatures are starting to reduce crop yield.[65,66] Like some other agricultural industries, many tree farms are family-owned, and a sustained loss in crop yield could force the farm out of the industry.[67]

Some agricultural industries rely heavily on low-wage workers, who are also at elevated risk of economic disruption due to climate change. Low-wage workers generally have less flexibility and are more likely to lose their jobs if they are temporarily displaced or unable to go to work due to a natural hazard. In these cases, low-income workers may not be able to recover from a loss of income, which can be compounded if they experience other losses (e.g., home damage) due to the event.

North Carolina's tourism industry is also vulnerable to climate change. For example, following Hurricane Dorian in 2019, Ocracoke Island was closed to visitors for 77 days.[68] Many tourism industry employees are seasonal, low-wage workers often with minimal job security, particularly common in hospitality, restaurants, and retail. These workers are likely less able to cope with income interruptions. The entire state will experience the economic impacts of climate change due to decreasing tourism because visitor spending reduces the tax burden on each North Carolina household.[69]

3. African American Property Ownership

Property ownership has always been entangled with race in the United States, which creates particular sensitivities for African Americans coping with climate change in North Carolina. African Americans were not allowed to own property until Congress passed the Southern Homestead Act in 1866, ninety years after the founding of America. Following the Civil War, former slaves used this new right to build freedmen settlements across the nation. African Americans were typically limited to owning and settling land that white Americans did not want – like swamps or low-lying areas. Many of the settlements that remain today are susceptible to flooding.

In the twentieth century, public policy and sanctioned discriminatory practices limited the places where African Americans could live and restricted their opportunities to own property. Deeds that prohibited racial minorities from purchasing a particular property were popular until they were outlawed in 1948, and real estate brokers and property owners were permitted to discriminate on the basis of race until 1968. Employing a local development tool known as redlining, racial demographic data was used to advise and support real estate investors and developer's decisions against investing in neighborhoods of racial minorities for decades. These policies and practices resulted in steep declines in the property ownership and capital investment by African Americans. Repeated over generations, the inability to own land and property is estimated to cost hundreds of billions of dollars in unrealized wealth for African Americans.[70,71]

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[65] WFDD. (2019). *Climate Change Poses Threats to NC Christmas Tree Crop.* Retrieved from https://www.wfdd.org/story/climate-change-poses-threats-nc-christmas-tree-crop

[66] WRAL. (2019). *Warming temperatures may move NC farmers to switch crops.*

[67] WFAE. (2019). *How Climate Change Affects Fall Crops in North Carolina.* Retrieved from https://www.wfae.org/post/how-climate-change-affects-fall-crops-north-carolina#stream/0

[68] Charlotte Observer. (2019). *77 days after Dorian crashed into the Outer Banks, Ocracoke will reopen to visitors.* Retrieved from https://www.charlotteobserver.com/news/state/north-carolina/article237259289.html

[69] Curtis, S., Arrigo, J., Long, P., & Covington, R. (2010). Climate, weather and tourism: Bridging science and practice. *Publication of the Center for Sustainable Tourism, Division of Research and Graduate Studies. East Carolina University: Greenville, NC.*

[70] Presser, L. (2019 July 15). Their Family Bought Land One Generation after Slavery. The Reels Brothers Spent Eight Years in Jail for Refusing to Leave It. *ProPublica.* Retrieved from https://features.propublica.org/black-land-loss/heirs-property-rights-why-black-families-lose-land-south/.

[71] In North Carolina, the Land Loss Prevention Project has been working to curtail this trend for nearly forty years.

Barriers to property ownership have resulted in a number of climate resilience concerns specific to African American homeowners and historic African American communities. A disproportionate share of African Americans live in low-lying areas in the Southeast[72], which are more susceptible to drainage and flooding problems. Figures 4-10 and 4-11 illustrate this truth in two historic Black settlements, Princeville and James City. In both towns, a considerable extent of the communities' streets, and therefore development, lies in floodplain and floodplain-adjacent land.



Figure 4-10: Floodplain Covers much of Princeville, NC



Figure 4-11: Floodplain Encroaches on James City, NC

Given the barriers to property ownership among African Americans, land often holds particularly high historical and cultural value for Black households. In some cases, land has been in the same family for many generations. The decision to consider a buyout, if offered one by a state or local program, is particularly fraught for these homeowners. On the other hand, if owners do decide to accept a hazard mitigation buyout or relocate, generational land tenure (also known as heir or heirs' property) can be a barrier to selling the property to complete the buyout. Legal Aid of North Carolina and other pro bono legal services work hard to serve individual homeowners in such situations, but the scale of their property in North Carolina creates a legal barrier that is present for White and Native American property owners

[72] Jeff Ueland and Barney Warf. Racialized Topographies: Altitude and Race in Southern Cities. Geographical Review. Vol. 96, No. 1 (Jan., 2006), pp. 50-78



but especially prevalent among African American property owners.[73]Statutory and regulator treatment of their property has been cited repeatedly a driving forces of African American land and wealth loss. [74]

Other racial, cultural, and ethnic groups hold unique connections to particular land and land ownership. Specific sites or environmental functions of land are often important to the diverse cultural heritage of Native American tribal communities.[75] Some examples are burial grounds, sacred mounds, ceremonial places, and lands used for hunting, fishing, and gathering. Connectivity of land and heritage creates unique cultural risks associated with climate change impacts, especially the possibility of displacement or relocation.[76]

4. Insurance Inequalities

Insurance coverage is key to resilience to natural hazards. For one, insurance policies pay for the majority of costs for physical recovery of insured property damaged by weather. Public disaster recovery programs, such as those funded by FEMA, will never be able to provide the same level of quick and thorough loss recovery as insurance. In addition, insurance companies may provide incentives for investments in hazard mitigation, which creates more resilient housing stock.[77] Typically, mortgage lenders require property owners to hold all-hazard insurance for the life of the mortgage. All-hazard insurance does not cover flood losses, however, the purchase of flood insurance is only mandatory for all federal or federally related financial assistance for the acquisition and/or construction of buildings in Special Flood Hazard Areas (SFHAs), an increasingly poor predictor of the location of severe flooding. As North Carolina experiences progressively increased damage from natural hazards in the state, insurance access and coverage will influence the survival of entire neighborhoods and towns. However, homeowners across the state are not evenly covered by all-hazard or flood insurance.

Socially vulnerable populations have lower insurance coverage for several reasons. Often cited is prohibitive cost, and unsurprisingly, higher income households are more likely to hold insurance coverage.[78] Properties that are owned outright are no longer required to have insurance coverage due to a mortgage, so many long-time homeowners, such as senior citizens or households in properties passed down through generations, do not hold insurance. Insurance policies are difficult to decipher, even among highly educated homeowners.

However, even among those who hold hazard insurance, the process of making claims does not treat people equally. Making an insurance claim requires affected individuals, who have just experienced a traumatic event, to navigate a complicated insurance system. Many socially vulnerable communities experience barriers to successful claims or appeals, such as limited English proficiency, limited internet

[73] Gaither, C.J. (2016 October). *Have Not Our Weary Feet Come to the Place for Which Our Fathers Sighed? Heirs' Property in the Southern United States*. United States Forest Service. Retrieved from https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs216.pdf
[74] Douglas, L. (2017 June 26). African Americans Have Lost Untold Acrres of Land Over the Last Century. *The Nation.* Retrieved from https://www.thenation.com/article/archive/african-americans-have-lost-acres/
[75] Wildcat, D.R. (2014). "Introduction: climate change and indigenous peoples of the USA." *Climate Change and Indigenous Peoples in the United States: Impacts, Experiences and Actions.* Springer.
[76] National Congress of American Indians. (n.d.) *Climate Change.* Retrieved from http://www.ncai.org/policy-issues/land-natural-resources/climate-change
[77]Kousky, C. (2019). The role of natural disaster insurance in recovery and risk reduction. *Annual Review of Resource Economics*, *11*, 399-418. Retrieved from https://www.annualreviews.org/doi/abs/10.1146/annurev-resource-100518-094028?journalCode=resource
[78] Landry, C.E., Jahan-Parvar, M.R. (2010). Flood Coverage in the Coastal Zone. *Journal of Risk and Insurance*. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1539-6975.2010.01380.x

access, cultural barriers, and limited access to government officials.[79,80] Even when individuals have insurance and successfully make claims, researchers have found differences in insurance settlement claims based on race. Minorities are more likely to receive insufficient settlement amounts even when they have appropriate insurance coverage.[81] The demographic, social, or economic characteristics that make a population vulnerable to negative disaster impacts may be the same as those that limit their ability to benefit from insurance, yet another compounding vulnerability.

Establishing equitable access and utilization of insurance policies is critical to resilience interventions. Government, nonprofit organizations, and community groups can provide information and training to individuals and assist them with both obtaining insurance and making claims on an insurance policy. Subsidies for hazard insurance policies should be carefully considered in a suite of resilience options for low-income homeowners. Currently, NCORR offers flood insurance support to participants in its ReBuild programs, and the General Assembly has set aside some additional funds for insurance subsidies as well.

D. Climate Justice Recommendations

To address the climate justice issues described in this chapter, the following recommendations are put forth by the authors of this chapter. These recommendations should be implemented with sufficient funding, staff or contracting support, and interagency cooperation to ensure effective action.

1. Recommendations for Cabinet Agencies

Entity Responsible	Recommendation
Interagency Climate Council	Develop an equitable public participation framework for all climate change mitigation and resilience efforts. For use by state agencies as well as boards and commissions.
	Design an interagency process to survey and educate staff on unified definitions of equity; vulnerability; climate risk; resilience and other terms needed to demonstrate state's understanding and to ensure common ground within resilience work.
	Release a North Carolina Climate Justice Report as part of future North Carolina Resilience Plans with opportunities for public involvement.
North Carolina Emergency Management	Increase emphasis on communication with non-English speakers, older adults, rural communities, etc. Explore new risk communication methodologies

[79] Bergstrand, K., Mayer, B., Brumback, B., & Zhang, Y. (2015). Assessing the relationship between social vulnerability and community resilience to hazards. *Social indicators research*, *122*(2), 391-409. Retrieved from https://link.springer.com/article/10.1007/s11205-014-0698-3
[80] Blaikie, P. M., et al. (1994). At risk: Natural hazards, people's vulnerability, and disasters. London: Routledge.
[81] Fothergill, A., Maestas, E. G. M., & Darlington, J. D. (1999). Race, ethnicity and disasters in the United States: A review of the literature. Disasters, 23(2), 156–174. Retrieved from https://onlinelibrary.wiley.com/doi/abs/10.1111/1467-7717.00111

Entity Responsible	Recommendation
	Continue to update existing state hazard mitigation, emergency preparedness, and response plans with increased emphasis on protecting, communicating with and serving low-income populations, communities of color, older adults and people with disabilities during and after emergencies.
	Continue to support development of local hazard mitigation plans.
	Provide recommendations and guidance to local governments on maximizing the quality and effectiveness of local or regional hazard mitigation plans, especially in rural areas.
	Provide recommendations and guidance on stakeholder engagement in development and implementation of meaningful hazard mitigation plans and the inclusion of equity, diversity, and inclusion in local plans.
North Carolina Office of Recovery and Resiliency	Increase communication and interaction with all communities, including (especially) vulnerable and historically marginalized communities.
	Develop university partnerships to address gaps in research on climate resilience, especially issues that affect populations differently, and to offer capacity in the state to smaller and more rural communities to do effective and equitable resilience work.
	Develop a strategic plan for resilience-focused capacity building within socially vulnerable communities.
	Assist local governments in identifying additional resources to aid in advancing resilience.
	Seek funding that would be distributed to fund community based resilience projects.
	Create a Local Government Climate Resiliency Toolkit.
	Create and strengthen working relationships among state agency advisory boards that focus on equity and inclusion, such as the DEQ Environmental Justice and Equity Advisory Board.
NC Department of Commerce	Set aside clear, numerical percentages for the number of newly established jobs/ contracts/ projects that should go to vulnerable communities & for which historically marginalized business receive priority bidding.

Entity Responsible	Recommendation
	Partner with the DOA Office of Historically Underutilized Businesses, NC Institute of Minority Economic Development and other entities to increase outreach efforts of bidding and contracting opportunities for marginalized communities.
	Increase outreach efforts in impacted communities.
	Leverage Disaster Recovery Funds and other sources of capital to promote equitable job creation and inclusive business development in communities most vulnerable to climate change.
NC Department of Environmental Quality	Provide updated mapping when detailed climate projections come out, including overlap with socially vulnerable communities using 2020 Census and other up-to-date data.
	Continue enhanced engagement strategies for potentially underserved communities and translation and interpretation services for non-English speakers (as laid out in the DEQ's Public Participation and LEP Language Access Plans).
	Pursue continuation and expansion of Weatherization Assistance Program (WAP).
NC Department of Health and Human Services	Support the Building Resilience Against Climate Effects (BRACE) program and expand the tracking of epidemiological health impacts of climate change in North Carolina.
	Support increasing Back@Home initiative funding (post Hurricane housing initiative) to $16 million.
All Agencies Administering Disaster Recovery Funds	Increase outreach efforts in impacted communities. Implement a coordinated, strategic approach to increase communication and interaction, with an emphasis on vulnerable and historically marginalized communities.
	Offer adequate social services support to North Carolinians navigating the multitude of government processes during recovery.
	Increase the ability of community groups to communicate with state agencies on disaster recovery needs and the effectiveness of disaster recovery efforts.

Entity Responsible	Recommendation
	Publish clear, percentages of newly established jobs or contracts that should go to vulnerable communities and for which historically marginalized businesses receive priority bidding. Increase outreach efforts for hiring in communities where work will be completed.
	Continue to partner with the DOA Office of Historically Underutilized Businesses, NC Institute of Minority Economic Development and other entities to increase outreach efforts of bidding and contracting opportunities for underserved communities
	Leverage disaster recovery funds and other sources of capital to promote equitable job creation and inclusive business development in communities most vulnerable to climate change. Other sources of capital to explore include: Opportunity Funds, Donor Advised Funds, New Markets Tax Credits, Low Income Housing Tax Credits, activities of Community Development Financial Institutions, Small Business Investment Companies, Rural Business Investment Companies, and investments required by the Community Reinvestment Act.

2. Recommendations for All Branches of State Government

As the report describes, most resilience planning and programming in North Carolina has been led by local governments. However, imbalanced capacity and resources across local governments leaves smaller or poorer jurisdictions without resilience interventions. To equalize these opportunities, North Carolina must advance equitable resilience through state government policies and programs, and provide resources for communities to invest in their own futures.

Recommendation Type	Recommendation
State Policy Changes	Adopt the targeted universalism approach for resilience, in which policies and programs begin by addressing the needs of those who are most vulnerable to climate change, and seek to improve the resilience of the entire state.
	Develop metrics to determine progress of equity and resilience initiatives.
	Adopt incentive or funding programs that encourage best practices for equitable resilience within state government and quasi-governmental organizations and among local governments, businesses, and non-profit organizations. For example, competitive funding programs within the state might include a resilience component in their scoring rubric.

Recommendation Type	Recommendation
	Advocate for funding from the General Assembly for climate science specific to North Carolina and for resiliency programs, policies, and interventions that support our shared efforts to prosper into the twenty-first century and beyond.
	Work with agency Human Resource offices to set goals and strategies for diversifying staff and leadership in recovery and resilience, and for hiring disaster survivors into recovery and resilience positions.
	With agency communications offices, set goals and strategies to increase interaction with communities that have historically frayed relationships with government and government officials.
	Reduce substandard housing and increase access to adequate cooling and other climate risk reduction measures.
	Advocate for funding for new or continuing weatherization programs that target low-income homeowners.
State Role in Building Local Sources of Resilience	Build capacity and leadership within communities most vulnerable to climate change impacts by promoting, supporting and leveraging community-specific strategies, projects and events. This recommendation could be accomplished through the North Carolina Resilient Communities program detailed in Chapter 7. These initiatives could be led by local governments or by community or faith-based organizations.
	Identify and communicate resilience resources, including educational and funding opportunities, already available to local governments and communities.
	Fund a grant program to support community or regionally-based resilience projects. This program could be sponsored by public and private funds.
	Engage community and faith-based organizations that work on disaster response to incorporate other elements of resilience into their programming.
	Explore opportunities to provide financial resources for climate preparation efforts to culturally specific organizations

Recommendation Type	Recommendation
	Improve local resilience by ensuring that recovery programs, plans, and investments leave the community with additional capacity to cope with the next event. For example, a recovery program might include formal capacity building activities, a recovery fund might facilitate regional gatherings for grantees to share lessons learned, and planning efforts might identify clear, realistic implementation steps for after the plan is complete.
Information Needs	Improve the accessibility of hazard and climate change data to non-experts through web portals, infographics, classroom education modules, or other communication channels
	Provide resources for community and K-12 education on climate change and resiliency

3. Community Voice in Resilience Policy, Planning, and Programs

- Resilience plans and assessments should continue to engage local voices and focus especially on inviting the most impacted communities to drive the narrative about their resilience. Public participation should not be treated as a perfunctory requirement

- Resilience and resilience-related programs should engage new types of partners in their work, such as institutions that are frequent points of contact in the lives of socially vulnerable people, e.g. schools, medical clinics, retail outlets, houses of worship, and transit services.

- Resilience programs should recognize that community agency and bridging social capital are critical components of resilience. Enhancing capacity and social capital among socially vulnerable communities should be treated as equally important goals for state resilience programs as building the resilience of infrastructure and the built environment

4. Research Recommendations

North Carolina should continually learn from natural and social sciences about climate change, climate change impacts, and the effectiveness and equitability of our responses. The state should consider partnerships with universities to address the research needs identified by vulnerable communities. The state should engage with faculty who have recent publications or have been known to work alongside the vulnerable communities we seek to engage.

- Research that seeks to affect policy should engage government from the beginning to ensure that policy-relevant questions are asked and the knowledge of government officials is included in shaping research and reaching findings. This requires interest and initiative among researchers and responsiveness among government officials.
- Researchers should consider building long-standing and sustainable research partnerships with communities. Researchers should follow widely available best practices for building mutually beneficial community-based research partnerships.

Researchers within and outside government should consider the following research needs:

Research Recommendations
Examine the distribution of climate hazard exposure and impact, adaptive capacity, and benefits and burdens of resilience interventions among different groups of socially vulnerable populations.
Identify opportunities for citizen science and community observations to add value to research used by the state. For example, analyze ways for risk assessment to include qualitative methods and local knowledge.
Evaluate the effectiveness of methods for engaging different underrepresented groups in climate resilience plans, programs, and policies.
Investigate under-recognized sources of community resilience by learning more about the support systems local communities have created to 'fill in gaps' of disaster response.
Continue to map climate risks and social vulnerabilities together. Re-visit this mapping based on 2020 Census data. Use geospatial and other analyses to understand the distinction among different regions of the state and in urban, suburban, and rural areas. Extend this research to identify "hotspot" areas where climate justice issues are likely to be most severe.
Determine the best ways to measure and capture compounding vulnerabilities, or climate impacts that are experienced in the context of inequalities across health, housing, and economy.
Analyze the business and workforce development opportunities in risk and resilience fields. The results of such a study should inform programmatic decisions in the state's workforce development systems and organizations.
Analyze insurance coverage among socially vulnerable populations, especially in light of changing insurance markets and new developments with the National Flood Insurance Programs. Recommend strategies to improve insurance coverage among low-income households, including renters, in high-risk areas. Analyze insurance coverage of public assets in all communities, especially those with smaller budgets where insurance may have fallen to the wayside.

Chapter 5

Vulnerability, Risk, and Potential Options for Addressing Climate Related Hazards

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5. Vulnerability, Risk, and Resilience Strategies for Addressing Climate-Related Hazards

A. Building a Shared Understanding

1. Introduction

Collectively, North Carolina state Government serves people, safeguards natural and built infrastructure, maintains cultural resources, and supports the functioning of other public and private assets. This chapter focuses on ways in which climate-related hazards impact government functions and assets. It also explores the ways that vulnerability and risk profiles for those impacts could shift as a result of climate change.

In a changing climate, agencies will face increasing challenges in fulfilling their responsibilities. Building upon the North Carolina Climate Science Report (Chapter 3 and Appendix A), agency representatives describe ways in which climate-related hazards impinge upon the delivery of government services, the maintenance of physical assets, threaten personnel, or otherwise jeopardize the mission of the many agencies represented herein.

The best way to prepare for potential future impacts of climate change is to build resilience to present-day climate-related hazards while adding a margin of safety for changing conditions.[1] Such preparation can pay for itself in myriad avoided recovery costs. Preparing and planning for climate-related disasters can bring a benefit-to-cost ratio between 4 and 15.[2] An avoided disaster also defrays a cascading set of hardships for individuals, government at all levels, the economy, and more.

This chapter documents the work done by agency representatives from throughout North Carolina state government for 11 sectors (Chapter 2: Plan Development Process) to understand the implications of climate change on the success of agency missions and identified opportunities to build resilience at the state level.

Impact Assessments

The impacts in this chapter concern government agency *responsibilities* (such as state-owned natural or constructed assets) and *services* (such as regulatory functions and programs that provide funding, technical assistance, and other resources to communities, industries, and local governments). If those services and responsibilities had been or could be impacted by climate-related hazards, sector teams noted those impact pairs (*hazards* paired with *services and responsibilities*). In the sections that follow within this chapter, each sector provides a table that links *hazards* to impacted *services and responsibilities*. A complete risk assessment and determination of adaptation options was not possible given the large

[1] IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 869-898.
[2] Healy A and Malhotra N (2009) Myopic Voters and Natural Disaster Policy. American Political Science Review 103(3): 387-406.

number of potential impacts, so they undertook an abbreviated assessment for a subset of those potential impacts (Table 5A-1).

Table 5A-1: Sector teams and the number of impacts analyzed as part of the risk assessment documented in this chapter.

Sector	Impact Pairs	Risk Assessments
Agriculture and Forestry	92	7
Coastal Resources & Infrastructure	139	4
Commerce and Business	57	1
Cultural Resources	39	4
Ecosystems	91	3
Energy	57	3
Health and Human Services	55	4
Housing, Buildings, and Support Services	24	6
Public Safety	61	3
Transportation	35	4
Water and Land Resources	94	9
Total	*744*	*48*

This chapter establishes a baseline for a future quantitative risk assessment and resilience analyses to update the NC Resilience Plan. Employing the Steps to Resilience[3] (Figure 5A-1), team members qualitatively describe exposure to climate-related hazards, vulnerability and risk associated with those hazards, and provide some resilience strategies for adaptation. Both *climate* and *non-climate stressors* can alter the severity or likelihood of any given hazard (Figure 5A-2). This chapter focuses attention on hazards whose frequency or intensity can be altered by climate variability and climate change. These are called "climate-related hazards" throughout the text. Sector teams further identify actions to build climate resilience, meaning steps that could be taken to prevent or moderate potential impacts. Typically, actions for building resilience focus on non-climate stressors (for example via nature based solutions) and safeguarding services or responsibilities. Impact assessments should include indicators or measurable impacts so that impacts and adaptation actions can be evaluated through time. All of these concepts are interrelated, as shown in Figure 5A-2. When climate impact assessments include all



Figure 5A-1. The Steps to Resilience.

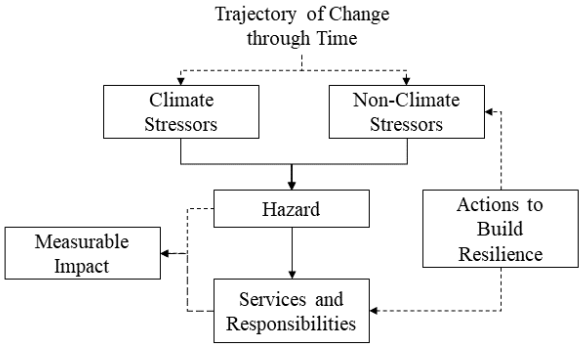


Figure 5A-2. A conceptual model of impacts and ways to address climate-related hazards.

[3] This is a risk management and decision-making framework designed to allow people from disparate backgrounds use climate information within their job functions. See https://toolkit.climate.gov/#steps



of these elements, it is possible to communicate clearly about climate resilience concerns and decisions.

2. Structure of Sector Contributions

In the following pages, each of the 11 sectors include an **overview** of the services, assets, and functions that state government provides followed by a description of **overall exposure** to climate-related hazards. Examples of **vulnerability, risk, and resilience strategies** detail how state agencies view the threat of climate change to meeting their missions and some ways to remediate the potential shortfalls introduced by climate-related hazards. Definitions and details about vulnerability and risk assessments are available elsewhere.[4] Finally, a **summary** recaps the most salient issues that climate change poses to each respective sector along with a concise list of recommendations that could follow this risk assessment to ensure continuity in delivering services and meeting responsibilities in the face of ongoing climate stressors and related hazards.

[4] Gardiner E. P., Herring D. H., and Fox. 2019. The U.S. Climate Resilience Toolkit: evidence of progress. Climatic Change 153(4): 477-490.

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Agriculture & Forestry

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B. Agriculture and Forestry

Key Observations

- Agriculture, forestry, and endangered native plants are tied to climate due to biological, physiological, and ecological constraints. Elevated night-time temperatures will have outsized negative impacts due to disruptions in plant physiology.
- Must attract and retain experienced personnel as well as maintain equipment to meet a growing set of hazards.

Critical Impacts and Resilience Strategies

- Inland flooding is the greatest climate-related hazard to North Carolina Department of Agriculture and Consumer Services (NCDA&CS) assets (research stations, state forests, and nurseries) and to private farms and forests. Must focus on adaptive capacity (e.g., levees) to protect crop and pasture lands statewide.
- Research and development are needed on adaptive varieties and species for crops, livestock, and poultry to more resistant to extreme heat.
- Education of stakeholders can provide adaptive capacity for drought and wildfire. This is personnel-intensive and personnel are currently directed toward response.
- Protecting North Carolina's endemic and nearly endemic species, species that exist only in our state or a handful of places is a unique responsibility of the state.
- Regenerative practices that sequester carbon.

1. Sector Overview

The mission of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) is to provide services that promote and improve agriculture, agribusiness, and forests; protect consumers and businesses; and conserve farmland and natural resources for the prosperity of all North Carolinians.

Divisions throughout NCDA&CS regulate and serve diverse needs: agronomy; animal health; weights and measures; gas and oil inspection; crop and livestock statistics; USDA commodity distribution; food and drug protection; agricultural marketing and grading; research station operations; seed and fertilizer inspection; farmland preservation; nursery and plant pest eradication activities; protecting and conserving imperiled plant species; regulation of the structural pest and pesticide industries; agricultural environmental issues; soil and water conservation; forest management and protection; state and federal agricultural legislation; emergency programs; and agricultural economic analysis. These are the primary NCDA&CS staffs that are activated in response to emergency events.

The state's economy is highly dependent upon agriculture and agribusiness's ability to produce food, fiber, fuel, and forest products. Agriculture and forestry account for one-sixth of the state's income ($91.8 billion of the $538 billion of the gross state product) and employment. There are approximately 8.4 million acres of operating farm land and 18 million acres of operating timber land in the state accounting for just over **76% of the total land in North Carolina**.[1]

[1] Walden, M., (2019). *Agriculture and Agribusiness*: North Carolina's Number One Industry. Retrieved February 14, 2020 from, https://cals.ncsu.edu/agricultural-and-resource-economics/wp-content/uploads/sites/12/2019/05/agribusiness2019Brochure.pdf



2. Overall Exposure

Climate encompasses sunlight, temperature, precipitation, and basic soil conditions throughout the life cycle of a crop; so farm, forest, and fish productivity are directly linked to climate. Therefore, climate-related events directly influence management and strategic investments in this sector (Table 5B-1). The NCDA&CS acts as a living laboratory assessing climate and ecological issues faced by farm and forest landowners across the state. A goal of this effort is to address agency-wide exposure and risks to climate-related events and develop strategies that will serve the state's citizens and industries.

Table 5B-1. Exposure to climate-related hazards state of agriculture and forestry assets and services throughout the state.

Assets, Regulations, and Services	Air Pollution	Changed Seasons	Drought	Extreme Cold	Extreme Heat	Flooding (River and Land)	Forest Insects and Diseases (Native and Invasive)	Inundation (includes SLR)	Landslides	Non-Native Invasive Plants	Saltwater Intrusion	Severe Winter Weather	Storm Surge	Water Shortage (Drought)	Wildfire related Air Pollution	Wildfire	Wind
Crop and pasture lands	*		*		*	*		*	*	*	*	*	*	*		*	*
Livestock and poultry	*				*	*						*		*			*
Shellfish and freshwater aquaculture		*	*		*	*		*	*			*	*	*			*
Department-owned facilities						*		*	*		*		*			*	*
Department-sponsored programs and services	*	*			*	*		*	*		*	*				*	*
Emergency response and wildland firefighting resources and equipment	*	*			*	*		*	*		*					*	*
Forest resource and nursery	*	*			*	*	*	*	*	*	*	*		*		*	*
Forest Service employees; all services provided	*	*		*	*	*		*	*		*			*	*	*	*
Endangered and protected plant species.	*	*	*		*	*	*	*	*	*	*		*	*	*	*	

North Carolina Department of Agriculture and Consumer Services (NCDA&CS)

While there are expected to be many climate-related impacts on agriculture, the most significant are expected to be related to **flooding**, **drought** and **extreme heat**. Additional non-climate stresses include weeds, diseases, insect pests, and pollinator ecology. For this document, the term "farming" is all-inclusive, encompassing activities that fall under the broad umbrella of farming throughout the state, including livestock, poultry, aquaculture, and mariculture. Unless otherwise noted, all discussion of climate change impacts on the NCDA&CS's operations and assets directly reflects the same impact as those experienced by farmers and forest landowners.

The NCDA&CS is sometimes referred to as the state's largest farmer with 18 research stations across the state (Figure 5B-1). Each station is a laboratory where researchers from North Carolina State University, USDA, and North Carolina A&T State University work to solve problems facing agriculture today and into the future. Each station has unique climate and soil conditions and focuses on distinct regional crops, forestry concerns, livestock, poultry, and aquaculture. The NCDA&CS's Research Stations Division supports these studies by providing land, water, equipment, buildings, and staff who work around the clock to help build a stronger foundation for the future of agriculture.

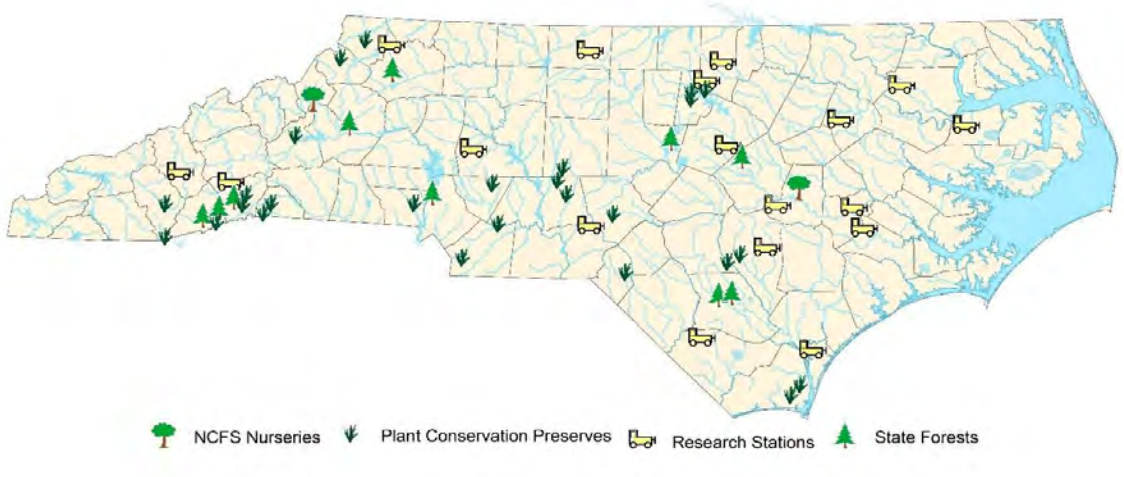


Figure 5B-1. A subset of assets managed by the North Carolina Department of Agriculture and Consumer Services across the state.

In addition to being the state's largest farmer, the NCDA&CS has considerable responsibility for managing a variety of state assets. The NCDA&CS has a physical presence in all 100 counties with responsibility for 1,190 buildings and nearly 96,000 acres of croplands, forests and plant conservation sites (Figure 5B-1).

When analyzing climate-related risk and resilience for agriculture and forestry, the NCDA&CS focuses on 6 key assets:

- Crop and pasture lands
- Livestock and poultry
- Shellfish and freshwater aquaculture
- Department-owned facilities
- Department-sponsored programs and services
- Endangered and Protected Plant Species



North Carolina Forest Service

The primary goals of the NC Forest Service are to protect, manage, and promote the state's forest as well as provide leadership on the issues concerning forest resources. To accomplish these goals in the face of a changing climate, the focus is on the following 3 critical assets and how they could be influenced by climate-related events:

- Forest Resource and Nursery
- Private Landowner Services
- Emergency Response and Wildland Fire Fighting Resources and Equipment

The NC Forest Service operates and maintains ten state forests, including DuPont State Recreational Forest, Bladen Lakes and Headwaters State Forests, and seven educational state forests. These forests provide services to the public, such as: educational courses; self-guided trails and recreation; and timber production for wood products, wildlife habitat, and hunting opportunities. The NC Forest Service Nursery Program annually produces nearly 15 million tree seedlings representing over 40 tree species. These seedlings are critical to meeting reforestation, restoration, and wildlife habitat improvement projects across North Carolina. When the NC Forest Service nursery lost nearly all its crop due to Hurricane Matthew's flooding in 2016, the available seedling supply for numerous species was not adequate to meet the needs of seedling customers and natural resource partners.

Outside of state-owned forested lands and the nursery program, the NC Forest Service provides many programs and services for private landowners with the primary goal of keeping forested lands forested and ensuring standards for water quality are met.

The NC Forest Service is mandated by the NC General Statutes to detect and suppress all forest fires under the jurisdiction of the state. A combination of ground and aerial resources is required to provide for the safety of firefighters and the public to minimize the loss of forestland, homes, and personal property to wildfires. The service also responds to other natural disasters, including, but not limited to, winter weather events, tornadoes, hurricanes, and floods. The NC Forest Service operates in all 100 counties of North Carolina. There are also 13 district offices and three regional offices. Being established in all 100 counties allows for the NC Forest Service to operate quickly and efficiently during emergency events such as wildfires and flooding.

Current NC Forest Service capacity to respond to routine, short-term wildfire events and other natural disasters is adequate. Large-scale, long-term, and overlapping events such as the 2016 hurricane and fall fire season which required allocation of resources in multiple areas of the state at the same time overwhelmed the state's capacity (available employees, equipment, and fiscal resources) to respond. During the 2016 fall fire season, personnel and equipment were needed from all around the country to help adequately respond to the numerous fires occurring on private, state, and federal lands in the state.

Key climate stressors that are amplifying the vulnerability and risk of forest resources in North Carolina include wildfire, extreme precipitation, and hurricane intensity. The most prominent are **wildfire** and the events and variables that induce wildfire. Increasing **heavy precipitation events** are leading to more frequent flooding, causing erosion and loss of tree seedlings. **Drought** induces stress to trees and makes forested lands more susceptible to insects, disease, and wildfires. Hurricanes cause damaging winds, coastal flooding, and facilitate saltwater intrusion, resulting in forest land loss. Each of these hazards also impacts the critical infrastructure needed to access and maintain forests and farms. As conditions for wildfires, tropical storm events, and flooding are predicted to increase, current and future capacity to respond as an agency have been taken into consideration in this report.



An increasing population in North Carolina is leading to not only increased demand for wood products for construction materials, fuel, and paper products, but is also stimulating increased development which causes land-use change and increasing forest fragmentation. Fragmentation of the state's forests creates several issues that make sustainable forest management more difficult. An expanding population is increasing the wildland urban interface which increases the public safety risks associated with wildfire. With the increase in impermeable surfaces, more water is being funneled downstream, causing increased flooding on farmland, forested lands, and rural communities. Other non-climate stressors include regulations and current abilities to manage fuel loads in the state's forests. Inability to manage fuel loads properly due to social, environmental, and economic variables greatly increases the risk of large and intense wildfires across the state. Many climate-related events directly (i.e. drought and extreme heat) or indirectly (i.e. storms, insect outbreaks, and disease) increase the risk of wildfires by increasing flammable vegetation that would ignite.

3. Examples of Impacts, Vulnerability, and Risk

Crop & Pasture Lands / Flooding, Drought, & Heat

Impact Summary

Flooding, whether from tropical cyclones or other heavy precipitation events, has proven to have tremendous negative impacts on farming throughout the state. Because agriculture has such a large footprint in North Carolina, flooding anywhere in the state can be destructive to this sector.

In September 2004, western North Carolina was hit by two hurricanes within nine days. Losses to crops, farm equipment, and farm infrastructure were estimated to be $129 million. Since most of agriculture in western North Carolina is associated with river-influenced soils, crop losses due to destruction, contamination, and subsequent plant and animal diseases associated with flooding were close to 100% in many locations.

In 2016, flooding in eastern North Carolina from Hurricane Matthew resulted in an estimated $544 million in agricultural losses, and in 2018, flooding from Hurricane Florence resulted in an estimated $2.4 billion in agricultural losses across the state (see figures 5B-1 and 5B-2). In most widespread flooding events, crops experience partial, if not complete destruction. Obviously, the timing of the flooding event is critical. The greatest impact occurs when crops are still in the field with little to no harvesting completed. For many crops, food safety rules prevent a crop from being used after it has been covered by flood waters. Inland flooding events are occurring more frequently, limiting farmers' ability to recover between events.



Figure 5B-1. Flooded NCDA&CS crop and pasture lands following Hurricane Matthew in 2016.



Figure 5B-2. NC Forest Service helicopter dropping resources to research stations inaccessible due to flood waters from Hurricane Matthew 2016.



Vulnerability and Risk

Agricultural lands are inherently susceptible to inland flooding due to soil type, lower elevation, proximity to available water, and upstream development, including increased impervious surfaces. Further, increasing population creates demand for more development, pushing farming practices to riskier sites.

The NCDA&CS has experienced direct and indirect losses from flooding. Research stations have lost their investment into many research projects due to crop loss. During and following Hurricane Matthew, the Cherry Research Station in Wayne County was effectively an island with hay and other feed stocks having to be air lifted to feed the station's livestock. Overbank flow events are expected in any floodplain agricultural system, so levies are typically built to accommodate floods. Levies reduce vulnerability but must be maintained. Hurricane Matthew compromised a levy system designed to protect the station from flooding. Because the levy system has not been repaired, subsequent storms have brought additional flooding.

While flooding is generally thought to be related to extreme storm events, the rise of sea level and water tables in coastal regions also threatens otherwise productive land with saturated, saline conditions. The blacklands area of eastern North Carolina (Beaufort, Hyde, Tyrell, and Washington Counties) are some of the most productive row crop areas on the East Coast. The NCDA&CS Tidewater Research Station is located in this area. Rising water tables and saltwater intrusion in some of the blacklands counties are already proving to be a challenge to crop production, especially in the Engelhard area.

North Carolina has suffered from severe drought conditions in recent years, and droughts will likely continue to be a risk that the NCDA&CS and farmers must deal with in the future. Many farmers can sustain their crops through normal periods of drought. However, a lengthy drought event may exceed their water storage capacity or the access to water needed for irrigation. Crops, livestock, and poultry cannot survive without water. Livestock and poultry can be sold off, but crops dry up in the field—all of which results in loss of income for farmers and a negative impact to the state's economy.

The impact of increasing annual temperature is more of an unknown to farming operations. Of particular concern is higher temperatures in the winter months, which can lead to premature sprouting and budding of plants. When this happens, those plants are susceptible to injury from subsequent frost and freeze events, resulting in lower yields or even complete loss. Some tree crops like peaches require a certain number of chilling days (normal colder winter temps) in order to flower and produce full yields. Warm winter months already compromise current peach varieties available in North Carolina.

Prolonged periods of higher temperatures in the summer months can also have a negative effect on crop production. Extreme drought conditions, which cause crop distress and mortality, often coincide with periods of prolonged higher temperatures. Many crops are able to tolerate high daytime temperatures and short periods of drought as long as sufficient cooling takes place at night to allow plants to recover. Future increases in nighttime temperatures during the summer could cause significant loss in photosynthetic energy due to increased nighttime respiration, resulting in reduced crop yields and decreased overall stress tolerance.

Resilience Strategies

To address persistent flooding, the system of levees in agricultural fields must be evaluated for efficacy and potential modification. Currently, the Cherry Research Station operates at diminished capacity due to a breached levy system that allows flood waters to flow through the farm rather than being trapped. More frequent flooding results in longer periods of flooded fields and pastures.



Researchers at North Carolina's land-grant universities, who heavily utilize the state's research stations, generally have a breeding objective of developing and improving crops that can tolerate and thrive in the face of emerging climate conditions. However, plant breeding is a long-term endeavor; it can take several years to develop and release new varieties of crops. A pertinent question, therefore, is how can the latest advances in technology be utilized to accelerate plant breeding efforts to keep pace with climate change? The state's research stations, and the deployment of technology will be key to these efforts.

The NCDA&CS has invested in irrigation infrastructure at its Research Stations, but long periods of drought negatively impact revenues and research at these facilities. Additional investments in irrigation at the stations across the state will be necessary to manage research projects. Other resilience strategies previously reported in the Climate Ready North Carolina: Building a Resilient Future[2] report include:

- Promote research and technological innovation for new crop types/varieties and improved pesticides/herbicides to adapt to changing growing conditions.
- Provide education/outreach to the farming community regarding recommendations for adaptation of new crops, varieties, or technologies.
- Ensure availability of adequate flood/crop insurance in order to maintain land in agricultural production instead of a more intensive land use that has the potential to be more susceptible to flooding events and will have higher damages when flooding events occur.
- Provide for maintenance of drainage infrastructure to minimize flood severity and duration.
- Encourage adoption of agricultural best management practices to conserve water, reduce erosion, and increase soil productivity.
- Provide technical and financial assistance to producers to encourage adoption of water storage/water use efficiency technologies.
- Increase available on-farm water storage capacity to minimize drought impacts.
- Improve the availability of irrigation infrastructure in order to relieve drought/heat stress.
- Promote adoption of more efficient irrigation technology to minimize drought stress and maximize the benefits of available water.

Livestock & Poultry / Flooding, Extreme Temperatures, & Drought

Impact Summary

Livestock and poultry operations, specifically confined animal feeding operations (CAFOs) for poultry and hogs, are especially vulnerable to inland flooding. Although planning and relocation of animals mitigate livestock loss, flood damage to structures and equipment, potential environmental impacts from manure, and residual impacts to local economies due to loss of production are significant. Extreme temperature fluctuations for animals produced in CAFOs may cause increased energy and water consumption to maintain healthy growing environments; pasture-raised livestock will be more susceptible to temperature extremes. Prolonged drought affects food, forage and water availability for pasture-raised animals. Drought extremes deplete aquifers and available water sources for production facilities that use water systems for cooling as well as animal hydration.

[2] NC Interagency Leadership Team. (2012). *Climate Ready North Carolina: Building a Resilient Future.* Retrieved February 14, 2020, from: https://connect.ncdot.gov/municipalities/InteragencyLeadership/Goals/Climate%20Ready%20North%20Carolina%20-%20Building%20a%20Resilient%20Future.pdf

Vulnerability and Risk

The impact of flooding on livestock and poultry may be more limited depending on the exact location of the flooding and the time farmers have to prepare for an anticipated event. Flooding events over the past few years have seen much less livestock and poultry mortality compared to earlier flooding events because farmers have made adaptive decisions to deal with a recurring issue. Livestock and poultry farmers, given enough time, can move their stock to safer locations or send them to market even if not at the desired time in the growing cycle. However, with major floods, there may be damage to infrastructure which will result in a farmer not being able place stock back into a housing structure in a timely fashion, resulting in loss of income.

Droughts are a natural part of the climate of North Carolina. Future droughts are likely to be more intense than they were historically, resulting in rapid drying and negative impacts on livestock production and performance. Water for livestock and poultry consumption is not thought to be a great concern unless the drought is prolonged and occurs during times of high temperatures. A prolonged and widespread drought can have a severe impact on feed stocks such as grains, hay, and grazing pasture lands. North Carolina is a grain-deficient state, meaning grain must be imported to meet demands.

Extreme temperature changes have a negative impact on livestock and poultry production systems. Prolonged exposure results in production losses across the board and higher input costs. Livestock and poultry operations are somewhat vulnerable to feed supply chain disruptions due to climate factors. In contrast, North Carolina is typically able to meet the need for hay. A statewide drought in 2006 resulted in the NCDA&CS becoming a hay broker transporting hay from the Midwest and Canada. Corn stalks were also baled in North Carolina and transported to impacted areas of the state. The estimate for drought damage to North Carolina agriculture in 2007 was $500 million.

Resilience Strategies

The NCDA&CS should monitor supply chain vulnerabilities to help producers in the state anticipate and respond to feed shortages. Other resilience strategies previously reported in the Climate Ready North Carolina: Building a Resilient Future[3] report include:

- Conduct research regarding breeds of livestock most suitable for current climatic conditions, as well as educate/advise the livestock sector of adaptive strategies for dealing with variation in climate.
- Encourage livestock producers to select breeds that are genetically adapted to prevalent climatic conditions.
- Support funding for programs that remove vulnerable livestock and poultry operations from flood prone areas.
- The NCDA&CS should monitor supply chain vulnerabilities to help producers in the state anticipate and respond to feed shortages.

[3] NC Interagency Leadership Team. (2012). *Climate Ready North Carolina: Building a Resilient Future.* Retrieved February 14, 2020, from: https://connect.ncdot.gov/municipalities/InteragencyLeadership/Goals/Climate%20Ready%20North%20Carolina%20-%20Building%20a%20Resilient%20Future.pdf



Shellfish & Freshwater Aquaculture Farmers / Temperature and Precipitation Extremes

Impact Summary

Short-term impacts of climate change on aquaculture and mariculture include the unpredictable nature of weather patterns, especially extreme high temperatures and excessive rainfall, both of which result in losses of production or infrastructure.

Shellfish and freshwater aquaculture farming occur in two completely different environments. Marine aquaculture, also called mariculture, takes place in the sounds, rivers, and creeks along the coast, while freshwater aquaculture can occur anywhere in the state where there is access to fresh water. North Carolina freshwater aquaculture is diverse. Farms typically grow trout, catfish, hybrid striped bass, prawn, crawfish, tilapia, and baitfish, depending on their environment and water source.

Mariculture in North Carolina, which is centered on oysters and clams, is performed on leased public bottoms using traditional methods such as cultch on bottom or modernized methods such as bottom cages or floating gear. The NC Division of Marine Fisheries administers the Shellfish Lease Program through the Habitat and Enhancement Section for the purposes of shellfish mariculture. In North Carolina, the leasing of public trust bottom for the use of shellfish aquaculture has been practiced for over 150 years. Recently, there has been tremendous growth in the industry, coupled with a shift to using intensive gear such as floating cages and bags. With more growers utilizing more gear, the cost of mariculture has increased, creating greater economic burdens for growers from coastal storms and flooding events.

Vulnerability and Risk

Coastal storms, with the associated **wind and waves** that destroy or wash away gear and inventory, can devastate production. Although mariculture has moved to growing oysters in vertical columns, there are still some growing operations where the cages sit on the bottom. During **heavy inland flooding** events, sediment is washed over the bottom cages, resulting in complete loss of production. Whether the loss is from wind and wave action or excessive sedimentation, the farmer has lost not only the gear but his entire inventory. Heavy rainfall accompanied by tropical cyclones can cause substantial coastal flooding, resulting in damage to wastewater treatment, agricultural runoff, and widespread closures of shellfish harvest areas. When wastewater enters shellfish growing areas due to flooding or excessive rainfall, the Division of Marine Fisheries issues a mandatory 21-day shellfish harvest closure. The closure results in loss of production and income.

The issues faced by freshwater farmers are different from mariculture farmers. Trout depend on cold water; 58°F is optimal. When the water temperatures exceed 65° F in the summer months, trout do not thrive. The producer can cut back on feed to avoid stress and manage the inventory by grading them, moving them, or even crowding them to load onto a hauling truck, all of which are challenging. These management actions, if done improperly, can lead to mortality.

The summer of 2019 was difficult for North Carolina trout producers. For two months, there was no rain, daytime ambient temperatures were in the mid to upper 90s, and water temperature exceeded 70° F. This created the perfect environment for bacterial diseases; medicated feed did little to thwart devastating losses, and often the water temperatures were too warm to feed. The combination of the hot days and warm water was the catalyst for disease and mortality. The western North Carolina trout industry lost productivity to mortality. To quote a major western North Carolina trout farmer, “It seems like the fall and spring are shorter and the summer is longer”. The primary growing season has been reduced by the delay of cooler temperatures in the fall and the earlier arrival of warmer temperatures in the spring.

Eastern pond producers face similar issues with climate-change-related extremes. Excessive summer pond temperatures limit production for hybrid striped bass and catfish, often forcing growers to halt feeding for extended periods. Unusually hot, cold, or cloudy weather can stress fish and cause disease. Catfish can be affected by off-flavor, making them unmarketable. Hybrid bass face an increased risk to bloating, often leading to major kills. Catfish and hybrids are more adaptable to warm water than trout; catfish prefer water temperatures in the 80s and hybrids in the 70s. When pond temperatures reach or exceed the upper 90s, issues can arise. There are reports from farmers where water temperatures have reached triple digits. These extreme temperatures affect optimum feed conversion and disease management, but also contributes to difficulty in managing dissolved oxygen. When water temperatures exceed 85°F, the pond water loses most of its ability to contain dissolved oxygen--leading to increased aeration costs and long nights battling dissolved oxygen levels in ponds.

Resilience Strategies

The NC Division of Marine Fisheries, in collaboration with growers and other partners, is working to develop a storm management plan for growers. Planning and preparing for extreme weather events can help mitigate economic damage to gear and product. The plan will include proactive measures for growers to consider when preparing for a storm event.

Production systems for trout must adapt to changing conditions. Two such considerations are to adjust fish stocking densities according to water flows and expected duration of favorable temperatures as well as utilizing smaller streams in more distributed production to compensate for lower stocking densities.

Adaptive practices are in place for controlling excessive rain water overflow. Due to oversight by the Division of Water Resources in DEQ, catfish farmers are currently required to mitigate impoundment overflow by using a 12-18 inch freeboard to catch excessive rainfall amounts. This practice can help them by limiting pumping requirements, but there is risk involved when drought occurs. Even with this practice, when excessive rainfall amounts occur, excess rainwater naturally leaves the farm; however, the Division of Water Resources does not recognize excessive rainwater overflow and treats all water leaving the farm as wastewater discharge.

Department-Owned Facilities / Extreme Weather & Sea Level Rise

Impact Summary

The NCDA&CS leases or owns facilities in 99 counties. Inland flooding is the major issue impacting those assets. In recent years, flooding has been mostly attributable to hurricanes and other severe weather events. Forest Service offices and research stations were heavily impacted by Hurricanes Matthew and Florence. Increased flooding also negatively impacts forest condition and composition often resulting in the need for reforestation. Facilities in the coastal region are likely to be susceptible to predicted sea level rise in the future. The following are damage estimates provided for two recent storms.

Hurricane Matthew

- $584,167 Forest Service
- $33,134 Plant Industry
- $775,134 Research Stations
- **$1,393,167 Total**

Hurricane Florence

- $5,607,107 NC Forest Service; $5 million of this represents damage sustained at the NC Forest Service Duplin/Pender Zone site
- $110,200 Research Stations
- $10,000 Plant Industry
- **$5,727,307 Total**

Vulnerability and Risk

Programs and services offered by the department, for example NC Forest Service's tree seedling production at Claridge Nursery, are critical elements to this sector's success. Claridge Nursery is currently highly vulnerable to flooding, as shown during the 2016 hurricane season. The ability to sustainably manage the state's forest resource and provide adequate tree seedlings for reforestation is essential to the NC Forest Service's ability to complete its mission. The rest of the department's divisions are consistently impacted by hurricanes and other extreme weather events.

Severe weather events, whether in summer or winter, tend to be in short duration and not widespread. If such weather events become more frequent and severe with climate change, their impact will become more problematic.



Figure 5B-3: 2016 Hurricane Matthew Flooding at Claridge Nursery (J. West)



Figure 5B-4: Aerial View of 2016 Hurricane Matthew Flooding at Claridge Nursery (J. West)

Resilience Strategies

To address risk and vulnerability to flooding, NC Forest Service offices can be relocated to higher ground, but that will be an expense the state must be willing to undertake. Research Stations cannot be relocated due to their size and the unique soils and climate they contribute to their research mission. Certain facilities on the stations can be relocated to higher ground, but again, the state must be willing to undertake that expense. Efforts are underway now to relocate offices and other structures at the Cherry Research Station. The NC Forest Service Duplin/Pender Zone site must be relocated because it was rendered unusable and beyond repair from Hurricane Matthew flooding. Although sea level rise is not generally a major concern for the department's facilities and assets, the Tidewater Research Station in Plymouth may be diminished in value in a few decades if sea level rise occurs as predicted. The same is likely true for selected NC Forest Service county sites.



Figure 5B-5. Hurricane Florence flooding at the NC Forest Service Duplin/Pender Zone site (2018)



Figure 5B-6. Flooding from Hurricane Matthew (2016) at Cherry Research Station and NCDA&CS First Responders



Endangered and Protected Plant Species / Flooding, Heat, & Wildfire

Impact Summary

The Plant Conservation Program is tasked with the conservation and protection of North Carolina's native flora under the authority of the NC Plant Protection and Conservation Act.[4] Under this act, the Plant Conservation Board creates and maintains the state's Protected Plant Species List (**02 NCAC 48F .0301)** which designates legally protected species as endangered, threatened, or special concern. The Plant Conservation Program implements the organizational rules and regulations related to the Act and carries out conservation programs including protecting listed plant species on Plant Conservation Preserves. These Preserves are state-dedicated nature preserves owned and managed by the Department for the protection of imperiled plant species in perpetuity. These Preserves are critical for the long-term survival of many of the state's listed species, and in the case of endemic species found only in North Carolina, survival in these sites is equivalent to their survival worldwide.

As an example of the impacts to natural resources and Departmental assets, a wildfire in 2011 caused severe damage to a stand of trees at a Plant Conservation Preserve. A salvage harvest was subsequently conducted to avoid a southern pine beetle outbreak. Not only did the salvage harvest require significant resources to manage, the full value of the harvested trees was also not obtainable, resulting in a net loss of both immediate and future assets. Similarly, flooding from recent hurricanes caused infrastructure damage at multiple Plant Conservation Preserves, including compromised culverts, washed out roads, and damaged structures. The damage to roads and culverts also caused severe delays in planned site management activities such as prescribed burning and tree harvest.

Vulnerability and Risk

The Plant Conservation Preserves are the only state-owned lands with the express purpose of protecting imperiled plant populations. Importantly, many of North Carolina's imperiled plant species are adapted to narrowly-defined environmental conditions. Additionally, many preserves protect some of the state's last remaining populations of the various target species. Safeguarding these sites is critical for the ongoing protection of North Carolina's natural heritage.

There are several concerns for preserves in the face of climate-related hazards. Flooding can cause damage to preserve infrastructure such as access roads and culverts, damage to natural resources such as inundation-caused death of trees and other plants, and the introduction of off-site materials detrimental to natural areas, including pollution, invasive plant seeds, etc. Increased heat and incidence of drought can also directly impact the survival of imperiled plant species, especially those with narrow climatic tolerances, such as high elevation species for which there is no further habitat to retreat to under rising temperatures. Importantly, these two risks amplify one another and also lead to an increased risk of wildfire.

[4] Plant Protection and Conservation Act, N.C. Gen. Stat. §§ 106-202.12 - 106.202.22



Figure 5B-7: 2018 Hurricane damaged road at Hog Branch Ponds Plant Conservation Preserve, Brunswick County

Although many species of plants in this state benefit from prescribed burning at suitably low intensities, wildfires tend to burn with higher intensity and over greater area. Wildfires and flooding can also cause detrimental turnover of species composition by enabling invasive exotic species to colonize previously undisturbed areas. Forests are especially vulnerable to these impacts, causing irrevocable damage to important natural communities. All these impacts are especially detrimental to small populations which are more vulnerable to stochastic events—this applies to many of the state's unique protected plant species.

Non-climate stressors such as increased urbanization (causing greater wildland-urban interface, increased impervious surfaces, and urban heat-island effects) amplify the impacts of climate-related risks such as increased flooding and extreme heat in and around Plant Conservation Preserves. Forest insect and disease outbreaks are other examples of non-climate stressors which will increase the impact of climate-related risks, especially wildfires. As an example, Hemlock Wooly Adelgid is causing hemlocks, which are a keystone species, to die off in great numbers in the mountain region of North Carolina. Having so many dead trees in a forest warms and dries the forest floor, which not only exacerbates the impacts of extreme heat under climate change, but also leaves the impacted areas more vulnerable to wildfire and storm damage.

Although forest insects and disease concerns tend to be somewhat localized, at least to a geographic region, there are examples of these same or similar concerns across the state, making the geographic variability of impacts similar, although via differing vectors. For instance, the Emerald Ash Borer is killing significant numbers of ash trees in the Piedmont region, while the coastal region is experiencing similar concerns over Red-bay Ambrosia beetle and the spread of Laurel Wilt Disease. Outbreaks of these insects and/or the diseases they spread can be rapid and difficult to treat or reverse. These outbreaks

cause rapid changes in the natural community structure on Plant Conservation Preserves with negative impacts to the rare species populations protected therein.

The severity and scope of each of the different climate-related hazards will vary across the state given the geographic variability of North Carolina. For instance, flooding will likely be the most important concern for the Preserves in the coastal region which are at low elevation, have less variable topography, and are at the downstream end of most of North Carolina's rivers. In contrast, the impacts of extreme heat will likely be the most important concern for Preserves at high elevations, such as those the mountain region. Increased wildfire and invasions by invasive exotic species are likely to be of equal concern for all 26 of the Plant Conservation Preserves, regardless of geographic region.

The Plant Conservation Program has limited human or technological resources available to oversee the management and maintenance of present and future climate-related damages on Plant Conservation Preserves. Response to major events like wildfires or severe flooding would be beyond the capacity of the program to respond to without significant support from elsewhere, such as the NC Forest Service or with funds from state or federal programs like FEMA. Mitigating climate change hazards at the preserves is presently geared toward reducing the likelihood of wildfire and refining methods for repairing damaged infrastructure from floods.

Resilience Strategies

Adaptive Management

The Plant Conservation Program is working to increase ecosystem resilience to climate change within the Plant Conservation Preserves through adaptive management. This strategy includes prescribed burning and mid-story thinning which help remove excessive vegetation/fuels to lessen the vulnerability of these protected areas to wildfires. As wetlands are helpful in absorbing and slowly releasing flood waters, restoration of wetlands on Plant Conservation Preserves also reduces the negative impact of flooding.

These activities not only benefit the Preserves, but also to the surrounding communities to the extent that they are able to mitigate some fire and flooding impacts. These adaptive management techniques are helping to reduce the exposure and sensitivity of the current and increasing risk of wildfire and floods. These methods and other restoration efforts for wetlands can help reduce the sensitivity to increased flooding and increase the overall adaptive capacity at the Preserves.

Conservation efforts

The Plant Conservation Program is also working with state and regional partners to collect seeds and other germplasm from imperiled species at the Plant Conservation Preserves for long-term storage offsite. Seed-banking and other long-term storage techniques offer a complementary way to safeguard these populations from predicted and unforeseen negative impacts due to climate-related hazards. Offsite conservation efforts, such as long-term seed-banking, are increasing the adaptive capacity of the Plant Conservation Program for managing the imperiled plant populations at the Plant Conservation Preserves. The greatest barrier to implementing these and other adaptive management actions is a limit to available resources.

The prescribed burning that is possible with current capacity in the Plant Conservation Program and with support from NC Forest Service is helping to meet current burn management goals. However, additional resources in both of these divisions would be needed to adequately prepare for future climate-related hazards. Potential partners toward this goal include other agencies, like the U.S. Forest Service, NC Wildlife Resources Commission, or non-governmental organizations such as The Nature Conservancy,



which itself manages considerable acreage across North Carolina. Additional funding to support effective wetland restoration projects would help mitigate localized flooding impacts at both the Plant Conservation Preserves and possibly their surrounding communities as well.

Plant Surveillance

Additional resources to monitor the responses of rare and imperiled plant species (as well as those which are common now but are predicted to be sensitive to future changes) to changing climate conditions would provide valuable information for determining future actions, including where and how to prioritize protecting the most vulnerable species and understanding which mitigation actions are the most effective. Potential partners in this effort include the NC Natural Heritage Program which conducts valuable field surveys of rare species and important conservation areas; research universities and institutions, especially those training future field biologists and ecologists; and federal agencies such as Department of Defense, Department of Interior, and U.S. Department of Agriculture which conduct similar research for similar purposes.

Personnel, Resources and Equipment Constraints / Wildfire

Impact Summary

There are approximately 23 million acres that fall under the state's jurisdiction where wildfire may flare up and require suppression. On average, North Carolina has around 4,000 wildfires annually that burn approximately 26,000 acres. Extreme drought conditions, coupled with other aberrant weather patterns like those seen in 2016, resulted in more than 5,000 fires and 88,000 scorched acres. Outside of wildfire, NC Forest Service employees respond to other natural disasters that include hurricanes, flooding, and winter weather events.

Vulnerability and Risk

The scale of wildfire across the landscape is increasing due to climatic changes including prolonged droughts, extreme wind events, and changing precipitation patterns as well as non-climate stressors such as increased flammable vegetation near inhabited areas. More specifically, North Carolina has 13.5 million acres in the Wildland Urban Interface (where homes meet woodland), which is the highest in the nation. North Carolina is also one of the fastest growing states by population, and with this growth the Wildland Urban Interface is expected to also increase and put further strain on the NC Forest Service to adequately suppress wildfires.

Human activity, another non-climate related stressor, is a major cause of wildfires across the state. Most wildfires result from careless use of fire or accidental ignitions. In any given year, only 1% of the wildfires that occur in North Carolina are a result of lightning. In 2018, arson accounted for 5%. The data on human-caused fires go back to 1971 and the trend is not expected to change as more and more people move into the state.

Although the NC Forest Service operates in all 100 counties, resources and manpower are often shared between counties, depending on the size and duration of an emergency event. The 2016 wildfire and hurricane season significantly strained the agency's capacity to respond, requiring additional resources from across the nation. The NC Forest Service employs 647 full time personnel, and of those, 330 are initial attack county level resources. However, during the peak of the 2016 wildfires, more than 3,000 personnel were engaged in wildfire control activities across the state.

Wildfires in the Wildland Urban Interface zone have a significant effect on real property in North Carolina, and in fiscal year 2017 there were 425 homes and structures destroyed, with an estimated financial impact of $8.9 million dollars. During that same period, 81,142 homes and structures were protected with an estimated value of $1.2 billion dollars, in part due to the significant support from out-of-state resources.

The tools used to fight wildfire in the state are aging, and current funding limits the replacement of high dollar items such as heavy equipment. The state fleet of bulldozers used to create fire breaks and the transport systems used to carry them are well behind the desired replacement schedule. There are currently 35 bulldozers (37% of the fleet) and 38 transport systems (25% of the fleet) on the replacement list. This aging fleet is resulting in increased maintenance costs and longer down times due to non-availability of parts. As incidence of wildfire is likely to increase under climate change conditions, there will be an even greater need for these critical resources to not only combat wildfire, but also preemptively protect against it.

Resilience Strategies

The NC Forest Service continues to look for options to deal with the state's wildfire problem. The NC Forest Service works year-round to educate the public on the wildfire problem and solutions to reduce risk and vulnerability. Fire itself is not the problem, as this state and its many ecosystems have evolved with fire over time. However, the timing of fires and their ignitions do pose a problem.

All wildland fire agencies understand that prescribed fire is the best tool to combat wildfires, but there is a need for greater public education promoting the value of controlled burns as well as other risk reduction activities. Examples include forest management techniques and removal of flammable fuels near homes and businesses. As more people move into the state from other parts of the country, this education piece becomes more necessary and more difficult. In many parts of the country, fire is not used to manage the environment on the scale that is needed here in this state, thus public education is critical. The recent wildfires in California are an example of what happens when fire is not used in the environment as it should be, regardless of the reason it was excluded[5].

In terms of equipment, the agency must work within the constraints of its budget to procure the tools necessary to fight wildfire in the state. To replace the heavy equipment that currently meets replacement criteria would require at least $16 million. In addition, the NC Forest Service is in the process of upgrading its radio system, but it is estimated to cost $1.76 million to complete the transition.

Departmental Workforce Capacity / All Climate Hazards

Impact Summary

NC Department of Agriculture and Consumer Services employees are responsible for conducting and assisting in emergency response to natural disasters and extreme weather events. NC Forest Service is specifically mandated to provide emergency response for wildfires and natural disasters such as hurricanes, flooding, and ice. Employees, both permanent and temporary, are located to provide the best

[5] Little, J.B. (2018). *Fighting Fire with Fire: California turns to Prescribed Burning.* Retrieved February 14, 2020, from: https://e360.yale.edu/features/fighting-fire-with-fire-california-turns-to-prescribed-burning



response times throughout the state and to allow prompt dispatching of additional resources when requested. Training is available to all employees on proper emergency response procedures. A timely response to any type of event is essential to reduce the impacts to this sector and North Carolina's citizens.

Vulnerability and Risk

The ability of the Department to respond to any emergency or natural disaster is dependent upon access to a full staff of trained employees. The current vacancy rate in NC Forest Service alone is close to 10%, with the majority of vacancies in entry-level positions. The current trend in NC Forest Service hiring has resulted in 50% of staff having fewer than 10 years of service, with 32% of those employees having fewer than 5 years of service. These employment trends have led to employees with minimal experience responding to these types of events which can increase the risk of loss of life or permanent injury.

Providing resources to respond to events such as the 2016 wildfires as well as Hurricanes Matthew and Florence required shifting employees statewide. This shifting of employees leaves minimal staffing at assigned duty stations to respond to everyday requests and local emergency response. As the climate changes, the potential for increased natural disasters may occur, putting additional requirements on current staffing levels.

There are many factors influencing the Department's ability to hire and retain employees. The current job market is extremely competitive, and current salaries are not aligned with private industry. Outside of the competitive job market, there are hazards and stresses associated with emergency response. This requires extra hours beyond the normal work day which impacts personal and family time and is not conducive to an acceptable work-life balance. Employees frequently responding to emergency events are more likely to become burnt-out and over-stressed, resulting in health issues, lost work time, and seeking alternate employment with fewer hazards and stresses.

Resilience Strategies

To retain and hire qualified employees, salaries need to be increased to a level that is competitive with the current market. NCDA&CS Human Resources Division has assessed those job classifications with the highest turn-over rates to identify equity issues and the funding needed to bring all employees in these classes to the appropriate salary level. The ability to retain employees that have been trained and to hire qualified employees will better prepare the department to respond to emergencies on a statewide level. Hiring qualified employees can also help reduce the time and funding needed to train staff. Fixing salary equity issues requires salary adjustment funding which must be approved by the NC General Assembly. Although requested, such funds have not yet been approved.



4. Summary

The Agriculture and Forestry sector, including protecting North Carolina's endangered plants species, is uniquely tied to climate due to the biological and physiological constraints of plants and animals. As stated by Walthall et. al. , "The vulnerability of agriculture to climatic change is strongly dependent on the responses taken by humans to moderate the effects of climate change."[6] The impacts to this sector directly reflect the impacts to North Carolina's rural and suburban citizens. The greatest departmental assets are experienced personnel, who interact with the public daily and in times of crisis to address a growing set of hazards related to a changing climate. Attracting, retaining, and protecting these personnel and addressing the upkeep and/or replacement schedule of aging infrastructure and equipment will be critical to meet future needs.

At present, inland flooding is the greatest climate-related threat facing agriculture and forestry statewide. However, during periods of extreme temperatures with associated drought, the threat shifts to wildfire and widespread loss of agricultural productivity. Most department-owned facilities, as well as crop and pasture lands, cannot be easily relocated to mitigate the risk of flooding due to the unique agricultural and climatic characteristics that tie them to the varied farming and forestry regions across the state. Options to mitigate extreme heat and drought include research and development of adaptive varieties and species of crops, livestock, and poultry and increasing available on-farm water storage capacity. Lastly, reducing wildfire risk hinges on public education and proactive actions to reduce the causes of wildfire. Response to increased emergency events and natural disasters, especially wildfires, will impact the department with an outsized impact on the NC Forest Service which is mandated by the North Carolina General Statutes to detect and suppress all forest fires under the jurisdiction of the state. Emergency events in the most recent past have highlighted the need for increased capacity and measures to improve resiliency in the future. Funding for necessary equipment, training, and salaries, as well as internal assessments of future capacity that allow the NCDA&CS to stay at the forefront of these issues, are imperative to the state's economy and overall resilience to climate change.

[6] Walthall, C. L., Anderson, C. J., Baumgard, L. H., Takle, E., & Wright-Morton, L. (2013). *Climate change and agriculture in the United States*: *Effects and adaptation*. Retrieved February 14, 2020, from: https://www.usda.gov/oce/climate_change/effects.htm



Coastal Resources & Infrastructure

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C. Coastal Resources and Infrastructure

Key Observations

- Flooding from storms and extreme tides, magnified by sea level rise, is severely affecting land use, public infrastructure, and natural resources along the coast of North Carolina
- The intensity of recent storms and flooding have challenged the state's response and recovery plans. We should plan for greater extremes in the future.
- Climate hazards intensify existing social inequalities and lack of ability to adapt in economically challenged counties in the coastal region.

Critical Impacts and Resilience Strategies

- Climate change is impacting coastal habitats, fisheries, and the ecosystem services provided in coastal communities. State monitoring, research, and education can enhance understanding of impacts and potential adaptation strategies.
- Immediate focus must be on developing strategic priorities for public and natural infrastructure improvements as well as actions that integrate climate resiliency into agency operations, local disaster recovery programs, and long-term planning.
- Future climate conditions and resiliency should be integrated into current public investment decisions in local and regional water and transportation infrastructure improvements and other critical assets.
- State leadership should model adaptive behavior and incentivize local resiliency efforts that balance protection of life, property, and the environment. Inter-agency coordination can help build local capacity and action through funding and technical assistance.

1. Sector Overview

Coastal North Carolina is known for its extensive natural resources, including 320 miles of ocean beaches, 12,000 miles of estuarine shoreline, the second largest estuary in the nation, and numerous coastal and estuarine protected areas. Approximately one-half of the oceanfront is developed, and there are over 100 miles of national seashore. From broad, shallow sounds such as the Albemarle and Pamlico, to narrow bodies of water such as Bogue and Masonboro sounds, North Carolina has 2.2 million acres of estuarine waters and 726,000 acres of coastal ocean waters. These features present a significant opportunity to protect, restore, and enhance our natural infrastructure to bolster community and ecosystem resilience, and to endure and recover from future storms.

Coastal N.C. is predominantly rural, with a diffuse population that is dependent on natural systems for its economic well-being. These same natural resources also provide important protection from storm surge, flooding, and other impacts associated with climate change. The North Carolina coast is complex and dynamic, with a diversity of demographics, hazards, jurisdictional authorities, and economic drivers, including agriculture, extractive industries, tourism, military, and shipping.
Most cabinet agencies have assets or responsibilities that intersect with the coast, including the Department of Environmental Quality's (DEQ) Divisions of Water Resources and Marine Fisheries (DMF), the Wildlife Resources Commission, and the Departments of Transportation and Public Safety, the latter of which houses the new Office of Recovery and Resiliency (NCORR).

This section primarily addresses programs and assets within DEQ's Division of Coastal Management (DCM), which houses DMF and the Albemarle-Pamlico National Estuary Partnership (APNEP). Other agency programs are discussed more in-depth in other parts of this document.



The ***DCM*** carries out the state's Coastal Area Management Act (CAMA), Dredge and Fill Law, and the rules and policies of the Coastal Resources Commission (CRC), in the state's 20 coastal counties. The CRC is charged under CAMA with the protection, preservation, orderly development, and management of the coastal area of North Carolina, including public trust resources. DCM, which provides staff support to the CRC, is responsible for several programs, including permitting, land use planning oversight, coastal policy, the Coastal Reserve program, and numerous grant programs.

DCM's Coastal Reserve protects and manages more than 44,000 acres of coastal and estuarine land and water for research, education, and compatible traditional uses at ten reserve sites along N.C.'s coast. Four of these sites comprise the National Estuarine Research Reserve, a state-federal partnership between DCM and the National Oceanic and Atmospheric Administration (NOAA).

The ***DMF's*** mission is to ensure sustainable marine and estuarine fisheries and habitats for the benefit of the people of North Carolina. This includes the management of North Carolina's marine and estuarine fisheries out to three miles offshore, and monitoring the state's fisheries habitat, encompassing all 2.9 million acres of coastal waters (marine and estuarine) and over 412,000 miles of coastline.

The ***APNEP's*** mission is to identify, protect, and restore the significant resources of the Albemarle-Pamlico estuarine system. The partnership is a cooperative effort hosted within DEQ under a cooperative agreement with the U.S. Environmental Protection Agency. APNEP works closely with the Commonwealth of Virginia, as the program area extends across both states, from its headwaters in the Virginia mountains and North Carolina Piedmont, through a broad coastal plain and out to the string of barrier islands bordering the sounds.

2. Overall Exposure

Climate Stressors

North Carolina is one of the states most impacted by, and vulnerable to, climate-related changes in coastal hazards such as storms, coastal flooding, beach erosion, and sea level rise. Flooding from precipitation, storm surge, and tides, amplified by sea level rise, has become a more frequent and damaging hazard in recent years. Storm floods are typically geographically limited, but devastating events. Sea level rise, by contrast, is a gradual but significant hazard that affects the entire coastal region. Unlike storm flooding, sea level rise does not recede.

Sea level rise intensifies other coastal hazards such as flooding, storm surge, shoreline erosion, and shoreline recession. Sea level rise can also pose a threat to freshwater resources and quality, private property and development, tourism and economic vitality, historic and cultural resources, agriculture, forestry, and public property and infrastructure. Proactive adaptation and resilience building can help to minimize economic, property and natural resource losses, minimize social disruption and losses to public trust areas and access, and lessen the need for disaster recovery spending.

Non-Climate Stressors

North Carolina has large areas of high social and economic vulnerability, and needs to build human and environmental capacity to adapt to the changing climate, particularly at the local community level. This lack of capacity is costly in economic, environmental, and most importantly, in human terms.

3. Examples of Impacts, Vulnerability, and Risk

Division of Coastal Management

Impact Summary

The most visible impacts of climate change on coastal resources and structures result from more intense storminess, precipitation, and flooding (Table 5C.1). Sea level rise, driven by warming ocean temperatures and melting land ice, amplifies these impacts. Catastrophic damage occurs to private and public property, both in the built and natural environment. While DCM does not own any physical property, the agency's programs and operations, and resources and uses that the division manages, are impacted by climate-related hazards. In addition, structures and activities that the division regulates, as well as public trust resources, are also impacted. Coastal flooding, from storms and sea level rise, impacts both the natural and built environment. Transportation, housing, critical facilities, businesses, utilities, and other infrastructure—many of which are located within DCM's jurisdictional Areas of Environmental Concern (AECs)—can be damaged or destroyed, and will require permits from DCM to be rebuilt.

Table 5C-1: Division of Coastal Management Exposure Table

Assets, Regulations, Services	Tidal Flooding	Flooding (River and Land)	Coastal Erosion	Storm Surge	Sea Level Rise	Saltwater Intrusion	Water Shortage (Drought)	Wildfire	Wind
Division of Coastal Management									
CRC rules & policies	*	*	*	*	*				*
CAMA permitting	*		*	*					*
Land use planning	*	*	*	*		*	*		*
Access grants		*	*						
Coastal resiliency initiative	*	*	*	*	*				*
Science & data	*		*		*				

Public trust resources such as beaches and wetlands can be damaged or lost due to climate-amplified processes. While sediment supply is a primary determinant of beach width, storms, sea level rise, and management decisions also contribute to beach and dune condition. In particular, powerful storms can remove huge volumes of sand from the beach and dunes, and erode wide swaths of coastal wetlands, in a matter of hours. The loss of public trust beaches, dunes, and wetlands equals a loss in wildlife habitat for sea birds, turtles, crustaceans, invertebrates, etc. Economic damage can be extremely high; damaged and destroyed buildings and infrastructure means less tourist revenue, and money spent on beach re-nourishment and habitat restoration.

DCM's mission statement focuses on the importence of a comprehensive approach to coastal issues, including not only permitting, but also planning, conservation, reearch, education, and outreach. As coastal development continues at a rapid pace, DCM's limited number of staff are already handling a significant volume of permitting, enforcing, rule development, and legal issues. In addition, DCM has limited financial resources to address the growing needs associated with climate adaptation and resilience planning. However, DCM is well situated to develop and implement a coastal resilience program given its exsiting state authorities, federal grants, local planning, grants, and technical assistance efoorts over the past several years. An expanded coastal resilience program at DCM wouold require additional staff support and a clearly defined partnership with NCORR, which is currently in development.



Figure 5C-1 North Carolina's 20 coastal (CAMA) counties

Vulnerability and Risk

Coastal AECs are tidal waters of the ocean, sounds and rivers, and the beaches, dunes and lands adjacent to them. As such, AECs, and the permitted development within them, are often the first areas to be affected by storms and chronic sea level rise. DCM's role is to authorize development in AECs according to standards established by the Coastal Resources Commission, but it is the permittee that bears the vulnerability and risk of damage. Sensitivity of structures and ecosystems varies by location and development patterns, including protective and avoidance measures, and the scale of impacts ranges from minor and temporary, to catastrophic and permanent. Financial ability to take adaptive actions varies across individuals and communities, and similarly, potential adaptive actions vary widely by complexity, cost, feasibility, and effectiveness. Along non-oceanfront shorelines, storms and sea level rise impact both natural and developed areas, putting both wildlife habitat, valuable marshes, and development at risk.

High water events, including storms, nor'easters, extreme tides, and other weather-related events cause surge and either erode sand out to sea, or cause overwash inland, covering roads, yards, parking lots, and other infrastructure. With sea level rise and higher storm intensity, erosion and overwash are becoming more frequent, removing sand from public trust beaches. Despite some localized natural accretion, there is usually a net loss of sand to an impacted area. Fully restoring the beach, or returning overwashed sand to the ocean beach, requires expensive intervention, and ideally a long-term program for beach and dune maintenance. Long-term programs require reliable funding and adequate sediment supply, coordination, and permitting. Good examples exist in North Carolina of successful long-term programs, but not all beach communities have the financial, sand, or organizational resources required to implement long-term



beach maintenance programs. Beaches and dunes are among the first systems assessed for damage after a storm because of their high vulnerability and the importance of the protective, ecological, and economic services they provide. Beaches have no natural defenses, and most permanent structures to combat erosion are prohibited by law because they would protect one area at the expense of another or result in loss of public trust beaches over time.

Resilience Strategies

There are countless actions and strategies that may advance coastal resilience. A few are highlighted here, taken from local governments suggestions from two regional workshops in 2019, and others submitted by environmental NGOs.

Create and fund a program to build local capacity for climate resilience. The program should incentivize and reward communities for meeting defined standards for long-term planning, preparedness, and community engagement, and help them to plan shovel-ready projects in order to capitalize on federal and state funding opportunities. DCM and NCORR are currently researching other states that have created similar programs.

Incentivize communities to protect, enhance, and restore natural infrastructure that can provide flood protection, ecosystem, and economic benefits. Increase appropriations to natural resource trust funds for acquiring and/or enhancing priority coastal lands. Simplify rules for ditch clearing and make nature-based solutions easier to permit.

Identify and re-evaluate policies and subsidies that incentivize or allow risky investment decisions. Require or encourage rebuilds and retrofits to be constructed more resilient than pre-damaged condition. Consider climate change and sea level rise in future investments decisions. Incorporate more low impact development practices.

Provide data to local government staff through a best practices website, and assist with interpretation. Continue to do sea level rise assessments, and fund data collection, research, and monitoring. Integrate coastal hazards and rainfall data into updated spatial analysis of vulnerabilities, e.g., sea level rise, rainfall flooding, and storm surge. Host regular training webinars and workshops. Consider placing trained resiliency coordinators at regional councils of government or community colleges.
Strengthen hazard mitigation plan requirements based on updated county vulnerability analyses, and require CAMA land use plans to be consistent with updated hazard mitigation plans. Integrate resiliency planning into existing planning requirements, such as capital improvements, economic development, hazard mitigation, and comprehensive or land use plans.

Demonstrate state leadership. Prioritize major state investments using resiliency criteria. Create a scoring system to quantify risk of state-funded projects to communities of concern. Centralize resiliency programming into one agency or organization and assist with state match for federal funding opportunities. Strengthen interagency, local, private, and academic partnerships. Empower stakeholders to be equal partners.

Regulations and Policies

The division's legislative authorities are the N.C. Coastal Area Management Act (G.S. 113A-100 *et seq.*), the N.C. Dredge and Fill Law (G.S. 113-229) and the federal Coastal Zone Management Act (CZMA) of 1972, as amended. The division administers the rules set by the CRC in Title 15A, Section 7 of the N.C. Administrative Code. CAMA was enacted to fulfill four overarching goals, and the CRC's rules are all designed to meet the following mandates:



- To preserve and manage natural ecological conditions and productivity;
- To ensure that the development, use or preservation of land and water resources is consistent with ecological conditions;
- To ensure orderly and balanced use and preservation of coastal resources; and
- To establish policies, guidelines and standards for development, preservation, use, and protection of public trust rights and resources.

CAMA, Dredge and Fill, and the CRC's rules are all designed to protect property and the environment. To accomplish this, the statutes and regulations require that DCM's programs measure and account for dynamic and sometimes volatile conditions, shifting boundaries, flooding, storm surge, erosion, and any other processes or events that could undermine the desired protections. To date, DCM has done this by analyzing historic data, with the inherent presumption that future conditions will approximate past conditions. Climate change is forcing DCM to consider how best to account for future conditions in today's programs and operations.

Unlike the state's oceanfront shoreline where permanent erosion control structures are mostly illegal, North Carolina allows permanent hardening of estuarine shorelines using vertical bulkheads and other hardened erosion control structures. In recent years, DCM has been promoting "living shorelines" using constructed oyster reefs and marsh plantings for shoreline erosion control, as they mimic a naturally-occurring shoreline and deliver multiple benefits. Living shorelines are being found to outperform vertical bulkheads for storm protection and longevity, and also preserve vital intertidal habitat that would be lost as sea level rise approaches a vertical bulkhead.

The DCM is responsible for several programs, including:

Permitting

CAMA permits are required if a proposed project is in one of the 20 CAMA counties, in an area of environmental concern (AEC) designated by the CRC, meets the statutory definition of "development," and is not an exempt activity by rule or statute. CAMA defines development as: "any activity in a duly designated area of environmental concern ... involving, requiring or consisting of the construction or enlargement of a structure; excavation; dredging; filling; dumping; removal of clay, silt, sand, gravel or minerals; bulkheading; driving of pilings; clearing or alteration of land as an adjunct of construction; alteration or removal of sand dunes; alteration of the shore, bank or bottom of the Atlantic Ocean or any sound, bay, river, creek, stream, lake or canal; or placement of a floating structure in an Area of Environmental Concern" as designated by the CRC.

Land-use planning

CAMA requires each of the 20 coastal counties to have a local land use plan in accordance with guidelines established by the CRC; however, the policies included in the plans are those of the local government, not the CRC. As of 2020, nearly 40 cities and towns have also voluntarily adopted their own plans, although CAMA does not require them to do so. Each land use plan includes local policies that address growth issues such as the protection of productive resources (i.e., farmland, forest resources, fisheries), desired types of economic development, natural resource protection, and the reduction of storm hazards. Once a local land use plan is certified by the CRC, DCM uses the plan in making CAMA permit decisions and federal consistency determinations. Proposed projects and activities must be consistent with the policies of a local land use plan, or DCM cannot permit the project.



Beach and waterfront access

DCM awards about $1 million a year to local governments, as matching grants for projects to improve pedestrian access to the state's beaches and waterways. Funding for the Public Beach and Coastal Waterfront Access Program comes from the N.C. Parks and Recreation Trust Fund. North Carolina currently has approximately 1,000 beach, shoreline, and boating access sites, many of which received funding through this program for land acquisition and improvements.

Coastal resiliency

DCM's Coastal Adaptation and Resiliency website[1] provides links to climate data and forecasts, assessment and planning tools, adaptation examples, and sources of funding for planning and implementation. It is geared primarily towards local government staff and other stakeholders interested in coastal resilience in North Carolina. DCM's Resiliency Guide[2] is designed to walk users through some of the key steps and questions required for effective community-level resiliency planning. It presents a process for building resilience and climate change considerations into existing efforts such as comprehensive land use, hazard mitigation, or capital improvement planning, while also focusing on other co-beneficial strategies for risk reduction.

Federal consistency

Under provisions of the federal CZMA, DCM is authorized to review proposed federal actions such as permits or lease sales, and direct federal activities such as channel dredging or construction, to determine whether the proposed action or activity could have a reasonably foreseeable effect on resources or uses in the state's coastal zone. DCM coordinates with state resource and regulatory agencies, subject matter experts, and other interested stakeholders, to evaluate potential impacts and ensure that the proposed action or activity is maximally consistent with applicable state laws and regulations.

Science and data

The CRC's Science Panel prepared the state's first ever Sea Level Rise Assessment Report in 2010, providing projections to the year 2100. In 2015 the Science Panel released their second report, with regional projections to 2045. The Science Panel will release their third Assessment in 2020. DCM has also been building a geographic information systems (GIS) program since the early 1990s. Today, DCM is incorporating this technology into a number of its programs, using GIS to help support land-use planning and regulatory decisions. DCM is using GIS to better manage development in coastal high-hazard areas by analyzing data such as inlet dynamics and shoreline erosion patterns. The results help to determine setback requirements for oceanfront construction. DCM maintains an interactive map and smartphone app of public access sites and facilities. DCM also collects and analyzes data for erosion rates, wetlands conservation and restoration, and to assess the impacts of coastal development.
The N.C. Clean Marina Program rewards marina operators who help safeguard the environment by using management and operations techniques that go above and beyond regulatory requirements. Clean marinas may fly the Clean Marina flag and use the logo in their advertising, signaling to boaters that the marina cares about the cleanliness of area waterways. The Marine Sewage Pumpout and Dump Station Grant Program provides grants of up to $20,000, from the U.S. Fish and Wildlife Service, to marinas and other boat-docking facilities for the installation and renovation of pumpout and dump stations in North Carolina.

[1] https://deq.nc.gov/about/divisions/coastal-management/coastal-adaptation-and-resiliency
[2] https://ncdenr.maps.arcgis.com/apps/MapSeries/index.html?appid=e2eb18546943471b93f0264659744a81

North Carolina Coastal Reserve & National Estuarine Research Reserve

Impact Summary

Coastal storms and flooding, compounded by climate stressors, directly impact reserve ecosystems and the services they provide (Table 5C-2). Impacts include forest damage, wetland loss, sand movement and loss, habitat loss or conversion, damage to marine access infrastructure, loss of visitation and educational program days, loss of signage, increased marine debris including vessel groundings, and increased maintenance and repair costs.

Table 5C-2: Coastal Reserve & National Estuarine Research Reserve Exposure Table

Assets, Regulations, Services	Extreme Heat	Flooding (River and Land)	Coastal Erosion	Changed Seasons	Sea Level Rise	Saltwater Intrusion	Storm Surge	Tidal Flooding	Wildfire	Invasive Species & Species Range Shifts	Vessel Groundings
North Carolina Coastal Reserve & National Estuarine Research Reserve											
Reserve Sites		*	*	*	*	*	*	*	*	*	*
Site Support Structures		*	*		*		*	*	*		
Research Program	*	*		*	*		*	*	*	*	
Research Infrastructure		*	*		*		*	*	*		
Stewardship Program	*	*	*	*	*		*	*	*	*	*
Education & Training Program	*	*			*		*	*	*	*	

In recent years, hurricanes have been the primary impact to reserve sites. This includes damage to the Currituck Banks and Rachel Carson Reserves' boardwalks; downed trees at multiple sites that blocked trails, creating a hazard for staff and visitors; increased marine debris and vessel groundings on sites that also posed a hazard to staff and visitors; and erosion at multiple sites. Visitation to reserve sites is impacted when sites are closed to protect safety which has potential implications for local economies. Reserve programs are also impacted, as training and education programs are affected by delays or cancellations and the research program's sampling schedule is delayed. Storm impacts also increase



workload for staff during the immediate response and long-term recovery process. With the increasing frequency and intensity of storms, more resources are needed to facilitate response and recovery.
The reserve recognizes that the changing climate will have an impact on its sites and programs. The NCNERR Management Plan 2020-2025 identifies coastal hazards resilience as a cross-cutting topical area the reserve is currently working on that will continue into the future; an excerpt from the plan is below:

> *The natural geography and topography of North Carolina's coastline make it vulnerable to coastal hazards, such as flooding, coastal storms, shoreline erosion, and sea level rise. Assessing the vulnerability of coastal and estuarine ecosystems at reserve sites is accomplished through existing monitoring programs like the System-Wide Monitoring Program (SWMP), natural species surveys, habitat mapping, and elevation data analysis. The reserve's ability to monitor and characterize these processes and changes is increasingly important when it comes to understanding and planning for coastal hazards to ecosystems and coastal communities. The reserve is equipped to improve the knowledge of coastal communities about the necessity of establishing long-term resilience through education, training, research, and stewardship activities that promote monitoring programs, encourage implementation of adaptation strategies to address observations and plan for future scenarios, and the important role natural infrastructure plays in coastal resilience.*

The following objectives are part of the reserve's identified work in the plan:

- Assess vulnerability of reserve natural resources to coastal hazards and use results to inform management decisions.
- Increase understanding and communicate knowledge of the importance of natural infrastructure (e.g., oyster reefs, marsh, living shorelines) to coastal resilience.
- Increase understanding of sea level rise implications and resilience opportunities for reserve sites and coastal and estuarine ecosystems by participating in local, regional, and state initiatives.

Vulnerability and Risk

The reserve is working to better understand the specific vulnerability of its sites and habitats. Also, the reserve is assessing its adaptive capacity to protect representative coastal ecosystems and the services they provide in the face of a changing climate. Many reserve sites also serve as very important storm buffers to local communities. If the integrity of the sites is compromised due to climate change impacts, their protective services for these communities will decline, putting infrastructure and residents at greater risk. Currently, the vulnerability and risk are not known for all habitats at all reserve sites and work to better understand this is prioritized for sites that are generally understood to be vulnerable based on the site characteristics.

The sensitivity of the reserve sites is variable based on habitat type (e.g., salt marsh, tidal flat, ocean beach, maritime forest, dune ridge, non-riverine swamp forest) and location in the landscape (e.g., region of the coast and sea level rise rates, exposure to ocean energy within the region). It also varies based on event intensity, duration, and frequency. Lower-lying habitats are more sensitive to flooding, erosion, and shoreline recession from storm and king tides, and lower- to mid-range habitats to habitat transition as a result of higher water levels.

An example of an effort to better understand vulnerability and risk is the reserve's use of the Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH) to evaluate the vulnerability of saltmarshes at the four NCNERR sites in 2017[3]. CCVATCH is a decision support tool that improves

[3] http://nerrssciencecollaborative.org/media/resources/Report_Salt_Marshes_Southeast_Climate_Change_Vulnerability_Assessment.pdf



understanding of the specific vulnerabilities of a habitat to climate change in order to inform current and potential management actions. Through this data assessment process, users of this tool determine the potential for applying adaptation strategies as well as the main sources of vulnerability.

The NCNERR sites scored as 'high' in sensitivity-exposure (SE) to climate impacts, but ranged from 'low' to 'high' in adaptive capacity (AC). The Currituck Banks Reserve scored 'high' for both SE and AC, for an overall 'moderate' vulnerability score. Sea level rise and storms were the overall highest scoring climate-exposures, and invasive species and erosion were the highest scoring stressors at this site. The Rachel Carson Reserve was divided into two sections, Middle Marsh and Town Marsh, both of which both scored 'high' in SE. The sites differed in AC, with Middle Marsh scoring 'low' and Town Marsh receiving a 'moderate' score, for an overall vulnerability assessed as 'very high' at Middle Marsh and 'high' at Town Marsh. At Middle Marsh, the direct effects of sea level rise and the interaction of erosion with sea level rise and extreme climate received the highest scores. At Town Marsh, the interaction of erosion and sea level and the direct effects of extreme climate events contributed the most to the SE score.

The Masonboro Island and Zeke's Island Reserves both had 'high' levels of SE and 'moderate' scores for AC, for overall 'high' vulnerability scores. Impacts from climate exposures of sea level rise and storms scored highest for both reserve sites. The direct effects of climate change and erosion were overall the highest scoring stressors for Masonboro Island Reserve, while invasive species and nutrients had the overall highest stressor scores at Zeke's Island Reserve. This assessment will be helpful as the program prioritizes sites or areas within these sites that present the most risk and considers potential adaptation strategies in the future to enhance resilience.

Resilience Strategies

The reserve is committed to taking actions to address climate hazards. On each site, the reserve will continue to employ the Steps to Resilience.[4] The reserve will collaborate with land managers, researchers, and relevant stakeholders to assess the vulnerability of natural resources and prioritize strategies based on the greatest vulnerabilities and risks. The reserve will implement strategies that are most likely to improve resilience and provide the greatest benefits overall, given available resources. For example, the reserve has sought funding to use existing research results and vulnerability assessments to develop an environmental resilience plan, including shovel-ready projects, for the Rachel Carson Reserve.

Adaptive capacity

One of the reserve's greatest forms of adaptive capacity is its education, training, research, and stewardship programs. These programs are rooted in the local communities and professional networks, making them nimble in their response to changing conditions. This nimbleness also allows the programs to pivot their focus to achieve the reserve's mission in the face of climate change. For example, the reserve's training and education programs are increasingly incorporating climate science and resilience messages into programming as well as helping stakeholders work collaboratively on these issues. The research program is monitoring the impact of changing conditions on habitats, as well as supporting partners' work on this topic, to help increase understanding of coastal habitat resilience. Research staff and partners are also examining different "living shoreline" stabilization techniques that both maintain ecosystem services and stabilize the shoreline under different water level and energy regimes. Stewardship staff are monitoring the reserve sites for change and working towards management actions to increase site resilience. Stewardship staff have also facilitated the acquisition of additional parcels of land

[4] Gardiner E. P., Herring D. H., and Fox. 2019. The U.S. Climate Resilience Toolkit: evidence of progress. Climatic Change 153(4): 477-490. Also see https://toolkit.climate.gov/#steps

which were incorporated into existing reserve sites to protect additional habitat and support habitat migration.

Efforts are underway to address lessons learned from recent hurricane events to enhance program preparedness and response in future events. This includes engaging resource agencies and organizations to proactively leverage assistance across agencies for event response and recovery; and work with DEQ agencies and other state agencies and organizations on event-related marine debris and grounded vessels removal and policy. Future options include:

- implementing shovel-ready projects to enhance site resiliency;
- conducting vulnerability assessments at additional reserve sites;
- considering land acquisition opportunities adjacent to existing reserve sites to facilitate habitat protection and migration; and
- improve understanding of reserve ecosystems, including the ecosystem services they provide, the threats they face, and how to best protect them.

Monitoring

The reserve will continue to implement the SWMP, sentinel site, and natural resource monitoring to understand vulnerability of species, habitats, and sites and changes related to climate hazards. This includes continuing to conduct and explore opportunities to expand the *Sentinel Sites for Sea Level Rise and Inundation* module of SWMP to assess the resilience of marshes to sea level rise, evaluate the performance of living shorelines over time and during storms, and assess the impact of shoreline hardening on marshes.

Education

The reserve's training program will use vulnerability assessments and resilience strategies to educate communities and coastal decision-makers on what coastal hazards are and the importance of natural infrastructure, such as living shorelines and coastal wetlands, for coastal resilience. This includes enhancing or developing educational materials, research presentations, training events, and hands-on stewardship activities that incorporate this information. The training program will assist coastal communities to implement actions that increase their resilience to coastal hazards through technical assistance. The reserve's education program will develop and deliver hands-on resilience related curricular activities to K-12 students and teachers.

The reserve will leverage its programs to support DCM and DEQ initiatives to address sea level monitoring, resilience planning, and public engagement. Additionally, the reserve will lead and/or participate in local, regional, and state initiatives to advance collaborative efforts to address climate hazards such as the N.C. Sentinel Site Cooperative[5] and the Coastal Resilience Community of Practice.

Regulations and Policies

The reserve's legislative authorities are the N.C. Coastal Area Management Act (G.S. 113A-129) and federal Coastal Zone Management Act of 1972, as amended. The reserve rules in the N.C. Administrative Code are in section 15A NCAC 07O. The NCNERR portion of the program must also comply with federal regulations for the NERRS, 15 C.F.R. Part 921.1(a). The N.C. Administrative Code and NERRS regulations require that the reserve maintain management plans for the sites. Management plans cover 9 of the 10 sites currently; the most recent update is the soon to be approved NCNERR Management Plan for 2020-2025. Dedicated Nature Preserve authority is the Nature Preserves Act (G.S. 143B-135.250-272) and N.C. Administrative Code rules are in section 07 NCAC 13H.

[5] https://oceanservice.noaa.gov/sentinelsites/north-carolina.html



The reserve will continue to meet its legislative authorities, regulations, and policies in light of climate-related hazards, yet the program's services will need to be nimble in response and the hazards to be addressed prioritized. Significant effort is needed to understand the reserve assets' vulnerability and to plan for and implement adaptation strategies. Reserve services will need to adapt accordingly to meet this need. Capacity at the reserve is limited to meet authorities, regulations, and policies currently and resources may need to be diverted from current topics to address increasing climate-related hazards.

The mission of the N.C. Coastal Reserve and National Estuarine Research Reserve (reserve) is *to practice and promote informed management and appreciation of North Carolina's coastal and estuarine ecosystems and provide protected sites for research, education, and stewardship.* The reserve, a program within DCM, accomplishes its mission and purposes identified in the N.C. Administrative Code (15A NCAC 07O) through its education, training, research and monitoring, and stewardship programs, each of which is devoted to fostering that aspect of the program.

The education program increases awareness of the importance of coastal and estuarine ecosystems and inspires protection of these ecosystems for K-12 students and teachers, educators and the general public through its programs and materials.

The Coastal Training Program promotes informed decisions regarding coastal resources by providing target audiences, such as local officials, realtors, state agency staff, resources managers, non-profit organizations and others, with science-based training opportunities on a variety of coastal topics.
The research and monitoring program conducts, promotes and facilitates research at Reserve sites focused on ecosystem dynamics, coastal hazards resilience and human influences on estuarine systems and also provides long-term data on water quality, weather, biological communities, habitat and land-use and land-cover characteristics through its System-Wide Monitoring Program (SWMP).

The stewardship program maintains and protects the natural character of 10 reserve sites by integrating science, community input and volunteer monitoring efforts to ensure suitable environments for research and education, and to protect and restore coastal and estuarine species and habitats of environmental, economic and traditional use value to North Carolina.

The reserve's 10 sites protect more than 44,000 acres of coastal and estuarine land and water along the coast of N.C. (Figure 5C-2), providing essential habitat for wildlife and serving as platforms for program implementation such as educational opportunities for students, teachers and the public, and living laboratories for scientists. Additionally, reserve sites are available for compatible traditional public trust uses and are popular places for ecotourism, nature observation, walking, boating, and hunting.
Populations of feral horses roam on the Currituck Banks and Rachel Carson Reserves which are well-loved by N.C. citizens and visitors. Many of the sites provide a buffer to coastal communities from storms and rising sea levels.

The reserve was established as a multi-site reserve to take advantage of both the Virginian and Carolinian biogeographic regions in the state and as such, the sites are geographically disparate and represent diverse coastal and estuarine habitats. Four of the ten sites comprise the federally-designated N.C. National Estuarine Research Reserve (NCNERR). All sites, with the exception of the Permuda Island Reserve, are also Dedicated Nature Preserves through the N.C. Natural Heritage Program.
The NCNERR is one of 29 reserves within NOAA's National Estuarine Research Reserve System (NERRS), operated by the Office for Coastal Management (OCM). As such, the NCNERR is managed as a federal-state partnership between NOAA's OCM and DCM. The OCM implements the National Coastal Zone Management Program and NERRS with authorization from the federal Coastal Zone Management Act of 1972 (CZMA). The OCM provides funding, technical assistance, and national coordination and

oversight to reserves within the NERRS. The DCM manages the sites on behalf of the N.C. Department of Administration, and provides staff, programming, and matching funds for implementation of the NCNERR. The N.C. Coastal Area Management Act (CAMA) provides authority for the reserve at the state-level and officially includes the NCNERR in the program.

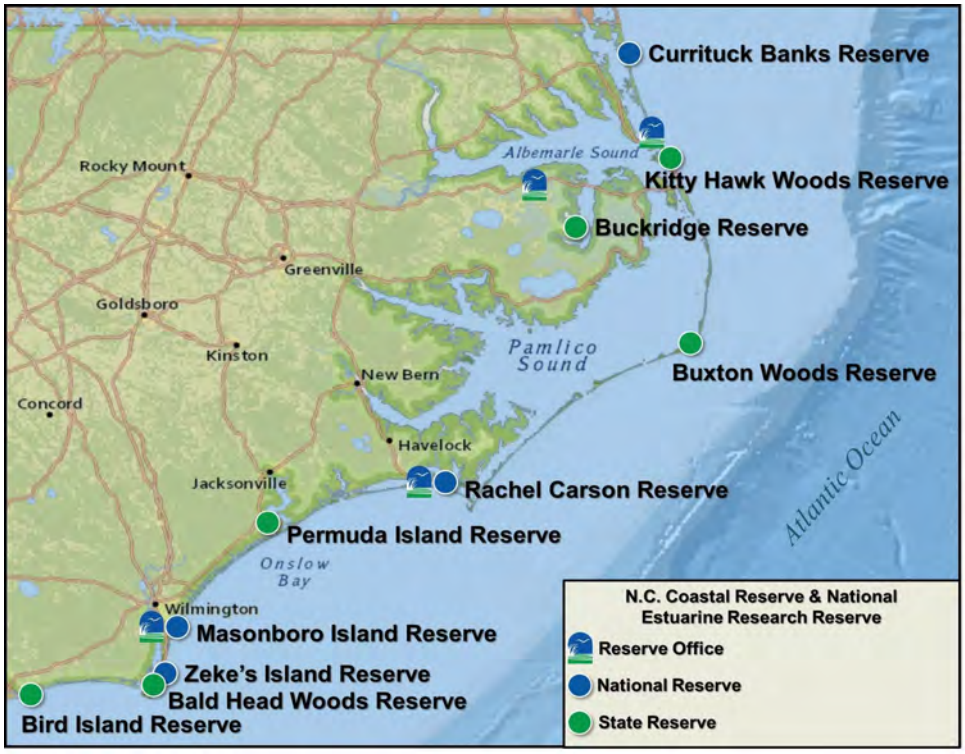


Figure 5C-2: Map of the North Carolina Coastal Reserve and National Estuarine Research Reserve Sites

Division of Marine Fisheries

Impact Summary

Climate change impacts such as salinity changes and saltwater intrusion from breached inlets and sea level rise, increasing water temperatures, shifts in currents and tides, and decreased water quality from increased storm runoff will have effects on all of North Carolina's coastal habitats and the marine organisms that call them home. As the distributions of coastal habitats changes, so will the distribution and abundance of the economically important fisheries species and the availability of the food they need to thrive. Climate adaptation for fisheries will involve continued adjustment of fishing regulations to maintain sustainable stock levels and acquiring the needed supporting science. Management based on changes in recruitment, growth, survival, and reproductive success can be done under the existing regulatory framework of the Fisheries Reform Act (FRA) by incorporating climate change science, more adaptive management actions, and ecosystem based management in the Fishery Management Plans (FMPs) and Coastal Habitat Protection Plan (CHPP) processes. Infrastructure supporting research-based management of fisheries and coastal habitats and the ability to enforce regulations will also be affected by

climate change and will need to be addressed to ensure the continuity of the DMF mission statement (Table 5C-3).

Table 5C-3: Division of Marine Fisheries Exposure Table

Assets, Regulations, Services	Extreme Heat	Flooding (River and Land)	Water Shortage (Drought)	Changed Seasons	Inundation due to SLR	Saltwater Intrusion	Storm Surge	Tidal Flooding	Wildfire	Dam Failure	Invasive Species & Species Range Shifts	Wind
North Carolina Division of Marine Fisheries												
Fisheries Research	*	*	*	*	*	*	*	*			*	*
Division Infrastructure		*			*		*	*	*			*
Research Programs	*	*	*	*	*	*	*	*		*	*	*
Research Infrastructure		*			*		*	*	*			*
Fisheries Management	*	*	*	*	*	*	*	*		*	*	*
Fisheries Infrastructure (Commercial & Recreational)	*	*			*		*	*	*			*
Coastal Habitat Protection	*	*	*	*	*	*	*	*	*	*	*	*
Outreach Programs	*	*		*	*		*	*	*		*	*
Shellfish Sanitation	*	*			*			*				
Recreational Water Quality	*	*						*				

Vulnerability and Risk

Climate change increases the variability of ecosystem factors and will affect all coastal habitats and species in North Carolina. As climate change and related impacts continue, North Carolina will see warming water temperatures, rising sea level, and more intense tropical storms, which affect hydrodynamic flows as well as nutrient and carbon loading to North Carolina's coastal rivers, sounds, and ocean waters (Fig. 5C-3). Climate change may cause a regime shift in tropical cyclone flooding and associated ecosystem impacts. North Carolina has experienced very high precipitation rates since the late 1990s, with increasingly high precipitation associated with tropical cyclones, which could have major



ramifications for hydrology, carbon, nutrients, habitat and water quality in North Carolina[6]. If we are seeing a regime shift in storms and rising temperatures, we can also expect to see species distribution shifts within North Carolina's coastal habitats. Changes to environmental variables such as salinity will also have impacts to both coastal habitats and the important species utilizing them.

The effects of the climate change-driven shift in distribution of coastal habitats will affect the aquatic organisms of the coast of North Carolina that use these important coastal habitats as nursery areas, refuge from predation, and for food supply. The changes in distribution of coastal habitats could indirectly affect fish populations due to limited habitat and food availability. Wetland loss to sea level rise and continued development will outpace the rate of wetland migration inland in many areas. In developed coastal waterfront areas, many wetlands cannot migrate landward due to hardening by vertical stabilization, topographic alteration, or structure obstruction. Loss of wetlands will result in habitat losses that will impact fisheries and degraded water quality due to the decreased in stormwater buffering capacity. Experts indicate the potential for increased Harmful Algal Bloom (HAB) occurrence is possible due to increased nutrient loading in the water and increasing water temperature attributed to changing climate.[7] Certain species of algae contain toxins that can be taken up by shellfish and cause health issues if consumed by humans. HABs can also harm humans and pets if exposed to contaminated waters.

[6] Paerl, H. W., Hall, N., Otten, T. G., Rossignol, K. L., Kudela, R. M., & Xu, H. (2019, December). Combating Global Proliferation of Harmful Algal Blooms Along River to Sea Continuum in the Face of Nutrient Over-Enrichment and Climate Change. In *AGU Fall Meeting 2019*. AGU

[7] Paerl, H. W., Hall, N., Otten, T. G., Rossignol, K. L., Kudela, R. M., & Xu, H. (2019, December). Combating Global Proliferation of Harmful Algal Blooms Along River to Sea Continuum in the Face of Nutrient Over-Enrichment and Climate Change. In *AGU Fall Meeting 2019*. AGU.



Figure 5C-3: Satellite images of river outflows to the Atlantic Ocean in the wake of Hurricane Florence show water discolored by organic matter including debris and pollutants. (Image credit: NASA)

Submerged aquatic vegetation (SAV), also known as seagrass or underwater grass, is a critical habitat to many important fishery species and serves as an ideal indicator for water quality and climate changes because its distribution is highly responsive to changes in salinity, water temperature, and water clarity. The expected changes to water conditions due to climate change are likely to result in reduced abundance of SAV. Eelgrass (*Zostera marina*) occurs at the southern limit of its distribution on the east coast and is the dominant seagrass species in North Carolina. Heat stress in the shallow waters is expected to cause a decline in that species in particular.

Shell bottom, which includes oysters, clams, and scallops, serves as both a fishery resource and an essential coastal habitat and will also be directly affected by climate change. Increased precipitation will increase the amount of polluted runoff entering the estuaries, resulting in more shellfish growing area closures and recreational swimming advisories issued by DMF. As sea level continues to rise, intertidal oysters will be inundated and have to adapt to the subtidal environment. The acidification of ocean waters, a consequence of excess carbon dioxide in the atmosphere, will also cause oysters and other shelled organisms like clams and mussels to be unable to grow their shells. The loss of shell bottom habitat will not only affect the fishery, but the marine organisms that rely on them for habitat.



Runoff containing excess nutrients can lead to hypoxic (low oxygen) conditions, resulting in mass mortality of oysters and fish. Additionally, increased water temperatures could result in more occurrences of illness from shellfish consumption, which is a significant public health issue and can also disrupt shellfish markets.

In addition to shifts in coastal habitat availability and species distribution, economic impacts and regulatory issues will need to be addressed. The predicted changes in temperatures, salinity, and ocean currents will also have a direct impact on the fish population of the North Carolina's coast. In recent years, it has been predicted that hundreds of fish and invertebrate species will be forced to move northward by climate change[8]. The range of valuable fisheries species in North Carolina, including black sea bass (*Centropristis striata*) and summer flounder (*Paralichthys dentatus*), have already been seen shifting northward while other species such as white shrimp (*Litopenaeus setiferus)* are shifting farther north or having greater biomass following warm winters[9]. Other species, such as spot *(Leiostomus xanthurus*) are shifting their migration route to occur further offshore or deeper in the water column, affecting catchability.[10] Environmental changes are affecting how species use certain estuaries and habitat types, such as bull sharks (*Carcharhinus leucas*) using North Carolina's estuary as a nursery area when in the past adult sharks only used the area as a place to feed[11].

It has also been noted that climate change may increase habitat suitability allowing some fish species, such as spotted seatrout, to expand their range. However, under the same climate change scenarios, their prey species show significant decreases which could result in a food-limited population.[9] North Carolina already exhibits one of the greatest northward shifts in commercial fishing effort, with average vessel landings occurring 24km further north each year.[10] As fish move north, the commercial fishermen follow, resulting in North Carolina fishermen landing more fish in North Carolina ports that were caught outside of state waters. This can cause confounding regulatory issues when trying to determine the new or expanded ranges and distributions of the fish species. The management of commercially and recreationally important finfish and shellfish species is vital to ensuring the sustainability of these species.

Infrastructure supporting research-based management of fisheries and coastal habitats and the ability to enforce regulations will also be affected by climate change and will need to be addressed to ensure the continuity of the DMF mission statement (Table 5C-3). This is especially important considering that several regional and field offices providing critical functions, personnel, and equipment for shellfish sanitation, marine patrol, and fisheries management have already been damaged or destroyed during hurricane Florence (2018). These damages caused major disruptions in work and displacement of staff (Figure 5C-4).

[8] Morley, J. W., Selden, R. L., Latour, R. J., Frölicher, T. L., Seagraves, R. J., & Pinsky, M. L. (2018). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. *PloS one*, *13*(5).
[9] Morley JW, Batt RD, Pinsky ML. Marine assemblages respond rapidly to winter climate variability. Glob Chan Bio. 2017; 23:2590–2601.
[10] South Atlantic Fishery Management Council. 2018. SAFMC Fishery Ecosystem Plan II Implementation Plan.
[11]Bangley, Charles & Paramore, Lee & Shiffman, David & Rulifson, Roger. (2018). Increased Abundance and Nursery Habitat Use of the Bull Shark (Carcharhinus leucas) in Response to a Changing Environment in a Warm-Temperate Estuary. Scientific Reports. 8. 10.1038/s41598-018-24510-z.
[9] Kearney, K. A., Butler, M., Glazer, R., Kelble, C. R., Serafy, J. E., & Stabenau, E. (2015). Quantifying Florida Bay habitat suitability for fishes and invertebrates under climate change scenarios. *Environmental management*, *55*(4), 836-856.
[10] Bradford A. Dubik, Elizabeth C. Clark, Talia Young, Sarah Bess Jones Zigler, Mikaela M. Provost, Malin L. Pinsky, and Kevin St. Martin. "Governing fisheries in the face of change: Social responses to long-term geographic shifts in a U.S. fishery." *Marine Policy*, Volume 99, Pages 243-251. 2019.



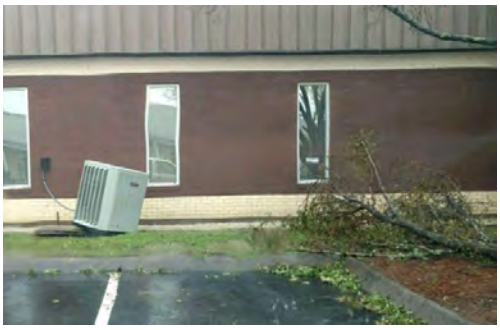


Figure 5C-4: Damage to sections of the Wilmington Regional Office where DMF is housed after Hurricane Florence 2018 disrupting work flow and causing displacement of staff for almost a year.

Resilience Strategies

Fisheries Management

Develop management based on changes in recruitment, growth, survival, and reproductive success. This can be done under the existing law by incorporating climate change science and more adaptive management actions in FMPs. Incorporate climate and environmental variables, when possible, into stock assessments and in rebuilding schedules with steps towards more ecosystem based management. Staff to review and incorporate, as applicable, the Atlantic States Marine Fisheries Commission (ASMFC) and federal fishery management councils developed stock assessments terms of reference for climate change into DMF assessments and plans. Continue participating in interstate & federal management based on shifting species distributions while recognizing historical importance of communities.

Coastal Habitat Protection

The CHPP Plan should be used to better outline the effectiveness of the actions in sequestering carbon, improving resilience of coastal habitats through restoration and protection of coastal habitats, and improving resilience of coastal communities and ecosystems. In conjunction with the 2018-2020 action items for the CHPP goal of "Develop metrics on habitat trends," integrate determining associated trends in marine and estuarine fish abundance and habitat usage in efforts to move towards more ecosystem-based management.

Coastal Habitat Conversation and Restoration

Help facilitate coastal habitat restoration by assisting state, federal, and local governments with incorporating climate change considerations into their planning processes to increase resilience. Help build understanding of the benefits of protecting and restoring coastal habitats to help ensure stakeholders and the public are aware of the importance of these actions including resilient ecosystems and communities.

Map, Assess, and Monitor

The extent and condition of coastal habitats should be mapped to inform models and enable detection of change over time, and to provide the best available scientific information for formulating actionable conservation, protection, and restoration strategies. Continued regular monitoring and analysis should be ensured to assess change in distribution and composition and to address potential impacts to dependent

fish species. For example, SAV mapping on a regular basis has been difficult due to no dedicated funding. Algal monitoring should also be expanded using sentinel sites especially in North Carolina's coastal waters where it would have the potential to affect shellfish and human health.

Natural and Nature-based Solutions

Nature-based solutions, such as living shorelines, have the potential to restore coastal ecosystems and increase resilience to natural disasters and should be used whenever possible. Common living shoreline designs combine restored salt marsh with a breakwater constructed of granite rocks or oyster shells, designed to protect landward vegetation and encourage oyster recruitment. One study showed that living shorelines exhibited better resistance to landward erosion during Hurricane Matthew than bulkheads and natural marshes.11 Additionally, living shorelines were more resilient than hardened shorelines, as they maintained landward elevation over the two-year study period without requiring any repair. Living shorelines can also enhance marsh grass stem density over time when compared to natural marshes. Living shorelines have been shown to enhance services such as wave dampening, carbon sequestration, and nursery provision for juvenile fish.

Infrastructure

Funding is needed to invest in resilient planning and infrastructure maintenance and upgrades to ensure the continuity of the DMF mission statement. In the event of the loss of offices and/or equipment, contingency plans should be made for all sections within the division with a priority focus on the Shellfish Sanitation section and Marine Patrol because of their role in human health, public safety, and regulatory enforcement.

Climate Change Integration

DMF staff should review existing guidelines and strategic plans to develop and integrate climate change adaptation and resiliency strategies within these documents, and continue to monitor rule making authority (i.e., state, councils, federal government, ASMFC) for species of fish that may become more abundant in our waters as the ocean continues to get warmer. North Carolina's marine fishery resources are economically and socially important to many of the state's residents, visitors, and coastal communities requiring the state to acknowledge the impacts of climate change through management strategies to allow flexibility as fishery resources change.

Regulations and Policies

Recognizing the importance of protecting fish and their habitats, the N.C. legislature passed the Fishery Reform Act in 1997 (FRA), that required Fishery Management Plans (FMPs) and a Coastal Habitat Protection Plan (CHPP) be developed:

FMPs

- General authority for stewardship of the marine and estuarine resources by the DEQ is provided in G.S. 113-181.
- The DMF is the branch of the DEQ that carries out this responsibility.
- The Marine Fisheries Commission (MFC) was created to "manage, restore, develop, cultivate, conserve, protect, and regulate the marine and estuarine resources of the state of North Carolina including aquaculture facilities which cultivate or rear marine and estuarine resources" (G.S. 113-132

[11] Smith, C. Puckett, B., Gittman, R., and Peterson, C. (2018*). Living Shorelines enhanced the resilience of saltmarshes to Hurricane Matthew (2016)*. Ecological Applications, 8 (4), 871-877.



and 143B-289.51). The MFC can regulate harvest times, areas, gear, seasons, size limits, and quantities of shellfish harvested and possessed (G.S. 113-182 and 143B-289.52). General Statute 143B-289.52 allows the MFC to delegate authority to implement its regulations for fisheries "which may be affected by variable conditions" to the Director of DMF by issuing public notices called "proclamations".

- DEQ is the agency directed by North Carolina General Statute 113-182.1 to prepare FMPs for all commercially or recreationally significant species or fisheries that comprise state marine or estuarine resources.
- These plans must be approved and adopted by the North Carolina Marine Fisheries Commission (MFC). Many different state laws (General Statutes - G.S.) provide the necessary authority for fishery management in North Carolina.
- Marine Patrol under G.S. 113-136 is granted, as inspectors, the powers of peace officers anywhere in this state, and beyond its boundaries to the extent provided by law, in enforcing all matters within their respective subject-matter jurisdiction being wildlife and fisheries management.

CHPP

- G.S. 143B-279.8 requires that a CHPP be drafted by the DEQ, and reviewed every five years. The purpose of the plan is to recommend actions to protect and restore habitats critical to the enhancement of North Carolina's coastal fisheries. The Marine Fisheries, Coastal Resources, and Environmental Management commissions are required to approve the plan recommendations. DMF is the lead in administering the CHPP.
- The Shellfish Sanitation Program is conducted in accordance to guidelines set by the Interstate Shellfish Sanitation Conference and contained in the National Shellfish Sanitation Program (NSSP) Guide for the Control of Molluscan Shellfish Model Ordinance. The NSSP is administered by the Food and Drug Administration (FDA).
- The guidance for the Recreational Water Quality Program is set by the Beaches Environmental Assessment and Coastal Health (BEACH) Act, which is administered by the EPA.

Albemarle-Pamlico National Estuary Partnership

Impact Summary

APNEP works to protect and restore the coastal resources described elsewhere in this chapter, and other sectors including ecosystems and water resources, with a focus on estuarine ecosystems and the river basins and surrounding watersheds that flow into the Albemarle-Pamlico estuarine system. The impacts

to these resources have been thoroughly described elsewhere in this report. APNEP recognizes that the changing climate will have an impact on its partners and programs and existing and pending projects.

Vulnerability and Risk

In 2019 staff conducted an initial assessment of climate change impacts to implementation to the 2012 – 2022 CCMP. The exercise resulting in a ranking of none or minimal impacts to each of the CCMP implementation actions themselves. The greatest initial threats arise from impacts that directly affect APNEP partners and their infrastructure or ability to function. If the partners have reduced capabilities the partnership is equally impacted.



Additionally, changes in estuarine habitat may have impacts on APNEP priorities and abilities to implement the CCMP. These potential changes are mainly addressed by DMF in examples presented elsewhere in this chapter.

Resilience Strategies

APNEP will continue to work with partners to implement the actions identified in the CCMP and CHPP described above. The partnership will begin updating the CCMP in 2021 and will consider actions identified in this report and through the Natural and Working Lands stakeholder process as it develops future priorities and focus areas.

Staff have joined the DCM and the Reserve in a cross-agency effort to co-lead a Coastal Resilience Community of Practice. The workgroup consists of diverse coastal stakeholders including agency representatives, local governments, and non-profit organizations who have agreed to focus on how ecosystem resiliency can help build local community resilience.
APNEP pursues its mission with guidance and support from its overarching Comprehensive Conservation and Management Plan (CCMP), the Management Conference (advisory groups), and regional partners. APNEP was among the first of 28 National Estuary Programs established by the Clean Water Act in the late 1980's.

APNEP's staff works closely with diverse stakeholder committees whose members include citizens, local business leaders, environmental organizations, and local, state, and federal agencies. APNEP engages citizens and organizations through its committees to ensure a coordinated approach to managing the Albemarle-Pamlico estuarine system. By facilitating communication and collaboration among different organizations throughout the region, APNEP seeks to leverage its resources and those of its partners to accomplish more together than any individual organization could alone.
APNEP staff is advised by a Management Conferences authorized by N.C. Governor's Executive Order #26 (2017), The APNEP's guiding plan is its 2012-2022 Comprehensive Conservation and Management Plan[12] (CCMP), which was created in a stakeholder-driven process with an ecosystem-based management approach.

In conjunction with its partner organizations, APNEP has a long history of working closely with coastal communities as they face climate and natural hazard challenges. In addition to supporting research and the development of tools and models to help resource managers and local governments make informed decisions, APNEP continues to dedicate resources towards connecting communities to the best available science and tools as they develop adaptation planning strategies. APNEP initiatives related to climate change, sea level rise, ecosystem and community resilience are aligned with the following 2012-2022 CCMP actions:

- Create and improve projections of land use and climate change related impacts on the regional ecosystem.
- Support research on adapting to impacts associated with climate change and sea level rise.
- Develop and implement a strategy to improve decision makers' understanding of coast and benefits of environmental protection, restoration, planning and monitoring.
- Provide assistance to state, regional, and local governments to incorporate climate change and seal level rise considerations into their planning processes.

[12] https://apnep.nc.gov/resources/publications-and-reports/ccmp



In addition, APNEP works closely with DMF, DCM and DWR on implementing the CHPP. While differences in scope, geography and mission exist, implementation of APNEP's CCMP and the CHPP are complimentary with regard to coastal habitat protection and restoration strategies. Submerged aquatic vegetation mapping and oyster reef research and restoration are two areas where APNEP has tackled issues that are critical to both the CCMP and the CHPP. APNEP's Coastal Habitats Coordinator works closely with the three commissions and their divisions within DEQ to ensure that both plans are implemented in a coordinated and integrated fashion.

The specific actions within the CCMP that also align with the CHPP and need and policies for adapting to changing climate and include the following:

- Assist local governments in the development of incentives for protecting natural shorelines.
- Reduce wastewater overflows and spills
- Facilitate the restoration of riparian and estuarine shorelines.
- Construct new oyster habitats.
- Facilitate research to improve oyster restoration technologies and methods.
- Mapping and monitoring SAV

4. Summary

North Carolina is one of the three U.S. states that experiences the most tropical storm activity[13]. Coastal communities throughout North Carolina have been dealing with the impacts of coastal storms and sea level rise over their entire history, but vulnerability and risk continue to increase with rising population and growth. Storms and sea level rise will certainly continue, and recent storm trends and flooding have been at historical levels of intensity. To advance towards the goal of climate resiliency, cabinet agencies must work together with our local, private, and academic partners.

Increasing climate resilience in coastal North Carolina requires working together to adapt to climate-related extreme events and long-term risks, by integrating resilience thinking and actions into our way of working and living. Increased resilience in a changing climate preserves economic, natural, and cultural resources; minimizes social disruption and displacement from extreme events; and lessens the need for disaster recovery spending.

State agencies must work to increase adaptive capacity at multiple scales—internally, among partners and sister agencies, and most importantly at the local government level. The goal of local government capacity building is to ensure that all coastal communities attain a minimum level of risk awareness, planning, preparedness, and recovery capability, and can make continuous improvements with state and federal support. Ultimately, climate resilience should become business as usual, fully integrated in normal operations, existing planning efforts, and investment decisions.

[13] https://www.aoml.noaa.gov/hrd/tcfaq/E19.html



Commerce & Business

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D. Commerce and Business

Key Observations

- The greatest impact of recent climate hazards was business interruption. Getting people back to work and transitioning to a more resilient economy are critical.

Critical Impacts and Resilience Strategies

- Supporting rural economies with education, training and additional resources.
- Public/private partnerships help leverage risk. Government can help build resilience into infrastructure, which helps lower risks for small businesses.
- Include resilience training in North Carolina Main Street and Rural Planning programs for small towns and Main Street communities along with the businesses they support.
- The business sector needs to drive continual improvement of resource optimization.

1. Introduction to Sector

The ***North Carolina Department of Commerce (NCDOC)*** connects businesses with the site locations, workforce and infrastructure they need to succeed in one of the nation's top states for business. NCDOC also connects local communities with the grants and funding they need to attract new business and ensure future prosperity.[1]

Taking a comprehensive approach to economic development, the Department's work reaches many areas. The Department helps people find jobs and employers find and retain a qualified workforce. The Department administers the state's employment security system, supporting workers during career transitions. The Department provides local communities with grants and planning services to spur infrastructure development and economic growth and administers the state's economic incentive programs.

NCDOC executive branch agency administers the state's economic incentives program and publishes data and reports for those interested in the state's economy. Marketing North Carolina as a business and visitor destination is handled by the Economic Development Partnership of North Carolina (EDPNC), a public-private organization established by the North Carolina General Assembly in 2014.[2]

All North Carolina businesses are affected by weather and climate, no matter where they are located or what economic sector they represent. A changing climate brings some downsides, but there are also opportunities for new business creation. The NCDOC recognizes that businesses rely on a strong working relationship with their communities. Resilience plans must be holistic to cover issues such as supply chains, reliable transportation corridors for their employees to get to work, and a reliable source of power to support their businesses. In turn, communities rely on their businesses to provide sustainable income and careers for their citizens and tax revenue to support local needs.

[1] North Carolina Department of Commerce: https://www.nccommerce.com/ Retrieved February 10, 2020.
[2] Economic Development Partnership of North Carolina: https://edpnc.com/ Retrieved February 10, 2020.



The NCDOC recognizes the importance of resilience because a resilient state economy can "bounce back" more quickly from hazards and have less business interruption. Therefore, this chapter focuses on what the state can do to support its business sector in becoming more resilient with a focus on the following options:

- Building resilience to support business continuity and operations
- Supporting rural economies with resilience training as they expand existing businesses and capitalize on new opportunities
- Establish Public/Private Partnerships (like the Wanchese Seafood Industrial Park) to provide state assistance for small industry

Overview of the North Carolina Economy[3]

North Carolina has the 9th largest state population and had a GDP of nearly $566 billion in 2018. The state's economy is slightly larger than that of Sweden.[4] Over the previous century, it transformed from an agricultural state with a manufacturing base in tobacco, textiles, and furniture to an advanced economy with strengths in finance, biotechnology, advanced manufacturing, and the knowledge economy more broadly. Throughout this transformation, the North Carolina economy has, in many ways, become more like the U.S. economy.

North Carolina has benefitted from Sunbelt migration over the past several decades, particularly during the 1990s and 2000s. This developed large metro areas in Charlotte, Raleigh, and the Piedmont Triad, as well as the smaller, but fast-growing metros of Asheville and Wilmington. This process added people from other parts of the U.S. as well as through international immigration.

Still, North Carolina has the second largest rural state population in the U.S. with 34% of the state's residents living in rural areas.[5] The rural population, however, has not benefitted to the same extent from the transformation of the state and its economy. Out-of-county commuting has increased in recent years. Only 14 out of 100 counties in the state had more than 50% of their workers living and working in the same county as of 2017, down from 47 counties in 2002.[6]

North Carolina's population faces certain larger structural challenges including a slowing population growth rate, an aging workforce, along with issues of inequality and regional disparities. Like the U.S., the state has become less homogenous. There are prosperous urban areas (characterized by knowledge-intensive service industries) and less prosperous rural areas which are reflective of manufacturing's legacies. North Carolina is also experiencing larger changes to the economy due to technological advancements, global trade and interdependence, and the slowing of economic growth, new firm formation and productivity.

Any disruption caused by a climate-related hazard of either a person's workplace or the transportation route connecting his home to his workplace has a direct impact on that person's ability to collect a paycheck. Therefore, the growing vulnerability of the *Transportation* sector has a direct bearing on the *Commercial and Business* sector. Business disruption in our urban centers also has a direct economic impact on our rural communities through this live-work-commute relationship.

[3] North Carolina Department of Commerce, Labor and Economic Analysis Division, *North Carolina Annual Economic Report* (2019).
[4] U.S. Census Bureau, Bureau of Economic Analysis, International Monetary Fund (2018)
[5] U.S. Census Bureau, 2010 Census (2010).
[6] North Carolina Department of Commerce, Labor and Economic Analysis Division, Quarterly Census Employment and Wages (2018)



Assets and Service

The NCDOC has several divisions and resources that may be impacted by climate related events:

The ***Division of Employment Security*** (DES)[7] is responsible for the administration of the unemployment insurance program in the state. This program is a federal-state partnership, funded by federal and state unemployment taxes, which employers pay on the wages of their employees. Benefits are paid to eligible workers who lose their job through no fault of their own and are able, available, and actively seeking work.

The ***Division of Workforce Solutions*** (DWS) administers a statewide system of workforce programs that prepare North Carolinians for employment, providing services for adults, veterans, and youth jobseekers as well as helping employers find the qualified talent they need. DWS has 80 certified Career Centers across the state, coupled with other NCWorks access points, that cover 85 of the 100 Counties in North Carolina.

The ***NC Seafood Industrial Park Authority***[8] operates the two marine parks, the Wanchese Seafood Industrial Park and the Engelhard Marine Industrial Park. These parks provide opportunities to foster fishing and marine industries in the eastern part of the state. These venues support marine industries such as seafood processing, boat building and fishing supplies.

The ***Rural Economic Development Division*** houses the Community Development Block Grant (CDBG) program, the Rural Grants program, the North Carolina Main Street program[9] the Rural Planning Center, and the Appalachian Regional Commission (ARC) Office. This division provides training, grants and other services for rural communities across the state.

The ***CDGB program*** administers federally funded grant programs such as building reuse grants, demolition grants, and community housing grants. Projects including CDBG grants from the division are located throughout the state (Figure 5D-1). CDBG[10] team, part of our Rural Economic Development Division, administers several federally-funded grant programs:

- A Building Reuse program, using CDBG-Economic Development funds
- Public Infrastructure grants, also from CDBG-Economic Development funds
- Demolition grants
- Community Housing Grants

The Rural Grant Programs[11] team, part of our ***Rural Economic Development Division***, administers several state-funded grant programs:

- The state Rural Building Reuse program

[7] North Carolina Department of Commerce Division of Employment Security: https://des.nc.gov/des, Retrieved February 10, 2020.
[8] North Carolina Department of Commerce Seafood Industrial Park Authority: https://www.nccommerce.com/about-us/boards-commissions/nc-seafood-industrial-park-authority#perquimans-marine-industrial-park Retrieved February 10, 2020.
[9] North Carolina Department of Commerce Rural Economic Development Division: https://www.nccommerce.com/about-us/divisions-programs/rural-economic-development-division, Retrieved February 10, 2020.
[10] North Carolina Department of Commerce Community Development Block Grants https://www.nccommerce.com/about-us/divisions-programs/rural-economic-development/community-development-block-grants-cdbg Retrieved February 10, 2020.
[11] North Carolina Department of Commerce Rural Grant Programs: https://www.nccommerce.com/about-us/divisions-programs/rural-economic-development/rural-grant-programs Retrieved February 20, 2020.



- The state Public Infrastructure grants
- The state Demolition grants
- The special, legislatively directed grants to local governments for downtown revitalization and economic development from 2017, 2018 and 2019
- 2016 Disaster Recovery funds
- The Rural Housing Recovery Infrastructure Program

The ***NC Main Street & Rural Planning Center***[12] works in regions, counties, cities, towns, downtown districts, and in designated North Carolina Main Street communities, to inspire placemaking. The center works to build asset-based economic development strategies that achieve measurable results such as investment, business growth, and jobs. The staff provide program services such as economic development strategic planning, technical services and training.

NC Main Street program is a national program to develop vibrant downtowns through historic preservation, economic development, promotion and design. There are 88 Main Street Communities across the state

The ***Rural Planning Center*** has offices located throughout the state in each of the state's Prosperity Zones. These offices are in Asheville, Albemarle, Fayetteville, Greenville, Jacksonville, Lexington, North Wilkesboro, Sylva, and Wilson.

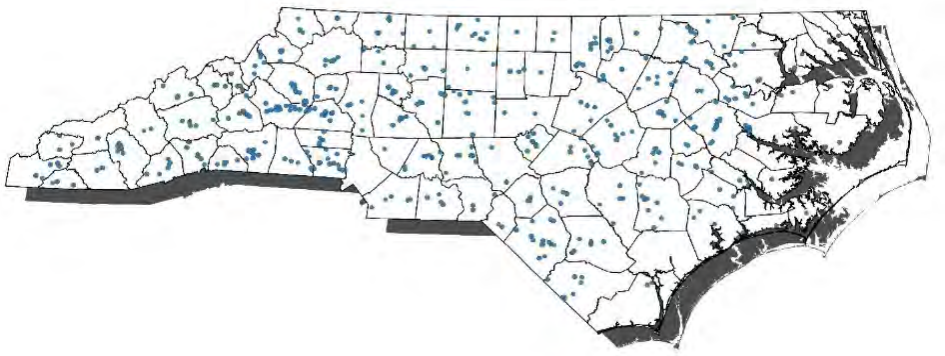


Figure 5D-1: Projects and assistance provided by the Rural Economic Development Division.

[12] North Carolina Department of Commerce Main Street and Rural Planning Center: https://www.nccommerce.com/about-us/divisions-programs/rural-economic-development/nc-main-street-rural-planning-center Retrieved February 20, 2020.



Figure 5D-2: The North Carolina Main Street and Rural Planning Center's Prosperity Zones.

The **Appalachian Regional Commission** (ARC)[13] is a unique federal-state partnership that provides social and economic support for a 13-state region stretching along the Appalachian Mountains from southern New York to northern Mississippi. Established by the United States Congress in 1965, when Appalachia was considered "a region apart" from the rest of the nation, ARC has worked to bring Appalachia's 22 million people into America's mainstream economy.

ARC supports economic development activities in 29 North Carolina counties: Alexander, Alleghany, Ashe, Avery, Buncombe, Burke, Caldwell, Cherokee, Clay, Davie, Forsyth, Graham, Haywood, Henderson, Jackson, Macon, Madison, McDowell, Mitchell, Polk, Rutherford, Stokes, Surry, Swain, Transylvania, Watauga, Wilkes, Yadkin, and Yancey counties.

2. Overall Exposure

Climate Stressors

Climate stressors for the NCDOC will vary according to location (Table 5D-1). Each program will face different exposure to climate-related impacts.

DWS Career Centers, staff, and customers are vulnerable to a wide variety of climate change related disasters due to the geographic diversity of our state. For this reason, DWS operates a mobile unit capable of responding during disaster-related events. The mobile unit can assist first responders and provide humanitarian assistance, as well as temporarily assist those NCWorks Career Centers damaged by a natural disaster until more permanent locations have been secured. The mobile unit can also be used as a command center if DWS' central office is damaged by a natural/manmade disaster. Finally, the mobile unit allows DWS to work closely with the Division of Employment Security to expedite the processing of unemployment insurance claims for jobseekers impacted by natural disasters.

[13]North Carolina Department of Commerce Appalachian Regional Commission: https://www.nccommerce.com/about-us/divisions-programs/rural-economic-development/appalachian-regional-commission Retrieved February 20, 2020.



The Division of Employment Security (DES) faces ***flooding*** and ***extratropical storms*** as climate stressors and hazards. The current location of DES limits the vulnerability of climate related events. However, with increased climate stressors and the associated weather impacts, there is increased potential for inland hurricanes and damaging events such as tornadoes. The current disaster recovery plan for operations is a key step in resiliency for conducting these operations and ensuring unemployment benefits are not interrupted.

The NC Seafood Industrial Park Authority[14] operates the two marine parks, the Wanchese Seafood Industrial Park and the Engelhard Marine Industrial Park. These parks provide opportunities to foster fishing and marine industries in the eastern part of the state. These venues support marine industries such as seafood processing, boat building and fishing supplies.

For the seafood industrial parks, ***storm surge***, ***extratropical storms***, ***tidal flooding*** and ***sea level rise*** are important climate stressors and hazards. There are no known non-climate stressors for this physical asset. Impacts on this asset are:

- threat of storm surge and damage to real property and structures;
- interruption of financial processing, food processing, seafood distribution;
- loss of wages in the industrial park; and
- indirect costs losses

The climate stressors and hazards for Main Street communities would range from ***mudslides*** to ***flooding*** to ***storm surge***. The NC Main Street Program has low risks to disaster due to the location of state staff. Most can work remotely if needed in the event of a disruption of operations at the NCDOC. The NC Main Street Program can potentially assist communities to plan for disaster if funding and training are provided to the state staff.

The eight Rural Planning Center economic development planners are located across the state within the Prosperity Zones. The climate stressor and hazards in the communities served by Rural Planning are reflective of geographic vulnerabilities of that community and include ***landslides***, ***extratropical storms*** and ***flooding***. The biggest impact to these assets involves planners unable to travel due to hazards or threats from flooding and extratropical storms.

[14] North Carolina Department of Commerce Seafood Industrial Park Authority: https://www.nccommerce.com/about-us/boards-commissions/nc-seafood-industrial-park-authority#perquimans-marine-industrial-park Retrieved February 10, 2020.



Table 5D-1: Exposure to climate-related hazards of Commerce and Business assets and services throughout the state.

Assets, Regulations, Services	Extreme Heat	Flooding (River and Land)	Water Shortage (Drought)	Changed Seasons	Landslides	Saltwater Intrusion	Storm Surge	Tidal Flooding	Wildfire	Dam Failure
Division of Employment Security		*								
NC Seafood Industrial Park Authority (Wanchese, Engelhard)		*				*	*	*		
Division of Workforce Solutions		*								
Prosperity Zones										
North Central Prosperity Zone		*								
Northeast Prosperity Zone						*	*	*		
Northwest Prosperity Zone					*					
Piedmont Triad Prosperity Zone		*								
Sandhills Prosperity Zone		*	*							
Southeast Prosperity Zone		*				*	*	*		
Southwest Prosperity Zone					*					
Western Prosperity Zone					*				*	
Regional Planning Offices										
Southeast Regional Planning Office						*	*	*		
Western Regional Planning Office					*				*	
Rural Economic Development Division										
NC Community Development Block Grant Program (CDBG)	*	*	*	*	*	*	*	*	*	*
NC Main Street Program	*	*	*	*	*	*	*	*	*	*
NC Commerce Incentives and Grants	*	*	*	*	*	*	*	*	*	*
Appalachian Regional Commission		*							*	*

3. Examples of Impacts, Vulnerability, and Risk

Wanchese Seafood Industrial Park / Coastal Storms and Sea Level Rise

Impact Summary

The Wanchese Industrial Park is located in the unincorporated fishing village of Wanchese along the Roanoke Sound. The park has been affected by sea level rise and flooding. Extratropical storms also impact the site. The NC Seafood Industrial Park Authority, an eleven-member state board whose members come from counties in the region, operates three marine parks: the Wanchese Seafood Industrial Park, the Engelhard Marine Industrial Park, and the Perquimans Marine Industrial Park.

Wanchese Park is home to numerous marine businesses, including boat building, commercial fishing, marina, and supply chain operations. During hurricanes and other extratropical storms, storm surge leads to damage to property and structures. Additional impacts include interruption of financial processing, food processing, loss of wages in the Industrial Park, seafood distribution, and indirect costs losses.

Vulnerability and Risk

The park is vulnerable to sea level rise and flooding along with extratropical storm impacts due to its location on Roanoke Island. The building and its infrastructure are at risk to damage for wind and storm surge and inundation. The industries located in the park are at risk to damage from water and wind which will affect output and income would be lost if the facilities were damaged or destroyed.

The park is highly vulnerable to sea level rise and flooding associated with extratropical storms. The infrastructure is at risk to damage for wind, water and salt. Properties on Roanoke Island are the most vulnerable because they support a large amount of local business and the buildings are in an area exposed to coastal flooding.

Because the park was established in 1981, the design guidelines for the buildings did not require a base flood elevation building standard. Also, the road that serves as access to the Park does not have adaptive capacity integrated into its design. In 2015, the Wanchese Seafood Industrial Park had an annual economic impact to North Carolina of $105 million. This equates to a daily impact of $350,000[15]. That means that business interruption of even just three days has a $1 million consequence.

The industries located in the park would also be at risk to damage from water and wind, which would affect output and income would be lost if the facilities were damaged or destroyed. Risk is increasing due to increased chance (probability) of extreme storms causing damage to the park and limiting access.

Resilience Strategies

For the Wanchese Seafood Industrial Park, the facility has a hazard mitigation plan for severe weather for the physical site. Industries located in the park should have a business continuity plan that can deal with hurricanes, flooding and damages from other weather events. NCDOC can provide education/training for the industries in the Park about the increasing climate-related risk of flooding and related business interruption. Building resilience usually looks at three main categories - reducing exposure, building

[15] North Carolina Department of Commerce Seafood Industrial Park Authority: https://www.nccommerce.com/about-us/boards-commissions/nc-seafood-industrial-park-authority#perquimans-marine-industrial-park Retrieved February 10, 2020.



adaptive capacity, or supporting more response and recovery. Because this is a seafood industry park, it cannot be moved to reduce exposure. Economic incentives should be considered for either building adaptive capacity or supporting faster recovery.

4. Summary

Impacts of climate change have already been felt in the economic development and rural development sector through increased incidents of flooding and heavy precipitation, often associated with more severe hurricanes. Communities have already experienced damage to facilities, loss of records, financial expense, and damage to area infrastructure. Some of these procedures and rules may need updating to adapt to the realities of climate change driven impacts, such as repeated flooding. Development of adaptive capacity, where possible, will need to continue in coordination with all stakeholders to realize meaningful results.

As part of the NC Office of Recovery and Resiliency's Recovery Support Team, the Business Recovery Collaborative in a collection of partner agencies that have developed a process to deliver experienced business counseling resources to businesses impacted by a disaster in order to provide them with crucial information and resources.

The members of the Collaborative include the EDPNC, the NC Community Colleges' Small Business Center Network, the NC Department of Commerce, the NC Rural Center, the NC Small Business and Technology Development Center and the U.S. Small Business Administration.

A resilient state economy can "bounce back" more quickly from hazards and have less business interruption by identifying climate related impacts and reduce disruption to economic development in North Carolina. Although county and city jurisdictions are not in the hierarchy of Commerce Operations, the Rural Economic Development Division works directly with these communities. The NCDOC will continue to work to enhance climate resiliency efforts and identify resources to assist communities with climate resiliency planning.

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Cultural Resources

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E. Cultural Resources

Key Observations

- Cultural resources such as state and local historic sites and museums are irreplaceable, making them inherently sensitive to sea level rise and the increasing frequency and severity of heavy precipitation and flooding.
- The North Carolina Department of Natural and Cultural Resources (DNCR) is active across all 100 counties, so resources are limited. The threat of the hazard is growing.
- DNCR has regulatory authority over destruction of any public records managed on a local level.
- Much of the technical and constituent services for cultural assets are provided in a collaborative environment with federal, state, local, and private interests all having a stake in the solutions.

Critical Impacts and Resilience Strategies

- There is no single solution to protect cultural assets from "water where it doesn't belong".
- The focus for now, and in the near-term, should be building resilience into assets owned and managed by the state, such as state museums, historic sites and parks.
- DNCR must provide greater services such as technical assistance to locally-owned cultural resources
- Develop and enhance federal, state, local, and private partnerships to build cross-boundary resiliency capacity for cultural assets.

1. Introduction to Sector

The rich and diverse cultural heritage of North Carolina is promoted, preserved, and enhanced through the efforts of the History and Arts units of the North Carolina Department of Natural and Cultural Resources (NCDNCR). Under state law, the department's duty in this regard is:

"to provide the necessary management, development of policy and establishment and enforcement of standards for the furtherance of resources, services and programs involving the arts and the historical and cultural aspects of the lives of the citizens of North Carolina."[1]

Many cultural resources exist within North Carolina, including music and the arts, archival records, museums with artifact collections, and historic and archaeological sites. North Carolina boasts many historic landscapes and structures, and historic districts within rural and urban settings, many of which, together with artifact and archival collections are in private ownership rather than under public stewardship. The History and Arts units of NCDNCR function under state and federal law to preserve and protect these resources and expand public awareness of the state's cultural heritage through the direct management, operation, and/or support of these units, organizations, and facilities.[2]

[1] NC GS § 143B-50(1).

[2] Chapter 121 of the North Carolina General Statutes, including the North Carolina Archives and History Act, outlines much of the state statutory authority for these programs. Subsection 5 of Chapter 121 outlines the State Archives' regulatory authority over the destruction of all public records. Article 2 of Chapter 143B likewise provides the legal authority for the department. The federal National Historic Preservation Act of 1966 is the underlying legal authority for the State Historic Preservation Office, and Chapter 70 (Indian Antiquities, Archaeological Resources and Unmarked Human Skeletal Remains Protections) and sections of Chapter 65 (Cemeteries) provide authority for archaeology and cemetery protection to the Office of State Archaeology.



NCDNCR recognizes the value and necessity of a prepared, climate-resilient North Carolina to sustain our efforts to directly manage state-owned cultural assets, as well as to provide constituent services for assets managed by local government and private entities. Climate-related hazards threaten the loss of irreplaceable cultural resources. Indeed, at risk is the continued survival and vitality of North Carolina's historic communities, sites and places, archival records, and artifacts – all of which serve to define our state's identity and to provide citizens with fundamental societal and economic stability.

Much of NCDNCR's mission rests in its **stewardship management role** for the direct management of historic properties, artifacts, and records and supporting facilities owned by the state of North Carolina on behalf of the people (Table 5E-1). Public accessibility and visitation drive many programs, and the irreplaceable nature of these assets makes their preservation paramount.

Table 5E-1. Public history and cultural resource units of the Department of Natural and Cultural Resources charged with direct management of or responsibility towards historical resources and cultural assets owned and managed by the state or constituents.

- The State Library
- The State Archives (including the Outer Banks History Center and the Western Regional Archives)
- 27 Historic Sites
- 7 History Museums
- The Historical Research Office (including the statewide Highway Historical Marker program in coordination with the NC Department of Transportation)
- The Office of State Archaeology
- The State Historic Preservation Office
- The Federation of North Carolina of Historical Societies
- The North Carolina Symphony
- The North Carolina Arts Council
- The North Carolina Museum of Art
- Facilities and historic assets at State Parks (including visitors' centers and amenities, including National Register listed cabins)

In specific instances, such as the state archives' oversight of the destruction of public records, the agency plays a **hybrid stewardship management and regulatory role** by encouraging public records not under the direct management of the agency to be properly preserved while maintaining authority over the destruction of those records if they are damaged in a weather-related event.

The department acts as a **constituent service and regulatory agency** to fulfill its duty for "establishment and enforcement of standards for the furtherance of resources, services and programs" to aid the public *and* private sectors through direct outreach, technical consultation, and constituent-oriented programs to foster private and public stewardship of irreplaceable cultural resources including:

State Archives is the official state agency and constituent service office for the preservation of public records, regardless of format. It maintains and provides access to records of permanent value, both public records and collections from private donations. It operates state records center facilities for the benefit of

state agencies. It also operates two regional archival facilities at the Outer Banks History Center in Manteo and the Western Regional Archives in Asheville. Services to custodians of public records include consultations with government offices on records management and the delivery of training on the protection of and access to public records. Records retention and disposition schedules developed in consultation with and approval of the records creators serve as the primary means of promulgating normal records disposition instructions.

State Historic Preservation Office is the official state agency and constituent service office for historic preservation and revitalization of residential and commercial districts and individual properties.

Office of State Archaeology provides protection of archaeological sites, data and site inventory, technical assistance to and educational outreach for constituent (including cemetery and burial issues), permanent curatorial responsibilities for publicly owned archaeological artifacts, and project review. It includes terrestrial, underwater, and curatorial branches.

Liaison to the Federation of North Carolina Historical Societies (FNCHS) is a coalition of historical societies, museums, historic sites, associations, and commissions dedicated to preserving and promoting history. This statewide network of history organizations collaborates to share ideas, develop skills, and serve as local and regional partners for NCDNCR's Office of Archives and History.

Cultural Resources Emergency Support Team (CREST) is an interdivisional group of more than twenty collections preservation experts who regularly lead sessions for departmental staff and partner organizations to share disaster planning guidance and other preparedness techniques. Since 2011, the team has deployed help post-disaster for museums and libraries to recover collections.

A 2010 departmental survey of cultural heritage institutions (museums, libraries, archives, and historic house museums) identified nearly 1,000 entities statewide. Many are small, privately funded, and rely on volunteers for regular operations. Most local museums function with budgets of less than $50,000 per year. Through the Cultural Resources Emergency Support Team and the liaison, NCDCNR provides technical assistance to these partner organizations to help collection stewards prepare for and recover from disasters.

At the heart of its critical technical assistance role, NCDNCR collaborates, cooperates, and guides local efforts to preserve and protect the state's cultural assets, but ultimately **many of the decisions that may protect – or threaten – cultural resources rest in the hands of non-state entities at the local level**, such as city and county governing boards, clerks of courts and county and city clerks as official local record keepers, and planning and zoning departments as well as private property owners.

2. Overall Exposure

Climate stressors and hazards of greatest concern to our agency include multi-faceted "water-where-it-doesn't-belong" threats, particularly those posed by tropical cyclones, more frequent and intense heavy precipitation and flooding events, and sea level rise. Water, whatever the source, can produce catastrophic risks to cultural assets of all types. Erosion, drought, landslides, wildfires and heat waves likewise present serious challenges.

Contributing to these climate stressors are a variety of non-climate stressors, including development, marine traffic and dredging, infrastructure considerations (including inadequacies and means of installation), topographical considerations, impermeable surfaces, inadequate staff capacity, deferred property maintenance, and communication infrastructure.

Cultural resources are exposed to a broad suite of climate-related hazards (Table 5E-2), but our sector is particularly concerned about assets located in the Coastal Plain as well as flood-prone areas throughout the state. These areas are subject to direct impacts from hurricanes, flooding, heavy precipitation, and sea

level rise. The Office of State Archaeology estimates nearly 5,800 prehistoric and historic archaeological sites in the Coastal Plain of North Carolina lie within 30 feet of mean sea level.[3] Many of these sites are already subject to severe damage from shoreline erosion and land loss due to flooding and wave action.

Table 5E-2. Exposure of cultural resources throughout the state.

Assets, Regulations, and Services	Coastal Erosion	Flooding (River and Land)	Landslides	Inundation (includes SLR)	Severe Winter Weather	Storm Surge	Tidal Flooding	Water Shortage	Wildfire	Wind
Archival repositories, historic properties and museums		*		*		*			*	*
Archaeological resources	*	*		*		*		*	*	
Near-shoreline resources, e.g., historic wharves, shipwrecks, cemeteries and other sites	*	*		*		*	*			
State-owned or controlled lakes								*		
Regulation of destruction of all public records		*		*		*				*
Technical assistance to federal and state agencies	*	*		*		*	*			*
Technical assistance to local preservation commissions and records officials at municipal and county level	*	*	*	*		*	*			*
Training and technical assistance for disaster preparations and recovery of object and archival cultural heritage collections in museums and libraries		*		*	*	*				*

[3] North Carolina Interagency Leadership Team. (2012). *Climate Ready North Carolina: Building a Resilient Future*.

Sea-level rise (SLR) will likely increase the rate of site damage and loss from inundation, as well as from the enhanced energy from waves and coastal storms. In the future, changes in sea level rise will result in the complete loss of certain types of archaeological sites, such as Middle to Late Woodland prehistoric shell middens (circa 300 B.C. to A.D.1600) and associated habitation sites (a near extinction of certain site types). In addition, significant resources in areas like Roanoke Island (site of the famous Lost Colony) may be completely inundated. "Water where it doesn't belong" is among the gravest climate-related threats to cultural resources throughout North Carolina.

A chief factor that affects the degree to which exposed assets, people and services are impacted include the widespread dispersal of historic resources across all 100 counties of the state. For example, following Hurricane Florence (2018), 20% of North Carolina's National Register of Historic Places listings (est. 16,000 buildings) were located in the most-impacted zone in counties where both FEMA public and individual assistance was offered. There are over 50,000 documented archaeological sites throughout the state, and over 1,000 cultural heritage institutions besides the state's 27 state historic sites, 7 history museums, and 6 state archival facilities.

While some assets can be relocated because of their portability (such as key public documents or museum artifacts), the scale of an archival or artifact collection and need for special packing and transportation considerations may make moving it out of harm's way difficult, if not impossible, when time is short in the days before a hurricane, or with little warning, such as a flash flood or wildfire. For the historic built environment and archaeological sites, moving a threatened building or performing salvage excavations are expensive and may not be practically feasible.

3. Examples of Impacts, Vulnerability, and Risk

To emphasize the danger posed to cultural resources by "water where it doesn't belong", this section concentrates on the triple threats of flooding, heavy precipitation, and sea level rise to cultural resources. Vulnerabilities and risks as well as recommendations and options may consequently overlap.

Hurricanes and Flooding

Impact Summary

North Carolina has been impacted by nearly 400 hurricanes since 1851.[4] Tropical cyclones and the associated storm surge, high winds, prolonged precipitation, and flooding together threaten museums, archival records, historic districts and other state historic and archaeological sites. Storm impacts result in disruption to utilities needed for climate control for historic asset protection. Facility closure, financial expense, loss of historical integrity, loss of critical documentation, loss of future economic development potential (including heritage tourism), and loss of community identity and cohesion are all possible impacts of climate stressors.

State Historic Preservation Office damage assessments for historic properties from Hurricanes Irene, Matthew, and Florence demonstrate the destructive effect of flooding, fallen trees, and wind-driven rain to historic structures, cultural institutions, and cemeteries alike. Storm surge has brought about fast-paced erosion to maritime archaeological sites, like the artifact rich colonial wharves at Brunswick Town and Civil War earthwork forts, such as Fort Anderson and Fort Fisher; dredging and marine traffic in the Cape Fear contribute to this situation.

[4] North Carolina Climate Office. (2019.) *North Carolina Tropical Cyclone Statistics (1851 - 2019)*. Retrieved January 16, 2020 from https://climate.ncsu.edu/climate/hurricanes/statistics.

Flooding from hurricanes (and seasonal storms with heavy precipitation) will continue to damage archaeological and historic sites on floodplains and terraces across all three physiographic regions and within every river basin in the state. Many of these sites will be damaged by accelarated riverbank and floodplain erosion, sediment transportation, and sediment deposition. Transportation and deposition of archaeological and structural materials lead to erroneous interpretation of prehistory and history. Flooding inundates and potentially destroys cultural resources, such as the following:

- state-owned facilities and historic sites
- privately owned historic properties listed in the National Register of Historic Places
- local records centers (like city halls and county courthouses)
- local cultural institutions with artifact and archival collections (e.g., house museums and historical societies)
- downtown historic districts

Vulnerability and Risk

Cultural resources are irreplaceable, making them inherently sensitive to hurricane-associated flooding. "Stall out" hurricanes like Matthew and Florence exacted significant damage to historic sites, historic structures and archival records located not only along the coast but also inland, particularly in riverine or flood prone areas with days of prolonged, sustained heavy rainfall in concentrated areas. Hurricane Florence brought widespread damage and effects to historic resources with over 400 National Register-listed properties located in flood zones in the affected counties, and many flooded during Florence.

Hurricane precipitation can damage buildings in a variety of ways, particularly when high winds are present. At landfall, Hurricane Florence arrived with 115 mph winds and with a zone of tropical storm force winds nearly 400 miles wide, and a soaking rain of several days' duration. Wind damage to historic structures included "peeled" roofs and broken windows that allowed water infiltration as well as sustained wind-driven rain that penetrated the interior of masonry walls (for example, the Pender County Courthouse, as well as residences in the Wilmington National Register Historic District) damaging ceilings, floors, plaster walls, and electrical and HVAC systems.[5] Additionally, heavy precipitation loosens tree roots; historic grave markers in National Register-listed cemeteries suffered damage from falling trees after Hurricane Florence (example, Trinity Cemetery near Chocowinity in Beaufort County).[6]

Flooding during Hurricanes Matthew and Florence also impacted areas where little to no flooding had happened in previous memory. Fair Bluff, North Carolina, with a historic downtown, was severely flooded by the Lumber River in both Matthew and Florence, and local businesses have largely not reopened and may be unlikely to do so. The town hall was also flooded, and was rebuilt with federal funds after Florence on slab in the same flood prone location next to the river. Jones County's county seat of Trenton is largely a National Register Historic District and experienced "bathtub-like" flooding from the Trent River during Florence, damaging its courthouse. The Town of Pollocksville in Jones County experienced flooding in its town hall, rendering it so damaged that records swollen with water blocked doors and prevented town officials from entering rooms. These events are harbingers of more severe hurricane damage and the need to prepare. Flooding in New Bern from a combination of storm surge and river rise inundated National Register Historic Districts as well as the North Carolina History Center at

[5] WECT News. (June 14, 2019). "Inside the damaged Pender County Courthouse in Burgaw." Retrieved January 17, 2020 from https://www.wect.com/2019/06/14/highway-inside-damaged-pender-county-courthouse-burgaw/; State Historic Preservation Office damage assessment reports from constituents.
[6] State Historic Preservation Office staff reports from constituent reports and site visits.



Tryon Palace, damaging exhibits and closing the facility to the public for a time. [7]

In Windsor, 17 inches of rain in 72 hours from the remnants of Tropical Storm Julia brought flooding to town, including the town-owned Craftsman and Farmer Museum, damaging its artifacts, and triggering a CREST deployment of artifact preservation specialists to aid in saving the artifacts from mold and debris damage. Hurricane Matthew came on the heels of this storm and flooded the same area once again within weeks.[8]

Although the coastal plain gets much attention from hurricane-related flooding, the mountains are not immune from flooding from weather events, and subject to their own vulnerabilities and risks. Flooding from non-tropical seasonal storms over the mountains caused the French Broad River to rise seven feet in 12 hours in late December 2018 in Marshall, the county seat of Madison County. Flooding occurred at Blannahassett Island, site of the National Register-listed former Madison County High School, now art studios and important to the town's burgeoning arts community. Spring rains repeated the scenario in April 2019, this time sending floodwaters into its downtown streets, part of its National Register Historic District, and threatening the courthouse.[9] Even Asheville itself is not immune, with the Biltmore Village historic district being flooded regularly, disrupting businesses in this nerve center of western North Carolina heritage tourism.[10]

Damage to state-owned facilities and historic resources can lead to extended public closures and costly repairs; risk is itself a function of probability and potential consequence. Hurricane Matthew brought flooding to the basement of the Archives/Library building causing damage to the archival record facility for the State Historic Preservation Office's architectural survey records, costly repairs to records storage rooms, and restricted public access to records for a number of months while records were relocated during repairs to facilities. A 2019-2020 repair and renovation project on this building seeks to improve drainage around the building perimeter to reduce incidents of water intrusion during heavy precipitation events and to improve the resilience of the facility for future events.

In the case of the Brunswick Town / Fort Anderson State Historic Site, roof damage from Hurricane Florence allowed water infiltration, and combined with a lack of electrical power and road access because of a road washout, mold erupted in the building, rendering it uninhabitable for months and endangering the artifacts housed there. We expect future hurricane-related damage to the electrical grid and transportation network to disrupt preservation and recovery efforts for cultural resources in the future.

Hurricanes accompanied by heavy precipitation also threaten the public records of all levels of government, posing significant risk to the agency's archival and records mission. The majority of public records of permanent value created on the local level remain in the office of creation. Heavy precipitation risks the preservation of these resources, particularly for smaller municipal offices with limited resources to protect records in the face of oncoming hurricanes. Prior to the arrival of Hurricane Isabel in 2003, the Hyde County Register of Deeds relocated records stored below the high-water mark from flooding experienced after Hurricane Floyd in 1999. While that protected a large quantity of records, flooding in the courthouse after Isabel exceeded the record mark set during Floyd, devastating public records in all

[7] "Two Hurricanes, Two Floods: North Carolina Town Fights to Stay Alive." (June 5, 2019.) *Circle of Blue.* Retrieved January 17, 2020 from https://www.circleofblue.org/2019/world/fairbluff/; North Carolina State Historic Preservation Office notes.
[8] Campbell, Colin. "Experts help save artifacts from flooded Windsor farming museum." (September 30, 2016). *Raleigh News Observer*. Retrieved January 17, 2020 from https://www.newsobserver.com/news/politics-government/article105274651.html.
[9] "Marshall Flooding." (December 28, 2018.) *Asheville Citizen-Times.* Retrieved January 17, 2020 from https://www.citizen-times.com/story/news/madison/2018/12/28/marshall-nc-flooding-threatened-french-broad-river-asheville/2436125002/; "Landslide collapses apartment building in Marshall as French Broad rises." (April 19, 2019). *Asheville Citizen-Times.* Retrieved January 17, 2020 from https://www.citizen-times.com/story/news/madison/2019/04/19/landslide-collapses-apartment-building-marshall/3526595002/.
[10] "Some Asheville streets reopen after flooding; swollen rivers have crested." (April 20, 2019.) *Asheville Citizen-Times*. Retrieved January 17, 2020 from https://www.citizen-times.com/story/news/local/2019/04/20/asheville-flooding-biltmore-village-streets-reopen-french-broad-swannanaoa-river-crest/3528081002/.

offices of the building. Records from courthouses, municipal buildings, universities, libraries, and local medical providers have all been damaged in the last decade when hurricanes impact the state.

Non-climate stressors may become more acute in the future, particularly development pressures that bring more impermeable surfaces for parking. Adjacent jurisdictions with differing policy approaches and ordinances may bring about a fragmented, uncoordinated approach to land use rules and floodplain management. Limited funding for infrastructure solutions may exacerbate the situation. Regional topography will continue to be a consideration with anticipated upslope development in the mountains and interest in developing heretofore undeveloped land with wetlands in the Coastal Plain. Urban impacts may be more variable because of the higher population density, diversity of economic opportunity, and availability of local funding versus a depopulating rural North Carolina with fewer financial resources and less robust economic development.

Resilience Strategies

Staff capacity to deal with these issues is limited at all levels because of existing workloads and focused programs. Regional disasters, such as major flooding events, can quickly deplete the staff capacity of NCDNCR's Cultural Resources Emergency Response Team (CREST). Options to addressing climate-related threats to cultural resources are detailed below.

Constituent education

Broader constituent education for resiliency measures, such as restoration workshops on how to flood-proof or dry out buildings, CREST-led disaster planning training, and Register of Deeds training, would aid in better statewide preparation for flooding events. The Historic Preservation Office (HPO) has incorporated the NC Department of Public Safety's hazard mapping layers, especially for flood zones and flood prone areas, into its mapping enterprise HPOWEB for historic resources in the state, which can aid long-term planning capacity for local governments. Staff capacity and current funding are limitations.

Essential records protection program

The State Archives offers a program to back up essential minutes for local government offices. They also offer consultations and training on protection of all vital records. Staff capacity and current funding are limitations.

Building modifications

Building adaptations include elevating buildings, wet or dry flood-proofing, site and landscape adaptations, protection of utilities, filling basements, elevating on a new foundation or through the interior structure, abandoning the first story, or moving the building to a less vulnerable location. Building adaptations for government offices also serve to protect the essential records stored within. Grants and incentive programs should include criteria for these resiliency measures.

The Technical Preservation Services unit of the National Park Service has recently developed national flood adaptation guidelines to the elevations and other design solutions for historic buildings threatened by flooding. This document endeavors to balance design and floodplain management considerations with historic preservation.[11] Our agency will encourage local jurisdictions to incorporate these guidelines into local planning efforts and regulatory schemes as well as departmental capital projects; they likewise could be adopted by private constituents on a voluntary basis.

[11] National Park Service. (November 2019.) *Guidelines on Flood Adaptation for Rehabilitating Historic Buildings*. Retrieved January 17, 2020 from https://www.nps.gov/tps/standards/rehabilitation/flood-adaptation.htm.

Other states, namely Florida and Maryland, have developed state-specific disaster planning and hazard mitigation guides for historic resources, which recommend many of the options set forth in this section.[12] North Carolina should follow their lead.

Over the last years, multiple private property owners on Ocracoke Island preemptively elevated their historic buildings (often residences) with sensitivity to their historic nature, and consequently had reduced or no damage from flooding from Hurricane's Dorian heavy rain and storm surge. We note that many of these elevation projects were accomplished as projects using the federal and/or state rehabilitation tax credit program as administered by the National Park Service and/or State Historic Preservation Office. We would like to encourage more of this activity in flood prone areas.

Certified Local Governments

A federal designation for local jurisdictions with an active historic preservation program are eligible for 10% of the state's federal Historic Preservation Fund grant monies, and implementation of guidelines and adaptive strategies for resiliency could be fostered through this grant program.

Infrastructure approaches

Engineering solutions for flood control, such as levee systems, dams, and other stormwater drainage means exist. For example, Asheville is working with the U.S. Army Corps of Engineers to reduce Biltmore Village flooding by 2023 through a flood mitigation project.[13] Funds to undertake large scale infrastructure projects to control or reduce flooding are expensive and beyond the scope of our agency's independent capacity, and would have to be planned and funded in collaboration with a wide range of partners.

Strategic siting / relocations

Archival or artifact collections can be relocated from vulnerable locations or re-housed in more strategically selected sites, but the critical question of where is difficult because of storage, accessibility, and security requirements. Funding remains an issue.

- Archaeological sites need to be assessed and prioritized for potential salvage excavations in vulnerable locations.
- To reduce vulnerability for directly managed state assets, controlling agencies should consider strategic siting, such as farther inland or out of flood plains, and building adaptation, including potentially elevations.
- Threatened archaeological sites can be excavated and their artifacts salvaged, but their locations are not always known, and it may not be financially feasible to do so on a large scale. Cemetery relocation is likewise fraught with difficulty, including how and where to relocate remains legally; state law requires descendant notification. Historic building or historic district relocation

[12] Division of Historical Resources, Florida Department of State, Division of Emergency Management, Florida Department of Community Affairs, & 1000 Friends of Florida. (2006.) *Disaster Planning for Florida's Historic Resources*. Retrieved January 31, 2020 from https://1000fof.org/wp-content/uploads/2019/08/disaster-planning.pdf; University of Florida Levin College of Law, Conservation Clinic. (June 2017.) *Protecting Florida's History from Hazards: A Guide to Integrating Cultural Resources into Disaster Planning.* Retrieved January 31, 2020 from https://www.law.ufl.edu/law/wp-content/uploads/2017/07/Protecting_Floridas_History_20July2017_1Sided.pdf; 1000 Friends of Florida, Florida Department of State, Division of Historical Resources, Florida Division of Emergency Management. (August 2008). *Disaster Mitigation for Historic Structures: Protection Strategies.* Retrieved January 31, 2020 from https://dos.myflorida.com/media/697182/fdem-disaster-mitigation-for-historic-structures.pdf. Preservation Design Partnership, LLC. (2018). *Flood Mitigation Guide: Maryland's Historic Buildings*. Retrieved January 31, 2020 from https://mht.maryland.gov/documents/PDF/plan/floodpaper/2018-06-30_MD%20Flood%20Mitigation%20Guide.pdf.

[13] WLOS. (April 22, 2019.) "New project could reduce flooding in Asheville." Retrieved January 17, 2020 from https://wlos.com/news/local/new-project-could-reduce-flooding-in-asheville.



is even more complex, because the site itself is important to the resource's historic significance and integrity. Moving structures is expensive, particularly when distance and utility relocation are factors for transit.

Heavy Precipitation

Impact Summary

Heavy precipitation can put a facility out of service and threaten the artifact or archival collection in turn. If the damage is severe enough, the facility may be destroyed, requiring a replacement for records storage or visitors' facilities. The situation is more acute if the resource is an irreplaceable archaeological site or historic building.

Changing climate will increase the frequency and intensity of storms and heavy precipitation events across the state. These include impacts from more intense rain, nor'easters, and associated tornados. These types of storms will pose major threats to cultural resources from wind and water damage to historic structures and districts, historic records and archives, museum collections, cemeteries, and archaeological sites. Two specific issues related to increased and more intense precipitation include erosion and flooding.

After the heavy precipitation of Hurricane Florence, State Historic Preservation Office staff noted large piles of debris from historic buildings in the multiple National Register Historic Districts in New Bern. Owners discarded historic materials, such as mantelpieces, flooring, and wainscoting because of water damage and fear of mold. However, through our staff's intervention and technical assistance with drying techniques, some of these elements were subsequently salvaged.

Inability to access damaged artifacts and documents in 24 to 36 hours following exposure dramatically increases the risk of damaging mold growth. More intense tropical storms that bring widespread flooding increase the likelihood of a delay in getting access to buildings with damaged cultural assets before mold damage.

Vulnerability and Risk

Heavy precipitation regularly causes street flooding near the Archives/Library building in Raleigh. Unable to keep up with the water capacity, storm drains back up water into the building loading dock which can cause subsequent water incursions into the Archives' sub-basement security vault. These water incursions threaten a collection of security microfilm stored in the vault.

Mold infiltration in flooded or otherwise compromised buildings multiplies the repair cost, and for some people, makes the building less attractive for continued occupancy because of the fear of mold-related health issues in the future, threatening the long-term preservation of the building.[14]

[14] North Carolina Department of Health and Human Services. (September 21, 2018.) "Mold in Buildings Flooded by Hurricane Florence Presents Health Risks; Health Officials Encourage Precautions." Retrieved January 17, 2020 from https://www.ncdhhs.gov/news/press-releases/mold-buildings-flooded-hurricane-florence-presents-health-risks-health-officials; North Carolina State Historic Preservation Office staff reports based on site visits and constituent outreach; Wallace, Lewis Raven. (January 22, 2019.) "Lingering long after a storm, mold and mental health issues: North Carolinians are organizing against 'toxic resiliency,' focused on healing from trauma." *Environmental Health News*. Retrieved January 17, 2020 from https://www.ehn.org/lingering-long-after-a-storm-mold-and-mental-health-issues-2625546179.html?rebelltitem=2#rebelltitem2; New Hanover Regional Medical Center. (October 10, 2018.) "Mold: A Serious Threat after Hurricane Florence." Retrieved January 17, 2020 from https://www.nhrmc.org/blog/2018/10/mold.

Heavy precipitation from any source that infiltrates a building can foster mold growth. However, heavy rain during hurricanes is even more hazardous to cultural resources when it combines with high winds and loss of electrical power, because flooded buildings experience mold growth from standing water in interior spaces and further exposure to wind-driven rain from compromised roofs, windows, and masonry.

The Brunswick Town / Fort Anderson visitors' center remained closed for several months after Hurricane Florence because of mold remediation after rain collected inside the building through the hurricane-damaged roof, and a loss of electrical power and washout of the main road to the site exacerbated the situation without climate control and access to the building for an extended period. CREST deployed to aid the Public Schools of Robeson County Indian Education Program Museum at the National Register-listed Pembroke High School, and discovered mold damage to tribal artifacts after rain infiltrated its roof during Hurricane Florence.

Impermeable surfaces, such as parking lots, roads, and other modern development are exacerbated during periods of heavy precipitation. These surfaces have altered the natural water flow, exacerbating flooding and sending floodwaters in areas previously viewed as "high and dry." This non-climate stressor makes flooding potential for cultural resources more difficult to predict and therefore widens the scope of areas in need of adaptability or other resiliency solutions.

Non-climate stressors may become more acute in the future, particularly development-related increases in impermeable surfaces, fragmented policy and legal approaches taken by separate local jurisdictions in land use rules and floodplain management, and limited infrastructure funding.

Resilience Strategies

Options available to address heavy precipitation include not only expansion of the aforementioned constituent education statewide but also include the following:

Essential records protection program

The State Archives offers a program to back up essential minutes for local government offices. They also offer consultations and training on protection of all vital record. Staff capacity and current funding are limitations.

Disaster response program

The State Archives and CREST leadership consult with public and private custodians of cultural assets on the development of a robust disaster response plan, including comprehensive response contact information and action steps. A thorough plan also includes regular facility reviews and steps to increase protection of collections in situ. Staff capacity and current funding are limitations to expanding this option for increased adaptive capacity.

Building adaptation / strategic siting

In addition to the adaptations identified for flooding, more resilient roofs with redundant features, such as hurricane clips, are important. Regular roof maintenance is also key. Historic tax credits can be helpful to make these adaptations. To reduce vulnerability for directly managed state assets, controlling agencies should consider a combination of strategic siting and building adaptations.

Infrastructure approaches

In addition to the large-scale infrastructure solutions identified for flooding, installation of gas-powered generators for cultural institutions can provide continued climate control to help prevent mold growth.



Sea Level Rise

Impact Summary

Rising sea level does and will continue to pose a threat to numerous state historic sites, museums, and other cultural institutions within the Coastal Plain. North Carolina's low-lying Coastal Plain and barrier islands include many famous historic towns and villages. These sites draw thousands of visitors each year, generating significant economic benefit in that region. Many of these resources may be inundated or subject to increased coastal and shoreline erosion and ultimately damaged or destroyed. It is likely that disruptions to or limitations on utility and transportation infrastructure that serve these areas, such as saltwater intrusion into drinking water sources and recurring flooding on roadways, may independently set a trajectory for adaptive strategies for and/or abandonment of historic resources.

The Coastal Plain contains thousands of our state's cherished historic houses, downtown buildings, public buildings, churches, and cemeteries. These coastal counties and municipalities also manage records of permanent value to the state. Many private properties in the Coastal Plain are considered significant and are listed on the National Register of Historic Places.

Sea level rise will cause loss of economic development opportunities, community identity, and historic resources; population migration; and abandonment of communities. Given the very direct and devastating nature of the impacts from sea-level rise, cultural resources are expected to be at risk within the Coastal Plain.

Vulnerability and Risk

Protecting and preserving historic and cultural sites is critical to our state's heritage. The type of construction material (e.g., masonry versus wood frame) and elevation status for historic buildings are crucial to climate vulnerability assessments. Site location and determining whether something can be easily moved is also an important component in rehabilitative or adaptive planning for sea level rise.

From our perspective, flooding and storm surge events are temporary precursors to what can be expected from permanent sea level rise inundation, which will leave many areas, including its historical resources and institutions, inundated or island-like. These areas will be surrounded by inundated land and marooned from the utility and transportation infrastructure networks, forcing the state and its citizens to plan for retreat or adjusting to new realities in place.

The State Historic Preservation Office projects that 76 National Register districts and property will be directly affected by inundation from a two-foot sea level rise.[15] Sea level rise may very well lead to wholesale abandonment of communities and the immovable cultural resources contained within, and to societal disruption and a loss of community identity on a scale hard to contemplate.

Sea level rise projections indicate that the rising waters make no distinction as to jurisdictional boundaries, such as county lines or city limits, or road maps. The risk derived from this vulnerability is that affected areas will think and act "small and local" when we need to think and act "big and regional" to develop solutions and options on the scale posed by the sea level rise threat.

[15] In January 2020, the State Historic Preservation Office compared the GIS data of the Sea Level Rise Viewer of the NOAA Office for Coastal Management (available at https://coast.noaa.gov/digitalcoast/tools/slr.html) to its own GIS enterprise HPOWEB (which includes mapping of National Register listed properties in North Carolina).



Resilience Strategies

More research is needed to determine at a more granular level the scope of risk for these resources, type of impacts, and needed adaptation strategies**.** There will also be the need to consult and coordinate climate resilience efforts with other federal and state governmental agencies, private individuals, municipal and county governmental agencies, and private organizations.

Regional planning coordination

Other states, including Florida and Virginia, have begun to work on these issues on a regional, rather than individual local jurisdictional, basis. This approach will be meaningful for North Carolina, particularly given its dispersed coastal geography.[16]

Resource adaptation

Adaptation strategies identified for flooding are applicable for sea level rise but relocation of historic resources will be the most likely solution in many cases.

Essential records protection program

The State Archives offers a program to back up essential minutes for local government offices as well as consultations and training on protection of all vital records. Staff capacity and current funding are limitations.

Abandonment versus relocation

Critical will be a triage methodology to determine what should be moved and to where or otherwise salvaged versus documented and abandoned in place. The survivability and adaptability of transit and utility infrastructure and portability of resources (artifact / archives versus building or archaeology site) will likely impact this decision making. Archaeological sites need to be assessed and prioritized for potential salvage excavations in vulnerable locations.

Inventory of threatened sites

Approximately one hundred of North Carolina's cultural heritage collecting institutions would be affected by a three-foot sea level rise. If these institutions do not relocate, the cultural assets they steward will be lost. As water levels rise, it will be important to strengthen NCDNCR's network with an inventory of threatened repositories, especially in eastern North Carolina, to begin discussing the possibility of a regional collections storage facility, which would likely need state funding.

The time frames for these options are highly dependent on further study of SLR with North Carolina specific projections. As a result, it is difficult to provide a time horizon needed for these strategies. Constituents and partners in both the private and public sectors and levels of government should be involved. The insurance industry is emerging as a leader in these discussions.

[16] Examples include the Southeast Florida Climate Change Regional Compact (https://southeastfloridaclimatecompact.org/) and efforts of the Hampton Roads Planning District Commission (https://www.deq.virginia.gov/Portals/0/DEQ/CoastalZoneManagement/FundsInitiativesProjects/task54-13.pdf).



Wildfire and Drought

Impact Summary

Extended and/or intense drought is likely to increase the probability of wildfire and extensive forest fires. These climate stressors have the potential to destroy or heavily damage historic structures and create exposed landscapes, facilitating erosion. Other indirect impacts may result from the necessary efforts to fight fires, such as construction of fire lines, backfires, and heavy water use from lakes. The Office of state Archaeology works closely with agencies such as the U.S. Forest Service (USFS) in North Carolina to assess the impacts to cultural resources from activities associated with containment and suppression of fires within the major national forests within the state.

Vulnerability and Risk

Lack of proper forest maintenance because of staff capacity or private party decision-making can exacerbate wildfire risk. The heat of fires and their duration can adversely affect the underlying topsoil, destroy intact archaeological resources (as well as the built environment), and set up a scenario where reforestation is difficult because of erosion and lack of host soil. Choice of construction materials for buildings and their landscaping present in wildfire-prone areas can likewise exacerbate the spread of wildfires – a flammable wood frame building with close-in undergrowth versus a masonry building with metal roof and a "swept" yard – and can determine survivability of the buildings (and what they contain) during a fire event.

Intense and prolonged drought will cause certain types of vegetation to die and in some cases produce exposed landscapes denuded of a protective vegetative cover. For historic sites and archaeological sites, the lack of covering vegetation will likely facilitate greater levels of erosion whenever precipitation resumes, particularly on exposed slopes, including mountainous terrain, river bluffs, and military earthworks. This type of erosion may serve to destroy or heavily damage the integrity and context of some of these sites. Once damaged in this manner the interpretive quality of some sites is irreparably destroyed. In addition, certain types of historic structures on exposed slopes such as early tobacco barns, ordering rooms, cabins, and tenant houses will likely be heavily damaged by increased or more intensive erosion.

Increased drought will likely impact cultural resources present within certain lakes across the state (e.g., Phelps Lake, Lake Mattamuskeet, Pungo Lake, New Lake, Lake Waccamaw, Falls Lake, Kerr Lake, and others), such as prehistoric Native American dugout canoes or evidence of earlier settlements. Extended drought could cause significant drops in lake levels and in some cases would expose these archaeological resources to the damaging effects of air and sunlight. Many of these resources are located at relatively shallow depths and may possibly be exposed if the lake level drops significantly during a prolonged drought. Once exposed, these types of resources will be damaged rather quickly and subject to looting.

Resilience Strategies

Working with its partners in state and local government as well as federal agencies such as the USFS, the DNCR anticipates it will adjust to most of the impacts from drought and wildfire. Currently, programmatic agreements with USFS to address compliance with Section 106 of the National Historic Preservation Act provide opportunities to address these issues further.

Additionally, funding and staff capacity for survey and documentation of threatened resources would aid in better long-term planning for their preservation.

4. Summary

Impacts of climate change have already been felt in the cultural resources sector through increased incidents of flooding and heavy precipitation, often associated with more severe hurricanes. Communities have already experienced damage to facilities, loss of archival records, financial expense, loss of historical integrity, loss of critical documentation, and damage to heritage tourism. In addition to flooding and heavy precipitation, sea level rise also presents a real threat to assets in this sector.

NCDNCR is already working to incorporate resilience strategies that will increase our adaptive capacity to mitigate risks and reduce vulnerabilities. Because NCDNCR conducts so much of its critical technical assistance and constituent services work in a collaborative environment, it should be reiterated that many of the decisions that could protect cultural assets that are not under direct state management rest in the hands of local government entities and private property owners. Promulgation of regulations and provision of resources to increase adaptive capacity may also be tied to federal regulations. Some of these rules may need updating to adapt to the realities of ongoing and persistent climate change impacts, such as repeated flooding. Sector development of adaptive capacity where possible will need to continue to be done in coordination with all stakeholders to realize meaningful results.

A one-size-fits-all expectation or approach is not appropriate for assessing how cultural assets will respond to climate hazards. An archaeological site located on a property outside of a flood zone or coastal surge area may be least affected. A high altitude historic district in the mountains that is also in a river valley could experience devastating flash flooding. A well-maintained building with a resilient roof (perhaps featuring hurricane clips or structural redundancies) versus a dilapidated one with an older roof may better survive high winds from a tropical cyclone, and a masonry building may be better poised to weather a flooding event than a wood frame one on the adjacent parcel.

Development pressure, local land use planning rules, jurisdictional divisions, and private property rights will shape adaptation strategies and local and regional solutions. An additional consideration is the matter of staff capacity. Disaster situations put our agency into response mode, even though the regular business of the mission must continue to function. In these circumstances, people power is stretched thin, and constituent assistance is highly dependent on face-to-face interaction and relationships with constituent associations, such as the Administrative Office of the Courts and the North Carolina Association of Registers of Deeds. A related issue is how best to provide educational outreach to help constituents consider climate-related factors in planning at the community and individual property level, especially if the time horizon for action is uncertain or the most recent disaster past.

Our sector is highly dependent on cell phone communication for disaster response between field staff and Raleigh headquarters. If cell towers are not functional, our communication network is compromised to the detriment of our mission. To this end, updates of known information, including the location and the relative importance of various cultural resources, should be ongoing through updated surveys and communication with constituents.

To protect irreplaceable cultural resources from these multifaceted climate threats, complacency and delay are not options. Continued constituent education for resiliency measures should be expanded statewide and made available more often. Regional solutions to these large scale threats should be fostered through the cooperation of multiple local jurisdictions, supported by necessary state level frameworks and funding. Discussion of where we may need to relocate moveable cultural resources, such as archival and artifact collections, and how best to protect or adapt our built environment should be happening now, not the day before the hurricane arrives, the flood comes, or when sea level rise is more evident. The state's efforts to these ends can serve as models for local and regional institutions, especially:



- more extensive and frequent constituent education and training for records and artifacts preparation and protection, as well as resiliency adaptation or modification for the built environment;
- interagency collaborations with local governments and private and non-profit constituents for planning;
- development of a state-specific hazard mitigation guide for historic resources (following the example of Florida and Maryland);
- continued documentation of historical resources (for example, architectural survey, artifact and archival databases, 3-D scanning of buildings and artifacts);
- strategic siting and/or relocation of cultural repositories, including those for long-term storage;
- prioritization of archaeological site protection, especially those increasingly at risk;
- infrastructure solutions to protect historic resources better; and
- adaptation or relocation of historic resources, such as appropriate and historically sensitive elevations.

Through concerted effort and purposeful action, North Carolina's irreplaceable cultural resources have survived wars, social upheaval, and natural disasters. The responsibility to steward them for future generations must be done in concert with local partners, and with enhanced staff capacity and appropriate funding to address preparation, organization, and adaptation.


Ecosystems

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F. Ecosystems

Key Observations

- The North Carolina Natural Heritage Program assessed ecosystem vulnerability in 2010 and updated the assessment in 2019.
- Ecosystems in all 100 counties are affected by climate change and numerous land use changes that have occurred in recent decades.
- The ecosystems with the highest risk support a high concentration of rare species and have a low tolerance of environmental variation.
- Ecosystems are shaped by climate. Human impacts reduce ecosystems' natural resilience to disturbance and change.
- Conserving and managing land for key ecosystems yields benefits to other sectors, including water resources, tourism and commerce, and public health.
- Minimizing non-climate stressors will reduce the overall stress on ecosystems and help avoid catastrophic change and loss.
- Need multi-agency understanding of the financial value of ecosystem services.

Critical Impacts and Resilience Strategies

- To improve overall landscape resilience, create nature preserves as large as possible and maintain habitat connectivity across the landscape.
- Preserve and restore wetlands and natural areas alongside rivers and streams.
- Manage land for natural processes, such as prescribed fire and restoration of natural stream flows.
- Establish natural recreation areas such as parks, trails, and greenways that will improve resilience and public health, and become valued community assets that improve quality of life.
- Increase public awareness of the importance of land conservation, planning for resilience, and the value to people of ecosystem function and services.
- Business must adopt biomimicry practices to provide holistic regenerative economic value.

1. Introduction

To ensure the long-term health and functionality of North Carolina's ecosystems, we must understand how climate change will affect our natural areas and the species that inhabit our land and waters. North Carolina is a global center of diversity for many groups of organisms, including mountain trilliums and animals that rely on aquatic systems, such as salamanders and freshwater crayfish. North Carolina has a wide variety of habitat types, and this remarkable diversity is only partly explored. New species are still being discovered. Among the species found in the state, about 3% of plants and 6% of animal species are critically imperiled and at risk of extinction on a global basis.[1] Considering only their numbers and ranges within the state of North Carolina, 15% of plants and 8% of animal species are considered Endangered, Threatened, or Special Concern by the NC Department of Agriculture and the Wildlife Resources Commission. Every native species has its place in North Carolina's natural heritage, and we are already

[1] *North Carolina Natural Heritage Program Biotics Database*. (2020). NC Department of Natural and Cultural Resources, Raleigh, NC. (Accessed: January 16, 2020).



seeing changes in some natural communities that will make it impossible for some species to survive in areas of their current range.

North Carolinians have a long heritage of appreciating and caring for the land and water. North Carolina government agencies work together, along with federal and local organizations, to identify, understand, and protect the plants and animals that live in North Carolina, to ensure these species continue to thrive in their natural ecosystems for future generations. These public trust resources are protected through laws, policies, and state conservation lands that provide space, shelter, and food for the species and places for the public to visit their habitats.

North Carolina's government plays a crucial role in efforts to protect our state's ecosystems. Agencies directly involved with managing and regulating North Carolina's ecosystems include programs and divisions within the Department of Natural and Cultural Resources (DNCR), the Department of Environmental Quality (DEQ), the Department of Agriculture and Consumer Services (NCDA&CS), and the Wildlife Resources Commission (WRC).

Department of Natural and Cultural Resources

The Natural Heritage Program maintains North Carolina's inventory of biodiversity information and administers the North Carolina Nature Preserves Act, protecting 440,737 acres of Dedicated Nature Preserves and 783,488 acres of Registered Heritage Areas.

The Division of Parks and Recreation conserves and protects representative examples of North Carolina's natural beauty, ecological features, recreational and cultural resources within the state parks system; provides and promotes safe, healthy and enjoyable outdoor recreational opportunities throughout the state; and provides educational opportunities that promote stewardship of the state's natural and cultural heritage. Manages 82 sites including state parks, state natural areas, and state trails, totaling 287,011 acres under the state Parks Act and the state Nature and Historic Preserve Dedication Act.

The Clean Water Management Trust Fund (also known as North Carolina Land and Water Fund) awards grants to non-profit and governmental organizations to protect land for natural, historical and cultural benefit, limit encroachment on military installations, restore degraded streams, and develop and improve stormwater treatment. This is a primary source of grants allowing local governments, state agencies, and conservation nonprofits to address water pollution, protect clean water supplies, and conserve land.

The Parks and Recreation Trust Fund (PARTF) supports land acquisition and improvements within the state park system. PARTF is the main source of funding for local parkland acquisitions, facility improvements, and public beach and estuarine access.

Department of Environmental Quality

***The Division of Marine Fisheries (DMF*)** mission is to ensure sustainable marine and estuarine fisheries and habitats for the benefit and health of the people of North Carolina. This includes the management of North Carolina's marine and estuarine fisheries out to three miles offshore, and monitoring the state's fisheries habitat, encompassing all 2.9 million acres of coastal waters (marine and estuarine) and over 412,000 miles of coastline. The DMF carries out the rules and policies of the Marine Fisheries Commission (MFC).

The MFC is a nine-member board appointed by the Governor to manage, restore, develop, cultivate, protect and regulate the state's marine and estuarine resources. It does this by adopting rules and policies, implementing management measures for fisheries and advising the state on marine fisheries within the jurisdiction of regional and federal boards and councils.



The Division of Coastal Management (DCM) carries out the state's Coastal Area Management Act (CAMA), Dredge and Fill Law, and the rules and policies of the Coastal Resources Commission (CRC), in the state's 20 coastal counties. The CRC is charged under CAMA with the protection, preservation, orderly development, and management of the coastal area of North Carolina, including public trust resources. DCM, which provides staff support to the CRC, is responsible for several programs, including permitting, land use planning oversight, coastal policy, the Coastal Reserve program, and numerous grant programs.

DCM's Coastal Reserve protects and manages more than 44,000 acres of coastal and estuarine land and water for research, education, and compatible traditional uses at ten reserve sites along NC's coast. Four of these sites comprise the National Estuarine Research Reserve, a state-federal partnership between DCM and the National Oceanic and Atmospheric Administration (NOAA).

The Division of Water Resources (DWR) ensures safe drinking water in accordance with federal requirements, evaluates environmental water quantity and quality, and carries out enforcement actions for violations of environmental regulations. This division administers the laws, policies, and rules established by the U.S. Environmental Protection Agency, the state's Environmental Management Commission, and the NC General Assembly.

The Albemarle-Pamlico National Estuary Partnership's (APNEP) mission is to identify, protect, and restore the significant resources of the Albemarle-Pamlico estuarine system. The partnership is a cooperative effort hosted within DEQ under a cooperative agreement with the U.S. Environmental Protection Agency. APNEP works closely with the Commonwealth of Virginia, as the program area extends across both states, from its headwaters in the Virginia mountains and North Carolina Piedmont, through a broad coastal plain and out to the string of barrier islands bordering the sounds. The Coastal Habitat Protection Plan (CHPP) recommends actions to protect and restore habitats critical to the enhancement of North Carolina's coastal fisheries. The Marine Fisheries, Coastal Resources, and Environmental Management commissions are required to approve the plan recommendations.

Department of Agriculture & Consumer Services

The NC Forest Service manages 58,967 acres of state forests and provides forest management advice and assistance to private landowners; protects state and privately owned land from wildfires and provides assistance with prescribed fire.

The Plant Protection Section manages 14,205 acres of plant conservation preserves and administers the Plant Protection Act.

The Wildlife Resources Commission

The Wildlife Resources Commission conserves and sustains the state's fish and wildlife resources through research, scientific management, wise use, and public input; is the regulatory agency responsible for the enforcement of NC fishing, hunting, trapping and boating laws, maintaining endangered, threatened, and special concern species, and stewardship of public trust fish and wildlife. Manages 520,424 acres of game lands for nongame and game species and their habitats.



2. Overall Exposure

North Carolina's three physiographic regions differ from each other in terms of their most critical climate stressors and their adaptive capacity. Western North Carolina hosts a diversity of elevations, precipitation patterns, and geologic formations, and therefore supports a diversity of ecosystems and many endemic species known from nowhere else in the world. Drought, heat, and extreme precipitation could easily shift conditions to regimes that will not support the diversity of life that currently characterizes this region.

North Carolina's biggest cities and highways are in the Piedmont. The rivers and streams of the Piedmont region are especially important ecologically, harboring a diversity of aquatic species including some endemic organisms such as the Neuse River Waterdog (*Necturus lewisi)*. The presence of rare and endemic fish, mussels, and amphibians in Piedmont rivers indicate places where water quality remains clean enough to support animals that are sensitive to pollution and sedimentation. Water temperature change, sedimentation, and pollution runoff associated with extreme precipitation compound stresses already threatening the aquatic species associated with Piedmont streams and small rivers.

In the Coastal Plain, the people and natural communities in closest proximity to major rivers, sounds, and the ocean are most vulnerable to flooding from extreme precipitation and sea level rise. Coastal streams, floodplains, and freshwater tidal wetlands are all vulnerable to flooding, saltwater inundation, and invasion of nonnative species. Coastal fringe areas are losing habitat due to erosion, and marine species are responding to changes in coastal water temperatures.

A risk assessment of North Carolina's Ecosystems[2] was originally conducted in 2010 and updated in 2019. As part of this assessment, the Natural Heritage Program, with input from other conservation agencies, evaluated the likely effects of climate change on North Carolina's ecosystems and species and then integrated this information with knowledge of ongoing threats, particularly habitat loss and invasion of exotic species. This analysis was conducted at several levels of biological organization and, where appropriate, over several different regions of the state: The Mountains, Piedmont, and Coastal Plain (Table 5F-1).

[2] *North Carolina Ecosystem Response to Climate Change: DENR Assessment of Effects and Adaptation Measures*. (2010). Department of Environment and Natural Resources, Raleigh, NC.



Table 5F–1: Exposure matrix listing the most vulnerable NC ecosystems (taking into account sensitivity to threats and adaptive capacity) and climate hazards that affect them.[1]

Most Vulnerable Ecosystem Types	Change in Seasons	Coastal Erosion	Dam Failure	Extreme Heat	Flooding	Inundation due to Sea Level Rise	Landslides	Saltwater Intrusion	Severe Winter Weather	Storm Surge	Tidal Flooding	Water Shortage due to Drought	Wildfire	Wind
Coastal Plain Floodplains	*		*		*			*	*	*	*			*
Coastal Plain Large River Communities				*	*			*		*	*	*		
Coastal Plain Nonalluvial Mineral Wetlands								*		*	*		*	
Coastal Plain Stream/Swamp Communities			*	*	*			*		*	*	*		
Estuarine Communities	*	*				*		*		*	*			
Freshwater Tidal Wetlands	*	*				*		*		*	*			
High Elevation Forests and Outcrops	*			*					*			*	*	*
Maritime Grasslands	*	*		*		*		*		*	*	*		
Maritime Upland Forests		*								*	*			*
Maritime Wetland Forests		*				*		*		*	*			*
Mountain Streams	*		*	*	*		*					*	*	
Mountain Bogs and Fens	*			*	*							*		
Piedmont Streams and Small Rivers			*	*	*							*		
Shell Bottom (estuarine)	*					*		*		*	*			
Soft Bottom (estuarine)	*					*		*		*	*			
Submerged Aquatic Vegetation (Seagrass)	*					*		*		*	*			



Climate stressors and hazards were identified for each ecosystem group and then rated by a team of biologists based on likelihood of impact (high, medium, or low), effect (positive, negative, or mixed) and magnitude (high, medium, or low). Predictions of future ecological conditions are complicated by the interactions among climate, biological, and ecological processes. Because of the emerging nature of the impacts, many ratings were based on expert opinion drawing from first-hand field experience observing the species and ecosystems, rather than from extensive experimental research or modeling.

The ecosystems analysis is represented by 45 groups of ecosystems that share certain ecological characteristics and are likely to respond to climate change in similar ways. Species included in this analysis incorporate the majority of federal and state Threatened and Endangered species that occur in North Carolina, as well as those considered Significantly Rare by the Natural Heritage Program and the majority of animals identified as Priority Species in North Carolina's Wildlife Action Plan. These analyses enumerate impacts that cascade from higher to lower hierarchical levels (i.e. from ecosystems to species), although some impacts are likely unique to each separate unit within the levels.

Climate Stressors and Hazards of Greatest Concern

The many climate stressors each act on North Carolina's ecosystems in different ways, as shown in Table 5F-1. At the same time, many of North Carolina's ecosystems are already strained by other human-caused changes in the environment. Climate change can magnify the stress from other ongoing impacts, including land use changes, invasive exotic species, habitat fragmentation, and fire suppression.

Heavy precipitation events are expected to damage waterways and riparian zones by causing excessive flooding and scouring. Hurricane-related impacts are not limited to coastal regions. Flooding and scouring from heavy rainfall due to hurricanes has affected all 100 counties in North Carolina. In the estuarine environment, flooding from extreme precipitation events can lead to high loads of organic matter, organic nitrogen, and phosphorus which fuels phytoplankton production resulting in algal blooms and associated hypoxia. After Hurricane Florence (2018), many fish species were affected by this condition, including largemouth bass (*Micropterus salmoides*) and Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*).

Winds associated with storms are expected to damage trees and forests across the state. Wind intensity and frequency appear to be two key factors that determine the extent of wind effects on forest dynamics and diversity in the Piedmont. Canopy gaps created by wind damage provide places for invasive exotic and shade-intolerant plant species to become established. At the coast, changes in wind driven tides increase tidal flooding and shoreline erosion. Salt laden tropical cyclone and extratropical nor'easter winds often adversely affect vegetation near the ocean and estuarine waters.

Storm surge erodes shorelines and kills vegetation in maritime grasslands, tidal marshes, estuaries, lower reaches of Coastal Plain rivers, and low-lying wetlands near estuaries. Increased saltwater from storm





Figure 5F–2: Tidal Freshwater Marsh at Pine Island (photo credit: Michael Schafale), Sensitive jointvetch (*Aeschynomene virginica)* (photo credit: Misty Buchanan).

surge damages Tidal Freshwater Marsh, habitat for Sensitive Jointvetch (*Aeschynomene virginica)* which is considered Threatened under the U.S. Endangered Species Act (Figure 5F–2)

Sea level rise affects coastal ecosystems in several ways. Saltwater intrusion due to sea level rise is expected to change the salinity of estuarine communities and convert lower coastal floodplains from swamp forest to marsh. Inundation due to sea level rise is expected to submerge some freshwater tidal wetlands and convert some maritime forests to grasslands. Coastal erosion will reduce the extent of freshwater tidal wetlands, maritime uplands, and maritime wetlands. Endangered and threatened species that are vulnerable to storm surge and erosion on beaches are likely to decline, including seabeach amaranth (*Amaranthus pumilus*), nesting sea turtles, and nesting shorebirds such as piping plover (*Charadrius melodus*) (Figure 5F–3).



Figure 5F–3: Threatened Seabeach Amaranth (*Amaranthus pumilus*) at base of coastal dunes (photo credit: Dale Suiter), Piping plover *(Charadrius melodus)* on ocean beach (photo credit: Scott Pohlman).

Extreme heat and extended periods of hot weather negatively impact mountain streams, mountain bogs, high elevation forests and rock outcrops, Piedmont headwater streams, and Piedmont small rivers (Figure 5F–4). The North Carolina Climate Science Report[3] predicts overall average temperatures in NC are very likely to increase by 2 - 5°F by mid-century and 5 -10°F by the end of this century, and it is very likely that summer heat index values and the number of very warm nights each year will increase.

Many animal species are not able to tolerate increased temperatures and even those that can tolerate some changes in temperature may still be affected. Animal breeding behavior, gender, parasites, and food availability can all be affected by temperatures. For aquatic species, higher water temperatures often contribute to lower dissolved oxygen levels in water. As water temperatures increase with climate change, aquatic species may experience more frequent and extended periods of low dissolved oxygen, causing physiological stress that can interfere with feeding and reproduction. This would be in addition to both natural and pollution-caused anoxic episodes, which already periodically kill large numbers of fish and other aquatic species.

[3] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K.D. Dello, J. P. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: *North Carolina Climate Science Report*. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr



Figure 5F–4: Little Lick Creek reservoir in Durham County during severe drought of 2005 (photo credit: Natural Heritage Program Staff).

Water shortage due to **drought** increases the exposure to and risk of catastrophic wildfire, temporarily reduces availability of suitable habitat for wetland and aquatic animal populations and can cause outright mortality for individual animals and plants that are not able to migrate to suitable habitat.

Mild winters are expected to promote the expansion of invasive exotic species. This will be a factor in many ecosystems, including aquatic as well as terrestrial, with the greatest impacts anticipated in Coastal Plain and Piedmont floodplains. Cogon grass (*Imperata cylindrica*), Chinese tallowtree (*Triadica sebifera*), and fire ants (*Solenopsis invicta*) are all examples of invasive species that may spread to more parts of North Carolina with warmer winters.

Increasing air temperatures contribute to warming streams, lakes, and ocean temperatures, with impacts to marine and aquatic animals including increased stress and higher metabolic rates, and loss of habitat as waters warm.[4] Warmer waters may remove suitable habitat for species already at the edge of their thermal tolerance, including native brook trout. Climate change vulnerability depends on whether organisms can disperse rapidly enough to keep pace with shifting temperatures and find suitable habitat along the way. Nonnative fishes which may prey on and compete with native fishes are likely to increase in numbers and distribution as climate changes.

Ocean temperatures are expected to increase, which will have far-reaching and complex impacts on marine fisheries and estuarine habitats. Warmer ocean temperatures may disrupt migratory pathways for anadromous species. Warmer waters often contribute to lower levels of dissolved oxygen, leading to fish kills in coast waters. Warmer water temperatures also allow some species of aquatic animals to expand into areas that were previously too cold for them to survive. DMF has already recorded a northward range

[4] Williams, J. E., Isaak, D. J., Imhof, J., Hendrickson, D. A., and McMillan, J. R. (2015). *Cold-Water Fishes and Climate Change in North America. Reference Module in Earth Systems and Environmental Sciences*. Retrieved from http://dx.doi.org/10.1016/B978-0-12-409548-9.09505-1



shift for summer flounder off the coast of North Carolina[5] and the center of the Atlantic Croaker population is forecast to shift 50–100 km northward before the year 2100.[6] Fisheries management will need to adapt to a changing definition of sustainable harvest that may shift with warming waters and find a way to be dynamic in managing capture fisheries due to this complexity.

Non-climate Stressors of Greatest Concern

Changes in **land use** (e.g., conversion from natural systems to commercial and residential development), continues to affect ecosystems across the state, including direct impacts to uplands and floodplains and secondary impacts to aquatic ecosystems and wetlands.

Changes in hydrology are of great concern for wetlands, rivers, and streams across the state, from mountain bogs to coastal wetlands. Impacts include flood regime alteration, groundwater depletion and water withdrawal, and impoundment of streams and rivers.

Water pollution threatens aquatic communities, including rivers, streams, and estuarine communities. In North Carolina, 22 species of aquatic animals are already listed as federally Endangered or Threatened.[7]

Loss of **riparian vegetation** threatens large rivers, streams and estuarine ecosystems, which rely on intact riparian zones for shade, bank stabilization, and filtration of pollutants and nutrients.

Invasive exotic species have already changed the species composition of many floodplain forests, rock outcrops, freshwater marshes, mountain bogs, and aquatic communities, and they continue to spread. Invasive species reduce the diversity of local native species, affect water availability and soil nutrients, and interrupt natural ecological interactions and processes. Chinese privet (*Ligustrum sinense*), Japanese knotweed (*Reynoutria japonica*), phragmites (*Phragmites australis*), and hydrilla (*Hydrilla verticillate*) are a few of the many invasive exotic plants in North Carolina that have been shown to damage the ecosystems where they dominate and outcompete native plants.

[5] Dubik, B. A. Clark, E.C. Young, T., Jones Zigler, S. B., Provost, M. M., Pinsky, M. L., and Martin, K. S. (2019). *Governing fisheries in the face of change: Social responses to long-term geographic shifts in a U.S. fishery*. Marine Policy, 99, 243-251.
[6] Hare, J., Alexander, M., Fogarty, M., Williams, E., and Scott, J. 2010. *Forecasting the dynamics of a coastal fishery species using a coupled climate-population model*. Ecological Applications, 20 (2), 452-464.
[7] Ratcliffe, J. (2019). *Natural Heritage Program List of Rare Animal Species of North Carolina*, Department of Natural and Cultural Resources, Raleigh, North Carolina.

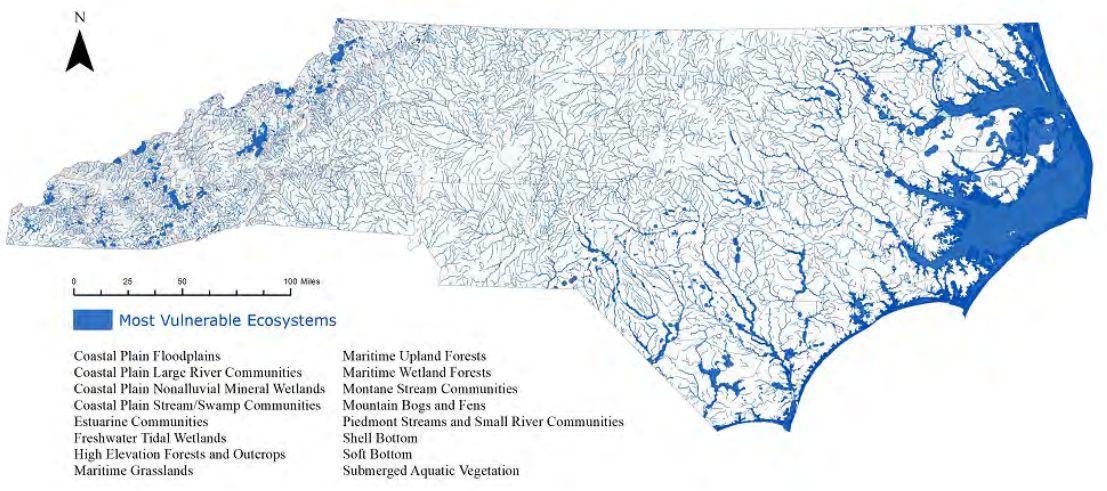


Figure 5F–5: Most vulnerable ecosystems identified by Ecosystem Risk Assessment Committee.

State-Owned Ecosystem Assets at Greatest Risk

We assessed the risks to state-owned lands by reviewing the climate-related stressors and hazards associated with each of 45 biological themes (broad ecosystem types) [8] and then we used maps of the themes and state-owned protected areas[9] to determine which state conservation lands are most vulnerable (Figure 5F–5). Based on this data-driven approach, the assessment showed that **four of the five state-owned conservation lands with the highest number of stressors and hazards are in the Coastal Plain** region of the state. These areas illustrate the breadth of potential impacts and the scope of concern.

Of the five sites, four are near the coast: **Bertie County Game Land** is composed of 3,880 acres of swamps, floodplains, and bottomlands along the Cashie River near Windsor. The **Emily and Richardson Preyer Buckridge Coastal Reserve** covers 28,766 acres along the Alligator River in Tyrell and Hyde counties. **Neuse River Game Land** is located in Craven and Pamlico Counties, in multiple patches north and south of New Bern, totaling 4,898 acres. **Roanoke River Wetlands Game Land** occupies 20,541 acres in Bertie, Halifax, Martin, and Northampton counties between Weldon and Williamston. These areas top the list of state-owned sites with multiple climate stressors and threats because they occur far enough inland to contain river floodplains, nonalluvial wetlands, and even some uplands, and extend down to sea level. Hazards unique to sea level areas include inundation due to steady sea level rise, tidal flooding, and storm surge during severe storms. Intrusion of saltwater, harmful or fatal to most of the freshwater plants and animals that occupy these lands, is associated with all of these hazards. The same waters that caused widely reported damage along the Neuse River in New Bern in recent hurricanes brought major disturbance to the natural systems in the Neuse River Game Land. In the meantime, ghost forests of dead trees where there once were dense swamp forests attest to effects of gradually rising sea level and increased penetration of normal tides.

[8] *North Carolina Ecosystem Response to Climate Change: DENR Assessment of Effects and Adaptation Measures*. (2010). Department of Environment and Natural Resources, Raleigh, NC.
[9] North Carolina Natural Heritage Program. (2020). *Geographic Information System (GIS) data*. NCDNCR, Raleigh, NC. Available at www.ncnhp.org. (Accessed: January 2020).

These areas, being close to the coast, also bear the brunt of the winds from hurricanes, tropical storms, and extratropical nor'easters. Increased severity or frequency of storms may push forested Coastal Plain ecosystems beyond the limit of what their natural adaptations can tolerate. More upstream parts of all these sites support Coastal Plain Floodplain ecosystems that can be affected by increased river flooding associated with extreme rainfall events. These four sites are also subject to many of the climate stressors and hazards that are more widely distributed across the state, including changes in timing of seasons, extreme heat, winter cold snaps, drought, and altered wildfire patterns.

The state-owned conservation land with the next most vulnerable ecosystems is **Pisgah Game Land,** covering 4,272 acres in multiple tracts scattered in Avery, Burke, Caldwell, McDowell, and Mitchell Counties. The ecosystems in Pisgah Game Land most threatened by climate stressors are high elevation forests and outcrops, as well as mountain streams and rivers. Changes in seasons, extreme heat, drought, and heat waves all affect plants and animals that were adapted to live in conditions unique to the high elevation mountaintops.

The Linville River, Wilson Creek National Wild and Scenic River, Harpers Creek, Roaring Creek, Bear Creek, and numerous other small streams and tributaries are featured at Pisgah Game Land. These waterways are known for their trout waters and scenic, recreational, and cultural/historical value. Changes in seasons, extreme heat and heat waves, cold snaps and low temperatures are likely to affect the aquatic environment and species that are not tolerant of changes in average temperatures. Severe weather, flooding, and landslides may increase erosion and add more sediment to waterways. Wildfires may also increase stream sedimentation. Wildfire can also damage high elevation forests and streams if they cause tree mortality leading to stream sedimentation.



Figure 5F–6: Clear waters of the Cane River, Mount Mitchell State Park in Yancey County (left); Shut in Creek near Cherokee in Jackson County (photo credits: Damon Hearne).

3. Examples of Impacts, Vulnerability, and Risk

High Elevation Forests and Rock Outcrops

Impact Summary

High elevation forests and outcrops are among the ecosystems most vulnerable to the effects of climate change of any in the state (Figures 5F–6 and 5F–8). The general pattern of **warmer temperatures, longer growing season, more hot spells, droughts, and severe storms** are expected to occur. **Drought** and associated **wildfire** are among the greatest risks of climate change in the high elevations. Plants occurring at rock outcrops can be dramatically affected by droughts because of the limited water available in shallow soils around the crevices of rocks. Changes in total precipitation may not be drastic but an increase in frequency or severity of drought is a threat, particularly if it brings wildfire into these non-fire-adapted areas.

Wildfire is a severe threat to spruce-fir forests. These forests almost never burned naturally, and most of their component species, including spruce and fir themselves, are not adapted to fire. Much of the environment at high elevations depends on moisture and thermoregulation from fog and cloud cover. It is uncertain if cloud cover will change in these high elevation communities, potentially altering moisture from fog deposition, but this could also contribute to water stress for high elevation plants.

Communities and species associated with this ecosystem are likely to be affected both by **warmer summer temperatures** and by **milder winters**. Warmer temperatures in winter could lead to an increase in damage to trees from **severe winter weather**, as precipitation trends from snowstorms toward more ice storms. As **temperatures increase**, native and exotic species from lower elevations may be able to invade these areas more easily. Thus, managing invasive species and protecting or restoring areas is critical to protect these habitats against these threats.

Given the high number of endemic and disjunct species, and the limited amount of land with the specific environmental conditions found above 5,000' elevation, **high elevation forests and outcrops are among the ecosystems in North Carolina where threats to biodiversity are the greatest.** Ecosystems on Mount Mitchell (North Carolina's oldest state park (1915) and the highest mountain (6,683') east of the Mississippi) are vulnerable. Grandfather Mountain and Cold Mountain are also among 17 high elevation state-owned conservation lands most vulnerable to climate-related impacts (Table 5F-2). Several species on these mountains face outright extinction.

Others, if lost, are unlikely to ever recover within the region. Although this ecosystem survived historical times when temperatures were substantially higher than they are now, the landscape is more fragmented with human-caused impacts than it was in historic times. Priority should be given to management actions that may secure them enough time and space to survive both short-term environmental disturbances as well as adapt to longer-term changes in the climate. Since almost all examples of this ecosystem group are located on public lands and already managed to preserve their natural features, implementation of recommended interventions should be more feasible than for many of the other ecosystems.

Table 5F–2: -owned, high elevation lands most vulnerable to climate-related hazards.

State-Owned Asset Name
Bear Paw State Natural Area
Beech Creek State Natural Area
Cold Mountain Game Land
Elk Knob Game Land
Elk Knob State Park
Grandfather Mountain State Park
Mount Jefferson State Natural Area
Mount Mitchell State Park
NC Division of Mitigation Services Easement
NC Forest Service Easement
Paddy Mountain Plant Conservation Preserve
Pisgah Game Land
Pond Mountain Game Land
Silver Game Land
Tater Hill Plant Conservation Preserve
Three Top Mountain Game Land
Yellow Mountain State Natural Area

Vulnerability and Risk

Most of the high elevation mountaintops in North Carolina are covered in spruce-fir forests. Both the Fraser-fir-dominated forests of the very highest peaks and the mixed red spruce-Fraser-fir-yellow birch forests of the rest of the spruce-fir zone have dense canopies under natural conditions, except where recently disturbed by storms. The introduced balsam **woolly adelgid has killed all of the mature Fraser fir in the last 60 years**, leaving a broken canopy or dense young stands in many places.

A variety of distinctive shrubs and herbs, many of them more common in the northern United States but some endemic to the southern Appalachians, occur beneath the canopy. Lush beds of moss and ferns cover the rocky soil, abundant fallen logs, and tree trunks in some areas. Animal species are a similar mix of northern and endemic species (Figure 5F–7). Some, such as the spruce-fir moss spider (*Microhexura montivaga*) and Carolina northern flying squirrel (*Glaucomys sabrinus coloratus*), are federally Endangered. Some, such as several species of ground beetles of the genus *Trechus*, occur on only a single mountain range. Numerous species of plants and animals are listed as Threatened or Endangered in North Carolina by North Carolina's Plant Conservation Program and Wildlife Resources Commission.



Figure 5F–7: Northern pygmy salamander (*Desmognathus organi*) (left) and Weller's salamander (*Plethodon welleri*), both endemic to high elevation forests (above 4000') of NC, VA, and TN (photo credit: Nathan Shepard).



Figure 5F–8: High Elevation Rocky Summit natural community at Paddy Mountain (left) and Spreading Avens *(Geum radiatum*), components of high elevation ecosystems threatened by climate change. (photo credit: Natural Heritage Program staff).

Northern Hardwood Forests are found on high mountain slopes with a cool climate and high levels of rainfall. They are dominated by combinations of moist-site hardwoods such as yellow birch, beech, yellow buckeye, and sugar maple. The herb layer is often lush and may range from low to fairly high diversity. These forests are subject to periodic widespread disturbances, such as ice storms or severe winds, which provide canopy openings, but probably seldom or never remove the whole canopy at once. The name refers to the resemblance of these forests to those in the northeastern United States, which have similar canopies, but the presence of Southern Appalachian endemic species makes the community types in North Carolina different from those of the north.



Figure 5F–9: Spruce-Fir Forest and High Elevation Rocky Summit natural communities at Grandfather Mountain (left) (photo credit: Wade Stubbs); Threatened Heller's Blazing Star (*Liatris helleri*) (photo credit: James Padgett).

Roan Mountain bluet (*Houstonia montana*), Heller's blazing star (*Liatris helleri*), spreading avens (*Geum radiatum*), rock gnome lichen (*Gymnoderna lineare*), and Blue Ridge goldenrod (*Solidago spithamaea*) – state and federally Threatened or Endangered plants – occur at high elevation rock outcrops (Figure 5F–9). If conditions become too warm and dry for these species, they are unlikely to migrate north because of the limited habitat available for migration corridors (mountaintops are effectively isolated from one another, making migration difficult or impossible for species with limited dispersal capabilities). Endemic species should be monitored closely for declines in the near future, and intervention may be required to prevent extinction.

Resilience Strategies

Protection from Wildfire

Fire suppression is one of the most important actions that can be taken to save the remnants of these communities. Fire suppression is probably already the policy of all current land managers, but suppression may take increased vigilance and effort if conditions become drier. Spruce-fir forests are not very flammable under the current climate but may become more so in the future. Increased **prescribed burning** in fire-prone lower elevation oak and pine forests, in addition to benefiting those forests, should make it easier to control wildfires and prevent them from spreading into the high elevation forests.

Conservation and Restoration

Historical timber harvest and slash fires have greatly reduced the extent of several large spruce-fir patches and broken them into fragments that may not be well connected. Restoration of spruce and fir canopy in these areas, especially in the higher elevation portions, would allow the species pool to expand back through a larger area, producing larger, more robust, and better distributed populations that would be better able to survive the future loss of lower elevation portions. Reintroduction of rare species to patches or mountain ranges where they have been lost, as well as to restored areas, would improve their prospects for survival in the future climate. The Great Balsam Mountains, Black Mountains, and portions of the Great Smoky Mountains are the places with the greatest potential to benefit from this kind of restoration.

Protection from Trampling

For rock outcrops, trampling associated with recreation is one of the biggest threats. Although most examples occur in conservation lands, this threat is difficult to control. Better management of trampling on currently accessible outcrops would allow rare and characteristic species to occupy more of the suitable habitat, producing larger, more robust populations that would be better able to survive climate-related stresses. Reintroduction of rare species to patches or mountain ranges where they have been lost, as well as to restored areas, would improve their prospects for survival in the future climate.

Mountain Streams

Impact Summary

Mountain streams (Figure 5F–10) contain many rare species that are vulnerable to extinction. Climate change is not the most severe threat to these systems. Pollution, sedimentation, and changes in hydrology caused by development and lack of riparian corridors all imperil these globally important ecosystems. Climate and non-climate factors may stress these systems to the point where several species are unable to persist. Because mountain streams exist at high elevations in separated headwaters, threatened species may not easily migrate to connected, cool, high quality habitat, thus resulting in possible extirpation or extinction.

Vulnerability and Risk

Cold water streams, found at higher elevations in the mountains, can be home to important native fish species. Representative habitats exist on a larger set of state lands (Table 5F-3).



Figure 5F–10: Big Creek in Great Smoky Mountains National Park (left)(photo credit: Nathan Shepard), Tuckasegee Stream Crayfish (photo credit: Michael Perkins).

Table 5F–3: State-owned lands with significant mountain streams.

State-owned Asset Name	
Armstrong Fish Hatchery	NC Division of Mitigation Services Easement
Beech Creek State Natural Area	NC Forest Service Easement
Beech Creek Unique Wetland	NC State University Easement
Buffalo Cove Game Land	NC Wildlife Resources Commission Easement
Bullhead Mountain State Natural Area	Needmore Game Land
Cedar Mountain Plant Conservation Preserve	New River State Park
Cold Mountain Game Land	Old Man's Meadow Wildlife Conservation Area
Dulany Plant Conservation Preserve	Paddy Mountain Plant Conservation Preserve
Dupont State Forest	Pisgah Game Land
Elk Knob Game Land	Pond Mountain Game Land
Elk Knob State Park	Rendezvous Mountain Educational State Forest
Gorges State Park	Silver Game Land
Grandfather Mountain State Park	South Fork New River-Boone Greenway
Green River Game Land	South Fork of the New River State Natural and Scenic River
Headwaters State Forest	South Mountains Game Land
Horsepasture State Natural and Scenic River	South Mountains State Park
Linville River State Natural and Scenic River	Stone Mountain State Park
Melrose Mountain Plant Conservation Preserve	Tater Hill Plant Conservation Preserve
Mitchell River Game Land	Three Top Mountain Game Land
Mount Jefferson State Natural Area	Thurmond Chatham Game Land
Mount Mitchell State Park	Toxaway Game Land
NC Agricultural Development and Farmland Preservation Trust Fund Easement	Upper Mountain Research Station
NC Department of Cultural Resources Easement	Wolf Creek Watershed Preserve
NC Department of Transportation Mitigation Site	Yellow Mountain State Natural Area

The degree that warming and disturbances impact particular habitats and species depends on the natural resilience of the habitat or species in question and is also based on the interactions of biological, geomorphic, and hydrologic systems. Impacts from climate change are likely to be more severe where stream and lake habitats are degraded or fragmented and less severe where habitats are robust and connected.[10] Disturbances such as **landslides, wildfires, and floods** are a historical part of the landscapes inhabited by trout and coldwater fishes.

Historically, these disturbances have been infrequent and short-lived, allowing the systems to recover between events or even improve conditions as new habitat patches were created in formerly homogeneous landscapes. In interconnected stream networks, native trout and other fishes may be able to escape

[10] Williams, J. E., Isaak, D. J., Imhof, J., Hendrickson, D. A., and McMillan, J. R. (2015). *Cold-Water Fishes and Climate Change in North America*. Reference Module in Earth Systems and Environmental Sciences. http://dx.doi.org/10.1016/B978-0-12-409548-9.09505-1



wildfires or floods and find suitable habitat conditions elsewhere within the stream network. However, **the same type of disturbance may eliminate the native fish populations if habitat is fragmented**, meaning fish may not be able to relocate to suitable conditions.

Changes in precipitation patterns may have numerous and varied effects. Severe and prolonged **droughts** may decrease streamflow, decrease groundwater recharge, and increase evaporation, varying with site-specific conditions in these coldwater systems. These effects can reduce the area of suitable habitat and cause habitat fragmentation. **Increased storm intensity** can lead to **flash flooding** and more prolonged flooding, with increased **stormwater runoff** and **increased erosion**, resulting in an increase in loading of sediments, nutrients, and contaminants into streams and potential negative effects on biota, such as fish kills. With a change in intensity and variability of rainfall, there are potential changes to streamflow patterns, channel hydrodynamics, and the volume of groundwater, all of which will affect fish habitat within the streams.

Many of the water quality and water quantity impacts resulting from climate change can be expected to exacerbate the impacts from economic development and population growth in North Carolina. Land use, development, and land conversion from forest continues to threaten the integrity of some streams through increased sediment, bank erosion, and stormwater runoff containing sediment and other potentially toxic materials. Economic growth and development increase water supply demands. Historical streamflow patterns are projected to be altered due to climate change impacts; however, these are already being altered due to rapid urbanization. An increase in impervious surfaces due to roads, parking lots, homes, and businesses increases the amount and speed of runoff being delivered into aquatic systems. Riparian vegetation is critical to the overall stream and streambank stability. Lack of riparian vegetation or inadequate width of forested buffer can increase streambank erosion and sedimentation. In addition to stabilizing streambanks, riparian vegetation serves as nutrient input to the stream community and helps regulate stream temperature by providing shade.

Resilience Strategies

Riparian Zone Protection and Restoration

Naturally vegetated riparian areas stabilize streambanks and provide erosion control, allow for sediment and pollutant deposition (by dissipating energy from runoff and allowing for filtration), allow infiltration of water runoff to recharge groundwater, regulate stream temperature by providing shade, provide flood control by attenuating storm flows, sequester and store carbon in mature woody vegetation, increase stream habitat complexity by contributing woody debris, provide habitat for terrestrial wildlife species, and serve as corridors for movement of terrestrial wildlife.

Riparian areas with forested vegetation have a greater capacity to serve these numerous functions, compared with riparian areas of grass, little mature vegetation, or no vegetation. Riparian areas are important for aquatic ecosystem health, in general, but they can also help mitigate for and provide resilience against climate change effects. Riparian vegetation is more resilient to flooding and drought than upland vegetation and should be restored in areas where it is lacking to establish native vegetation and manage for genetic diversity. Riparian areas can serve as movement corridors, and, because they occur along streams, can increase connectivity between habitats and across elevational zones. In addition, animals with thermoregulatory limitations are most dependent upon shaded refuge, and this will become increasingly important with anticipated increases in air temperatures.

To gain the most benefit from stream restoration efforts, **watershed-scale restoration** projects should target areas that are less susceptible to climate change, e.g., sites where models suggest thermal refuge will exist in the future, and that are more likely to harbor trout and native salmonids in the future.



Erosion Control

Erosion control is critical to protecting these waterways from excessive sedimentation. Bare or disturbed ground anywhere in the watershed allows mobilization of sediment that is likely to end up in streams. Most crucial is protection of riparian vegetation.

Bridge and Culvert Design

Future increases in precipitation and flash floods should be taken into consideration when designing bridges and culverts to allow for stream movement, aquatic organism passage, and road stability. Instream barriers and poorly designed culverts can prevent migration of aquatic animals along streams, impeding them from moving freely within the stream network to find suitable habitat and from fulfilling the migration required by their specific life histories, thus fragmenting populations. Improving culverts, bridges, and other stream/road crossings can enable the watershed to handle floods and large storms and increase the connectivity of stream systems.

Translocation and Propagation

Developing techniques for propagation of species–particularly those that are rare, at high risk of extinction or extirpation, and are difficult to maintain in a laboratory setting–is critical for preserving those species and their genetic stock. Propagation facilities can serve as gene banks for aquatic species. Translocation, or moving aquatic species, can involve reintroduction of species or augmentation – adding individuals to an existing population. This technique can be useful for rare species populations that are too sparse for successful reproduction in the wild.

Restoration of populations to places where they have been lost but which remain or have returned to suitable habitat can improve resilience to a species as a whole. Augmentation and reintroduction are techniques that have been and are currently being used, for example, in areas where there have been significant improvements in water quality or available habitat and species are either slow to or unable to recolonize the area on their own. Refinement of these techniques and careful monitoring of habitats that may worsen or improve over time will allow for successful intervention and the possible continuation of a full suite of aquatic species.

Submerged Aquatic Vegetation (Seagrass and Underwater Grass)

Impact Summary

North Carolina is home to the largest and most biodiverse Submerged Aquatic Vegetation (SAV) resource on the Atlantic seaboard and the second largest in the continental U.S (Figures 5F–11 and 5F–12, and Table 5F–4). Submerged aquatic vegetation is the foundation for ecological services that directly benefit coastal communities.[11] These services include primary production, habitat for aquatic species, shoreline and sediment stabilization, water purification, and carbon sequestration. Many organisms use SAV for refuge, spawning, forage, and nursery areas. Submerged aquatic vegetation is designated as Essential Fish Habitat by the South Atlantic Fishery Management Council for some important fisheries species, including penaid shrimps, and species in the snapper-grouper complex. Red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*) and blue crab (*Callinectes sapidus*) are also highly dependent on

[11]NCDEQ (Department of Environmental Quality). 2016. *North Carolina Coastal Habitat Protection Plan*. North Carolina Department of Environmental Quality, Raleigh, NC

SAV, and bay scallops occur almost exclusively in SAV beds. It has also been shown that SAV may reduce bacterial pathogens in the water column that can cause disease in humans and marine organisms.[12] Submerged aquatic vegetation provides ecosystem services that make habitat protection and restoration a priority in terms of its contribution to coastal resilience as well as economic and cultural values.[13]



Figure 5F–11. Submerged aquatic vegetation, also known as seagrass and underwater grass (photo credit: Casey Knight).

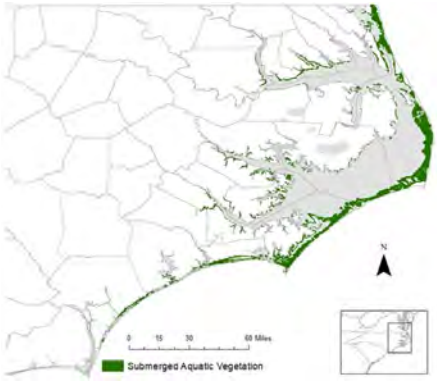


Figure 5F–12. Submerged aquatic vegetation (SAV), also known as seagrass or underwater grass, mapped at different points in time from 1981 to 2015. These delineated areas represent current and historic SAV habitat.

[12]Lamb, J. B., Van De Water, J. A., Bourne, D. G., Altier, C., Hein, M. Y., Fiorenza, E. A., … & Harvell, C. D. (2017). *Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates*. Science, *355*(6326), 731-733.
[13] Ibid

Table 5F–4: State-owned assets with Submerged Aquatic Vegetation (SAV), also known as seagrass or underwater grass.

State-owned Asset Name
Alligator River Game Land
Bald Head Island State Natural Area
Big Foot Island
Browns Island
Bull Neck Swamp
Buxton Woods Coastal Reserve
Carteret County Game Land
Currituck Banks Component of the North Carolina National Estuarine Research Reserve
Currituck Banks Game Land
Emily and Richardson Preyer Buckridge Coastal Reserve
Fort Fisher State Recreation Area
Fort Macon State Park
Goose Creek Game Land
Goose Creek State Park
Gull Island Wildlife Conservation Area
Gull Rock Game Land
Hammocks Beach State Park
Jockeys Ridge State Park
Kitty Hawk Woods Coastal Reserve
Masonboro Island Component of the North Carolina National Estuarine Research Reserve
NC Department of Transportation Mitigation Site
NC Division of Energy, Mineral, and Land Resources Easement
NC Submerged Lands
New River Inlet Islands
North River Game Land
Oregon Inlet/Roanoke Sound Islands
Port of Morehead City
Rachel Carson Component of the North Carolina National Estuarine Research Reserve
Roanoke Island Festival Park
Theodore Roosevelt Maritime Swamp Forest Unique Wetland
Theodore Roosevelt State Natural Area
White Oak River Game Land
Zekes Island Component of the North Carolina National Estuarine Research Reserve



Figure 5F–13: Submerged Aquatic Vegetation (SAV) in Carteret County (top) and Dare County (bottom) (photo credit: RK&K).

Two types of SAV ecosystems are found in North Carolina. One group includes underwater vascular plants that thrive in low salinity riverine waters, which are referred to as underwater grass, and a second group occurs in high salinity waters of the bays and sounds, which are referred to as seagrass. The two groups are distinguished by different species composition and living requirements. What distinguishes North Carolina from other coastal seagrass systems on the Atlantic seaboard is the overlapping distribution of temperate and tropical seagrasses in the higher salinity waters: eel grass (*Zostera marina*), a temperate grass at the southernmost extent of its range, and tropical shoal grass (*Halodule wrightii*) at the northern most extent of its range.

Submerged Aquatic Vegetation occurs in subtidal, and occasionally intertidal, areas of sheltered estuarine and riverine waters where there is sediment, adequate light reaching the bottom, and moderate to negligible current velocities or turbulence (Figure 5F–13). The primary factors controlling SAV distribution are water depth, sediment composition, energy, and the penetration of light through the water column.[14] Most seagrass habitat in coastal North Carolina occurs along the Outer Banks estuarine shoreline (Pamlico and Core/Bogue sounds), with sparse coverage along the mainland shores. Estuarine SAV occurs to a smaller extent south of Bogue Inlet to the South Carolina border. Waterbodies documented to support seagrass include: New River, Alligator and Chadwick bays, Stump and Topsail sounds, and areas along the Intracoastal Waterway and marsh creeks through northern New Hanover County.

As the system changes from open sound to riverine, low salinity SAV is abundant in larger blackwater systems, but rare in small blackwater streams due to irregular flows and shading from forested wetlands. Low salinity SAV can be extensive in low-salinity back bays and lagoons, such as Currituck Sound, and in coastal lakes such as Lake Mattamuskeet.

Due to its stringent water quality requirements and sensitivity to physical disturbance, SAV, (also known as seagrass and underwater grass) can be considered a “canary in the coal mine” serving as bioindicator of the overall health of our coastal ecosystems. Nutrient and sediment runoff increases with land use change in and adjacent to wetlands. Runoff can reduce water clarity, thus reducing light availability. Nutrients

[14]Thayer, G.W., Kenworthy, W.J., & Fonseca, M.S. (1984*). Ecology of eelgrass meadows of the Atlantic Coast: a community profile.*
Biber, P. D., Gallegos, C. L., & Kenworthy, W. J. (2008). Calibration of a bio-optical model in the North River, North Carolina (Albemarle–Pamlico Sound): A tool to evaluate water quality impacts on seagrasses. *Estuaries and Coasts*, *31*(1), 177-191.



can favor growth of algae and plants that outcompete seagrasses. Physical disturbance from construction, shoreline hardening, some aquaculture practices, and propeller scarring from boat traffic can cause uprooting, increased sedimentation, and over-shading, all of which contribute to the loss of SAV habitat. **Extreme rainfall, flooding,** increasing water temperatures, increasing salinity, and flow changes could further degrade environmental conditions favorable for SAV. Water quality degradation, given expected increases in **extreme rainfall events** and **flooding** associated with climate change, could be catastrophic to the future of SAV and the marine organisms that use them in North Carolina.

Vulnerabilities and Risk

In the U.S., SAV along the Atlantic seaboard has experienced significant declines directly or indirectly attributed to the stressors associated with degraded water quality. Submerged Aquatic Vegetation is especially sensitive to water quality impairment from nutrient and sediment pollution associated with land use, including urbanization, agriculture, and forestry. Due to its stringent water quality requirements, the presence of SAV is considered a barometer of water quality and serves as a valuable bioindicator of the overall health our coastal ecosystems. Conversely, the impairment of water quality is one of the most widespread threats to SAV ecosystems, with global losses estimated at over 29% during the last century.[15]

The majority of SAV loss can be attributed to large-scale nutrient enrichment and sedimentation, which reduces light penetration to the leaf. Nutrient enrichment and/or increased sediment loads affect light for SAV by:

- Reducing water clarity with suspended sediment or phytoplankton associated with algal blooms,
- Increasing epiphytic growth, sedimentation, drift algae coverage,
- Diminishing dissolved oxygen concentrations as photosynthesis from SAV beds decreases, coupled with increasing concentrations of hydrogen sulfide, resulting in toxicity.[16]

[15]Orth, R. J., Bieri, J., Fishman, J. R., Harwell, M. C., Marion, S. R., Moore, K. A., ... & Van Montfrans, J. (2006*). A review of techniques using adult plants and seeds to transplant eelgrass (Zostera marina L.) in Chesapeake Bay and the Virginia Coastal Bays*. In Proc. Conf. Seagrass Restoration: Success, Failure, and the Costs of Both. March 11, 2003. Sarasota, Florida (pp. 1-17).
Waycott, M., Duarte, C. M., Carruthers, T. J., Orth, R. J., Dennison, W. C., Olyarnik, S., ... & Kendrick, G. A. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the national academy of sciences*, *106*(30), 12377-12381.
Lefcheck, J. S., Orth, R. J., Dennison, W. C., Wilcox, D. J., Murphy, R. R., Keisman, J., ... & Patrick, C. J. (2018). Long-term nutrient reductions lead to the unprecedented recovery of a temperate coastal region. *Proceedings of the National Academy of Sciences*, *115*(14), 3658-3662.
[16]Greening, H., Janicki, A., Sherwood, E. T., Pribble, R., & Johansson, J. O. R. (2014). Ecosystem responses to long-term nutrient management in an urban estuary: Tampa Bay, Florida, USA. *Estuarine, Coastal and Shelf Science*, *151*, A1-A16.
Ruhl, H. A., & Rybicki, N. B. (2010). Long-term reductions in anthropogenic nutrients link to improvements in Chesapeake Bay habitat. *Proceedings of the National Academy of Sciences*, *107*(38), 16566-16570.

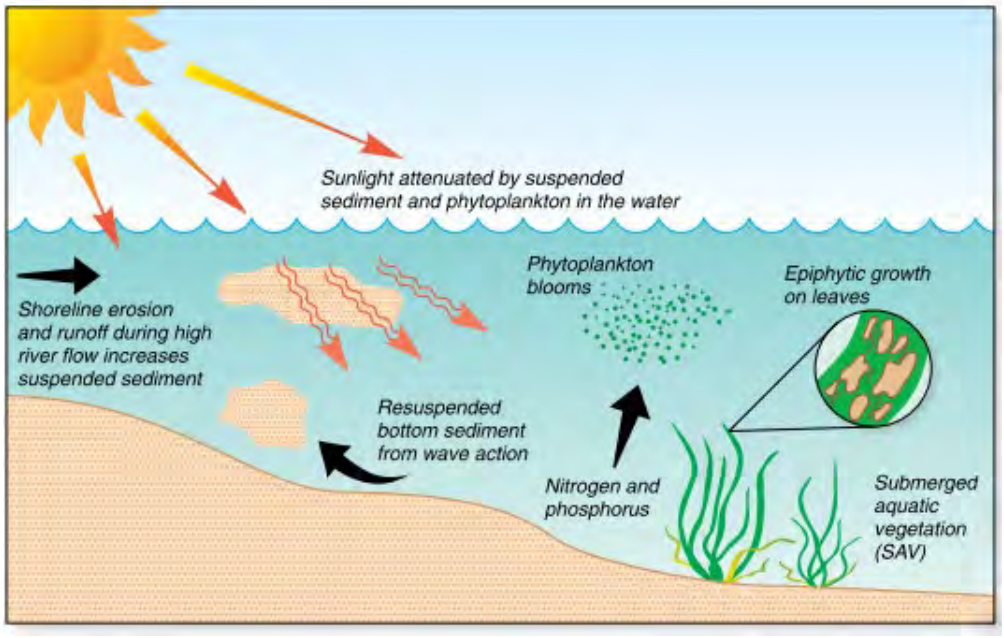


Figure 5F–14: Increased precipitation related to climate change impacts submerged aquatic vegetation (SAV) by increasing shoreline erosion, sedimentation and nutrient-rich runoff (and accompanying algal blooms), and epiphytic growth, all of which can affect the amount of sunlight reaching the plants (figure credit: Phillips, S.W., ed., 2007, Synthesis of U.S. Geological Survey science for the Chesapeake Bay ecosystem and implications for environmental management: U.S. Geological Survey Circular 1316).

Physical disturbances can directly affect SAV (Figure 5F–14); these include bottom-disturbing fishing gear, navigational dredging, dock, marina and aquaculture operation siting, propeller scarring by boats and personal watercraft, vessel wakes, mooring scars, and shoreline stabilization. Dredging causes physical loss of SAV and SAV habitat, but impacts extend beyond the dredge footprint from sloughing into the channel and sedimentation coverage on nearby SAV. Impacts from marina construction to SAV come from pile jetting/driving, shoreline stabilization, excavation, shading, wave attenuation, and construction of associated high ground facilities. Lesser recognized impacts come from associated boating activities. Some types of aquaculture for the production of oysters have been shown to impact SAV in the area through direct disturbance during placement and harvest, increased carbon content, sedimentation, and erosion, and over shading.[17] Mariculture is discussed more in section 5B.

As climate changes continue, North Carolina will continue to see **warming temperatures, rising sea levels**, and **more intense tropical storms**, which affect hydrodynamic flows as well as nutrient and carbon loading to North Carolina's coastal sounds and rivers. In turn, these will have major effects on the SAV ecosystem.

Extreme precipitation events result in flooding which leads to high loads of organic matter and organic nitrogen and phosphorus, fueling phytoplankton production and resulting in algal blooms and associated

[17] Everett, R. A., Ruiz, G. M., & Carlton, J. T. (1995). Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary. *Marine Ecology Progress Series*, *125*, 205-217.



hypoxia. Runoff from agricultural fields and urban development also add to the contamination of floodwaters into the watershed. These impacts to water quality could have major detrimental effects on the SAV beds and SAV habitat in North Carolina.

If we are seeing a regime shift in storms because of rising temperatures, we can also expect to see species distribution shifts within state's SAV ecosystem and the organisms that use these SAV beds. The distribution of eelgrass could be altered, with the potential for the southern range to shift north resulting in the extinction of eelgrass in North Carolina. It has been suggested that under the current emissions scenario, it is very likely that eelgrass will be extirpated in North Carolina and the Chesapeake Bay with the new southern range as far north as Long Island Sound by 2100. Research has shown that shoal grass could possibly exist in present-day eelgrass habitat should eelgrass disappear. However, there will be a loss of overall ecosystem services from eelgrass, resulting in a loss of eelgrass-associated species diversity.[18]

The effects of the climate-change-driven shift in distribution of SAV species will affect the aquatic organisms of the coast of North Carolina that use the SAV meadows as nursery areas, refuge from predation, and for food supply. The anticipated change in species composition could indirectly affect fish populations due to limited habitat and food availability. The **change in temperatures**, **salinity**, and **ocean currents** predicted due to climate change will also have a direct impact on the fish population of the NC coast. In recent years, it has been predicted that hundreds of fish and invertebrate species will be forced to move northward by climate change.[19] The ramifications of climates change on fisheries management is discussed more in section C, Coastal Resources and Infrastructure.

Resilience Strategies

Mapping and Monitoring

Understanding the distribution and health of SAV in North Carolina is critical to understanding the dynamics of shifts in SAV species extent, distribution, and compositions. Traditionally, SAV mapping is accomplished by taking aerial photos and delineating around the SAV habitat from the photos using computer software. Randomly generated sites within the mapped area are selected to ground-truth, to confirm what the images depict, including whether SAV is present, density and species of SAV, and environmental conditions (Figure 5F–15). Routinely monitoring changes in SAV habitat of North Carolina will allow managers to see the effects of climate and non-climate stressors on the estuarine ecosystem. By monitoring and protecting this habitat, we can improve the resiliency of the entire coastal ecosystem.

[18]Wilson, K. L., & Lotze, H. K. (2019). Climate change projections reveal range shifts of eelgrass *Zostera marina* in the Northwest Atlantic. *Marine Ecology Progress Series*, *620*, 47-62.
[19] Morley, J. W., Selden, R. L., Latour, R. J., Frölicher, T. L., Seagraves, R. J., & Pinsky, M. L. (2018). Projecting shifts in thermal habitat for 686 species on the North American continental shelf. *PloS one*, *13*(5).



Figure 5F–15. Picture of submerged aquatic vegetation (SAV) and a quadrant used to collect biological information and confirm the presence of SAV in areas identified by aerial photo sampling for submerged aquatic vegetation (photo credit: Casey Knight).

Water Quality Improvements and Protection

Degraded water quality is the leading driver of SAV habitat loss. Protecting and preserving the water quality of the rivers and sounds of North Carolina will directly benefit the SAV ecosystem. Land conservation and land use planning can help prevent erosion and sedimentation, increase buffers to absorb nutrients and sediment from runoff, and decrease the amount of shoreline stabilization and hardening.

Improvements in stormwater and wastewater management can also be made to help reduce the loading rate of nutrients and sediments entering estuaries via runoff during high rainfall events. Maintaining wastewater infrastructure can prevent inflow and infiltration issues, which can lead to untreated sewage entering estuarine waters. These efforts will result in a more resilient coast not only for SAV and other aquatic ecosystems, but also for the coastal community.

Protection from Physical Disturbance

While SAV is offered some protections from physical disturbance under several state, federal, and interstate policies and plans, further protections and increased mitigation requirements for impacts to SAV beds, such as restoration efforts, could be beneficial to the SAV ecosystem and add the its resiliency and the resiliency of the coastal community.[20]

[20]Kenworthy, W. J., Fonseca, M. S., Whitfield, P. E., Hammerstrom, K., & Schwarzschild, A. C. (2000). A comparison of two methods for enhancing the recovery of seagrasses into propellor scars: mechanical injection of a nutrient and growth hormone solution vs. defecation by roosting seabirds.



4. Summary: Proposed Mitigation/Protection Strategies for all Ecosystem Groups

Recommendations for Increasing Resiliency of North Carolina's Ecosystems:

- **Increase funding for land conservation**: Land conservation can help reduce vulnerability by protecting the natural resiliency of North Carolina ecosystems and by sequestering and storing carbon to reduce greenhouse gases in the atmosphere. Conservation lands also increase the quality of life for North Carolinians by providing natural areas for recreation, hunting, fishing, and education.
- **Protect riparian habitat**: Floodplains and wetlands enhance ecosystem resilience by providing wildlife habitat and migration space, flood water storage, erosion control, bank stabilization, regulation of stream temperature, and overall protection of water quality.
- **Restore floodplains, wetlands, and coastal habitat**: Restoration planning should combine first-hand knowledge of natural resources with historical data and future flood models to target areas that will provide the most resilience for human communities and natural systems.
- **Increase land-use planning**: Green infrastructure concepts can be used to 1) design the most cost-effective strategies for conserving forests, open space, farmland, rural landscapes, park lands, and cultural sites; 2) reduce fragmentation and habitat damage caused by development and human uses of land and water; 3) increase landscape resiliency to climate-related hazards and stressors.
- **Manage stormwater**: Plan for stormwater management to reduce the rate of runoff during rainfall events, limit erosion, and decrease sediment and nutrient inputs to streams. Structures such as stormwater wetlands, bioretention cells (rain gardens), cisterns, permeable pavement, vegetated swales, and filter strips can be used as stormwater best management practices. Good housekeeping of materials stored or left in the open can also be an important stormwater management measure. Limiting the impervious surface of new structures and removing existing impervious surface area when possible is the surest way to reduce stormwater volume and allow for the natural treatment of runoff pollutants.
- **Monitor environmental variables and ecosystem response:** Monitoring will help detect change over time, provide the scientific basis for future projections, and help inform management, restoration, and conservation strategies. Monitoring is especially important for inland and coastal fisheries management, game and nongame wildlife species, and threatened, endangered, and vulnerable plants and animals.
- **Increase public awareness**. Education and outreach efforts are needed to help people understand climate hazards and how they will affect NC ecosystems, engage the population in contributing to solutions, and recruit assistance through citizen science and environmental stewardship.
- **Design bridges and culverts to allow for increased stream flow**. Bridge and culvert design should account for increases in precipitation, to allow stream movement and aquatic animal passage. Avoiding culvert failure prevents sediment input and keeps roads passable during storms. Poorly designed culverts prevent animal movement and fragment wild populations, making them more vulnerable to climate changes.
- **Increase funding for land management**. Government agencies and private landowners can enhance ecosystem resiliency through land stewardship activities that improve natural ecosystem functions and wildlife habitat. Managing with prescribed fire, removing invasive



exotic species, avoiding excessive use of herbicides and pesticides, and restoring natural forests and riparian vegetation can all help support healthy resilient ecosystems.

Ecosystems across North Carolina from the mountains to the sea are already affected by climate and land use changes that have occurred in recent decades. The most vulnerable ecosystems, i.e., ecosystems supporting a high concentration of rare species and demonstrating a low tolerance of environmental variation, are the highest priorities for conservation, planning, and adaptive management. To help bolster ecosystems' natural resilience, negative impacts from human actions should be reduced. Reducing human impacts and conserving and managing land for key ecosystems also benefits North Carolina's economy, water resources, and public health.


Health & Human Services

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G. Health and Human Services

Key Observations

- The health of the environment impacts the health of all people.
- Cumulative hazards from heat and flooding are diminishing health.
- Existing inequities in environmental health exposures are exacerbated by climate change.

Critical Impacts and Resilience Strategies

- Ongoing medical and public health services to residents are impacted.
- Increased staffing needs during hurricanes, especially for NC Emergency Operations Center, emergency shelters, coordinating emergency services, and seeking administrative waivers for benefits.
- Need additional support for North Carolina Department of Health and Human Services (DHHS) programs: Building Resilience Against Climate Effects program, Back@Home program, mold and moisture education, and infectious disease tracking.
- Strategies for creating resilience should address existing toxic exposures, such as hazardous waste and lead in water or homes, in low-income communities and communities of color.

1. Introduction to Sector

Department of Health and Human Services (DHHS), in collaboration with state and local agencies, provides essential services to improve the health, safety, and well-being of all North Carolinians. DHHS tracks prioritized public health effects of climate change (e.g., heat-related illness), provides services in response to increasing extreme weather and wildfires (e.g., staffing medical shelters, deploying mobile hospital), and continues to provide daily services in the face of climate-related disruptions.

Divisions within the purview of DHHS include Public Health; Social Services; Aging and Adult Services; Mental Health, Developmental Disabilities, and Substance Abuse Services; state-operated Healthcare Facilities; and more. In addition to DHHS, this section includes impacts to the Department of Military and Veterans Affairs (DMVA) and the Department of Environmental Quality's Division of Air Quality due to a shared focus on public health and human services.

2. Overall Exposure

Across these departments, the health and human services sector is exposed to climate-related hazards in myriad ways (Table 5H-1). Health impacts associated with climate-related changes in the frequency or intensity of extreme events such as heat, heavy precipitation and flooding, and wildfires include excess emergency department visits for injury and illness.

Some communities, such as those in the eastern part of the state, are already experiencing the cumulative impacts of climate and social stressors such as an increase in warmer night-time temperatures overnight, inadequate access to cooling, and increasingly intense precipitation and flooding incidents (Figure 5H-1).[1] Additionally, the most vulnerable residents (e.g., socially isolated, low-income earners) are

[1] Harrison, C., et al. (2011). "Because you got to have heat": The networked assemblage of energy poverty in Eastern North Carolina. *Annals of the Association of American Geographers.* Vol 101, No 4.

disproportionately impacted by increasingly frequent[2] or intense floods, hurricanes, tornados, and storm surge as a result of sea level rise.[3] Due to the breadth of health impacts of climate change, a reduction in greenhouse gas (GHG) emissions is needed immediately.[4,5,6]

The military bases located in North Carolina are major drivers in our communities, through the synergy and partnerships that have developed between local and state government, military and defense sectors, and local businesses. The DMVA owns and oversees four skilled care state veteran homes whose housing capacity is 449 veterans and spouses whose health and safety DMVA plays a role in protecting. The DMVA is committed to providing facilities to meet the needs of a growing veteran population of older adults requiring skilled care and who are often vulnerable to extreme heat and extreme weather events. Additionally, four existing state-owned veteran cemetery sites with chapels have experienced site impacts from climate-related extreme weather that jeopardize staff working conditions and grave site visitation by family and friends.



Figure 5H-1. Hurricane Florence flooding, Lumberton, North Carolina.

Several population stressors may also combine with vulnerabilities and climate hazards to worsen public health impacts from climate change. These stressors include population growth, an aging population, deteriorating critical infrastructure, and coastal development.

Age, minority and veteran status, income, and existing health conditions all influence vulnerability to climate change impacts on health:

Children

Children can be impacted by an intense storm, loss of home or possessions, and dislocation. Dislocation is an Adverse Childhood Experience, a type of adverse health impact that impacts lifelong wellness.[7] Children are also more vulnerable to extreme heat.

Older adults

Older adults, those over the age of 65, are vulnerable to extreme heat and extreme weather events due to a higher prevalence of pre-existing health conditions, social isolation, and reduced ability to physiologically respond to extreme heat.

[2] VosIzNeias. (2019). *Lumberton, NC: Flooding from Hurricane Florence swamps neighborhoods.* Accessed January 28, 2020: https://vosizneias.com/2018/09/17/lumberton-nc-photos-flooding-from-hurricane-florence-swamps-neighborhoods/.
[3] National Association for the Advancement of Colored People. (2018). *In the eye of the storm* [White paper]. Retrieved January 10, 2020: https://live-naacp-site.pantheonsite.io/wp-content/uploads/2018/09/NAACP_InTheEyeOfTheStorm.pdf
[4] Watts, N., et al. (2019). The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. *The Lancet.* Vol 394.
[5] World Health Organization. (2020). *Climate change*. https://www.who.int/health-topics/climate-change#tab=tab_1.
[6] American Public Health Association. (2020). *Climate changes health: clean energy*. https://www.apha.org/topics-and-issues/climate-change/clean-energy
[7] Centers for Disease Control and Prevention. (2019). *Preventing adverse childhood experiences* [White paper]. Retrieved January 26, 2020 from: https://www.cdc.gov/violenceprevention/pdf/preventingACES-508.pdf.



Low-income populations

Populations with limited financial resources are less likely to have access to adequate cooling and heating, resilient housing, medical care, and healthy food, which are all important measures of adaptive capacity in the face of climate change.[3]

Minority populations

Where North Carolinians live is based in part on historical housing policy, which means that African-Americans, Latinos, and Native Americans are more likely to live in flood plains and experience increased risk to flooding from climate change.[8]

Veterans

North Carolina has one of the largest military footprints of any state in the country, with over 100,000 active military personnel and over 730,000 military veterans. Military and defense industries are the second largest employers in our state, and the military has an economic impact of $66 billion annually. Veterans are more likely to be older, minority, and residents of flood-prone areas.[9,10]

Climate change and public health resilience are inseparable from issues of injustice and the history of inequity in North Carolina, manifesting in the proximity of residential and industrial siting in locations susceptible to flooding and other hazards. For example, landfills, toxic waste sites, and industrial livestock operations are more frequently placed near communities of color or low-income communities. Cumulative impacts of climate events make it harder for people to climb out of poverty.

North Carolina DHHS is actively preparing for climate change. Since 2010, DHHS has used the Centers for Disease Control and Prevention's Building Resilience Against Climate Effects (BRACE) framework to prioritize public health adaptation to climate change through:

- Tracking heat-related illness patterns
- Community pilot projects for adapting to increases in temperature and air quality impacts of wildfire

BRACE helps public health officials understand and document exposure and responses in a changing climate and adapt to the changing climate's impact on health.[11,12,13] Based on that work, we understand the main hazards intensified by climate change, concomitant public health impacts, population vulnerabilities, and DHHS resources that can help North Carolinians adapt. Expanding the tracking of epidemiological health impacts of climate change in North Carolina is and will continue to be important for climate change adaptation.

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[8] Kennedy, B. (2018). '*Hurricane Florence is exposing North Carolina's racial and geographic inequalities'*, NC Policy Watch, 19 September, https://libguides.ioe.ac.uk/c.php?g=482485&p=3299819.
[9] Department of Veterans Affairs. (2017). *Minority veterans report* [White paper]. Retrieved January 16, 2020 from Department of Veterans Affairs: https://www.va.gov/vetdata/docs/SpecialReports/Minority_Veterans_Report.pdf.
[10] North Carolina Department of Military and Veterans Affairs. (2020). *Military bases in North Carolina*. Retrieved January 27, 2020: https://www.milvets.nc.gov/services/military-bases-north-carolina.
[11] Sun, X., et al. (2015). Pollen concentration and asthma exacerbations in Wake County, North Carolina, 2006-2012. *Science of the Total Environment.* Vol 544.
[12] North Carolina Department of Health and Human Services. (2019). *Climate and health.* Retrieved January 27, 2020: https://epi.dph.ncdhhs.gov/oee/programs/climate.html.
[13] North Carolina Department of Health and Human Services. (2016). *North Carolina climate and health climate adaptation plan.* Retrieved February 13, 2020: https://epi.dph.ncdhhs.gov/oee/climate/ClimateAndHealthAdaptationPlan.pdf.

Table 5H-1 Exposure of health and human services functions to climate-related hazards.

Assets, Regulations, Services	Wildfire	Flooding (River and Land)	Extreme Heat	Storm Surge	Tidal Flooding	Saltwater Intrusion	Dam Failure	Landslides
Health and Human Services								
Population Exposure	*	*	*	*	*	*	*	*
Vulnerable Populations: Children, Older Adults, Low-Income, Minority, Veterans	*	*	*	*	*	*	*	*
Health Service Infrastructure	*	*	*	*	*	*	*	
First Responders, Town Staff, Environmental Health Specialists	*	*	*	*	*	*	*	*
Toxic Waste Facilities		*		*	*	*	*	*
Livestock Waste Lagoons		*					*	
Infectious Disease Management		*		*				
Sewage		*		*	*			
Stormwater Runoff	*	*		*	*			*
Indoor Air Quality	*	*	*	*	*		*	
Outdoor Air Quality[14]	*	*	*	*	*			

In the following section, we provide additional detail about some of the impacts, vulnerabilities, risks, and strategies for resilience so that the state can meet its responsibilities for health and human services in the face of climate change.

3. Examples of Impacts, Vulnerability, and Risk

Outdoor Air Quality / Increased Precipitation

Impact Summary

The North Carolina Division of Air Quality (DAQ) works to protect and improve outdoor air quality by operating a statewide air quality monitoring network to measure pollutant levels, implementing plans to meet future air quality initiatives, ensuring compliance with federal and state rules, and assisting and educating the public about air quality issues. The DAQ air quality assets sensitive and vulnerable to climate stressor impacts range from a variety of support services to physical ambient air monitoring

[14] Flooding and storm surge impact DAQ's physical assets that work to monitor and protect outdoor air quality.



stations. There are various competing factors influencing air quality in addition to climate change impacts, including, changes in air pollutant emissions, changes in meteorology and land use, population growth, economic growth, and federal air quality standards. Despite this complexity, there are several DAQ service and physical assets likely to experience increased impacts under changing climate conditions discussed in the Fourth National Climate Assessment, Volume II for the southeastern United States and the North Carolina Climate Science Report Findings presented in this report.[15] These assets include planning services, ambient monitoring, and wildfire services.

Vulnerability and Risk

Planning Services

DAQ provides air quality planning services to support protection of public health through air quality implementation plans, rulemaking services, and through communication of current and future air quality impacts to the public. These planning services were evaluated for vulnerabilities to air quality impacts from 1) temperature and precipitation changes and 2) droughts.

Temperature and Precipitation Changes

Based on the North Carolina Climate Science Report findings, near-surface ozone concentrations tend to increase with temperature. However, changes in other climate conditions, such as increased precipitation, can counteract the temperature effect. Overall, it is uncertain what the net effect will be. Thus, there is low confidence concerning future changes in the conditions favorable for near-surface ozone concentrations. While there are projected future increases in non-climate stressors such as popoulation and economic development in North Carolina, continued advances in technology and health protective regulatory frameworks are expected to offset those factors. That, coupled with the uncertainty and the numerous competing meteorological factors under future climate change scenarios leads to a conclusion that the risk to ozone and air quality planning services due to climate change alone is considered low.

Drought

The North Carolina Climate Science Report findings states that it is likely that future major droughts in North Carolina will be more severe because of higher temperatures that will increase evaporation rates. As a result, it is likely that the climate conditions conducive to wildfires in North Carolina will increase in the future. Since rainfall is one of the primary mechanisms for removing $PM_{2.5}$ from the air, $PM_{2.5}$ concentrations can be impacted during droughts. It is not clear that the increasing intensity of droughts due to climate change will lead to significantly increasing the concentration of $PM_{2.5}$. However, it is reasonable to anticipate some occasional, localized increases in particulate matter emissions generated from activities such as construction, agriculture, road travel, quarrying, and wind-blown dust. An increase in particulate matter negatively impacts public health, especially populations sensitive to respiratory issues. In addition, workers in certain economic sectors such as agriculture, construction and mining, are at higher risk for exposure to elevated concentrations of particulate matter during periods of drought.[16]

Monitoring Services

The DAQ manages ambient air quality monitoring equipment located throughout North Carolina to meet federal National Ambient Air Quality Standards (NAAQS) and to protect public health. The equipment and monitoring services located in the coastal plain are vulnerable to climate stressor impacts including

[15] Fourth National Climate Assessment, Volume II (Chapter 19, Key Message 1, Air Quality and Human Health, p755
[16] Fugitive dust mitigation is often required to protect workers in these sectors.

sea level rise and other coastal flooding events (e.g., hurricanes, storm surges and king tides). For example, before Hurricane Florence landfall near Wilmington in September of 2018, hundreds of thousands of dollars in ambient monitoring equipment had to be shut down and evacuated from ambient monitoring stations located in the coastal plain around Wilmington. This effort cost DAQ hundreds of man-hours and increased risks to personnel during both the shutdowns and re-starts of this very expensive scientific monitoring equipment at these coastal stations. What's more, valuable air quality monitoring data was missing for several days from these shutdown stations leading to failed third quarter completeness requirements for the year 2018, which in turn negatively affects annual data completeness requirements. These completeness requirements enable the agency to demonstrate compliance with the NAAQS and maintain the attainment status for the counties in southeastern North Carolina.

Wildfire

Smoke from wildfire is the chief driver of fine particulate matter during wildfire events. They can occur in areas with high numbers of residents with asthma, diabetes, and cardiovascular conditions that place them at higher risk for adverse health effects from smoke exposure. The DAQ prepares and communicates wildfire air quality forecasts to first responders, local governments, and the general public. Climate change impacts in the form of an increased frequency and intensity of weather events, including but not limited to droughts, heat waves and wildfires, raises the potential for a growing threat of wildfire smoke posing a public health and safety risk. A non-climate stressor to wildfire is the increase of wildland urban interface (where homes meet woodland), currently estimated at 13.5 million acres (See Section 5.B Agriculture and Forestry). The number, size, and location of fires and the ability of the NCFS to respond to these fires also affect the air quality and public health impacts of wildfires. In 2017, the Division of Public Health and its partners developed a smoke vulnerability map for North Carolina as well as an elementary education program on wildfire prevention and health-related impacts.[17]

Pollen

The DAQ prepares and communicates pollen counts as part of the air quality forecasting services. The fast growth rate of urban areas in North Carolina contributes to aeroallergens, which are known to aggravate respiratory diseases such as asthma. Urban areas have higher concentrations of CO_2, which causes allergenic plants, such as ragweed, to grow faster and produce more pollen than in rural areas. Higher temperatures and atmospheric CO_2 levels are projected to further contribute to aeroallergens in cities.

Resilience Strategies

Air Quality Planning

The DAQ must continue to review research and modeling efforts to quantify the expected changes in regional meteorological parameters influencing ozone and $PM_{2.5}$ formation under various climate change scenarios. In addition, DAQ should review current $PM_{2.5}$ attainment status of various regions and how that status might be impacted by more intense drought conditions. For the regions that potentially have impacts, DAQ should review how the current implementation plans would lower concentrations of PM in these regions in the event of an exceedance. Lastly, DAQ should develop education and outreach materials to protect outdoor workers and others who may be exposed to localized high levels of particulate matter during droughts.

[17] https://epi.dph.ncdhhs.gov/oee/climate/SmokeIMSNorthCarolinaExecutiveSummary.pdf



Air Quality Monitoring

DAQ should continue to evaluate all ambient monitoring sites located in low drainage areas and where needed elevate the sites to minimize potential damage from water intrusion and/or potentially relocate the monitoring site to a higher elevation. DAQ should also develop and maintain a staffing and resource plan for securing monitoring sites and equipment in the event of extreme weather taking into account the possibility of prolonged shutdown of sites and/or equipment due to extreme weather.

Wildfires

The DAQ should ensure adequate staff and resources are available to monitor, forecast, and communicate air quality impacts from wildfires. This may include developing a program to share air quality staff and resources with other states, similar to state forest fighting services, to respond to these events. North Carolina currently allows controlled, also called prescribed, burning to manage habitat, agricultural productivity, and to reduce the amount of fuel available in forests and other fire-sensitive ecosystems. While this activity significantly reduces the risk of wildfires, it also produces smoke, but its effects can be mitigated to occur on days with less impact to air quality and communities. The DAQ currently works with a variety of stakeholders in order to ensure prescribed fires are conducted when conditions are favorable for dispersion of smoke. See Section 5B: Agriculture and Forestry for more information on resilience strategies for wildfires.

Human Services / Hurricanes and Flooding

Impact Summary

Climate change-intensified hurricanes and flooding have a tremendous cost to DHHS. Table 5H-2 demonstrates the cost of Hurricane Matthew – over $700,000 in unbudgeted labor expenses among nearly 1,500 staff that contributed approximately 23,000 overtime hours. Unbudgeted labor expenses impacts meeting the DHHS mission.

Table 5H-2: Hurricane Matthew labor hours and costs (2016).

Hurricane Mathew	Staff	Overtime Hours	Cost
State Medical Support Shelters	28	1,343	$44,833
Div of Public Health	40	547	$30,590
Div of Social Services	9	536	$22,139
Div of State Operated Healthcare Facilities	1398	20,349	$636,371
Office of Public Affairs	6	78	$3,272
Admin			$5,950
Totals	**1481**	**22,853**	**$743,155**

Hurricanes Matthew and Florence brought record rainfall and flooding that challenged communities in southern and eastern North Carolina (Table 5H-2).[18,19] The health issues among affected residents included: physical, mental, emotional trauma from the incident or the recovery; injuries from the flooding or clean-up; loss of housing; damage to housing that resulted in lasting poor indoor air quality; loss of classroom instruction time; degradation of community and cultural resources; and water contamination. During hurricanes, DHHS mobilizes a coordinated response based on the event, with an incredible breadth of services provided across the state.

Vulnerability and Risk

Human Services

Divisions across DHHS currently engage on many levels to respond to extreme events such as Hurricane Matthew. These activities can be considered part of the state's adaptive capacity as it exists today.

During a hurricane, the DHHS Division of Public Health staffs the State Emergency Operations Center and deploys and staffs the mobile hospital to affected areas. Public Health supports local and federal response teams and staff emergency shelters including deploying nurses.

The Divisions of Health Services Regulation, Public Health, and Social Services recruit and assemble volunteer teams of Environmental Health Specialists to conduct site visits of food, lodging, and institutions; other food establishments; private septic systems and private drinking wells and support mosquito abatement initiatives in impacted counties. These Divisions together also distribute Naloxone kits to shelters, call nursing and adult care homes to activate emergency plans, work with counties and other partners to ensure shelters are accessible and supportive of those with behavioral illnesses or intellectual and developmental disabilities. Divisions also ensure behavioral health providers and other resources are available in shelters and communities for those who need it.

These Divisions alert local emergency management of Medicaid beneficiaries who use medically necessary medical equipment that requires electricity. These Divisions seek federal waivers to allow for Medicaid flexibility; early refills of prescriptions; Special Supplemental Nutrition Program for Women, Infants, and Children and distribute Disaster Electronic Benefit Transfer cards. Finally, these Divisions secure assistive technology devices and equipment to help individuals who are displaced due to the storm or who have devices or equipment that is destroyed or lost.

The ***Division of Health Services Regulation*** works with local and federal response teams, serves as command and control/state liaison during the incident and staffs regional coordinating centers. Health Services Regulation also reviews requests from licensed facilities seeking temporary waivers of state rules to allow facilities to provide temporary shelter.

The ***Division of Social Services*** coordinates with Federal Emergency Management Agency to canvas neighborhoods and support impacted residents, issue disaster food stamps, and provide local agencies with resource referrals. Social Services also supports the needs of residents in state operated facilities directly impacted by storm related flooding. Social Services ensures continued safety of children in the child welfare system and track any displaced children in foster care. This division also determines the status of services and needs of older adults, including meal provision.

[18] National Weather Service. (2017). *Hurricane Matthew in the Carolinas: October 8, 2016*. Retrieved January 27, 2020: https://www.weather.gov/ilm/Matthew.
[19] National Weather Service. (2019). *Hurricane Florence: September 14, 2018.* Retrieved January 27, 2020: https://www.weather.gov/ilm/HurricaneFlorence.



The ***Office of Rural Health*** monitors status of safety net providers and assists with accessing generators and medications.

The ***Department's Division of Behavioral Health and Intellectual and Development Disabilities*** manages the Hope 4 NC Program, providing crisis counseling services to Hurricane Florence survivors in 28 counties. The goal of this program is to help people learn coping skills and strategies to reduce the trauma, loss and stress they experience from the storm and employ an on-the-ground approach to crisis counseling. A total of 267,863 individual survivors have been served through Hope 4 NC since September 14, 2018. More than 10% of the total population in the 28 most impacted counties have received Hope 4 NC crisis counseling services; 38,812 individuals were referred for more intensive community services, including health, behavioral health and disability services. Thousands more have benefited through collective impact of community engagement, social media and printed information shared widely.

Individuals in nursing homes, adult care homes, older adults, and those with disabilities are disproportionately impacted. Behavioral health services (mental health and substance abuse) to individuals and communities are impacted, as are state operated facilities for individuals with mental health and developmental disabilities. Services to residents are provided in a decentralized manner through local/regional health departments and departments of social services, as well as Local Management Entity/Managed Care Organizations for Behavioral Health and numerous non-governmental agencies through grants and contracts.

Hurricane-associated Health Impacts

Climate change intensified the heavy precipitation and associated flooding the state experienced during Hurricanes Matthew and Florence, increasing population exposure to dangerous conditions, particularly among vulnerable residents.[20] Young children and infants have higher sensitivity to flooding. Any extreme weather event that delays education or impacts the overall health of caregivers also impacts children.

Climate change-intensified precipitation events are playing out across the world. Migrating populations to NC from the US and around the world will stress our public health and human services resources.

Record-level flooding brought on by Matthew and Florence disrupted housing, provision of government services and access to health support services. Unmet needs for sheltering during Hurricane Florence were apparent among those living with disabilities, people with functional and access needs or persons with existing health conditions.

Hurricane-associated injuries, illness, and mental stress among residents of impacted areas were especially prevalent among veterans and their civilian families. Reduced indoor air quality from flooding, and subsequent mold and moisture, is a threat to those living in substandard housing. Poor indoor air quality and moisture/mold have been a problem for many veterans throughout the state and more recently reported at some military installations. DMVA staff spend a large amount of time responding to extreme weather events.

The impacts of these hurricanes were distributed inequitably. Historical housing policies resulted in disproportionate impacts based on race and ethnicity, placing minority and low-income communities in floodplains and in substandard housing. The burden of multiple flooding incidents, disproportionate numbers of housing in floodplains, and existing environmental injustice weighs heavily on some

[20] Reed, et al. (2019). Forecasted attribution of the human influence on Hurricane Florence. *Science Advances*. Vol 6, No 1.

communities of color and low-income communities. Figure H-1 highlights Hurricane Florence flooding in Robeson County, the home of the Lumbee tribe. For example, those living near existing industrial livestock operations experienced groundwater contamination due to flooding.

Resilience Strategies

Reducing inequity to all environmental hazards will increase communities' resilience in the face of climate change-intensified precipitation. For example, preventing pollution in communities of color and low-income communities will minimize exposure and increase these communities' abilities to regenerate after hurricanes and flooding. Incentivizing housing integration across race, ethnicity, and income, as well as reducing substandard housing, will reduce exposure to floods and poor indoor air quality resulting from flooding. Providing information on minimizing effects of moisture and mold will help those in housing with lasting flooding impacts.

Disaster Recovery Programs. One ongoing program, the Back@Home initiative, helps vulnerable residents secure housing, an important need post-hurricane. Funding the Back@Home initiative at a higher level will help those living with housing insecurity caused by climate change-intensified hurricanes. The additional funding would provide more affordable housing units for those currently displaced and would prepare for housing impacts of future storms.

Adequate social services for navigating recovery are needed, as navigating recovery services requires significant resources of time, energy, and money. Without adequate support, residents will be unable to utilize government services to support health and recovery post-hurricane.

Renewable energy and microgrids will provide resilient energy infrastructure to support communities and protect health during hurricanes. Examining the viability and benefit of microgrids in health care and emergency facilities located in storm-prone areas may more quickly restore vital services and contribute to on-going clean low-cost energy generation, providing more continuous care for those people with functional and access needs or persons with existing health conditions.

Heat

Impact Summary

The entire state is experiencing more frequent extreme heat, high heat days, higher nighttime temperatures, and more prolonged periods of high heat. From 2009-17, there has been an overall increase in emergency department visits due to heat-related illness (Figure H-3).[21] Pregnant people and children experience disproportionate impacts, as extreme heat is associated with an increased risk of preterm birth.[22,23] Those who cannot avoid exposure to the heat, such as outdoor workers and those who cannot afford adequate cooling are also at increased risk for heat exposures. Rising heat and poor air quality have disproportionate impact on maternal and infant mortality, young children, and older adults.

[21] Hawaldar K, et al. (2019). *Changes in the Distribution of Heat-Related Illness Emergency Department Visits – North Carolina, 2009-2017.* Presented at Council of State and Territorial Epidemiologists, 2019.
[22] Centers for Disease Control and Prevention. (2019). *Preterm birth*. Retrieved January 29, 2019: https://www.cdc.gov/reproductivehealth/maternalinfanthealth/pretermbirth.htm.
[23] National Institutes of Health. (2016). *Extreme temperatures could increase preterm birth.* Retrieved January 29, 2019: https://www.nih.gov/news-events/news-releases/extreme-temperatures-could-increase-preterm-birth-risk

Vulnerability and Risk

Access to a few hours of cooling during high temperatures helps reduce the likelihood of heat-related illness. However, many residents cannot afford to cool their living places because of low-income levels and inefficient or substandard housing. Poverty limits residents' access to adequate cooling. Improving substandard housing and providing the ability to cool off for several hours daily during high temperatures protects health in the face of increasing temperatures. Older adults are at increased risk for heat-related illness due to social isolation, decreased ability of the body to cool itself, and potentially fixed or limited income.

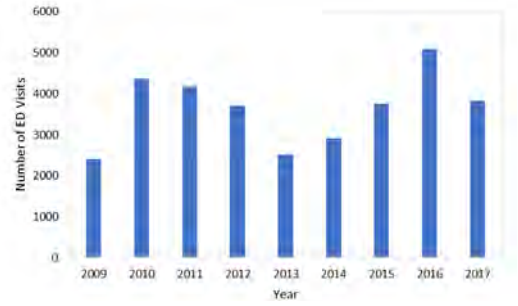


Figure H-3: Number of Heat-Related Illness Emergency Department Visits by Year, 2009-2017.

Resilience Strategies

Expanding energy efficiency and renewable energy programs specifically targeted at underserved markets and low-income communities will allow communities to regenerate in the face of higher temperatures. Improving housing and access to adequate cooling will also help communities adapt.

Infectious Disease / Changing Weather Patterns

Impact Summary

Infectious diseases sensitive to changing weather patterns are present in North Carolina. A general increase in reported cases of vibriosis, typically manifesting as gastrointestinal illness, has been documented in the state. Similarly, increases in reported cases of *Legionellosis* have been documented throughout the United States.[24] Historically, North Carolina has had a high burden of tick and mosquito-borne diseases.

Vulnerability and Risk

Increased surface water temperatures and salinity can increase the abundance and exposure risk from *Vibrio vulnificus*.[25] Legionellosis is a temperature and precipitation sensitive respiratory illness that can be severe. The severity of resulting respiratory infections, and an increasing aging population at risk, make it imperative to increase our ability to prevent, detect and respond to waterborne infections including vibriosis, Legionnaires', and primary amoebic meningoencephalitis (very rare disease that is climate-dependent). Further, climate change may allow for the expansion of disease-causing ticks and mosquitoes or may allow for the introduction of non-native ticks and mosquitoes.[26,27,28]

[24] Rubin, R. (2018). Why are Legionnaires Disease diagnoses becoming more common in the United States? *Journal of American Medical Association*. Vol 319 Issue 17.
[25] Deeb, R., et al. (2018). Impact of climate change on *Vibrio vulnificus* abundance and exposure risk. *Estuaries Coast.* Vol 41 Issue 8.
[26] Githeko, A., et al. (2000). Climate change and vectorborne diseases: a regional analysis. *Bulletin of the World Health Organization.* Vol 78 Issue 9.
[27] Kilpatrick, A., et al. (2008). Temperature, viral genetics, and the transmission of West Nile virus by Culex pipens mosquitoes. *PLoS Pathogen*. Vol 4 Issue 6.
[28]North Carolina Department of Agriculture and Consumer Sciences. (2018). *Longhorned tick found in Polk County.* Retrieved January 29, 2020: http://www.ncagr.gov/paffairs/release/2018/LonghornedtickfoundinPolkCounty.htm



Resilience Strategies

Enhanced and Ongoing Surveillance

It will be imperative for public health to develop and maintain comprehensive tick and mosquito surveillance, and to increase its ability to prevent, detect, and respond to waterborne infections.

4. Summary

The health of our environment and the health of North Carolina residents are directly linked (Table 5H-3). The connection between weather and health is established, and changes to weather patterns from climate change will unequivocally impact health. Air pollution, rising heat, and flooding events affect vulnerable populations. During events, staff are deployed to emergency operations and this impacts the entire department. A summary of proposed strategies to protect public health amidst a changing climate follows:

- Reduce Earth-warming air pollution. Reduces smoke exposure to sensitive populations.
- Reduce pollution in communities of color and low-income communities.
- Incentivize housing integration. Reduce substandard housing. Increase access to cooling.
- Increase social and behavioral health supports in vulnerable communities.
- Expand energy efficiency and renewable energy programs specifically targeted at underserved markets and low-income communities
- Deploy micro-grids of solar arrays with battery back-up in hurricane-prone areas to provide power after storm events, reduce overall operational energy costs, increase usage of renewable energy sources, and decrease carbon emissions.
- Support the Building Resilience Against Climate Effects program and expand the tracking of epidemiological health impacts of climate change in North Carolina.
- Invest $16 million in Back@Home initiative.
- Provide information on minimizing effects of moisture and mold.
- Offer adequate social services support to North Carolinians navigating the multitude of government processes during recovery.
- Examine the viability and benefit of microgrids in health care and emergency facilities located in storm-prone areas to more quickly restore vital services and contribute to on-going clean low-cost energy generation



Table 5H-3: Resources Needed to Address Prioritized Public Health Impacts.

Climate Hazard	Public Health Impact	Populations of Concern	DHHS Resources Needed
Wildfires	Decreased air quality, respiratory illnesses	Persons with existing health conditions, children, older adults, pregnant women, disabled veterans	Continued staffing and support resources to develop DAQ air quality forecasts (see Section 5.B Agriculture and Forestry for other needs)
Flooding	Injuries, exposures to floodwater (toxic substances, animal waste, sewage), contaminated drinking water, property damage, infectious disease, crop loss, mold/endotoxins, gastrointestinal illnesses	Persons living in the flood plains, low income persons, minority populations, veterans	Reducing pollution in communities of color and low-income communities Provide information on minimizing effects of moisture and mold
Increased Frequency and Intensity of Hurricanes	Injuries, loss of housing and essential health services, displacement, mental and psychological impacts	Low income earners, minority populations, persons with functional and access needs, children, persons with existing health conditions, first responders, veterans	Increase Back@home funding Incentivize housing integration, reduce substandard housing Offer adequate social services support to North Carolinians navigating recovery
Extreme Heat	Heat related illness, respiratory diseases such as asthma, allergies, cardiovascular disease	Farmworkers and other outdoor workers, children, low income persons, minority populations, pregnant women, veterans, those living in mobile homes	Improving housing and access to adequate cooling Renewable energy resources to reduce utility costs of low-income families and maintain power during emergency events.

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Housing, Buildings
& Support Services

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H. Housing, Buildings, and Support Services

Key Observations

- Critical infrastructure and cross-agency assets make this sector important but difficult to prioritize.
- Need to have detailed, quantified risk assessments at a local level.

Critical Impacts and Resilience Strategies

- Flooding is the biggest hazard.
- Aging infrastructure is vulnerable, so many solutions will be costly and take time to implement.
- State-managed recovery is an immediate and growing need which shows that building resilience is important to reduce recurring impacts.
- Meet the growing demand of housing for veterans. Promote building resilience strategies for vulnerable VA hospitals.
- Waste management and its planning are important prior to and after any damage caused by environmental impacts.

1. Introduction to Sector

The Housing, Buildings, and Support Services Sector is made up of those agencies within the Department of Commerce, Department of Environmental Quality, Department of Public Safety, Department of Administration, Department of Military and Veterans Affairs, and Department of Information Technology that provide a broad range of diverse services to the citizens of North Carolina pertaining to the built environment.

The ***Department of Commerce, Rural Economic Development Division*** maintains business, community, and military base contacts that supports the data/communications and infrastructure for emergency management, public safety, medical facilities, communications, and non-government emergency services.

The ***Department of Environmental Quality (DEQ)*** manages permitting, inspections, and compliance enforcement for solid waste management and hazardous waste facilities. The DEQ directly manages the public water supply, industrial water supply, and agricultural water use, as well as directs the cleanup of non-permitted releases of petroleum and other hazardous substances from pipelines and storage tanks to protect the water quality. The DEQ also provides safety inspections, condition assessments, plan review approvals, and enforcement for dams across the state. The DEQ maintains regional office buildings, state-owned vehicles, furniture, field equipment, and staff to provide continuous service to all regions of North Carolina.

The ***Department of Public Safety (DPS)*** administers recovery programs for critical infrastructure managed by counties and municipalities and local governments. They also manage recovery programs for recurring pre- and post-disaster mitigation. The DPS includes the Division of Emergency Management, which provides technical and logistical support to local partners for emergency operations services before, during, and after disasters. The DPS also includes the Division of Prisons, which provides humane living conditions for incarcerated individuals. The Department of Administration (DOA) provides technical and maintenance oversight for approximately 68 buildings over 3,000 square feet in size each in Wake County.



The ***Department of Military and Veterans Affairs*** supports over 730,000 veterans. North Carolina has one of the largest military footprints of any state in the country. Military and defense industries are the second largest employers in our state, and the military has an economic impact of $66 billion annually. Veterans and immediate family of veterans are housed in the Department of Military and Veteran Affairs nursing homes facilities. The Department plans to continue to develop more homes to further support a growing veteran population of older adults. A secondary service provided to veterans includes the four existing state-owned veteran cemetery sites with chapels.

The ***Department of Information Technology*** administers data centers and communication transmission infrastructures at and for state property and buildings which support emergency management communications capabilities, public safety services, medical facilities and services communications, sensors/monitoring tools, and non-government emergency services.

The ***Department of Administration*** acts as the business manager for North Carolina state government. The department oversees Government Operations such as building construction, purchasing and contracting for goods and services, managing state vehicles, acquiring and disposing of real property, and operating auxiliary services such as courier mail delivery and the sale of state and federal surplus property.

In addition, the department provides facility services and advocacy programs. Facility services include the maintenance of state-owned buildings and grounds, and the department's advocacy programs provide advocacy, assistance and services to diverse segments of the state's population that have been traditionally underserved.

2. Overall Exposure

There are several climate stressors that are increasing vulnerability and risk to housing, buildings and support services in North Carolina. Increasing heavy precipitation, most frequently associated with tropical cyclones, is leading to more flooding and dam failure. Rising sea level is leading to increases to storm surge, coastal flooding, and saltwater intrusion. Heat waves and associated droughts are increasing in severity and frequency.

Climate Stressors

Heavy precipitation

Heavy precipitation events, especially tropical storms and its associated flooding, can cause significant damage to public and private structures in the floodplain and infrastructure such as roads, utility services, and dams. Flooding can directly contaminate source waters, resulting in drinking water service interruptions and the potential for adverse public health outcomes. Transportation infrastructure (land, air and marine-based) can be inundated and/or damaged, disrupting the movement of people and goods as well as the provision of emergency services.

Rising sea levels and accompanying storm surge

In coastal areas, sea level rise and increasing storm surge can result in damage to and loss of homes and businesses; transportation, energy, water/sewer and communications infrastructure; and other coastal structures. Rising sea level can negatively impact water supplies for municipalities and industries. There are additional vulnerabilities to public water supply associated with rising sea level including salt water intrusion that could affect water supply and quality.



Heat waves

Heat waves create higher demands for cooling and water supplies to buildings. Heat waves and high temperature days have the potential to produce significant increases in ground-level ozone, particularly for the highest-ozone events. Heat waves can also affect transportation facilities and operations, such as rail lines and associated rail passenger service.

Drought

Increased temperatures can compound the availability of water during times of drought. Reduced public and industrial water supplies can threaten public health, business continuity and employment, while reduced stream flows can reduce electric generation from hydropower projects.

Wildfires

Higher ambient temperatures in combination with declines in precipitation create the conditions conducive to wildfires. Climate projections show that the frequency of drought conditions in North Carolina will increase the risk of wildfires.

Table 5H-1. Exposure of housing, building, and support services assets and services to climate-related hazards.

Assets, Regulation, Services	Changed Seasons	Extreme Heat	Flooding (River and Land)	Inundation (includes SLR)	Landslides	Severe Winter	Storm Surge	Water Shortage (Drought)	Wildfire	Wind
Prison facilities	*	*	*	*			*	*		*
DOA-administered state buildings in Wake County	*	*	*			*		*		*
State-owned underground and above ground storage tanks			*							
Emergency management communications; DEQ/DOT Sensors/monitoring tools		*	*							
DEQ regional offices, office buildings, state-owned vehicles, furniture, field equipment, staff			*							
Regulatory oversight over public or private landfills, transfer stations, temporary disaster debris sites, solid waste management facilities			*			*				*
Regulatory oversight over the long-term cleanup of non-permitted releases of hazardous substances, support in emergency situations.			*				*			
Petroleum and hazardous substance spill response teams			*							
NIST Risk Management Framework (RMF) 800-53 Security Controls. General Statute Chapter 143B, Article 15; approvals, inspections, compliance										*

Non-climate Stressors

Non-climate stressors are also increasing vulnerability and risk to housing, buildings, and support services in North Carolina. An increasing population in North Carolina is leading to not only increased demand for water and related services but is also creating land use change and increased runoff in many areas of our state. Aging infrastructure and limited surface water storage are increasing the stress on our state's water and land resources. This issue is exacerbated by limited resources available for maintenance and replacement of growing water distribution and treatment infrastructure as well as for dams. Additionally, there is the challenge of protecting private development rights without sacrificing public trust rights and resources.

3. Examples of Impacts, Vulnerability, and Risk

Housing and Infrastructure / Inundation

Impact Summary

North Carolina's Coastal Plain counties contain a diverse mix of natural and built environments within a few feet of sea level. The risk of flooding will be highest for these low-lying areas of the state, and this threat is growing due to increases in frequency and severity of heavy rainfall events including tropical storms. The Coastal Plain typically has lower population density, but the topography is not as steep as in the Piedmont and Mountain regions, which correlates to longer periods of inundation, especially as floodwaters from inland sources make their way to the Coast.

Homes, businesses, and associated infrastructure may fail due to inundation. Water and wastewater may derive from overland (pluvial), riverine (fluvial), or man-made sources such as septic tanks, sewer lines and pump stations. Septic systems failures in poorly drained soils require alternative waste treatment systems.

Vulnerability and Risk

Rising sea level poses a significant threat to public infrastructure, public trust resources and private property and development along the coast. The consequences of inundation include loss of life, damage to property and agricultural production, and damaged infrastructure and utilities. Many homes and businesses are in low-lying areas, where they already face risk of storm-related damage. Already, shoreline erosion has required structural defense and loss of homes along the beach. Decisions will need to be made about the long-term sustainability of some communities.

Flooding risk varies by location within the state. Floodplains, are inherently susceptible to significant impacts. In the Piedmont and Mountain Provinces, historical and cultural centers are situated along watercourses, concentrated within floodplains. In the coastal region, development has occurred everywhere from the oceanfront beaches to the protected sandhills on the southern Coastal Plain, to the flatter and wetter pocosins and farmland on the northern Coastal Plain.

Development patterns are nearly as diverse as the natural environment, from modest inland cottages to oceanfront mansions to multi-million-dollar condominium towers. The diversity of coastal landscapes and development creates a high level of complexity for assessing potential risks from climate change, as well as possible strategies for adaptation.



Adding to the complexity is the challenge of protecting development without sacrificing public trust rights and resources. Beach tourism is one of the state's biggest economic engines, and commercial fishing remains an important cultural and economic activity. Public waters and beaches will be adversely impacted if the response to climate change and sea level rise are not properly managed.

Resilience Strategies

Recovery Programs

When pump stations, sewer lines, and wastewater treatment plants are inundated, the infrastructure must be replaced and the surrounding contaminated environment must be remediated. When flooding occurs and causes enough qualifying damage for federal or state disaster declarations to be approved, recovery programs may be available to repair damage not otherwise covered by flood insurance. Some programs from FEMA and CDBG-Mitigation can be used preventively on qualifying projects to anticipate and reduce flood risks.

Adaptive Development Strategies

Across the state, programs should be established to educate residents about the dangers of building within floodplains. For infrastructure components that have to be placed within the floodplain, evaluate the implications of defensible estimates of increased risks associated with changes in climate patterns. Adapt development policies and construction techniques to minimize the detrimental impacts related to increased levels of risk. The Department of Insurance's Building Code Council should reestablish the two-foot freeboard requirement for new or substantially improved buildings within the regulatory floodplain, and consider a four-foot freeboard for the twenty coastal counties regulatory floodplains. Advancing this program and securing the outstanding EAPs and Dam Safety Education is an ongoing priority and a key way to build resilience.

Risk Assessments

North Carolina will need to work with local governments to evaluate climate risks to their buildings, structures and support services. This work should consider incorporating the most current scientific and valid studies for future hurricane, flooding, and inundation risks. Local partners should also receive recommendations for cost-effective measures to improve their climate resiliency.

For the highest risk areas (i.e., the twenty coastal counties), the state should provide local governments and coastal residents information on sea level rise trends, projections, implications, and adaptation options through ongoing collaboration with federal and other state agencies and the scientific community. The Coastal Resources Commission (CRC) should provide an assessment of sea level rise to the twenty coastal counties at least every five years to include projected flood inundation in local land-use and hazard mitigation planning. Session Law 2012-202 requires the Coastal Resources Commission's Science Panel to update its 2010 report on sea level rise in North Carolina every 5 years.

The CRC's charge to the panel is to conduct "a comprehensive review of scientific literature and available North Carolina data that addresses the full range of global, regional and North Carolina specific sea level change." The CRC further directed the panel to include scenarios of sea level rise on at least a 30-year time frame, and the panel is beginning its next update cycle in 2020. The review is required to tailor its findings to consider regional trends and differences in subsidence rates along North Carolina's coast.

Because sea level rise is not uniform across the state's coastal zone, the state should support the development and dissemination of scientific data that are tailored to the different regions of the coast, and

encourage coastal communities to consider regional trends and projected rates of sea level rise in hazard mitigation, local land use, and development planning.

Management of Disaster Debris / Extreme Weather

Impact Summary

The Division of Waste Management within the Department of Environmental Quality is the agency that ensures the proper management and disposal of all solid waste, including debris generated from hurricanes and floods, for the purposes of protection of public health and the environment.

Throughout the United States, managing storm-generated debris is one of, if not the highest costs, associated with storm response and recovery over the last 30 years. Therefore, having support services in place that promote pre-planning efforts and efficient and timely management of debris are essential to lowering those direct costs. The longer debris stays in communities, the more severe the economic impacts are on restoration of other public services, redevelopment, and tourism.

More frequent and severe weather events are generating larger quantities and varieties of wastes at one time, including atypical wastes for those communities' normal waste infrastructure. In addition, the wastes are being generated across multiple county areas, placing a greater emphasis on the proper and timely management of debris and the possible need for regional approaches to management.

Non-climate stressors include local development pressures (increasing or decreasing population), access to contractors and equipment to collect and manage debris, as well as proximity and transportation routes to disposal facilities and re-use markets to take the growing volumes of generated debris. Given this assortment of stresses, pre-planning efforts are even more critical. Regionally, this hazard has a greater impact and frequency on the Coastal Plain communities due to tropical cyclones, but is shared across the state in those areas that have experienced tornado outbreaks, winter ice storms, and inland flooding.

Vulnerability and Risk

Having a statewide program that can provide guidance and training, and maintaining a network of pre-approved temporary debris staging sites is critical to our local governments, businesses, and state and federal agency partners to assist in speeding recovery efforts. Often, the economic burden on the state and its communities can greatly shift if resources are not in place and procedures are not being followed in the days **before** a storm occurs. Existing adaptive capacity hinges upon pre-planning activities, including partnering with the NC Department of Transportation and Department of Public Safety – Emergency Management, FEMA and local governments across the state to provide training on proper debris management, developing policy and procedures, and discussing the implementation of strategies to assist communities in lessening their vulnerabilities and risk.

The management of storm-generated debris carries a huge cost from collection, processing and final disposition. The recovery of these costs is critical to the budgets of local governments especially those in the more rural communities. Temporary debris site approvals and compliance with state laws and rules is required by FEMA for cost reimbursement, therefore not following that process can prevent a local government from getting funding, or at the minimum, add weeks or months delay.

An often overlooked impact to the mis-management of debris is that it can lead to additional climate impacts, both short and long term, primarily from greenhouse gas emissions due to increase volume of trucks traveling in and out of already impacted communities, along with prolonged operations of heavy equipment such as loaders, grinders, etc. The division has also seen a recent increase in requests from local governments for permits to burn vegetative debris, either through open or air-curtain burners, in many cases due to delays due to widespread impacts in recent storms.

The unusually large volumes of debris generated from a hurricane could easily overwhelm the operations and capacity of a smaller local government owned landfill. In many areas in NC, landfills have closed, and daily generated waste is managed through a transfer station, shipping waste to other communities in NC and beyond. Having plans and procedures in place that allow debris to be managed separately or in alternative ways to the normal day-to-day promotes the opportunity to sort and recycle some materials lessening the impact on disposal facilities and also allows those facilities to return to normal operations sooner as waste will continue to be generated by citizens and businesses.

Managing hurricane generated storm debris in an inland county presents different challenges than the barrier island communities. Inland areas tend to have a well-maintained road system with multiple travel options and access to disposal and recycling opportunities for both vegetative and demolition wastes within the county and surrounding communities. Outer Banks communities, such as Ocracoke Island, have faced collection, storage and transportation challenges. Many areas on the island are restricted and off limits to manage debris; whereby, getting debris off the island is highly dependent on the passenger ferry system to either community to the north or to the mainland.

Resilience Strategies

The Division of Waste Management will continue to work with local, state, and federal partners to participate in and conduct training and to provide guidance via division webpages. Additionally, the division will pursue the approval of rules regarding the establishment of temporary debris sites.

The division should also work with other local, state and federal entities, and waste and recycling facilities to improve and/or develop and implement strategies that promote the proper management of storm debris and its impacts to statewide communities by:

- increasing waste segregation efforts facilitates reuse, recycling, and proper disposal of the various waste streams;
- expediting the removal of disaster-related waste from impacted communities;
- maximizing reuse and recycling opportunities available to impacted communities;
- growing waste reduction programs to maintain landfill capacity to withstand periodic influx of storm related debris;
- promote local ordinances in building practices that eliminate exposure risks resulting in less waste being generated during storm events;
- working with public and private waste management facilities to ensure their acceptance of disaster-related wastes.

Spills from Underground and Aboveground Storage Tanks / Extreme Weather

Impact Summary

The Underground Storage Section within the Division of Waste Management, Department of Environmental Quality is the agency that has statutory responsibilities to ensure petroleum releases (above and below ground) are properly cleaned up and/or restored as closely as possible to previous conditions. A regulatory function of the agency involves developing guidance, providing training to facilities, and maintaining an assessment team for identifying, logging and responding to petroleum releases.

This vital support service functions to assist local governments, businesses, and state and federal agency partners in speeding recovery efforts to return their communities to normal function. Therefore, having support services in place that promote pre-planning efforts, efficient and timely management of

stabilizing and removing petroleum contamination are key to lowering those direct costs and protecting soil, groundwater and surface water within those impacted communities.

More frequent and severe weather events are generating larger numbers of individual releases, including residential heating oil tanks, oil water separators and other containment systems that are typically not associated with a high number of releases.

Vulnerability and Risk

The risks associated with degraded water quality due to storm water runoff are high due to probable health and ecosystem impacts. The growing population of North Carolina demands more drinking water. Petroleum-contaminated soil can leach into the groundwater, contaminating aquifers. Contamination can disperse wherever it remains in contact with water. Petroleum-impacted groundwater requires long-term monitoring and/or remediation systems.

The most vulnerable area of North Carolina is the Coast. The coastal region sees the most intense rainfall events and suffers from some of the most severe impacts of flooding which causes the transport of petroleum contamination via storm water runoff.

Non-climate stressors include local development pressures (increasing or decreasing population) and the accompanying increased transportation and storage of petroleum products. Regionally, this hazard has a greater impact and occurs more frequently in Coastal Plain communities due to tropical cyclones, but it is shared across the state in those areas that have experienced tornado outbreaks, winter ice storms, and inland flooding.

Resilience Strategies

The division will continue to work with our local, state, and federal partners. We will participate in and conduct training and provide current guidance on our Division webpages. To improve and/or implement strategies to properly manage petroleum storage, we propose the following:

- increase UST facility awareness and preparation prior to hurricane season;
- increase involvement in County Local Emergency Planning Committees (LEPC);
- identify unpermitted petroleum storage containers (Above Ground Storage Tanks); focused within flood zones but including all of NC facilities in an outreach program consisting of awareness and preparation prior to hurricane season

State Buildings and Facilities / Storms and Heavy Precipitation

Impact Summary

Electrical power is essential to the proper operation of all buildings. Major climate-related hazards that can shut down building electrical systems include: high winds, storms, and flooding, each of which may be associated with hurricanes and other high wind events. Ice storms and heavy snowfall may also result in loss of electrical power. Loss of electrical service in any of the downtown Raleigh complex buildings would necessitate evacuation of the building until the electrical outage is resolved. If the outage is for an extended period, below-grade spaces may need pumping if pumps were disabled during the power outage. Additionally, a waiting period may be necessary for cooling, heating, and potable hot water services to stabilize after an extended power loss.

Vulnerability and Risk

The vulnerability and risk of electrical power loss to the downtown Raleigh complex is considered low to moderate, depending on the severity and duration of the storm or flooding event. There is a low

likelihood of extended electrical power loss but a moderate likelihood of temporary electrical power loss. It is likely that electrical power loss in the Raleigh complex will affect much of the downtown area in addition to the state's complex of buildings. Although we have not quantified it, the risk is growing due to increases in frequency and severity of heavy rainfall, storm and hurricane events in North Carolina.

Resilience Strategies

Emergencies related to extreme events (e.g. hurricanes) resulting in the loss of main electrical power can possibly be offset by the rental of large trailer-mounted temporary electrical generators. This option assumes that generators will be available in the quantity and electrical capacity necessary to power key buildings in the downtown Raleigh complex. Rental of temporary generators is a very expensive alternative to hardening the electrical infrastructure serving the downtown complex.

Resilience and adaptive capacity can be improved by establishing the necessary temporary electrical hookups, at predetermined locations, at all key buildings if temporary generators need to be brought in. A transfer switch will be needed at each location where a temporary generator is installed. A single point electrical hookup for all state buildings in the downtown complex is not feasible.

State Buildings and Facilities / Extreme Heat

Impact Summary

The Department of Administration, through the Facilities Services Group, provides chilled water to many state-owned buildings in the downtown Raleigh complex. Chilled water supplied to these buildings is supplied by large chillers located at two primary chilled water plants, plus smaller chillers available at several individual buildings. This chilled water is piped through numerous air handling units in the downtown complex buildings to cool the buildings in spring, summer and fall seasons. During periods of extreme heat, the ability of the chilled water system to provide adequate quantities of chilled water may cause loss of building use. Potential consequences of loss or inadequacy of chilled water capacity range from uncomfortably warm buildings to complete loss of building use due to excessive interior heat and/or humidity.

Vulnerability and Risk

Adequate chilled water system capacity currently exists to handle the summer cooling load in DOA buildings and to maintain current levels of indoor comfort if average summer temperatures increase by no more than one to two degrees Fahrenheit in the foreseeable future. It is important to note that loss of one existing chiller will lead to unacceptably high interior temperatures in DOA buildings under current climate conditions. A major non-climate stressor is the aging infrastructure of the downtown complex chilled water system.

Resilience Strategies

Funding for additional chiller capacity has been requested in order to improve system reliability if one or more chillers experience mechanical failure. It is anticipated that additional chiller capacity would be online within two years after funding is appropriated for this additional chiller capacity. Since new equipment can be brought online within two years, the DOA should be able to stay ahead of climate-related load changes assuming that funds are appropriated in a timely manner for the necessary equipment.



Information Technology / Extreme Precipitation and Flooding

Impact Summary

Information technology, including data collection resources, can be sensitive to climate-related hazards. This infrastructure supports emergency management, public safety, medical communications, and non-government emergency services. When information technology is impacted by flooding, additional sites are needed to meet operational requirements, which increases operational costs.

Vulnerability and Risk

Exposure to flooding varies by location (e.g., urban vs. rural or watershed position). Enclosed facilities are more sensitive than open ones. Those with redundant power supply have built-in adaptive capacity that others do not have. Potential consequences of flooding include loss of operations, property damage, and environmental contamination. The risk of these events needs to be calculated on a site by site basis.

Resilience Strategies

IT infrastructure may be made more resilient by installing protective bulwarks and redundant power sources. Some specific options include:

- adding green roofs to deal with rainwater and heat;
- increasing air conditioning systems that are more efficient and less dependent on fossil fuels;
- incentivizing lighter-colored roofs for data centers;
- installing devices to prevent flooding;
- raising information technology buildings near flood-prone areas.

4. Summary

North Carolina's buildings and the associated infrastructure and state services that support these physical assets are at increasing risk from climate change stressors and impacts. Historically, damage or destruction to these assets has principally resulted from flooding associated with extreme precipitation events. A warming global climate that contributes to a rising sea level will likely produce additional coastal flooding, inundation and possible destruction of these state facilities. All agencies within this sector can expect an increase in risk and damage costs to their facilities/assets, as well as the continued increases in demand for their services and higher operating costs. State managed recovery programs are facing an increasing need to enhance existing or develop new resilience strategies, and efforts to promote building resilience is important to reducing the climate change impacts.

Climate impacts will have environmental, societal, and economic consequences, and will be most severe for the coastal region of the state. However, all regions of the state will have to contend with the challenges of a warmer climate and the associated increase in frequency and severity of extreme flooding events. State programs associated with housing, buildings, and support services need to immediately start outreach and educational efforts to inform policy makers and residents about the dangers of increased flooding and avoiding increased investments within floodplains. For existing assets and infrastructure components that have limited adaptive capacity many of the solutions will be costly and take time to implement. Future assets and infrastructure need to be evaluated to consider the implications of defensible estimates of increased risks within the content of associated changes in climate patterns.

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Public Safety

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I. Public Safety

Key Observations

- A permanently funded resiliency office, requiring personnel and budget, is needed.
- Public Safety is the largest state government cabinet agency with over 25,000 employees. It manages response and recovery for climate hazards and the growing number strains resources. North Carolina is viewed as a nationwide leader for these services.
- Resilience services will require greater interagency support and resources. Operational, logistical, maintenance, and resiliency challenges are synergistic in nature. All must be simultaneously addressed.
- Correctional facilities will require substantial upgrades. North Carolina is responsible for the custodial care of more than 35,000 inmates and 200 juveniles, vulnerable groups with higher exposure and low adaptive capacity.

Critical Impacts and Resilience Strategies

- Building resilience into critical infrastructure that supports response and quality of life must be an immediate priority.
- Working with local governments to build resilience is critical but will require time to build trust, institute new policies and regulations, and properly allocate resources.
- Long-term master planning is needed to determine the most cost-effective means to address, maintain, and operate resiliency plans through their life cycles.
- New and more strategically located facilities may serve well during a natural disaster.
- Training, tabletop exercises and continuity of Operation Plans for each of our divisions need to occur on an annual basis.

1. Introduction to Sector

The ***North Carolina Department of Public Safety*** (NCDPS) is the primary state agency affected by or responsible for climate-related impacts to the Public Safety Sector. The NCDPS includes the Divisions of Adult Correction and Juvenile Justice, North Carolina Emergency Management (NCEM), North Carolina National Guard, Administration, state Capitol Police, state Highway Patrol, Professional Standards, Policy, and Strategic Planning, and the North Carolina Office of Recovery and Resiliency (NCORR). The NCDPS occupies or operates over 700 sites and 19 million gross square feet (GSF)[1] of space and 32,000 acres spread throughout the state of North Carolina.

The mission of NCDPS is to safeguard and preserve the lives and property of the people of North Carolina through prevention, protection and preparation with integrity and honor. The NCDPS goals are to strengthen the department's unity of effort as a consolidated and allied entity, to create a true culture of prevention, protection, and preparedness, and to create and maintain an environment where NCDPS employees are engaged, accountable, and recognized for the contributions they make to enhance public safety in North Carolina. NCDPS has 25,000 employees and a general fund of $2.2 billion.

NCDPS primarily provides services and enforces existing laws, regulations and rules. The primary climate change impact to NCDPS mission is in the services NCDPS provides. Climate-related impacts

[1] Franklin, C. Central Engineering. "NCDPS Asset – FTE Chart1 Derived from Department of Insurance and State Property Office Data 2018" report compiled by Central Engineering.



primarily affect Adult Correction and Juvenile Justice, Emergency Management, NC National Guard, state Capitol Police, state Highway Patrol, and the North Carolina Office of Recovery and Resiliency. Some of these services are provided to local governments (counties and municipalities), while others involve direct services provided to the public.
The only permitting responsibilities under NCDPS are related to alcohol, precious metals businesses, private protective services businesses, and alarm system licensing. The direct impact of climate change on these permitting activities is judged to be minimal. Additionally, any climate change impact on changes in criminal laws and regulations would be minimal, and NCDPS would appropriately respond to and enforce any such changes.

2. Overall Exposure

There are several factors or climate stressors that are increasing vulnerability and risk to emergency management services, NCDPS Correctional Institutions, and NCDPS employee health and safety (Table 5I-1). Given the impacts of recent hurricanes, much attention has been on the drivers of riverine and overland flooding and storm surge. A recent example just occurred in February 2020 when Neuse Correctional Institute was evacuated as a precautionary measure due to potential flooding after heavy rainfall from a strong low-pressure system with an associated cold front. In the long run, sea level rise and tidal flooding will become larger drivers of permanent land loss, potentially affecting evacuation routes. Wildfire and extreme heat will also be major concerns. Drought and water shortages will require emergency responses.

As North Carolina is a geographically and climatically diverse state with a climate already defined by extreme and changeable weather it is highly likely that the climate impacts identified in this report will exacerbate the frequency and impact of natural hazard events across all regions of the state. It is important to note that response to extreme weather events and disasters are a routine part of NCDPS mission and services.

Because of North Carolina's naturally variable climate, plans and protocols already exist for response to the existence of the natural hazards outlined in the Climate Science Report[2], including the North Carolina Emergency Operations Plan and the North Carolina Hazard Mitigation Plan. Trainings are already offered on many of these hazards across each Division, and tabletop exercises allow the testing of responses to hazard scenarios. This effort needs to be strengthened through the addition of the Department of Corrections (Prisons and Enterprise) and Central Engineering.

The overall impact of climate change will then be shifts in the frequency, magnitude, duration, or scale of the responses to hazards North Carolina already experiences. Plan and process improvements will be needed to accommodate extreme events that occur more often, more intensely, last longer, or cover broader areas of the state.

[2] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K.D. Dello, J. P. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: *North Carolina Climate Science Report*. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr



Table 5I-1. Exposure to climate-related hazards of public safety assets and services.

Assets, Services, Regulations	Extreme Heat	Flooding (River and Land)	Water Shortage (Drought)	Changed Seasons	Severe Weather	Landslides	Saltwater Intrusion	Storm Surge	Tidal Flooding	Wildfire	Dam Failure
Emergency Management: mitigation, preparedness, planning, response, recovery	*	*	*	*	*	*	*	*	*	*	*
Employee Safety	*	*			*			*		*	*
Law Enforcement	*	*			*			*	*	*	*
Emergency Sheltering support		*			*			*			
Flood Risk Management		*			*			*	*		
Correctional Institution Inmate Health and Safety	*	*			*					*	*
Correctional & Juvenile Justice Institutions	*	*	*		*			*	*	*	
Prison Wastewater Treatment		*									*
Prison Food: Caledonia Farmland	*	*	*	*	*						*
State-managed recovery programs (FEMA PA, HUD CDBG-DR, State DRA) for critical infrastructure managed by counties and municipalities	*	*						*	*	*	
State-managed recovery programs for housing (FEMA IA, HUD CDBG-DR, State DRA, Hazard Mitigation Grant Program)	*	*						*	*	*	

Climate Stressors

Extreme heat will lead to more and longer summer heat waves. Exposures will be across NCDPS during events, with employees who work outside needing to be concerned about adverse impacts to their health. Adult and juvenile inmates in state custody will be affected in facilities with old or inadequate HVAC systems.

Storm-related heavy precipitation and flooding will affect rivers as well as increase flash flood events. NCEM and the National Guard assist in the provision of emergency response services during events, and NCEM and NCORR provide recovery services after large events that qualify for state and/or federal disaster declarations. Expanding mapping of these hazards through NCEM Risk Management programs



would assist local governments who lack capacity for such mapping. Adult corrections and Juvenile Justice also have to evacuate the inmate population from affected facilities. Wastewater treatment facilities and crop yields from correctional institution agricultural facilities are also negatively impacted.

When ***droughts*** occur, NCEM assists other state agencies in preparation and response. Droughts also negatively impact yields at prison agricultural facilities, which serve as part of the food supply for the correctional institution system and provide work opportunities for inmates. Droughts that affect water supply to prison facilities would increase costs to provide drinking water.

A ***longer freeze-free season*** will affect productivity and yields on prison farmland. Changed seasons may also impact the patterns of disasters when extreme events compound unusually wet or dry seasons, changing the scale of an emergency response. Warming seasons may change the nature of mosquito habitat and the risk of vector-borne disease. Vector-borne disease plans would need to be updated to accommodate these changes.

Any changes in other ***extreme weather*** event frequency or severity will change the length or scale at which emergency response services must deploy. Frequent events in short succession may begin to fatigue existing disaster response and recovery resources.

Landslides require NCEM to assist when affected county emergency services' response capacities are exceeded. Landslides large enough could qualify for disaster declarations, requiring continued and coordinated state recovery services.

Salt water intrusion during drought could pose a threat to water supplies. NCEM would need to consider how to provide emergency assistance to communities if drinking water treatment facilities were unable to provide drinking water on a scale in excess of the response capacities of affected county governments.

North Carolina's coast is already highly vulnerable to storm surge, but ***sea level rise*** and ***stronger hurricanes*** and ***extratropical storms*** could exacerbate both oceanfront and sound side surge heights. In addition to above discussion of changes in preparedness, response, and recovery services needed, infrastructure is particularly vulnerable. By 2050, the Southeast is the region expected to have the most vulnerable bridges. Bridges serve as important human evacuation outlets, but can be impacted by increased wave loads from storm surges and in areas where sea level rise is pronounced.

High tide flooding is now posing daily risks to businesses, neighborhoods, infrastructure, transportation and ecosystems in the Southeast. ***Sea level rise*** will result in the rapid conversion of coastal, terrestrial and freshwater ecosystems to tidal saline habitats. NCEM and NCORR recovery and resiliency services will need to adapt the planning and technical support they provide to local communities who retain control of local land use decisions.

New collaborative partnerships with local governments can help direct development out of places at risk, reducing the scale of services needed during emergencies. Expanding mapping of these hazards through NCEM Risk Management programs would assist local governments who lack capacity for such mapping. Some correctional and juvenile justice institutions are located in areas vulnerable to sea level rise, storm surge, and tidal flooding.

Intra-annual droughts are expected to increase, which would require NCEM and other agencies to scale up responses to wildfires. Correctional institutions which are located in areas vulnerable to wildfire would need to consider response and planning options.

Greater increases of ***flooding*** could further stress aging dam infrastructure. NCEM partners with DEQ and other agencies on mapping risks and providing response to dam failures. Employee safety could also be affected across NCDPS for responders or for facilities downstream of failed dams. Correctional



institution facilities, particularly wastewater treatment plants and farmland, could be exposed to flooding and increased flows.

3. Examples of Impacts, Vulnerability, and Risk

Emergency Response and Disaster Recovery

Impact Summary

The North Carolina Division of Emergency Management (NCEM) coordinates response and recovery in communities that have been impacted by natural and human-caused hazards beyond their local capacity. Impacted communities are provided assets from other local agencies, state agencies, assistance from states with mutual aid agreements, and federal agencies. The NCEM and its sister agency, the North Carolina Office of Recovery and Resiliency (NCORR), together provide financial and technical support to local governments throughout the long-term recovery of communities from disasters and resilience to future disasters by administering disaster recovery funds. Because those disaster recovery dollars are to support local reconstruction, hazard mitigation, and relocation of housing and infrastructure, impacts to those services are discussed here, despite overlap with the Housing, Building, and Support Services sector.

The NCORR was established at the end of 2018 in response to North Carolina's qualification for the U.S. Housing and Urban Development's Community Development Block Grant–Disaster Recovery (HUD CDBG-DR) for both Hurricanes Matthew (2016) and Florence (2018). NCORR's mission is to provide general disaster recovery coordination and public information; citizen outreach and application case management; audit, finance, compliance, and reporting on disaster recovery funds; and program and construction management services. It is the grantee for all CDBG-DR and CDBG-Mitigation funds received by the state of North Carolina. Because these programs are not authorized by Congress, with each disaster Congress must publish new rules in the federal register before grantees may develop action plans and receive approval to withdraw funds. This process takes time; 500 days elapsed between the landfall of Hurricane Florence in September 2018 and the publication of the federal register notice in January 2020. This lapse allowed NCORR to develop a draft action plan to spend CDBG-DR funds allocated for that event. This delay underscores the need to coordinate the multiple disaster recovery programs from state, FEMA, other federal agencies, and HUD to speed aid to disaster survivors.

This impact summary will focus on disaster preparedness and response services, which are the primary domain of NCEM at the state level in support of the counties, and disaster recovery services provided by both NCEM and NCORR. It is important to also note that NC General Statutes Chapter 166A, the North Carolina Emergency Management Act, leaves many emergency services responsibilities to the counties, and climate impacts to county-level emergency services are outside the scope of this impact summary.

NCEM's primary resources are personnel and to a limited degree communications equipment and a small store of emergency supplies including tarps, bottled water and emergency food rations. During a disaster, counties manage local emergency responses, including the establishment of emergency shelters. Counties then make resource requests to NCEM when county resources are insufficient. NCEM personnel may provide supplies or services including assistance with interpreting risk information, supplying additional rescue teams, establishing or guaranteeing access to sheltering, conducting damage assessments, or other services including advice on procurement.

While NCEM's typical response is to weather events, impacts of climate change will almost certainly increase the frequency of response, the magnitude of certain events, and the size of the geographic area impacted. In addition to changes in frequency, intensity or duration of events, climate change may also usher in a regime in which multiple hazards such as wildfire, flooding and intense storm events may



overlap in both the temporal and spatial scale resulting in increased drain on local, state and federal resources calling for more personnel, equipment and supplies to build an adequate response and insure successful and timely recovery.

Vulnerability and Risk

Recent extreme events have heighted the sense of risk within both NCEM and NCORR. Tropical Storm-related flooding impacts on North Carolina, in particular from Hurricanes Matthew in 2016 and Hurricane Florence and Tropical Storm Michael in 2018, have been out of scale with previous impacts in terms of intensity and geographic extent. Flooding for all three events involved significant impacts outside of previously mapped flood hazard areas. Wildfire has also shown a marked increase in intensity and area involved in recent years.

As the population and built environment in North Carolina continue to grow and expand in the coming decades, more people and property will be exposed to hazards that are anticipated to increase in both frequency and intensity. The degree of this exposure will also depend upon local land use decisions and economic drivers of development in areas at risk, like current and future floodplains, in the wildland-urban (especially pertinent to wildfire exposure) interface, or in places where the pace of development exceeds the future capacity for safe and adequate drinking water supply.

Should the state arrive at a point where statewide flooding, severe weather, wildfire or other impacts occur, or where various multiple hazards impact diverse areas of the state or region simultaneously, the response and recovery capacity of all partners shall be challenged. To date tipping points have not been reached, but resources have been stretched and challenged particularly in the area of temporary and replacement housing because of an existing and ongoing affordable housing crisis throughout the state.

The closest threat to serious drought-related impact on water supply was observed in 2008. Fortunately, interconnected water systems and luck factored into recovery when a tropical storm brought higher than average rainfall to most of the state in a short period. Aging infrastructure will likely place additional demand on the water supply system.

The sensitivity of communities and individuals to extreme events are affected by the complex nature of state and federal recovery assistance programs. Housing damage leads to displacement or to negative health impacts of residing in moldy or unlivable conditions. Displacement for households with fewer resources leads to greater poverty, homelessness, adverse health impacts, stress, and negative educational effects for children. Inundation of flood waters can also cause loss in property values and can substantially damage the residence. Flood damage can necessitate retrofits to meet current building and safety codes, or in extreme cases may require demolition and relocation of residents. The housing stock needing recovery assistance is privately owned by individuals, but the state must administer disaster recovery programs. Eligibility for individual programs varies and is subject to changes in FEMA policy, individual guidelines published in Federal Register for CDBG-DR, and state programs developed or funded by the North Carolina General Assembly. Income requirements must be met, and these vary from program to program. Additionally, these programs may not duplicate benefits from either insurance or volunteer disaster recovery groups.

NCDPS staff administer and deliver these recovery programs to eligible applicants. As events become more frequent, the complexity of recovery integration across programs increases as duplications of benefit must be tracked across events. Staffing will need to keep pace with the scale of these events, but percentages of each program that can be used for administrative purposes are capped. The quantity of funds received from the federal government or allocated by the state must also be sufficient to cover unmet recovery needs. Repeated disasters also strain volunteer donations and group labor that fills critical gaps in meeting unmet needs when recovery dollars are not sufficient to cover uninsured damages.



Recovery failure could leave people with unsafe living conditions, and potentially cause severe property damage (e.g., homes, businesses, roads) and negatively impact local economies and utilities.

Federal and state policies on disaster funding eligibility and availability are important bulwarks for adaptive capacity within the state. FEMA, the White House and state Government will likely be pressed with more requests for disaster declarations and assistance requiring policy decisions concerning prioritization and allocation of funding and other resources. Any potential adaptation actions will need to be consistent with federal law, including the Stafford Act, and state law, including NCGS Chapter 166A, the North Carolina Emergency Management Act. The sensitivity factors that public safety officials must address include population density, economic health and stability, income, education, age of infrastructure, condition and availability of housing and shelter, relative health of the local environment, local government capacity, and recent disaster experience.

Given recent events, climate change trends, and non-climate factors, there is a risk that a tipping point exists beyond which emergency response and recovery service provision could be compromised. The ability of these systems to cope with climate change will be limited if federal and state funding are not adequate for the intensity, frequency, and duration of events experienced in North Carolina. This funding is needed both for personnel cross all phases of disaster at state and county levels, and for logistics and equipment needed during response.

Though it serves as a model for many other states, a traditionally robust NCEM has been under almost constant pressure for the past two decades. Through the use of both strategic and operational planning, training and outreach, NCEM has developed a robust and scalable program that could be expanded or contracted through use of contractors, temporary hires, volunteers and federal assistance. Absent a healthy NCEM program, many rural and economically distressed counties would not have sufficient capacity in regard to preparedness, response, recovery and mitigation activities.

It is highly likely that climate change will increase the demand for traditional emergency management services at the local and state levels. North Carolina also has mutual aid agreements with multiple states that may create a further drain on resources in times of widespread disaster, either through the need for NC to provide aid to other states or through other states' reduced abilities to provide aid to NC because of disasters there. These risks for capacity strain are sensitive to the intensity, duration, and frequency of extreme events both in NC and elsewhere.

Resilience Strategies

Cross-agency Coordination

NCEM recognizes the continued need to maintain and develop its cross-agency relationships across all levels of government to ensure the provision of emergency and recovery services remains robust under the impacts of climate change. This includes efforts to support county emergency services, like launching the statewide "Know Your Zone" campaign to support improving evacuation coordination. It also encompasses the continued need for engagement at the federal level on needs for aligning disaster response and recovery funding to ensure that response capacity is maintained and enhanced across federal, state, and local levels. It also includes efforts from NCORR and NCEM, like the Recovery Integration Team and the State Disaster Recovery Task Force (SDRTF), to continue finding efficiencies in internal recovery operations and identify opportunities external to state government recovery programs to fill gaps on unmet needs.

Risk Information Sharing

NCEM can also help leverage efforts to get risk information to local governments who lack the ability to produce it on their own. NCEM hosts vast amounts of spatial and geographic data that inform a growing number of risk identification and assessment tools, and partners with numerous university efforts. The

NCEM flood mapping program (NCFMP), the Flood Inundation Mapping Information Program (FIMAN) and the integrated stream gage system are three examples of data-based products that help provide a detailed and common operating picture for flood hazard events. Continued data development and application of these tools must be included in future plans addressing climate change impacts.

Land Use Planning

Actions to reduce climate change vulnerability (reducing exposure and sensitive and increasing adaptive capacity) must take place in a concerted fashion involving the public along with private and government enterprises through activities such as zoning and land use planning. Traditionally, this has not been a formal function of emergency management. The growing emphasis on resilience, as well as expanding literature on the nexus between disaster risk reduction and climate adaptation recognizes the long-term importance of using wise land use planning and directed economic development to reduce the burden on emergency services.

Local Partnerships

NCEM's sister agency NCORR includes a Resilience Team, established in 2019. While this team's role is still evolving, its interaction with local governments on disaster resilience with co-benefits for climate adaptation is an early activity. All additional supportive activities may require additional funding. The legal environment also provides an important constraining factor, as all land use decisions remain in the purview of local governments. This means that partnerships and trust must be established to find solutions for local governments that respect this responsibility but still meet local needs for growth and economic development.

NCDPS Correctional Institutions and Juvenile Justice

Impact Summary

The NC Department of Public Safety operates over 13 million gross square feet (GSF) of Public Order & Safety housing and correctional facilities, Juvenile Justice and Youth Development Centers and National Guard Readiness Centers statewide. Rising sea levels as well as more intense hurricane and heavy precipitation events affect the department's buildings, and, in turn, critical operations. During Hurricanes Florence (2018) and Matthew (2016), the Division of Prisons over 4,950[3] inmates were moved to other prisons and jails further inland and staff moved to those prisons to maintain security. In February 2020 Neuse Correctional Institution was evacuated due to flooding.

Prisons are built for a standard operating capacity, but during these evacuations, receiving facilities are stretched well beyond a sustainable capacity, even with the additional staff. When evacuations are required, food, clothing, bedding, medical supplies and staffing coordination must occur. The kitchens are required to produce substantially more food than usual; water and sewer utilization grows beyond capacity; and limited health care resources are overextended. As an additional result, a large number of employees who reside in affected coastal areas are displaced during the storm and its immediate aftermath and are not able to assist in storm response. On a more lasting level, as the sea level rises, there will be a number of prisons within the state that cannot continue to operate.

As part of its custody mission, the Division of Prisons is responsible for feeding its 35,000 inmates three meals a day. While the department purchases a large amount of food, it also produces food for the inmate population at the 7,000-acre farm at Caledonia Correctional Institution in Halifax County. This land, which is crucial to prison operations statewide, is vulnerable to extreme rainfall events, riverine flooding,

[3] Sutton, L. February 13, 2020. Email: *RE: How Many Inmates Were Relocated During Hurricanes Matthew and Florence.*



and eventually sea level rise. Loss of production capacity at this farm would require a vast increase in the amount of food purchased at a much greater budgetary impact.

Every evacuation event (emergency operation) requires a significant amount of planning and execution with already understaffed departments. Facility system obsolescence is further accelerated when maintenance gives way to emergency operations. In addition, these are evacuations of a population requiring close supervision and care. To a certain degree, safety cannot be assured at the same level when inmates are in a transitional stage in lieu of a stable environment.

Many correctional facilities have infrastructure and building systems that have exceeded their planned life expectancy. Heavier rain events and more frequent flooding will further exacerbate our aging roof inventory, and over burden our obsolete electrical distribution systems and aged air conditioning systems.

Extreme heat events will impact the inmate population in the number of correctional institutions (CIs) which have old and outdated HVAC systems. During heat events – which include not just the magnitude of extreme daily high temperatures, but heat stress from the number of nights in a row with extremely high minimum temperatures – inmates may be more vulnerable to heat-related illness. Adding air conditioning will be a substantial financial burden from both a construction and operational perspective, and, will increase our carbon footprint – further exacerbating climate stressors.

Vulnerability and Risk

NCDPS will require additional spatial climate information to quantify the vulnerabilities of and risks to correctional institutions from flooding and wildfire. Because prisons are often built on land that is not otherwise desirable for farming or development, they are frequently found in areas that are very vulnerable to rising sea level and heavy precipitation events. Many correctional institutions are also in remote locations, and in areas surrounded by forest in which wildfire will be an additional risk.

The vulnerability and risks for our Correctional and Juvenile Justice facilities will continue to increase with more frequent floods and heavier precipitation events, each of which exacerbate deferred maintenance challenges.

We are exposed by physical risk with facilities that cannot handle current let alone future impacts. The average age of our correctional facilities is 50 years.[4] A rough estimate of $200 million is needed to address current known issues.[5] Over 3.3 M square feet of roof on 195 buildings has been identified as a high priority for replacement.[6] We are exposed to production risk should our Correctional Enterprise operations not be capable of meeting their agricultural production quotas, which are necessary for feeding inmates.

Our correctional facilities will require substantial upfits to address resiliency, including physical and operational challenges. Almost 30% of these facilities are not air conditioned, subjecting a large segment of the population within our custodial care to a high level of sensitivity to climate change and with low adaptive capacity. To air condition these spaces will require approximately $28 million and is estimated to add an additional yearly utility cost of $2 million.[7] Many of our electrical distribution systems have surpassed their expected lifespan by 20 to 30 years. Water distribution systems are increasingly leaking

[4] Cunningham, R. Central Engineering. February 2020. "DOP Maintenance Conference Presentation 032020 By Central Engineering".
[5] All numbers cited are orders of magnitude/rough estimates and subject to current market conditions, inflationary pressure, and continued refinement in understanding and evaluating of our facility conditions. These are NCNCDPS Central Engineering estimates February 2020.
[6] Cunningham, R. Central Engineering. February 2020. "DOP Maintenance Conference Presentation 032020 By Central Engineering".
[7] Stout, M. Central Engineering. Order of Magnitude Estimate. Email. September 20, 2019.



since the systems are past their design life. Last year leaking water distribution systems at Nash CI resulted in over $550,000 in lost water, sewer and heating costs.[8]

Over the coming decades, the state will need to construct bed space for its inmate population in less vulnerable locations than current facilities. Where sea level rise is the main vulnerability leading to permanent loss of land, this will also mean intensified economic stress on areas affected by the loss of prison jobs when facilities must be relocated. Many rural communities depend upon correctional institutions for local employment, and the loss of any jobs due to facility loss would be felt even in nearby communities at higher elevations further inland.

As with correctional institutions, National Guard Readiness Centers are often in areas vulnerable to climate-related hazards, and they are key locations for disaster response. Loss of readiness centers close to disaster sites, such as in the aftermath of a hurricane, may cause greater delay in reacting to the disaster. The primary purpose of these readiness centers is to be an armory for national defense, and strategic military considerations must come ahead of the centers' role as an emergency management hub in weather events. In recent years, many National Guard readiness centers have been relocated, but additional spatial analysis is needed to determine remaining vulnerabilities and risks.

Resilience Strategies

Logistical Operations

Additional information needs include more specific analysis of the potential impact of drought and flooding to the farmland at Caledonia Correctional Institution. To determine NCDPS's ability to adapt to threats to this food supply, NCDPS should evaluate at what tipping point this land would no longer produce a reliable food supply, identify any alternatives at less vulnerable institutions, and determine the costs to re-establish production capacity. NCDPS would then need to compare these costs to the costs of simply purchasing more food for the inmate population and evaluate any loss of benefit from inmates receiving fresher locally grown food.

Correction Enterprises has a "Continuity of Operation" Plan for emergency operations. This is updated yearly and table-top simulations are held to continually improve the effectiveness of this plan. A similar plan for Adult Corrections would further enhance Enterprise and Corrections ability to handle their response to these events.

Maintenance and Upfit

All resiliency efforts have synergistic relations with site facilities maintenance, correctional officer operations, emergency event planning and logistics, and design/new construction/renovations. Therefore, all these challenges must be addressed. We can do so by addressing on a site by site or building by building basis, or from an overarching master planning effort potentially involving fewer but new sites. Several important factors must be considered to determine which strategies will be the most life cycle cost-effective means of addressing these challenges.

There are concerns for addressing sites/buildings individually. Anecdotally, Central Engineering is seeing renovation costs approach new construction costs[9]. In addition, renovating existing buildings/sites in the correctional arena requires relocating inmates (on the site or across the state). There is a significant construction premium when working at an existing site due to security logistics.

[8] Szigeti, M. Sud & Associates. June 18 2019 "Leak Detection Summary Report DRAFT". JO 3846
[9] Central Engineering Staff Discussion. February 12, 2020

Many individual projects will generally be costlier to execute than fewer, larger projects. Exceeding certain thresholds will trigger Americans with Disabilities Act of 1990 (ADA) accessibility requirements and will be included in the upfit costs.

Our large number of sites, spread across almost every county in the state, requires substantial "windshield"/non-productive time for Regional Maintenance and Central Engineering staff as they work to maintain/upfit/repair these facilities.

Decentralized HVAC systems generally require more maintenance than centralized systems. Utility costs will also generally be higher. Energy efficiency opportunities may or may not be addressed in the required upfits.

We are having a difficult time staffing remotely located sites/facilities. Logistics (soft costs) are higher because of the number of sites and locations.

Opportunities and Challenges for New Construction

There is a present need for increased energy and water efficient systems to be installed. Water and energy costs will likely be less. Sites and buildings will likely be easier to maintain with fewer, more centralized systems. Building new sites out of harm's way with excess capacity could reduce logistical challenges and logistics should improve if there are fewer sites to maintain. If a dormitory requires renovations, the inmates could simply move from one building to the next at the same site. ADA accessibility costs could be much lower in new facility/site construction. Other Executive Order 80 initiatives including zero emission vehicles and charging stations can be more easily integrated into fewer and new facilities.

For these reasons, Central Engineering recommends a comprehensive masterplan be undertaken that addresses all the logistical (both normal and emergency), operational, staffing and resiliency needs. A comprehensive plan engaging all stakeholders will result in best outcomes. New and more centrally and strategically located sites and/or facilities may prove to be the answer addressing all these challenges. A current order of magnitude cost estimate is $25 million.

Employee Health and Safety

Impact Summary

The Department of Public Safety is a statewide operation that deploys employees into communities across North Carolina for a variety of purposes. The most significant community presence is with the state Highway Patrol and the Division of Community Corrections, as well as juvenile court counselors. Employees in these divisions are on the state's roads every day enforcing the law and protecting the public. As such, these critical functions are dependent on passable roads. As flooding becomes more frequent, our department's ability to fulfill its community presence is impinged. During extreme heat events, employees from across the department may also be required to work outdoors in extreme conditions.

Flooding and hurricane evacuations affect the state Highway Patrol and the North Carolina National Guard in multiple ways. First, the Highway Patrol is the lead agency to enforce and facilitate evacuations. When the Governor declares a state of emergency, coastal communities are routinely encouraged to evacuate. The patrol pulls resources from across the state to manage the surge of traffic leaving the coast to safer ground. This means that highway safety coverage for the rest of the state is reduced. Following a flood event, roads may be impassable due to high water or completely washed out. The Patrol cannot respond to calls for assistance beyond these cut-off points, leaving communities isolated and unsafe.



Similarly, it is the mission of probation officers and juvenile court counselors to enforce court orders and work with offenders in their homes to reduce recurrent criminal activity. When roads are impassable, these officers cannot reach their caseload in person, and cannot assure compliance with court-imposed sanctions. This can lead to relapse on the part of offenders and reduced safety for their families. When communities are evacuated, it can become difficult for these officers to know the whereabouts of offenders on their caseload, elevating the risk of offenders absconding from supervision.

Vulnerability and Risk

The department's vulnerability to this impact needs additional quantitative analysis. If catastrophic flooding becomes a more regular occurrence, it will significantly impact NCDPS operations. Additional spatial information is needed on both sea level rise and changing flood frequency to quantify the magnitude of exposure on each facility. This specific exposure information can then be used to identify facilities most at risk and identify tipping points beyond which it is more beneficial to relocate facilities.

Resilience Strategies

NCDPS currently does not have a plan to address the impact of flooding and road closure on community operations. The department can work with the Department of Transportation to identify high-risk roads and communities and develop location-specific responses to local flooding. The Division of Community Corrections has protocols for maintaining contact with offenders during evacuations that will be refined over time.

With more frequent extreme heat events, NCDPS may need to examine best practices for employee training that helps those who must work outdoors to acclimate. For other workers, operations plans could be developed to shift outdoor responsibilities outside of peak hours for extreme heat.

4. Summary

The NC Department of Public Safety (NCDPS) routinely experiences, manages, and provides services during extreme weather events and disasters. As climate changes, shifts in the intensity, duration, frequency, and scale of these events will increase demand for emergency services from NCEM. Vulnerabilities to correctional institutions from flood, sea level rise, drought, extreme heat, and wildfire will have significant impacts on future capital budgeting needs for the agency. NCDPS will also need to develop plans for employee health and safety during more frequent extreme events.

In addition to traditional agency services, NCDPS will continue to evaluate and develop additional ways to support local governments to ensure that public safety remains protected as the climate changes. In some cases, this may mean that counties may require more targeted assistance with services in their traditional purview, including evacuation and sheltering. Because land use decisions are in the power of local governments to make, new initiatives will be needed to determine appropriate ways to partner with local governments to help them understand risk and use beneficial land use practices to guide development towards less risky areas under climate change and therefore improve public safety.

The NCDPS is the largest state agency in North Carolina with approximately 25,000 employees. In addition to safeguarding lives and property in the state, the department is responsible for the well-being of 35,000+ inmates and 79,000+ parolees in the state's correctional system.

The list of services that NCDPS provides include: law enforcement, emergency management coordination, floodplain and other hazards mapping and surveillance, adult and juvenile corrections and justice and supports the North Carolina National Guard. As such, NCDPS plays a crucial role in preparedness, response, recovery and mitigation activities across the state. Local Emergency Response is a local responsibility, but NCDPS, including NCEM, the North Carolina National Guard, North Carolina



Highway Patrol, and the North Carolina Office of Recovery and Resiliency provide critical support and services when conditions are beyond the response and recovery capabilities of local government.

Although North Carolina's climate has long been defined (as compared to other states and regions) as consisting of widely variable and sometime extreme weather, all indications point to a continuation of that pattern with more frequent and more intense extreme weather events (Chapter 3). In addition to consequences from flooding, wind, wildfires, and landslides, the chronic impacts of climate change, such as rising temperatures, will also have an effect on NCDPS facilities and services across the agency.

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Transportation

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J. Transportation

Key Observations

- The core of NCDOT's mission—connecting people, products and places safely and efficiently—is being heavily impacted by a growing number of climate-related hazards.
- NCDOT directly owns and maintains a large and diverse number of assets statewide. Storm-related damage threatens public safety, creates economic disruptions and impacts the budget, requiring a strategy to reprioritize spending.

Critical Impacts and Resilience Strategies

- Maintaining critical connections and access must be the immediate near-term priority. Whether it is coastal during major storms, or the piedmont during heavy precipitation, or the mountains due to landslides.
- All modes of transportation must be assessed for resilience to build adaptive capacity and redundancy moving forward.
- NCDOT is committed to collaborating and partnering with communities and businesses to build the resilient infrastructure they require.
- NCDOT will develop and apply resilience policies in three main areas: (1) long range transportation planning; (2) individual project planning and design; and (3) operations and maintenance.

1. Introduction to Sector

Increasing frequency, intensity, and variability of extreme weather events is detrimentally affecting the NC Department of Transportation's ability to fulfil its mission. The NCDOT operates and maintains an 80,000-mile roadway network. Six intercity passenger trains operated by Amtrak currently serve cities in North Carolina with NCDOT operating trains between Raleigh and Charlotte. Commuter rail is available in Charlotte. Freight rail service is provided in 86 of the state's 100 counties, with most of the almost 3,500-mile rail system owned, operated, and maintained by the private sector. The NCDOT's Ferry Division operates the second largest state-run ferry system in the United States. The North Carolina state Ports Authority owns and operates the Ports of Wilmington and Morehead City, and there are inland terminals in Charlotte, the Piedmont Triad at Greensboro, the Global Transpark in Kinston, and the new CCX Intermodal Terminal near Rocky Mount. North Carolina has 72 publicly owned and nearly 300 privately owned airports. Of the 72 publicly owned airports, 11 have scheduled service and the remaining 61 are for general aviation.

The North Carolina Department of Transportation's mission is connecting people, products and places safely and efficiently with customer focus, accountability and environmental sensitivity to enhance the economy and vitality of North Carolina.

Transportation is the backbone of North Carolina's economic activity, connecting manufacturers with supply chains, consumers with products and tourism, and people with their workplaces, homes, and communities across both urban and rural landscapes. During disasters, roads, airports, and harbors can serve key modes of evacuation or become hubs for emergency personnel. Post-disaster they are the lifeline for relief

NCDOT Average Annual Storm Costs
2004 – 2016 = ~$65 Million
2017 – present= >$222 Million



and rebuilding supplies. In addition to loss of life and negative effects to businesses and the state economy, the NCDOT has seen a dramatic rise in its operating costs, with a significant portion of that rise due to post-storm recovery repair.

Table 5J-1. Exposure to climate-related hazards of transportation assets and services throughout the state.

Assets, Regulations, Services	Changed Seasons	Coastal Erosion	Extreme Heat	Flooding (River and Land)	Landslides	Severe Winter Weather	Storm Surge	Tidal	Water Shortage (Drought)	Wildfire	Wind
Transportation Sector											
Operation and maintenance of land transportation including state roads, bridges, and culverts		*	*	*	*	*	*		*		
Pavement resurfacing operations and budgets			*								
Employee Safety			*	*		*				*	
Aviation Operations and Maintenance			*	*		*				*	*
Marine Transportation Operations and Maintenance		*				*	*	*			*
Ports (Marine and Inland)		*	*	*		*	*	*			*
Rail			*	*	*	*					
Public Transport			*	*		*					
Bicycle/Pedestrian	*		*	*						*	*
Freight and Logistics Plan			*	*						*	
2023-2032 STIP Development		*	*	*		*	*	*	*		
NC Moves 2050 Plan		*	*	*		*	*	*	*		
Stormwater Management				*				*			
Roadside Environmental (vegetation management)	*		*	*		*			*		
Roadside aesthetics (Lights)Rail			*	*	*	*					*
Public Transport Roadside aesthetics (Lights)			*	*		*					*

2. Overall Exposure

North Carolina's transportation sector consists of an interconnected system of assets and derived services. A changing climate undermines the system's ability to perform reliably, safely, and efficiently. Heavy precipitation, coastal flooding, heat, and changes in average precipitation and temperature could impact individual assets across all modes (Table 5J-1). These impacts threaten the performance (defined by national goals listed in 23 U.S.C. § 150) of the entire network, with critical ramifications for safety, environmental sustainability, economic vitality, congestion and mobility, and system reliability.

Freight movement at major ports can be delayed under extreme weather events that include heavy rains and/or high winds affecting crane operations and truck service.

For North Carolina, transportation systems that are most vulnerable to the recent observed and projected increases in precipitation intensity are those where stormwater drainage is already at capacity, where projected heavy rainfall events will occur over prolonged periods, and where changing winter precipitation increases transportation hazards from landslides and washouts.

Climate Stressors of Concern

Tropical Storms/Hurricanes

North Carolina has suffered the effects of numerous tropical storms and hurricanes. Changing air and ocean temperatures mean that storms may become more frequent and will very likely be more intense. These storms bring multiple damaging actions including wind, rain, storm surge, and increased wave activity. Hurricanes are usually associated with coastal areas where all these actions can impact transportation facilities. However, hurricanes often track inland and while they usually downgrade to tropical storms or depressions, they can still bring with them damaging winds and rain. A few examples include: Hurricane Hugo (1989), Hurricane Fran (1996), and Hurricane Florence (2018).

Increasingly, it is the varying combination of impacts associated with tropical storms and hurricanes that are causing disruptions to North Carolina's transportation infrastructure. Storm timing, wind intensity, speed, and direction can compound lunar tides exacerbating storm surge flooding, all of which will be increased by rising sea levels. Storm speed and track also play a role in the length of time that winds or rain act on a given area. Lower category hurricanes or tropical storms may cause less wind damage but they can still bring significant rainfall.

Storm-related disruptions include road closures due to debris, rainfall or storm surge flooding and wash out; bridge damage due to debris, flooding (overtopping), wave action damage, or foundation scour; pipe or culvert failures (washouts); airport disruptions or closures; port disruption or closures; and ferry terminal disruption or closures.

North Carolina's transportation system has already experienced the impacts associated with damage from past hurricanes. More intense tropical storms in the future could produce even more damage. The impact of tropical storms on land transportation could include more debris on roads and rail lines, interrupting travel and movement of people and goods. Storms of this magnitude could generate increased damage to signs, lighting fixtures, and supports. Along the coast, highways that are exposed to storm surge could be expected to have shorter functional life spans.

For air transportation, hurricane force winds can produce significant damage to airport facilities, including signals, signage and ground transportation, runways and terminals, parking structures, and facilities. In addition, such storms can cause more frequent interruptions in air service including system functionality and reliability, operations of runways and terminals, as well as internal and external vehicular access routes.

The impact of tropical storms on marine transportation could include damage to port and ferry infrastructure resulting from wave action and storm surges. Implications for facility maintenance and safety management include operations of ferry services and ports and facility safety. Tropical storms can also cause marine channels to fill in. This may impede general mobility along the waterways and the state's ferry service along the marine highway system.

Extreme Rainfall/Precipitation

Changing weather patterns are projected to concentrate rainfall into more intense storms. Changes in the amount, intensity, frequency, and type of precipitation could have a serious impact on transportation.



Heavy precipitation events, often associated with tropical storms, have resulted in severe problems for transportation infrastructure and operations. Rainfall from these events typically falls over multiple days, with increased runoff filling streams and rivers (fluvial runoff) leading to flooding of pipes and culverts, bridges, and roads.

Changing weather patterns may be producing more intense, isolated rain events not necessarily associated with tropical storms. These intense rain events generate significant localized runoff (pluvial runoff) that can result in dangerous driving conditions and can overload drainage systems causing water backups, resulting in street and highway flooding. Flooding can also disrupt rail operations. Flooding can impact railroad embankments and bridges, compromising railroad integrity. In addition, transportation construction activities can be disrupted by flooding and inundation. Intense rainfall can inundate partially constructed projects which can lead to costly delays as well as downstream sediment/water quality problems.

Sea-level rise

Low-lying coastal areas of North Carolina and the state's fragile barrier island system are immediately vulnerable solely to relative sea level rise. As sea level rises, the frequency of high-tide flooding (events typically without a local storm present) has increased by an order of magnitude over the past several decades, turning it from a rare event into a recurrent, and often, disruptive problem.[1,2]

When added to local storm effects, higher sea levels worsen the impacts of storm surge, high tides, and wave action[3], absent any changes in storm frequency and intensity. The long-term, upward shift in sea level is an underlying driver of impacts to the coast, essentially creating a new baseline upon which the effects of day-to-day tidal fluctuations and wave action are magnified.

The impacts of sea level rise could potentially affect the infrastructure and operations of both land and marine transportation systems in the coastal areas of North Carolina. Transportation infrastructure may be impacted by the inundation of roads, more frequent or severe flooding of low-lying infrastructure, the erosion of road base and bridge supports, and the loss of barrier shoreline due to sea level rise. Increased storm surges may also cause more frequent interruptions in travel on coastal and low-lying roadways and may also require evacuation of vulnerable areas.

The state's marine transportation system could also be affected. Rising sea levels may require some changes in port and ferry facilities to accommodate higher tides and storm surges. More severe storm surges may also result in interruptions to ferry services, shipping services, and port operations.

A few general aviation airports in close proximity to the water may be vulnerable to the impacts of sea level rise. Sea level rise could also increase maintenance and repair costs and result in a reduction of overall system reliability in vulnerable areas.

Temperature

Extended periods of high temperatures can cause significant damage to transportation infrastructure. Pavement and structure design parameters and material choices are derived from research regarding the impact of climate stressors, distress of materials, and estimates of service life.

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[1] Sweet, W., M. Menendez, A. Genz, J. Obeysekera, J. Park, J. Marra (2016). *In Tide's Way: Southeast Florida's September 2015 Sunny-day Flood* [in "Explaining Extremes of 2015 from a Climate Perspective"]. Bull. Amer. Meteor. Soc., 97 (12), S25–S30, doi:10.1175/BAMS-D-16-0149.

[2] NC King Tides Project. http://nckingtides.web.unc.edu/ Retrieved January 30, 2020.

[3] Theuerkauf, E. J., A. B. Rodriguez, S. R. Fegley, and R. A. Luettich Jr. (2014). *Sea level anomalies exacerbate beach erosion,* Geophys. Res. Lett., 41, 5139–5147, doi:10.1002/2014GL060544.



Higher temperatures could lead to softening of asphalt, the buckling of pavements, and traffic related ruts. Extreme heat can also produce unanticipated expansion and movement of bridge materials, and misalignment of rail lines. At airports, heat waves can produce heat-related weathering and damage to pavement.

Elevated temperature, combined with increased salinity and humidity, can accelerate deterioration in bridges and roads constructed with concrete.[4] Higher ambient temperatures and extreme heat events can negatively impact pavement performance and, in turn, increase costs due to increased maintenance or material upgrades to accommodate higher temperatures. Material upgrade costs are only modestly offset by less frequent maintenance.

It is possible that projected warmer conditions could have some positive effects. Milder winters may mean fewer winter storms reducing disruptions associated with snow, ice, and freezing rain.

Drought

While drought may not have many notable effects on transportation infrastructure in North Carolina, drier conditions could have impacts on the safety of the transportation system. Roadways, bridges, and airports located in drought-susceptible areas may be affected by the potential increase in wildfires. Smoky conditions could decrease visibility for road, air, and ferry travel, potentially causing delays and reduced safety.

Non-Climate Stressors of Concern

Land Use

According to the U.S. Census Bureau**,** North Carolina's population grew to an estimated 10.5 million people as of July 1, 2019[5]. From July 1, 2018 to July 1, 2019, the state's population increased by nearly 106,500 individuals. This marks the fourth year in a row that North Carolina has grown by more than 100,000 new residents. Only Texas (367K), Florida (233K), and Arizona (121K) gained more residents over the past year. With a growth rate of 1.0% since 2018, North Carolina grew twice as fast as the national average (0.5%) and was the 10th fastest-growing state.

With this population growth comes the need for more housing, transportation services, and infrastructure. Development associated with increased population requires changes in land use which in turn increases impervious surface area, decreasing rainfall infiltration and increasing runoff. Roadway embankment heights, bridge lengths and heights, as well as culvert and pipe sizes are based on certain land use characteristics within a watershed. As these characteristics change, stream and river flows change particularly in response to storm events. Increased urbanization is also linked to flashy stream flow, stream incision, and bank erosion, which can lead to the build-up of sediment that can block bridge and culvert openings.

Maintenance/Debris

The need for maintenance of all transportation facilities will likely increase as the effects of severe weather events increase. Pavement management, bridge maintenance, shoulder maintenance, asset management, maintenance of traffic, road weather management, vegetation management, and emergency repairs are all areas that will need to be addressed in response to storms, flooding, winter weather, and heat. Maintenance operations usually operate on a fixed annual budget cycle making it difficult to meet any emergent demands in addition to the life cycle needs of an aging system. For this reason, it is important for maintenance operations to prioritize needs and carefully allocate resources to achieve

[4] Khatami, D., and B. Shafei, (2017). Climate change impact on management of deteriorating bridges: A case study of US Midwest region. In 96th Transportation Research Board (TRB) Annual Meeting, January 8-12, Washington, DC., No. 17-04849
[5] United States Census Bureau - https://www.census.gov/newsroom/press-releases/2019/popest-nation.html



maximum long-term effectiveness[6]. Climate change and the associated increase in extreme weather occurrences is an important factor in the yearly estimation of maintenance operating budgets.

Pipes and culverts are common roadway features typically managed by maintenance units. Culvert failure can be gradual, as evidenced by dips in the overlying embankment, or failure can be catastrophic resulting in sudden loss of integrity threatening both the traveling public and downstream residents. Increased rainfall intensity and the associated increases in stream flow beyond culvert capacity can cause flows to back up, building hydraulic head and the risk of catastrophic failure. This situation is especially possible for poorly maintained culverts plugged with woody debris and sediment.

Aging Infrastructure

The increasing age of all transportation assets makes them more vulnerable to extreme weather events. While all fixed assets adhere to this concept, it is particularly applicable to North Carolina's older bridges, culverts, and pipes. For the first few decades of their useful life, properly designed culverts require little maintenance beyond clearing the occasional build-up of debris. However, as decades pass, steel and concrete age, watersheds urbanize, and maintenance forces will likely find themselves increasingly busy with demand maintenance. Older water conveyances are more likely to be under-designed for the changed watershed conditions around them. Older steel and concrete may also be degraded making it more susceptible to failure during runoff events at peak capacity.

Dam Breach

Many transportation facilities are located downstream of dams. Dam breach often results in sudden increases in stream flow that can be catastrophic downstream, washing out roadway embankments and inundating bridges and culverts that may already be at their limit of conveyance during an extreme rainfall event.

3. Examples of Impacts, Vulnerability, and Risk

Hurricane Florence / Record Breaking Rainfall and Storm Surge

Impact Summary

On September 14th, 2018, Hurricane Florence made landfall just south of Wrightsville Beach, NC. Florence was only a Category 1 storm when it struck, but the storm's massive wind field brought a huge storm surge to the coast, with water levels recorded at 10.1 feet above ground in New Bern, NC. Although the storm weakened as it slowly moved inland, it became the wettest tropical storm recorded in North Carolina with many places receiving record-breaking rainfall. More than 30 inches of rainfall was recorded in multiple locations. For example, Elizabethtown had 35.9 inches (913mm) and Swansboro had 33.9 inches (861mm).

[6] National Academies of Sciences, Engineering, and Medicine (2014). *Strategic Issues Facing Transportation, Volume 2: Climate Change, Extreme Weather Events, and the Highway System: Practitioner's Guide and Research Report*. Washington, DC: The National Academies Press. https://doi.org/10.17226/22473.

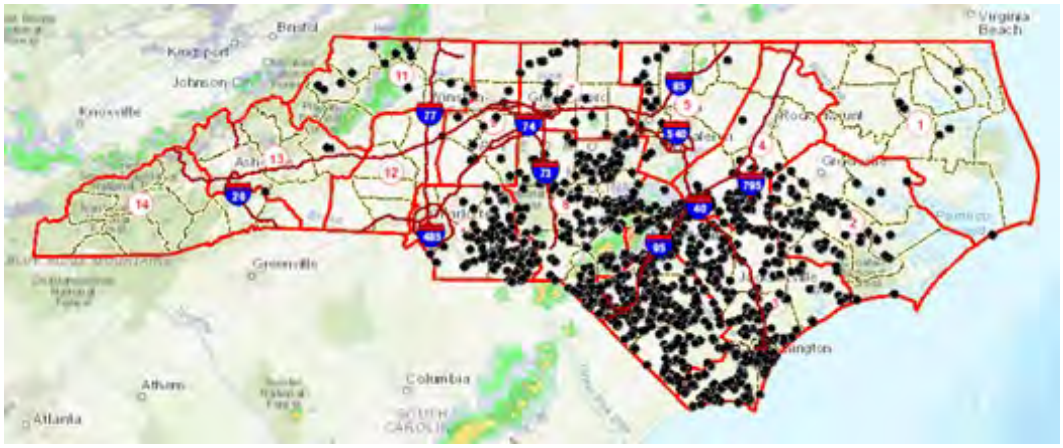


Figure 5J- 1: Approximately 2,500 individual road closures (black dots) resulted from Hurricane Florence

Wilmington International Airport and the Port of Wilmington were both closed. The City of Wilmington became entirely isolated as all roads to the city were flooded and deemed impassable. This included sections of I-40 and US 421. In addition, sections of I-95 in Lumberton and Fayetteville were also flooded and impassable. About 2,500 road closures were recorded.



Figure 5J- 3: I-40 near Wallace was closed for 9 days.



Figure 5J- 2: US-421 at the Pender/New Hanover County Line was closed for 10 days

Vulnerability and Risk

Hurricane Florence highlighted multiple vulnerabilities in the transportation network of eastern North Carolina. Around Wilmington, the *exposure* of coastal communities to storms was evident, as was the *sensitivity* of coastal regions to the compounding effects of wind, rain, wave action, and storm surge. System redundancy was also tested as multiple road routes, as well as air and port facilities were affected, effectively isolating the town of Wilmington for approximately 24 hours.



Figure 5J- 4: I-95 near Lumberton was closed for 8 days

Major highways in coastal areas serve as **critical evacuation routes**. Evacuation routes must be protected from flooding and damage, so they may be used for emergencies. Major highways in coastal areas also serve as critical routes for emergency personnel and supplies for post-storm recovery. Away from the coast, low-lying areas of the Coastal Plain are still vulnerable to heavy rainfall from slow moving storm systems.



Resilience Strategies

Update Engineering Standards

Instead of simply replacing the washed-out culverts on US 421 at the New Hanover/Pender County line, NCDOT engineers chose to design for better resilience. The culverts were replaced with two, 2-lane bridges at 562 feet long, providing significantly greater hydraulic. The first bridge is already complete, and the other is expected to open in 2020.

Improve Traffic Operations

As Hurricane Florence evacuation orders took effect, the NCDOT began implementing evacuation routing plans to support the additional traffic demands. During the storm, staff at the statewide Transportation Operations Center (STOC) established a routing room that was focused on monitoring real-time conditions and defining passable routes for emergency responders and critical freight movement to reach impacted areas. For the first time during a major weather event, the NCDOT used its newly developed drone program with resources from the Division of Aviation. This activation provided real-time imagery and video of affected routes, allowing staff to confirm if roads were passable for the public or accessible as detours for emergency vehicles.

Traffic operations preparation has continued after major events with procedural assessments, improving the real-time availability of traffic count data, coordination with partner agencies, and coordination with navigation companies to provide even better service during future storm events.

Flood Resilience Assessment

Following the effects of Hurricane Florence and a preceding event in 2016, Hurricane Matthew, an I-95/I-40 Flood Resilience Feasibility Study was commissioned to identify improvement options and estimated costs to increase flood resilience along the following corridors: I-95 from Benson to South Carolina; I-40 from Benson to Wilmington; and the NC-24 Connector from I-95 to I-40. The results and recommendations from the I-95/I-40 Flood Resilience Feasibility study are being considered in the I-6064 project which is widening and improving I-95 through Lumberton, NC.

U.S. 401 Washout in Rolesville (~1000-year rainfall event)

Impact Summary

On June 8, 2019, an intense rain storm caused the headwaters of the Little River to flood, washing out part of highway US-401 near Rolesville, northeast of Raleigh. The storm dropped between 6 and 9 inches of rain between Rolesville and Youngsville in less than 5 hours. NOAA calculations estimated this rain event had a 1-in-1,000 chance, or 0.1%, of happening in any given year.[7] The rapid increase in runoff to the Little River inundated the existing 4-barrel culvert, overtopping the roadway and ultimately washing out the roadway embankment on either side of the structure.



Figure 5J-5: The Little River washed out US- 401 in northeast Wake County

[7] NOAA Atlas 14. Precipitation-Frequency Atlas of the United States - Volume 2. Version 3.0: Delaware, District of Columbia, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia; rev. 2006



Vulnerability and Risk

Flooding vulnerability is not confined to the coastal and low-lying areas of North Carolina. Likewise, it is not only associated with tropical storms or hurricanes. Changes in land use can lead to increased storm water runoff, which when combined with aging pipes or culverts can result in hydraulic conditions near design limits. Warming atmospheric conditions will mean that the air can hold more water vapor, likely leading to more frequent extreme precipitation events that could lead to failures like the one near Rolesville.

Resilience Strategies

Rehabilitation and armoring

Rehabilitation of existing pipes and culverts by adding headwalls or wingwalls where water enters the structure can protect the pipe and roadway embankments from washing out. Low-lying road embankments vulnerable to overtopping by floodwater can also be armored with riprap to protect them until the water recedes. Both these options make the roadway resilient to floods but do not protect the traveling public.

Real-time/Early Warning Systems

North Carolina Emergency Management (NCEM) has developed a Flood Inundation Mapping and Alert Network (FIMAN). The system provides real-time data on stream elevation, rainfall, and weather parameters from over 550 gages across the state. The data are posted on the internet to provide real-time flood inundation maps and alerts. NCDOT has collaborated with NCEM to produce a pilot version of FIMAN for transportation (FIMAN-T). By combining the FIMAN real-time gage data and flood prediction models with roadway and bridge data, NCDOT will be able to provide real-time flood inundation maps and alerts. NCDOT will even be able to predict 24 to 48 hours ahead when roadways and bridges may flood.

Collaboration

Partnering with local governments and planning organizations to better contain stormwater runoff in developing watersheds protects infrastructure and improves downstream water quality. Planning concepts like Low-impact development (LID) promote land planning and engineering design to manage stormwater runoff as part green infrastructure.

Coastal Highways / Storm Surge

Impact Summary

On September 6th, 2019, Hurricane Dorian made landfall at Cape Hatteras, as a Category 1 Hurricane. Ocracoke Island just south of Cape Hatteras took the main hit. The storm moved quickly, but it left the island ravaged from waters that rose like a tidal wave in only two hours. An approximately 7-foot storm surge from the Pamlico Sound inundated the village of Ocracoke flooding homes and destroying businesses. Floodwaters in the village reached the greatest depths since a 1944 storm.

The storm destroyed the protective dune line between NC-12 and the ocean, as well as breaking and buckling about 1,000 feet of pavement. Damage to NC-12 in Hatteras Village, just north of Ocracoke Island, prevented access to the Hatteras-Ocracoke Ferry Terminal. For days the only people who could get to the island were emergency relief personnel and resources.

Repairs began immediately with contractors installing sandbags, reconstructing the dune line, and completely rebuilding and repaving the roadway. The NCDOT Ferry Division's dredge, the *Manteo*, pumped sand from the old Hatteras ferry channel to supply sand for the reconstruction. NCDOT's total repair costs for Hurricane Dorian were approximately $45 million.



Figure 5J- 5: NC-12 on Ocracoke Island washed out after Hurricane Dorian

Additionally, powerful storms impacted the area in mid-October and mid-November, causing additional damage to NC 12 near Rodanthe and delaying the re-opening of NC-12 on Ocracoke Island. These storms were nor'easters—non-tropical, low-pressure systems that usually remain offshore and produce strong northeast winds along the coastline. While nor'easters are not uncommon during the fall, winter, and early spring, these were particularly strong.

Vulnerability and Risk

The vulnerability and fragility of North Carolina's Outer Banks and NC-12 is well established. The Civilian Conservation Corps constructed dunes to establish and protect sections of the Outer Banks in the depression-era, and the highway has been experiencing storm-related disruptions since during its construction in the late 1940's. While NC-12 has been washed out before, Hurricane Dorian and the subsequent nor'easters highlighted specific problems and costs associated with multiple storm events, both hurricanes and non-tropical storms, in close succession.

Resilience Strategies

Short Term

Beach and dune nourishment projects provide short-term solutions to help preserve NC-12 and other properties on the Outer Banks. In response to severe beach erosion and a breach of NC-12 caused by Hurricane Sandy, the Federal Highway Administration in March 2013 approved emergency relief funds to pay for a beach nourishment project that used 1.6 million cubic yards of sand dredged from two sandbars in the Atlantic Ocean. The project – a short-term solution to preserve the highway until a long-term solution to the breach could be developed and built – was completed in fall 2014.

Long Term

As the long-term solution, NCDOT is elevating a portion of NC-12 onto a 2.4-mile bridge over the Pamlico Sound that extends from the southern end of the Pea Island National Wildlife Refuge into northern Rodanthe. This includes the section of NC-12 known as the "S-curves" that was washed out during Hurricane Sandy in 2012, and Hurricane Irene in 2011.

Real-time/Early Warning Systems

NCDOT is also collaborating with NCSU and the UNC-Institute of Marine Science to improve computer-modeled storm surge data with that available through the Coastal Emergency Risk Assessment (CERA) in order to predict storm surge conditions 24 to 48 hours ahead. These data are being incorporated into FIMAN-T for coastal areas to predict where storm surge may affect roads during storm events.

Rockslides / Extreme Precipitation

Impact Summary

Rockslides (and smaller landslides) can damage and disrupt transportation corridors leading to roadway and railway closures which in turn lead to economic losses and expensive repairs. The causes of landslides are directly related to geology, hydrology, topography, vegetation, and human-related ground disturbing activity that has destabilized slopes. While rockslides themselves are not specifically a climate hazard, their occurrence is directly linked to the frequency and magnitude of precipitation events.

In the western counties of North Carolina, a December 2018 snowstorm with 10 inches of accumulation in many locations (maintenance/repair costs $45 million), followed by a January 2019 snow/ice event (maintenance/repair costs $20 million), then a third storm occurred in February 2019 leading to a February 22nd rockslide in Haywood County. The rockslide closed I-40 in both directions for five days (maintenance/repair costs $16 million). This section of road carries over 26,000 vehicles a day with significant truck traffic. NCDOT's detour was a long but familiar one of approximately 150 miles.



Figure 5J-6: Boulders blocking I-40 in both directions following a 2009 rockslide

This portion of I-40 is notorious for rockslides and rocks falling onto the highway. In 1985, a severe rockslide buried the westbound entrance to one of two tunnels that carry the highway through the gorge. Repair of the slide area and the tunnel required shifting westbound traffic to the eastbound tunnel, while eastbound traffic was diverted onto a temporary viaduct around the tunnels. In July 1997, a rockslide near the Tennessee state line closed the entire road for nearly three months.

On October 25th, 2009, a large rockslide occurred at mile marker 2.6 along I-40 near the Tennessee state line. The 150-foot-tall rockslide closed the interstate in both directions for several weeks. Engineers installed 543 bolts into the rock face designed to keep the rock wall from shearing off in the future.

Vulnerability and Risk

While smaller-scale slope failures or debris flows are known to have occurred in the Piedmont and Coastal Plain of North Carolina, the most vulnerable transportation assets to slope failures are the roads and rail lines in the foothills and mountains of western North Carolina. The mountainous topography of western counties often means that these vulnerable transportation links have little redundancy, with road closures resulting in very long detours or sometimes, no detour at all.

Resilience Strategies

Presently, the NCDOT has two avenues of response to rockslides: (1) ***emergency mitigation*** and (2) the ***consideration of resilience in slope design***.

NCDOT's biggest asset in the mountains is a small but well-trained and credentialed staff capable of producing specific mitigation plans within 24 to 72 hours.

The NCDOT Geotechnical Engineering Unit has developed an asset management framework with ratings that take in to consideration the impact of a potential failure along a route and consider impacts of detour disruption. The NCDOT is carefully evaluating approaches to new designs and mitigation of landslides. These approaches consider the likelihood of any geotechnical assets failing and potential consequences. With changing weather conditions and the increased likelihood of more intense precipitation events, the



designing slopes is a moving target due to the wide-ranging sensitivity of inputs. Topographic and environmental restrictions on right-of-way constrain slope designs and make recommendations such as wider shoulder widths not feasible.

Preliminary investigations have also begun into known high levels of Magnesium oxide (MnO) in certain weathered rock and soils. Indications are that high MnO levels may be associated with increased failure risk. Mapping of high MnO areas need to be incorporated with existing North Carolina Geologic Survey (NCGS) County Hazard Maps.

4. Summary

NCDOT has already begun multiple individual or regional projects and initiatives to address past weather-related disruptions and to develop adaptation strategies to prepare for, withstand, and recover from future events. These individual efforts will need to be aligned and combined into a more holistic, statewide approach to resilience.

The STC is a network of critical multimodal transportation corridors considered to be the backbone of the state's transportation system. These 25 corridors, 5 international or major freight airports, and 3 seaports, move most of our freight and people, link critical centers of economic activity, and support interstate and international commerce. They must operate well to help North Carolina attract new businesses, grow jobs and catalyze economic development. These strategic corridors are considered the state's highest priority when analyzed within the framework of regional or local transportation plans.

NCDOT secured funding in November 2019 through the NC General Assembly with Senate Bill 356 to:

- Establish the Transportation Emergency Reserve as a specific fund within NCDOT
- Expand FIMAN-T to other areas of the state
- Perform a Flood Risk and Vulnerability Assessment of the state's Strategic Transportation Corridors (STC; see text box).
- Expand NCDOT's work with Living Shoreline projects

The ***American Transportation Infrastructure Act (ATIA) of 2019***, currently before the Senate, will authorize $287 billion from the Highway Trust Fund over the next 5 years. The five-year funding level is more than a 27% increase above the Fixing America's Surface Transportation Act (FAST Act) of 2015. While resiliency was already a required planning factor in the state Transportation Improvement Program under the FAST Act, ATIA will specifically invest $4.9 billion on a new resiliency program for roads and bridges. NCDOT will work to secure a portion of these funds for NC projects.

Forward-looking plans and policies will need to be developed, and NCDOT is currently finalizing its ***NC Moves 2050 Plan***. This is the culmination of a two-year, multi-phased study that involves examining all aspects of North Carolina's transportation system. Input has been collected from local governments, planning organizations, and the public about transportation performance and anticipated challenges in the future. The plan is focused on creating a more responsive, diverse and inclusive transportation system for keeping people and freight moving safely and efficiently.

NCDOT has been working closely with the Department of Public Safety (NCDPS), specifically Emergency Management, to develop early warning strategies (FIMAN-T) and develop emergency response plans. NCDPS's newly formed ***Office of Recovery and Resiliency*** provides another collaborative opportunity to provide resources and tools to communities with vulnerable populations and help them become more resilient. NCDOT is also working locally in eastern North Carolina in partnership



with the North Carolina Division of Coastal Management and the North Carolina Coastal Federation to implement Living Shoreline projects and LID practices.

Continued collaboration and information sharing with the U.S. Department of Transportation's Volpe National Transportation Systems Center, Federal Highway Administration, other state DOT's, and international partners like Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and Water Management) will help NCDOT stay at the forefront of innovation, adaptation practices, and design concepts.

Moving forward, NCDOT will develop a comprehensive resilience policy to guide decision making in long-range transportation planning; individual project planning and design; and operations and maintenance. By addressing these three main areas, the department will be able to deliver a robust transportation system that can adapt to, withstand, and quickly recover from climate-related hazards.

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Water & Land Resources

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K. Water and Land Resources

Key Observations

- Reliable, clean supplies of freshwater and land resources are essential to human and ecological health.
- Water availability affects all sectors and is vulnerable to climate change and increased demands from a growing population.
- The Water and Land Resources sector has directly managed assets and provides a number of services that require a uniquely trained and experienced workforce.
- Water infrastructure funding programs cannot meet existing demand to help communities meet their water infrastructure needs without considering additional needs due to climate change.

Critical Impacts and Resilience Strategies

- Dam and water infrastructure impacts from flooding are a big concern.
- Landslides are increasing due to extreme rainfall events.
- Water quality impacts to our drinking water and ecosystems as a result of polluted runoff are a continuing issue. Sediment is the largest pollutant by volume of our surface waters and carries excess nutrients and many other pollutants with it.
- Stormwater requirements and design specifications including rainfall intensity statistics should be assessed for future needs and revised as needed.

1. Introduction

The Water and Land Resources sector is made up of those Divisions within the North Carolina Department of Environmental Quality (DEQ) that regulate, protect, conserve and provide technical assistance on matters of water quality, water quantity, water supply, land and mineral resources, wetlands, dam safety, landslide mapping, stream and wetland restoration, and water infrastructure. Together, this sector provides oversight for more than 5,300 public water supply systems, 6,000 dams, 730 mines, 8,000 active construction sites, 18,000 state and National Pollutant Discharge Elimination System (NPDES) stormwater facilities, 2,857 wastewater discharge permits, 17 river basins, 1.6 million acres of shellfish growing waters, and 285 miles of recreational "swim" beaches throughout the state. Its management and planning activities are critical for the welfare and safety of the public, the continued growth of the economy, and the ecological health of water and land resources. The assets and responsibilities of primary concern to the Water and Land Resources sector are as follows:

- Land and Water Quality
- Water Quantity
- Water Infrastructure
- Dams
- Mines
- Mineral Resources

The primary Divisions of DEQ performing these efforts are:

- The ***Division of Water Resources (DWR)*** is responsible for surface and groundwater quantity and quality throughout the state. DWR issues pollution control permits, monitors permit compliance, evaluates environmental water quantity and quality, and carries out enforcement actions for violations of environmental regulations.



- The ***Division of Energy, Mineral, and Land Resources (DEMLR)*** has responsibilities that include environmental permitting and compliance for activities and developments that include mining and mine reclamation, dam safety, stormwater quality, sedimentation and erosion control, and landslide and geologic mapping.
- The ***Division of Mitigation Services (DMS)*** is a DEQ initiative that restores and protects streams, wetlands and buffers to offset unavoidable environmental impacts.
- The ***Division of Water Infrastructure (DWI)*** provides financial assistance for projects that improve water quality. Programs within DWI fund many types of projects, including sewer collection and treatment systems, drinking water distribution systems, water treatment plants, stormwater management systems, and stream restoration.
- ***The Division of Marine Fisheries (DMF)*** is responsible for monitoring water quality in the coastal region for recreational use and classifying shellfish growing waters.

Reliable, clean supplies of freshwater and land resources that meet their intended uses are essential to human and ecological health. The Water and Land Resources sector supports effective management of lands, wetlands, water resources, and floodplains to meet those goals. The sector is central to the economy and contributes significantly to the resilience of many other sectors, including Agriculture, Ecosystems, Energy, Health and Human Services, Public Safety, Transportation, Coastal Resources, Commerce and Business, and Housing, Building and Support Services. Because of a growing population and aging infrastructure, water supply systems, sewerage systems, and dams face considerable risk, even without anticipated future climate change impacts.

Providing environmental protection and promoting wise use of land and water resources for the citizens of North Carolina are the primary responsibilities of all the Divisions within DEQ through multiple avenues:

- administration of the laws, policies and rules established by the U.S. Environmental Protection Agency;
- administration of laws, policies and rules established by the N.C. General Assembly and several state commissions including the Environmental Management Commission, Coastal Resources Commission, Sedimentation Control Commission, Mining Commission, Oil and Gas Commission, Marine Fisheries Commission; and
- permitting, compliance, technical assistance, education, stream and wetland mitigation, emergency response, grants and river basin and watershed planning efforts.

2. Overall Exposure

As a result of the increasing stress imposed by a changing climate as well as the pressure imposed by an increasing population, the hazards that historically impacted assets managed by the Water and Land Resources sector of the North Carolina government will be of increasing concern in future years. This is demonstrated in the exposure matrix below (Table 5K-1).



Table 5K-1: Exposure of assets, regulated activities, or services provided to the state of North Carolina through the Water and Land

Assets, Services, Regulations	Extreme Heat	Flooding (River and Land)	Water Shortage (Drought)	Changed Seasons	Landslides	Saltwater Intrusion	Storm Surge	Tidal Flooding	Wildfire	Dam Failure
Land and Water Quality										
Sedimentation, stormwater and wastewater permitting	*	*	*			*	*	*	*	*
State-owned groundwater monitoring wells		*				*		*		
Monitoring, survey and invasive species removal programs for waterbodies	*	*	*	*		*				
State stream and wetland restoration sites	*	*	*			*				*
Landslide mapping program	*	*			*				*	
Shellfish Growing Area Program	*	*		*		*	*	*		
Recreational Water Quality Program	*	*		*			*	*		
Water Quantity										
Municipal water supply			*		*	*			*	*
Agricultural water use	*	*	*	*		*	*			*
Various water supply watersheds statewide		*				*				*
Water Infrastructure										
Public water systems	*	*	*		*	*	*	*		*
Wastewater treatment plants	*	*					*	*		*
Septic systems		*				*	*	*		
Water treatment plants	*	*	*			*	*	*		*
Dams										
State-owned dams		*			*				*	*
Dam safety program		*			*					*
Privately owned dams		*			*				*	*
Mines										
Regulation of active mines	*	*	*		*		*		*	*
Other										
DEQ staff	*	*	*		*		*	*	*	*
Floodplain development		*								*



Climate Stressors

Heavy precipitation events (3 inches or more in a day) are on the rise in North Carolina, with the last four years (2015–2018) having seen the greatest number of events since 1900.[1] When extreme rainfall exceeds the limits of engineering design standards set by law that are used to design dams, stormwater, sediment control and flood control structures, both the rainfall and associated flooding can cause dams and flood control structures to overtop and/or fail. The resulting rapid release of stored water can cause significant damage downstream in the floodplain, including houses, roads, utility services, surface water pollution and even additional dams. The destruction of dams and surface water pollution can jeopardize municipal drinking water, health of streams, damage transportation and utility corridors and impact cooling water for thermo- and hydro-electric plants.

Heavy precipitation events can deliver sediment, untreated sewage, and animal waste into waterways, contaminating water supplies, and flooded lands degrading water quality and causing health hazards. Sediment and other accompanying pollutants degrade biotic integrity in streams. It may also make septic tanks and spray fields inoperable. Contaminated source waters can interrupt drinking water service when water treatment plants cease to function nominally as well as degrade their overall ecosystems. Heavy precipitation events can also trigger precautionary shellfish harvest closures and recreational swimming advisories.

Rising sea level can impact water supplies for municipalities and industries. The degree of impact may vary, depending on whether it is caused by temporary flooding during storm surge or extreme high tides, or because a low-lying area becomes permanently inundated. Treating saline water for drinking water is very costly. Infrastructure improvements and interconnections to other water systems (septic tanks and pump stations) may be needed. Saltwater intrusion can also negatively affect ecosystems and agriculture as waters shift from fresh to brackish.

Drought emerges from many factors, including prolonged high temperatures combined with decreased precipitation. A vicious cycle can emerge since drought conditions tend to increase water demands for agriculture, human consumption, energy, and in-stream uses. Droughts have the potential to impact the state's economy through agricultural losses and water restrictions. It is likely that future severe droughts in North Carolina will be more intense due to higher temperatures leading to increased evaporation.

Non-Climate Stressors

An increasing population in North Carolina is leading to not only increased demand for water and related services but is also creating land use change and increased runoff in many areas of our state. As a result, water resources stressed by climate change will be further impacted by a growing population in many areas of the state.

It is also important to recognize that as rural water (i.e., both drinking water and wastewater) utilities face these climate change issues, it is in the context of socio-economic changes that also impact the system's resiliency. While the state may be increasing in population overall, many rural areas are losing populations and larger water customers such industrial and commercial facilities. In addition, like many urban areas, water customers are using less water (which is good from a water conservation point of view). All of these issues result in less revenue. At the same time, costs are increasing for construction and operations. These all dictate higher water bills since most water utility expenses are fixed. This leads to a deficit in management capacity in these smaller systems to implement utility best practices, such as asset management planning, needed to provide safe and environmentally sound water and sewer services. All of these issues create water affordability pressures for low-income residents in these rural

[1] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K.D. Dello, J. P. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: *North Carolina Climate Science Report*. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr

communities. Looking ahead, these systems will need significant resources to address both socio-economic and climate change concerns.

Aging infrastructure and limited surface water storage are increasing the stress on our state's water and land resources. This issue is exacerbated by limited resources available for maintenance and replacement of growing water distribution, treatment infrastructure and dams. In North Carolina this infrastructure is privately and publicly owned. Private water providers and dam owners, like their public counterparts, find maintenance, repair and replacement challenging due to limited resources. Whereas public providers have governmental mechanisms such as municipal bonds, property and taxing assessments, private operators have fixed incomes and may find maintenance and repair prohibitive in some cases.

All of these issues create challenges in planning for water infrastructure projects and paying for those projects. For example, drought can increase efforts to conserve water during the drought which can create permanent reduction of water usage. For example, a study of 119 utilities in North Carolina by the UNC Environmental Finance Center indicate that while the number of connections increase by 382,359, water usage over that same time period decreased by 11.7 millions of gallons per day (MGD). This success in water conservation can also result in a long-term reduction in water utility revenue. At the same time, additional rainfall will create more financial stress if the utility has significant inflow and infiltration on the sewer portion of the utility increasing utility sewer expense. As the climate oscillates between extremes, it creates challenges to utilities to determine the appropriate capital improvement priorities while trying to keep water bills affordable for the community's water and sewer users. This will increase the demand on the water infrastructure funding grants to provide subsidized financing that can significantly increase infrastructure needs over the next 20 years. These estimates were generated before the impacts of Hurricanes Matthew and Florence.

In the following section, we provide examples of impacts, vulnerabilities, risks, and resilience strategies for nine of the principal climate-related hazards that the Water and Land Resources sector will remain responsible for addressing within North Carolina's state government.

3. Examples of Impacts, Vulnerability, and Risk

Dam Failure/Flooding and Heavy Precipitation

Impact Summary

The Dam Safety Program within DEMLR is a regulatory agency and as part of its responsibilities responds to emergency situations and incidents that could cause dam failure. Dam failure can be lethal, damage property, and disrupt local or regional economies. Long-term economic impacts may include diminished property values around or below the impoundment.

Following an incident such as dam overtopping, dam staff must respond in a timely manner with Emergency Management to assess the situation and deploy resources needed to avoid a failure situation. Examples include installing pumps, sandbagging, and using heavy equipment to move earth. In times of imminent threat of failure, evacuation protocols must be initiated. During recent hurricanes in 2016 and 2018, greater than 50 dams failed in North Carolina, causing millions of dollars in damage and forcing the evacuation of more than 500 homes. In 2017 and 2018, the state breached two dams under controlled and permitted conditions as a result of damage from Hurricane Matthew in 2016.

Vulnerability and Risk

All regulated dams in the state are inspected on a tiered priority basis ranging from once per year for "High Hazard Coal Ash Dams" to once every five years for "Low Hazard Dams." Hazard Classification



(Table 5K-2) does not measure likelihood of failure but rather the negative consequence should the dam fail. For example, if a dam were to fail and the consequence would be loss or life due to impact to a home or cause over $200,000 in property damage it would be considered "High Hazard". There are nearly 1,300 "High Hazard" dams in NC, second highest in the United States.

The *sensitivity* of any given dam relates to its age, structural integrity, design impoundment capacity, spillway capacity, design certification, integrity of the building materials, industrial activities that put loading on the dam (e.g., coal ash), maintenance and operation status, and financial resources of the owner/operator. Deterioration in any one or a combination of these factors could result in dam failure. The potential consequences of dam failure include loss of life, property damage, damage to the environment from pollutants stored in the dam impoundment, and health and economic impacts due to damaged utilities.

Table 5K-2: Hazard Classification of dams subject to inspection by the Dam Safety Program.

Hazard Classification	Description	Quantitative Guidelines
Low	Interruption of road service/low volume roads	Less than 25 vehicles per day, Less than $30,000
	Economic Damage	
Intermediate	Damage highways/interruption of service, Economic Damage	25 to less than 250 vehicles per day, $30,000 to less than $200,000
High	Loss of human life, Economic damage, Probable loss of human life due to breached roadway or bridge on or below the dam	Probable loss of 1 or more human lives, More than $200,000, 250 or more vehicles per day

The adaptive capacity of any given dam hinges on the financial, engineering, and construction resources of the owner or operator to correct deficiencies and relieve threat to that dam's safety. This ability requires time and financial resources, however. During an emergency situation, engineering responses and modifications are limited. Pumping impoundments down or performing emergency breaches are risky and require human and financial resources that are not always readily available.

Adaptive capacity by dam owners and the state agency that regulates dams in North Carolina varies widely. Solutions to correct deficiencies and respond appropriately to emergencies depend on the financial resources of the dam owners and the state's resources. The risk of dam failure is growing due to increases in frequency and severity of heavy rainfall events, including hurricane events. Risk varies depending on location within the state.

The Piedmont and Mountain regions of North Carolina have a higher number and density of dams, as well as a higher population and population density, than the Coastal Plain due to topography and stream density. The majority of recent dam failures occurred in the Coastal Plain due to a number of recent heavy precipitation and hurricane events that have struck that region. The Coastal Plain typically has lower population density, more erodible soils, but the topography is not as steep as in the Piedmont and Mountain regions giving longer times for inundation. In contrast though, had the western regions of the state received the same storms there would have been greater impact to lives and property and therefore a much higher risk for our state.



Resilience Strategies

Enhance Dam Safety

Increasing the adaptive capacity of the state Dam Safety Program rests within the tools and resources it is provided. North Carolina has 17 Full Time Equivalents (FTEs, i.e., budgeted positions) funded through appropriations, receipts and federal grants to ensure compliance on 6,000 dams that have been inventoried in North Carolina. These FTEs have been distributed throughout 8 offices around the state to address construction plan approvals, Emergency Action Plan approvals, inspection and compliance and respond to emergency situations on dams as they arise resulting in an average of 353 dams per FTE. Resources to increase staffing and salaries in this very focused field of engineering and safety should be addressed to accomplish the missions of the dam safety program and to meet the needs of North Carolina. That is on average 353 dams per FTE. Also, because of the varying financial abilities by dam owners to operate and maintain their dams the state needs to develop new options and funding resources to address, at least on an emergency basis, ways to respond to those emergencies, including enhancing the capability to drain impoundments and implement emergency breaches to render the dam safe.

Increase Dam Releases

During large rainfall events, either from large tropical cyclones or heavy precipitation events, the state Emergency Response Team (SERT) might require dam owners to increase discharges to prevent overtopping. Such procedures have not been tested and studied. In most cases, the Dam Safety Program would look at evacuation of the downstream vulnerable population as the appropriate emergency action. A widespread, extreme precipitation impact from a slow-moving extensive tropical cyclone could be reduced by a coordinated SERT message to dam owners to increase dam releases to drawdown impoundments. The volume of releases prior to such events may reduce flooding downstream and would definitely reduce impacts from dam failure. One of the issues that remains an obstacle here is the inability of many dams to drain their impoundment levels.

Advance Emergency Action Plans

North Carolina also has requirements for dam owners to submit Emergency Action Plans (EAPs) which lay out a plan to the owner and the state on what to do and whom to contact in the event of an emergency. The state has had this requirement for the last 5 years for "High" and "Intermediate" Hazard dams and has received and approved over 50% of these. Advancing this program and securing the outstanding EAPs and dam safety education is an ongoing priority and a key way to build resilience. Resources to permanently fund four EAP FTEs are imperative to re-establish this program which was only marginally funded by non-recurring funds between 2014 and 2017.

Modeling and Predictions

The state Dam Safety Program is currently performing hydrologic and hydraulic (H&H) modeling, using hurricane disaster recovery funding, on many “High” Hazard dams in the Neuse and Lumber river basins and plans to initiate a study in the Cape Fear river basin in 2020. These studies will determine hydraulic loading of the dams and the hydraulic capacity of their spillways. This information helps the state to understand the current predicted resiliency of the dams in the study and to help focus its limited resources in times of heavy rainfall or emergency.

Resilience development for dams and the Dam Safety Program will continue to require resources, public and private, to further develop the EAP program, expand the H&H modeling efforts to all river basins in the state, provide education and resources to dam owners and to upgrade or remove existing dams that do not meet the engineering standards required by law. Increased studies on these dams, updated statutory language in our law, along with the efforts mentioned above will support improvements in resilience for North Carolina.



Water Quality/ Flooding and Heavy Precipitation

Impact Summary

Extreme storm events increase nonpoint source pollutant loading due to the larger volume of runoff, exceedance of stormwater control capacities, and increased mobilization of pollutants, sediment, and sediment-associated pollutants. Flooding can result in increases in inflow and infiltration and more frequent sanitary sewer overflow events. In addition, wastewater plants, onsite septic systems, hog manure lagoons, and other sources of pollutants can become inundated and release pollutants which would be controlled under normal conditions. The frequency and magnitude of extreme storm events is expected to increase.

Vulnerability and Risk

Nutrients, sediment, pathogens, and chemical constituents are transported in runoff to surface waters during rain events. Extreme events greatly increase the loading of these nonpoint source pollutants. Many areas do not have stormwater controls and runoff directly enters surface waters. Urban areas frequently have stormwater controls, but these are usually not sized to handle events greater than the 1-year, 24-hour storm.

Sewer lines often occur in low-lying areas and may be susceptible to inflow and infiltration. When an area is inundated, water can enter sewer systems through manholes and cracks in lines resulting in the treatment plant being overwhelmed with the additional load. Sewage can also leak from sewer lines in parts of the system away from flooded areas or cause a sanitary sewer overflow (SSO) at manholes or treatment plants.

Unanticipated releases of pollutants can occur from inundation of storage facilities, such as hog lagoons and onsite septic systems, which may be located in floodplains. The result is that surface waters receive loadings of a wide variety of pollutants that result in exceedances of the state water quality standards for human health and aquatic life. Increased nutrient loading, in addition to warmer water temperatures, also creates additional environmental and public health concerns over the potential influx of harmful algal blooms.

The sum of these pollutants found in runoff also poses the risk of increasing the amount of closures to shellfish growing areas and recreational waters along the coast. Using standards set forth by the Food and Drug Administration (FDA) and Environmental Protection Agency (EPA), bacteria levels must remain below a certain threshold to maintain usability for harvest of shellfish as well as recreational use. As pathogens and nutrients increase in the watershed beach closures will increase and result in a shortened shellfish harvest season.

Resilience Strategies

There are several strategies to increase North Carolina's resilience to water quality impacts from flooding, including the following:

Land use guidance

One critical strategy is to guide land use in riparian zones and floodplains. Natural land adjacent to waterways attenuates pollution from overland runoff. Several watersheds in North Carolina have rules that protect riparian buffers, typically enacted due to nutrient over-enrichment. The NC Flood Act of 2000 requires that communities regulating land uses prohibit certain uses in the 100-year floodplain, including new solid waste disposal facilities and sites, hazardous waste management facilities, salvage yards, and chemical storage facilities shall not be permitted, except by variance. Expanding and enforcing these protections statewide would increase the capacity of the landscape to assimilate pollutants before they



enter waters of the state. In addition to the water quality benefits, riparian buffers slow down and store water from precipitation events which helps reduce the severity of flooding.

Through ordinances and regulations, state and local government can encourage siting development and pollution sources away from riparian areas and floodplains. Utilities can continue to flood-proof assets and rehabilitate sewer infrastructure to reduce the risk of inflow and infiltration and sanitary sewer overflow. Government and extension agency staff can also work with land owners and operations managers to plan for extreme floods.

Voluntary Removal

A near-term priority is to identify animal operations, waste lagoons, wastewater treatment plants, industrial facilities, fields for land application of wastes, and other potential sources of pollution that are located within floodplains or flood prone areas. In some cases, these facilities can be moved or removed. The Department of Agriculture and Consumer Services manages a buyout program that provides financial assistance to owners of high risk and previously flooded animal operations to voluntarily close out their facilities. Bolstering this program and creating similar programs for other facilities in floodplains would make it possible for more potential contaminant sources to be voluntarily moved out of these high-risk areas.

Stormwater Control Measures

Another strategy is to encourage stormwater control measures to be incorporated into new development as well as implemented as retrofits to existing development or other activities (e.g. agriculture). Stormwater control measures capture precipitation close to where it falls and facilitate treatment and storage, reducing the amount of pollution that ends up in nearby streams. These practices can include cisterns, rain gardens, constructed wetlands, bioretention, and permeable pavement. Where there are issues with sanitary sewer overflows, implementation of distributed stormwater control measures can help reduce the occurrence and severity of overflows.

Asset Mapping

The state can also encourage sewer and stormwater infrastructure mapping and inventory efforts. DWR administers several grant programs that provide assistance for these activities; Nonpoint Source Management grant program, Water Quality Management grant program, and the Water Resources Development grant program. These programs should be continued and expanded where possible. When municipalities understand where their assets are, how they are connected, and the condition they are in, they can make informed decisions about capital improvements.

Data-driven Decision Making

As with any environmental program, more data and research support better resiliency planning and decision-making. DWR can, either internally or with academic partners, investigate data needs to better understand the sources and amount of nonpoint source pollution, as well as evaluate effectiveness of the DWR permitting requirements and programs that are intended to manage nonpoint source pollution.

Adaptive capacity of the Shellfish Sanitation and Recreational Water Quality Program to meet growing needs associated with increased rainfall and flooding is dependent upon continued adherence to guidelines set by the Interstate Shellfish Sanitation Conference contained in the National Shellfish Sanitation Program Guide for the Control of Molluscan Shellfish Model Ordinance, EPA's BEACH Act, and the National Beach Guidance and Required Performance Criteria for Grants Program.



Water Availability / Drought, Heat, and Precipitation

Impact Summary

Historical data for North Carolina indicate that precipitation has become more variable, stream low flows are decreasing in many areas, and drought frequency is increasing. Longer-term droughts are expected to intensify in the Southeast due to longer periods of dry weather and more extreme heat.[2]. An increase in drought frequency and/or intensity, coupled with higher demands from an increasing population, could compromise stream ecology, threaten water supply reliability, and affect treatment requirements for both water users and dischargers.

Vulnerability and Risk

Water resources are critical needs for a wide variety of sectors including Agriculture, Ecosystems, Public Water Supply, and Energy production. In many cases, water requirements are sensitive to timing and quantity. For example, municipal water supplies see their highest demands during the summer. The predicted increase in precipitation variability and evapotranspiration due to higher temperatures will disrupt the current balance between supply and demand.

In North Carolina, irrigation is not widespread and farmers generally rely on rainfall to provide water for crops. Timing of rainfall is critical, needing to occur during specific periods of the crop cycle. Droughts, even those less than a few months, can result in extensive crop losses and have significant economic impacts. Each crop is a large investment for farmers and a lost crop can completely bankrupt an operation.

River ecosystems also require some minimum rainfall, runoff, water levels, and discharge to provide habitat and ecosystem services. Long-term drought would reduce available habitat, increasing water temperatures, and harming native species. Reduced flows may result in degraded water quality and standards violations.

Many municipal and industrial water supplies in North Carolina use surface waters as their primary source. Low stream flows resulting from drought can result in poor water quality, high turbidity, and even an inability for water intakes to function properly. Some municipalities and industries withdraw water from reservoirs, but reduced inflow would also compromise the reliability of these resources. Some coastal towns and industries have been affected by drought as the saltwater reaches further upstream and impacts freshwater intakes. Past droughts have required water restrictions affecting millions of North Carolina residents.

Power generation in North Carolina is predominantly thermoelectric and is the largest water user. Generation facilities use either stream flow or reservoir water to generate power using steam driven turbines. Some of the water that is withdrawn is lost to evaporation while the majority is returned to surface waters. Power plants may face reductions in power or temporary shutdowns if water supply is insufficient.

Water quality impacts may be seen during drought periods. Point source discharge limits are based on the assimilative capacity of the receiving water, and that capacity is calculated based on historic low flows. If flows fall below this level, conditions may not meet water quality standards due to the limited assimilative capacity of the water body. If droughts occur during spates of high temperature, biological

[2] Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidard, Terese (T.C.) Richmond, K. Reckhow, K. White, and D. Yates, 2014: Ch. 3: Water Resources. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 69-112. doi:10.7930/J0G44N6T.

and chemical oxygen demand may increase, or harmful algal blooms may proliferate. As noted earlier, water resources are also becoming stressed due to higher demands as a result of population growth.

Resilience Strategies

The scale and magnitude of drought makes increasing resiliency a challenge. Public water systems and agriculture may have the most options for adaptation but face challenges. Reservoirs provide water during dry periods, but changes to or construction of large water supply reservoirs is land-intensive, expensive, and faces many environmental and regulatory requirements. Long-range planning with a focus on conservation, water reuse, interconnections between systems, and emergency supplemental supplies are key components of resilience for municipal and industrial supplies.

Drought-tolerant Crops

Irrigation can meet crop needs but increasing irrigation can further stress surface water resources during drought and irrigation from groundwater is not always feasible. Coordination with agricultural extension offices to identify drought-tolerant crops is one solution for resilient agriculture.

Monitoring and Protection

The scale of natural ecosystems makes providing supplemental water infeasible, but protection and enhancement of natural lands can provide flow resilience that developed land cannot because rainfall infiltrates into the soil and slowly returns as base flow. Monitoring and protection of groundwater levels and instream flow are also necessary to meet the potential changes associated with climate change.

Power generators

Power Generators can improve water efficiency in existing plants and transition to recirculating cooling systems.

Public Water Supply and Irrigation Water in Coastal Regions / Sea Level Rise

Impact Summary

Among the many consequences of sea level rise is saltwater intrusion into freshwater sources. Saline water is not suitable for irrigation or as a drinking water source. Saltwater intrusion due to sea level rise will limit agricultural productivity as irrigation water becomes saline and salt builds up on fields. Public water systems may need to switch sources or build reverse osmosis systems to provide potable water in the future.

Vulnerability and Risk

Sea level along the northeastern coast of North Carolina has risen about twice as fast as along the southeastern coast, averaging 1.8 inches per decade since 1978 at Duck, NC, and 0.9 inches per decade since 1935 at Wilmington, NC.[3] Projections show the rate of sea level rise will increase.

Irrigation water from shallow groundwater or surface water in some areas has already become more saline. Slightly saline water can be used for irrigation but fields will see salt buildup, reducing productivity. Large areas of agriculture that rely on irrigation during dry periods may be affected in the future.

[3] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K.D. Dello, J. P. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: *North Carolina Climate Science Report*. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr



Public water supplies that rely on groundwater are also vulnerable. In most cases, groundwater systems only need to provide minimal treatment of the groundwater before supplying it to their customers. Some systems have already reported the need to abandon wells due to high salinity.

Resilience Strategies

New wells can be drilled deeper to tap into different aquifers or drilled further inland to avoid the saltwater intrusion zone. Water systems and farmers can utilize surface water supplies but in many cases these sources may already be over-utilized. Reverse osmosis treatment can allow a water system to continue to utilize their current sources, but the construction and operation costs can be burdensome.

Long-range planning with a focus on conservation, water reuse, interconnections between systems and emergency supplemental supplies are key components of resilience for municipal and industrial supplies. Coordination with agricultural extension offices to identify drought or salinity-tolerant crops is a solution for resilient agriculture.

Stormwater and Water Quality / Flooding

Impact Summary

DEMLR's Stormwater Program is responsible for regulating stormwater runoff through various programs. The federally mandated National Pollutant Discharge Elimination System (NPDES) Program regulates over 4,000 industrial sites and 122 municipal separate storm sewer systems (MS4s). The state post-construction stormwater program regulates over 15,000 development sites statewide for long-term stormwater management. The state Water Supply Watershed Program regulates stormwater discharges in watersheds designated for water supply.

During rainfall events, pollutants such as sediment, nutrients, heavy metals and pathogens are collected from land surfaces by stormwater runoff, which eventually ends up in the state's lakes, rivers, estuaries and the Atlantic Ocean. Development increases both the amount of stormwater runoff and the concentration of pollutants in runoff that is discharged, ultimately affecting water quality and other issues such as streambank erosion. Increasingly frequent and intense storms exacerbate these issues and can cause the discharge of significant amounts of untreated stormwater, as well as damage to stormwater infrastructure and increased maintenance requirements.

Vulnerability and Risk

Water quality is directly tied to a variety of important ecological and economic benefits, and the risks associated with degraded water quality due to stormwater runoff are high due to adverse health and ecosystem impacts. Pollutants associated with stormwater runoff, such as sediment, excessive nutrients, fecal coliform and petroleum products all impair water quality in streams, rivers, reservoirs, and coastal estuaries.

Pollutants from stormwater runoff, particularly nutrients, have also been shown to contribute to water quality impairments in water supply reservoirs, such as Jordan Lake and Falls Lake. Poor water quality can contribute to negative health impacts, increased cost of water treatment, degraded water quality and negatively impact recreation and other water uses, such as fishing, boating and swimming. Industrial sites have the potential to discharge high levels of pollutants, including heavy metals, oils, grease, and toxic chemicals. Stormwater runoff has resulted in closures of beaches and shellfish growing areas, which are important economic drivers for coastal North Carolina.

The growing population of North Carolina is causing further development of open areas of the state, which increases impervious coverage. This in turn directly increases the amount of stormwater runoff and

the pollutant concentrations. Traditional stormwater management techniques aim to reduce the pollutant concentrations and sometimes the runoff volumes leaving the site through on-site stormwater control measures. These stormwater control measures require frequent maintenance, and increasingly intense storms increase the risk of damage to the existing and future stormwater management devices that are being installed throughout the state. Further, it has proven a challenge to ensure that the approved and existing stormwater control measures are owned and operated by the proper party and that frequent maintenance is occurring. This further increases the risk of damages due to stormwater runoff.

The coastal region is the most vulnerable to heavy precipitation events and suffers from some of the most severe impacts of stormwater runoff (e.g., beach closures, shell fishing closures). It is for this reason that the coastal post-construction stormwater management program was created in 1988. Since that time, over 14,000 permits have been issued to development sites in the 20 coastal counties. These permits address the design and implementation of stormwater control measures for water quality purposes, as well as operation and maintenance of the permitted systems. The increasing frequency and intensity of heavy precipitation events overwhelms the treatment capacity of these systems and can cause infrastructure damage, greatly increasing the cost of regular maintenance, which is often paid for by homeowners.

The Stormwater Program also regulates development in High Quality Waters (HQW) and Outstanding Resource Waters (ORW) watersheds. These are watersheds that are rated excellent based on biological and physical/chemical characteristics through monitoring or special studies, primary nursery areas designated by the Marine Fisheries Commission, and other functional nursery areas designated by the Marine Fisheries Commission. These include specific water supply watersheds and commercial shell fishing waters. Stormwater pollution is a threat to the unique characteristics of these watersheds and must be managed closely to maintain their important ecological and economic functions.

Resilience Strategies

The ability to further improve the way that stormwater is managed is a major challenge. Traditional stormwater management techniques are limited in their ability to treat large storm events and the economic return decreases with increasing treatment requirements. Further review of storm patterns and design standards could help to indicate the best treatment goals to adapt to changing climatic conditions.

Increased resources to aid the stormwater program in managing existing permitted sites would be very useful to ensure that existing stormwater control measures are built and maintained in accordance with permitted standards. Further expansion of stormwater programs into areas that are currently without a program would help curb unregulated development. Finally, the current stormwater regulations are limited in scope to addressing primarily water quality. The state should consider options to determine the use of this program to also regulate stormwater quantity up to the 25-year design storm. This would not only increase water quality treatment but also address reducing runoff that contributes to some flooding events.

Landslides

Impact Summary

The greatest landslide hazard is in the western North Carolina Mountains, but localized landslides also occur on steep slopes in the Piedmont and Coastal Plain. Rapidly moving landslides like debris flows (mud flows) are the most frequent type of landslide and pose the greatest threat to public safety as they can travel at speeds of 30 miles per hour. Rock slides and other landslide types damage and disrupt transportation corridors, utilities, homes, business, surface waters and other cross-sector entities leading to expensive repairs and economic losses.



The causes of landslides are directly related to geology, hydrology, topography, vegetation, and human-related ground-disturbing activity that has destabilized slopes. Since 1876 there have been 9 major storms, including tropical cyclones, that each produced hundreds or thousands of landslides resulting in many fatalities and widespread damage throughout the Mountains. The average frequency of these major landslide events is about 16 years. However, damaging landslides occur on an annual basis. There have been 11 fatalities and 30 destroyed homes (uninsured) from landslides since 1977. A conservative estimate of losses from landslides since 1977 of $48 million does not include many NCDOT direct costs, and indirect economic losses from disrupted transportation corridors.

Vulnerability and Risk

The North Carolina Geological Survey (NCGS) responds to many requests for technical assistance on landslides from emergency managers, federal, state and local agencies as well as the public. Reports prepared from responses to over 300 landslides document impacts and factors that contribute to landslides and their dissemination improves knowledge to help reduce losses from future landslides.

Landslide mapping identifies locations vulnerable to damage from landslides. The greatest exposure to landslides is in the mountains. Sensitivity is related to past landslide activity, geology, topography (slope and position on the landscape), vegetation (or lack thereof due to wildfire), and ground disturbance due to improperly located, constructed and maintained slopes and drainage systems. Less rainfall is required to trigger landslides on slopes destabilized by human activity than is required to trigger landslides on natural forested slopes, thereby increasing the vulnerability of some disturbed slopes.

The risk of damage and loss of life from landslides is high as the frequency of extreme precipitation events increases in areas of continued population growth and past and current development in vulnerable locations in the Mountains. Heavy rainfall events are the main trigger for landslides. The frequency of landslide events is directly linked to the frequency and magnitude of extreme rainfall events and weather patterns. As population increases so does the dependence on critical infrastructure. When major transportation corridors like I-40 are impacted by landslides, disruption and economic losses are felt over large areas in the Mountains because alternate routes are limited by terrain constraints.

The likelihood of repeated, and potentially increased, landslide occurrence is very high as evidenced by landslides from tropical cyclones that impacted the Mountains since 2004: Frances, Ivan (2004), Cindy (2005), Ernesto (2006), Fay (2014), Alberto (2008), and Florence (2018). Recurring extreme weather patterns such as record annual rainfall amounts in 2013 and 2018 led to increased landslide activity. During these extended periods of above-normal precipitation, numerous lower intensity storms triggered hundreds of landslides because of persistent, elevated levels of soil moisture. Aging infrastructure increases the likelihood of landslides related to failing drainage systems and deteriorating slopes on major transportation routes like I-40, I-26, the Blue Ridge Parkway, and other highways.

Resilience Strategies

Landslide hazard maps show where landslides have happened or are happening; where landslides like debris flows are likely to start; and, if debris flows start, where they are likely to go. Therefore, continued and recurring funding for four to nine FTEs to provide this response capacity and reporting, and to increase the coverage of landslide maps is important to meet the future resilience needs of North Carolina.

Other options include enhancing collaboration to anticipate and communicate the threat of landslide hazards, and coordinate emergency responses to landslide events. State and local governments could provide incentives for smart growth and development in safe locations and discourage development in vulnerable locations. Because local jurisdictions, homeowners and homeowners' associations are often financially incapable of funding major slope stabilization or mitigation projects, the state should improve and develop landslide mitigation funding strategies.



Mining / Flooding

Impact Summary

The Mining Program within DEMLR is a regulatory agency that issues permits to mining operations requiring environmental compliance and ultimately site reclamation when mining is complete. The Stormwater Program also within DEMLR is also a regulatory agency that issues NPDES permits for mining operations that discharge stormwater or process wastewater to surface waters.

Flooding impacts can cause environmental harm to receiving waters and other property, as well as damage and harm the mining operation, its materials and equipment. Riverine water flooded several mines during Hurricanes Matthew (2016) and Florence (2018), causing damage to equipment and rendering the mines unusable until floodwaters could be pumped out per permit conditions. Impacts in future events on other mines could include tons of sediment loss, sediment loading of surface waters, water quality impacts, and economic impacts to the mine operations and downstream public.

Vulnerability and Risk

The sensitivity of environmental and property exposure of a mine site to heavy precipitation events and hurricanes and resulting damage varies based on the following:

- installation and maintenance of Erosion and Sediment Control best management practices (BMPs);
- up-to-date maintenance of those BMPs, engineering design standard used (currently 25-year design storm, set by statute and rule);
- water classification (ex. Class C versus High Quality Water or Trout Water, measure of quality of use); and
- physical location of project (in floodplain, near floodplain, out of floodplain, topography).

If BMPs are implemented and maintained correctly, they provide adaptive capacity to counteract exposure and damage, and reduce water quality sensitivity at least up to their design storm size. A 25-year design storm is required for all mines in all water classes per current statute and rule. Location matters as sites subject to flooding are not only threatened by flash flooding of the mine site, but by riverine flooding that could be a result of a precipitation event upstream of the site that may have received little or no direct precipitation.

Vulnerability is also a function of land use (urban -vs- rural, population, development density), size of mine, location within a watershed (ex. in floodplain -vs- not, this relates to sensitivity within the environment), location (Mountains, Piedmont, Coastal Plain), types of soils, type of mineral mined, type of onsite processing and topography (slope) among others.

Construction requirements in NC require a 25-year frequency design storm for BMPs on mine facilities. Even given the best construction practices and if every operator met every legal requirement during construction, multiple 25-year and larger storms in multiple locations throughout NC (all of which have been observed and are likely in the future) will likely overwhelm the intended design capabilities of BMPs. Because of this, it becomes evident that our Intensity, Duration, and Frequency (IDF) curves need updating or replacing. IDF curves are the tools that engineers, hydrologists and other professional consultants use to size constructed BMPs for control of erosion, sedimentation and stormwater.

Resilience Strategies

Adaptive capacity varies with input by the state and by individual mine operators. Education for designers, developers and mine operators to properly design and install appropriate measures is relatively easy. Some workshops are taught in NC and online by DEQ, NCSU, NCDOT, International Erosion

Control Association (IECA) and the National Association of State Land Reclamationists (NASLR). More education and training and resources for these efforts on a state level can lead to a better understanding of potential impacts, improved siting determinations for facilities to relocate out of sensitive areas where possible, choosing appropriate measures based on location to avoid or minimize impacts and adequate emergency response and ultimately reduced enforcement actions. Statutory and rule changes are required to update design standards and IDF curves, the latter of which will also require scientific study and review.

Stream and Wetland Mitigation / Flooding

Impact Summary

Stream, wetland and buffer mitigation is realized by way of restoration. Successful restoration is dependent on the degree of functional improvement attained by the restorative process and the ability to demonstrate water quality and aquatic habitat improvement over a 7-year monitoring period. Increases in precipitation and/or changes in precipitation magnitude, duration, intensity and frequency can negatively impact restoration projects. These changes will affect the magnitude, duration, intensity and frequency of stream discharge and overland flow.

Increased discharge will result in increased streambank erosion rates and the delivery of sediment and phosphorus to streams. Increased overland flow due to intensity and frequency of precipitation will likely result in the accelerated delivery of pollutants (e.g., nitrogen, fecal coliform) to streams. If the rate of pollutant abatement associated with restoration is outweighed by the rate of pollutant delivery, the ability of DMS to achieve improvements in water quality by stream, wetland and buffer restoration will be affected. The increased variability of climatic conditions will affect DMS and mitigation providers by amplifying monitoring data variability and putting into question the success of restoration projects.

Vulnerability and Risk

A restoration project is considered a state asset with an environmental value as well as a monetary value. From the mountains to the coast on over 600 projects, DMS works to protect more than three million feet of stream and 76,000 acres of natural areas. These projects are required to offset stream and wetland impacts resulting from transportation and development. The success of DMS projects directly effects DWR and USACE permitting as well as DMS compliance.

Resilience Strategies

The variability of climatic changes (i.e., increase/decrease in precipitation/discharge/overland flow), is a challenge to resiliency. However, some resiliency may be achieved by tracking overall success rates and by analyzing monitoring data for trends. DMS currently has databases to facilitate data analysis. Observation and analysis may help to inform restoration providers to design projects with data trends in mind.

Sedimentation and Erosion Control / Heavy Precipitation

Impact Summary

The Sediment Program within the DEMLR is a regulatory agency that issues Erosion and Sedimentation Control Plan Approvals to developments subject to the Sediment Act and requires environmental compliance and ultimately site stabilization upon completion of construction. The Stormwater Program also within DEMLR is also a regulatory agency that issues National Pollutant Discharge Elimination System (NPDES) permits for construction.



Heavy precipitation events and associated flooding impacts can cause environmental harm to receiving waters and other property and can also cause environmental and property damage not only to the development but to receiving surface waters and other property. These issues occur during heavy rains and hurricanes resulting in environmental violations dozens of times each year. Best Management Practices (BMPs) are designed for 10- and 25-year return frequency storms depending on water zone classifications in the state. North Carolina is seeing more and more recurring 10- and 25-year storms multiple times each year causing us to question the validity of IDF curves used in design of BMPs.

Vulnerability and Risk

A variety of factors, such as location (i.e., urban vs. rural), size of development, terrain position (e.g. in floodplain vs. not), physiographic region (Mountains, Piedmont, Coastal Plain), soil type, and topography (slope), all affect the sensitivity of source watersheds and receiving waters. Furthermore, exposure of a construction site to heavy precipitation events (including hurricanes) varies based on pre-existing adaptive capacity due to installation and maintenance of Erosion and Sediment Control BMPs, up-to-date maintenance of those BMPs, design standard used (10 year or 25-year design storm, set by statute and rule), water classification (e.g. Class C versus High Quality Water or Trout Water), and physical location of project (e.g., in floodplain, near floodplain, out of floodplain).

BMPs provide adaptive capacity on construction and development sites. If BMPs are installed correctly and well maintained, they are less sensitive to exposure and damage at least up to their design storm size. A 25-year design storm is less sensitive than a 10-year design storm but 25 years is the maximum required for HQW zones classifications only and the predominating requirement is for 10-year design per current statute and rule. Also, location plays a big part here as site subject to flooding are not only threatened by flash flooding of the construction site but by riverine flooding that could be a result of a precipitation event upstream of the site that may have received little or no direct precipitation.

Resilience Strategies

Education and training for designers, developers and contractors to properly design and install appropriate measures is relatively easy and workshops are taught in NC by DEQ, NCSU, NCDOT and the International Erosion Control Association (IECA) multiple times each year. Adaptive capacity for design standards and Intensity/Duration/Frequency (IDF) curves is low to intermediate because that will take statutory and rule changes and IDF curves will require a different way of putting together with scientific review.

More data and research addressing new materials, siting, buffers and processes will support and improve resilience efforts moving into the future. DEQ has worked with several universities, especially with North Carolina State University's Soil Science Department, and has been the recipient of their research in efforts to improve BMPs and processes used in construction to reduce erosion of the land and sedimentation of our surface waters. DEQ can and should continue to work closely with these research efforts to identify funding, continue research, reduce sedimentation pollution and improve resilience from construction impacts to the state due to heavy precipitation events.

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4. Summary

A central challenge to water and land planning and management is learning to plan for plausible future climate conditions that are wider in range than those experienced in the 20th century. Doing so requires approaches that evaluate plans over many possible futures instead of just one. Real-time monitoring and forecast products allow better management decisions, especially in the face of extreme precipitation and drought, whose impacts are described above. A thorough risk assessment of the state's water infrastructure would provide essential insight into the potential costs and impacts associated with climate-related hazards.

We note several opportunities to update policies and engineering principles. For example, we recommend new research and implementation of IDF curves and Probable Maximum Precipitation (PMP) studies be incorporated into storm design standards using the best available geoscience-based understanding of planetary change. Recent examples of adaptation responses undertaken by large water management agencies, including major metropolitan water utilities and the U.S. Army Corps of Engineers, are promising. These examples include development of climate change based IDF curves for Alexandria, Virginia and Raleigh, North Carolina, a new surge wall and levees built in New Orleans, and infrastructure adaptation engineering in New York City as a result of hurricane impacts in those areas.

Water management during droughts is coordinated by DWR and the North Carolina Drought Management Advisory Council. Federally owned and licensed dams have protocols in place to manage reservoir storage and releases during high water and drought events. The state also requires local governments and large community water systems to have a Water Shortage Response Plan in place that specifies water restriction levels and associated conservation efforts based on measurable conditions such as reservoir or stream levels. The state also encourages resiliency efforts such as interconnections and regionalization to provide emergency water supplies.

Water and land impacts and strategies are closely inter-related. The condition of the land, i.e. natural, managed, or impervious, directly affects the volume and quality of runoff. This in turn influences the availability of water, erosion, sedimentation, landslides, dam safety, pollutant loading to receiving waters, and ecosystem health. The condition of North Carolina's water and land resources are also closely connected to most other sectors which support the state's human and ecological health and economic prosperity. For this reason, strategies to meet the challenges posed by climate change will also require close coordination with these other sectors.

Planning and response to emergency events and natural disasters, especially heavy precipitation and hurricanes, will impact DEQ with an exceptional impact on the landslide, dam safety, stormwater, erosion & sedimentation control, water quality, and water supply programs which are mandated by North Carolina General Statutes to address development in a responsible manner to provide for the life, health, safety and protection of property. Emergency and disaster events in the recent past have showcased the need for increased capacity and additional measures to improve resiliency in North Carolina for the future. Resources, specifically funding, for increased necessary permanent personnel for example in the landslide mapping and dam safety emergency action planning programs, equipment such as laboratory equipment and high capacity pumps, training for very specialized staff in all Divisions, and appropriate salaries, as well as internal assessments of future capacity that allow DEQ to keep up with these issues, are an absolute necessity to the state's lives, health, safety, economy and overall resilience to climate change.


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Energy

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L. Energy

Key Observations

- Energy drives commerce, transportation, environmental controls, emergency response, agriculture, housing, and many other parts of our economy and therefore solutions must be integrated across these sectors.
- Energy resources, regulations, technology innovation, consumer demand, carbon reduction goals, and market pressures are rapidly changing the industry. This creates an opportunity to build resilience through the modernization of the energy supply and delivery infrastructure.
- North Carolina utilities, regulators, policy makers, energy planners, and emergency response planners should develop resiliency metrics to quantify human and economic costs of power outages and apply a risk-based framework to accelerate decision making related to energy infrastructure planning and operations.

Critical Impacts and Resilience Strategies

- Disruptions to the electric power grid from increased storm intensity can be mitigated by securing a diverse source of utility scale and distributed generation assets such as microgrids equipped with renewable energy and battery storage devices, hardening the grid/transmission infrastructure, reducing demand for power, and modernizing existing grid assets with smart meters, controllers, automation, and analytics to manage a diverse source of power supply, transmission, and distribution system components.
- Stress on thermoelectric power plant cooling due to drought can be addressed with non-traditional water and energy sources, water capture and dry cooling to protect water quantity and quality, and demand side management programs.
- Fuel supply chains disruption from increased storm intensity may benefit from alternative fuel infrastructure and hardening existing pipelines, terminals, and fuel stations to facilitate evacuation routes and protect critical infrastructure.
- The North Carolina Disaster Recovery Framework, led by NC Emergency Management, should expand to focus on how to integrate resiliency planning for both storm-related outages and cyberattacks into its disaster recovery planning. The effort should evaluate how new and existing infrastructure can best be deployed to reduce recovery efforts.

1. Introduction to Sector

The energy sector is the engine that drives our state's growing economy and population. In 2018, North Carolina had the 11th largest economy in the nation at gross domestic product (GDP) of nearly $566 billion.[1] North Carolina is also one of the most populous states in the nation, ranking ninth at about 10.4 million people in 2018. In 2020, North Carolina's population is expected to reach 10.6 million people.[2]

North Carolina's thriving economy and communities consume about 2.6% of the total energy consumed in the nation, ranking 12th within the residential, commercial, industrial, and transportation sectors.[3] At

[1] Steven Pennington, NC Annual Economic Report: Gross Domestic Product, NC Department of Commerce, November 4, 2019. Retrieved from https://www.nccommerce.com/blog/2019/11/04/nc-annual-economic-report-gross-domestic-product
[2] North Carolina Budget and Management, Facts and Figures. Retrieved from https://www.osbm.nc.gov/facts-figures
[3] U.S. States Profiles and Energy Estimates, U.S. Energy Information Administration, 2017. Retrieved from https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_te.html&sid=US

annual consumption rate of 2,500 trillion British Thermal Units (TBtu) of energy, North Carolina relies heavily on imported fuel and energy sources; 74% of the state's annual consumption is imported. Figure 5L-1 shows energy consumption by fuel type and by the end use sectors.

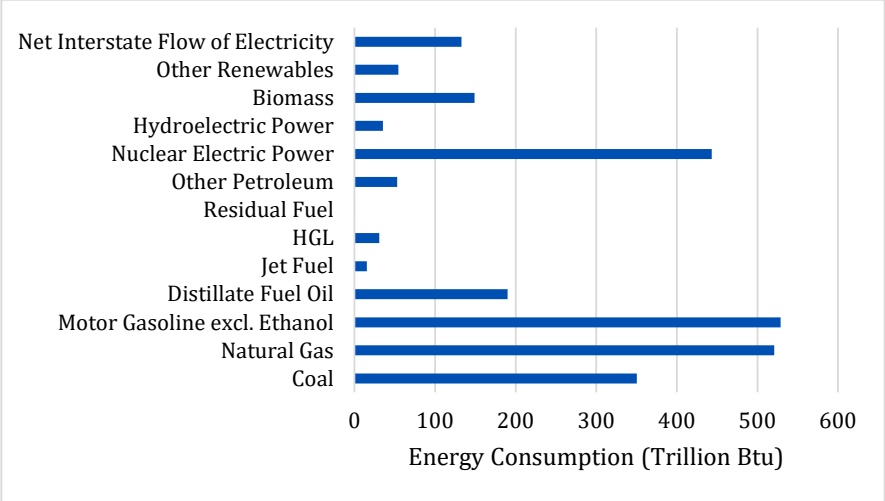


Figure 5L-1. North Carolina Energy Consumption by Fuel Type

Motor gasoline and diesel fuel used by cars and trucks on North Carolina's heavily traveled highway system and jet fuel consumed at airports make the transportation sector the largest end-use energy-consuming sector in the state, with a state ranking of 7th highest vehicle miles traveled in 2017.[4] Approximately 3% of all U.S. refined petroleum is consumed in North Carolina.[5]

The residential sector follows the transportation sector, accounting for one-fourth of North Carolina energy consumption. The residential sector is a significant consumer of electricity, ranking as the fourth highest in the nation.[6] The commercial and industrial sectors each consume slightly more than one-fifth of the state's total energy consumption.[7]

North Carolina is also among the top 10 electricity-generating states in the nation. The state's nuclear power plants produced nearly 5% of the nation's total electricity net generation in 2018 (5th among all the states).[8] During the same year, North Carolina ranked second after California in the amount of installed solar power generating capacity. Natural gas is the primary source of fuel for electricity generation in North Carolina, increasing from 15% to 65% of state consumption in the past decade, while coal use has declined significantly.[9]

North Carolina's energy infrastructure is owned and operated by the private sector, rural electric cooperative, and local governments and is regulated by federal bodies, state utility commission, and the

[4] U.S. EIA, State Energy Data System, Table C3, Primary Energy Consumption Estimates, 2017.
[5] Petroleum Industry Preparation, Response & Recovery to Hurricane Florence, presented by David McGowan, NC Petroleum Council, NC Energy Policy Council Meeting, Archdale Building, February 20, 2019 meeting, Raleigh, NC. Retrieved from https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Energy/Energy%20Policy%20Council/EPC-Combined-Presentations.pdf
[6] U.S. EIA, North Carolina State Energy Profile. Retrieved from https://www.eia.gov/state/print.php?sid=NC
[7] U.S. EIA, State Energy Data System, C1, Energy Consumption Overview: Estimates by Energy Source and End-Use Sector, 2017.
[8] U.S. EIA, Electric Power Monthly (February 2019), Tables 1.3.B, 1.9.B.
[9] U.S. EIA, North Carolina Natural Gas Deliveries to Electric Power Consumers, 1997-2018.



legislature. The North Carolina State Energy Office (SEO), housed within the Department of Environmental Quality, does not have direct responsibility for the state's energy infrastructure. Nevertheless, the SEO has conducted a qualitative assessment of the climate and non-climate impacts, risks and vulnerabilities based on available information, assistance from public/private partners, and information on current projects led by energy providers, regulators, planners, and other stakeholders.

Pursuant to Governor Cooper's executive order 80, the Department of Environmental Quality released a Clean Energy Plan[10], which contains a set of recommendations to help create a modern, resilient, and low carbon electrical energy system in the state. The plan calls for requiring utility companies to develop projects focused on distributed energy resources (DERs), community solutions, and microgrids at critical infrastructure locations (e.g. hospitals, shelters) to enhance resilience and to coordinate resilience planning with disaster recovery operations center.

The Department of Energy's Grid Modernization Laboratory Consortium (GMLC) defines resiliency as "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents." [11] In the following sections, we provide an overview of exposure to climate-related hazards (section 2), examples of impacts, vulnerabilities, risks, and resilience strategies for three potential impacts from climate-related hazards (section 3), and a framework based on federal guidelines, to help policy makers identify energy infrastructure resilience issues, resilience barriers, and enhancement options (section 4). A combined effort among the private sector, utilities, regulators, and local, state, and federal governments would be necessary to prioritize state investments to build energy system resilience capacity.

2. Overall Exposure

A 2012 Congressional Research Service report estimates that storm-related power outages cost the U.S. economy $20-$55 billion annually, and outages from weather-related events are increasing.[12] These outages are the result of both climate (increasing storm intensity and frequency) and non-climate stressors (aging infrastructure and increasing development). In recent years, the number and cost of billion dollar disasters have increased nationally, including many in North Carolina. As a result of the increasing stress imposed by a changing climate as well as the pressure imposed by non-climate stressors, the hazards impacting energy sector assets and services will be of increasing concern in future years as shown in Table 5L-1.

[10] North Carolina Clean Energy Plan – Transitioning to a 21st Century Electricity System, Policy and Action Recommendations, North Carolina Department of Environmental Quality, October 2019. Retrieved from https://deq.nc.gov/energy-climate/climate-change/nc-climate-change-interagency-council/climate-change-clean-energy-16

[11] "Grid Modernization: Metrics Analysis Reference Document, Version 2.1," Grid Modernization Laboratory Consortium, May 2017. Retrieved from https://gmlc.doe.gov/sites/default/files/resources/GMLC1%201_Reference_Manual_2%201_final_2017_06_01_v4_wPNNLNo_1.pdf

[12] CRS 2012. Weather-Related Power Outages and Electric System Resiliency. 5-5700 R42696 Washington D.C.: Congressional Research Service. Retrieved from http://www.fas.org/sgp/crs/misc/R42696.pdf

Table 5L-1. Exposure of assets and services related to the energy sector

Assets, Services	Extreme Heat	Flooding (River and Land)	Water Shortage (Drought)	Strom Intensity	Changed Seasons	Landslides	Saltwater Intrusion	Storm Surge	Tidal Flooding	Wildfire	Dam Failure
Power Generation											
Nuclear and Hydrocarbon Power Plants		*	*	*			*	*			*
Renewable Energy Generating Facilities		*			*	*				*	
Hydroelectric Power Plants		*	*	*				*			*
Electric Power Delivery											
Transmission and Distribution Grid	*	*		*		*	*	*	*	*	*
Substations and Other Support Systems		*		*		*		*	*	*	
Fuel Supply Chain											
Natural Gas Pipelines		*		*		*		*			
Petroleum / Gasoline Pipelines		*		*		*		*	*	*	
Petroleum Storage and Bulk Terminals		*		*	*			*	*		
Gasoline Distribution and Fueling Stations		*		*	*	*		*	*		
Ports, rail and roads	*	*		*		*		*	*		

Climate Stressors and Climate-Related Hazards

Heavy Precipitation and Flooding

Energy-generating facilities are often located along inland watersheds and coastal areas in order to take advantage of available water resources. Though the location is beneficial for operation purposes, infrastructure near water sources is subject to fluctuations in river discharge and flooding from heavy precipitation.[13]

Energy storage and transport infrastructure are vulnerable to inundation and other related damage. For instance, buried pipelines which have been exposed due to flooding can be damaged further by debris. This is true of both inland and coastal infrastructures. Coal and petroleum transported by rail lines or highways which parallel rivers can flood, disrupting the energy supply chain. These same transport routes provide access to critical energy infrastructure, so flooding can cause service disruptions.

[13] Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.



Sea Level Rise and Coastal Storms

North Carolina, especially the Outer Banks, is often hit by severe tropical storms and hurricanes, and is second only to Florida in tropical cyclone landfalls.[14] Rising sea level and continual increase in coastal storm intensity is a risk for exposed energy infrastructure on the coast. Low-lying thermoelectric power plants and energy infrastructure housed on the coast are vulnerable to saltwater intrusion and corrosion, as well as coastal erosion. Hurricanes Florence and Matthew caused historic flooding in the Carolinas with about 3 million customers losing power within the Duke Energy territory. Duke Energy reported that power for 90% of customers was restored within three days for both storms.[15] The storms resulted in one of the largest mobilization of power restoration activities in the company's history. In rural areas of the state, the NC Electric Cooperatives reported about 350,000 customers without power between the two storms.[16]

Damage to this infrastructure can cause delays in the electricity supply chain.[17] Following Hurricane Fran, the Brunswick nuclear power plant shut down temporarily and was operating at 15% of capacity one week after landfall. The Sutton natural gas combined cycle plant near the coast went offline for six days after landfall, and operated at partial capacity seven weeks after landfall.[18] The outages were due to: (1) excessive flooding, (2) storm damage to the fencing around the plant's security zone, (3) down power lines, also due to storm damage, and (4) storm debris that made the 10-mile emergency evacuation routes inaccessible. Disruptions to central power plant operation cascade to the bulk transmission and distribution system, where other connected distributed energy systems are unable to deliver power to customers. For example, during hurricane Florence, 5 of 403 utility-scale photovoltaic (PV) systems surveyed (1.2%) were damaged by tornadoes while the remaining systems were producing electricity. The disruptions to central power plants and the electric grid prevented the PV systems from being able to deliver the energy until the grid was able to come back up.[19]

Exposure of coastal energy infrastructure to large coastal storms is magnified by sea-level rise, which amplifies the size of storm surges. Critical production and transmission infrastructure on the coast is vulnerable to physical damage from inundation as well as water and-air-borne debris during a coastal storm. Coastal ports and terminals which transport energy products are vulnerable to high winds and storm surge. This can disrupt or even halt energy production across the state. A recent study by Moody's Investor Services cited Duke Energy as one of the top three utilities facing "red flag" (highest) hurricane risk in the U.S.[20]

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[14] Donegan, Brian, "North Carolina Second Only to Florida for U.S. Tropical Storms and Hurricanes," The Weather Channel, September 11, 2018.

[15] Duke Energy's Hurricane Preparation, Impacts, and Response, presented by Duke Energy, NC Energy Policy Council Meeting, Archdale Building, February 20, 2019 meeting, Raleigh, NC. Retrieved from https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Energy/Energy%20Policy%20Council/EPC-Combined-Presentations.pdf

[16] Hurricane Florence & Tropical Storm Michael, presented by S. Lee Ragsdale, NC Electric Cooperatives, NC Energy Policy Council Meeting, Archdale Building, February 20, 2019 meeting, Raleigh, NC. Retrieved from https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Energy/Energy%20Policy%20Council/EPC-Combined-Presentations.pdf

[17] US Department of Energy. 2015. Climate Change and the US Energy Sector: Regional Vulnerabilities and Resilience Solutions. Retrieved from https://www.energy.gov/sites/prod/files/2015/10/f27/Regional_Climate_Vulnerabilities_and_Resilience_Solutions_0.pdf

[18] Renewable Energy, Energy Assurance, and North Carolina Energy Policy, presented by Ivan Urlaub, NC Sustainable Energy Association, NC Energy Policy Council Meeting, Archdale Building, February 20, 2019 meeting, Raleigh, NC. Retrieved from https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Energy/Energy%20Policy%20Council/EPC-Combined-Presentations.pdf

[19] Ibid

[20] Moody's Investor Services. 2020. *Regulated electric utilities – US Intensifying climate hazards to heighten focus on infrastructure investments.*



Hurricanes can also damage wetlands and natural barriers which help to protect energy infrastructure from storm surge.[21] Damage to these barriers increase vulnerability to subsequent storms. Disruptions in service during a disaster can have further implications on emergency services such as trains, subways, data clouds, medical systems, and telecommunication services which are all reliant on the functionality of the grid system.[22]

Increased Temperature and Drought

Under the business as usual emissions scenario, North Carolina is projected to experience 2°– 5°F temperature increase by the middle of this century and 6°– 10° by the end of the century.[23] Studies have found that increased temperatures and an increase in the number of days above 65°F lead to an increase in energy consumption, especially in the summer and during peak demand hours.[24] Conversely, higher temperatures during the winter months will decrease the demand for heating, reducing energy consumption. However, energy saved by decreased heating in the winter will only marginally offset the pressure on the energy sector and will lead to an overall net increase from average higher annual temperatures.[25] In response to warmer temperatures, customers who use alternative energy sources such as propane and natural gas for heating are expected to decrease consumption, increasing demand for electricity for cooling purposes.

Another consequence of higher temperatures is the likelihood of increased evaporation and drought. Thermoelectric power plants, which require cold water to cool steam used to power a turbine-generator, are subject to decreases in efficiency due to the lack of available water in reservoirs. Additionally, increasing water temperatures could cause thermoelectric power plants to exceed thermal discharge limits and force a temporary shutdown.[26]

Hydroelectric power plants are especially affected by severe drought. There are 38 hydroelectric power plants using over 7,500 million gallons of water a day on thermoelectric power generation in North Carolina.[27] Hydroelectric power plants require enough water in their reservoirs to provide the pressure needed to drive turbines and produce energy. Severe droughts are expected to decrease hydroelectric efficiency and generation, especially in the western region of the state.[28]

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[21] Ibid

[22] Myers-Jaffe, A., Busby, J., Blackburn, J., Copeland, C., Law, S., Ogden, J.M., Griffin, P.A. 2019. *Impact of Climate Risk on the Energy System.* Center for Geoeconomic Studies. Retrieved from https://cdn.cfr.org/sites/default/files/report_pdf/Impact%20of%20Climate%20Risk%20on%20the%20Energy%20System_0.pdf

[23] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K. Dello, J. Dissen, G. Lackmann, R. Luettich, B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A. Terando, 2020: North Carolina Climate Science Report. North Carolina Institute for Climate Studies.

[24] Sullivan, P., Colman, J., Kalendra, E. 2015. Predicting the Response of Electricity Load to Climate Change. National Renewable Energy Laboratory (NREL). Retrieved from https://www.nrel.gov/docs/fy15osti/64297.pdf

[25] Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.

[26] US Department of Energy. 2015. Climate Change and the US Energy Sector: Regional Vulnerabilities and Resilience Solutions. Retrieved from https://www.energy.gov/sites/prod/files/2015/10/f27/Regional_Climate_Vulnerabilities_and_Resilience_Solutions_0.pdf

[27] Dieter, C.A., Linsey, K.S., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Maupin, M.A., and Barber, N.L., 2018, Estimated use of water in the United States county-level data for 2015 (ver. 2.0, June 2018): U.S. Geological Survey data release. Retrieved from https://doi.org/10.5066/F7TB15V5

[28] Dieter, C.A., Linsey, K.S., Caldwell, R.R., Harris, M.A., Ivahnenko, T.I., Lovelace, J.K., Maupin, M.A., and Barber, N.L., 2018, Estimated use of water in the United States county-level data for 2015 (ver. 2.0, June 2018): U.S. Geological Survey data release. Retrieved from https://doi.org/10.5066/F7TB15V5



Non-Climate Stressors

Growing Population

North Carolina's population increase makes it one of the top 10 growing states in the country. With an expected population increase of almost 18% from 2020-2039, it can be expected that demand for energy products and services will increase significantly, requiring the need for a stronger, more efficient, and resilient energy system.[29]

Aging Infrastructure

Higher temperatures and increased demand on the electric grid reduce the generating capacity and efficiency of thermoelectric power plants and reduce the capacity of distribution lines. Extended periods of added demand on the electric power grid can cause outdated electric systems to fail.[30] Increased strain during peak hours could result in disruptions in generation and service, including widespread outages throughout service areas. Energy systems in North Carolina will ultimately benefit from modernization and installation of preventative infrastructure to protect from flooding and sea level rise, as well as a diversified electricity supply system to meet demand. Mitigation of these disruptions can be done by updating existing infrastructure, building additional infrastructure, and enabling alternate, renewable sources of energy, all of which will be reflected in retail costs.

Supply Chain Interruptions. Our economy is becoming more vulnerable to supply chain interruptions. Direct and intentional attacks on the energy system are becoming increasingly prevalent, such as physical attacks on the energy infrastructure and cyber-attacks on communications, control and operational equipment. The state of North Carolina – like any state in the U.S. – is prone to such attacks, which are a growing concern as the state becomes more reliant on third-party owned devices and distributed generation systems. Extreme electromagnetic incidents caused by an intentional electromagnetic pulse (EMP) attack or a naturally occurring geomagnetic disturbance (GMD, also referred to as "space weather") could damage significant portions of the critical infrastructure, including the electrical grid, communications equipment, water and wastewater systems.

Interconnected Nature of the Energy System

The energy sector infrastructure is comprised of a complex array of physical assets such as power plants (both utility scale and non-utility scale distributed between customers and central power stations), electricity transmission and distribution grid, natural gas pipelines, petroleum delivery systems, and other ancillary structures such as bulk gasoline terminals, gasoline distribution stations, railways, compressor stations, poles and wires, and electricity substations. This infrastructure is highly interconnected with other critical infrastructure systems, i.e., communications, transportation, agriculture, manufacturing, pollution control.

North Carolina relies on two pipelines to transport refined petroleum products (gasoline, diesel, jet fuel, home heating, military fuels) from the Gulf Coast refineries to East Coast markets. The Colonial Pipeline transports approximately 70-75% of daily volume, and the Kinder-Morgan/Plantation Pipeline supplies the remaining volume.[31] These pipelines support petroleum products to six major bulk terminal

[29] US Census Bureau. 2019. North Carolina OSBM, Standard Population Estimates, Vintage 2018 and Population Projections, Vintage 2019. Retrieved from https://www.census.gov/programs-surveys/popest.html
[30] Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*. U.S. Global Change Research Program, Washington, DC, USA, 1515 pp. doi: 10.7930/NCA4.2018.
[31] Petroleum Industry Preparation, Response & Recovery to Hurricane Florence, presented by David McGowan, NC Petroleum Council, NC Energy Policy Council Meeting, Archdale Building, February 20, 2019 meeting, Raleigh, NC. Retrieved from https://files.nc.gov/ncdeq/Energy%20Mineral%20and%20Land%20Resources/Energy/Energy%20Policy%20Council/EPC-Combined-Presentations.pdf



complexes in Charlotte, Greensboro, Selma, Apex, Fayetteville, and Wilmington, which in turn use trucks to distribute the fuel to approximately 4,550 filling stations.

Severe weather events can adversely affect the state's petroleum and natural gas infrastructure. Direct impacts of delays in fuel transmission and distribution lines include revenue losses, disability of critical services like public transit and emergency services, evacuation options, and associated macroeconomic consequences. Maintaining a continuous supply of fuel and electricity is crucial to North Carolina's economy and quality of life. Large-scale disruptions to the energy supply and delivery system is an area of great concern at both federal and state levels and has led to renewed efforts within all levels of the government, private sector, and communities to ensure the resilience of our energy systems.

Disruptions to energy infrastructure in the form of extended power outages or delays in fuel supply can lead to cascading and escalating failures that can propagate across multiple jurisdictions and affect the economic viability of a region for a long time after a disaster occurs. Even business owners without direct physical damage to their workplaces may be shut down temporarily by loss of power, because employees are unable to come in to work as a result of road closures, or due to personal property damage. As discussed in North Carolina's Hazard Mitigation Plan, many businesses that shut down after a major disaster never re-open their doors, which can have a major negative impact on local economies, especially in smaller communities.[32]

If power or communications systems are damaged or temporarily shut down, some aspects of the built environment will be impacted such as traffic lights, streetlights, and cell phone towers. Electronic equipment and control systems, water and wastewater systems, gas stations, and pipelines could all be damaged or their operations could be disrupted.

Loss of power can create very cold indoor conditions for residents. Residents may try to heat their home using alternative means, which runs the risk of carbon monoxide poisoning caused by improperly ventilated heating sources. In addition, dangerously cold temperatures increase the risk of wind chill, frostbite, and hypothermia. Another indirect impact is on public and private schools due to closings and delays due to the lack of power and heat. During times of extreme heat, air conditioning units work harder and require more electricity, making brownouts and blackouts possible if electricity demands exceed generation. Power outages occurring in the summer result in similar financial and societal impacts to the public and businesses.

[32] North Carolina Department of Public Safety, Division of Emergency Management, State of North Carolina Hazard Mitigation Plan (February 2018), page 3-207. Retrieved from https://files.nc.gov/ncdps/documents/files/State%20of%20North%20Carolina%20Hazard%20Mitigation%20Plan%20Final%20As%20Adopted.pdf



3. Examples of Impacts, Vulnerability, and Risk

Electric Power Grids / Intense Storms

Impact Summary

Increased storms across North Carolina have the most tangible and visible impact on the power grid and transmission system. Downed power lines, frequent or extended outages, and delayed repairs due to flooding and reduced access to the system all lead to impacts large and small on businesses and consumers. Companies suffer business interruption and costs of repairs; retail customers have myriad inconveniences and loss of property and productivity; and schools and work places shut down. The North Carolina Climate Science report indicates that the frequency and intensity of severe thunderstorms in North Carolina are ***very likely*** to increase.[33]

Rising average temperatures in the summer months put greater stress on the grid as air conditioners strain to provide relief from hotter days. At the same time, North Carolina's growing population and business community are increasing demands on the energy system, while demand side management, energy efficiency and customer cited energy sources are reducing some of this demand growth.

Vulnerability and Risk

North Carolina has approximately 13,600 miles of transmission infrastructure, 68,100 miles of overhead distribution pole miles, and 20,600 miles of distribution underground lines.[34,35] Transmission and distribution systems in North Carolina have been designed, built, and have been operating safely and efficiently by local electric utilities for decades. By adhering to good design standards, maintenance practices, and inter-cooperation, the electric utilities in North Carolina have a good reputation for providing highly reliable, low-cost electricity.

The goal of the power grid and transmission system is to deliver reliable electricity at a reasonable cost. Climate-related hazards and other stressors to the system work against these goals by lowering the efficiency of the grid and transmission system and reducing the overall capacity. This is in addition to the more obvious impacts of outages, especially long duration and high impact outages such as those in rural or remote areas, or those impacting hospitals and other critical services.

The existing energy and distribution infrastructure is evolving as renewable energy adoption grows due to lower costs, environmental goals, innovation and other market forces. Distributed energy resources (DER) such as small-scale wind, solar, electric vehicles (EV), or battery storage are creating new types of load impacting the grid.[36] These multiple, small- scale and intermittent resources are gaining ground,[37]

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[33] Kunkel, K.E., D.R. Easterling, A. Ballinger, S. Bililign, S.M. Champion, D.R. Corbett, K. Dello, J. Dissen, G.M. Lackmann, R.A. Luettich, Jr., L.B. Perry, W.A. Robinson, L.E. Stevens, B.C. Stewart, and A.J. Terando, 2020: North Carolina Climate Science Report. North Carolina Institute for Climate Studies, 233 pp. https://ncics.org/nccsr

[34] United States Department of Energy. (2015). State of North Carolina Energy Sector Risk Profile. Retrieved from https://www.energy.gov/sites/prod/files/2015/05/f22/NC-Energy%20Sector%20Risk%20Profile.pdf

[35] North Carolina Utilities Commission. (2003, November). Feasibility of Placing Electric Distribution Facilities Underground. Retrieved from http://www.ncuc.commerce.state.nc.us/reports/undergroundreport.pdf

[36] BusinessWire (2019). *Navigant Research Report Shows Global Revenue from DER Capacity Is Expected to Experience a Compound Annual Growth Rate of Nearly 16%.* Retrieved from https://www.businesswire.com/news/home/20190619005076/en/Navigant-Research-Report-Shows-Global-Revenue-DER

[37] Public Service Commission of North Carolina (2019). Duke Energy Docket no. E-7 Sub 1214. Retrieved from https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=cb13c39e-5f6b-457d-be23-5cc33ffa8d7f



fueled in part by a flurry of new EV charging stations across the state in areas both remote and densely populated.[38]

Utility-scale renewable energy is also growing across the state as costs plummet and demand escalates for energy options with lower emissions. Although the overall percentage of renewables in North Carolina's electricity mix is still small,[39] it is likely to increase due to Duke Energy's carbon neutrality by 2050 commitment, corporate interest in renewables, and bipartisan voter interest in clean energy deployment. The current transmission system is ill-equipped to capture the full capacity and value of these new resources, leading to lower returns on investment in generation when curtailment is necessary.

New investments in microgrids and distributed/community energy are developing to satisfy the demands of under-served or vulnerable markets, or to simply create a sense of empowerment for local jurisdictions, but these efforts bring new challenges to the traditional system by peeling off revenue that would otherwise support the traditional grid for the majority of communities that still rely on it.

Without sufficient transmission and load-balancing capacity, these resources can reach a saturation point where additional generation does not provide anticipated kilowatt hours and revenue, leading to a less efficient than anticipated system.[40] Energy storage options are continuing to develop to capture the full value of these resources,[41] but potential for curtailment from renewable energy resources remains until storage or transmission lines can capture all the generation.

Environmental commitments for corporations, including utilities, are driving action and creating policy signals across the nation, fostering increased adaptive capacity towards resilience goals. In North Carolina, 39 companies doing business in the state have set goals to be powered by 100% renewable energy, and 21 of these companies have already achieved 100% or plan to within the next 6 years.[42] Companies in a range of industries doing business in North Carolina have set clean energy goals, including major technology companies Amazon, Apple, Facebook, Google and SAS as well as American Express, BlueCross Blue Shield North Carolina, Ikea, Kohl's, New Belgium Brewing and Starbucks.[43]

In addition to these goals, more companies are committing to disclose their climate risks, leading these companies to look more closely at the impacts of climate change across their operations.[44] Globally, 340 investors representing nearly $34 trillion in assets have committed to engage the world's largest companies in evaluating and disclosing their climate risks,[45] which will lead to pressure on these companies to understand and address the underlying issues. Fueled in part by investor interest and corporate disclosures, more data are now available to pinpoint climate risk by geography, industry and corporation.[46]

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[38] Public Service Commission of North Carolina (2019). Duke Energy Docket no. E-7 Sub 1214. Retrieved from https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=cb13c39e-5f6b-457d-be23-5cc33ffa8d7f

[39] North Carolina Clean Energy Plan (2019). Retrieved from https://files.nc.gov/ncdeq/climate-change/clean-energy-plan/NC_Clean_Energy_Plan_OCT_2019_.pdf

[40] Rackliffe, G. (2019). *Duke University Energy Conference 2019: Energy Resilience & Climate Change – A Grid Perspective.* Retrieved from https://www.youtube.com/watch?v=RynPq40cxcw&feature=youtu.be

[41] National Governors Association (2017). *Powering Up: State Trends For Advancing The Use Of Energy Storage.* Retrieved from https://www.nga.org/center/publications/powering-up-state-trends-for-advancing-the-use-of-energy-storage/

[42] Ceres (2019). *NC Clean Energy Plan Stakeholder Workshop Presentation: Corporate Support for Clean Energy. Presented at CEP Facilitated Workshop #4*.

[43] Ibid

[44] Task Force on Climate-Related Financial Disclosures (2019). *Task Force on Climate-Related Financial Disclosures: Status Report.* Retrieved from https://www.fsb-tcfd.org/wp-content/uploads/2019/06/2019-TCFD-Status-Report-FINAL-053119.pdf

[45] Ibid

[46] Mazzacurati, E. (2019). *Scenario Analysis for Physical Climate Risk: Equity Markets*. Retrieved from http://427mt.com/2019/06/18/scenario-analysis-for-physical-climate-risk-equity-markets/



For the first time, climate change is becoming a credit risk issue potentially impacting access to and cost of capital.[47] Moody's, one of the big three credit rating agencies worldwide, has acquired a climate data company and recently identified Duke Energy as one of the nation's top utilities at risk from hurricanes due to climate change, with the most severe risks along Duke Energy's coastal Carolina operations and parts of their Florida service area.[48] Overtime, these risks can impact bond ratings, resulting in increased cost of doing business.

Resilience Strategies

There are opportunities for North Carolina power generation, transmission, and distribution system owners and operators to add technology and system improvements to increase reliability and resilience. Also, as the location and production of the new generation sources change, the need for and use of transmission, and especially distribution systems, must change. Accordingly, there may be opportunities for infrastructure owners to integrate grid modernization into future plans.

For weather-related risks, numerous actions have been planned or proposed by Duke Energy in their recent rate case filings with the Public Utilities Commission.[49] Targeted undergrounding of transmission lines in high risk and/or high impact areas is a key strategy to reduce the potential for physical damage and resulting outages.[50] In addition, there is an array of means to hardening grid and transmission infrastructure and increase the intelligence and security of these systems.[51] Renewal of existing energy infrastructure assets, automation and analytics may all help foster a more resilient grid.[52]

To address the impacts of increasing generation from intermittent and distributed renewable energy resources, we must develop *"load that can use it, transmission that can move it, or storage that can save it."*[53]

For **load management**, ongoing efforts are underway to reduce peak demand and to shift demand to meet generation. The NC Electric Cooperatives are piloting and implementing a variety of energy efficiency, load management, and distribution system operation methods to reduce peak demand. Other possible options are to determine the drought conditions that would cause the State of North Carolina to put limits on electricity production and to add back-up power supply for grid disruptions.

On the transmission side, we can improve reliability of grid systems through back-up power supply, intelligent controls, smart analytics, micro-grids, and distributed generation to better respond to disruptions. We must continue to build out lines to capture generation from renewable energy resources and DERs and to increase transmission capacity within and between regions to overcome localized disruptions.

Storage solutions are under development nationwide with efforts to reduce costs, increase capacity and innovate. Storage solutions can buffer peak demand and add capacity to minimize disruptions.

Coordination with **local governments** should continue through efforts such as the Environmental Defense Fund's Cities Initiative which has a series of meetings scheduled in 2020 and offers an opportunity for

[47] Moody's (2020). *Research Announcement: Moody's US regulated electric utilities face varied exposure to climate hazards.* Retrieved from https://bit.ly/2u7MH9V
[48] Downey, J. (2020). *Duke Energy ranks high among utilities at risk from hurricanes, other impacts of climate change.* Retrieved from https://www.bizjournals.com/charlotte/news/2020/01/16/duke-energy-ranks-high-among-utilities-at-risk.html
[49] Public Service Commission of North Carolina (2019). Duke Energy Docket no. E-7 Sub 1214. Retrieved from https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=cb13c39e-5f6b-457d-be23-5cc33ffa8d7f
[50] Ibid
[51] Ibid
[52] Rackliffe, G. (2019). *Duke University Energy Conference 2019: Energy Resilience & Climate Change – A Grid Perspective.* Retrieved from https://www.youtube.com/watch?v=RynPq40cxcw&feature=youtu.be
[53] Ibid



collaboration on initiatives and new perspectives. In addition, energy providers need to coordinate with local essential services and consider Business Continuity Planning.[54]

Physical resilience can also be achieved through renewal of existing energy infrastructure assets and **building redundancy** into facilities to allow for continued operation during partial disruptions. This may include storm-hardening energy infrastructure and/or elevating water-sensitive equipment to address high water levels.

Microgrids – used for both community-scale applications and critical infrastructure – could have significant benefits in many parts of North Carolina. A microgrid is a small electric system that combines local energy resources and control technologies to provide power to a defined area. They are typically deployed at critical infrastructure locations such as hospitals, but they can also be deployed for all or part of a community. These microgrids allow entities to operate as small islands when the larger grid is experiencing a major outage, and thus they represent an excellent opportunity for providing greater resiliency in the face of weather-related disasters. In many cases, these microgrids can utilize renewable resources and battery-based energy storage.

Both investor owned utilities and cooperatives have been able to benefit from the distributed resources installed as part of a larger microgrid. The state should encourage its utilities and rural cooperatives to consider additional microgrid projects to improve recovery from storm-related issues.

For all of these efforts to bear fruit, *the state must continue the work of the* **North Carolina Clean Energy Plan** *to build capacity of stakeholders in all areas*. Currently, combined PV and energy storage are probably not economical in North Carolina under most traditional cost-benefit calculations as confirmed by the recent energy storage study in North Carolina.[55] If one places a value on the losses incurred from grid disruptions; however, PV+ storage can potentially become a fiscally sound investment.[56] The state should examine the viability and benefit of installing several projects at state or locally owned facilities that are in particularly storm-prone areas. As these projects proceed, the state should disseminate the results to promote similar thinking in the private sector.

Power Plant Cooling / Water Shortage

Impact Summary

Historical data for North Carolina indicate that precipitation has become more variable, stream low flows are decreasing in many areas, and **drought** intensity is increasing. Projected temperature and rainfall estimates indicate that this trend may continue. If there is a severe drought and adequate water is not available to cool thermoelectric power plants, or if the water becomes too warm, these plants may operate inefficiently and may risk partial or full shutdowns. Priority given to electricity production may decrease water supply availability for residential, commercial and industrial customers. Decreased power generation also means other, more expensive plants will need to produce electricity that use costly fuels or purchase from other utilities raising the cost of operations.

The utility companies may experience strains on power supplies as people increase power usage through increased use of air conditioning in times of excessive heat. Increased energy demand during heat waves

[54] National Governor's Association (2020). *State Strategies To Improve Energy Resilience Through Distributed Technologies* (webinar). Retrieved from https://www.nga.org/webinars/eie-webinars/state-strategies-to-improve-energy-resilience-through-distributed-technologies-webinar/
[55] https://energy.ncsu.edu/storage/wp-content/uploads/sites/2/2019/02/NC-Storage-Study-FINAL.pdf
[56] https://www.energy.gov/sites/prod/files/2018/03/f49/Valuing-Resilience.pdf



and drought periods can lead to greater emissions of greenhouse gases and air pollutants, decreased air quality, and public health concerns.

Vulnerability and Risk

Droughts have multiple implications for power systems, ranging from reduced hydroelectricity generation, to limited availability of cooling water for power stations, or to increased demand for power needed for pumping and treatment. Some examples of these vulnerabilities, as outlined in a 2013 Department of Energy report, follow.[57]

The average summer capacity at thermoelectric power plants by mid-century (2031-2060) is projected to decrease by between 4.4 and 16%, depending on climate scenario, water availability, and cooling system type, as compared to the end of the 20th century.[69]

Increasing air and water temperatures can reduce the **efficiency** of thermoelectric power generation and could reduce available generation capacity. Power plants using natural gas, coal, nuclear fuel, bioenergy, and geothermal are all affected by elevated air temperatures. One such event occurred in August 2007, when drought, heat waves, and elevated water temperatures forced Duke Energy to curtail operations at two coal-fired power plants, causing scattered power outages. In August 2006, two nuclear units at Exelon's Quad Cities Generating Station in Illinois reduced electricity production to less than 60% of available capacity because the temperature of the Mississippi River was too high to discharge heated cooling water from the reactors.

Power plants are at risk of exceeding thermal discharge limits established to protect aquatic ecosystems and incurring financial penalties or forcing curtailments. In 2007, 2010, and 2011, the Tennessee Valley Authority's (TVA) Browns Ferry Nuclear Plant in Athens, Alabama, had to reduce power output because the temperature of the Tennessee River was too high to receive heated cooling water without risking ecological harm to the river. Such incidents have forced the TVA to curtail power production of its nuclear reactors, in some cases for nearly two months. The cost of replacement power was estimated at $50 million. In July 2012, four coal-fired power plants and four nuclear power plants in Illinois requested permission to exceed their permitted water temperature discharge levels because the temperature of their cooling water pond is regulated to prevent adverse ecological impacts. The Illinois Environmental Protection Agency granted special exceptions to the eight power plants, allowing them to discharge water that was hotter than allowed by federal Clean Water Act permits.

Low flow conditions in rivers and low lake levels due to drought pose an operational risk to power plants. Most of the plants use once-through cooling systems, which are particularly vulnerable to low streamflow conditions due to the large volumes of water withdrawn. For example, in 2007, severe drought in the Southeast caused the Chattahoochee River, which supports more than 10,000 MW of power generation, to drop to one-fifth of its normal flow. Overall, hydroelectric power generation in the Southeast declined by 45%. In July 2012, power production from U.S. nuclear plants hit their lowest seasonal levels in nine years as drought and extreme heat forced plants from Ohio to Vermont to cut back on output.[58] According to a 2010 study on coal-fired power plants in the U.S. conducted by the National Energy Technology Laboratory, 580 plants (60% studied) are located in areas subject to water stress (i.e., limited water supply and/or competing water demand from other sectors). Most are in the Southeast as shown in Figure 5L-2. Note, several of the coal-fired power plants in North Carolina have shut down since the study was conducted.

[57] U.S. Department of Energy, U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather, July 2013, DOE/PI-0013.
[58] Natural Resource Defense Council. Issue Brief, April 2014. Power Plant Cooling and Associated Impacts. Retrieved from www.nrdc.org/policy



Figure 5L-2. The 100 most vulnerable coal-fired power plants based on water stress.

Resilience Strategies

The magnitude of the impact from increasing air and water temperatures on specific power plants can vary based on plant- and site- specific factors. The water use intensity and the impact of decreasing water availability depends on the type of power plant, cooling system employed, geographic location of the plant, and source of cooling water.

Most of the water withdrawn by thermoelectric power plants is for once-through cooling systems. Figure 5L-3 shows cooling configurations of North Carolina's plants. [59] Once-through cooling systems are particularly vulnerable to low streamflow conditions due to the large volumes of water withdrawn. Adaptation measures that use technologies and practices that are more climate-resilient should be considered. Several commercial options are currently available. Closed cycle systems (recirculating) use lower water withdrawals per unit of power produced compared to once-through systems, but evaporative loses could require cooling towers to need more water as compared to lower ambient temperatures. Dry-cooling technology rather than recirculating cooling systems can be used, thus dramatically reducing water requirements and lowering vulnerability to reduced water availability. Dry-cooling systems have been installed in several natural gas-fired combined cycle power plants in the U.S.

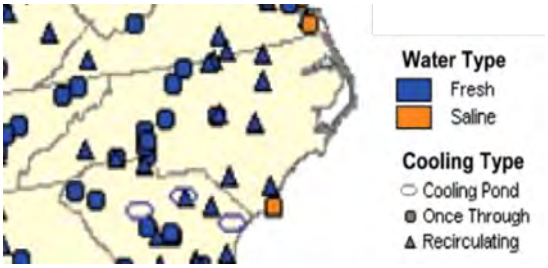


Figure 5L-3. Locations of plants requiring cooling water and their cooling types

[59] NETL (National Energy Technology Laboratory). 2008. Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements. DOE/NETL-400/2008/1339. Retrieved from http://www.netl.doe.gov/technologies/coalpower/ewr/pubs/2008_Water_Needs_Analysis-Final_10-2-2008.pdf.

Other options for actions related to vulnerability and risk include:

- expanding the use of water recapture and reuse technologies for existing and future thermoelectric power plants;
- using nontraditional waters such as brackish and saline groundwater and municipal wastewater, or reclaimed water for cooling existing and future thermoelectric power plants;
- integrating improved design and placement of cooling water intake and outflow system channels and pipes to address changes in water levels and temperatures;
- building redundancy into facilities to allow for continued operation during partial disruptions;
- deploying more energy-efficient freshwater extraction, distribution, use and treatment technologies;
- locating new facilities to areas with sustainable water supply;
- adding peak generation and power storage capacity to minimize disruptions; and
- assuring regional fuel product reserves to address vulnerable fuel supply disruptions.

Alternatively, measures that reduce the amount of power needed or shifting to less resource-intensive generation methods could be employed. For example, utilities can increase the deployment of enhanced demand-side management strategies and use of energy efficient appliances, equipment, buildings, and processes. Utilities can also increase the use of non-centralized and non-water intensive energy technologies (e.g., wind, photovoltaic solar, battery storage, microgrids).

Fuel Supply Chain Disruption / Increased Storm Intensity

Impact Summary

Extreme storm events can impact the natural gas pipeline infrastructure and petroleum pipeline, storage, and distribution infrastructure. Excessive **flooding** from a storm event can disrupt upstream compressor stations which would be unable to pump the fuel through the pipeline system. Excessive flooding, **landslides** or other storm-related hazards can damage the pipelines, interrupting the flow of fuel to end users. Flooded roads can disrupt trucking operations from delivering fuel to gas stations which can create long gas lines and hinder emergency response operations. These impacts can cascade into other disruptions such as power plant operations, evacuation routes, public safety, emergency response, critical infrastructure operations, business operations, and many other micro and macro-economic operations.

Vulnerability and Risk

North Carolina relies on a limited number of natural gas pipelines and petroleum pipelines to support the electricity, transportation, and industrial sectors. North Carolina's electric infrastructure is increasingly tied to the natural gas infrastructure as power generation shifts away from coal burning plants. Gas-dependent electrical generators can experience outages at the same time as gas supply disruptions caused by extreme storm events. In its 2013 Infrastructure Report Card, the American Society of Civil Engineers (ASCE) stated that North Carolina "is almost entirely dependent on [the] Transco Gas Pipeline for its natural gas requirements" and this heavy reliance on Transco Pipeline for natural gas availability presents fuel supply vulnerabilities.[60,61]

[60] American Society of Civil Engineers. (2017). North Carolina Infrastructure Report Card. Retrieved from https://www.infrastructurereportcard.org/state-item/north-carolina/
[61] Energy Policy Council. (2016, March). Energy Policy Council Report, pp. 4. Retrieved from https://ncdenr.s3.amazonaws.com/s3fspublic/documents/files/Energy%20Policy%20Council%20Report%20March%202016.pdf



Related to the transportation sector, North Carolina acquires all of its petroleum products from other states and from abroad. The Colonial and Plantation pipelines from the Gulf Coast supply the state with petroleum products. The Dixie Pipeline, a major supplier of propane to the Southeast, terminates in Apex, North Carolina, where a terminal and above-ground storage tanks are located. Tankers from other states and other countries deliver a very small amount of North Carolina's total petroleum products to the Ports of Wilmington. Disruptions to both the natural gas and petroleum pipeline systems create further vulnerabilities in systems that depend on them, and pose public health, safety, economic, and other risks to the state's population and economy.

Resilience Strategies

Fuel terminal resilience can be enhanced through existing emergency plans for severe weather events. Fuel terminals can undertake appropriate hardening and resilience measures to protect their facilities from future storms and make provisions to restore operations after storms. Example includes back-up generators that can be mobilized and manually hooked into the terminal power feed to operate main terminal pumps.

The State Emergency Response Team (SERT) monitors energy security and energy assurance issues related to severe weather events. The SERT keeps in close communication before, during, and after storms with fuel terminals regarding the adequacy of their fuel supplies to meet demand from residential, commercial and industrial customers. It is organized by the North Carolina Division of Emergency Management (EM) to provide, coordinate, and arrange for emergency assistance to the counties. It is responsible for coordinating and directing state government and emergency management field activities in response to emergencies and recovery from disasters.

DEQ's State Energy Office (SEO), supports EM's Emergency Support Function, ESF-12 (Energy) and serves within the Operations Section Infrastructure Support Group during all SERT activations. The SEO provides information about the condition of the state's energy supply and infrastructure from commercial news sources, government information sharing systems, industry information services and private sector contacts. It shares pertinent information with EM, Federal ESF-12, and energy industry partners as appropriate.

An **Energy Assurance Plan** has been written and exercised by state emergency managers in collaboration with the SEO. The plan includes procedures to coordinate the permitting necessary to bring repair equipment into the state, as well as waivers for the seasonal change in motor vehicle fuel composition. Pipeline companies have been included in these exercises, as well as representatives from the fuel marketers trade groups. The Energy Assurance Plan can integrate resilience strategies by coordinating with the NC Utilities Commission to evaluate completeness and integrate into SERT activities such that all activities under the emergency support function – energy can be covered.

North Carolina should also develop and implement an **Alternative Fuel Infrastructure Plan** for storm resilience to enhance alternative fuel vehicles fleet and to improve the disaster preparedness of fueling facility, recovery planning, and resilience by increasing alternate fuel diversity including electrical vehicle infrastructure options. Under a recent Department of Energy award, E4 Carolinas, SEO, federal and local governments, advocacy groups, utilities, fuel suppliers, and many other partners in North and South Carolina are conducting infrastructure disruption research, assessing potential for future disruption, and developing a plan that lays out best practices for resilience or recovery strategies.

4. Framework for Energy System Resiliency Planning

The NC Disaster Recovery Framework (NCDRF) was developed by NC Emergency Management (NCEM) and is updated on an annual basis. The Framework describes the role of state agencies and their partners in assisting with recovery efforts and is designed to address the complex and unique nature of

disasters. Successful recovery efforts rely upon the whole community. The NCDRF considers the impacts of grid-related disasters, including threats from tropical cyclones, winter storms, and cyberattacks. The framework is an evolution from the operational plan previously maintained by the state.[62]

The current framework is focused on how the state should respond to and recover from disasters. Inherently, the approach is focused on recovery. Recent studies have shown that every dollar spent on disaster preparedness can offset as much as six dollars spent on recovery efforts.[63] The state should thus consider how to integrate resiliency planning into its disaster recovery planning, including how assets can best be deployed to reduce recovery efforts. For example, microgrids installed at critical infrastructure such as hospitals and first-responder facilities can potentially make first response efforts more effective. The state should study the impact of such investments and potentially consider several pilots. Ultimately, such planning should be incorporated into the NCDRF.

Investing in resources that provide greater resiliency can be very expensive. For example, grid-hardening measures and selective installation of microgrids may be excellent for preventing major long-term outages, but the cost must be borne by the ratepayers and those costs may be deemed too high for ratepayers to bear. If one begins to consider the total cost of outage prevention – including the regional economic impact and the impact on individual families that come from large storms – it is possible that the upfront cost of targeted resiliency measures can become more palatable. The state should encourage a deeper investigation into this question, and this investigation should be based on the true **social and economic costs** of recent events in NC. This analysis should be conducted in a way that promotes social and economic equity, for example by being careful not to calculate the human cost of outages differently for communities of different economic means.

One starting point is to apply the Resilience Analysis Process developed by the Sandia National Labs.[64,65] This process (shown in Figure 5L-4) provides methods for measuring and increasing energy resilience,



Figure 5L-4. Resilience Analysis Process starting with defining resilience goals (Sandia National Laboratory)

[62] https://files.nc.gov/ncdps/documents/files/2018%20NC%20Disaster%20Recovery%20Framework_Final_0.pdf
[63] https://www.bloomberg.com/news/articles/2019-06-11/u-s-hurricane-season-is-unnecessarily-dangerous
[64] Jean-Paul Watson, Ross Guttromson, Cesar Silva-Monroy, Robert Jeffers, Katherine Jones, James Ellison, Charles Rath, Jared Gearhart, Dean Jones, Tom Corbet, Charles Hanley, La Tonya Walker. *Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States*, Sandia National Laboratories, Albuquerque, New Mexico, SAND2014-18019, September 2015. Retrieved from https://www.energy.gov/sites/prod/files/2015/09/f26/EnergyResilienceReport_Final_SAND2014-18019.pdf
[65] Other examples include Argonne National Laboratory's *State Energy Resilience Framework and National Academies of Sciences*, Engineering and Medicine's *Enhancing the Resilience of the Nation's Electricity System*.



including definitions, means of measuring, and analytic methodologies that can be used to make decisions for policy, infrastructure planning, and operations. The risk-based framework contains a standard definition of resilience metrics and explains how the metrics can be applied to accelerate the resilience of energy infrastructure.

Currently in North Carolina, a collaborative study on resiliency metrics is underway between the SEO, UNC Charlotte EPIC, North Carolina State Clean Technology Center, and the DOE that attempts to develop a method to quantify the human costs of power outages from certain North Carolina storm events, and integrate these costs when evaluating grid modernization plan components related to resilience.[66] Others have developed metrics shown in Table 5L-2 to recognize additive property to reliability metrics that recognize low-probability, high-impact events have on outages and system recovery.

Table 5L-2. Example Resilience Metrics for Measuring social and economic impacts[1]

Consequence Category	Resilience Metric
Direct	
Electrical service	• Cumulative customer hours of outages • Cumulative customer energy demand not served • Average number (or percentage) of customers experience an outage during a specified time period
Critical electrical service	• Cumulative customer hours of outages • Cumulative customer energy demand not served • Average number (or percentage) of critical loads that experience an outage
Restoration	• Time to recovery • Cost to recovery
Monetary	• Loss of utility revenue • Cost of grid damages (e.g., repair or replace lines, transformers) • Cost of recovery • Avoided outage cost
Indirect	
Community function	• Critical services without power (hospitals, fire stations, police stations) • Critical services without power for more and N hours (e.g., N>hours or backup fuel requirement)
Monetary	• Loss of assets and perishables • Business interruption costs • Impact on Gross Municipal Product (GMP) or • Gross Regional Product (GRP)
Other Critical Assets	• Key production facilities without power • Key military facilities without power

[66] University of North Carolina Charlotte Energy Production and Infrastructure Center, N.C. Department of Environmental Quality and N.C. Clean Energy Technology Center. Planning an Affordable, Resilient, and Sustainable Grid in North Carolina, December 12, 2019. Retrieved from https://nccleantech.ncsu.edu/2019/12/12/planning-an-affordable-resilient-and-sustainable-grid-in-north-carolina/



Utilities, state regulators, elected officials, local governments, energy planners, emergency response planners, and others take disaster preparedness seriously but are often working in their own jurisdictions to fulfill their administrative mandates. It is suggested that North Carolina stakeholders develop an effective collaborative process to ensure a cost-effective statewide resilience framework and develop resilience metrics that are tied to measured outcomes for the affected residences and communities.

Case Study Example

As mentioned earlier, a collaborative study on resiliency metrics is being conducted between the SEO, UNC Charlotte EPIC, the North Carolina Clean Technology Center, and the DOE. The project team is utilizing the Resilience Analysis Process (RAP) outlined in Figure 5L-4 to evaluate the potential impact that various grid-modernization investments might have in achieving a desired set of resiliency goals.

RAP is a framework that provides a state or region with a methodical approach for evaluating resiliency investment. The method can be used to understand how various measures could have improved performance in past storms, or it can be used in a stochastic manner to understand how future storms might impact a region. The team is applying the RAP to understand measures that could have benefited North Carolina in recent storm events, using Hurricanes Matthew and Florence as canonical examples. In this case, the team is working in two specific steps. First, the team is conducting a baseline resilience assessment to compare grid performance during and after Hurricanes Matthew and Florence to specific resilience targets. Second, the team is evaluating which investment options would better improve the resilience of the system in the face of a storm similar to Matthew or Florence.

The team is considering a mix of alternatives that include both proposals from Duke Energy's Grid Improvement Plan as well as other potential solutions such as microgrids sited to serve facilities performing key community functions. The focus of the work is to demonstrate how resilience metrics and targets can be defined for North Carolina, using the impact on the Wilmington area during Matthew and Florence as illustrative examples. This section provides a brief overview of that process.

Define Resilience Goals

The first step in resilience assessment is to define the goals that establish the scope. Table 5L-2 lists specific metrics that others have defined as additive beyond traditional reliability metrics related to recovery following an outage. The team is performing its analysis using historic data from Duke Energy to understand the extent and duration of power outages to critical and non-critical loads. The work recognizes the role that the utility plays in enabling basic community functions, and that some of these functions were interrupted due to storm-caused power outages. The team is also reaching out to community leaders to understand municipal and community needs and weaknesses. Utilizing a detailed stakeholder engagement process, the team seeks to identify and quantify key objectives. Potential examples include the following:

- The storm's effect on power delivery to hospitals, waste-water plants, police stations, and fire stations, and other key community facilities.
- The extent and duration of power outages.
- The cost borne by the utility to restore power following an outage.

The specific metrics will be identified through a process of analysis and stakeholder engagement.

Define Consequence Categories and Resilience Metrics

Once goals have been identified through a stakeholder engagement process, the team will work to quantify specific resilience targets. Examples could include the following:

- Zero hospitals, police stations, and fire stations without power for more than 48 hours.

- No more than a specified number of customer-days without power. Depending upon the number of customers, this would translate to an expected number of outage hours per customer.
- Restoration costs below a specified threshold.

The goal of the RAP is to select investments that satisfy these requirements. The specific targets will be identified through the stakeholder engagement process already described.

Characterize Threats and Determining the Level of Disruption

The goal of the RAP is to propose and evaluate measures that can achieve the resilience targets noted previously. To do so, it is essential to understand the specific ways in which past storms have impacted the region. Much of the damage caused by Hurricane Florence, for instance, resulted from flooding. The storm produced rainfall exceeding 10 inches across much of southeastern and southcentral North Carolina and northeastern South Carolina, with totals exceeding 20 inches from the North Carolina-South Carolina border eastward across southeastern North Carolina. The slow forward speed of Florence prior to and after the hurricane made landfall resulted in persistent rain bands moving inland off the Atlantic Ocean and training over the same area from Wilmington to Elizabethtown, North Carolina, resulting a narrow swath of rainfall totals exceeding 30 inches. Figure 5L-5 shows rainfall analysis for the eastern seaboard from 13 to 18 September 2018[67].

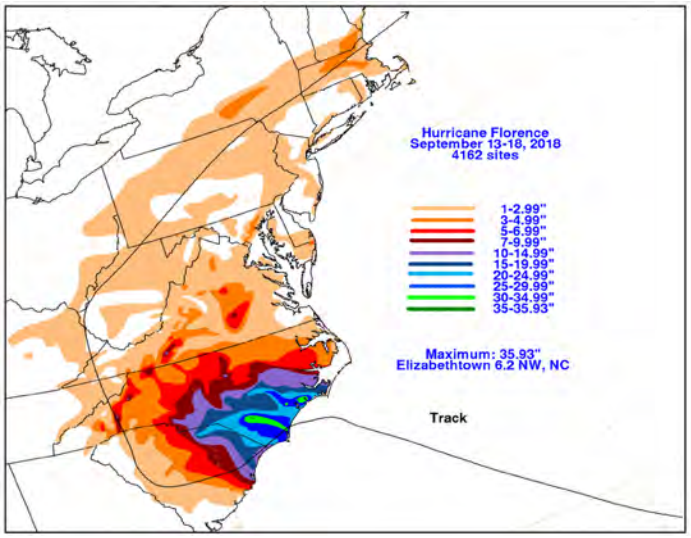


Figure 5L-5: Rainfall totals on the eastern seaboard during Hurricane Florence[68].

The catastrophic flooding resulting from the tremendous rainfall had a significant impact on inland waterways such as the Cape Fear River. During the initial period following Florence's landfall, every major road into New Hanover County was impassable, including I-40 and I-140. Such road closures can have a major impact. For example, on Sunday September 16, Cape Fear Public Utility Authority issued a dire warning that without an influx of diesel and gasoline, it would run out of fuel for its water-treatment plant, cutting off both drinking water for many customers as well as water for the major regional hospital[69]. This issue was caused by impassable roadways.

[67] S. Stewart and R. Berg. "National Hurricane Center Tropical Cyclone Report - Hurricane Florence", National Oceanographic and Atmospheric Administration, SAND2014-18019, May 2019. Retrieved from https://www.nhc.noaa.gov/data/tcr/AL062018_Florence.pdf
[68] Ibid
[69] P. Sullivan and K. Zezima, "Florence has made Wilmington, NC, an island cut off from the rest of the world," Washington Post, September 16, 2018.



Evaluate and Propose Resilience Improvements

The goal of the RAP is to evaluate various measures that could meet the targets identified in the early stages of the process. For example, the analysis of the impacts from Hurricane Florence indicate that Wilmington is extremely vulnerable to the impacts of flooding and can be effectively cut-off for substantial periods of time. The team is considering two sets of investments that could potentially improve the targets outlined previously. These include the following:

- Proposals included in the North Carolina Grid Improvement Plan filed for both Duke Energy Carolinas and Duke Energy Progress[70]
- Proposals beyond the Grid Improvement Plan including techniques such as customer-sited microgrids

The effectiveness of these measures will be evaluated as a means for achieving the targets outlined previously. As an example, the Grid Improvement Plan recommends measures such as targeted undergrounding and substation hardening. Several of these measures are planned for the Wilmington area, and include measures such as moving feeder exit cables from overhead supports to underground enclosures. Such measures will most certainly improve goals for minimizing the number of customer-hours without power, but they may not necessarily have a strong impact on other indirect community functions. For instance, a potential resilience goal might be to ensure that an important community facility such as the water-treatment plant are never without power. This would, of course, require a robust back-up power solution that does not rely on fuel that must be transported via roadway. Localized natural gas generation or a microgrid consisting of some form of renewable power could be one solution that would prevent such failures.

The wastewater treatment facility is a key example of the type of measure not necessarily included in utility rate plans. Localized generation does not necessarily benefit all ratepayers on a normal basis, but it may be essential to meeting key community functions during and after major storms. The stakeholder process is intended to quantify these indirect community benefits. Legislative change may be needed for the utility commission to be able to evaluate such proposals, but a key outcome of the process is to expose such issues for further evaluation and discussion.

5. Summary

North Carolina's energy infrastructure, with its diversified generating plants, robust transmission and distribution infrastructure, fuel pipeline systems and renewable resources, is susceptible to both natural and man-made incidences that may result in local or statewide energy emergency events. As current operations evolve in response to changes in fuels and electricity production technologies, various areas of the energy sector should consider future hazards, and then plan ahead to reduce vulnerabilities and risks to achieve a reliable supply of energy.

For the transmission and grid participants in the energy sector, planning ahead means hardening and modernization of the grid, targeted undergrounding and renewing existing assets with automation, intelligent devices and controllers, and successful integration of distributed energy resources. For power plants, getting ahead of future water shortages may involve alternative or lower volume water resources. To protect North Carolina's heavily imported fuel and gas supplies during storm disruptions and other power emergencies, alternative fuel infrastructures and hardening existing fuel pipelines, terminals and distribution infrastructure may be needed to protect emergency evacuation options and critical infrastructure.

[70] https://starw1.ncuc.net/NCUC/ViewFile.aspx?Id=cb13c39e-5f6b-457d-be23-5cc33ffa8d7f



All of these resiliency efforts will benefit from improved metrics for measuring and increasing resiliency across the energy sector. North Carolina's policymakers and regulators can turn these metrics into actions and create accountability for energy providers for delivering resilience and other customer value.


Cross-Sector Impacts

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M. Cross Sector Impacts and a Coordinated Action on Resilience

1. Introduction

The integration of climate risk management into existing agency missions and operations can help state government agencies coordinate and plan their response to climate impacts and inform state-level adaptation and resilience solutions in both the short and long terms. The following synthesis draws upon the expertise of 11 sector sectors to outline common themes, provide recommendations to reduce impacts, and offer an opportunity to focus inter-agency efforts on shared priorities. Each impact assessment focused on state agency assets, services, and responsibilities. This synthesis uses that framework and can be used to guide a strategic approach to climate resilience prioritization, planning, and action in future phases of work in the state of North Carolina.

2. State-Owned Assets: Forward-Looking Infrastructure Design and Planning

The state of North Carolina owns and manages a limited number of assets, but those that it does are critical to all sectors of life and the economy. The focus of this section is on integrating climate resilience into the state-level designing and planning process those state owned and managed assets which include but are not limited to public roads, buildings, dams, and other infrastructure**.**

Road Design

Chief among the assets owned and managed by the state are its roads. Primary roads throughout the state support commerce in all sectors and provide critical conveyance for citizens and emergency responders during and after climate-related events.

> **"NCDOT directly owns and maintains a large and diverse number of assets statewide. Storm-related damages are threatening public safety, creating economic disruptions, and causing budgetary shortfalls that require a strategic refocusing."**
>
> *Transportation*

The *North Carolina Department of Transportation (NCDOT)* is committed to working with and serving local government and the citizenry (**Section 5J**). Doing so will require a forward-looking road infrastructure design and planning process. This is one of the greatest priorities of a future North Carolina resilience plan because roads are integral to so many other functions of government and daily life within the state. The challenges identified in **Section 5J** differ by physiographic province. For instance, storm surge and flooding all affect coastal roads, but landslides are the primary drain on financial resources otherwise dedicated to road maintenance in the mountains.

The importance of the transportation network is underscored within the ***Coastal Resources and Infrastructure***, ***Commerce and Business***, ***Energy***, ***Health and Human Services***, ***Water and Land Resources,*** and ***Public Safety*** sections which highlight the work of *the Department of Environmental Quality (DEQ), Department of Commerce (DOC), and the Department of Health and Human Services (DHHS).* These sectors have a vested interest in climate-informed investment decisions pertaining to transportation. Pre-planning with these departments is an essential component of *adaptive capacity* within the **Department of Transportation.** For example, the NCDOT works with the **Departments of Public Safety and Environmental Quality** within state government, FEMA at the federal level, and local governments across the state to reduce vulnerability and risk associated with landslides and debris.

Building and Site Design

New design and engineering standards should be incorporated into the design of new structures. Building design was mentioned within the ***Housing, Buildings, and Support Services*** assessment above (**Section 5H**) in discussions of veterans housed within the Veterans Affairs hospital system, in the discussion of prisoners, and in the discussion of minors housed in North Carolina facilities.

The *Department of Agriculture and Consumer Services* owns and maintains buildings across the state, as do the *Department of Administration, Department of Commerce, Department of Natural and Cultural Resources*, and others. Buildings can be protected by implementing reasonable new building standards, including freeboard that incorporates expected conditions during the lifetime of the property. Some buildings should be moved, as suggested in the ***Agriculture and Forestry*** analysis (**Section 5B**).

Extreme Precipitation and Landslides

Landslides are most common in the mountain areas of western North Carolina, though they do occur on steep slopes in the Piedmont and Coastal Plan. The frequency of landslides is directly linked with the frequency and magnitude of prolonged or heavy rainfall. Potential consequences of these events include loss of life and injury, property damage, and impeded response capacity of critical emergency response services. Aging infrastructure increases the likelihood of landslides related to failing drainage systems and deteriorating slopes on major transportation routes resulting in economic losses from disruptions to transportation networks. Impacts cut across the ***Public Safety, Water and Land Resources, Commerce, Transportation, Public Health,*** **and** ***Coastal Resources and Infrastructure*** sectors.

Cross-agency options include each of the following:

- Enhance state and local collaboration to (a) anticipate and communicate the threat of landslide hazards and (b) coordinate emergency responses to landslide events.
- Provide incentives for smart growth and development in safe locations.
- Improve and develop landslide mitigation funding strategies.

3. Regulations and Policies: Strengthening Climate Resilience across State Agencies

Allocate Resources and Support for Interagency Resilience Efforts

A recent publication by the Governors' Institute encouraged state governments across the nation to ensure that there is a clear line of authority from the governor to an individual authorized to coordinate resilience activities across cabinet agencies.[1] This recommendation is echoed in the Public Safety narrative (**Section 5I**), which calls for a resiliency office whose new staff positions would be permanently funded. These

[1] Building Resilient States: A Framework for Agencies. 2015. Governor's Institute for Community Design, SmartGrowth America.



staff would serve numerous roles, including annual table-top exercises focused on Continuity of Operations that involve all aspects of state government.

In addition, the ***Public Safety*** sector recommends strengthening the state's hazard mitigation plan, allocating resources to response and recovery, and authorizing a quantified risk assessment as part of the Steps to Resilience (Figure 5A-1).

The quantified risk assessment could build on previous efforts by the *Natural Heritage Program* (**Section 5F**) and ***Water and Land Resources*** **(Section 5K)** sector, each of which has a system in place for measuring vulnerability and risk for the assets they manage. If a water supply risk assessment were conducted, for example, local governments would have better information about the rationale and importance of collaborating with neighboring authorities to manage water supply in the face of drought, flooding that brings contamination, and other water management concerns that arise in relation to climate-related hazards.

The **NCDOT** has secured funding from the state legislature for a Flood Risk and Vulnerability Assessment of the Strategic Transportation Corridors which focuses on the most vital transportation corridors within the state (**Section 5J**).

Quantitative spatial analysis of correctional institutions, readiness centers and other facilities used by the *Department of Public Safety* to maintain a community presence is needed to identify facilities most at risk. Addressing these risks would require a comprehensive master plan to balance maintenance, logistics, and relocation requirements (**Section 5I**).

DEQ has also secured disaster recovery funding from the General Assembly to address recovery and resilience projects within the *Divisions of Water Infrastructure, Waste Management, and Energy, Mineral, and Land Resources.*

Strengthen Workforce Capacity and Response/Recovery Resources

The capacity of state government is only as strong as the people who comprise its workforce. This theme emerged in many ways throughout the risk assessment process. The ***Health and Human Services*** sector (**Section 5H**) and ***Water and Land Resources*** sector (**Section 5K)** highlighted the critical need for personnel during and after hurricanes to serve at North Carolina Emergency Operations Centers, shelters, as emergency responders, and in supporting administrative roles critical to the delivery of services and support. Along with staffing, funding, medicine, food, and other resources are also needed in order to meet the need of North Carolinians suffering immediate setbacks as well as longer term obstacles to recovery.

The ***Agriculture & Forestry*** **(Section 5B),** ***Commerce and Business*** **(Section 5D),** ***Public Safety*** **(Section 5I),** ***Transportation*** **(Section 5J), and** ***Water and Land Resources*** **(Section 5K)** narratives each mention the need to increase funding to attract and add human resources and retain qualified staff who understand the complexity of their job function well enough to adapt and respond amidst the duress imposed by emergency response or chronic stresses on the resources they manage, as well as their own physiology. A hotter climate system which brings longer and more frequent heat waves will chronically stress anyone whose job requires they work outside, such as environmental inspectors, transportation workers, Highway Patrol, Marine Patrol, Wildlife Officers, and National Guard employees.



Conserve and Maintain Ecosystems Services

"Conserving / managing land for key ecosystems yields benefits to other sectors, including water resources, tourism and commerce, and public health."
Ecosystems (Section 5F)
"The health of the environment impacts the health of all people."
Health and Human Services (Section 5H)

Land use regulations and policies can lead to effective and inexpensive ecosystems services, a term that encompasses the benefits to society and typically at no charge, such as water quality, flood management, and preserving the valued natural heritage of a place. The ***Ecosystems*** **(Section 5F),** ***Water and Land Resources*** **(Section 5K), and** ***Agriculture and Forestry*** **(Section 5B)** sector each mention the value of improving water infiltration through wise land use. The benefits include reducing pollution to waterways, including nutrients and sediment which are the most abundant and widespread source of turbidity and contamination (**Section 5K**).

When toxic waste, livestock waste lagoons, wastewater treatment plants, and other sources of potential contamination are exposed to floodwaters, a complex set of engineering, water quality, ecological, and public health issues ensue. Because of the complexity of such problems, cross-sector and cross-departmental coordination will continue to be essential to implement wise land use and regulatory decisions in concert to preserve ecosystem services, such as clean water, that protect humans and other values to the state of North Carolina.

The same land use strategies that yield high water quality and reduce flooding also protect endangered species. For example, the DEQ Stormwater Program regulates development in the Goose Creek, Six-mile Creek and Waxhaw Creek watersheds. These waters are important for threatened and endangered species, most notably the endangered Carolina Heelsplitter (*Lasmigona decorate*) (see **Section 5F**). As the authors of the ***Water and Land Resources*** (**Section 5K**) state:

"Water and land impacts and strategies are closely inter-related. The condition of the land, i.e. natural, managed, or impervious, directly affects the volume and quality of runoff. This in turn influences the availability of water, erosion, sedimentation, landslides, dam safety, pollutant loading to receiving waters, and ecosystem health. The condition of North Carolina's water and land resources are also closely connected to most other sectors which support the state's human and ecological health and economic prosperity. For this reason, strategies to meet the challenges posed by climate change will also require close coordination with these other sectors."

Multiple Climate Hazards Create a Cascade of Tipping Points

Recent extreme events signal the risk that tipping points exist beyond which state and local emergency response and recovery service provision can be effective. In the event that the state arrives at a point where climate-related hazards co-occur (e.g., statewide flooding, severe weather, or wildfire), or where multiple climate hazards impact diverse areas of the state or a region simultaneously, the response and recovery capacity of state agencies will be challenged.

The most recent threat to reaching a tipping point involved the serious drought and extreme heat-related impact on water supply during the 2007-2008 drought in which 30 cities around the state were within 100 days of running out of water. In addition to changes in water supply, the drought fueled 30% more wildfires and negatively impacted agriculture, public health, economic activity, and resulted in energy loss. Relief came from both (a) emergency water supply from an interconnected water supply system and (b) a tropical storm which brought higher than average rainfall to most of the state within a short period of time.

4. Resources and Services: Support Community-Driven Resilience

Build Capacity and Meaningfully Engage Local Leaders

Working with local governments and communities to build resilience will require time to "... build trust, institute new policies and regulations, and properly allocate resources" (**Section 5I**). Regional and local government support is a vital service that any state government provides. For example, state governments are responsible for applying to the U.S. Housing and Urban Development Department for Community Development Block Grants that address mitigation of hazards as well as disaster recovery. Those funds are then disbursed statewide to regional and local agencies. Climate change necessitates a means of prioritizing the planning and execution of those grants in light of the climate-related hazards that have been experienced or that are anticipated. If North Carolina establishes an interagency resilience capacity (see Regulations and Policies above), this program would provide resources and services to regional and local governments (i.e., through risk-based prioritization, planning, grant allocation, support during and after emergencies, and new initiatives).

"Long-term master planning is needed to determine the most cost-effective means to address, maintain, and operate resiliency plans through their life cycles."

-Public Safety (Section 5I)

Complementarily, other departments and agencies will adopt their own climate resilient policies to provide resources and services at more local levels of government. The ***Cultural Resources*** (**Section 5E**) sector highlights numerous ways that its policies can filter down and support the local entities entrusted with assets valued by the entire state. Protecting or preserving archeological sites, museums, specimens, and manuscripts requires a common set of methods whether managed by the state or local entity, so the state *Department of Natural and Cultural Resources* can provide leadership in setting appropriate standards for taking appropriate actions to mitigate the greatest risks.



The ***Coastal Resources and Infrastructure*** (**Section 5C**) sector has elaborated on a variety of ways that state leadership can incentivize communities to protect, enhance, and restore infrastructure. They recommend a program be funded to build local capacity to assess risk and incorporate that understanding into the implementation of policies such as land use planning and zoning.

The Housing, Buildings, and Support Services **sector (Section 5H)** has outlined the *DEQ Division of Waste Management's* proposed efforts to work with local, state, and federal entities' waste and recycling facilities to improve and/or develop and implement strategies that promote the proper management of storm debris and its impacts to statewide communities.

Expand Incentives, and Partnerships to Increase Resilience of Local/Community Infrastructure, Services, and Natural Resources

The ***Coastal Resources and Infrastructure*** sector (**Section 5C**) highlights that the coast is the most vulnerable area in the state in terms of infrastructure damage. The coastal region sees the most intense rainfall events and suffers from some of the most severe impacts of stormwater runoff. It will be imperative to incorporate future climate change and sea level rise scenario information into long-term investment decisions in local and regional water and transportation infrastructure improvements (**Section 5C**).

The ***Commerce and Business*** sector (**Section 5D**) of North Carolina's government underscores the value of education, training, and additional resources specifically targeting rural parts of the state. Their NC Main Street and Rural Planning programs for small towns and the businesses they support represent existing capacity that could be augmented with locally relevant climate adaptation resources.

The ***Agriculture and Forestry*** sector (**Section 5B**) encourages stakeholder engagement and education specifically focused on drought and wildfire—two climate-related hazards that particularly affect natural and working lands. Engagement should also include the effects of extreme rainfall and inundation.

The ***Public Safety*** sector highlights the connection between climate-smart land use planning and reduced burden on emergency services. The North Carolina Coastal Area Management Act provides the Division of Coastal Management the authority to provide land use planning oversight in twenty coastal counties. The *Public Safety* sector recognizes the importance of building partnerships, such as with the Division of Coastal Management, that are supportive yet mindful of local control over land use decisions. However, while the Coastal Area Management Act provides the *Division of Coastal Management* the authority to provide land use planning oversight in twenty coastal counties. Such state-level regulatory influence may be lacking elsewhere. Accordingly, the ***Public Safety*** sector recognizes the importance of building partnerships that are supportive yet mindful of local control over land use decisions.

Several other sectors also mentioned options to provide specific guidance for policies to be implemented within municipalities or North Carolina Soil and Water Conservation Districts. For example, the ***Water and Land Resources*** (**Section 5K**) sector recommends a systematic evaluation of best management practices, levies, and dams, given changing engineering requirements under new precipitation and river discharge regimes.



Leverage Services to Vulnerable Communities for Multiple Benefits

The ***Health and Human Services*** (**Section 5G**) and ***Coastal Resources and Infrastructure*** (**Section 5C**) sectors both emphasize the notion that the most vulnerable populations that have pre-existing illnesses due to exposure to polluted air and water, toxins, or other morbidities associated with low income, racial disparities, age-related risk, or other related factors. Heat islands and heat waves often affect targeted populations that can be mapped and prioritized for mitigation actions.

Expanding energy efficiency and renewable energy programs specifically targeted at underserved markets and low-income communities would allow communities to function in the face of higher temperatures (**Section 5L**). Improving housing and access to adequate cooling would help communities adapt.

5. Advancing Science-informed Data, Technology, and Tools

The ***Coastal Resources and Infrastructure*** sector (**Section 5C**) urges state government to provide data and best practices to equip local government to perform and regularly update county vulnerability assessments. Their *Division of Coastal Management* Coastal Adaptation and Resiliency website provides links to climate data and forecasts, assessment and planning tools, adaptation examples, and sources of funding for planning and implementation.

"Strategies for creating resilience should address existing toxic exposures, such as hazardous waste and lead in water or homes, in low-income communities and communities of color… Existing inequities in environmental health exposures are exacerbated by climate change."

-Health and Human Services (Section 5G)

The *NC Department of Transportation* (**Section 5J**) is collaborating with NCSU and the UNC Institute of Marine Science to improve computer modeled storm surge and other data through the Coastal Emergency Risk Assessment (CERA) to predict storm surge conditions 24 to 48 hours in advance. These data are being incorporated into the Flood Inundation Mapping and Alert Network (FIMAN-T) for coastal areas to predict where storm surge may affect roads during storm events, thus providing critical warning and support for coastal communities.

The *Department of Environmental Quality's* Dam Safety Program (**Section 5K**) is working with the Division of Emergency Management to identify and model dam impoundment capacity and breach inundation areas as well as identify state and local government owned dams to install water level monitoring systems in order to prioritize resilience plans, emergency action planning, and emergency response protocols. These efforts will also serve to improve communication and response efficiency.



Case Study: Hurricane Florence (2018)

Record-level heavy precipitation and associated flooding brought about by Hurricane Florence disrupted the provision of state government services and resulted in wide-ranging impacts across multiple sectors, including:

- ***Agriculture*:** flooding resulted in an estimated $2.4 billion in agricultural losses across the state (**5B**).
- ***Coastal Resources / Ecosystems:*** increased nutrient loading in storm water runoff post-storm resulted in unsafe water quality and fish kills (**5C**) and the increased risk for harmful algal blooms (**5F**).
- ***Commerce and Business:*** storm surge during hurricanes damages property and infrastructure resulting in economic and supply chain interruptions in coastal communities (**5D**).
- ***Cultural Resources*:** heavy precipitation brought about significant damage to historic cultural resources along the coast and inland in flood prone areas (**5E**).
- ***Health and Human Services:*** storm and related flooding resulted in a number of adverse public health impacts including physical injuries, loss of life, mental/emotional trauma, and air, water, and environmental contamination, as well as loss of housing (**5G**).
- ***Transportation:*** record breaking rainfall and storm surge highlighted multiple vulnerabilities in the transportation network and resulted in more than 1,200 individual road closures (**5J**).
- ***Energy*:** historic flooding resulted in ~3 million customers losing power and resulted in one of the largest mobilization of power restoration activities in Duke Energy's history (**5L**).

The provision of emergency response and recovery services during events such as Hurricane Florence requires shifting employee staffing levels statewide. A consequence of these shifts involved disruptions in work flow resulting in understaffed duty stations that quickly become overtaxed in responding to everyday request and local emergency response needs.

Due to the ongoing affordable housing crisis throughout the state there is a shortage of temporary and replacement housing. Extreme weather serves as an affordable housing crisis multiplier and disproportionately impacts low-income neighborhoods and communities of color during recovery efforts. More federal and state funding is needed to enhance personnel capacity across all phases of disaster at state and county levels, derive equitable response and recovery solutions, and increase availability of coordinated logistics and equipment needed during response.

Rising sea level and increasing coastal storm intensity is a risk for exposed energy infrastructure on the coast. Hurricane-related storm damage often results in a loss of electrical power and transportation access due to road washout. Disruptions to the electrical grid and transportation network result in compromised response and post-recovery efforts.



N. Conclusion

1. Summary: A Coordinated Action

This chapter has proposed dozens of resilience strategies for addressing the hazards, impacts, and risks introduced by a changing climate on State Government Assets, Regulations and Policies, and Resources and Services.

The greatest number of assets owned and managed by the state are the roads under the purview of the *NC Department of Transportation (NCDOT).* The NCDOT has undertaken vulnerability assessments in the past and recognizes the importance of the transportation network to the citizens, economy, and the State Government itself. Due to the critical nature of these assets, the NCDOT must maintain working relationships with local government, institute a transparent policy of vulnerability and risk assessment, and incorporate climate science updates into its capital planning for maintenance and improvements to the state's transportation system.

The *Department of Administration, Department of Public Safety, and the Department of Agriculture and Consumer Services,* manage most buildings under the state's ownership. The recommendations in this chapter highlight engineering requirements that need to be addressed to prevent future buildings from being designed and constructed in a way that puts them at undue risk of climate-related hazards and impacts. In some cases, buildings are small and can be moved out of harm's way. Older facilities that cannot be moved can be bolstered against climate impacts through raising the foundations or other bulwarks. For critical infrastructure such as correctional institutions and other facilities used by the *Department of Public Safety,* comprehensive master planning may be required.

Some states that have undertaken resilience plans, such as California and Rhode Island, have recognized the importance of ensuring that all investments by the state, whether in the form of operations, maintenance or new facilities, increase resilience to flooding and other climate threats.

This chapter presents three sets of Regulations and Policies subject to adaptation measures to accommodate climate change. Much of the content of this chapter touches on issues that affect more than one sector of government and the public. Policies could be implemented to allocate resources to support interagency resilience efforts to streamline the planning and implementation of adaptation or resilience efforts that do require cooperation among many departments and/or members of the public outside of state government. Such a plan might include a permanent role for a recognized resilience officer, with support from sub-cabinet representation across all departments. Such an arrangement could allow for coordination where needed.[1]

Many of the impacts of a changing climate will be felt by state personnel, especially those whose jobs require outdoor working conditions. These people (exposed to flooding, heat, wildfire, and other meteorologically driven events) will need training, resources, and incentives to deliver the highest level of service possible in the face of increasing frequency, duration, or intensity of climate-related hazards.

Watershed protections, best management practices, protecting endangered species, protecting open space, and other ecosystem management practices may be the least expensive ways to deliver clean water,

[1] Building Resilient States: A Framework for Agencies. 2015. Governor's Institute for Community Design, SmartGrowth America.



protect lives and property, and maintain the quality of life for which North Carolina is known for Regulations and Policies can orient toward the preservation of these ecosystem services.

State Resources and Services could increasingly support local action informed by a clear understanding of climate-related risk. The NC state government is a constitutionally mandated go-between for local government and federal resources. Therefore, state employees and programs can hone their capacity to understand and meet the requirements of local officials to protect lives and property by supporting risk assessment, planning, and project implementation. In parallel, the state government can use its understanding of local requirements to hone its requests of the Federal Government to best serve North Carolina's citizens.

Such service delivery will be a long-term engagement involving relationship-building in tandem with climate analyses. Existing programs that serve water utilities, business, natural resource management, and other aspects of local government can be augmented to include climate-smart service delivery.

Departments throughout North Carolina's state government enterprise are committed to using science, data, technology, and tools to make better decisions. This chapter provides examples of the appropriate blending of those themes to improve decision making, for example the Coastal Emergency Risk Assessment and the NCDOT Flood Inundation Mapping and Alert Network.

In addition to expanded use of quantitative information to make decisions at the state level, North Carolina also has the opportunity to provide this information and related expertise to local communities. Several states, including California, Massachusetts and Rhode Island, have made this a priority to enable resilience planning at the municipal level

The development of this report is yet another example of that blend of science and decision making, for it came about through close collaboration among the NC state government, academics, especially at NC State University, and federal partners, especially through the U.S. Climate Resilience Toolkit, and input by community organizations and local stakeholders.

2. Next Steps

This chapter was developed to build capacity for agency staff so they might continue identifying and prioritizing resilience actions in an informed way beyond March 2020. Many agencies and departments have already learned from extreme events of the past. This report identifies many potential avenues for augmenting that work and developing initiatives that would expand the capacity of the state government to respond to climate-related hazards. In order to prioritize which programs to augment or initiate, each department must agree on how they will describe climate-related hazards and impacts.

This chapter presents a qualitative evaluation of exposure, vulnerability, and risk. Its preparation helped establish a shared vocabulary and catalogued exposure of exemplary state-level responsibilities to climate-related hazards. A clear next step would be to establish and conduct a quantified risk assessment of critical infrastructure and assets managed by the state so that resources can be allocated to the address the greatest risks to North Carolina. Once a quantified vulnerability and risk assessment is done, it will be possible to prioritize adaptation actions.

Flooding is often cited by the authors of this chapter as the most frequent, devastating, and important climate-related hazard to focus upon. The state should consider a pilot project focused on flooding. Flooding occurs due to tidal events, storm surge along the Coast, along rivers ("fluvial" flooding), and due to overland flow and accumulation of water ("pluvial" flooding). Modeling, observational data,



mapping, and socioeconomic analysis could be brought together to evaluate the spatial extent of exposure. A quantified assessment could reveal the degree of vulnerability and risk of property, people, and other resources. Options for adaptation could then be considered with a clear understanding of how those factors differ through space and time throughout the state.

An even more focused project might exclude analyses to coastal flooding to reveal the many ways that resources can be garnered to understand, plan for, and respond to the devastating impacts of climate-related hazards. A detailed exercise in partnership with local governments that focuses on one set of hazards within a constrained geographic extent would help state agencies prioritize the delivery of services as well as provide information for communities to undertake local resilience planning.

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Chapter 6

Nature Based Solutions to Resilience

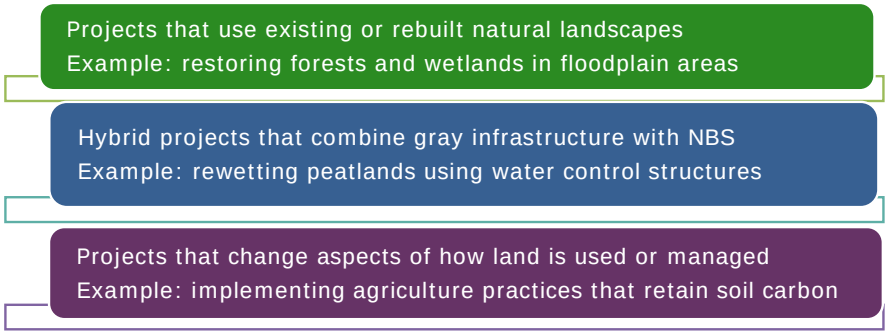
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6. Nature-Based Solutions for Resilience

Nature-based solutions (NBS) refer to conserving, restoring, and managing North Carolina's natural and working lands (NWL) to tackle socio-environmental challenges, such as climate change, by leveraging the unique properties of these resources. NBS can be used to address infrastructure needs such as storm water retention, protect from climate impacts such as storm surge, and act as hazard mitigation tools such as increasing drought and flood tolerance. These solutions have been used successfully for many decades, most notably for stormwater management and watershed protection. Now, they are being recognized for their true economic potential to protect our ecosystems and people from the devastating impacts of climate change.

Nature Based Solutions fall into three basic categories given below:



NBS are a unique win-win answer to both mitigating and responding to climate change impacts because of their long-term cost-effectiveness and many co-benefits compared to grey infrastructure. Their advantages over grey infrastructure include:

- Mitigation of GHG emissions and sequestration of carbon is improved,
- Build out has a smaller carbon footprint than grey infrastructure,
- Effectiveness normally grows overtime rather than degrading,
- Economic opportunities increase for food/fiber producers and the rural workforce,
- Communities develop long-term sustainability,
- Quality of water, air, soil and ecosystems improves, and
- Aesthetic natural beauty is maintained for recreation and tourism.

When state/local government and business leaders choose projects to build resiliency, cost-effectiveness is a basic requirement. Currently, investors and decision makers do not have uniform methods for comparing the NBS to more traditional approaches to building resiliency in communities. In addition, NBS may appear to be "new" or "unproven" uses of precious recovery dollars. Therefore, implementation of NBS in place of grey infrastructure requires developing economic analysis methods and financial tools that acknowledge the special properties of NBS, such as longer time periods, growth over time, sustainability, risk reduction, economic and ecosystem benefits. A good starting point for cost-effectiveness is US EPA's Green Infrastructure program.[1]

[1] "Green Infrastructure" US EPA, Accessed on February 21, at https://www.epa.gov/green-infrastructure.



A. North Carolina Natural and Working Lands Action Plan

1. Purpose of the Plan

The purpose of the Natural and Working Lands Action Plan, located in Appendix B, is to identify and create opportunities and outline specific projects for North Carolina's natural and working lands (NWL) that sequester carbon, build resilience, provide ecosystem benefits, and enhance our economy.

This action plan is intended to be used by 1) public and private landowners and managers, 2) impact partners such as universities and non-profit organizations, corporations, land-use consultants and investors, and 3) federal, state and local government, resiliency and local planners, and NWL policymakers to facilitate meeting North Carolina's goals identified under the plan. Specifically, the Action Plan addresses the following issues:

- Define the stakeholders' shared goals developed for the action plan,
- Present the current state of our natural and working lands,
- Quantify the potential impact of various actions,
- Recommend specific actions that facilitate meeting the shared goals,
- Identify implementation pathways, partners, and funding to facilitate taking action,
- Discuss roadblocks currently preventing the use of certain action pathways, and
- Encourage working on broad policy initiatives that would greatly enhance meeting our goals.

The North Carolina Natural and Working Lands (NWL) Action Plan is the first step toward utilizing NBS to build resiliency in our state. Many of its recommendations can be implemented by state and local government in our communities. These actions also require effort on the part of our "impact partners" – public and private landowners/managers, universities, non-profit organizations, corporations, land-use consultants, and investors. However, the large-scale change required to truly reduce risk and build resiliency to climate change impacts will require policymakers and the Legislature to work together to create new mechanisms for NBS.

The large-scale change required to truly reduce risk and build resiliency to climate change impacts will require North Carolina to redirect political commitments and investments.

The primary driver in building the plan was Section 9 of Governor Roy Cooper's Executive Order 80[2] issued in October of 2018, which laid out two primary goals; to reduce statewide greenhouse gas emissions to 40% below 2005 levels, and develop the North Carolina Climate Risk Assessment and Resilience Plan.

The second driver was the DEQ GHG Emissions Inventory issued in January of 2019. The inventory estimated agriculture emissions at 10.5 million metric tons of carbon dioxide equivalent GHG emissions (MMT CO_2e) as shown in Figure 6-1. On the other hand, the land use and forestry sector sequestered carbon on the order of 34 MMT CO_2e in 2017. This is a significant portion, 23%, of the gross GHG emissions emitted by all other sectors combined. This figure indicates the land use and forestry sector has the potential to offset significant GHG emissions from other sectors.

[2] Executive Order No. 80: North Carolina's Commitment to Address Climate Change and Transition to a Clean Energy Economy, signed October 29, 2018, accessed at https://governor.nc.gov/documents/executive-order-no-80-north-carolinas-commitment-address-climate-change-and-transition

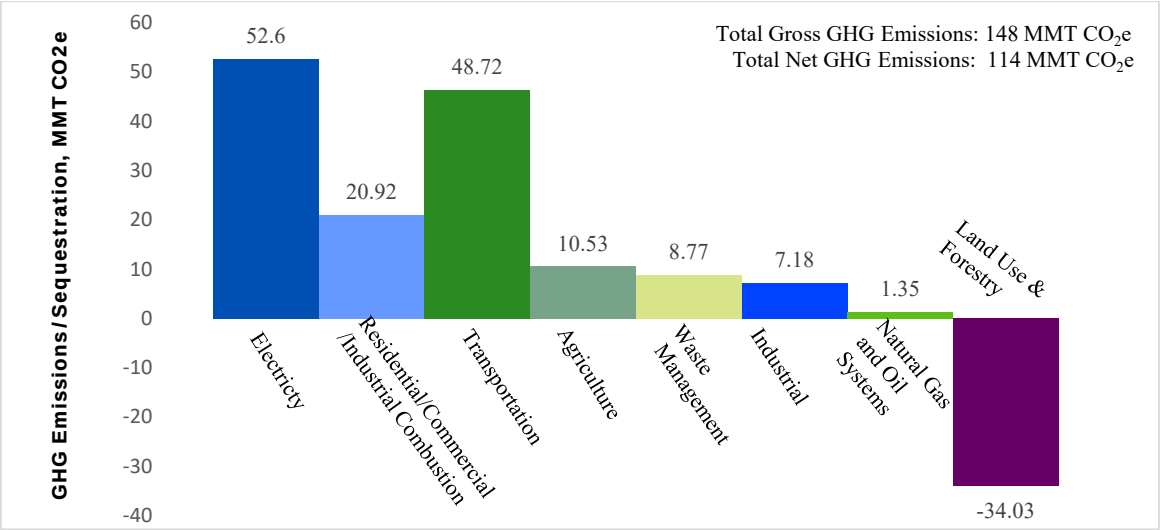


Figure 6-1: North Carolina GHG Emissions Inventory in MMT CO2e, 2017

The NWL Action Plan was a stakeholder driven process. Close to 100 people participated in six subcommittees developing and vetting 25 priority recommendations for the plan. The purpose of NWL Action Plan is to create opportunities and implement projects on North Carolina's natural and working lands that achieve the following goals shared by the plan's stakeholders:

1. Enhance the ability of natural and working lands to sequester carbon and mitigate emissions.
2. Build resiliency in ecosystems and communities.
3. Provide public health and ecosystem co-benefits.
4. Create economic opportunities for agribusiness, recreation, and tourism.
5. Ensure implementation of any action is a socially equitable process.

The recommendations in the plan were developed during 2019 by the six subcommittees listed in Figure 6-1.[3] Each subcommittee met numerous times to develop concrete recommendations that were supported by the majority of the members. In October of 2019, a 2-day meeting was held with all six subcommittee members to prioritize the recommendations that would go into the plan.

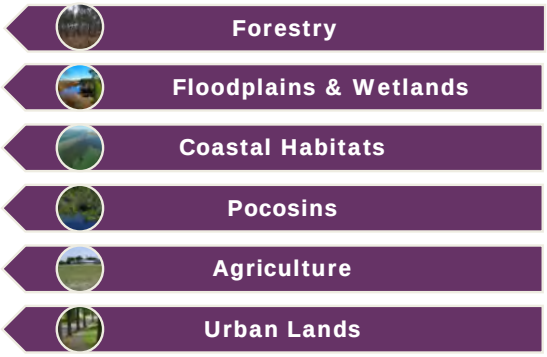


Figure 6-2: Natural and Working Lands Subcommittees

[3] For a full list of subcommittee participants, see the full report in Appendix V: NC Natural and Working Lands Action Plan.

2. Natural and Working Lands Basics

North Carolina consists of 31.1 million acres of land area and 2.6 million acres of open water. Figure 6-3 presents the percentage of each land type in acres for 2016. [4] Forests make up 18.1 million acres or 42% of the area. About 85% of this forest land is owned by private individuals and families. Agriculture is the next largest land area at 6.9 million acres. Woody and herbaceous wetlands span 4.9 million acres of the land area, while "other use" makes up 1.6 million acres. Developed land area is currently 3.6 million acres, or 11% of North Carolina's land area use. This is an increase of about 1.1 million acres from the 1990 developed land area. This figure indicates that the majority of North Carolina is natural and working lands.

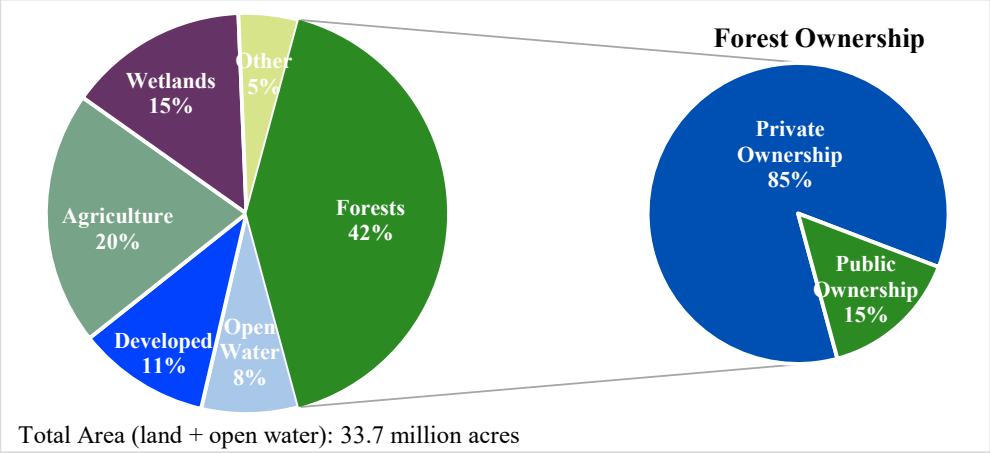


Figure 6-3: Total Land Use in North Carolina, 2016

North Carolina is one of the fastest growing states in the nation. **Since 1990, the population has increased by 55% while developed land area has increased by 1.16 million acres, a 3.7% increase relative to the state's total land area over**. [5,6] Despite this high conversion rate, in 2015 the urban tree canopy was estimated at 54%, the fourth-highest urban tree canopy in the US. While our canopy percentage is currently high, it is in decline and we need to promote the retention and management of this canopy as our population continues to grow.[7]

North Carolina has a substantial land connected to waterways and has 17 river basins. Table 6-2 presents the miles of rivers and coastline in the state.[8] **Restoration of riparian corridors along the 38 thousand miles of river has a large potential for flood protection and carbon sequestration**.[9] North Carolina's 320 miles of ocean beaches and 12,000 miles of estuarine shoreline are a key component to resiliency in coastal communities, including flood and storm surge protection. It also provides many co-benefits to

[4] Data extracted from the National Land Cover Database (NLCD) 2016, Multi-Resolution Land Characteristics (MRLC) Consortium, accessed at https://www.mrlc.gov/ and retrieved by Duke University's Nicholas Institute for Environmental Policy in 2019.
[5] North Carolina census data provided by North Carolina Office of State Budget and Management in January 2018.
[6] Developed land-use area was approximately 2.4 million acres in 1990 based on "Urban Forest Data for North Carolina", US Forest Service, US Department of Agriculture, last updated December 8, 2008, accessed at https://www.nrs.fs.fed.us/data/urban/state/?state=NC.
[7] Urban canopy is being lost at a rate of 4,500 acres/year and impervious surface is increasing based on Nowak D. J., and E. J. Greenfield, "US Urban Forest Statistics, Values, and Projections", Journal of Forestry, March 2018, accessed at https://www.fs.fed.us/nrs/pubs/jrnl/2018/nrs_2018_Nowak_003.pdf.
[8] Data extracted from the National Land Cover Database (NLCD) 2016, Multi-Resolution Land Characteristics (MRLC) Consortium, accessed at https://www.mrlc.gov/ and retrieved by Duke University Nicholas Institute for Environmental Policy in 2019.
[9] Riparian land refers to land adjacent to rivers.



communities beyond resiliency such as carbon sequestration, ecosystem preservation, improved water quality, habitat for fisheries, and corridors for species migration.

Table 6-2: Miles of Coastline and Rivers in North Carolina

Waterways	Length (miles)
Miles of Rivers	37,853
Miles of Ocean Coastline	320
Miles of Estuarine Coastline	12,000

2. Mapping Resilience Opportunities

An example of how the recommendations offer opportunities to increase ecosystem and community resilience and sequester carbon is given in Figure 6-4. Protecting existing forests and woody wetlands and creating new forests through reforestation projects can enhance community resilience by 1) reducing flood risks to people and property; 2) removing air and water pollutants; 3) preserving high-quality drinking water supplies and 4) cooling air and water. Opportunities to reduce flood risks are concentrated in the coastal plain, especially along major rivers, while opportunities to enhance the quality of water supplies and benefit urban areas occur throughout the Piedmont and mountains. Protecting and restoring forests also provides carbon benefits by removing $CO_2$from the atmosphere and storing in forests.

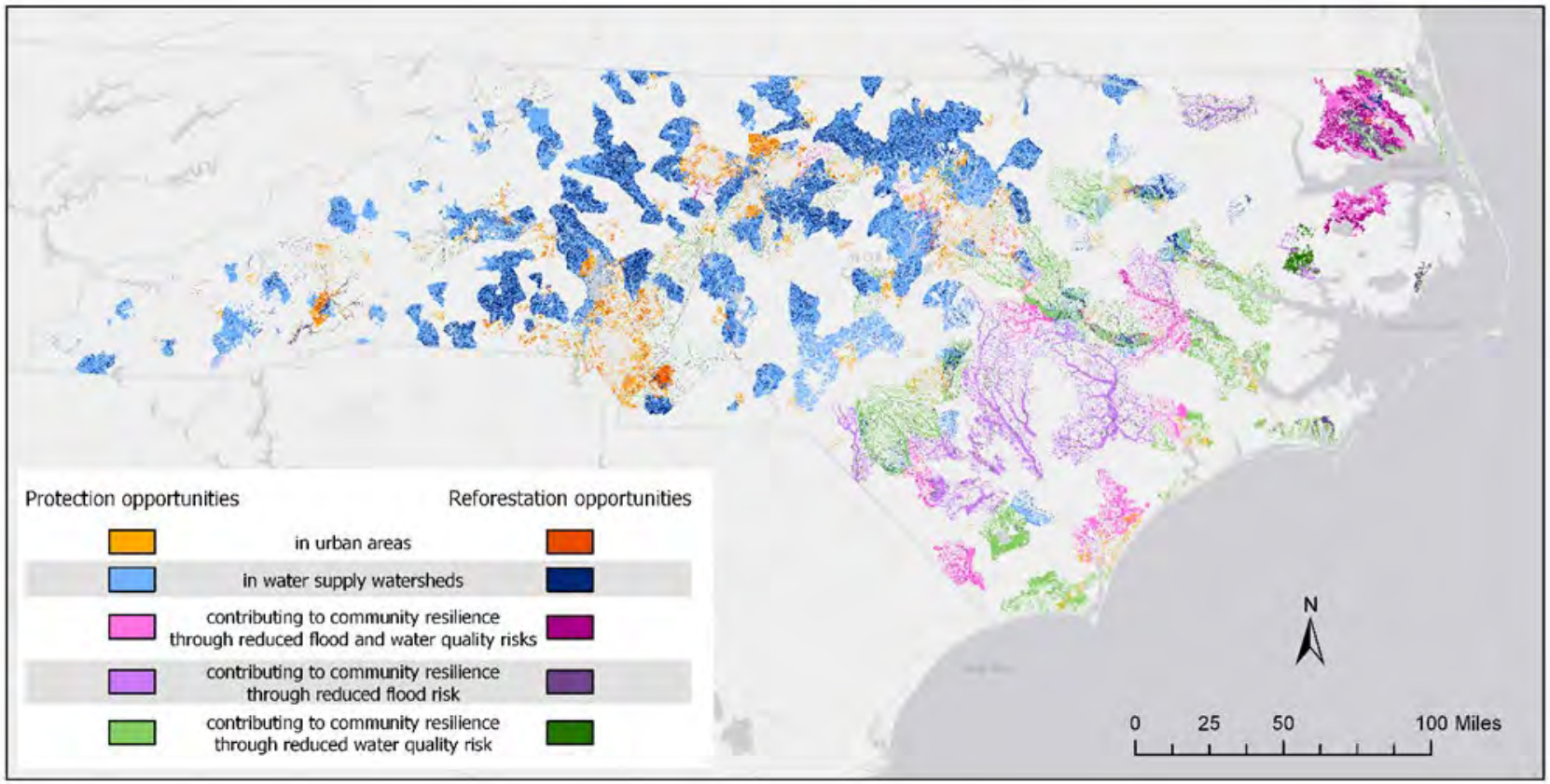
The NWL recommendations that are reflected in this map include:

- Protect forest lands;
- Restore forest lands;
- Promote urban forests; and
- Protect forested lands in water supply watersheds.

More information on the methods used to identify these areas is available in Appendix B: NC Natural and Working Lands Action Plan.

For in depth information on North Carolina's current land use and its ability to both sequester carbon and build community and ecosystem resilience, click on the link and access **Duke University's Natural and Working Lands Storymap.**





Source: Nicholas Institute for Environmental Policy Solutions at Duke University

Figure 6-4: Protection and Reforestation Opportunities with Community Resilience Benefits



B. Natural and Working Lands Recommendations

The Natural and Working Lands Action Plan seeks to identify and prioritize short-term, cost-effective, and pragmatic solutions to achieving the shared goals for NWL. It also identifies longer-term actions that require more effort and funding, such as legislative support or programmatic changes. There are four basic types of recommendations in the plan to increase resilience and sequestration of carbon as shown below.

1. ***Transformative***: cross cutting actions that will result in large amounts of NWL sequestration and resilience
2. ***Protect Land:*** acquisition of land or conservation agreements to develop additional natural areas
3. ***Restore Land*** restoration of land to a natural state to increase sequestration and resilience
4. ***Enhance Land***: improved use/management of existing NWL to increase sequestration and resilience

1. Summary of Recommendations

A summary of each recommendation is presented below. These recommendations are actionable by both state/local governments and impact partners such as universities and conservation organizations. Several already have teams working on their design and implementation including two of the transformative recommendations; 1) catalyze a state facilitated voluntary carbon offset program and 2) build a multi-state natural and working lands solutions toolbox. In some cases, the recommendations appear to have a heavy lift and significant barriers. However, the stakeholders feel their cost and complexity may be reasonable given the tremendous economic losses and cost to human health and wellbeing that the people of North Carolina has suffered in recent years because of the changing climate.

Table 6-3: Natural and Working Lands Action Plan Recommendations

Transformative Recommendations
1. Protect and restore forests and wetlands within flood prone areas. This recommendation seeks to significantly increase funding or create a funding mechanism for conservation and restoration of forest land. Conservation of 1.0 million acres of existing forest land with potential to protect against climate change impacts protects 170 MMT CO_2e of stored carbon and 1.7 MMT CO_2e that the forests sequester each year. Reforestation of 1.0 million acres would sequester 3.1 MMT CO_2e annually.
2. Facilitate voluntary landowner participation in carbon offset and ecosystem services markets. Given our potential to sequester carbon in forests and the growing carbon offset and ecosystem services markets, North Carolina should develop a state program to coordinate and encourage private landowner participation in carbon offset markets.
3. Build a multi-state NWL solutions toolbox. Establish ongoing funding for a state-supported toolbox with mapping capability that identifies the areas and communities most vulnerable to climate-related disasters and displays how NBS can reduce risks and impacts.
4. Integrate climate adaptation and resiliency strategies into local government comprehensive plans. NC General Statutes, Chapter 160D should be amended to mandate that all North Carolina counties and municipalities incorporate climate adaptation and resiliency strategies into their comprehensive plan.



Recommendations for Forest Lands	
Protect	**5. Conserve forest lands through easements and acquisition**. Protecting forests from conversion to other land uses maintains our current level of carbon sequestration and resilience. Land acquisition by public agencies and nonprofit conservation organizations provides permanent protection. Increased and recurring funding of land acquisition grants by the legislature and private entities would expand the scale and rate of forestland conservation.
	6. Modernize forest policy and tax incentives. A few changes in forest policy can reduce the threat of converting forests to other land uses and maintain our current level of carbon sequestration and resilience. Modernization of forest policy includes 1) expanding aspects of the current present use value (PUV) system, 2) creating conservation tax credits, and 3) implementing a "No Net Loss" forest policy. These changes encourage landowners to retain their forestland and invest in management and restoration rather than harvesting prematurely or even selling the land for financial gain.
Restore	**7. Expand restoration efforts on publicly owned lands**. Publicly owned lands may require restoration due to 1) land use/management before its acquisition or 2) removal of invasive exotic species or diseased trees. Restoring forest lands increases aboveground storage of carbon and ecosystem services such as resiliency/water quality. Restoration should focus on publicly owned pocosin wetlands, riparian lands, and coastal zones to provide the highest carbon sequestration and resilience benefits.
	8. Encourage restoration and reforestation on private lands. Several forest management practices improve forest health, productivity, and increase carbon sequestration. However, landowner access to existing programs for assistance with these practices is limited. Additional resources are needed to 1) enroll landowners; 2) develop private forest management plans; and 3) to cost-share costs implementation of practices.
Enhance	**9. Increase access to forest management technical assistance for landowners.** A number of forest management practices strengthen forests and increase carbon sequestration. However, access to existing programs to educate and assist landowners with these practices is limited. Additional resources and funding are needed to 1) enroll more landowners 2) develop more private forest management plans and 3) to share costs of these management activities.
	10. Support the wood products markets. Landowners need a strong wood products market to provide financial incentives to actively manage their forestland. Trees store about 80 tons of carbon per acre when they are actively growing. When trees are turned into products, much of that carbon stays in those products and out of our atmosphere. Access to strong and diverse markets for forest products, especially in long-lived products such as furniture and building supplies, provides incentives for forest landowners.



Recommendations for Floodplains and Wetlands	
Protect and Restore	**11. Coordinate the state's floodplain buyout and restoration program to increase resilience.** Federal and state programs buy flood-damaged properties on a voluntary basis after natural disasters. These often result in a "checkerboard" pattern of land acquisition within communities. It is recommended that state government develop a coordinated program to utilize the buyout processes to create functional floodplain areas and greater resilience. Connected, natural, permeable floodplains build flood resilience within at-risk communities while reducing costs for local governments and sequestering carbon. Local governments can create parks, trails, and greenways in floodplains, returning these areas to productive use and enhancing communities. The program should include farmland and be tied to the local planning process.

Recommendations for Coastal Habitats	
Protect	**12. Provide incentives to stakeholders for coastal habitat protection**. Protecting coastal habitats, such as natural shorelines, coastal wetlands, oyster beds, and submerged aquatic vegetation (SAV), through landowner incentives will provide benefits to community and ecosystem resilience and increase carbon sequestration. Providing these incentives can ensure protection of coastal habitats and the ecosystem services they provide. This protection will result in increased hazard mitigation and decrease costs required to repair assets and property and restore coastal habitats after major storm events.
	13. Facilitate salt marsh migration through protection of migration corridors. There is significant need for the state to facilitate conservation of migration corridors (natural areas without barriers such as development) for salt marsh, and other coastal habitats. Ensuring these migration spaces remain undeveloped is key to facilitating marsh migration with sea-level rise, and therefore preserving the coastal protection, ecological functions, and carbon benefits of North Carolina's marshes. Minimizing risk and expenses of hazard damage by ensuring protection and migration of salt marsh and other coastal habitats will increase ecosystem and community resilience.
Restore	**14. Prioritize climate change and sea-level rise in coastal habitat restoration planning**. Climate change and sea-level rise considerations need to be incorporated into planning processes for coastal habitat restoration by state, federal, and local governments. Currently, federal habitat restoration programs consider the impacts of climate change and SLR, and North Carolina should also require these impacts be considered when planning habitat restoration projects. Improved restoration planning will allow for more targeted and cost-effective efforts that will increase coastal resilience and carbon sequestration.

Recommendations for Pocosins	
Restore	**15. Rewet hydrologically altered peatlands to prevent soil loss and catastrophic fire**. Over 70% of North Carolina's peatlands have been ditched and drained resulting in substantial loss of soil carbon, land subsidence, and increased wildfire risk. Rewetting altered peatlands, using approved and verified methods, reverses the soil carbon loss and land subsidence while increasing adaption and resilience of coastal communities/ecosystems to sea-level rise and extreme weather events. Restoration costs are relatively low and provide co-benefits in addition to those listed above. Implementation can begin immediately on tens



Recommendations for Pocosins	
	of thousands of state-owned and private lands using the return on restoration investments that come from selling verified credits in carbon offset markets. Educating and engaging private landowners is also key.
	16. Reforest peatlands with Atlantic White Cedar. Large areas in eastern NC will be flooded by rising sea-level during the next century, resulting in major losses in plant and animal communities, some of which are rare and threatened. Healthy forests that are adapted to wetter conditions will be important for climate adaptation and resilience of eastern ecosystems. Atlantic white cedar (AWC), a historically important species classified as "threatened", occurs mostly in peatland swamps in eastern NC and does not tolerate saltwater. There is a potential for these stands to be lost unless we establish a plan and prioritize areas for mitigation plantings further inland and fund it using cost sharing programs and tax incentives.
Enhance	**17. Enhance soil health and retention on working peatlands via best management practices and drainage management**. Traditional agricultural practices and drainage on these soils result in high soil and soil carbon losses. Holistic planning of agricultural operations, water management, and adoption of existing technologies/practices, such as no-till and drainage management systems, would significantly decrease this loss. These improvements maintain or even increase carbon sequestration and reduce GHG emissions. They also improve sustainability of the farms and surrounding communities in the face of climate change. Existing Natural Resource Conservation Service cost-share and state grant programs could be utilized to facilitate planning and installing systems.
	18. Implement targeted interventions to protect peatlands from sea-level rise and saltwater intrusion guided by scenario-based modeling. Artificial drainage, extensive timbering and agricultural activities have altered the natural hydrological processes of the pocosins region. These alterations increase the vulnerability of the land to salinization and eventual loss of the freshwater ecosystems. This recommendation assists stakeholders in prioritizing locations for climate change defense and adaptation of peatlands. Existing models for hydrology, saltwater intrusion and habitats can be used to predict outcomes under various management scenarios to facilitate decision-making.

Recommendations for Urban Lands	
Protect	**19. Promote urban forests through statewide programs to foster the retention of urban trees and their proper management**. The NC Forest Service's Urban & Community Forestry program should be expanded to provide hands-on assistance to NC communities to manage their urban canopy. The Forest Service already has the program in place but due to limited resources they provide mainly guidance and recommendations through a 2-person team. Staffing for this program should be expanded to at least 4-person team to assist local governments with their forestry programs and to help homeowners/landowners better manage their urban trees. Funding would be needed through the NC Department of Agriculture and Consumer Services and the NC Legislature to permanently support the new positions.



Recommendations for Urban Lands	
Protect and Restore	**20. Protect and restore forested lands in water supply watersheds.** Water supply watersheds already have limits on development to protect the quality and quantity of water supply systems. However, preservation and restoration of forested lands in these watersheds may mitigate the impacts of future urban and suburban population growth and water demand. Key steps include 1) facilitate regional planning, 2) prioritize areas with high hydrology/water quality benefits within the watershed, 3) implement a stakeholder approach, 4) employ new funding mechanisms, and 5) determine the appropriate agencies and authorities to implement.
Enhance	**21.Improve site preparation and soil amendment during land development**. Urban planning and development should utilize a set of best practices that include using soil with adequate organic content, maintaining tree stands in high-value habitats, planting native vegetation, maintaining streams/wetlands, and reducing impervious surface. Best practices would have many benefits including sequestering carbon and building resilience by increasing soil carbon and water capacity, and reducing soil erosion, stormwater runoff, and pollutant loading of waterways. Developers will require incentives to use BMPs and create green infrastructure, carbon sequestration, and manage stormwater for the future.
	22. Urban forestry climate adaptation research and urban canopy baseline needs. Research on understanding the impact of climate change on urban forests and ecosystem services is still needed. This includes 1) developing a template for canopy studies for each region, 2) compiling existing urban tree canopy assessments into a database, 3) funding additional urban tree canopy assessments and inventories. This research would allow for state-level management and priority setting for urban forests.

Recommendations for Agriculture	
Enhance	**23. Encourage adoption of high mitigation agricultural conservation practices on croplands and pasturelands**. The adoption of conservation practices that produce GHG mitigation co-benefits has been dominated by conservation tillage (69%) in North Carolina; however, other well-established practices also have a substantial potential to mitigate GHG emissions through biological carbon sequestration in croplands and pasturelands. Adopting these practices conserves farmland by increasing the productivity/profitability of farms, restoring soil health, and enhancing climate resilience of agricultural businesses and rural communities. The existing network of Soil and Water Conservation districts is well-positioned to promote these practices; however, these programs are chronically underfunded. Additional funding from the Legislature and/or other public and private sources would increase the adoption of these practices by North Carolina farmers.
	24. Improve manure management on North Carolina farms. This recommendation focuses on installing anaerobic digesters with methane capture coupled with combustion of the methane either on-farm or off-farm for energy recovery. This approach is a near-term, cost-effective management system that will lead to substantial GHG emission reductions. However, RTI International is currently tasked with studying the costs, impacts, resilience, and equity of large-scale implementation of off-farm use of renewable natural gas (RNG). The outcome of this study will determine the feasible of off-farm RNG across the state. In the long-term, alternative non-methane generating manure management systems and add on



Recommendations for Agriculture	
	technologies to further reduce pollutants should be explored and supported by the state and its impact partners.
	25. Food system efficiency through reducing food loss and waste. Food loss/waste occur at the farm, within the supply chain, during processing, at retail stores and food service facilities, and with the consumer. There are various options for reducing this loss and waste including field gleaning, tax credits for donations, farm to food bank initiatives, redirecting waste from landfills to animal feeding or composting. Developing coordinated mechanisms, creating new strategies, and educating stakeholders to address food loss/waste will be required to realize the GHG mitigation potential of reducing food loss and waste.



C. Implementing Solutions in Time for Our People

Implementation of NBS across the natural and working lands of North Carolina requires a focused commitment of financial and human capital. In order to protect existing NWL areas and have the required land area in a functional "green-infrastructure" state to help mitigate climate change impacts and sequester carbon, we need to act quickly. The time to implement NBS is *now* due to the time required to plan, implement and grow these solution**s**. Some solutions begin working in a short time frame, such as improved crop practices or rewetting drained pocosins, where the carbon and soil benefits are realized quickly and extend out for the life of the restoration. Others, such as reforestation, may take decades to fully realize the carbon and ecosystem co-benefits. Given its carbon sequestration potential, sustainable management and financial support of the 14 million acres of forest owned by North Carolina's private forest landowners must be a cornerstone of any NWL actions taken by the state.

Funding for NBS is taking shape. The recommendations call for expansion of traditional funding from federal/state/local governments and philanthropic sources. Recent projects are using carbon offset markets as an alternative to traditional funding. Disaster funds can also be used to build resilience with NBS in local communities. Increasingly, NBS are being recognized as a cost-effective tool to reduce rick and increase sustainability for private entities as well.

A key element of success, however, is the leadership and support from state agencies**.** Agencies can "lead by example" and begin to integrate NBS into the 2020 Resilience Plan. This will encourage the people of North Carolina to look to these innovative ways to build resilience and sequester carbon while providing economic and ecosystem benefits.

The NWL Action Plan recommendations, along with the expert stakeholders who developed the plan should be the first resource for agencies building resilience in the state

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Chapter 7

Path Forward to Climate Resilience

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7. The Path Forward for a Climate Resilient North Carolina

A. Introduction

The climate is changing in North Carolina. Our own experiences, big and small, confirm what the science tells us. In recent years, we have experienced the devastating flooding and storm surges of Hurricanes Matthew, Florence, and Dorian; landslides in the mountains; and one of the earliest spring "leaf outs" along coastal North Carolina in the last forty years, as trees began to bud and flowers bloom this year almost a month earlier than normal; all against the backdrop of a global pandemic.

But there is cause for optimism. North Carolina has the resources—in our government, economy, and communities—to rise to this challenge. We will build a resilient North Carolina, where our communities, economies, and ecosystems are better able to rebound, adapt, and thrive amid changing conditions and challenges, including natural hazards and climate change. This shared vision of resilience will enable us to maintain and improve quality of life, nurture healthy growth, and ensure long lasting and sustainable social, economic, and environmental systems. A resilient North Carolina will also safeguard our ability to conserve resources for present and future generations. This chapter outlines the path forward.

First, this chapter lays out the Guiding Principles that frame North Carolina's action on climate resilience, based on the analyses and recommendations of this plan's authors and contributors. Next, it reviews the progress that the state has made to date through Governor Cooper's 2018 Executive Order 80 (EO80) and this 2020 Resilience Plan, which build on earlier efforts included in the 2012 Climate Ready North Carolina: Building a Resilient Future plan. This chapter then explains the four elements of the North Carolina Resilience Strategy, including how the contents of this 2020 Resilience Plan contribute to that plan. Finally, the path forward identifies priority initiatives and offers recommendations for state government to build resilience capacity and enhance the ability of residents, businesses, and communities to cope with climate change.

The principles, plans, proposed initiatives, and strategies outlined below implement recommendations from experts in the fields of climate science and environmental policy, as well as from local government, community partners, and the members of the public via pubic workshops and presentations. They incorporate best practices on climate assessment and resilience planning, including practices and approaches from the U.S. Global Change Research Program's Climate Resilience Toolkit Steps to Resilience, [1] reports on using climate science for making decisions from the Independent Advisory

[1] U.S. Global Change Research Program. (2016). *Steps to Resilience*. Retrieved February 18, 2020, from https://toolkit.climate.gov/#steps.



Committee on Applied Climate[2,3], and nationwide analyses of implementation status from resilience and climate adaptation plans published in peer-reviewed academic literature. [4]

B. Guiding Principles

The following principles will guide North Carolina's decision making and actions as we continue to address the effects of climate change on our state. They serve as both values and goals. The threat of climate change requires effective and decisive action, made with a clear-eyed understanding of the very real challenges we face in our state and in our world. These principles light the path.

Principle 1: Act quickly and decisively to reduce the most harmful impacts of climate change—flooding, drought, landslides, and wildfires

As our communities continue to recover from the devastation caused by recent hurricanes and flooding, we must act quickly and deliberately to address the most damaging effects of climate change—many of which we are already experiencing. The following actions further this principle:

- Incorporate resilience into state programs, policies, properties, and investments, through both budget neutral initiatives and through added resources not currently available
- Use interagency collaboration to continuously build resilience in state government policies and operations
- Align federal, state, and local funding and project prioritization to promote multiple natural and community benefits
- Incentivize local government and private endeavors that minimize and address future risks
- Protect existing natural infrastructure and invest in additional natural infrastructure to enhance existing natural features, processes, and solutions

Principle 2: Act thoughtfully and collaboratively to develop equitable solutions for the most socially challenging effects of climate change

Many of the current and anticipated effects of climate change challenge the way we think about our communities and live our lives. Only by coming together in pursuit of shared solutions can we address these challenges in a way that builds, rather than undermines, equity and fairness. The following actions further this principle:

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[2] Moss, R.H., S. Avery, K. Baja, M. Burkett, A.M. Chischilly, J. Dell, P.A. Fleming, K. Geil, K. Jacobs, A. Jones, K. Knowlton, J. Koh, M.C. Lemos, J. Melillo, R. Pandya, T.C. Richmond, L. Scarlett, J. Snyder, M. Stults, A. Waple, J. Whitehead, D. Zarrilli, J. Fox, A. Ganguly, L. Joppa, S. Julius, P. Kirshen, R. Kreutter, A. McGovern, R. Meyer, J. Neumann, W. Solecki, J. Smith, P. Tissot, G. Yohe, & Zimmerman, R. (2019). A Framework for Sustained Climate Assessment in the United States. Bulletin of the American Meteorological Society 100, 897–907, https://doi.org/10.1175/BAMS-D-19-0130.1

[3] Moss, R.H., S. Avery, K. Baja, M. Burkett, A.M. Chischilly, J. Dell, P.A. Fleming, K. Geil, K. Jacobs, A. Jones, K. Knowlton, J. Koh, M.C. Lemos, J. Melillo, R. Pandya, T.C. Richmond, L. Scarlett, J. Snyder, M. Stults, A.M. Waple, J. Whitehead, D. Zarrilli, B.M. Ayyub, J. Fox, A. Ganguly, L. Joppa, S. Julius, P. Kirshen, R. Kreutter, A. McGovern, R. Meyer, J. Neumann, W. Solecki, J. Smith, P. Tissot, G. Yohe, and R. Zimmerman, 2019: Evaluating Knowledge to Support Climate Action: A Framework for Sustained Assessment. Report of an Independent Advisory Committee on Applied Climate Assessment. *Weather, Climate, and Society*, 11, 465–487, https://doi.org/10.1175/WCAS-D-18-0134.1

[4] Woodruff, S.C., Meerow, S., Stults, M., & Wilkins, C. (2018). Adaptation to Resilience Planning: Alternative Pathways to Prepare for Climate Change. Journal of Planning Education and Research. 10.1177/0739456X18801057.



- Engage diverse groups of stakeholders across the state to develop a common understanding of goals, values, and ideas for creating a resilient North Carolina under these future scenarios and to communicate the current level of knowledge on impacts and best practices for implementing equitable solutions
- Build new and existing partnerships with academia; federal, state, local, and tribal governments; industry representatives; and nongovernmental organizations to evaluate the cross-sector impacts of long-term changes to the climate on people, communities, businesses, industries, and infrastructure in North Carolina, along with opportunities to address them
- Center issues of social equity and social vulnerability in state resilience efforts, and provide state agency staff with the training to do so and the time built into project timelines for authentic and equitable engagement
- Support community-based resilience efforts and community leadership development
- Ensure that disaster recovery efforts provide impacted communities with new capacities to cope with the next event or take the next steps towards resilience

Principle 3: Invest in safe, affordable, and connected communities

The investment required to address the effects of climate change provides an opportunity to create a safer, more affordable, and more connected North Carolina. As North Carolina builds climate resilience, we can also build a stronger and more livable state for us all. The following actions further this principle:

- Prioritize building a portfolio of resilience efforts, including serving both places and populations likely to experience the most challenging impacts and places and populations least able to cope with or adapt to climate change
- Accelerate public and private funding to locate affordable housing in low-risk, low-vulnerability areas
- Partner with organizations that represent diverse professions and communities, and engage in resilience conversations across public, private, and community-based leadership
- Connect local workers and businesses to opportunities created by investments in safe, affordable, and connected communities
- Develop “safe corridors” with redundant transportation routes within and between communities to maintain supply chains, emergency access, and evacuation routes
- Promote multimodal transportation options that reduce greenhouse gas emissions while improving reliability, access, and mobility

Principle 4: Strengthen regional economies

North Carolina’s economy is strengthened by its diversity—from biotech to agriculture to tourism, in small towns and big cities. North Carolina is only as resilient as its regional economies. Resilience requires continued investment in regional and local infrastructure, government, and community capacity. The following actions further this principle:

- Promote economic growth that aligns with healthy populations
- Support agricultural, forestry, and seafood workers and related industry jobs
- Expand entrepreneurial opportunities, especially in rural communities and towns
- Support regions, towns, cities, and state- and federally-recognized Tribes in becoming more resilient through providing information, capacity building, and funding



- Support, foster and, promote a healthy and sustainable economy by attracting and retaining industrial and commercial businesses and jobs that protect and support our natural environment and the health of our communities

Principle 5: Support healthy communities, local identity, and recreational access to nature

From the Blue Ridge Mountains to the Outer Banks, and the farmlands and urban centers of the Piedmont in between, North Carolina's strong local communities and the beauty of our state are a source of pride and enjoyment for residents and tourists alike. Supporting our unique and diverse rural communities, towns, and cities and their connection to the natural world protects our individual and collective health and our economy. The following actions further this principle:

- Preserve what makes local communities unique
- Harness public and private research to inform communities of risk and vulnerability using easily understandable language and formats
- Increase access to nature for healthy outdoor recreation and ecotourism
- Identify opportunities when natural infrastructure can be used to improve resilience and fund the use of nature-based practices when feasible

Principle 6: Implement resilience best practices

We achieve a resilient and prosperous North Carolina through everyone's continuous hard work and collaboration. As the principles above are implemented, state agencies and other actors can ensure that all actions taken embody the most up to date best practices in building resilience:

- Begin all resilience efforts by establishing clear purposes, visions, goals, and objectives
- Base resilience efforts on the best available state of knowledge on climate change exposure, risks, vulnerabilities, and options for action
- Recognize potential sources of uncertainty in climate science and impacts, and provide support for using multiple scenarios to develop flexible strategies and identify "no-regrets" actions
- Provide guidance across agencies and levels of government on strategies to prioritize and make decisions that ensure resilience goals are achieved
- Acknowledge the diversity of stakeholders affected by decisions that build resilience and ensure equitable engagement of all in developing and implementing solutions
- Ensure resilience policies and actions will not have discriminatory effects
- Support local and tribal governments and industries in identifying opportunities to incorporate resilience building into everyday practice
- Recognize when new sources of funding are needed for resilience challenges and identify significant and sustainable funding sources to address those challenges
- Establish platforms for coordinating across local, state, and federal decisions that affect adaptation options
- Develop metrics and best practices for measuring progress toward resilience goals, and provide support across the state for monitoring and regularly adjusting action plans when needed



C. Resilience and Climate Change Mitigation Accomplishments

This 2020 Resilience Plan builds upon significant resilience work in North Carolina over the past decade. The following list is not comprehensive, but it highlights some of the milestones in state government. Communities, universities, businesses, and non-profits have provided invaluable leadership and expertise during this period to increase North Carolina's resilience, and those efforts are gratefully acknowledged.

1. Executive Order 80: North Carolina's Commitment to Address Climate Change and Transition to a Clean Energy Economy

In 2018, Governor Roy Cooper issued **EO80**, which laid out a series of goals for the state to strive to accomplish by 2025:

- Reduce statewide greenhouse gas emissions (GHG) to 40% below 2005 levels
- Increase the number of registered, zero-emission vehicles (ZEVs) to at least 80,000
- Reduce energy consumption per square foot in state-owned buildings by at least 40% from fiscal year 2002-2003 levels

EO80 also required state cabinet agencies to evaluate the impacts of climate change on their programs and operations and integrate climate change mitigation and adaptation practices into their activities. It created the **Climate Change Interagency Council** (Council), comprised of representatives of each cabinet agency and chaired by the Secretary of the Department of Environmental Quality (DEQ). EO80 directed the Council to finalize strategic plans in key action areas and directed the creation the 2020 Resilience Plan.

In 2019, the Department of Environmental Quality published the **North Carolina Greenhouse Gas Inventory (1990-2030)**, a detailed account of GHG emitted or stored from 1990 to 2017, as well as a projection of North Carolina's anticipated GHG emissions from 2018-2030.

2019 also saw the development of the **North Carolina Clean Energy Plan: Transitioning to a 21st Century Electricity System** by the DEQ, a plan required by Governor Cooper's EO80. The plan, which is intended to be revised every three to five years, identifies the following goals:

- Reduce electric power sector GHG by 70% below 2005 levels by 2030 and attain carbon neutrality by 2050
- Foster long-term energy affordability and price stability for North Carolina's residents and businesses by modernizing regulatory and planning processes
- Accelerate clean energy innovation, development, and deployment to create economic opportunities for both rural and urban areas of the state

The Department of Transportation developed in 2019 the **Zero Emission Vehicles (ZEV) Plan,** also called for by EO80. The plan recommends strategies for increasing the number of ZEVs on North Carolina roads. These strategies are organized into four action areas: education, convenience, affordability, and policy.



To address the use of ZEVs by state government, the Department of Administration developed the **2019 Motor Fleet Zero Emission Vehicles Plan**, also called for under Governor Cooper's EO80 mandate. The plan identified 572 traditional vehicles for replacement with ZEVs, finding that doing so would save taxpayers an estimated $3.8 million and reduce emissions by over 22,000 metric tons over the lifetime of the vehicles.

Governor Cooper's EO80 also required the Department of Commerce to issue **Clean Energy and Clean Transportation in NC: A Workforce Assessment**, which it did in the fall of 2019. This assessment evaluates the clean energy and clean transportation sectors in North Carolina, assesses the skills and education needed in these sectors, and recommends actions for supporting an expanded workforce in North Carolina.

2. State agency resilience-building programs

The **North Carolina Interagency Leadership Team** issued the **Climate Ready North Carolina: Building a Resilient Future** report in 2012, which identified climate trends and risks associated with those trends, and recommended overarching cross-sector strategies. This report established critical information and analysis for the 2020 Resilience Plan. Since that time, numerous state agencies built on the report by developing programs to address climate change impacts. Selected initiatives are described below.

In 2018, following the devastation of Hurricane Florence amidst the ongoing recovery from Hurricane Matthew, the **North Carolina Office of Recovery and Resiliency** (NCORR), a division within the Department of Public Safety (DPS), was established to administer funds received by the state through the U.S. Department of Housing and Urban Development's Community Development Block Grants for Disaster Recovery Program. Working closely with **North Carolina Emergency Management** (NCEM), whose **Hazard Mitigation** and **Recovery** Programs administer funds received from the Federal Emergency Management Agency (FEMA), DPS provides disaster recovery coordination with services that include oversight of recovery funding, processing of program applications, construction and vendor management, and public outreach and education, among other responsibilities such as creating safe and affordable housing solutions.

The **NCEM** in the Department of Public Safety runs the state's **Hazard Mitigation Grant Program (HMGP)** under the state **Enhanced Hazard Mitigation Plan (EHMP)**. The HMGP enables North Carolina families to move out of dangerous flood zones, have their homes elevated, or have their homes torn down and rebuilt to enhanced flood safety standards. The EHMP is described in detail for its continuing role in the North Carolina Resilience Plan, in Section D below. The 2018 iteration of the EHMP met FEMA's requirement to include consideration of future conditions by using data from the Southeast chapter of the Third U.S. National Climate Assessment (NCA), the version of the NCA most recent at the time of EHMP publication.

In 2019, Governor Cooper appointed a state **Chief Resilience Officer (CRO)** to lead NCORR's resilience staff and direct the state's initiative to help storm-impacted communities rebuild smarter and stronger in the face of future natural disasters and long-term climate change. NCORR's resilience staff works to improve collaboration among state agencies, local governments, non-profits, the private sector and academia, with a goal of developing solutions that enhance the resilience of communities and the natural environment. As part of that work, the NCORR resilience staff coordinates the State Disaster Recovery Task Force (SDRTF) and its subcommittees, the Recovery Support Functions (RSFs). The RSFs bring together experts in the field of recovery and resiliency within federal, state, and local



government, as well industry and non-government organizations. Each RSF provides and promotes recommendations through NCORR and NCEM to state government and the General Assembly on ongoing disaster recovery efforts and future resilience-building.

In 2019, DEQ's **Division of Coastal Management (DCM)** built an online **Coastal Adaptation and Resilience Clearinghouse**, intended to help local governments find information, tools, and technical resources (e.g., geospatial data, policy guidance, case studies, and funding opportunities) to help them build resilience. A companion tool, the **North Carolina Coastal Community Resiliency Guide**, is an ArcGIS Story Map that helps local government understand the sequencing of steps they can take to build their team, assess their climate vulnerability and risk exposure, and identify and implement adaptation strategies.

DEQ has also developed the **North Carolina Beach and Inlet Management Plan** (BIMP) (2009 and 2016) as an inventory of projects and resources for maintaining ocean beaches and navigational waterways. The BIMP also recommends strategies for identifying sand and financial resources needed to protect this infrastructure. Maintaining healthy beaches and dune systems, and repairing damage to these systems after storms, is vital to protecting the social, economic and environmental benefits that these systems provide.

The Coastal Resources Commission's Science Panel produced the **Sea Level Rise Assessment Report** in 2010 and 2015 and is currently drafting its 2020 report. The reports include sea level rise projections based on Intergovernmental Panel on Climate Change (IPCC) emissions scenarios, broken down by different sections of the coast, and takes into account the rates at which coastal land is sinking. The commission provides these reports as an informational resource for local governments and other interested parties for use at their discretion.

The **Albemarle-Pamlico National Estuary Partnership** issued **Climate Ready Estuaries: A Blueprint for Change** report in 2012, which provides findings and recommendations for increasing the region's climate resilience, compiles a resource of up-to-date science on sea-level rise impacts, and serves to educate the public and decision makers about the opportunities and challenges inherent in becoming a climate ready estuary. Additionally, APNEP conducted **Climate Resilience Evaluation and Awareness Tool Exercise** with towns Manteo and Columbia to examine the potential impacts of rising sea levels on their wastewater infrastructure using the Environmental Protection Agency (EPA) Climate Risk Evaluation and Assessment Tool (CREAT) as part of the EPA's Creating Resilient Water Utilities (CRWU) initiative. The report provides engineering and financial recommendations for realistic measures the towns might take to improve their resiliency to coastal hazards and flooding to consider for integration into their capital improvement planning processes.

The **North Carolina Climate and Health Program** in the Department of Health and Human Services (DHHS) is part of a national public health effort to anticipate and prepare for human health effects related to global and local climate change. The program is supported by the Centers for Disease Control and Prevention's Climate and Health program. DHHS implemented the **Building Resilience Against Climate Effects (BRACE) Framework** to identify likely climate impacts, potential health effects associated with these impacts, and the most vulnerable populations in the state. This funding initiative led to the development of the 2015 Climate and Health Profile Report, which determined the health impacts of heat-related illness and wildfire smoke as the greatest concerns in North Carolina. DHHS continues to track public health effects of climate change, to provide services in response to increasing extreme weather and



wildfires, and to accommodate disruptions from climate-related conditions to the daily services DHHS provides.

D. North Carolina Resilience Strategy

To guide the path forward, the state will maintain and update the North Carolina Resilience Strategy. The North Carolina Resilience Strategy is a compilation of documents organized into four elements: (1) The North Carolina Science Report, (2) State Agency Resilience Strategies, (3) Statewide Vulnerability Assessment and Resilience Strategies, and (4) the North Carolina state EHMP.

Table 7-1: North Carolina Resilience Strategy Elements

North Carolina Resilience Plan Element	Current Components	Earlier Versions	Update Cycle
1. Science Report	2020 North Carolina Climate Science Report	Chapter 2 ("Climate Trends") of 2012 Climate Ready NC	As needed to incorporate new decision-relevant information
2. State Agency Resilience Strategies	Chapter 5 ("Climate Impacts, Risks and Vulnerabilities") of 2020 Resilience Plan		Agency Resilience Strategies finalized March 2021, and annually thereafter.
3. Statewide Climate Vulnerability Assessment and Resilience Strategy	Chapter 4 ("Climate Justice"), Chapter 6 ("Nature-Based Solutions"), Chapter 7 ("Path Forward") of 2020 Resilience Plan; Chapter 3 ("Impacts, Risks and Vulnerabilities for North Carolina"); Appendices B through E of 2012 Climate Ready NC	Chapter 4 ("Cross-Sector Strategies") of 2012 Climate Ready NC	• Priority 1: 2022 and every 4 years thereafter • Priority 2: 2024 and every 4 years thereafter
4. State Hazard Mitigation Plan	2018 North Carolina state Hazard Mitigation Plan	2013, 2010, 2007, 2004 SHMP	Current FEMA mandate: every 5 years

Table 7-2: North Carolina Resilience Plan Going Forward

PLAN ELEMENTS	NEXT STEPS	PARTICIPATION	RESOURCE NEEDS
1. North Carolina Climate Science Report	• Update 2020 Climate Science Report as deemed necessary • Synthesize decision-relevant studies and contracted analysis from Elements 2 and 3	• Universities • Federal agencies • State agencies • External contractors	• U.S. National Climate Assessment updates • Contracting funds for scientific expertise • State agency staff participation
2. State Agency Resilience Strategies	• Develop Agency strategies based on 2020 Resilience Plan Chapter 5 ("Climate Impacts, Risks, and Vulnerabilities") • Agencies seek advisory capacity on strategies from NCORR State Disaster Recovery Task Force Recovery Support Function teams (RSFs) as needed • Agencies publish Agency Resilience Strategy	• State agency resilience lead staff • NCORR resilience staff (general guidance; administration of SDRTF RSFs) • Universities • External contractors • Local governments • Stakeholders representing agency priority areas	• Funding for state agency resilience leads (1 new FTE per agency) • Each agency will have different resource needs for implementing resilience in its programs, which may include: o Contracting funds for agency-specific quantitative and qualitative risk and vulnerability assessments o Contracting funds for facilitating prioritization discussions and strategy development • NCORR guidance
3. Statewide Climate Vulnerability Assessment and Resilience Strategy	Identify, perform supporting vulnerability assessment, and develop Resilience Action Plan for Cross-Cutting Challenges: • Priority 1 Challenges: extreme events and actions potentially eligible for federal funding, such as Enhanced Hazard Mitigation Plan funding • Priority 2 Challenges: long-term issues not addressed through Priority 1	• Statewide Strategy development process established by NCORR, with advisory input from Interagency Resilience Team and SDRTF RSFs	• Contracting funds for facilitating prioritization discussions and strategy development to gather input and prioritize actions
4. State Enhanced Hazard Mitigation Plan	• Incorporate climate science data into FEMA required Risk and Vulnerability Assessment process • Incorporate Element 3 Priority 1 Cross-Cutting Resilience Action Plan items into FEMA required Hazard Mitigation Strategy	• NCEM Hazard Mitigation, with advisory input from NCORR resilience staff (Resilience Strategy support and SDRTF administration)	• Contracting funds for quantitative and qualitative risk and vulnerability assessments • Contracting funds for facilitating prioritization discussions and strategy development to gather input and prioritize actions across levels of government



1. North Carolina Climate Science Report

The 2020 North Carolina Climate Science Report (NCCSR) provides a rigorous, comprehensive, peer-reviewed assessment of the weather and climate future of North Carolina. This report relies upon the best available research and modeling about climate change in North Carolina, thoroughly documenting all sources and using best practices for peer review. The current Climate Science Report can be found in Appendix A of this document. A summary of the Report is included in Chapter 3 ("North Carolina Climate Science Report"). The NCCSR updates Chapter 2, "Climate Trends," of the 2012 *Climate Ready North Carolina* report.

The Climate Science Report will help inform all levels of decision making, including state government, local government, farmers, businesses, researchers, households, and others. The report will also help to reduce the complexity, uncertainty, and ambiguity that are a part of resilience-oriented decision making by describing the projected weather changes this state will experience due to climate change. Report data help to define vulnerabilities and quantify risks to ensure that decisions and policies are appropriately implemented. Going forward, the Climate Science Report will be updated as needed as new decision-relevant information becomes available, which will ensure that North Carolina has the best available fact base from which to consider how to build resilience. This allows North Carolina to focus future efforts in ways that implement the recommendation of Moss et al. (2019) to assess climate knowledge in the decision-making context in which it will be applied.[3] This "as needed" update cycle will provide flexibility to dedicate time and resources to tailoring climate information toward solving North Carolina's practical challenges and to supporting new avenues of scientific research and policymaking as our understanding of climate science and our state's needs develop over time.

The science of climate adaptation is constantly evolving to best inform the kinds of practical challenges that agencies identified in Chapter 5. Fortunately, North Carolina is home to a robust climate science community, including the State Climate Office of North Carolina (housed at North Carolina State University), the North Carolina Institute for Climate Studies, and many other federal and university-based climate science and impact programs. Agencies can work with the scientific community to identify the best possible uses of existing climate science to address risks identified. Likewise, the scientific community will find the resilience goals and action steps of the North Carolina Resilience Strategy to be valuable resources for identifying future climate research needs. The Statewide Climate Vulnerability Assessment and Resilience Strategy (discussed below) should capture these ongoing collaborations and provide a means for tracking their findings, in addition to building on the findings of the NCCSR and the U.S. National Climate Assessment.

The NC Climate Science Report was written by a multi-institutional team led by North Carolina Institute for Climate Studies, in partnership with the National Oceanic and Atmospheric Administration's National Centers for Environmental Information, all working on a pro bono basis for the state. Future updates to this report will require funding, as well as state agency staff time to manage production, coordinate state resources, and provide information.

2. State Agency Resilience Strategy Reports

The second element of the North Carolina Resilience Strategy addresses the resilience of state agencies' missions, assets, and programs. Through development of this 2020 Resilience Plan, state agencies analyzed the vulnerabilities and risks associated with two to three climate stressors, such as flooding, drought, and extreme heat events. By this effort, agencies were able to outline the climate stressors that



affect them and the impacts of those stressors, while increasing institutional understanding of climate change and interagency collaboration to address those threats.

Chapter 5 of this plan constitutes the second element of the North Carolina Resilience Strategy, which will be updated and enhanced as agencies develop Agency Resilience Strategies. Agencies each will develop an Agency Resilience Strategy to be published by March 1, 2021, and updated annually thereafter. Each agency's Agency Resilience Strategy will build on the work that agency has completed for Chapter 5 of this plan, describing any changes or additions to the agency's latest understanding of its climate vulnerabilities and risks. It will also briefly outline the agency's current and planned actions to increase resilience. Because of the diversity of state agencies and the scope of their missions and jurisdictions, these strategies will likely include a range of actions, from proposed studies and planning activities to capital projects. In some cases, an agency may already have adequate scientific and risk information to take specific action to build resilience. In other cases, where agencies have identified long-term challenges needing more research and engagement before implementing a project or policy, agencies can outline their plans, funding needs, and timelines to accomplish such work. These strategies also should report progress on implementing strategies previously identified by the agency.

Agencies will each develop an Agency Resilience Strategy on an ongoing basis, with a progress report published annually, beginning on March 1, 2021. Annual updates will reflect the agency's deeper understanding of its vulnerabilities and provide specific strategies and recommendations for mitigating those vulnerabilities. These updates also should report progress on implementing strategies previously identified by the agency. The iterative process of annual report updates allows agencies to maintain a custom resilience strategy that aligns with agency needs and resources. It also helps the public and stakeholders understand each agency's priorities and how to support agencies.

Agencies should designate a resilience lead to provide a primary point of coordination to accomplish this work across divisions within the agency. This lead will also serve on the Interagency Resilience Team, described below. Agencies would benefit from a senior advisor for climate change and resilience (described in Section F below), which could serve as the agency's resilience lead. Additional funding would enable each agency to establish such a full-time advisor. The quality and scope of Agency Resilience Strategies and agencies' ability to implement priority strategies will depend upon available funding for contracting and analyses.

NCORR will provide guidance to agencies in the development and updating of their Agency Resilience Strategy. Additionally, through communication with NCORR, the state agencies will be able to access the subject matter expertise of relevant Recovery Support Function subcommittees of the SDRTF. The SDRTF and its constituent RSFs are advisory bodies that inform disaster recovery and resilience in the state. Annual updates to and implementation of Agency Resilience Strategies are steps consistent with Section 2 of Executive Order 80: "Cabinet agencies shall evaluate the impacts of climate change on their programs and operations and integrate climate change mitigation and adaptation practices into their programs and operations."

3. Statewide Climate Vulnerability Assessment and Resilience Strategy

The third element in the North Carolina Resilience Strategy is a statewide climate vulnerability and impact assessment that establishes resilience action steps. This Statewide Climate Vulnerability Assessment and Resilience Strategy (Statewide Assessment) encompasses the information and the strategic direction that guide decisions where climate change is a relevant factor. These decisions are made by state government, as well as local and tribal governments, businesses, nonprofits, and residents.



In order to accomplish these goals, the Statewide Vulnerability Assessment will need to rely not only on academic research, but also the everyday experiential knowledge of North Carolina's public and private leaders.

The current Statewide Climate Vulnerability Assessment and Resilience Strategy is summarized in multiple sections of the 2012 Climate Ready North Carolina: Chapter 3 ("Impacts, Risks and Vulnerabilities for North Carolina") and Appendices B through E. Various sections of this document complement and enhance the Climate Ready North Carolina report: Chapter 4 ("Climate Justice"), Chapter 6 ("Nature-Based Solutions"), Chapter 7 ("Path Forward"). In this way, sections of this plan round out and update the second element of the North Carolina Resilience Strategy.

In future updates, the Statewide Assessment will use information from analyses of impacts, along with the expertise of stakeholders, to recommend action on resilience. This may include a variety of approaches, from tackling our largest climate resilience problems to modernizing routine, discrete tasks so they consider future weather. The Statewide Assessment should identify challenges to building resilience that cut across different sectors of our society and economy and different levels of federal, state, local, and tribal government. These cross-cutting challenges require multidisciplinary, regional-scale solutions that may be implemented over the course of decades — such as the coastal impacts of sea level rise or drinking water availability during drought — and propose actions to address those challenges.

Prioritizing feasible, effective actions to build resilience will require additional user-driven, quantitative and qualitative assessments. These assessments should encompass both physical and social science approaches to inform all aspects of how implementation decisions are made. Analysis could include investigating impacts previously identified in the 2012 Climate Ready NC and in Chapter 5 of the 2020 North Carolina Resilience Plan in more detail, and identifying as well as investigating additional significant impacts to people, the economy, the built environment, and natural resources.

Developing solutions to the biggest climate change risks for the state will require not only interagency collaboration, but also collaboration across state, local, and tribal governments and with other stakeholders, including community-level engagement. Accordingly, updates to the Statewide Resilience Strategy can provide information that supports decision making at all levels to address the climate crisis. Updates also can outline pathways to implementing those solutions, including identifying challenges such as needed capacity and funding. Concrete, measurable action steps designed to address implementable solutions to our most significant climate vulnerabilities will provide a path forward for all types of stakeholders across state, regional, and local government and in the public and private sectors.

Many of the cross-cutting climate resilience challenges identified in the Statewide Resilience Strategy will take years to solve. Thus this chapter proposes a two-phased approach to updating the Statewide Resilience Strategy. The first phase of this process will examine challenges related to extreme events. These "Priority 1 Challenges" will be addressed first so that they may inform the next update of the state EHMP, due in 2023 (described further below), and other near-term funding opportunities from the federal government or elsewhere. The EHMP identifies needs and actions required to address extreme events, which actions may then be eligible for federal funding. By first examining these Priority 1 Challenges in the Statewide Strategy, North Carolina can take efficient advantage of this funding opportunity.

Other cross-cutting climate resilience challenges, such as long-term drinking water availability or planning for sea level rise over a number of decades, require additional attention and resources outside of established federal funding opportunities like the EHMP process. While these challenges are no less



important, these "Priority 2 Challenges" will be addressed in phase two of the Statewide Resilience Strategy with a long timeline for initial planning and future updates. These two phases of the Statewide Resilience Strategy will be updated every four years, with the initial Priority 1 Challenges Statewide Resilience Strategy published in October 2022 and the initial Priority 2 Challenges Statewide Resilience Strategy published in October 2024.

Strategic stakeholder engagement will be important in developing and implementing the Strategy. Updates to the Statewide Resilience Strategy will depend upon investment of both staff time and significant funding for data gathering and scientific research, engagement with subject matter experts and stakeholders, action prioritization, and monitoring implementation progress.

NCORR will coordinate updates to this third element of the North Carolina Resilience Strategy. The Interagency Resilience Team, described below, will support NCORR to make certain that state agencies' expertise is incorporated throughout this process. The SDRTF RSFs, when not otherwise engaged in providing advisory knowledge and expertise on disaster recovery, may also provide input and guidance on the Statewide Resilience Strategy process.

4. State of North Carolina Enhanced Hazard Mitigation Plan

The Statewide Climate Vulnerability Assessment and Resilience Strategy will be incorporated into the EHMP, which is a critical means for the state to access federal funding for disaster resilience. This constitutes the fourth element of the North Carolina Resilience Strategy. FEMA currently recognizes the quality of the North Carolina State Hazard Mitigation Plan by designating North Carolina an "Enhanced Plan Status" state. This status increases the amount of Hazard Mitigation Funds the state is eligible for after a disaster.

The current EHMP was released in 2018, and federal law requires it to be updated every five years. Future updates of the EHMP will integrate into aspects of the North Carolina Resilience Strategy as appropriate, such as statewide and agency-specific vulnerabilities and resilience strategies and climate science. North Carolina Emergency Management and NCORR will partner to ensure that this future EHMP process encourages both a focus on large scale extreme events and to climate-driven changes in localized, small scale, repetitive hazard events. An integrated EHMP — meaning one that includes both hazard mitigation and climate adaptation and resilience — benefits North Carolina by identifying hazard mitigation activities that also benefit climate adaptation. In addition, this guidance assists local governments and regional coalitions of counties on planning activities that could be eligible for non-emergency Stafford Act assistance and FEMA disaster mitigation grants when funding is available.

E. Priority Resilience Initiatives

The following priority resilience initiatives complement the North Carolina Resilience Strategy by implementing recommended actions and providing opportunities for education and collaboration across stakeholder groups and sectors. This section describes the initiatives and identifies funding needs.

1. Manage and coordinate statewide resilience

The NCORR team will lead the state's resilience efforts. This involves supporting coordination among state agencies and maintaining productive relationships and partnerships between state, tribal, and local and regional governments, business and non-profit partners, and community stakeholders. Collaboration



and interaction among partners inside and outside of state government helps all entities leverage expertise throughout the state to build a more resilient North Carolina.

NCORR provide resilience expertise to state government across the executive and legislative branches and all state agencies. The CRO also facilitates strategic planning and supports state agencies and offices as they continuously expand their capacity for and attention to resilience. Among other responsibilities, NCORR issues guidance to state agencies as they develop and annually update their Agency Resilience Strategy.

2. Convene a dedicated Interagency Resilience Team

The CRO will convene an Interagency Resilience Team, which will include at least one resilience lead from each agency. These leads should be staff experts from each agency who have the authority, capacity, and expertise to collaborate on resilience work among agencies. This team will provide a coordinating structure for tackling interagency resilience issues. It also will support the development and release of updates to the North Carolina Resilience Plan in collaboration with the Climate Change Interagency Council. Ideally, this team will include representation from all state agencies, not only cabinet agencies.

3. Continue resilience efforts through the North Carolina Climate Change Interagency Council

The Climate Change Interagency Council is an interagency leadership body for the state's efforts in climate change mitigation and adaptation. Per Executive Order 80, its charge includes:

- Recommend new and updated goals and actions to meaningfully address climate change;
- Develop, implement, and evaluate programs and activities that support statewide climate mitigation and adaptation practices;
- Establish workgroups, as appropriate, to assist the Council in its duties;
- Consider stakeholder input when developing recommendations, programs, and other actions and activities;
- Review and submit to the Governor plans, recommendations, and/or assessments that further North Carolina's commitment to address the effects of climate change on the state and its residents.

The Climate Interagency Council will continue to serve as a public forum for state agencies to provide updates on their work to reduce emissions and increase resilience. It is also a setting for the public and Climate Interagency Council to learn from subject matter experts about resilience and other topics as well as hear recommendations and input from residents

4. Establish the North Carolina Resilient Communities Program

Building resilient communities is critical to protecting North Carolina's residents from the effects of climate change. Communities in North Carolina's mountains, Piedmont, and coast are on the frontlines of climate impacts. In public listening sessions, meetings, and events across the state during development of this 2020 Resilience Plan, community leaders and residents repeatedly emphasized that building local resilience required access to resilience expertise, support for analysis planning, and funding to implement measures that advance long-term resilience.



To address these local needs, North Carolina will establish the North Carolina Resilient Communities Program. The program will build capacity, incentivize and reward action, and produce coordinated, holistic, and continuous progress.

Components of the North Carolina Resilient Communities Program may include the following:

Develop an online Climate Resilience Clearinghouse and Toolbox. This online resource would point users to relevant climate data and best practices for building resilience in an equitable way. It would also house the North Carolina Resilience Plan and related state resources on resilience.

This online tool will fill an information gap for local communities, regions, and sectors. Critical climate data and guidance on best practices are often not available to support these stakeholders' decisions. Serving internal and external partners with this resource will move North Carolina toward preparing diverse networks of leaders to make decisions about climate-related risks. With a menu of options, stakeholders can reach their own conclusions about the options that are best suited to them. This resource could be developed by federal, state, local, university, and nongovernmental organizations as partners.

Resilience training program for communities. Trainings would help communities develop and deliver consistent resilience goals, principles, and strategies applicable to local government actions. This could include robust training programs and ongoing collaborations for local and tribal governments, regional councils of government, and nonprofit and business entities on how to use emerging climate information and established best practices to build climate resilience.

North Carolina Resilient Communities grant funding. A key aspect of community resilience programs in Massachusetts, Rhode Island, Florida, and other states is resilience grant funding. Local governments and other entities use these grants for resilience education, planning, and strategic investments consistent with priorities identified in their resilience plans.

The local governments in North Carolina that have made progress with climate resilience planning include municipalities that have partnered with universities to access academic grants and with state and federal agencies to leverage funding and expertise. These partnerships have achieved results. For example, DCM conducted a Coastal Resilience Pilot Program that helped the Towns of Oriental, Edenton, Duck, Pine Knoll Shores, and Hatteras Village map community assets that may be vulnerable to coastal hazards and climate change. These successes demonstrate that local governments are willing and able to make progress on resilience when they have access to subject matter experts, capacity building resources, and funding for implementation.

If funded, this program would provide additional grants to local and tribal governments and other community entities for education, planning, and investment in resilience strategies and projects.



F. Cross-Sector Resilience Strategies

This section recommends various cross-cutting resilience strategies that would advance resilience planning and implementation across agencies, sectors, and communities statewide. These and similar recommendations may be addressed in more detail in future updates to the Statewide Resilience Strategy discussed above. These cross-cutting resilience strategies are an evolution from the cross-sector strategies identified in the 2012 resilience report. For a list of those cross-cutting strategies and how North Carolina has implemented them, see Chapter 2.

1. Consider resilience criteria in making state investments

The state can take a leadership role in assessing and mitigating against the potential for climate risks to people and property. For example, state agencies can continue to evaluate current and future climate risks to programs, investments, construction and other activities and develop sensible standards of safety and risk tolerance. Reviews will utilize, and supplement as necessary, the state's data on future climate conditions to ensure that state activities occurring in or near risk areas avoid adverse impacts and remain reasonably safe from climate risk for the lifetime of the project or activity. Where activities within areas at risk cannot be avoided, the agencies should employ the appropriate solutions to mitigate risk or to improve resilience, including those relying on or incorporating natural features. The State Construction Office in the Department of Administration has a critical role in setting goals, criteria, and scopes of work used to develop Requests for Proposals for the state, and it should be engaged in identifying concerns and developing solutions.

2. Update plans, standards, and design values

Planning documents, standards, design values, and cost-benefit analyses offer opportunities to integrate resilience into all sectors. State agencies, local governments, and other decision-making bodies can work with stakeholders and industry to identify opportunities for incorporating climate science information into plans, standards, designs, and budgeting. Updates could occur in the following areas: incentivizing or requiring low impact development, including for stormwater management; engineering designs for infrastructure; comprehensive land use planning and zoning to protect lives and property from impacts from flooding, erosion, and wildfire; updating building codes for flood, wind, and fire resilience; economic valuing of natural infrastructure; grant selection criteria; and insurance requirements. Examples of design standards and values that must be updated include the "Probable Maximum Precipitation" study and "Intensity, Duration, and Frequency" curves used in design of water management structures and facilities.

3. Increase resilience capacity in state agencies

To become sufficiently resilient to the effects of climate change outlined in the Climate Science Report and the 2020 Resilience Plan, state agencies will need to significantly enhance in-house expertise and incorporate resilience practices throughout each agency.

Agencies would benefit from hiring at least one full-time employee, such as a senior advisor, to focus on climate change mitigation and resilience. This subject-matter expert would coordinate resilience activities and communicate resilience practices across agency divisions. This advisor would coordinate the continued development and implementation of its Agency Resilience Strategy, participate on the Interagency Resilience Team, and support updates to each element of the North Carolina Climate



Resilience Strategy. In addition, the advisor would enable agencies to regularly evaluate their resilience programs to measure performance and build upon past work. Regular training and professional development for state agency employees on resilience will also be beneficial.

4. Identify sustainable funding sources for resilience

Some resilience actions are no-cost or low-cost, but many will require significant investment. For example, ongoing projects in neighboring states like in Norfolk, VA, or Charleston, SC, suggest that major transportation, riverine flood mitigation, or coastal protection efforts could cost millions to billions of dollars and take decades to complete. Today, state and local governments and nonprofits often fund resilience investments through a variety of federal, state, and local sources. These funding sources often target specific types of infrastructure and may not describe resilience as a core objective of the fund. Some funding sources are good fits for one-time projects, while other sources are better suited to sustaining long-term programs. A comprehensive understanding of funding options for building North Carolina's resilience is needed, along with recommendations of novel financing approaches. Research on this topic would explore financing for state, local, tribal, and private resilience efforts in the built environment as well as funding for data and planning. Such research would address the following:

- Analyze existing state and federal programs that currently fund resilience efforts in North Carolina or in other states. For example, state revolving loan funds, FEMA mitigation funds, HUD mitigation funds, and mitigation banking.
- Identify resilience financing best practices and innovative policies in other states and municipalities, such as resilience bonds, public-private partnerships, resilience bank or revolving loan funds, resilience trust funds, revenue streams from excise taxes, and proceeds from cap-and-invest programs that govern greenhouse gas emissions.
- Make recommendations about the most promising funding sources and the steps needed to make more resilience funds more available to state government and local government, state and federally recognized tribes, nonprofits, and the private sector as appropriate.

5. Increase communication, outreach, and engagement on climate change

The state would benefit from agencies using a targeted approach to increase communication and interaction with all communities, especially with socially vulnerable and historically marginalized communities. Resilience-relevant programs should engage new types of partners in their work, such as institutions that are frequent points of contact for socially vulnerable people, e.g., schools, medical clinics, retail outlets, houses of worship, and public transit services.

Community agency and bridging social capital are critical components of resilience. Enhancing capacity and social capital among socially vulnerable communities are equally important goals to building the resilience of infrastructure and the built environment.

Other ways to increase communication and collaboration to address climate change include:

- Improving the accessibility of hazard and climate change data to non-experts through web portals, infographics, classroom education modules, or other communication channels.
- Building a North Carolina research network of scholars and students leading resilience-related work. National networks, such as the American Geophysical Union's Thriving Earth Exchange or



the Science to Climate Action Network, can serve as models. This network could leverage the model of the North Carolina Policy collaboratory or ongoing efforts of the Office of State Budget and Management to link researchers in the state to state agency research agendas.

- Providing resources for community and K-12 education on climate change and resiliency.

G. Conclusion

The path forward to greater climate resiliency relies on moving beyond assessment into action. The principles, plans, initiatives, and strategies set forth in this chapter outline a process for North Carolina to become more resilient to the impacts of climate change, even as we work to limit the magnitude of that change by reducing GHG emissions and transitioning to clean energy.

Supporting this ambitious path will require staff and funding. The ongoing process explained in this chapter acknowledges that everyone must commit to action – from state agencies to local and tribal governments, businesses to community stakeholders. It recognizes that building resilience requires supporting collaboration on developing solutions to North Carolina's most challenging climate resilience problems. Because climate-related initiatives touch everyone, including all business sectors, the public, and federal, state, and local agencies in different ways, statewide planning efforts can become overwhelmed with extensive analysis, writing, and meetings. There will be a need to keep this structure and process as simplified, streamlined, and nimble as possible in order to remain effective, while balancing the need for inclusiveness, thoughtfulness, and due diligence in prioritizing significant state investments in resilience initiatives. With adequate funding, the process proposed here for updating the North Carolina Resilience Strategy achieves this balance by ensuring state agencies are collaboratively planning to adapt to climate change. Quantitative and qualitative studies will help agencies, local and tribal governments, and stakeholders base resilience efforts on the best available science and practices. Providing adequate time and support in each Plan element for broad and sustained engagement will ensure that resilience priorities and actions are implemented equitably and meaningfully across North Carolina.

Designating clear leadership and communication structures is important to building climate resilience successfully. This chapter identifies NCORR as the lead to present, promote, coordinate, and manage efforts as described in this plan to prioritize and implement resilience activities in North Carolina. The Interagency Resilience Team will assist NCORR as necessary to carry out these duties. This structure will ensure that even as state agencies continue their own strategies to build resilience to climate impacts, North Carolina has the ability to coordinate and leverage efforts within and across agencies and sectors.

By setting clear goals, taking action, and evaluating progress on a regular basis, North Carolina can ensure that our resilient state thrives amid changing conditions and challenges. This shared vision of resilience will enable us to maintain and improve our quality of life, healthy growth, and durable systems and to conserve resources for present and future generations. The state of North Carolina will lead by example through its own agency actions and will support everyone in the state as we work together toward our shared vision of a more resilient North Carolina.

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deq.nc.gov/NCResiliencePlan

Estimate Interruption Costs

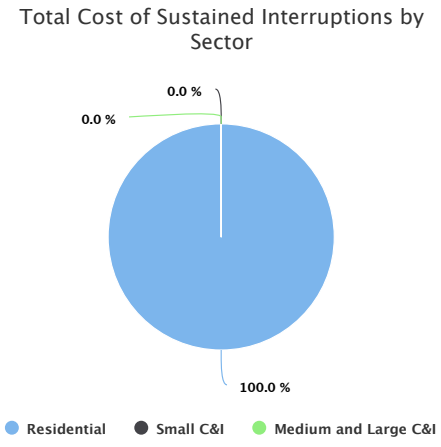
This module provides estimates of cost per interruption event, per average kW, per unserved kWh and the total cost of sustained electric power interruptions.

Model #1

SAIFI	SAIDI	CAIDI	#Residential	#Non-Residential	
12.000	720.0	60.0	2,000	0	Michigan

Interruption Cost Estimates

Sector	# of Customers	Cost Per Event (2016$)	Cost Per Average kW (2016$)	Cost Per Unserved kWh (2016$)	Total Cost (2016$)
Residential	2,000	$5.15	$5.57	$5.57	$123,639.49
Small C&I	0	$753.86	$203.19	$203.19	$0.00
Medium and Large C&I	0	$6,384.87	$51.36	$51.36	$0.00
All Customers	**2,000**	**$5.15**	**$5.57**	**$5.57**	**$123,639.49**



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Estimate Interruption Costs

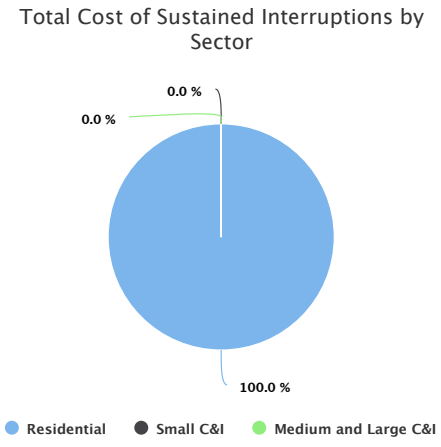
This module provides estimates of cost per interruption event, per average kW, per unserved kWh and the total cost of sustained electric power interruptions.

Model #1 Model #2

SAIFI	SAIDI	CAIDI	#Residential	#Non-Residential	
1.000	720.0	720.0	2,000	0	Michigan

Interruption Cost Estimates

Sector	# of Customers	Cost Per Event (2016$)	Cost Per Average kW (2016$)	Cost Per Unserved kWh (2016$)	Total Cost (2016$)
Residential	2,000	$21.88	$23.66	$1.97	$43,756.99
Small C&I	0	$8,660.91	$2,334.45	$194.54	$0.00
Medium and Large C&I	0	$47,721.56	$383.84	$31.99	$0.00
All Customers	**2,000**	**$21.88**	**$23.66**	**$1.97**	**$43,756.99**



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FOOD FACTS

U.S. FOOD & DRUG ADMINISTRATION

Food and Water Safety During Power Outages and Floods



Know the proper food safety precautions to take before, during, and after a power outage.

Emergencies can happen, especially with extreme weather conditions. When they do, the best strategy is to already have a plan in place. This includes knowing the proper food safety precautions to take before, during, and after a power outage — and being prepared to safely handle food and water in the event that flooding occurs.

Prepare Yourself *Before* Power Emergencies

1. Make sure you have **appliance thermometers in your refrigerator** *and* **freezer**.
   - Check to ensure that the freezer temperature is at or below **0° F**, and the refrigerator is at or below **40° F**.
   - In case of a **power outage**, the appliance thermometers will indicate the temperatures in the refrigerator and freezer to help you determine if the food is safe.
2. **Freeze containers of water** for ice to help keep food cold in the freezer, refrigerator, or coolers in case the power goes out. If your normal water supply is contaminated or unavailable, the melting ice will also supply drinking water.
3. **Freeze refrigerated items** such as leftovers, milk, and fresh meat and poultry that you may not need immediately. This helps keep them at a safe temperature longer.
4. **Group food together** in the freezer. This helps the food stay cold longer.
5. **Have coolers on hand** to keep refrigerated food cold if the power will be out for more than 4 hours.
6. Purchase or make **ice cubes in advance**, and freeze **gel packs** ahead of time. Store all of these in the freezer for future use in the refrigerator or in coolers.
7. Check out local sources to know where **dry ice and block ice** can be purchased, in case it should be needed.
8. **Store food on shelves** that will be safely out of the way of contaminated water in case of flooding.
9. Make sure to have a **supply of bottled water** stored where it will be as safe as possible from flooding. If your bottled water has an odor, do not drink or use it. Instead, dispose of it, or if applicable, call your bottled water provider to make arrangements to get a replacement.

During an emergency, if you use food or beverage containers to hold non-food substances like gasoline, dispose of them after use and do *not* recycle them.

FOOD FACTS

Power Outages: Before *and* After

If the Power Goes Out . . .

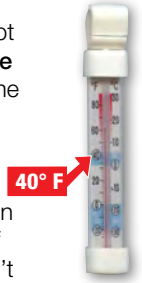
Follow these basic tips to keep food safe:



1. Keep the **refrigerator and freezer doors closed** as much as possible to maintain the cold temperature.
   - The **refrigerator** will keep food **cold for about 4 hours** if it is unopened.
   - A **full freezer** will keep the temperature for approximately **48 hours** (24 hours if it is half full) if the door remains closed.
2. Buy **dry or block ice** to keep the refrigerator as cold as possible if the power is going to be out for a prolonged period of time. Fifty pounds of dry ice should keep an 18 cubic foot, fully stocked freezer cold for two days.
3. If you plan to eat refrigerated or frozen meat, poultry, fish, or eggs while they are still at safe temperatures, it is important that each item is **thoroughly cooked to a safe minimum internal temperature** to ensure that any foodborne bacteria that may be present are destroyed. However, if perishable food has been held at room temperature for 2 hours or more (or 1 hour if outdoor temperatures are above 90° F) — **discard it**.

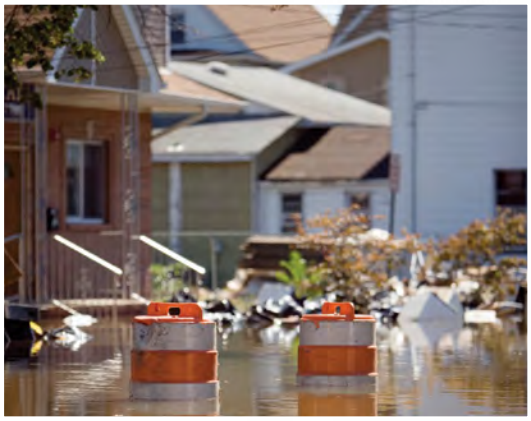
Once Power Is Restored . . .

Determine the safety of your food:



1. If an appliance thermometer was kept in the freezer, **check the temperature** when the power comes back on. If the freezer thermometer reads 40° F or below, the food is safe and may be refrozen.
2. If a thermometer has not been kept in the freezer, **check each package** of food to determine its safety. You can't rely on appearance or odor. If the food **still contains ice crystals** or is 40° F or below, it is safe to refreeze or cook.
3. **If the power was out for no more than 4 hours**, refrigerated food should be safe as long as the doors were kept closed. When the power comes back on, check the temperature in the refrigerator or of the food. **Discard any refrigerated perishable food** (such as meat, poultry, seafood, milk, eggs, or leftovers) that has been at refrigerator temperatures above 40° F for 4 hours or more. Perishable foods with temperatures that are 45° F or below (measured with a food thermometer) should be safe, but should be cooked and consumed as soon as possible.

Perishable food such as meat, poultry, seafood, milk, and eggs that are not kept adequately refrigerated or frozen may cause illness if consumed, even when they are thoroughly cooked.



Be prepared to safely handle food and water in the event that flooding occurs.

If Flooding Occurs

Keep Water Safe

Follow these steps to keep your **WATER SAFE during and after flood conditions**.

1. Only use **water from a safe source** for drinking and washing or preparing food.
2. Use **bottled water** that has not been exposed to flood waters, if it is available.
3. If you don't have bottled water, you should **boil or disinfect water** to make it safe. (see steps below)
4. If you have a **well** that has been flooded, the water should be **tested and disinfected** after flood waters recede. If you suspect that your well may be contaminated, contact your local or state health department or agricultural extension agent for specific advice.

FOOD FACTS

How to Boil or Disinfect Water To Make It Safe

If the water is cloudy, first filter it through clean cloths, or allow it to settle and then draw off the clear water for boiling/disinfecting. Then, follow one of these two procedures:

Boiling

Boiling water will kill most types of disease-causing organisms that may be present.

1. Boil the water for 1 minute.
2. Let it cool, and store it in clean containers with covers.

Disinfecting with Bleach

Bleach will kill some, but not all, types of disease-causing organisms that may be in the water.

1. Add 1/8 teaspoon (or 8 drops) of unscented, liquid chlorine bleach per gallon of water.
2. Stir it well and let it stand for at least 30 minutes before you use it.
3. Store disinfected water in clean containers with covers.



Keep Food Safe

Follow these steps to keep your **FOOD SAFE during and after flood conditions**.

1. **Do not eat** any food that may have come into contact with flood water.
2. **Discard any food and beverage** that is **not in a waterproof container** if there is *any* chance that it has come into contact with flood water.
   - Food containers that are waterproof include undamaged, commercially prepared foods in all-metal cans and “retort pouches” (like flexible, shelf-stable juice or seafood pouches).
   - Food containers that are *not* waterproof include those with screw-caps, snap lids, pull tops, and crimped caps.
   - Also discard cardboard juice/milk/baby formula boxes and home canned foods if they have come in contact with flood water, because they cannot be effectively cleaned and sanitized.
3. **Discard any food in damaged cans.** Damaged cans are those with swelling, leakage, punctures, holes, fractures, extensive deep rusting, or crushing/denting that is severe enough to prevent normal stacking or opening with a manual, wheel-type can opener. *See box on next page for steps to clean/save undamaged packages.*
4. **Thoroughly wash metal pans, ceramic dishes, and utensils** (including can openers) with soap and water, using hot water if available. Rinse and then sanitize them by boiling in clean water or immersing them for 15 minutes in a solution of 1 tablespoon of unscented, liquid chlorine bleach per gallon of drinking water (or the cleanest, clearest water available).
5. **Thoroughly wash countertops** with soap and water, using hot water if available. Rinse and then sanitize by applying a solution of 1 tablespoon of unscented, liquid chlorine bleach per gallon of drinking water (or the cleanest, clearest water available). Allow to air dry.

FOOD FACTS

How To Save Undamaged Food Packages Exposed to Flood Water

Undamaged, commercially prepared foods in **all-metal cans** and **"retort pouches"** (like flexible, shelf-stable juice or seafood pouches) can be saved if you follow this procedure.

1. Remove the labels, if they are the removable kind, since they can harbor dirt and bacteria.
2. Brush or wipe away any dirt or silt.
3. Thoroughly wash the cans or retort pouches with soap and water, using hot water if it is available.
4. Rinse the cans or retort pouches with water that is safe for drinking, if available, since dirt or residual soap will reduce the effectiveness of chlorine sanitation.
5. Sanitize cans and retort pouches by immersion in one of the two following ways:
   - Place in water and allow the water to come to a boil and continue boiling for 2 minutes.
   - Place in a freshly made solution consisting of 1 tablespoon of unscented liquid chlorine bleach per gallon of drinking water (or the cleanest, clearest water available) for 15 minutes.
6. Air dry cans or retort pouches for a minimum of 1 hour before opening or storing.
7. If the labels were removable, then re-label your cans or retort pouches, including the expiration date (if available), with a permanent marking pen.



Food in reconditioned cans or retort pouches should be used as soon as possible thereafter.

Baby Formula Tip

For infants, try to use prepared, canned baby formula that requires no added water. Otherwise, dilute any concentrated baby formula in reconditioned, all-metal containers with clean drinking water.

About Foodborne Illness

Know the Symptoms

Consuming dangerous foodborne bacteria will usually cause illness within 1 to 3 days of eating the contaminated food. However, sickness can also occur within 20 minutes or up to 6 weeks later. Although most people will recover from a foodborne illness within a short period of time, some can develop chronic, severe, or even life-threatening health problems.

Foodborne illness can sometimes be confused with other illnesses that have similar symptoms. The symptoms of foodborne illness can include:

- Vomiting, diarrhea, and abdominal pain
- Flu-like symptoms, such as fever, headache, and body ache

Take Action

If you think that you or a family member has a foodborne illness, **contact your healthcare provider** immediately. Also, **report** the suspected foodborne illness to FDA in either of these ways:

- Contact the Consumer Complaint Coordinator in your area. Locate a coordinator here: **http://www.fda.gov/Safety/ReportaProblem/ConsumerComplaintCoordinators**
- Contact MedWatch, FDA's Safety Information and Adverse Event Reporting Program:
  By Phone: **1-800-FDA-1088**
  Online: File a voluntary report at **http://www.fda.gov/medwatch**

For more information, contact the U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition's Food and Cosmetic Information Center at **1-888-SAFEFOOD** (toll free), Monday through Friday 10 AM to 4 PM ET (except Thursdays from 12:30 PM to 1:30 PM ET and Federal holidays). Or, visit the FDA website at **http://www.fda.gov/educationresourcelibrary**

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How Much It Costs to Stock the Average Family Refrigerator

Jodi Thornton-O'Connell

7–9 minutes



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Home refrigerators were originally used to store just a few perishable essentials like meat and milk. In fact, the first electric units of the 1920s were only slightly bigger than modern mini-fridges. Nearly 100 years later, refrigerators are bigger than ever and used to store the bulk of the food consumed by an American household.

Americans spend anywhere from $130 to just under $300 a week stocking up on food for a family of four, according to the United States Department of Agriculture. Those numbers include dry goods that wouldn't be kept in the fridge, and leave out fridge staples like condiments that families don't typically buy every week. However, once in a while, you might have to fill a fridge from scratch.

Take a tour of a modern fridge, and learn how expensive it is to stock a refrigerator for a family of four for a week.

The Door

Cost to Stock: $44.50

Although the newest refrigerators have ample door bins designed for stowing milk and eggs, putting these items there will shorten

shelf life and cost you more in the long run. Instead, stock the refrigerator door with butter and cooking oil, condiments, soda, bottled water and juice. Many modern fridges even have separate pass-through doors, which allow you to access these items without opening your entire fridge.

For best results, stock the door with a pound of butter ($4), two bottles of salad dressing ($5), a bottle of orange juice ($4), a bottle of apple juice ($4.50), extra virgin olive oil ($8) and a case of bottled water ($9). Remember condiments like ketchup ($3), mustard ($1.50), pickle relish ($2.50) and barbecue sauce ($3) to give your meals that extra zing.

Find Out: *Eat Healthy for $1 or Less With These 51 Foods*

The Low-Humidity Crisper Drawer

Cost to Stock: $39.85

Refrigerators usually have two to four crisper drawers for stowing fruits and vegetables. Adjustable slides let you adjust the humidity level in each drawer to keep your produce at the right level for maximum freshness. Because the USDA recommends two to four servings of fruit per person per day, you have to plan for 56 to 112 servings of fruit for your family of four to last the week. To maximize health without maximizing spend, stock your low-humidity crisper drawer with 8 pounds of apples ($10.40), 8 pounds of pears ($12.80) and 5 pounds of grapes ($16.65).

Save more money on produce by joining a food co-op, such as Bountiful Baskets. Operating in 25 states throughout the nation, the Bountiful Basket Co-op pools participant money to buy fresh, local produce directly from growers, netting the best prices. Buy at least two baskets at $15 each to feed a family of four for the week.

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Although you'll save a bundle on grocery prices, you won't get to pick the produce you want, and you have just a 20-minute window in which to pick up your produce on delivery day.

The High-Humidity Crisper Drawer

Cost to Stock: $33.21

Stock your leafy greens and other veggies in a separate drawer from your fruits and slide the humidity adjustment to the highest level to keep them from wilting. Fill this drawer with enough fresh veggies to equal the 84 servings of fresh veggies per week your family of four needs, including two 2-pound packages of baby carrots ($5), two bunches of broccoli ($4), three heads of romaine lettuce ($7), two bunches of spinach ($6), five bell peppers ($3.80), two bunches of green onions ($1.16) and 5 pounds of zucchini squash ($6.25).

Don't waste money by putting veggies in your fridge that don't belong there. Store garlic, onions, tomatoes and potatoes outside your refrigerator. And avoid storing potatoes and onions together, as they emit gases that make the other rot faster.

The Meat and Cheese Drawer

Cost to Stock: $69.67

In the latest refrigerators, you'll find the meat and cheese drawer just below the produce drawers. Some open from the outside, giving you easy access to deli meats, cheeses, bacon and hot dogs without having to open your refrigerator door. The USDA recommends two to three servings of protein per day, and this drawer is the perfect place to store easy-to-prepare meats and cheeses.

Costco is the best place to head for sandwich meat and other fixings perfect for budget family meals. Buy two 2-pound packages of turkey, ham, beef or pastrami lunch meat ($29). A 2-pound brick of Dubliner Imported Irish Cheese ($10) adds a lot of flavor without adding calories when thinly sliced. Finish stocking this drawer with a four-pack of 1-pound bacon packages for breakfast ($15.86) and a 1.5-pound package of beef franks for weekend cookouts ($14.81) or after-school snacks.

The Middle and Lower Shelves

Cost to Stock: $37.75

Delivering 13 essential vitamins and minerals and 6 grams of protein, eggs help spice up boring meals. Keep them on the middle shelf of your refrigerator, the coldest spot, along with other foods susceptible to bacteria. Store items such as raw meat or poultry on trays or in baking pans so any juices leaking from the packages don't contaminate other food.

Stock this shelf with three dozen eggs ($4.25), two gallons of milk ($6.50) and a protein for every night of the week. A serving of meat is just 4 ounces, so 3 pounds of ground beef ($11) and 5 pounds of boneless skinless chicken breast ($16) serve as a nice base for budget family meals throughout the week. Save money and protect your health by buying your meat twice during the week, as it can spoil in just a few days.

Related: *How I Feed My Family of 5 Well on $125 a Week*

The Top Shelf

Cost to Stock: $22.05

One of the warmer spots in your refrigerator, the top shelf should be limited to things that won't spoil quickly. Stock this spot with snacks for the kids, like peanut butter ($4.50) and jelly ($1.80), hummus ($3.50), fruit cups ($6.25) and salsa ($6).

The top shelf is also the ideal place to store leftovers. Distribute the food in smaller clear glass containers that prevent spills and spoiling. Additionally, you're more likely to eat snacks you can see clearly.

Grand Total

All together, stocking a fridge for a family of four for a week can

cost as little as $247.03 when you start from scratch. Depending on your family's preferences and eating habits, your food cost could be less or even more.

Protect your investment by preventing food-spoiling bacteria from building up in your fridge, and you won't have to worry about food-borne illnesses, either. Line shelves, drawers and compartments with easy-to-clean fridge mats. You can make your own by cutting some plastic placemats from the dollar store to fit or just line your shelves with plastic wrap that you can peel off and throw away.

Next Up: *10 Easy Meals Under $10 to Try This Weekend*

FRED Graph Observations
Federal Reserve Economic Data
Link: https://fred.stlouisfed.org
Help: https://fredhelp.stlouisfed.org
Economic Research Division
Federal Reserve Bank of St. Louis

CPIUFDSL Consumer Price Index for All Urban Consumers: Food in U.S. City Average, Index 1982-1984=100, Monthly, Seasonally Adjusted

Frequency: Monthly

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1995-04-01	148.100
1995-05-01	148.200

1995-06-01	148.300
1995-07-01	148.500
1995-08-01	148.600
1995-09-01	149.100
1995-10-01	149.500
1995-11-01	149.600
1995-12-01	149.900
1996-01-01	150.400
1996-02-01	150.800
1996-03-01	151.400
1996-04-01	152.000
1996-05-01	151.900
1996-06-01	152.900
1996-07-01	153.400
1996-08-01	153.900
1996-09-01	154.600
1996-10-01	155.500
1996-11-01	156.100
1996-12-01	156.300
1997-01-01	155.900
1997-02-01	156.500
1997-03-01	156.600
1997-04-01	156.500
1997-05-01	156.600
1997-06-01	156.900
1997-07-01	157.200
1997-08-01	157.700
1997-09-01	158.000
1997-10-01	158.300
1997-11-01	158.600
1997-12-01	158.700
1998-01-01	159.500
1998-02-01	159.400
1998-03-01	159.700
1998-04-01	159.700
1998-05-01	160.300
1998-06-01	160.200
1998-07-01	160.600
1998-08-01	161.000
1998-09-01	161.100
1998-10-01	162.000
1998-11-01	162.200
1998-12-01	162.400
1999-01-01	163.000
1999-02-01	163.300
1999-03-01	163.300
1999-04-01	163.500
1999-05-01	163.800
1999-06-01	163.700
1999-07-01	163.900
1999-08-01	164.200
1999-09-01	164.600
1999-10-01	165.000
1999-11-01	165.300
1999-12-01	165.500
2000-01-01	165.600
2000-02-01	166.200
2000-03-01	166.500
2000-04-01	166.700
2000-05-01	167.300
2000-06-01	167.400
2000-07-01	168.300
2000-08-01	168.700
2000-09-01	168.900
2000-10-01	169.000
2000-11-01	169.200
2000-12-01	170.000
2001-01-01	170.300
2001-02-01	171.200
2001-03-01	171.700
2001-04-01	172.100
2001-05-01	172.400
2001-06-01	173.100
2001-07-01	173.600

2001-08-01	174.000
2001-09-01	174.200
2001-10-01	174.800
2001-11-01	174.900
2001-12-01	174.700
2002-01-01	175.300
2002-02-01	175.700
2002-03-01	176.100
2002-04-01	176.400
2002-05-01	175.800
2002-06-01	175.900
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2002-10-01	176.400
2002-11-01	176.900
2002-12-01	177.100
2003-01-01	177.100
2003-02-01	178.100
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2003-08-01	180.500
2003-09-01	180.900
2003-10-01	181.600
2003-11-01	182.600
2003-12-01	183.500
2004-01-01	183.400
2004-02-01	183.900
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2004-06-01	186.400
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2004-11-01	188.400
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2005-08-01	191.100
2005-09-01	191.500
2005-10-01	192.000
2005-11-01	192.600
2005-12-01	192.900
2006-01-01	193.600
2006-02-01	193.700
2006-03-01	194.000
2006-04-01	193.800
2006-05-01	194.100
2006-06-01	194.700
2006-07-01	195.200
2006-08-01	195.700
2006-09-01	196.300
2006-10-01	196.900
2006-11-01	197.000
2006-12-01	197.100
2007-01-01	198.378
2007-02-01	199.736
2007-03-01	200.432
2007-04-01	200.952
2007-05-01	201.735
2007-06-01	202.557
2007-07-01	203.232
2007-08-01	204.008
2007-09-01	205.003

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2007-11-01	206.493
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2009-08-01	217.376
2009-09-01	217.258
2009-10-01	217.452
2009-11-01	217.581
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2011-03-01	225.213
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2011-06-01	227.515
2011-07-01	228.482
2011-08-01	229.634
2011-09-01	230.682
2011-10-01	230.899
2011-11-01	231.118
2011-12-01	231.557
2012-01-01	232.213
2012-02-01	232.140
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2012-06-01	233.683
2012-07-01	233.845
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2012-09-01	234.404
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2013-06-01	236.980
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2013-09-01	237.519
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2013-12-01	238.182
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2014-03-01	240.447
2014-04-01	241.241
2014-05-01	242.408
2014-06-01	242.646
2014-07-01	243.235
2014-08-01	243.792
2014-09-01	244.480
2014-10-01	244.866
2014-11-01	245.394
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2015-02-01	246.495
2015-03-01	246.072
2015-04-01	246.002
2015-05-01	246.239
2015-06-01	246.937
2015-07-01	247.157
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2015-12-01	248.206
2016-01-01	248.353
2016-02-01	248.606
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2016-06-01	247.683
2016-07-01	247.658
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2017-08-01	250.469
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2017-12-01	251.716
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2018-02-01	252.264
2018-03-01	252.365
2018-04-01	252.867
2018-05-01	252.864
2018-06-01	253.167
2018-07-01	253.598
2018-08-01	253.949
2018-09-01	254.302
2018-10-01	254.170
2018-11-01	254.887
2018-12-01	255.877
2019-01-01	256.533
2019-02-01	257.253
2019-03-01	257.681
2019-04-01	257.325
2019-05-01	257.818
2019-06-01	257.952
2019-07-01	258.059
2019-08-01	258.288
2019-09-01	258.865
2019-10-01	259.434
2019-11-01	260.048
2019-12-01	260.483
2020-01-01	261.262

2020-02-01	261.969
2020-03-01	262.718
2020-04-01	266.344
2020-05-01	268.098
2020-06-01	269.585
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2020-10-01	269.596
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2021-03-01	271.887
2021-04-01	272.711
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2021-06-01	276.007
2021-07-01	277.739
2021-08-01	278.927
2021-09-01	281.308
2021-10-01	283.917
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2022-02-01	292.982
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2022-11-01	316.551
2022-12-01	317.866
2023-01-01	319.623
2023-02-01	320.697
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2023-04-01	321.116
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2023-06-01	322.347
2023-07-01	322.969
2023-08-01	323.754
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2023-10-01	325.312
2023-11-01	325.870
2023-12-01	326.545
2024-01-01	327.813
2024-02-01	327.880
2024-03-01	328.212
2024-04-01	328.267
2024-05-01	328.721
2024-06-01	329.524

RESEARCH & ANALYSIS

Economic Well-Being of U.S. Households in 2021

May 2022



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FEDERAL RESERVE SYSTEM



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RESEARCH & ANALYSIS

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Executive Summary

This report describes the responses to the 2021 Survey of Household Economics and Decision-making (SHED). The Federal Reserve Board has fielded this survey each fall since 2013 to understand the wide range of financial challenges and opportunities facing families in the United States.[1] The findings in this report primarily reflect financial circumstances in late October and early November of 2021, before the increase in coronavirus (COVID-19) cases from the Omicron variant.

Despite persistent concerns that people expressed about the national economy, the survey highlights the positive effects of the recovery on the individual financial circumstances of U.S. families. In 2021, perceptions about the national economy declined slightly. Yet self-reported financial well-being increased to the highest rate since the survey began in 2013. The share of prime-age adults not working because they could not find work had returned to pre-pandemic levels. More adults were able to pay all their monthly bills in full than in either 2019 or 2020. Additionally, the share of adults who would cover a $400 emergency expense completely using cash or its equivalent increased, reaching a new high since the survey began in 2013.

Parents with children at home, who had been disproportionally affected by the pandemic in 2020, exhibited notable improvements in their financial well-being in 2021. After declining in 2020, parents' assessments of their financial circumstances rebounded in 2021. This improvement is consistent both with reduced childcare burdens as schools returned to in-person classes, as well as additional financial resources provided to parents such as the enhanced child tax credit (CTC). Most parents also said that their child was doing better academically, socially, and emotionally in 2021 than they were a year earlier.

The report also highlights several new topics added to the survey in 2021, such as disruptions from natural disasters, rental debt, and employer vaccine mandates. These new questions provide additional context on the experiences of U.S. adults in handling unexpected expenses, paying for housing, and navigating ongoing changes in the labor market.

To better understand consumer experiences with emerging products, cryptocurrencies and "Buy Now, Pay Later" (BNPL) products were included on the survey for the first time. While most adults did not use cryptocurrencies in the prior year, cryptocurrency use as an investment was far more

[1] The latest survey interviewed over 11,000 individuals in October and November 2021. The anonymized data, as well as appendixes containing the complete SHED questionnaire and responses to all questions in the order asked, are also available at https://www.federalreserve.gov/consumerscommunities/shed.htm.

common than use for transactions or purchases. However, while transactional use of cryptocurrencies was low, those using cryptocurrencies for purchases rather than as investments frequently lacked traditional bank and credit card accounts.

The report also provides insights into long-standing issues related to individuals' personal financial circumstances, including returns to education, housing situations, and retirement savings. In many cases, the report finds that disparities by education, race and ethnicity, and income persisted in 2021.

Key findings from the survey include the following:

Overall Financial Well-Being

In the fourth quarter of 2021, the share of adults who were doing at least okay financially increased relative to 2020. With these improvements, overall financial well-being reached its highest level since the survey began in 2013.

- Seventy-eight percent of adults were either doing okay or living comfortably financially, the highest share with this level of financial well-being since the survey began in 2013.
- Parents experienced particularly large gains in financial well-being over the prior year. In 2021, three-fourths of parents said they were doing at least okay financially, up 8 percentage points from 2020.
- Forty-eight percent of adults rated their local economy as "good" or "excellent" in 2021. This share was up from 43 percent in 2020 but well below the 63 percent of adults who rated their local economy as "good" or "excellent" in 2019, before the pandemic.

Income

The majority of parents received additional income in 2021 through the monthly CTC. Most higher-income parents primarily saved this money, while most lower-income parents primarily spent it on housing, items for their children, or food.

- Three in 10 CTC recipients with income less than $50,000 used the largest portion of their credit on housing expenses, just over 2 in 10 spent the largest portion on their child, and 15 percent spent the largest portion on food.
- Fifteen percent of adults with income less than $50,000 struggled to pay their bills because of varying monthly income. This challenge was even more acute among people who were parents in this income range, of whom 27 percent struggled to pay their bills because of income variability.

Employment

Many people switched jobs in 2021, and those who did generally said that their new job was better than their old one. Most employees also said that their employer was taking about the right amount of COVID-19 precautions, although some people not working indicated that concerns about the virus contributed to the choice not to work.

- Fifteen percent of workers said they were in a different job than 12 months earlier. Just over 6 in 10 people who changed jobs said their new job was better overall, compared with 1 in 10 who said that it was worse.
- Seventy-seven percent of employees said their employers were taking the right amount of precautions against COVID-19. Those who did not were almost evenly split between thinking their employers were taking too many and too few precautions.
- Seven percent of all prime-age adults said that they were not working and that concerns about getting COVID-19 contributed at least in part to their decision not to work.
- Among those working from home, the share of employees who would look for another job if their employer required they work in person was similar to the share who would look after a pay freeze.

Dealing with Unexpected Expenses

The overall share of adults who would cover a small emergency expense using cash or its equivalent increased to the highest level since 2013, when the survey began. Financial preparedness is an important buffer for those who encounter unexpected events, such as medical expenses or disruptions from natural disasters.

- Sixty-eight percent of adults said they would cover a $400 emergency expense exclusively using cash or its equivalent, up from 50 percent who would pay this way when the survey began in 2013.
- Twenty percent of adults had major, unexpected medical expenses in the prior 12 months, with the median amount between $1,000 and $1,999.
- Sixteen percent of adults experienced a financial disruption or hardship from a natural disaster or severe weather event in the prior year.

Banking and Credit

Most adults had a bank account and were able to obtain credit from mainstream sources in 2021, but notable gaps in access to basic financial services still exist among Black and Hispanic adults and those with low income.

- Six percent of adults did not have a bank account. Black (13 percent) and Hispanic (11 percent) adults were more likely not to have a bank account than adults overall.
- Eleven percent of adults with a bank account paid an overdraft fee in the previous 12 months, with higher shares of low-income adults having overdrafted over this period.
- Three percent of adults used cryptocurrency for purchases or money transfers. Among these transactional users of cryptocurrencies, 13 percent did not have a bank account.

Housing

Low mortgage rates resulted in a continuation of the wave of refinancing in 2021, although high-income borrowers were primarily the beneficiaries of this opportunity to reduce monthly housing costs. The share of renters who had been behind on their rent in the prior 12 months was higher than before the pandemic, and many still owed back rent at the time of the survey.

- Nearly one-fourth of all homeowners with a mortgage refinanced their mortgage in 2021. This includes nearly 3 in 10 mortgage holders with an income of at least $100,000, but a lower 16 percent of those with income under $50,000.
- Seventeen percent of renters were behind on their rent at some point in 2021, including 8 percent who were behind at the time of the survey in late 2021. Among those still behind in late 2021, the total outstanding back rent was between $9.3 billion and $10.9 billion.

Education

At the time of the survey, most parents of primary or secondary school students reported that their children were attending classes completely in person. Most parents also said that their child was doing better academically compared with a year earlier. In contrast to the experience of K–12 students, online education remained prevalent at higher education institutions in the fall of 2021.

- Ninety-three percent of parents with a child in public or private school said their youngest child who was enrolled in K–12 education was attending classes completely in person, compared with 27 percent attending completely in person in 2020.
- Fifty-six percent of parents with a child in public or private school said that their child's academic performance improved in 2021, compared with 7 percent who said it declined.
- Seventy-six percent of higher education students in 2021 said they prefer online or hybrid education, given the situation with the pandemic.

Student Loans

The share of student loan borrowers who were behind on their payments in the fall of 2021 declined relative to before the pandemic. These borrowers also saw increases in their financial well-being compared with prior years.

- Twelve percent of borrowers were behind on their payments in 2021, a significant decline from the 17 percent who were behind in the fall of 2019.
- Seventy-three percent of those who went to college and have student loans for their own education were doing at least okay financially in 2021, up from 65 percent before the pandemic.

Retirement and Investments

Among non-retirees, a higher share reported they felt like their retirement savings were on track than in either 2020 or 2019. However, a sizeable share of recent retirees said COVID-related factors affected the timing of their retirement decision.

- Forty percent of non-retirees thought their retirement saving was on track, up from 36 percent in 2020 and 37 percent in 2019.
- Twenty-five percent of adults who retired in the prior 12 months, and 15 percent of those who retired one to two years ago, said factors related to COVID-19 contributed to when they retired.

Overall Financial Well-Being

The share of adults doing at least okay financially rose to the highest level since the survey began in 2013.[2] Although financial challenges and risks to the recovery remain, this generally positive assessment of financial well-being was consistent with improved economic conditions and additional COVID-19 relief measures in 2021.

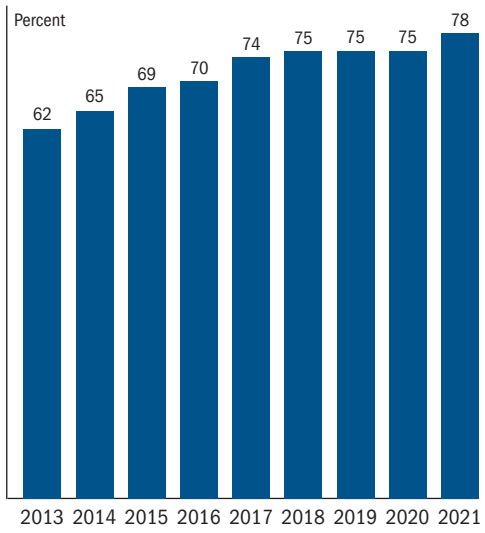
The increase in financial well-being occurred broadly across the population and was especially large among parents. Even so, existing gaps by education and by race and ethnicity persisted.

Current Financial Situation

At the end of 2021, 78 percent of adults were doing at least okay financially, meaning they reported either "doing okay" financially (39 percent) or "living comfortably" (39 percent). The rest reported either "just getting by" (16 percent) or "finding it difficult to get by" (6 percent). The 78 percent of adults doing at least okay financially in 2021 was up 3 percentage points from 2020 and was well above the 62 percent doing at least this well in 2013 (figure 1).

As further evidence of greater financial well-being in 2021, the share of adults who said they were living comfortably rose by 4 percentage points. This increase in financial well-being aligns with improved economic conditions and the additional COVID-19 relief measures enacted in 2021.[3]

Figure 1. At least doing okay financially (by year)



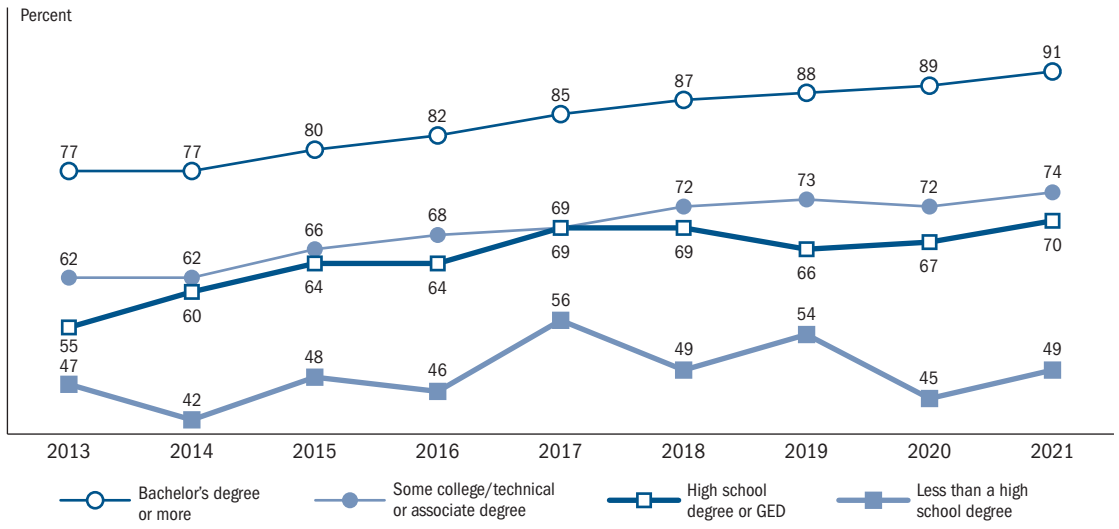
Note: Among all adults.

[2] The survey was fielded in October and November 2021 and results reflect financial situations at that time. References to "in 2021" refer to the 12-month period before the survey rather than the precise calendar year.

[3] The American Rescue Plan Act of 2021 became law in March 2021 and provided additional relief to most households to address the continued impact of the COVID-19 pandemic; see https://www.congress.gov/bill/117th-congress/house-bill/1319 and https://www.whitehouse.gov/wp-content/uploads/2021/03/American-Rescue-Plan-Fact-Sheet.pdf.

Adults with at least a bachelor's degree continued to be much more likely to be doing at least okay financially (91 percent) than those with less than a high school degree (49 percent). The 42 percentage point gap in well-being was little changed from the 44 percentage point gap in 2020 (figure 2). Moreover, looking over the past five years shows a steady and sizeable increase in financial well-being among those with at least a bachelor's degree (an increase of 9 percentage points in the share doing at least okay from 2016 to 2021), while adults with less than a high school degree have not experienced lasting gains in financial well-being.

Figure 2. At least doing okay financially (by year and education)



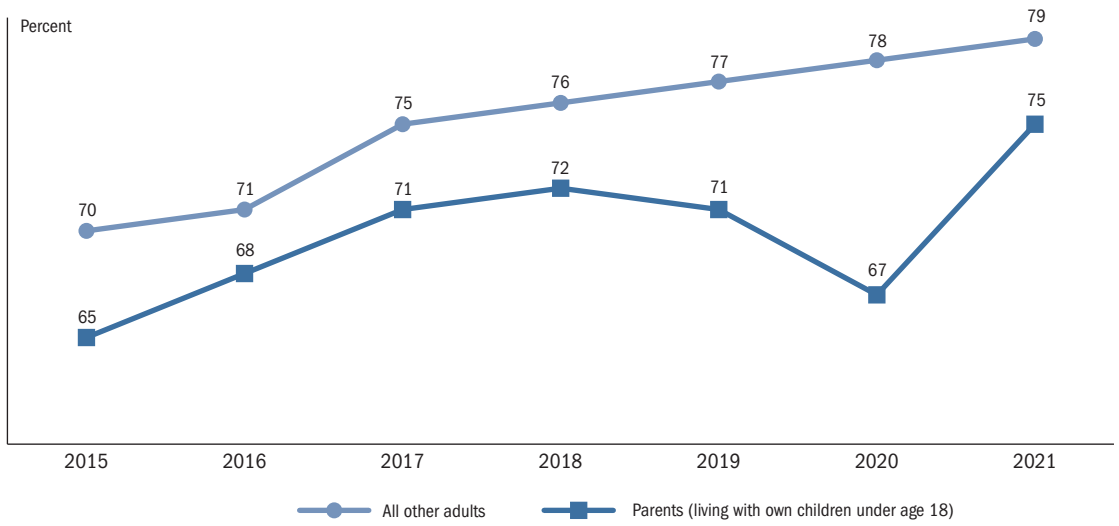
Note: Among all adults. Results for 2017 to 2019 differ slightly from previous reports because of adjustments in education coding for consistency.

Parents were one group that experienced particularly large gains in financial well-being over the prior year. In 2021, three-fourths of parents said they were doing at least okay financially, up 8 percentage points from 2020 (figure 3).

Low-income parents saw even more substantial increases in their financial well-being in 2021. Among parents with income under $25,000, the share doing at least okay financially rose by 13 percentage points, from 40 percent in 2020 to 53 percent in 2021. The share of parents with income between $25,000 and $49,999 who were doing at least okay financially increased by 7 percentage points, while those with higher income exhibited more modest improvements.

A potential explanation for the large rise in financial well-being among parents is the expansion of the CTC. The American Rescue Plan temporarily increased the CTC from $2,000 per child to $3,000 per child ($3,600 for a child under age 6), increased eligibility among low-income families,

Figure 3. At least doing okay financially (by year and parental status)



Note: Among all adults.

and paid the credit monthly (the "Income" section of this report discusses how parents used this credit).[4] Many families also saw a return to in-person schooling in the fall of 2021, which may have eased childcare responsibilities and allowed some parents to return to work or work more hours.

The increase in financial well-being among parents in 2021 contrasts with the decline they experienced from 2019 to 2020 (figure 3).[5] Parents were hit especially hard by the pandemic in 2020, having experienced higher rates of job loss and having faced disruptions to childcare and in-person K–12 schooling that affected their availability to work. (See the report *Economic Well-Being of U.S Households in 2020* for additional information).[6]

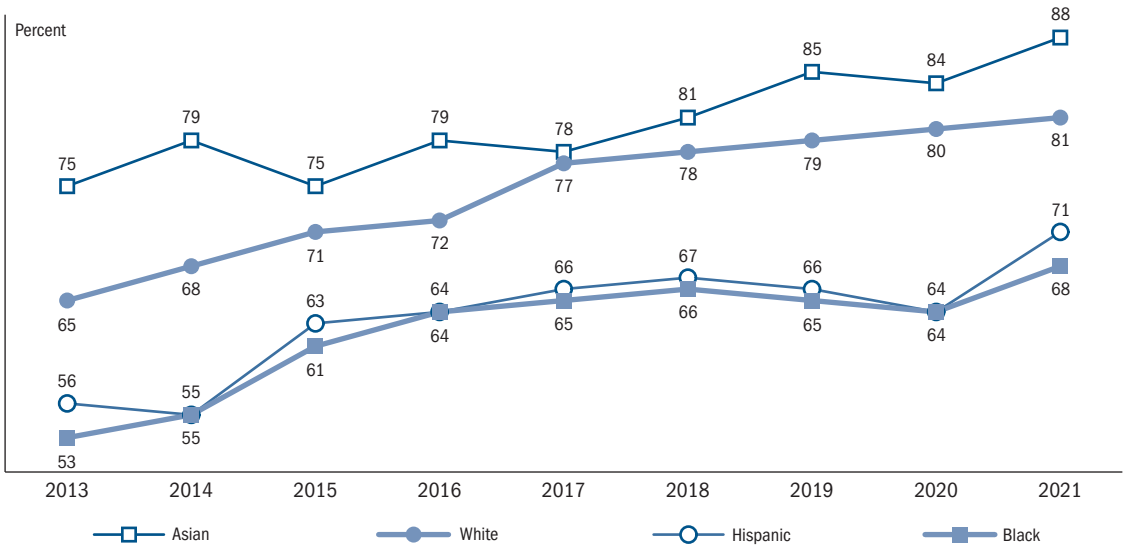
[4] More details on the enhanced CTC are available from U.S. Department of the Treasury, "Child Tax Credit," https://home.treasury.gov/policy-issues/coronavirus/assistance-for-american-families-and-workers/child-tax-credit.

[5] Results in earlier years were updated for consistency with 2021 methods for classifying education status so may differ slightly from earlier reports.

[6] See *Economic Well-Being of U.S. Households in 2020,* https://www.federalreserve.gov/publications/files/2020-report-economic-well-being-us-households-202105.pdf.

Differences in financial well-being across racial and ethnic groups persisted in 2021. Eighty-eight percent of Asian adults were doing at least okay financially, followed by 81 percent of White adults, 71 percent of Hispanic adults, and 68 percent of Black adults (figure 4).[7]

Figure 4. At least doing okay financially (by year and race/ethnicity)



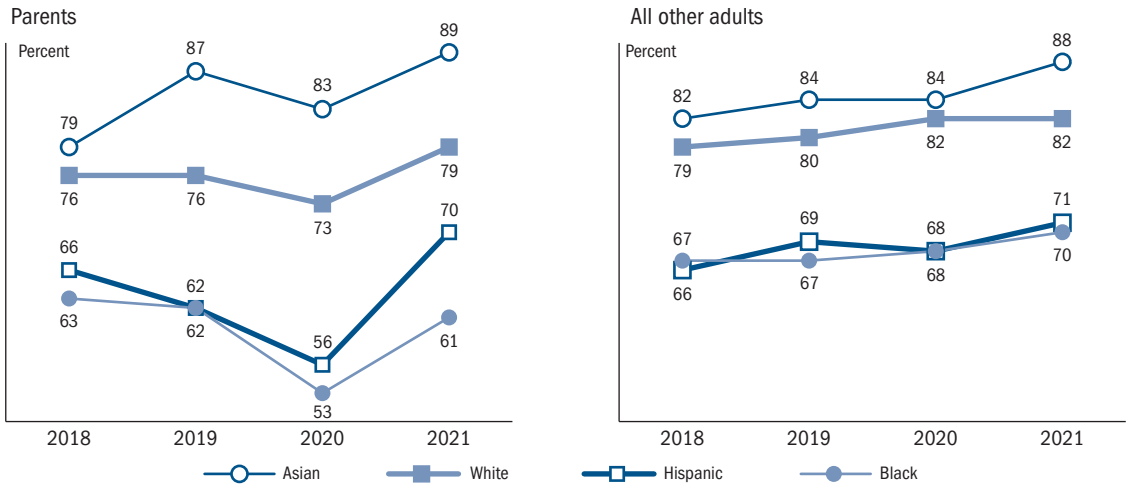
Note: Among all adults.

All racial and ethnic groups measured in the survey saw an increase in financial well-being over the prior year, with Hispanic adults seeing a particularly sharp increase. In 2021, the 71 percent of Hispanic adults who said they were doing at least okay was up 7 percentage points from 2020.

The increase in well-being for Hispanic adults was largely concentrated among parents, similar to the pattern for adults overall. The share of Hispanic parents doing at least okay increased 14 percentage points (to 70 percent) in 2021. However, Hispanic adults not living with their own children under age 18 saw a relatively slight increase (figure 5).

[7] The reported categorizations reflect the largest statistical groupings but are neither exhaustive nor the only distinctions important to understand. Sample sizes for other racial and ethnic groups and subpopulations are not large enough to produce reliable estimates. Asian adults were separately identified for the first time in the survey in the *Economic Well-Being of U.S. Households in 2020*, and in 2021 the Federal Reserve Board identified Asian adults in earlier years of the survey. However, results for Asian adults are sometimes excluded when the sample size is insufficient to provide a reliable estimate.

Figure 5. At least doing okay financially (by year, race/ethnicity, and parental status)



Note: Among all adults. Parents are adults living with their own children under age 18.

Other dimensions across which financial well-being differed include income, geography, LGBTQ+ status, and disability status (table 1). Fifty-five percent of adults with family income less than $25,000 were doing at least okay financially, compared with 96 percent of adults with family income greater than $100,000. People living in low- or moderate-income communities also had lower levels of financial well-being than those living in middle- or upper-income communities.[8] Additionally, those living in metro areas were faring better than those in non-metro communities.[9]

Other surveys have shown that adults identifying as LGBTQ+ were more likely to face economic insecurity, suggesting LGBTQ+ status may be associated with financial well-being.[10] Consistent with this evidence, the 2021 SHED found that 67 percent of adults identifying as LGBTQ+ were doing at least okay financially, compared with 78 percent of the overall population.[11] Moreover, an even lower 62 percent of adults who were transgender or nonbinary, or who reported their sexual

[8] Neighborhood income is defined using the Community Reinvestment Act definition. Under this definition, low- and moderate-income refers to communities that have a median family income of less than 50 percent of the area median income. For details on the definition, see https://www.federalreserve.gov/consumerscommunities/cra_resources.htm.

[9] Non-metro areas are defined throughout this report as being outside of a Metropolitan Statistical Area (MSA), and metro areas are those inside of an MSA, as defined by the Office of Management and Budget. This definition differs from the Census Bureau's definition of urbanized areas. For details, see U.S. Census Bureau, "2010 Urban Area FAQs," https://www.census.gov/programs-surveys/geography/about/faq/2010-urban-area-faq.html.

[10] For example, see U.S. Census Bureau, "Household Pulse Survey Shows LGBT Adults More Likely to Report Living in Households with Food and Economic Insecurity than Non-LGBT Respondents," https://www.census.gov/library/stories/2021/08/lgbt-community-harder-hit-by-economic-impact-of-pandemic.html.

[11] Survey respondents could report their sexual orientation and gender identity on a demographic profile survey previously conducted by the survey vendor. Respondents are classified as LGBTQ+ based on responses to these questions.

Table 1. At least doing okay financially (by demographic characteristics)
Percent

Characteristic	2021	1-year change	5-year change
Family income			
Less than $25,000	55	3	8
$25,000–$49,999	67	2	5
$50,000–$99,999	85	1	5
$100,000 or more	96	1	4
Disability status			
Disability	60	n/a	n/a
No disability	81	n/a	n/a
LGBTQ+ status			
Identifies as LGBTQ+	67	-1	n/a
Does not identify as LGBTQ+	79	2	n/a
Marital status			
Married	86	4	9
Not married	67	0	6
Place of residence			
Metro area	79	3	9
Non-metro area	72	3	4
Neighborhood income			
Low or moderate income	66	4	6
Middle or upper income	82	2	9
Overall	**78**	**3**	**8**

Note: Among all adults. Low- or moderate-income neighborhoods are defined here using the definition from the Community Reinvestment Act. LGBTQ+ status was first identifiable in the 2019 survey and disability status was first identifiable in the 2021 survey. Here and in subsequent tables and figures, percentages may not sum to 100 because of rounding.
n/a Not applicable.

orientation as something other than straight, gay, lesbian, or bisexual, were doing at least okay financially.[12]

Finally, 60 percent of adults with a disability were doing at least okay financially, markedly lower than the overall population.[13] Prior to 2021, the SHED did not include disability status, so we cannot observe how financial well-being has evolved for adults with a disability through the pandemic. However, as discussed in the "Employment" section of this report, other surveys find evidence of an increase in employment among adults with a disability in recent years.

Changes in Financial Situation over Time

The survey also tracks overall financial well-being by asking respondents whether they are better or worse off financially than they were 12 months earlier. Measuring well-being in this way helps track changes in perceived well-being over time, as some individuals may feel worse off financially than they were a year earlier, for instance, even if they feel they are still doing okay overall (or that their financial well-being is improving even if they are still struggling overall).

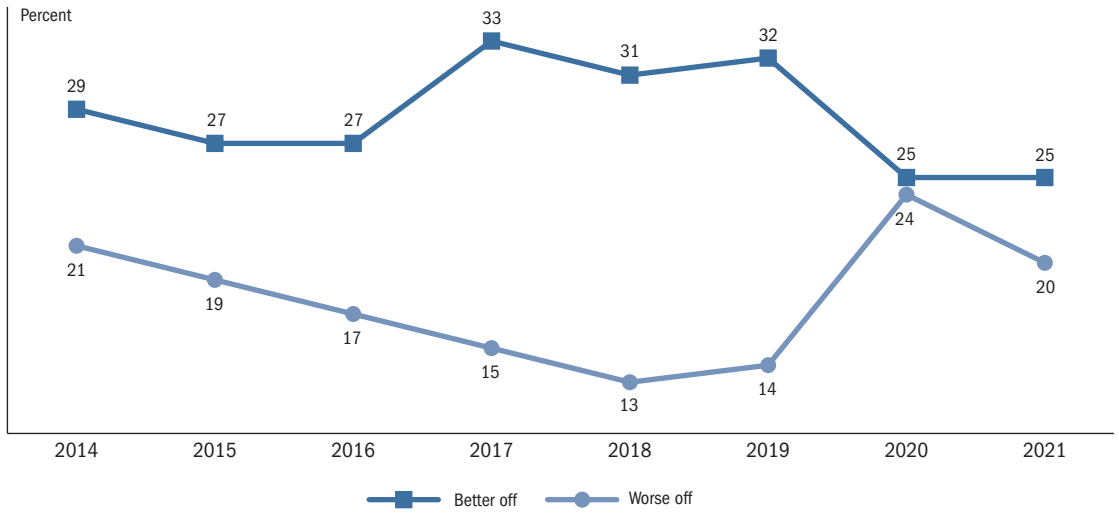
The share of adults who said they were worse off financially than a year earlier fell from 24 percent in 2020 to 20 percent in 2021, yet remained much higher than the 14 percent seen in 2019,

[12] Differences in financial well-being between adults identifying as LGBTQ+ and other adults were present across age groups. For example, only 58 percent of LGBTQ+ adults ages 45 to 54 were doing at least okay, compared with 75 percent among all adults in that age group.

[13] Disability status is defined based on a five-question functional limitation sequence that asks about hearing, vision, ambulatory, self-care, and independent living difficulties. This approach for determining disability status is similar to the six-question sequence used for the American Community Survey (see U.S. Census Bureau, "How Disability Data Are Collected from the American Community Survey," https://www.census.gov/topics/health/disability/guidance/data-collection-acs.html).

before the pandemic (figure 6). The share doing about the same as a year earlier increased 3 percentage points to 54 percent, while the share who said they were better off was unchanged at 25 percent.

Figure 6. Financial situation compared with 12 months prior (by year)



Note: Among all adults.

When asked to compare their financial situation to two years ago, before the pandemic, nearly one-fourth (24 percent) said they were worse off. Forty percent said they were doing about the same, and 36 percent said they were better off than two years ago.[14] Those who were doing worse off than before the pandemic were disproportionately adults with lower family income and less education.

To get a longer-term perspective, individuals were also asked to compare their current financial circumstances to how they perceived their parents' financial situation at the same age. Looking across a generation shows evidence of economic progress over time, despite financial setbacks during the pandemic. A majority of adults (57 percent) thought they were better off financially than their parents were, up from 54 percent in 2020 and back to the pre-pandemic level from 2019. Twenty-one percent thought they were worse off than their parents were at the same age.

[14] A subset of respondents completed both the 2020 and 2021 surveys. Combining the one-year change in well-being results in the 2020 and 2021 surveys for these repeat respondents leads to similar results. Twenty-four percent reported that their financial well-being declined in one year and did not improve in the other, while 34 percent indicated that their well-being improved in one year and did not decline in the other. The remaining 43 percent either said their well-being was about the same in each year (35 percent) or had an improvement in one year and a decline in the other (7 percent).

People holding at least a bachelor's degree were more likely to experience upward economic mobility, relative to those with less education. This is particularly true among first-generation college graduates, among whom 70 percent thought they were better off financially than their parents were.[15]

Local and National Economic Conditions

Along with questions about their own financial circumstances, people were asked to rate their local economy and the national economy as "excellent," "good," "only fair," or "poor." The share of adults rating their local economy favorably increased from 2020 to 2021. Forty-eight percent of adults rated their local economy as "good" or "excellent" in 2021, with the rest rating conditions as "only fair" or "poor." This share was up from 43 percent in 2020, but well below the 63 percent of adults who rated their local economy as "good" or "excellent" in 2019, before the pandemic.

Table 2. Self-assessment of the local economy as good or excellent (by race/ethnicity and place of residence)
Percent

Characteristic	2019	2020	2021
Race/ethnicity			
White	67	46	50
Black	46	32	42
Hispanic	57	39	44
Asian	72	44	61
Place of residence			
Metro area	65	44	50
Non-metro area	53	35	34

Note: Among all adults.

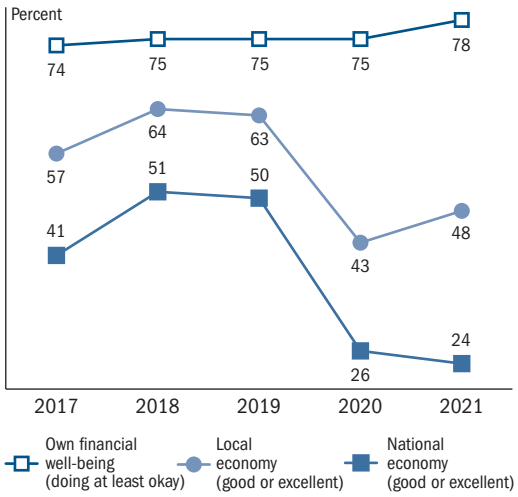
This pattern was generally similar across racial and ethnic groups, with higher shares rating their local economy favorably relative to 2020 but still below the share from 2019 (table 2). One exception was Black adults: the share of Black adults rating their local economy favorably increased 10 percentage points from 2020 to 2021, and was much closer to the pre-pandemic level than for other groups. However, Black and Hispanic adults remained the least likely to report that their local economy was faring well.

People's perceptions about their local economy diverged in 2021 for metro and non-metro areas. While perceptions of the local economy improved for residents of metro areas, perceptions ticked down 1 percentage point for those in non-metro areas. Additionally, the 34 percent of non-metro residents who rated their local economy as "good" or "excellent" remained far below the 53 percent that did so in 2019.

[15] First-generation college graduates are those who have at least a bachelor's degree and who report that neither of their parents completed at least a bachelor's degree.

Similar to people's perceptions of their local economy, the share rating the national economy favorably fell precipitously from 2019 to 2020, after the onset of the pandemic (figure 7). However, people's perceptions of the national economy continued to decline in 2021. Only 24 percent of adults rated the national economy as "good" or "excellent" in 2021, down 2 percentage points from 2020 and about half the rate seen in 2019. This trend contrasts starkly with people's increasingly favorable assessment of their own financial well-being.

Figure 7. Assessment of own financial well-being, local economy, and national economy (by year)



Note: Among all adults.

Overall Life Satisfaction

In addition to questions on financial well-being, the 2021 survey included a question on overall life satisfaction to provide a broader look at how people were faring. Respondents rated how satisfied they were with life as a whole on a scale from 0 to 10. Fifty-eight percent of adults reported "high" life satisfaction (rating 7 to 10), 30 percent reported "medium" life satisfaction (rating 4, 5, or 6), and 11 percent reported "low" life satisfaction (rating 0 to 3).

Life satisfaction was strongly associated with income. Nearly three-fourths (73 percent) of adults with family income of $100,000 or more reported high life satisfaction, compared with 41 percent among those with family income less than $25,000. Differences by education were also large, as were those by disability status and LGBTQ+ status (table 3).[16]

Differences in overall life satisfaction by race/ethnicity, on the other hand, were small. The shares of White, Black, and Hispanic adults reporting high life satisfaction were all within 2 percentage points of the share doing so for the overall population. Asian adults exhibited the largest difference from the overall population, with 63 percent reporting high life satisfaction.

[16] The scales used to measure life satisfaction and financial well-being are not directly comparable.

Table 3. Share of adults with high life satisfaction (by demographic characteristics)

Characteristic	Percent
Family income	
Less than $25,000	41
$25,000–$49,999	51
$50,000–$99,999	61
$100,000 or more	73
Education	
Less than a high school degree	40
High school degree or GED	53
Some college/technical or associate degree	55
Bachelor's degree or more	67
Race/ethnicity	
White	59
Black	56
Hispanic	57
Asian	63
Disability status	
Disability	41
No disability	62
LGBTQ+	
Identifies as LGBTQ+	46
Does not identify as LGBTQ+	60
Parental status	
Not living with own children under age 18	57
Parent (living with own children under age 18)	62
Place of residence	
Metro area	59
Non-metro area	53
Overall	**58**

Note: Among all adults.

Income

Income is central to most people's financial well-being. Recognizing this, the survey included a series of questions on income level and sources, as well as monthly income volatility.

Most parents with a child under age 18 received additional income in 2021 from the CTC. Parents used these monthly payments in a variety of ways, including saving them, spending them on food, and spending them on rent, mortgage, and utilities.

Most adults had income that was roughly the same each month. For adults with varying monthly income, 3 in 10 reported that the volatility caused financial challenges. Income variability was more likely to result in financial challenges among those with lower income.

Level and Source

Family income in this survey is the cash income from all sources, before taxes and deductions, that the respondents and their spouse or partner received during the previous year. Income is reported in dollar ranges and not exact amounts. Just over one-fourth of adults had a family income below $25,000 in 2021, and nearly one-third had $100,000 or more (table 4).

Table 4. Family income (by race/ethnicity)
Percent

Race/ethnicity	Less than $25,000	$25,000–$49,999	$50,000–$99,999	$100,000 or more
White	20	16	27	37
Black	43	18	22	17
Hispanic	40	18	22	20
Asian	17	10	23	51
Overall	**26**	**16**	**25**	**32**

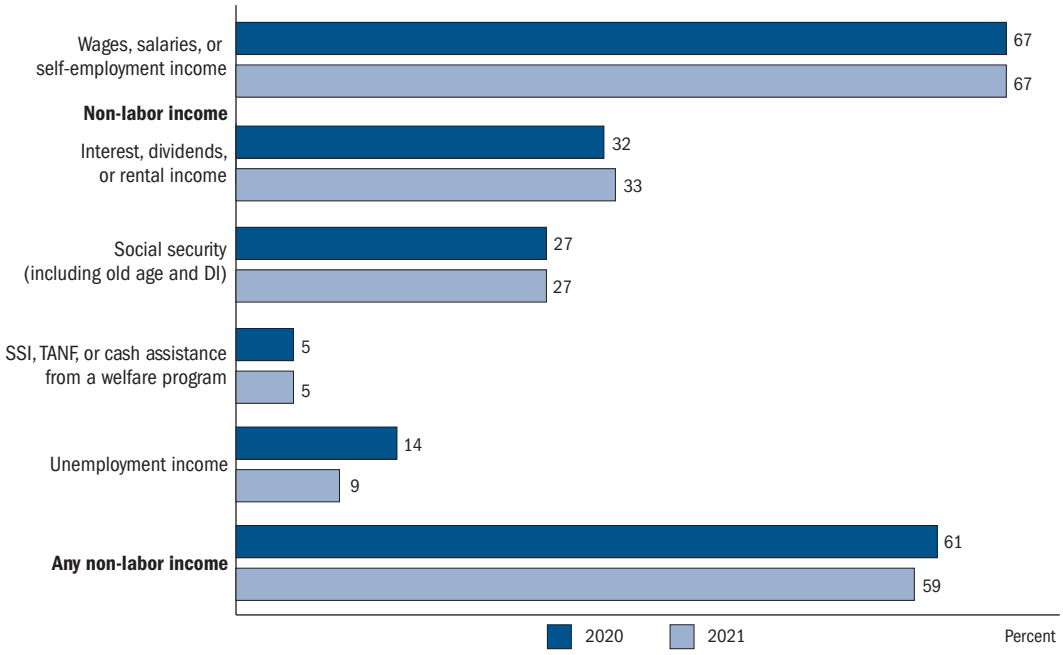
Note: Among all adults.

Family income varied dramatically by race and ethnicity in 2021. Forty-three percent of Black adults and 40 percent of Hispanic adults had a family income below $25,000. This is at least twice the rate among White and Asian adults. Conversely, White and Asian adults were disproportionately likely to have family income above $100,000.

Labor earnings were the most common source of income, but many people had other sources of income as well. Sixty-seven percent of adults and their spouse or partner received wages,

salaries, or self-employment income (collectively referred to here as labor income) (figure 8), matching the share from 2020. Yet, 59 percent of adults and their spouse or partner received non-labor income in 2021.[17]

Figure 8. Family income sources



Note: Among all adults. Respondents could select multiple answers. DI is Disability Insurance; SSI is Supplemental Security Income; and TANF is Temporary Assistance for Needy Families. Key identifies bars in order from top to bottom.

The share of adults receiving unemployment income in 2021 (9 percent) remained higher than before the pandemic but was lower than in 2020, when the job losses caused by the COVID-19 pandemic peaked. Individuals who received income from unemployment insurance in 2021 reported that they were most likely to learn about their eligibility from their employer (45 percent), followed by their own internet research (32 percent).

Assistance from nonprofits and private sources—including financial support from a friend or family member living outside of their home—can also supplement family income. Fifteen percent of adults ages 21 and older received at least one type of assistance from private or nonprofit

[17] Non-labor income is defined as income from interest, dividends, or rental income; social security (including old age and Disability Insurance (DI)); Supplemental Security Income (SSI), Temporary Assistance for Needy Families (TANF), or cash assistance from a welfare program; unemployment income; or income from a pension. Non-labor income does not include Economic Impact Payments, tax credits such as the Earned Income Tax Credit, or in-kind benefits.

sources in 2021 (table 5). Nearly 1 in 10 adults received groceries or meals from a food pantry, religious organization, or community organization, down 2 percentage points from 2020. Seven percent of adults ages 21 and older received financial assistance from a friend or family member living outside of their home, essentially unchanged from 2020. On the other hand, 15 percent of adults provided support to others.

Table 5. Financial assistance received (by educational attainment)
Percent

Characteristic	Free groceries or meals	Financial support from religious or community organization	Financial support from friends or family not in household	Received at least one type of private or nonprofit support
Less than a high school degree	27	5	15	34
High school degree or GED	13	2	7	17
Some college/technical or associate degree	10	2	9	17
Bachelor's degree or more	3	1	5	8
Overall	**9**	**2**	**7**	**15**

Note: Among adults age 21 and older. Respondents could select multiple answers.

Adults with less education were more likely to receive at least one type of assistance from private or nonprofit sources. More than 3 in 10 (34 percent) adults with less than a high school degree received this type of assistance, compared with less than 1 in 10 adults with at least a bachelor's degree.

Child Tax Credit

Starting in July 2021, most parents of children under age 18 saw their income supplemented by the enhanced CTC. Eighteen percent of all adults, and 70 percent of adults living with their children under age 18, reported receiving monthly CTC payments in 2021.[18] An additional 5 percent of adults living with children under age 18 did not know if they received monthly CTC payments.

Parents who received monthly CTC payments most frequently saved the payments, spent them on their child, or used them for necessities. Saving was the most common use of the monthly CTC payments, with 43 percent of recipients saying they saved at least a portion of them.

[18] This estimate corresponds to 27 million payments to 52 million children. Administrative data from the Treasury Department find that 36 million payments were made in December 2021 for 61 million qualifying children (U.S. Department of the Treasury, *By State: Advance Child Tax Credit Payments Distributed in December 2021* (Washington, DC: Department of the Treasury, December 2021), https://home.treasury.gov/system/files/131/Advance-CTC-Payments-Disbursed-December-2021-by-State-12152021.pdf). The lower estimate of parents reporting the credit in the SHED suggests that some parents either did not know their family received the payment or did not know that it was the CTC.

Table 6. Uses for Child Tax Credit (CTC)
Percent

Purpose	Used any for purpose	Used largest portion for purpose
Saved it	43	36
Paid off debt	21	10
Spent on child	40	20
Spent on rent, mortgage, or utilities	29	17
Spent on food	31	12
Spent on other things	12	5

Note: Among parents with a child under age 18 who reported receiving CTC payments. Respondents could select multiple answers.

Other common uses were spending on their child (40 percent); spending on food (31 percent); and spending on rent, mortgage, or utilities (29 percent) (table 6).

Respondents were also asked how they used the largest portion of the monthly CTC payments. Saving the monthly payment was again the most common response (36 percent), with many others saying that they spent the largest portion on their child or on rent, mortgage, or utilities.

The ways people used the CTC payments varied by income. Higher-income adults were most likely to save the largest portion of their credit, whereas lower-income adults were most likely to spend it on housing. For instance, 54 percent of recipients with income of at least $100,000 saved the largest portion of their credit, whereas only 18 percent of recipients with income less than $25,000 did so (table 7).

Table 7. Use for largest portion of Child Tax Credit (by family income)
Percent

Purpose	Less than $25,000	$25,000–$49,999	$50,000–$99,999	$100,000 or more
Saved it	18	15	33	54
Paid off debt	14	9	9	10
Spent on child	22	22	22	16
Spent on rent, mortgage, or utilities	29	33	18	6
Spent on food	13	19	15	7
Spent on other things	5	2	5	7

Note: Among parents with a child under age 18 who reported receiving CTC payments.

Income Variability

Since many bills must be paid monthly, variations in monthly income can lead to financial challenges. Most adults had income that was roughly the same each month, but about 3 in 10 had income that varied from month to month. This share was essentially unchanged from 2020.

Since income variability can result from either dips or spikes in monthly income, the survey asked those who reported varying monthly income whether they struggled to pay bills as a result. Thirty percent of those who experienced varying monthly income, representing slightly less than

1 in 10 adults overall, said they struggled to pay their bills at least once in the past 12 months because of varying monthly income.

Lower-income adults were more likely to have varying monthly income and to report that they struggled to pay their bills at least once in the past 12 months as a result (table 8). Fifteen percent of adults with income less than $50,000 struggled to pay their bills because of varying monthly income. Among lower-income parents, an even greater 27 percent struggled to pay their bills because of income variability.

Adults with and without a disability were similarly likely to experience income variability. However, when those with a disability experienced such variability, it was more likely to lead to a hardship.

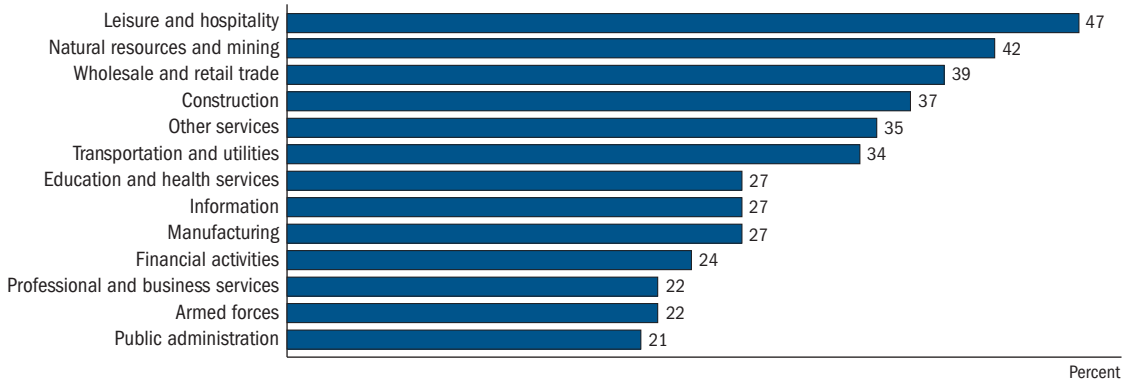
Table 8. Income volatility and related hardship (by family income, race/ethnicity, and disability status)
Percent

Characteristic	Varying income, causes hardship	Varying income, no hardship	Stable income
Family income			
Less than $25,000	16	23	61
$25,000–$49,999	14	17	69
$50,000–$99,999	6	18	75
$100,000 or more	1	19	79
Race/ethnicity			
White	7	19	75
Black	12	19	69
Hispanic	14	23	63
Asian	4	20	76
Disability status			
No disability	7	20	72
Disability	13	15	72
Overall	**9**	**20**	**72**

Note: Among all adults.

Income variability also continued to differ greatly by industry in 2021. Workers in the leisure and hospitality industry were the most likely to have varying monthly income (figure 9).

Figure 9. Income varied at least occasionally from month to month (by industry)



Note: Among adults who reported industry of employment.

These workers also reported the highest rates of hardship because of their varying income. However, the prevalence of income variability within the leisure and hospitality industry was similarly high both before and after the pandemic.

Employment

The share of adults who were working in late 2021 remained below the pre-pandemic level. Health limitations, concerns about COVID-19, and family responsibilities were common reasons for not working. Many also switched jobs in 2021, and those who did generally said their new job was better than their old one.

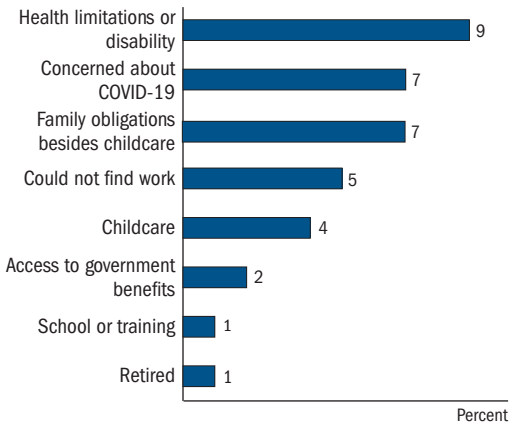
Reasons for Not Working

Twenty-three percent of prime-age adults (ages 25 to 54) were not working in October 2021, down from 26 percent in 2020, but up from 21 percent in 2019, before the pandemic.[19]

Health limitations and concerns about getting COVID-19 were commonly cited reasons for not working. Twelve percent of all prime-age adults were not working, at least in part, for one of these reasons. Health limitations or disability were cited by 9 percent and specific concerns about COVID-19 were cited by 7 percent (figure 10). Family responsibilities were also commonly cited as reasons for not working.

The proportion of prime-age adults who said that they were not working because they could not find work fell from 9 percent in 2020 back to 5 percent in 2021, the same as before the pandemic.[20]

Figure 10. Reasons for not working among prime-age adults



Note: Among adults ages 25 to 54. Respondents could select multiple answers.

Two percent of all prime-age adults said that they were not working, at least in part, because they didn't want to lose access to unemployment insurance or other government ben-

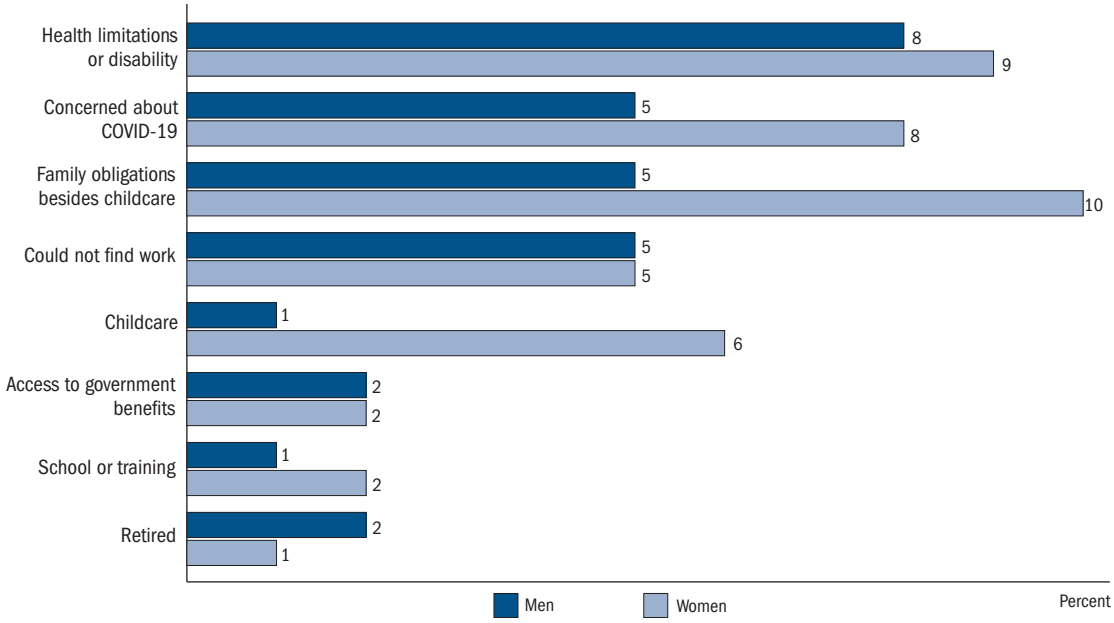
[19] This pattern is consistent with that observed by the Bureau of Labor Statistics, who reported 22 percent not working in October 2021, down from 24 percent not working at the time of the survey in 2020, but up from 20 percent in October 2019. See U.S. Bureau of Labor Statistics, "(Seas) Employment-Population Ratio—25–54 yrs.," https://data.bls.gov/timeseries/LNS12300060.

[20] Some of the decrease could have been due to a change in the questionnaire from 2020 to 2021 to include an additional reason that respondents could give for why they were not working, although respondents still could give multiple answers.

efits.[21] Among those whose family received government benefits in the prior year, 6 percent indicated that benefit eligibility contributed to them not working.[22] However, even among benefit recipients, other factors including concerns about COVID-19 exposure (15 percent) and an inability to find work (11 percent) were more likely to be cited as reasons for not working.

Prime-age women were particularly likely to say that they were not working because of childcare and other family responsibilities. Six percent of prime-age women cited childcare as a reason for not working, and 10 percent cited other family responsibilities, far exceeding that for men (figure 11). However, the share of women not working because of childcare responsibilities did not increase relative to that seen before the pandemic.

Figure 11. Reasons for not working among prime-age adults (by gender)



Note: Among adults ages 25 to 54. Respondents could select multiple answers. Key identifies bars in order from top to bottom.

Another difference between prime-age men and women is that women were more likely to say they were not working, at least in part, because of concerns about getting COVID-19. Eight percent of

[21] The survey was conducted in the fourth quarter of 2021, after the expiration of expanded unemployment insurance programs in September.

[22] Government benefit recipients include prime-age adults whose family received unemployment insurance, Social Security, Supplemental Security Income, TANF, other cash welfare assistance, SNAP benefits, Medicare, or Medicaid.

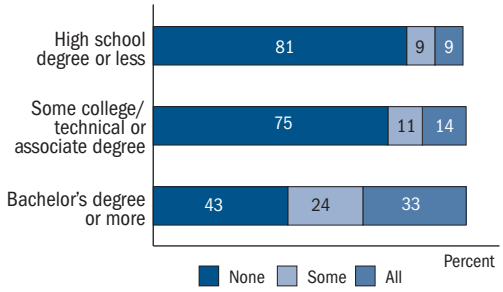
prime-age women cited concern about getting the virus as a reason for not working, compared with 5 percent of prime-age men. Previous studies have found that occupations with more women working in them before the pandemic had higher rates of COVID-19 exposure.[23]

Working from Home

A major change in many people's work lives since 2019 was the increased prevalence of working from home, also known as remote work. During the week of the survey in late 2021, 22 percent of adults who worked for someone else ("employees") worked entirely from home. This share was down from 29 percent in 2020, but well above the 7 percent who worked entirely from home in 2019, before the pandemic.[24] In addition, 17 percent of employees said they worked from home some of the time during the week of the survey in 2021. For some workers, such as those with disabilities, the increased prevalence of remote work in recent years may have facilitated greater participation in the labor market (see box 1).

Employees with more education were much more likely to work from home than those with less education. Thirty-three percent of employees with at least a bachelor's degree worked entirely from home, whereas 14 percent of employees with some college, and 9 percent with a high school degree or less, did so (figure 12).[25]

Figure 12. Amount of work done from home (by education)



Note: Among adults who worked for someone else. Key identifies bars in order from left to right.

One reason for the differences by education is that employees with more education were more likely to have a job where they could work from home. Nearly three-fourths of employees with a bachelor's degree or more either worked from home or said that they could if their employer would let them, compared with 29 percent of employees with a high school degree or less. Overall, 53 percent of employees either worked from home or said that they could if their employer would let them.

[23] Stefania Albanesi and Jiyeon Kim, "Effects of the COVID-19 Recession on the U.S. Labor Market: Occupation, Family, and Gender," *Journal of Economic Perspectives* 35, no. 3 (Summer 2021): 3–24, https://www.aeaweb.org/articles?id=10.1257/jep.35.3.3.

[24] The question asked in 2019 was different from 2020 and 2021. The 2019 survey asked where people worked in their main jobs most of the time.

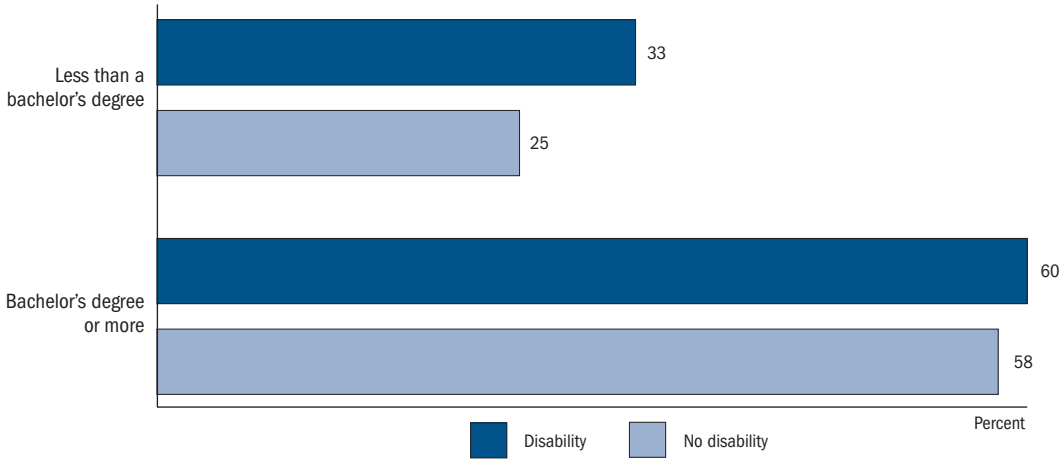
[25] There is variation across industry in the likelihood of working from home, although even within an industry those with a bachelor's degree are generally more likely to work from home than are those with less education.

Box 1. Pandemic Employment Experiences of Adults with a Disability

Individuals with a disability have long faced significant barriers in the labor market. Before the pandemic, in February 2020, the employment rate among individuals with a disability was only 19 percent, compared with 67 percent among those without a disability. Most of this gap was due to individuals with a disability being out of the labor force, meaning they were not looking for work.[1] The widespread disruptions to the labor market during the pandemic created unique challenges for adults with disabilities, but the restructuring of how work is conducted also created an opportunity for some to enter the labor force and contribute in ways that were not previously possible.

Despite the additional pandemic-related hurdles, employers' increased reliance on working from home and remote work had the potential to expand employment opportunities for a wide array of workers with a disability. Thirty-three percent of workers with a disability who had less than a bachelor's degree worked from home some of the time in the week before the survey, compared with 25 percent of their peers without a disability (figure A). Among workers with at least a bachelor's degree, a higher share worked from home, and the shares were similar among workers with and without a disability. The increase in remote work opportunities during the pandemic may have contributed to the more rapid recovery in employment rates since the start of the pandemic among workers with disabilities observed in other data.[2]

Figure A. Worked from home at least some of the time (by education and disability status)



Note: Among adults who worked in the month prior to the survey. Key identifies bars in order from top to bottom.

(continued)

[1] U.S. Bureau of Labor Statistics "(Unadj) Employment-Population Ratio—With a Disability, 16 Years and Over" https://data.bls.gov/timeseries/LNU02374597; and U.S. Bureau of Labor Statistics, "(Unadj) Employment-Population Ratio—With No Disability, 16 Years and Over," https://data.bls.gov/timeseries/LNU02374593.

[2] According to the U.S. Bureau of Labor Statistics, the employment to population ratio of workers with a disability in October 2021 was 1 percentage point above pre-pandemic levels from February 2020 while remaining 2 percentage points below pre-pandemic levels among those without a disability.

Box 1—*continued*

Nevertheless, with the unprecedented health challenges that the pandemic presented to the general population, adults with a disability faced significant difficulties that may be exacerbated by their disability. For some types of disabilities, contracting COVID-19 may present unique difficulties in going about one's day or receiving care. Further compounding matters, comorbidities are more prevalent among adults with a disability, meaning a COVID-19 infection may be more likely to result in serious illness or death.[3]

Consequently, workers with a disability may have different preferences on workplace COVID-19 precautions. This, in turn, could affect their employment decisions. After controlling for their level of education, employees with a disability were more likely to favor a vaccine mandate relative to those without a disability.

Additionally, among those who were not working, people with a disability were more likely to say that concerns about contracting COVID-19 contributed to their not working. Among adults with at least a bachelor's degree, 19 percent of those with a disability reported that COVID-19 concerns were a contributing factor. This is nearly twice the frequency of these concerns among similarly educated people without a disability. Among those with less than a bachelor's degree, just over one-fifth of nonworkers with a disability, and just under one-fifth of nonworkers without a disability, said that COVID-19 concerns were a factor in their employment decision. Consequently, while employment rates among workers with a disability have improved recently, health and safety concerns appear to be hampering their employment growth more than among other adults.

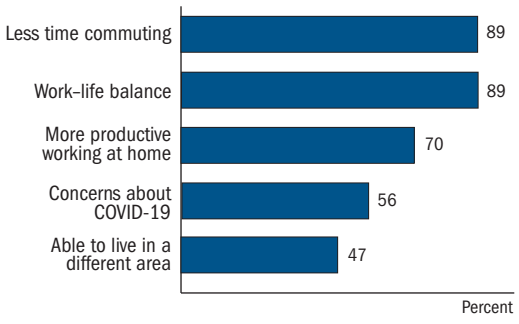
[3] Sally-Ann Cooper, Gary McLean, Bruce Guthrie, Alex McConnachie, Stewart Mercer, Frank Sullivan, and Jull Morrison, "Multiple Physical and Mental Health Comorbidity in Adults with Intellectual Disabilities: Population-Based Cross-Sectional Analysis," *BMC Family Practice*, 16, no. 1 (2015): 1–11.

Most employees who worked from home, or who said they could if their employer would let them, would prefer to work from home. Eighty-nine percent said they would like to work from home at least some of the time. Forty-one percent said they would prefer to do so all of the time.

Employees who preferred to work from home at least some of the time most commonly cited less time commuting and work-life balance as reasons (figure 13). Both were cited by 89 percent of employees who preferred to work from home.

Another common reason employees said they preferred to work from home was increased productivity. Seventy percent of employees who preferred to work from home said that one reason for their preference was that they were more productive at home. While lower,

Figure 13. Reasons employees prefer to work from home



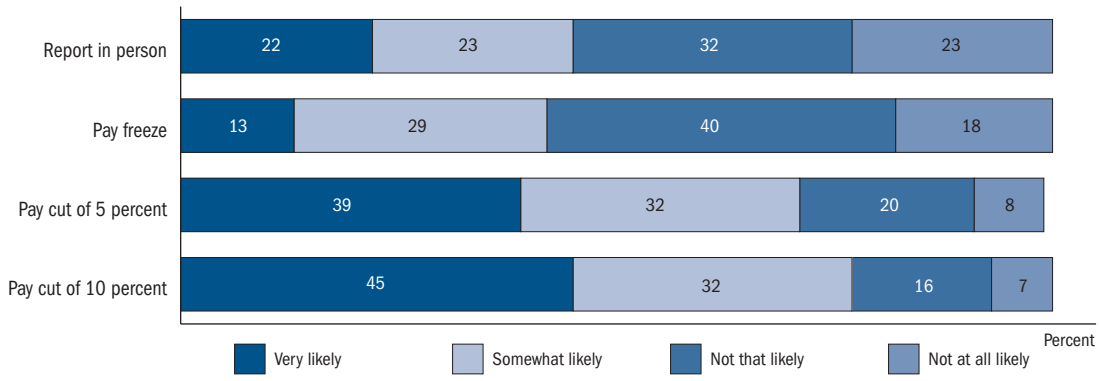
Note: Among employees who worked from home or could work from home if their employer allowed, who also said they preferred working from home at least some of the time. Respondents could select multiple answers.

56 percent of employees who preferred to work from home said that concerns about COVID-19 contributed to their preference.

Many of those who worked from home at least some of the time also said that they would actively look for another job if their employer required them to work in person each workday. Forty-five percent said they were at least somewhat likely to look for another job or leave their job if their employer required them to work in person each workday.[26] Twenty-two percent were very likely. Among those working from home full time, an even larger 55 percent said that they would be somewhat or very likely to look for another job if required to report in person each workday.

For context on the importance of the ability to work from home in people's job decisions, the survey also asked respondents about their likelihood of looking for another job if their employer froze their pay or cut their pay by various amounts.[27] The share of employees who were at least somewhat likely to look for another job if their employer required they work in person was similar to the share who would look after a pay freeze (figure 14).

Figure 14. Likelihood of looking for a new job (by required in-person work and pay cuts)



Note: Among adults working for someone else who worked from home at least some of the time. Key identifies bars in order from left to right.

Job Changes

In the fourth quarter of 2021, 15 percent of workers said they were in a different job than they were 12 months earlier. Most people who changed jobs said that their new job was better than

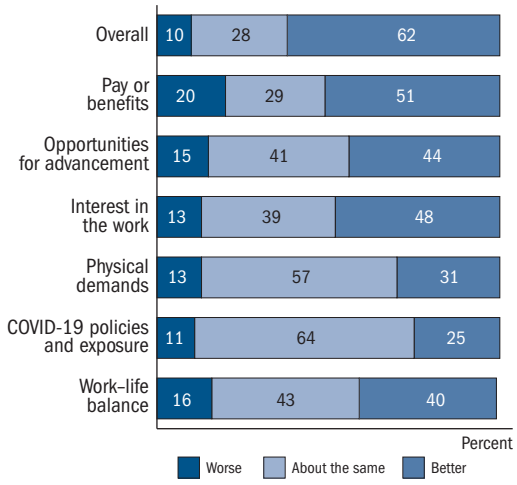
[26] However, 16 percent of those working from home who said that they would prefer to work in person also said that they would actively look for another job in this situation. This suggests that at least some of these individuals either were actively looking irrespective of the work location, or they value being given the choice of where to work even if they chose not to work from home.

[27] The order of the pay cut and telework questions was randomized in the survey, as was the amount of the pay cut that respondents were asked about.

their old one. Over 6 in 10 people who changed jobs said their new job was better overall, compared with 1 in 10 who said that it was worse.

Pay, opportunities for advancement, and interest in the work were frequently seen as better in the new job. Just over half of people who changed jobs said that their pay and benefits improved, compared with 20 percent who said their pay was worse. Similarly, far more people said that their work-life balance, opportunities for advancement, and interest in the work improved than said these measures declined (figure 15).

Figure 15. Change in quality of job characteristics after job change



Note: Among working adults whose main job was not the same as it was a year ago. Key identifies bars in order from left to right.

Of the characteristics considered, COVID-19 policies and exposure were the most likely to be the same in the old and new jobs. Nearly two-thirds (64 percent) of job changers said that COVID-19 policies and exposure were about the same, while one-fourth said that they were better, and 11 percent said that they were worse.[28]

Workers who experienced a layoff and changed jobs were less positive about their new positions than other job changers.[29] Those who were laid off were substantially less likely than those not laid off to say their new job was better overall.[30] They also were less likely to say that the pay and benefits, opportunities for advancement, and interest in the job improved at their new position (figure 16).

COVID-19 Precautions at Work

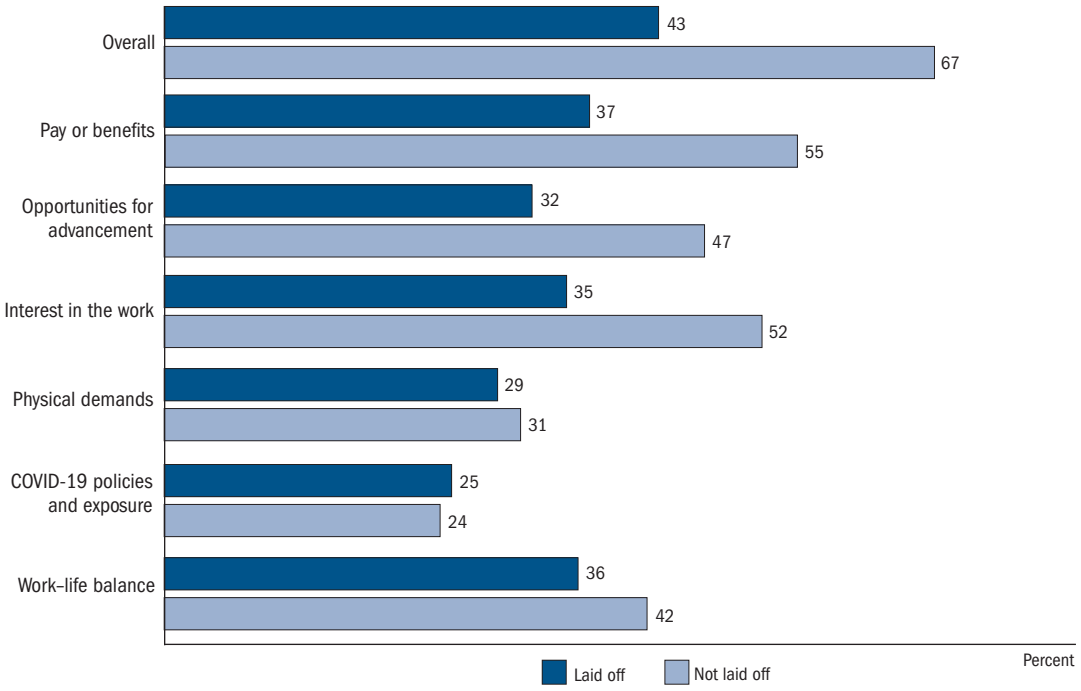
One factor in people's decisions on whether to work and where to work is their perceptions of workplace safety, including COVID-19 precautions. Employees mostly thought that their employers were taking the right amount of precautions to prevent the spread of COVID-19. Seventy-seven percent of employees said their employers were taking the right amount of precautions. Those who

[28] Better COVID-19 policies could mean stricter or more lenient policies, depending on the preference of the respondent. The survey did not define what better or worse policies meant.

[29] Seven percent of adults said that they were laid off in the 12 months prior to the survey.

[30] People's perceptions of their old jobs likely also reflect the circumstances of their leaving, including negative feelings from getting laid off. Moreover, while it is likely the laid-off worker is comparing their new job to the job they were laid off from, it is also possible they had another job in-between.

Figure 16. Share reporting that job characteristic is better after job change (by layoff status)



Note: Among working adults whose main job was not the same as it was a year ago. Key identifies bars in order from top to bottom.

did not were almost evenly split between thinking their employers were taking too many (11 percent) and too few precautions (12 percent).[31]

In terms of specific precautions, just under one-fourth of employees said that their employer had a policy requiring vaccination. An additional 19 percent of employees said that employees could either be vaccinated or be tested regularly. Forty-nine percent said their employer had no specific vaccine or testing requirement.[32]

Employees were almost evenly split on whether they wanted vaccine requirements in their workplaces. Forty-nine percent of workers said that they wanted their employer to require vaccinations of all employees, whereas 51 percent said that they did not. The share who wanted a vaccine requirement was higher (59 percent) among employees who had a COVID-19 vaccine themselves. Just 4 percent of workers who were not vaccinated wanted their employer to require vaccines.

[31] One important aspect, however, is that people who had left an employer over their level of precautions would not have been asked this question about the job that they left. In these cases, an individual will be asked about the precautions at their new job or, if not working, would not be asked the question at all. Nevertheless, most who changed jobs said that their new job's COVID-19 policies were no better or worse than at their previous job.

[32] The remaining 8 percent did not know if there were any requirements.

Part-Time Jobs, Temporary Jobs, and Irregular Schedules

Thirteen percent of adults worked part time at their main job, and 5 percent said that their main job was a temporary position. The share of adults who were working part time declined 1 percentage point from 2020 to 2021. Part-time work was more common among women than among men. Sixteen percent of women worked part time, while 10 percent of men did.

One indication of a stronger job market is that the share of part-time workers who said they wanted to work more hours declined to 41 percent in 2021, from 51 percent in 2020. Differences remained across the population, however. For example, a higher 58 percent of Hispanic part-time workers said that they wanted more work.

People who had a part-time or temporary job reported more financial strain than people who worked full time. Twenty-nine percent of part-time workers and 31 percent of temporary workers said that they were either just getting by or finding it difficult to get by. A smaller 16 percent of permanent, full-time workers reported the same levels of financial strain.

Some employees also had irregular schedules, including 16 percent who had a work schedule that varied based on their employer's needs. These workers with irregular schedules that they did not control tended to be under more financial strain. Twenty-seven percent of workers with a schedule that varied based on their employer's needs said that they were either just getting by or finding it difficult to get by. This compares with 16 percent of workers with a fixed schedule or with a schedule that they control.

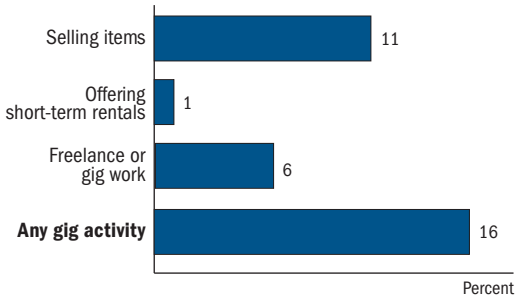
The Gig Economy

Individuals who perform gig work or other gig activities may be contributing to the economy in ways not observed through traditional employment measures. To understand this aspect of the economy, including the effects of the gig economy on household finances, the survey includes a series of questions about gig activities. Gig activities in this report include selling items at places such as flea markets and garage sales or through online marketplaces, short-term rentals of items or property, and freelance gig work such as ridesharing or other roles where people are paid for specific tasks and generally have flexibility about when and how to work.

Overall, 16 percent of adults had performed gig activities over the prior month.[33] This includes 11 percent who sold things, 1 percent who offered short-term rentals, and 6 percent doing other freelance or gig work (with some people performing more than one type of gig activity) (figure 17).

[33] It is not possible to compare how frequently people did gig activities in 2021 with prior years because the gig economy questions were revised substantially in 2021 to refine the definition of gig activities and to reduce respondent burden.

Figure 17. Gig activities performed



Note: Among all adults. Respondents could select multiple answers.

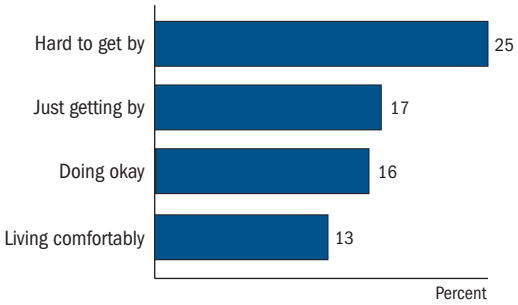
Most commonly, people sold things that they owned for personal use, like clothing. Eight percent of all adults sold a personal item in the prior month. A smaller 3 percent sold something that they purchased to resell, and 2 percent sold something that they made.

Gig activities were typically not full-time jobs. Sixty-four percent of those who performed gig activities (10 percent of all adults) said they spent less than 20 hours doing so over the prior month. That said, those doing freelance gig work were more likely than those selling or renting items to spend at least 20 hours on it over the prior month.

People performing gig activities often had another job. Over half of those performing gig activities (54 percent) also had a job working for someone else. Even among those who spent at least 20 hours on gigs, 46 percent reported that they had a job working for someone else.[34]

As a result, gig activities were rarely people's main source of income. Only 2 percent of all adults said they earned more than half of their income from gigs over the prior month. An even lower 1 percent of all adults said that they earned at least 90 percent of their income from gig activities.

Figure 18. Share performing gig activities (by financial well-being)



Note: Among all adults.

People with lower financial well-being were more likely to perform gig activities than those who were faring better financially. One-fourth of people who found it difficult to get by financially did gig activities, compared with 13 percent of those who were living comfortably (figure 18). At the same time, however, people who performed gig activities were more likely to say that they did it by choice (71 percent) than out of necessity (29 percent).

People who did freelance gig work also varied in how they felt their pay compared with what

[34] Gig questions were asked separately from the standard employment questions. One percent of all adults said that they were both not employed and spending at least 20 hours on gig activities in the prior month.

they could earn from a more traditional job. Thirty-three percent of people who did freelance gig work said that they earned more doing gig work than they could in a traditional job, while 39 percent said they earned less. The remaining 28 percent said they earned about the same amount as they could in a traditional job.

Dealing with Unexpected Expenses

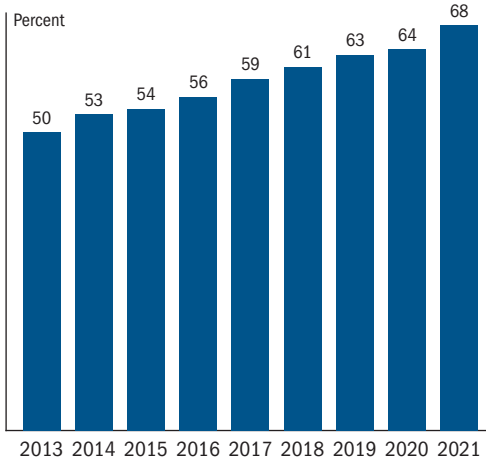
The overall share of adults who would cover a small emergency expense using cash or its equivalent increased to the highest level since 2013, when the survey began. Despite this positive trend, many still faced difficulty paying monthly bills. Black and Hispanic adults, as well as adults with lower income, disproportionately faced such challenges.

Small, Unexpected Expenses

Relatively small, unexpected expenses, such as a car repair or a modest medical bill, can be a hardship for many families. When faced with a hypothetical expense of $400, 68 percent of all adults in 2021 said they would have covered it exclusively using cash, savings, or a credit card paid off at the next statement (referred to, altogether, as "cash or its equivalent").[35] The remainder said they would have paid by borrowing or selling something, or said they would not have been able to cover the expense.

The share who would pay using cash or its equivalent was up 4 percentage points from 2020 and was at the highest level since the survey began in 2013 (figure 19). This increase is consistent with the results on overall financial well-being and may reflect improving economic conditions and the additional COVID-19 relief measures enacted in 2021.

Figure 19. Would cover a $400 emergency expense completely using cash or its equivalent (by year)

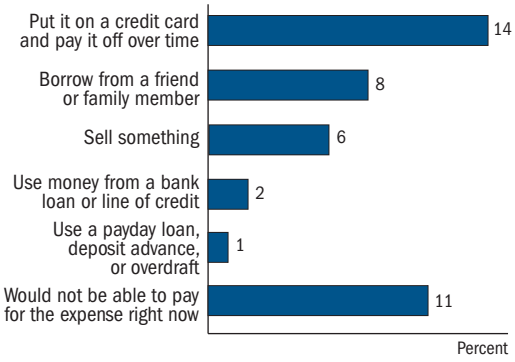


Note: Among all adults.

Like the results for overall financial well-being, parents saw a sharp increase in the share who would cover a $400 expense with cash or its equivalent—up from 56 percent in 2020 to 64 percent in 2021. Those not living with their own children under age 18 saw a smaller increase of 3 percentage points. One reason that parents experienced this sharp increase

[35] However, some who would not have paid with cash or its equivalent likely still had access to $400 in cash. Instead of using that cash to pay for the expense, they may have chosen to preserve their cash as a buffer for other expenses (See box 3 from the *Report on the Economic Well-Being of U.S. Households in 2019, Featuring Supplemental Data from April 2020* at https://www.federalreserve.gov/publications/files/2019-report-economic-well-being-us-households-202005.pdf.)

Figure 20. Other ways individuals would cover a $400 emergency expense



Note: Among all adults. Respondents could select multiple answers.

may be the expansion of the CTC. The most common way parents used their CTC payments was saving them, potentially improving their ability to handle unexpected expenses.[36]

Those who would not have covered a $400 expense completely with cash or its equivalent (32 percent of adults) may have found it more difficult to handle small, unexpected expenses. For these adults, the most common approach was to use a credit card and then carry a balance, although many indicated they would use multiple approaches (figure 20). Eleven percent of all adults said they would be unable to pay the expense by any means, similar to the 12 percent seen in 2020.

To understand more about covering household expenses, the survey asked about adults' ability to pay their monthly bills. As of October and November 2021, 24 percent of adults indicated that they had, or were close to having, difficulty paying bills for that month: 14 percent of adults had one or more bills that they were unable to pay in full, and an additional 10 percent said they would have been unable to pay their bills if faced with a $400 expense. The 24 percent having difficulty (or close to having difficulty) paying bills was down 3 percentage points from 2020 and down 4 percentage points from 2019. These declines are consistent with improvements seen in overall financial well-being.[37]

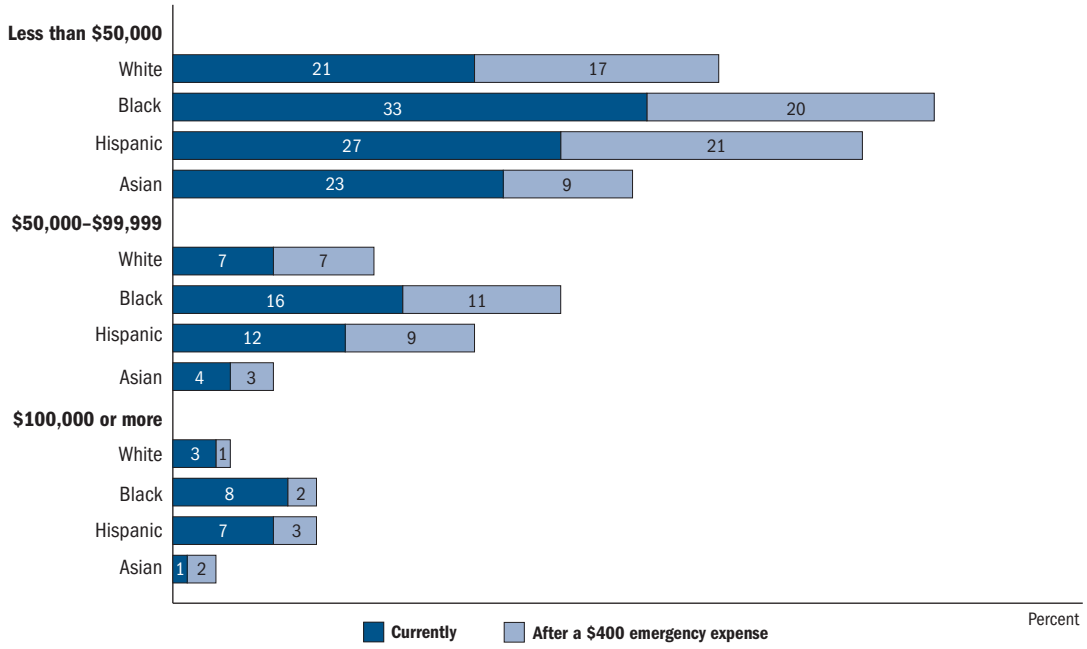
Lower-income adults were especially likely to face difficulty paying bills. Half of adults with a family income less than $25,000 had one or more bills that they were unable to pay in full that month or were one $400 financial setback away from being unable to pay them, compared with 5 percent for adults with a family income of $100,000 or more.

Black and Hispanic adults were much more likely than White or Asian adults to face difficulty paying bills, and these differences were present at all income levels (figure 21). Forty percent of Black adults and 35 percent of Hispanic adults had, or were close to having, difficulty paying bills, compared with 19 percent of White adults and 11 percent of Asian adults.

[36] More detail on the CTC is available in the "Income" section of this report.

[37] Hispanic adults and parents were two groups that experienced particularly large declines in the share facing difficulty paying bills, similar to results for financial well-being. (See the "Overall Financial Well-Being" section for results on financial well-being among Hispanics and parents.)

Figure 21. Not able to fully pay current month's bills (by income and race/ethnicity)



Note: Among all adults. Key identifies bars in order from left to right.

Looking across income levels shows that, even among adults with a family income of $100,000 or more, Black and Hispanic adults were more than twice as likely as White or Asian adults to face these challenges. Several interrelated factors, including discrimination or differences in credit access, could have contributed to the differences by race and ethnicity. (See box 2 on "Racial and Ethnic Discrimination" in the report *Economic Well-Being of U.S Households in 2020* for a discussion of discrimination, and the "Banking and Credit" section for differences in credit access.)[38]

Some financial challenges, such as a job loss, require more financial resiliency than would an unexpected $400 expense. One common measure of financial resiliency is whether people have savings sufficient to cover three months of expenses if they lost their primary source of income. In 2021, nearly 60 percent of people said they had set aside money specifically as emergency savings or "rainy day" funds, the highest share since the survey began in 2013.

For those who did not set aside money for this purpose, some would have dealt with a loss of their main source of income by borrowing, selling assets, or drawing on other savings. Fourteen percent

[38] See *Economic Well-Being of U.S Households in 2020,* May 2021, https://www.federalreserve.gov/publications/files/2020-report-economic-well-being-us-households-202105.pdf.

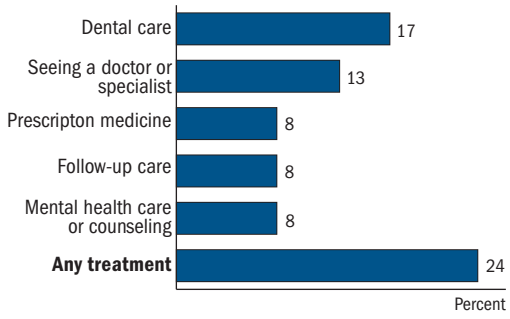
of adults said that they could have covered three months of expenses in this way. Twenty-seven percent of adults indicated they could not cover three months of expenses by any means.

Health-Care Expenses

Out-of-pocket spending for health care is a common unexpected expense that can be a substantial hardship for those without a financial cushion. As with the financial setbacks discussed earlier, many adults were not financially prepared for health-related costs at the time of the survey.

Twenty percent of adults had major, unexpected medical expenses in the prior 12 months, with the median amount between $1,000 and $1,999. Fifteen percent of adults had debt from their own medical care or that of a family member (not necessarily from the past year).

Figure 22. Forms of medical treatment skipped because of cost during 2021



Note: Among all adults. Respondents could select multiple answers.

Many went without medical care because they could not afford it. Twenty-four percent of adults went without some form of medical care because they could not pay, ticking up from 23 percent in 2020 but well below the 32 percent reported in 2013. Dental care was the most frequently skipped, followed by visiting a doctor (figure 22). Some people also reported skipping prescription medicine, follow-up care, or mental health visits.

The likelihood of skipping medical care because of cost was strongly related to family income. Among those with family income less than $25,000, 38 percent went without some medical care because they couldn't afford it, compared with 9 percent of adults making $100,000 or more.

Ability to afford health care may contribute to the finding that, as family income rises, the likelihood a person reported being in good health increases substantially. Among those in families with income less than $25,000, 75 percent reported being in good health, compared with 92 percent for those in families with income of $100,000 or more.

Health insurance is one way that people can pay for routine medical expenses and protect against the financial burden of large, unexpected expenses. In 2021, 91 percent of adults had health insurance, a slight uptick from 2020. Those without health insurance were nearly twice as likely to

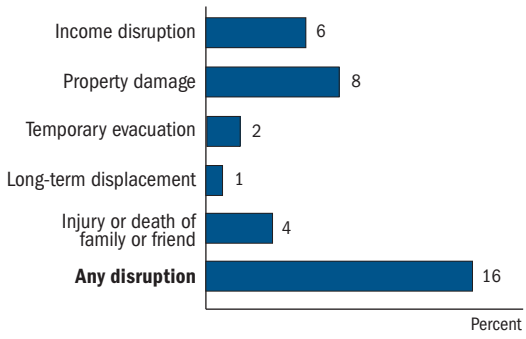
forgo medical treatment because they couldn't afford it. Among the uninsured, 40 percent went without medical treatment because they couldn't afford it, versus 22 percent among the insured.

Hardships from Natural Disasters

Those without a financial cushion may face unique and particularly severe challenges in the event of natural disasters. Natural disasters may cause disruptions to people's ability to work, damage to or displacement from their home, or higher bills for heating or cooling. These consequences all require some financial resources to manage, such as a rainy-day fund; access to credit; or support from family, friends, or the local community.

Almost one in six adults (16 percent) were directly affected by a natural disaster during the prior 12 months, meaning that they experienced one or more of the following five events as the result of a natural disaster or severe weather event: (1) an income loss or work disruption, (2) property damage, (3) a temporary evacuation, (4) longer-term displacement from home, or (5) the injury or death of a family member or close friend. The two most common ways that people were affected by natural disasters were property damage, which affected 8 percent of adults, and an income loss or work disruption, which affected 6 percent. Four percent of people had a close friend or relative who was injured or killed by a natural disaster (figure 23).

Figure 23. Disruptions from natural disasters in the prior 12 months



Note: Among all adults. Respondents could select multiple answers.

The effects from natural disasters are not uniform across segments of society. Adults with lower income or less education were more likely to be affected by natural disasters than those with higher income (table 9). Nearly 2 in 10 of those with income below $50,000 reported any disaster-related hardship.

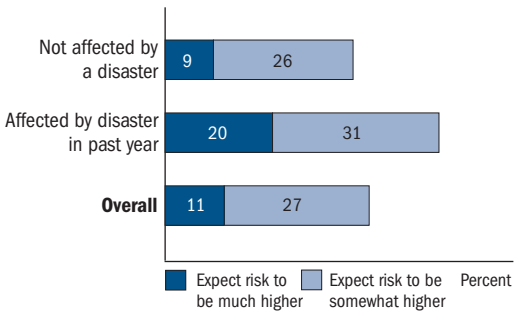
Looking at specific hardships, people with an income of less than $50,000 were more than twice as likely to experience an income loss or work disruption, longer-term displacement from home, or the injury or death of a friend or relative than someone with an income of $100,000 or more. Similar differences were observed across education levels. Black or Hispanic adults were also more likely to be affected by natural disasters than White or Asian adults, both overall and within specific income or education categories.

Table 9. Disruptions from natural disasters (by demographic characteristics)

Characteristic	Percent
Family income	
Less than $25,000	20
$25,000–$49,999	18
$50,000–$99,999	14
$100,000 or more	13
Education	
Less than a high school degree	23
High school degree or GED	15
Some college/technical or associate degree	17
Bachelor's degree or more	14
Race/ethnicity	
White	14
Black	19
Hispanic	21
Asian	15
Age	
18–29	17
30–44	17
45–59	17
60+	14
Homeownership status	
Own	15
Rent	18
Other	14
Overall	**16**

Note: Among all adults.

Figure 24. Expect risk of being affected by natural disaster to increase in the next 5 years (by whether affected in the prior 12 months)



Note: Among all adults. Key identifies bars in order from left to right.

Overall, most people did not expect their risk of experiencing a natural disaster to change in the near future. Fifty-eight percent of adults assessed their likelihood of experiencing a natural disaster in five years as "about the same" as it is currently. However, 37 percent of adults expected their risk of experiencing a natural disaster to be higher in five years, including 11 percent of adults who assessed their natural disaster risk to be "much higher." Less than 5 percent of adults expected their risk of experiencing a natural disaster to decrease.

In contrast to the overall population who expected their risk from natural disasters would be about the same in five years, most people affected by a natural disaster in the past year expected their risk of a natural disaster to be higher in five years. This includes 20 percent who expected their risk to be "much higher" (figure 24).

Some people undertook mitigation activities to reduce their risks from natural disasters. These mitigation activities differed substantially by homeownership status. Nineteen percent of renters investigated other places to live, which was about twice the rate of homeowners. Conversely, 18 percent of homeowners improved their property to mitigate the risks of disasters (figure 25).

While the risks from natural disasters appear higher for people with less education, these individuals were less likely to engage in natural-disaster mitigation activities (table 10). Twenty-two percent of renters with a bachelor's degree or more investigated other

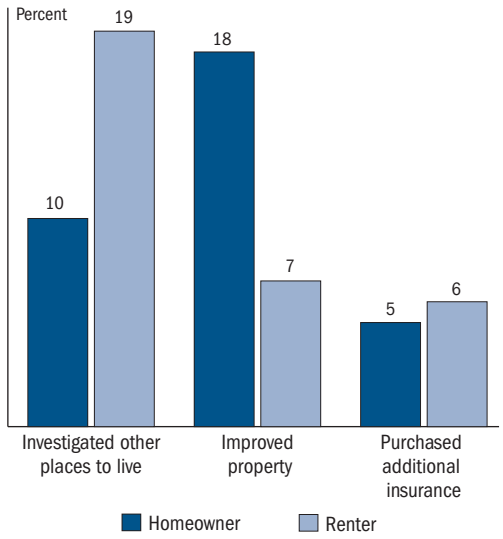
places to live in the prior 12 months because of natural disaster risks, double the 11 percent of renters with less than a high school degree who did so. Homeowners with college degrees were also more likely to improve their properties to reduce natural disaster risks than were those with less education.

Mitigation activities also differed significantly by age. Younger adults—regardless of whether they were renters or homeowners—were more likely to investigate other places to live because of natural disaster risk and more likely to invest in property improvements than older adults.

Mitigation activities were also much more common among people who expected their risk of experiencing a natural disaster to be higher in five years. Among adults who expected their natural disaster risk to be higher in five years, 28 percent of renters investigated other places to live, and 29 percent of homeowners improved their properties—each about 10 percentage points higher than the comparable rates for all renters and homeowners.

Fewer adults purchased additional insurance to mitigate their natural disaster risk compared with the other disaster mitigation activities asked about in the survey. Overall, 6 percent of renters and 5 percent of homeowners purchased additional insurance in the prior 12 months. While the rates were higher among people who expected their risk of experiencing a natural disaster to increase, they were less than 10 percent for that population.

Figure 25. Natural disaster mitigation activities (by homeownership status)



Note: Among all adults. Key identifies bars in order from left to right.

Table 10. Natural disaster mitigation activities (by homeownership status, education, and age)
Percent

Characteristic	Investigated other places to live		Improved property to reduce risk	
	Homeowner	Renter	Homeowner	Renter
Education				
Less than a high school degree	7	11	12	9
High school degree or GED	6	15	13	5
Some college/technical or associate degree	10	21	19	9
Bachelor's degree or more	11	22	20	6
Age				
18–29	15	21	20	8
30–44	12	21	18	6
45–59	10	16	17	5
60+	6	10	18	6

Note: Among all adults.

Banking and Credit

Access to financial services from banks and credit unions can be important for people's financial well-being. Most adults had a bank account and were able to obtain credit from mainstream sources in 2021, but notable gaps in access to basic financial services still exist among Black and Hispanic adults and those with low income.

Fewer applicants were denied credit in 2021, and the share of adults who were "very confident" that they would be approved for credit if they applied increased to the highest levels observed since the survey first asked this question in 2015. The use of alternative financial services such as money orders, check cashing, and payday loans was essentially unchanged after a years-long decline.

Unbanked and Underbanked

Most adults in the United States (81 percent) were "fully banked," meaning that they had a bank account and, in the past 12 months, did not use any of the alternative financial services asked about in the survey. Such services include money orders, check cashing services, payday loans or payday advances, pawn shop loans, auto title loans, and tax refund advances.

An additional 13 percent had a bank account but also made use of alternative financial services. These adults are considered "underbanked" because the banking services they accessed appear to have been insufficient to meet their financial service needs.

The rest of the adult population (6 percent) did not have a bank account. Less than half of these "unbanked" adults used alternative financial services.

Unbanked and underbanked rates were higher among adults with lower income, adults with less education, and Black and Hispanic adults. The largest differences were by education and income level. Twenty-four percent of adults with less than a high school degree, and 17 percent of adults with income below $25,000, were unbanked (table 11). The share of people with income under $25,000 without a bank account far exceeded that of the two highest income levels. As a result, 79 percent of all unbanked adults had income below $25,000, and 91 percent had income below $50,000.

Adults with less education and adults with lower income were also more likely to be underbanked. Nearly one-fourth of those with less than a high school degree and 20 percent of those with

Table 11. Banking status (by family income, education, and race/ethnicity)
Percent

Characteristic	Unbanked	Underbanked	Fully banked
Family income			
Less than $25,000	17	20	62
$25,000–$49,999	4	20	76
$50,000–$99,999	1	12	87
$100,000 or more	1	5	94
Education			
Less than a high school degree	24	23	53
High school degree or GED	10	15	75
Some college/technical or associate degree	5	17	79
Bachelor's degree or more	1	7	92
Race/ethnicity			
White	3	10	87
Black	13	27	59
Hispanic	11	18	71
Asian	2	6	92
Overall	**6**	**13**	**81**

Note: Among all adults.

income less than $25,000 were underbanked. In addition to being more likely to use alternative financial services, lower-income adults were also more likely to use cryptocurrencies for transaction purposes, as discussed in box 2.

Between 2020 and 2021, the shares of unbanked, underbanked, and fully banked adults were essentially unchanged. Looking at the longer-term trend, however, shows a 7 percentage point decline in the underbanked rate since 2015. During this same period, the share of adults with a bank account increased by 2 percentage points. As a result, much of the decline in the underbanked rate likely reflects the decline in the share using the alternative financial services asked about in the survey.

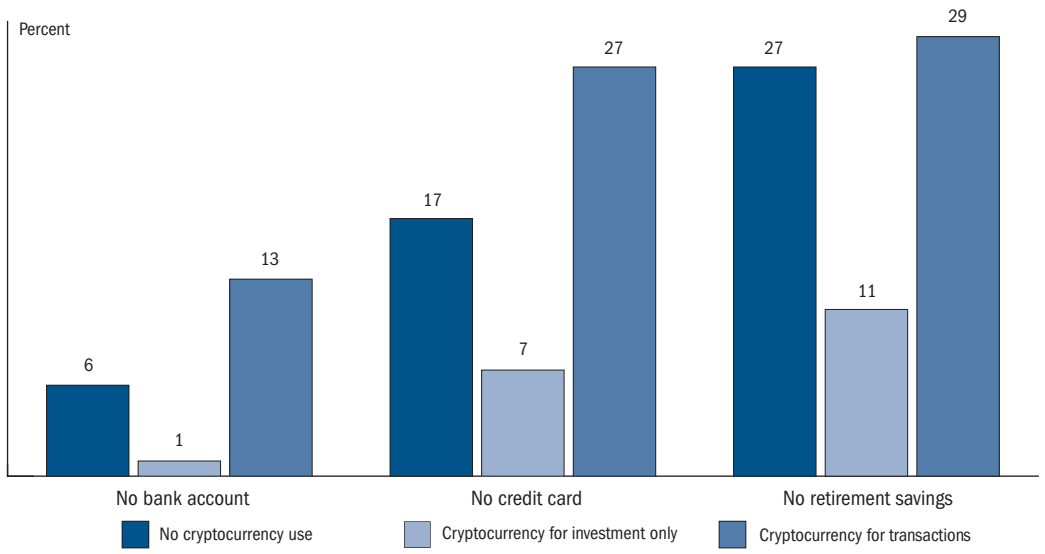
This decline does not necessarily reflect improvements in financial inclusion, however. The market for financial products and services has been evolving during this time, particularly in the digital space. As a result, while use of these alternative financial services have declined, people may have substituted away from the products and services asked about in the survey to other nonbank offerings that are harder to measure.

Box 2. Conducting Financial Transactions Using Cryptocurrencies

Cryptocurrencies are relatively new digital assets that may be held as an investment or used for conducting financial transactions.[1] In 2021, most people using cryptocurrencies did so for investment purposes. In 2021, 12 percent of adults held or used cryptocurrencies in the prior year. Eleven percent of adults had held cryptocurrency as an investment, while a far smaller 2 percent of adults said that they used cryptocurrency to buy something or make a payment in the prior 12 months, and 1 percent used it to send money to friends or family.[2]

Those who held cryptocurrency purely for investment purposes were disproportionately high-income, almost always had a traditional banking relationship, and typically had other retirement savings. Forty-six percent of those using cryptocurrencies only for investment had an income of $100,000 or more, while 29 percent had an income under $50,000. Additionally, 99 percent of those investing in cryptocurrency, but not using it for transactions, had a bank account, and 89 percent of nonretired cryptocurrency investors had at least some retirement savings (figure A).

Figure A. Share without a bank account, credit card, or retirement savings (by cryptocurrency use)



Note: Among all adults. Key identifies bars in order from left to right.

(continued)

[1] Cryptocurrencies are decentralized digital assets that have a distributed ledger and can be used for peer-to-peer payments. For additional information on cryptocurrencies, see Board of Governors of the Federal Reserve System, *Money and Payments: The U.S. Dollar in the Age of Digital Transformation* (Washington: Board of Governors, January 2022), https://www.federalreserve.gov/publications/files/money-and-payments-20220120.pdf.

[2] Because the survey is conducted online, the sample population may be more technologically connected than the overall population, which could increase the share of adults reporting use of emerging technologies such as cryptocurrencies.

Box 2—*continued*

The financial profiles of those who used cryptocurrency for transactions, however, were quite different. Nearly 6 in 10 adults who used cryptocurrencies for transactions had an income of less than $50,000. A far lower 24 percent of transactional users had an income of more than $100,000.

Transactional cryptocurrency users also were less likely to have a bank account. Thirteen percent of those who used cryptocurrency for transactions lack a bank account, compared with 6 percent of adults who did not use cryptocurrency. Similarly, 27 percent of transactional cryptocurrency users did not have a credit card, exceeding the 17 percent of non-users without a credit card.

Moreover, the longer-term decline in use of alternative financial services has been similar among both the unbanked and banked, providing more evidence that a wider availability of banking services may not explain the decline in the underbanked rate.

Table 12. Paid an overdraft fee on a bank account in the prior year (by demographic characteristics)

Characteristic	Percent
Family income	
Less than $25,000	16
$25,000–$49,999	16
$50,000–$99,999	10
$100,000 or more	5
Education	
Less than a high school degree	16
High school degree or GED	11
Some college/technical or associate degree	13
Bachelor's degree or more	7
Race/ethnicity	
White	9
Black	20
Hispanic	14
Asian	3
Age	
18–29	15
30–44	14
45–59	10
60+	5
Overall	**11**

Note: Among adults with a bank account.

Overdraft

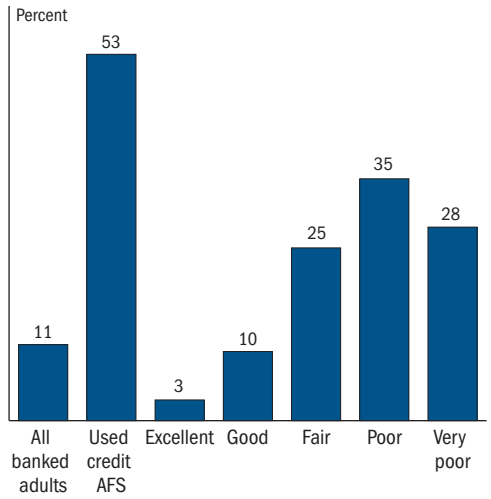
Overall, 11 percent of adults with a bank account paid an overdraft fee in the previous 12 months (table 12). Adults with income less than $50,000 were three times as likely to have paid an overdraft fee as people with an income of $100,000 or more. Similarly, the share of adults paying an overdraft fee tended to be higher among people with less education or of younger ages. Across races or ethnicities, a larger share of Black or Hispanic adults paid an overdraft fee in the past 12 months than the population as a whole. In contrast, 3 percent of Asian adults paid an overdraft fee, a rate about one-third of the population as a whole.

Adults with bank accounts who used credit alternative financial services and those with lower self-reported credit ratings were particularly likely to have paid an overdraft fee in the prior year.[39] Fifty-three percent of banked adults who used credit alternative financial

[39] Credit alternative financial services include payday loans or payday advances, pawn shop loans, auto title loans, and tax refund advances.

services also paid an overdraft fee in the prior 12 months, about five times the rate of the banked population overall (figure 26).[40] Additionally, 35 percent of those rating their credit as "poor" and 28 percent rating their credit as "very poor" paid an overdraft fee, compared with 3 percent of those rating their credit as "excellent."

Figure 26. Paid an overdraft fee on a bank account in the prior year (by use of credit alternative financial services (AFS) and self-reported credit rating)



Note: Among adults with a bank account.

One explanation for these patterns is that those using credit alternative financial services and those rating their credit as "poor" or "very poor" were in a precarious financial position, making them more likely to unintentionally overdraft their account. Another possibility is that people without access to cheaper forms of credit were intentionally using overdraft as a form of short-term, albeit high-cost, credit. Finally, use of online credit alternative financial services themselves may directly trigger an overdraft when the lender attempts to collect payment.[41]

Credit Outcomes and Perceptions

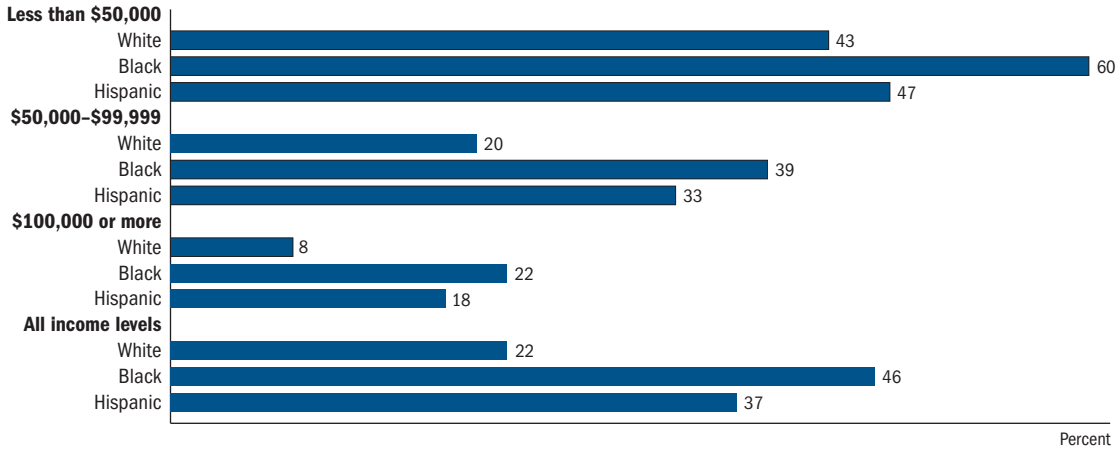
Thirty-eight percent of adults applied for credit in 2021, a slight increase over the share who applied in 2020. But among those who applied, the share who were either denied credit, or approved for less credit than they requested, fell about 3 percentage points to 28 percent. Consistent with the lower denial rates, consumer confidence about credit card applications improved. Sixty-five percent of adults were "very confident" that their application would be approved, 4 percentage points higher than in 2020 and the highest share since this question was first asked in 2015. Similarly, only 12 percent of adults were "not confident" that their application would be approved.

The share of adults who were denied credit, or approved for less than requested, differed by income level and by race and ethnicity (figure 27). Almost half of credit applicants with income below $50,000 experienced such actions, compared with 11 percent of those with income above $100,000.

[40] Overall, 4 percent of adults had a bank account and used credit alternative financial services.

[41] See Consumer Financial Protection Bureau, *Online Payday Loan Payments* (Washington: CFPB, April 2016), https://files.consumerfinance.gov/f/201604_cfpb_online-payday-loan-payments.pdf.

Figure 27. Denied credit or approved for less than was requested (by family income and race/ethnicity)



Note: Among adults who applied for some form of credit in the past 12 months.

Denial rates also differed by race and ethnicity, with Black and Hispanic applicants being particularly likely to report a denial or an approval for less credit than requested. For Black applicants, this was also true within income levels, although for Hispanic applicants with income below $50,000, the denial rates were comparable to others with similar incomes.

Credit Cards

People use credit cards in different ways. Some use credit cards as a convenient, if not necessary, way to pay expenses, paying off their balances in full each month and avoiding any interest costs. Others carry a balance and thus use credit cards as a source of credit to defer paying expenses.

Eighty-four percent of adults had a credit card in 2021. They were nearly evenly split between the people who paid off their balances in each of the previous 12 months and people who carried balances from month to month at least once in the prior year. Among those who carried a balance at least once, 73 percent were carrying a balance at the time of the survey.

Almost all people with income of at least $100,000 had a credit card. At lower income levels, having a credit card was somewhat less common, though adults at these income levels who did have credit cards were more likely to use them to carry balances from month to month. Consequently, middle-income adults were the most likely to have a credit card that they used to finance purchases by carrying balances from one month to the next. Almost half of people with income between $25,000 and $99,999 carried a balance on a credit card at least once in the past

12 months, exceeding the shares of adults with either lower or higher income levels who did so (table 13).

Similar patterns were observed across education levels, with more-educated adults being both more likely to have a credit card and less likely to carry a balance from one month to the next. Credit card usage also differed by race and ethnicity. Over 90 percent of Asian adults had a credit card but just under one in four of those with a credit card carried a balance at least once in the prior 12 months. Black and Hispanic adults were much more likely to carry balances on their credit cards than other racial or ethnic groups.

The share of adults with outstanding debt who were carrying less debt than 12 months ago was comparable with, though slightly higher than, the share carrying more debt. This pattern is similar to that in recent years, with the exception of 2020, when the share who had reduced their credit card debt exceeded the share who had increased it by 8 percentage points.

Table 13. Credit card access and usage (by demographic characteristics)
Percent

Characteristic	Has a credit card	Carried a balance (among credit card holders)	Carried a balance (among adults)
Family income			
Less than $25,000	57	57	33
$25,000–$49,999	84	59	49
$50,000–$99,999	94	50	47
$100,000 or more	98	36	36
Education			
Less than a high school degree	52	57	30
High school degree or GED	76	57	43
Some college/technical or associate degree	83	56	46
Bachelor's degree or more	96	35	34
Race/ethnicity			
White	88	42	37
Black	72	72	52
Hispanic	77	63	48
Asian	93	24	22
Self-reported credit rating			
Very poor	33	66	22
Poor	45	77	35
Fair	73	81	59
Good	90	65	58
Excellent	97	31	31
Don't know	40	39	16
Overall	**84**	**48**	**40**

Note: Among all adults. Carried a balance in the prior 12 months includes adults who carried an unpaid balance from one month to the next at least once in the 12-month period.

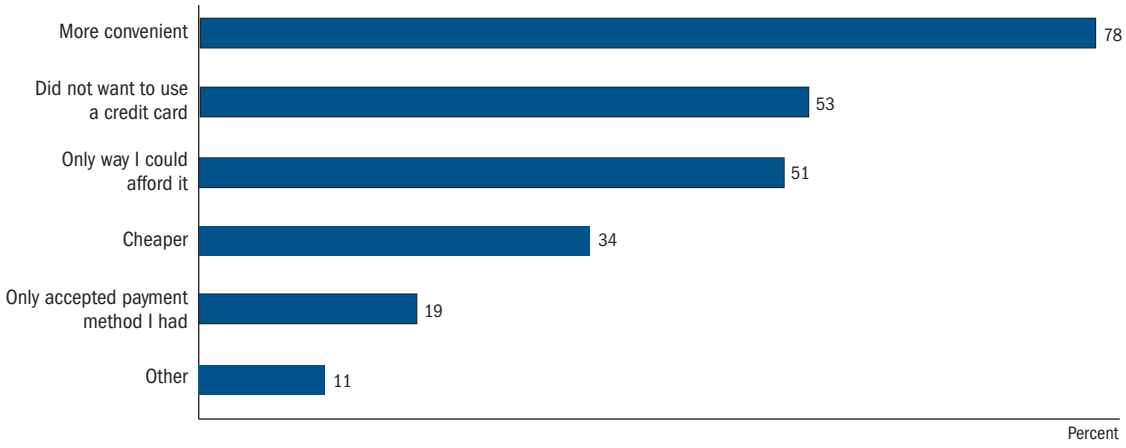
Buy Now, Pay Later

The 2021 survey introduced a series of questions about the use of BNPL services. BNPL allows people to finance a purchase by making a small number of equal payments, often without being charged interest. For example, someone purchasing a $100 item, instead of paying the entire amount upfront, may instead be able to make four monthly payments of $25, with the first payment due at the time of purchase.

Overall, 10 percent of people used a BNPL service in the previous 12 months. Seven percent were making payments under a BNPL plan at the time of the survey, with about half paying on just one purchase.

The most cited reasons for using BNPL services were convenience (78 percent) and not wanting to use a credit card (53 percent) (figure 28). Just over half of people who used BNPL also indicated that it was the only way they could afford their purchase (51 percent).

Figure 28. Reasons for using Buy Now, Pay Later (BNPL) services



Note: Among adults who have used a BNPL service in the past year.

The use of BNPL was more common among people with lower income and less education (table 14). Around 13 percent of those with income below $50,000 used BNPL in the prior year, compared with 7 percent of those with an income of $100,000 or more. Similarly, 14 percent of people with less than a high school degree used BNPL, compared with 8 percent of those with at least a bachelor's degree.

The reasons for using BNPL also differed with income and education levels. While convenience was universally the most cited reason for using BNPL, around 60 percent of people with income under $50,000 or with no more than a high school degree cited an inability to pay for the product otherwise, compared with about one-fourth of people whose income was at least $100,000. Moreover, around 25 percent of people in these lower income and education groups reported using BNPL because they lacked another accepted payment option, more than twice the rate for people in the highest income and education categories.

People also differed in their use of BNPL according to their self-reported credit rating. Those with lower credit ratings were more likely to use BNPL than were people who rated their credit as "excellent." Among those who used BNPL, adults with lower self-reported credit ratings were also more likely to cite an inability to afford the purchase otherwise or a lack of other payment options as reasons for using BNPL than adults who rated their credit higher.

Most people who use BNPL make their payments on time. Overall, 15 percent of people who used BNPL in the prior 12 months were late making a payment. Late payments were somewhat more common among people with income less than $50,000. Late payments were also more common among people with lower self-reported credit ratings. Adults who rated their credit as "poor" were over five times as likely to have been late making a BNPL payment as someone who rated their credit as "excellent." Among people who would not have been able to afford their purchase without BNPL, 23 percent paid late, compared with 7 percent of people who did not give that reason for using BNPL.

Table 14. BNPL service use (by demographic characteristics)
Percent

Characteristic	Used a BNPL service	Paid BNPL late (among users)
Family income		
Less than $25,000	12	23
$25,000–$49,999	14	18
$50,000–$99,999	11	11
$100,000 or more	7	6
Education		
Less than a high school degree	14	n/a
High school degree or GED	10	15
Some college/technical or associate degree	12	17
Bachelor's degree or more	8	10
Race/ethnicity		
White	7	10
Black	20	21
Hispanic	15	19
Asian	7	n/a
Age		
18–29	13	18
30–44	13	18
45–59	12	13
60+	6	9
Credit card ownership		
Has a credit card	10	14
No credit card	10	23
Self-reported credit score		
Very poor	13	n/a
Poor	21	29
Fair	22	13
Good	12	13
Excellent	5	5
Don't know	6	n/a
Overall	**10**	**15**

Note: Among all adults. Some results are not applicable because of small sample size.
n/a Not applicable.

Housing

Housing—especially the cost of housing and housing tenure type—affects people's economic well-being. The majority of adults owned their homes. Adults who rented their homes were disproportionately lower-income, Black, or Hispanic. The share of renters who had been behind on their rent in the prior 12 months was higher than the level before the pandemic. Among homeowners, the refinancing wave continued, although high-income borrowers were primarily the beneficiaries of this opportunity.

Living Arrangements

Living arrangements can affect family finances and well-being. Eighty-six percent of adults lived with other people, usually a spouse or a partner and frequently their children under age 18 (table 15). More than half (52 percent) of all adults lived in a household with a spouse or partner or with a child under age 18 and with no one else. Other types of living arrangements were less common. Still, more than one-fourth of adults (28 percent) lived in a household that contains multiple generations of adults, meaning that the adult respondents either lived with their parents or adult children.

Table 15. Other people living in household

Category	Percent
Live alone	14
Spouse or partner	66
Children under age 18	25
Adult children age 18 or older	16
Parents	13
Brothers or sisters	6
Other relatives	4
Other non-relatives	5

Note: Among all adults. Respondents (other than those who live alone) can select multiple answers.

Older adults, and older women in particular, were the most likely to live alone. Twenty-one percent of adults age 65 or older lived alone, and 27 percent of women age 65 or older lived alone. In contrast, young adults were very likely to live with their parents. But this rate drops significantly for adults in their mid- and late 20s: 47 percent of 22- to 24-year-olds lived with their parents compared with 27 percent of 25- to 29-year-olds. Fewer adults in older age cohorts live with their parents: 13 percent of 30- to 44-year-olds live with their parents and 7 percent of 45- to 59-year-olds live with their parents. Conversely, the share living with a spouse or partner increased with age, from 26 percent of 22- to 24-year-olds to 52 percent of 25- to 29-year-olds.[42]

[42] Among adults ages 22 to 24, the majority of those living with a spouse or partner are not married, and a smaller share are married. For the older age groups, the majority of adults living with a spouse or partner are married.

Table 16. Reasons for living with parents (by age)

Reason	22–24	25–29	30–44	45–59
To save money	92	88	63	48
To help them financially	31	44	57	61
To provide help with childcare or medical care	7	15	27	45
To receive help with childcare or medical care	13	16	20	15
Prefer living with others	46	40	36	23

Note: Among people living with parents. Respondents could select multiple answers.

A substantial majority of young adults living with their parents said that saving money was a reason for their living arrangement. Overall, three-fourths of people who lived with their parents said this was to save money. However, the direction of financial support flips for many older adults who live with their parents. Fifty-seven percent of adults ages 30 to 44 who lived with their parents said that providing financial help was a reason, as did 61 percent of those ages 45 to 59 (table 16).

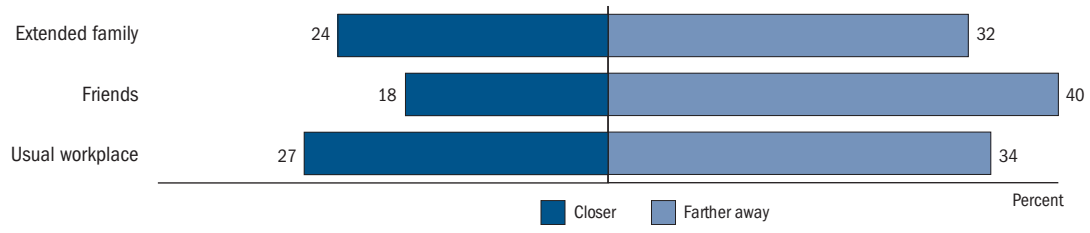
Another common reason for living with parents was to provide care, especially as people get older. Twenty-one percent of people who lived with their parents gave this reason. Adults in their 30s, 40s, and 50s who lived with their parents were more likely to say that they lived with others for caregiving reasons. Forty-five percent of 45- to 59-year-olds who lived with their parents said they lived with others to provide care.

Moving

The share of people who reported moving in 2021 was unchanged from 2020. Nine percent of adults said they moved to their home in 2021. The majority of individuals who moved remained in the same state. Just over one in four adults who moved—2 percent of all adults—crossed state lines in 2021.

Moving was generally associated with an increasing distance from family, friends, and other informal supports. Thirty-two percent of people who moved in 2021 said they moved farther away from family, while 24 percent said they moved closer (figure 29). Forty percent of adults who

Figure 29. Distance to friends, families, and workplaces after moves



Note: Among people who moved in 2021. Distance relative to one's usual workplace is among employed adults. Key identifies bars in order from left to right.

moved said they moved farther from friends. Another moving pattern that continued in 2021 was employed adults moving farther away from their usual workplace. Thirty-four percent of movers who were employed moved farther away from their usual workplace compared with 27 percent who moved closer.

Homeownership and Mortgages

Nearly two-thirds of adults owned their homes, though young adults, as well as Black and Hispanic adults, were less likely to own. Twenty-nine percent of 18- to 29-year-olds owned their homes, compared with 84 percent of people age 60 and older. Within each age group, there is substantial variation in the homeownership rate by race and ethnicity. For example, 4 in 10 Black adults and nearly 5 in 10 Hispanic adults ages 30 to 44 were homeowners. Among White adults in this age range, nearly 7 in 10 owned their home (table 17).

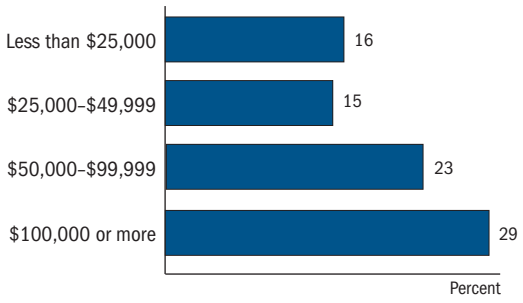
Table 17. Homeownership rate (by age and race/ethnicity)

Characteristic	Percent
18–29	
White	35
Black	18
Hispanic	20
Asian	34
Overall	**29**
30–44	
White	69
Black	40
Hispanic	49
Asian	71
Overall	**61**
45–59	
White	83
Black	57
Hispanic	63
Asian	90
Overall	**76**
60+	
White	88
Black	68
Hispanic	78
Asian	78
Overall	**84**

Note: Among all adults.

Many homeowners took advantage of the continued low interest rates in 2021 to refinance their mortgages. Nearly one-fourth of all homeowners with a mortgage refinanced their mortgage within the prior year. Higher-income homeowners were the predominant group who opted to refinance (figure 30).[43] Nearly 3 in 10 mortgage holders with income of at least $100,000 per year refinanced within the prior 12 months, compared with 23 percent of those with income between $50,000 and $99,999 and 16 percent of those with income under $50,000.

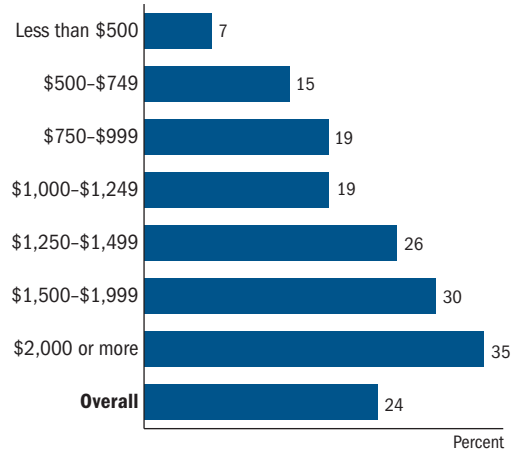
Figure 30. Share of homeowners with a mortgage who refinanced in the prior year (by family income)



Note: Among homeowners with a mortgage.

[43] This fact holds when considering individuals who refinanced in 2020 as well. Among those who have refinanced in the past two years, high-income (those with an income of $100,000 or more) homeowners with a mortgage were about twice as likely to have refinanced as those with an income of less than $50,000.

Figure 31. Share of homeowners with a mortgage who refinanced in the prior year (by current month mortgage payment)



Note: Among homeowners with a mortgage.

Mortgage holders with a higher mortgage payment were also more likely to have refinanced during the prior year. More than one-third (35 percent) of homeowners with a monthly mortgage payment of $2,000 or more refinanced, compared with 15 percent of homeowners with a monthly payment from $500 to $749 (figure 31).[44]

Renting and Evictions

More than one in four adults rent their home (27 percent). Benefits of renting include the flexibility to move more easily as well as the convenience of not having to manage repairs. But renting can also lead to less-stable living arrangements and less control over living spaces and repairs. Many renters do not own their home because of financial circumstances. (See box 3 for a discussion of renters who fell behind on rent during the pandemic.)

Adults with lower income, and those who are Black and Hispanic, are more likely to rent their homes. Forty-five percent of adults with a family income of less than $25,000 rent, compared with 10 percent of adults with family income of $100,000 or more (table 18). Forty-four percent of Black adults and 37 percent of Hispanic adults rent, compared with 21 percent of White adults and 23 percent of Asian adults.

Housing tenure varies by other demographic characteristics, including disability status and neighborhood income. Adults with a disability had a greater likelihood of being renters than adults with no disability. Forty-four percent of adults who live in low- and moderate-income neighborhoods rent. This is over twice the rate among adults who live in middle- and upper-income neighborhoods.

[44] While families with more income have higher mortgage payments on average, the increased prevalence of refinancing among those with higher mortgage payments holds even when controlling for income. In part, this may reflect that the potential savings from refinancing are greater for those with larger loans.

Renters with lower family income were frequently cost burdened, meaning that they spent more than 30 percent of their income on rent payments.[45] About half of renters with income between $25,000 and $49,999 had rent payments that exceeded 30 percent of their income.

Reflecting the flexibility that comes with renting, most people who moved were renters. Almost three-fourths of people who moved in the prior year did not own their home before the move. In general, these moves were to another rental, rather than a home purchase—just 26 percent of those who did not own their previous house and moved in the past year did so for a home that they purchased.

Some of these moves, however, resulted from an eviction. Slightly fewer than 1 percent of adults, which is about 1.8 million people, said they moved in the prior year because of an eviction or the threat of an eviction.[46] This represents approximately 8 percent of all people who moved during this period.

Table 18. Share who rent (by demographic characteristics)

Characteristic	Percent
Family income	
Less than $25,000	45
$25,000–$49,999	36
$50,000–$99,999	24
$100,000 or more	10
Race/ethnicity	
White	21
Black	44
Hispanic	37
Asian	23
Disability status	
Disability	36
No disability	24
Metro status	
Metro	28
Non-metro	21
Neighborhood income	
Low or moderate income	44
Middle or upper income	21
Overall	**27**

Note: Among all adults.

[45] Cost burdened is defined using the midpoint of both the monthly rent payment range and the family income range and comparing the ratio to the 30 percent threshold. The Department of Housing and Urban Development has established this "cost burdened" threshold of 30 percent. For details, see U.S. Department of Housing and Urban Development, "Rental Burdens: Rethinking Affordability Measures," https://www.huduser.gov/portal/pdredge/pdr_edge_featd_article_092214.html.

[46] In this report, people who experienced an eviction or the threat of eviction include those who reported they were evicted or received an eviction notice; had a landlord tell them or a person they were staying with to leave; missed a rent payment and thought they would be evicted; or were living in a property that was condemned by the city, forcing them to leave.

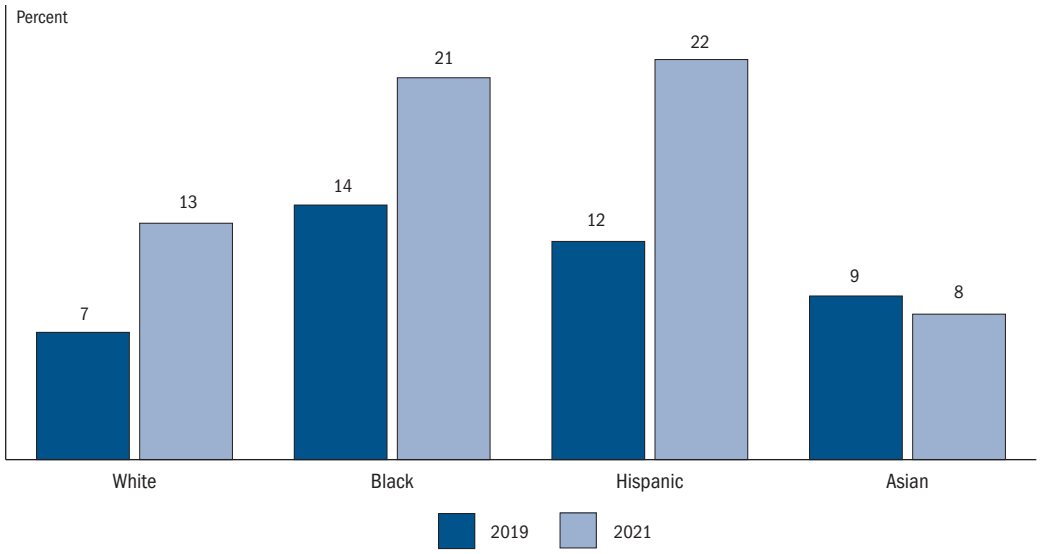
Box 3. Pandemic's Effect on Rent Payment

Many renters faced challenges paying their rent before the pandemic, but in the fall of 2021, after nearly two years of economic disruptions from the pandemic, a higher share of renters reported they had been behind on their rent in the prior 12 months. Moreover, many still owed back rent despite a variety of government supports including unemployment benefits, stimulus checks, and rental assistance.

More renters were behind on rent in 2021 than before the pandemic. When asked about their rent payments before the pandemic, 10 percent of renters reported they had missed a payment at some point in 2019.[1] In the fall of 2021, a higher 17 percent of renters reported they had been behind on their rent in the prior 12 months.

The pandemic increased the share of renters who were behind on rent for most racial and ethnic groups. When compared with pre-pandemic levels, White, Black, and Hispanic renters all saw increases in the share behind on rent sometime in the prior 12 months (figure A).

Figure A. Share of renters behind on rent during the year (by year and race/ethnicity)



Note: Among renters. Key identifies bars in order from left to right.

Black renters and Hispanic renters were more likely to be behind on rent payments, compared with other renters. This disparity was present in 2019 and persisted through the pandemic. In 2021, over one in five Black renters and Hispanic renters said they had been behind on rent in the prior year.

(continued)

[1] This question was asked of renters in 2021 about their rent payments in 2019. It was not asked on the 2019 survey.

Box 3—*continued*

Layoffs during the pandemic likely contributed to difficulty paying rent. Among renters who were laid off in the prior 12 months, 38 percent were behind on rent, compared with 15 percent of renters who were not laid off. Differences in layoffs by race and ethnicity may contribute to differences in being behind on rent since layoffs were more common for Black and Hispanic renters than other renters in 2020 and 2021.

Low-income renters were also hit particularly hard by the pandemic recession. The share of adult renters with income below $50,000 reporting being behind on rent increased from 12 percent in 2019 to 23 percent in 2021. For renters with income of $50,000 or more, a smaller 6 percent reported in the fall of 2021 that they had been behind on rent in the prior 12 months—similar to the 5 percent who said they were behind in 2019.

Many renters who fell behind during the year still carried rental debt as of late 2021. Forty-five percent of renters who were behind on their rent at some point in 2021 said that they still owed money for back rent or fees at the time of the survey. This represents 8 percent of renters (2 percent of adults) who still owed back rent or fees in late 2021. For this group of renters, the mean amount still owed was $2,064 and the median was $1,200. This mean amount of back rent suggests total estimated back rent for all renters as of late 2021 was between $9.3 and $10.9 billion.[2] These estimates are lower than October 2021 estimates from the Federal Reserve Bank of Philadelphia ($16.8 billion) and Moody's Analytics and the Urban Institute ($16.7 billion).[3]

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[2] These estimates are for adults who are renters. Because respondents who were married could have given the amount of back rent for their household, or just their individual share, the lower estimate divides the amount of back rent in half for married couples to account for married respondents who may have answered for their household rather than for just themselves.

[3] The Federal Reserve Bank of Philadelphia's estimate comes from a model simulating job loss and calculates total back rent for renters who experienced a job loss during the pandemic (Federal Reserve Bank of Philadelphia, *Household Rental Debt during COVID-19: Update for August 2021* (Philadelphia: FRB Philadelphia, July 2021), https://www.philadelphiafed.org/-/media/frbp/assets/community-development/briefs/updatedhouseholdrentdebt-final.pdf). Moody's Analytics and Urban Institute's estimate comes from Moody's baseline economic forecast and calculates back rent for all renters, including those without a job loss during the pandemic (Jim Parrott and Mark Zandi, "The Race to Save Millions from Eviction," Urban Institute, September 2021, https://www.urban.org/sites/default/files/publication/104762/the-race-to-save-millions-from-eviction.pdf). In contrast, the SHED estimates rely on survey questions that ask directly about the amount of back rent owed.

Education

Education is widely recognized as a path to higher income and greater financial well-being. The pandemic brought widespread education disruptions, including school closures for students of all ages in 2020. In 2021, K–12 schools largely returned to in-person education. At the time of the survey, most parents of primary or secondary school students reported that their youngest child was attending classes completely in person.

This shift to in-person learning likely reduced childcare responsibilities, and most parents said they preferred in-person classes over online or hybrid options. However, potentially reflecting ongoing concerns about COVID-19 transmission, some parents whose children were attending school in person in the fall of 2021 would have preferred online or hybrid classes for their child.

In contrast to the experience of K–12 students, online education remained prevalent at higher education institutions in the fall of 2021. Most higher-education students preferred at least some online classes.

Modes of Learning in Primary and Secondary School

In the fall of 2021, most parents of primary and secondary school students said their children had returned to completely in-person education after the widespread reliance on online learning in 2020.[47] At the time of the survey, 93 percent of parents with children in school said their youngest child enrolled in K–12 education was attending classes completely in person, compared to 27 percent with completely in-person classes in 2020.

Even among children attending school in person, however, disruptions occurred because of the pandemic. Over one-fourth (27 percent) of parents whose youngest child's classes were completely in person said that at least once, since the start of the school year, their child was unable to attend in person because of a pandemic-related disruption. For 7 percent of parents whose child's classes were completely in person, a disruption to in-person schooling led them to work fewer hours or take unpaid leave from work.

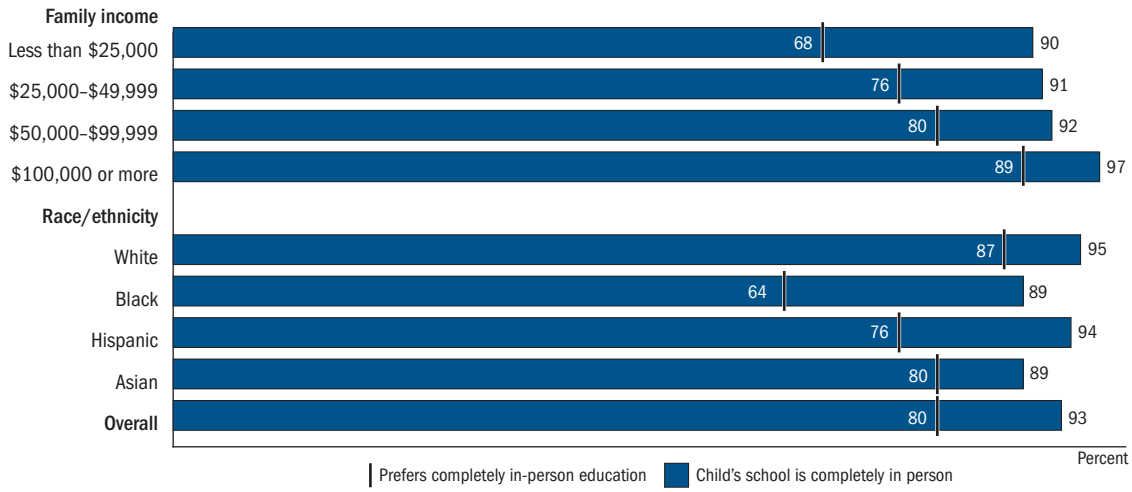
Though nearly all parents of K–12 students said that their child's classes were in person, lower-income parents were less likely to report in-person K–12 education than higher-income parents. Ninety percent of parents making less than $25,000 per year said that their child's classes were

[47] References to a child's education in this section refer to the individual's youngest school-age child. Parents of school-age children are respondents who lived with their own children under age 18 who were enrolled in a public or private K–12 school. Except where specified, parents who only home-school their children are excluded.

in person, compared with 97 percent of parents making $100,000 or more per year. Additionally, Black and Asian parents were less likely to say their child was attending school in person than White and Hispanic parents.

However, preferred modes of education also varied by income and race. Nearly 9 in 10 parents of school-age children with an annual income of $100,000 or more said they prefer completely in-person education, compared with fewer than 7 in 10 parents with an annual income under $25,000. Eighty-seven percent of White parents with school-age children said they prefer completely in-person education, higher than that seen among Black, Hispanic, or Asian parents (figure 32).

Figure 32. Actual and preferred mode of learning for K–12 (by income and race/ethnicity)



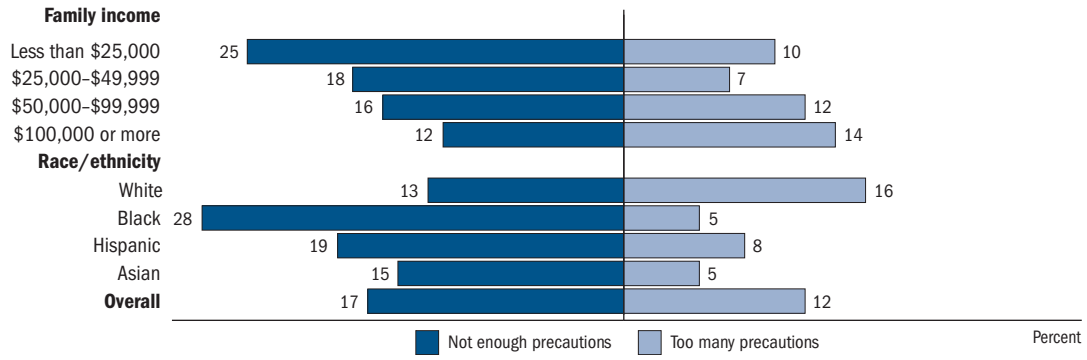
Note: Among parents with a child enrolled in public or private school. Based on the youngest child enrolled in public or private school who lives with their parent.

Additionally, parents' preferred mode of learning differed by the type and level of the school. Parents of children in public school were less likely (80 percent) than parents of children in private school (89 percent) to prefer completely in-person education, and parents whose youngest child is in middle or high school were less likely (76 percent) to prefer in-person class than parents with children in elementary school (84 percent).

Most parents (72 percent) felt that their child's school was taking the right level of COVID-19 precautions. Of those who did not, slightly more felt that the school was taking too few precautions (17 percent) than too many (12 percent). This is consistent with the observation that a larger share of students had in-person education than parents preferred.

Parents' views on the precautions taken by their children's schools varied along similar lines to their preferences for in-person education. Low-income parents were more likely than high-income parents to say their child's school was not taking enough precautions in light of the pandemic, and Black parents were over twice as likely as White parents to say this (figure 33).

Figure 33. Parents' views on precautions taken by child's school (by income and race/ethnicity)



Note: Among parents with a child enrolled in public or private school. Based on the youngest child enrolled in public or private school who lives with their parent. Key identifies bars in order from left to right.

Parents of children in public school were also more likely (18 percent) than those with children in private school (9 percent) to say their child's school was not taking enough precautions. However, parents' opinions on precautions at school did not vary by the age of their youngest child.

Some parents opted to home school their children in 2021. Just under 1 in 10 parents of school-age children said that one of their children was home schooled and not enrolled in public or private school. For most home-schooling parents, this was not because of COVID-19. Fifty-three percent said that COVID-19 concerns and school safety policies did not contribute to the decision. This is consistent with observations from other data that about half of the current rate of home schooling predated the pandemic.[48]

Of those who home schooled their children for COVID-19-related reasons, most did so because of concerns about exposure at school. Thirty-seven percent of parents who home school at least one child said they do so in part because of concern about COVID-19 exposure at school.

[48] The Census Household Pulse Survey indicates that, by the fall of 2020, the share of households with school-age children who home school their children was around 11 percent—about double the share who home schooled at the start of the pandemic. See https://www.census.gov/library/stories/2021/03/homeschooling-on-the-rise-during-covid-19-pandemic.html. By December 2021, the share of households with school-age children who reported home schooling in the Census Household Pulse Survey was still around 11 percent, similar to the share who reported home schooling in this year's SHED.

Fourteen percent said they decided to home school their child in part because the local school's safety measures were too strict.

Perceptions of Children's Performance in School

An important factor for parents as they are making work, spending, and housing decisions is the effects that these decisions have on their children. Parents may make changes in these areas that have implications for their family finances if they feel that their child is falling behind. Consequently, the survey asked parents how they felt that their child was faring as the educational environment shifted through the pandemic.

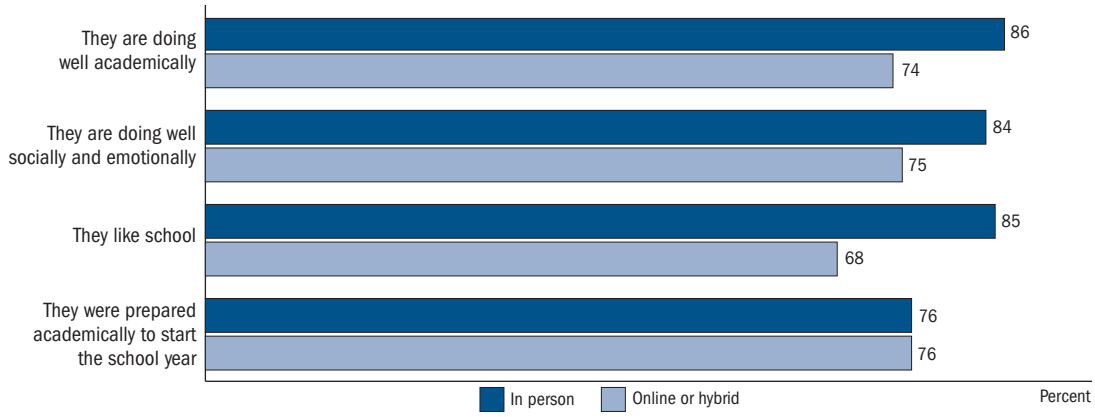
Many parents in the 2020 survey felt that the quality of their children's education had declined amid the pandemic. In 2021, parents generally said their youngest child in K–12 school was doing well, both academically and emotionally. Eighty-five percent of parents with a child in public or private school said that their child was doing well academically, 84 percent said that they were doing well socially and emotionally, and 84 percent said their child liked school. A slightly smaller majority (76 percent) said that their child was prepared for this school year.

A majority of parents with a child in public or private school also said that their child was doing better academically than in 2020. Fifty-six percent said that their child's academic performance improved, compared with 7 percent who said it declined. Similarly, a majority of parents (59 percent) said their child was doing better socially and emotionally compared with a year earlier, while many fewer parents (8 percent) said their child's social and emotional performance was worse than in 2020.

However, parents of children taking classes partially or completely online were less likely to say their child has improved socially and emotionally. Forty-three percent of parents whose youngest child was attending classes at least partially online said that their child was doing better socially and emotionally than in 2020, compared with 60 percent of parents whose youngest child was attending classes completely in person. In addition, parents of children in online or hybrid education were less likely to say that their youngest child likes school or that their child was doing well academically (figure 34). The share of parents who said their child had improved academically did not differ significantly between those with completely in-person classes and those with online or hybrid education.

While most parents said their youngest school-age child was doing well in school in the fall of 2021, parents' assessments of their child's educational performance varied by race and ethnicity. Seventy-six percent of Black parents believed their youngest child was doing well academically, lower than the share seen among the other racial and ethnic groups. Similarly, Black parents and Hispanic parents were least likely to say that their youngest child was prepared for the school year.

Figure 34. Parents' assessment of child's performance in school (by mode of education)



Note: Among parents with a child enrolled in public or private school. Based on the youngest child enrolled in public or private school who lives with their parent. Key identifies bars in order from top to bottom.

However, the share of parents who said their child likes school did not differ significantly by race and ethnicity (table 19).

Parents' assessments of their children's performance in school also increased with income. Seventy-seven percent of parents with under $25,000 in income said their child is doing well academically, compared with 89 percent of parents with $100,000 or more in income. Seventy-four percent of parents earning less than $25,000 agreed that their child was doing well socially and emotionally, whereas 88 percent of parents with income of $100,000 or more agreed with this statement.

Table 19. Parent's assessment of child's performance in school (by race/ethnicity)
Percent

Assessment	White	Black	Hispanic	Asian
They are doing well academically	87	76	83	82
They are doing well socially and emotionally	86	76	83	81
They like school	84	81	84	86
They were prepared academically to start the school year	79	70	74	79

Note: Among parents with a child enrolled in public or private school. Based on the youngest child enrolled in public or private school who lives with their parent.

Modes of Learning in Higher Education

While primary and secondary schools largely returned to in-person classes in 2021, online learning remained prevalent at higher education institutions. More than three-fourths of students enrolled in higher education said their classes were partly or completely online. Although many postsecondary students in the 2020 survey expressed concern about the quality of online classes, 76 percent of college students in 2021 said they prefer online or hybrid education.

Table 20. Prefer online only education (by type of degree program)

Characteristic	Percent
GED, technical, or associate degree	47
Bachelor's degree	29
Graduate or professional degree	47
Overall	**40**

Note: Among students currently enrolled in higher education.

Bachelor's degree students were the least likely to prefer completely online education, given the situation with the pandemic. Just fewer than 3 in 10 students enrolled in bachelor's degree programs said they prefer completely online classes (table 20). In contrast, 47 percent of students in either technical and associate degree programs or graduate and professional degree programs prefer online-only education. This may reflect that technical and associate degree students, as well as graduate degree students, were more likely to be older adults who may have other responsibilities. Sixty-four percent of technical and associate degree students and 78 percent of graduate degree students were over age 24. Among bachelor's degree students, a far lower 36 percent were over age 24.

College students generally expressed satisfaction with the amount of pandemic-related precautions taken by their school. Eight in ten postsecondary students said they thought their school was taking about the right amount of precautions, while just more than 1 in 10 said their school was not taking enough precautions.

Overall Value of Higher Education

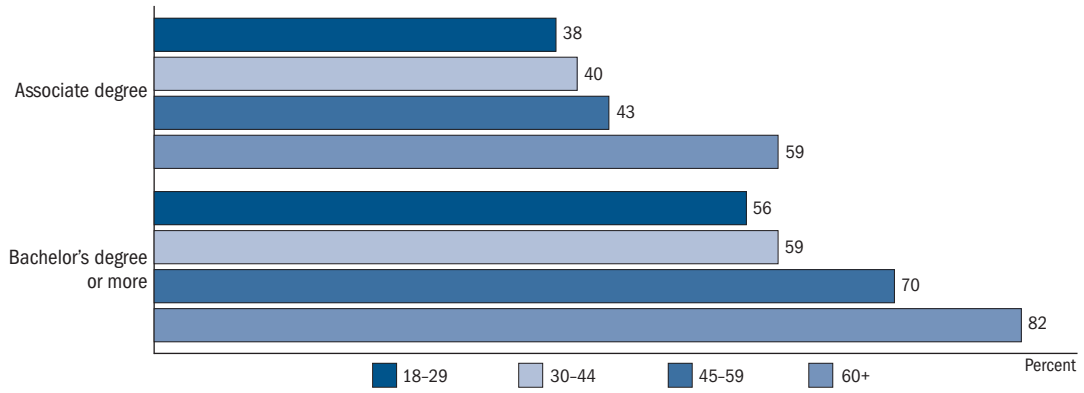
At the time of the survey, 70 percent of adults had ever enrolled in an educational degree program beyond high school, and 36 percent had received a bachelor's degree. Self-reported financial well-being rose strongly with education, although the effects differed across demographic groups (see the "Overall Financial Well-Being" section of this report for details on financial well-being by education).

Consistent with the higher rates of financial well-being among those who have more education, more than half of adults who went to college said that the lifetime financial benefits of their higher education exceeded the financial costs. Meanwhile, one in five said that the costs are higher. The rest saw the benefits as about the same as the costs. These self-assessments of the value of education have changed little in recent years.

The self-assessed value of higher education, while generally positive, depends on several aspects of a person's educational experience. Most importantly, those who completed their program and received a degree were more likely to see net benefits than noncompleters. For example, among those who went to college but did not complete at least an associate degree, 31 percent said the benefits of their education exceeded the cost. This fraction jumped to 46 percent of those with an associate degree and 67 percent of those with at least a bachelor's degree.

The self-assessed value of higher education also differed by age. Among those with at least an associate degree, older adults were more likely than younger adults to see the benefits of their education as greater than the costs (figure 35).[49] One explanation for this result could be that older respondents have had a longer time to experience the benefit of their education than younger respondents. This variation in views on the net benefit of college may also be driven by the rising cost of higher education—people who attended college more recently likely faced a higher cost than those who attended college further in the past.[50]

Figure 35. Benefits of education exceed costs (by education and age)



Note: Among adults who attended college. Key identifies bars in order from top to bottom.

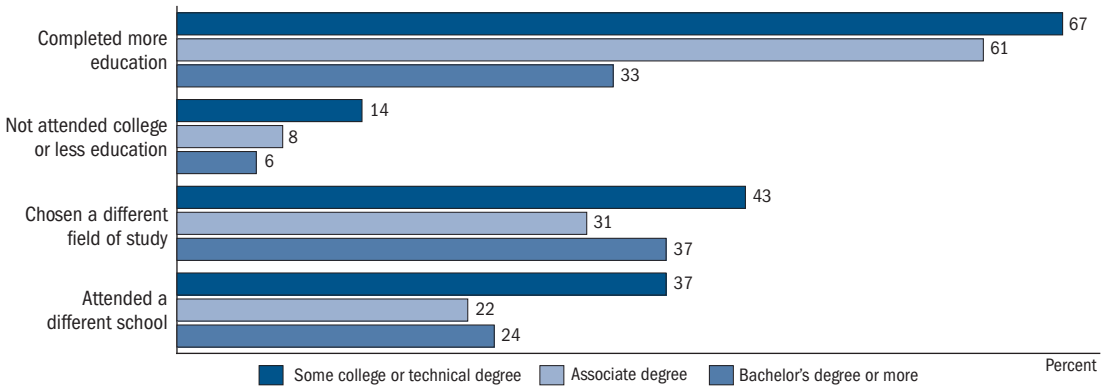
Additionally, the gap in valuations of higher education across age groups was wider among those with higher degree levels. Among those with an associate degree, fewer than 4 in 10 adults under age 30 said the benefits of their education exceeded the costs, compared with nearly 6 in 10 adults age 60 and over. Among those with a bachelor's degree or more, this gap was wider—56 percent of adults under age 30 thought the benefits of their education exceeded the cost, compared with 82 percent of adults age 60 and over.

One potential explanation is that younger adults are more likely to have taken out debt for their education and to be paying down these loans. Consequently, the costs of education may be more salient for them than for older adults (see the "Student Loans" section of this report for a discussion of educational debt and the self-assessment of the value of higher education).

[49] If adults currently enrolled in higher education levels are excluded, the share of adults who say the benefits outweigh the cost increases with age at every education level.

[50] From 1995 to 2015, net tuition, fees, room, and board rose 54 percent at public four-year institutions and 29 percent at private, nonprofit, four-year institutions. See College Board, *Trends in College Pricing 2014*, https://research.collegeboard.org/pdf/trends-college-pricing-2014-full-report.pdf. In the current school year, net tuition, room, board, and fees at public and private nonprofit institutions are about the same as they were in the 2014–15 school year (see https://research.collegeboard.org/pdf/trends-college-pricing-student-aid-2021.pdf).

Figure 36. Changes would now make to earlier education decisions (by education)



Note: Among adults who attended college and are not currently enrolled. Respondents could select multiple answers. Key identifies bars in order from top to bottom.

Another contributor to differences in how people viewed their education was the type of institution attended.[51] Consistent with previous years of the survey, 69 percent of those with bachelor's degrees from public institutions and 63 percent with bachelor's degrees from private not-for-profit institutions saw their educational benefits as greater than their costs. However, 43 percent of those with bachelor's degrees from for-profit institutions felt their education was worth the cost.

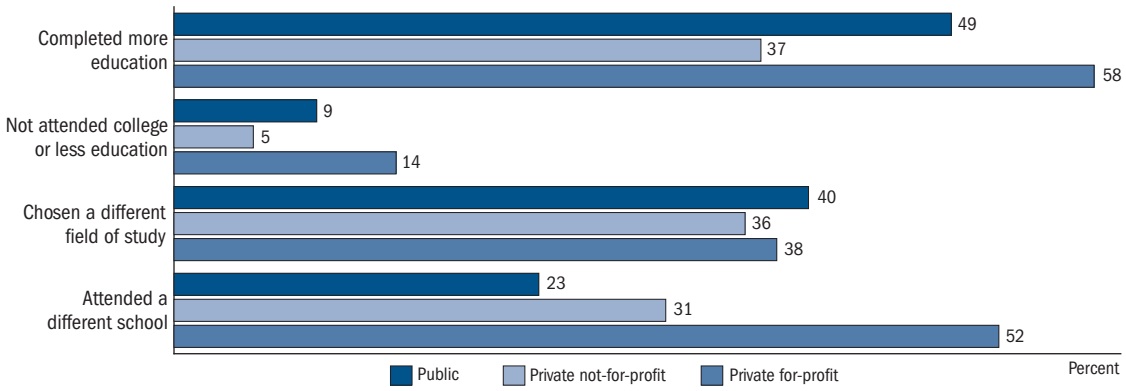
Look Back on Education Decisions

Another way to assess the value of education is to consider what people would have done differently if given the chance. Most people value the education they have, but with the benefit of hindsight and life experience, it is also common to think that different educational decisions could have been better.

Completing more education was the most common change that those with less education would have made if they were able to make a change. Sixty-seven percent of those without a college degree and 61 percent of those with an associate degree said they would like to have completed more education (figure 36). For those with a bachelor's degree or more, choosing a different field of study (37 percent) was the most common change they would make to their education. Few people of any education level said they would have completed less education if they could make their decisions again.

[51] Individuals do not self-report the type of institution in the survey. Instead, the institution type is assigned by matching the name and location of the college reported by the individual with data from the Center on Postsecondary Research at the Indiana University School of Education (https://cpr.indiana.edu/). For individuals who completed an associate or bachelor's degree, institution type is based on the school from which they received the degree. For other individuals, it is based on the last school attended.

Figure 37. Changes would now make to earlier education decisions (by institution type)



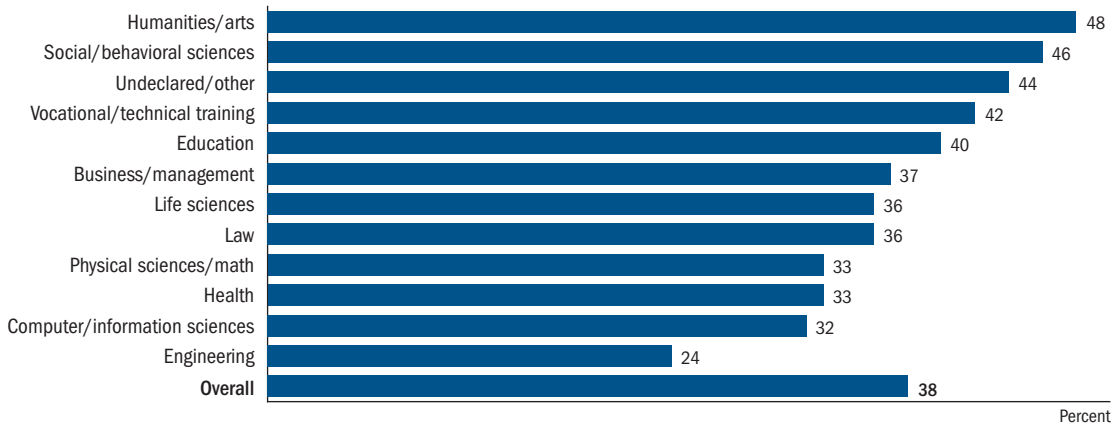
Note: Among adults who attended college and are not currently enrolled. Respondents could select multiple answers. Key identifies bars in order from top to bottom.

Additionally, reassessments of educational decisions varied by the type of institution attended. Slightly over half of those who attended a for-profit institution said they would have attended a different school, compared with 31 percent of those attending a private not-for-profit institution and 23 percent attending a public institution (figure 37). This difference remains even after accounting for the selectiveness of the institution, level of education completed, the parents' level of education, and demographic characteristics of the student.[52]

The changes adults who completed at least some college said they would now make to their educational decisions were also related to the field of study they pursued. In particular, the share who said they would study a different topic in hindsight varied by fields of study. Forty-eight percent of those who studied the humanities and arts, and 46 percent of those who studied social and behavioral sciences, said they would choose a different field. In comparison, a lower share (24 percent) of those who studied engineering said they would have chosen a different field (figure 38).

[52] Selective institutions, as defined by the Carnegie Classification, are those whose first-year students' test scores are in the middle two-fifths of baccalaureate institutions; more selective institutions are in the top one-fifth of baccalaureate institutions. See also "The Carnegie Classification of Institutions of Higher Education," web page, http://carnegieclassifications.iu.edu/. The remainder are referred to here as "less selective" institutions.

Figure 38. Would now choose a different field of study (by field of study)



Note: Among adults who completed at least some college who are not currently enrolled.

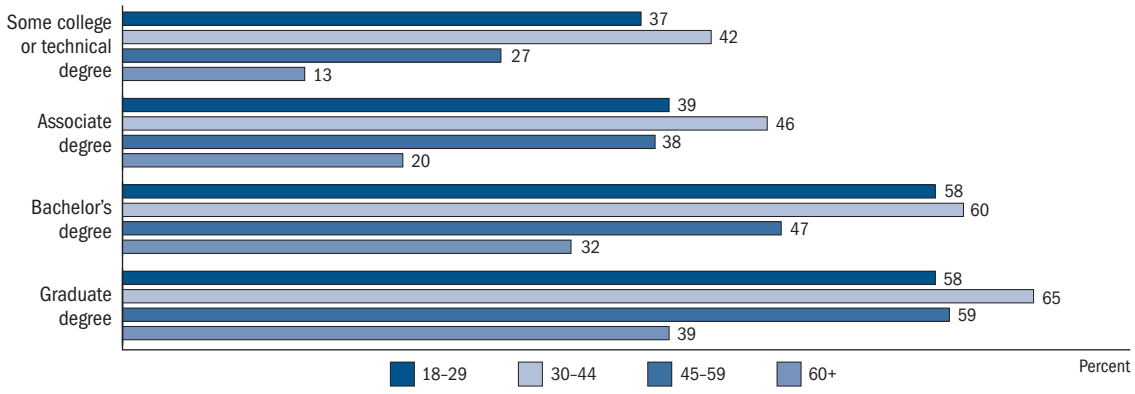
Student Loans

Education debt is prevalent among people who went to college, and especially among younger adults. In 2021, many student loan borrowers continued to receive delays in payment due dates for student loan bills because of ongoing pandemic relief measures. Consequently, the share of borrowers from a range of backgrounds who were behind on their payments in the fall of 2021 declined relative to before the pandemic. Additionally, borrowers who had outstanding student loan debt at the time of the survey reported higher levels of financial well-being compared with prior years.

Incidence and Types of Education Debt

Thirty percent of all adults—representing over 4 in 10 people who went to college—said they incurred at least some debt for their education. This includes 20 percent of college attendees who still owed money and 22 percent who borrowed but fully repaid their education debts. Adults under age 30 who attended college were more likely to have taken out loans than older adults, consistent with the upward trend in educational borrowing over the past several decades (figure 39).[53]

Figure 39. Acquired debt for own education, including repaid debt (by age and highest degree completed)



Note: Among adults who attended college. Key identifies bars in order from top to bottom.

[53] Student loan borrowing has declined since its peak in 2010–11 but remains substantially above the levels from the mid-1990s. (Jennifer Ma and Matea Pender, *Trends in College Pricing and Student Aid 2021* (New York: The College Board, 2021), https://research.collegeboard.org/pdf/trends-college-pricing-student-aid-2021.pdf).

The incidence of education debt varied by the type of institution attended. Among those who attended public institutions, 40 percent either previously held debt or currently had debt at the time of the survey, compared with 57 percent of those who attended private not-for-profit and 59 percent who attended private for-profit institutions. Among younger cohorts of students, those who attended private for-profit institutions were also more likely to have taken out student loans than those who attended either private not-for-profit or public institutions.

Table 21. Type of education debt
Percent

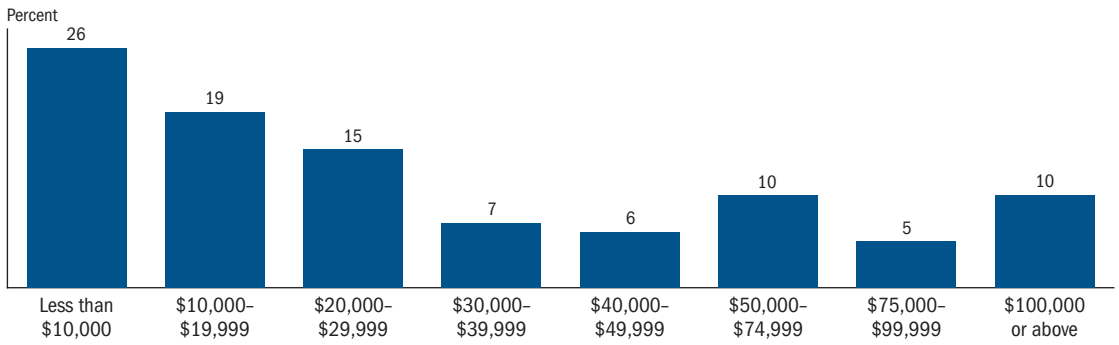
Debt type	Own education	Child's or grandchild's education
Student loan	96	88
Credit card	19	12
Home equity loan	4	9
Other loan	11	11

Note: Among adults with at least some debt outstanding for their own education or a child's or grandchild's education. Some people had more than one type of debt.

Not all education debt is in the form of student loans. Ninety-six percent of those with outstanding debt from their own education had student loans, but many borrowers had other forms of education debt as well (table 21). This includes 19 percent who borrowed with credit cards, 4 percent with a home equity loan, and 11 percent with some other form. Collectively, 24 percent of borrowers had one or more forms of education debt besides student loans for their own education.

Most student loan borrowers owe less than $25,000 on their loans. The median amount of education debt in 2021 among those with any outstanding debt for their own education was between $20,000 and $24,999. One-quarter of student loan borrowers had less than $10,000 in outstanding student debt (figure 40). Student debt balances vary across different demographic groups. Borrowers with an income of less than $50,000 a year were more likely to carry lower balances of student loan debt.

Figure 40. Distribution of adults with outstanding debt for their own education



Note: Among adults who borrowed for their own education.

Some people also took out education debt to assist family members with their education through either a co-signed loan with the student or a loan taken out independently. Although this is less common than borrowing for one's own education, 4 percent of adults owed money for a spouse's or partner's education, and 4 percent had debt that paid for a child's or grandchild's education. Like debt outstanding for the borrower's education, debt for a child's or grandchild's education can be in forms other than a student loan.

Student Loan Payment Status

The Coronavirus Aid, Relief, and Economic Security Act (CARES Act) and subsequent executive orders in response to COVID-19 provided federal student loan payment relief throughout 2021, dramatically reducing the share of borrowers who were behind on their payments.[54] Among adults with outstanding debt from their own education, 12 percent were behind on their payments in 2021, a significant decline from the 17 percent who were behind in the fall of 2019, before the pandemic.[55]

Consistent with previous years, borrowers with less education were more likely to be behind on their payments. Twenty-three percent of borrowers with loans outstanding who completed less than an associate degree reported being behind.[56] Among borrowers with an associate degree, 18 percent were behind. The delinquency rate was even lower among borrowers with a bachelor's degree (6 percent) or graduate degree (5 percent).

Borrowers who said neither of their parents had completed a bachelor's degree were more likely to be behind on their payments than those with a parent who had completed a bachelor's degree. In 2021, borrowers who did not have a parent with a bachelor's degree were almost twice as likely to be behind on their payments as those with a parent who completed a bachelor's degree (table 22). However, the difference in repayment status among these groups has narrowed since the fall of 2019.

[54] Beginning on March 27, 2020, the CARES Act granted relief to student loan borrowers by temporarily pausing payments—including principal and interest—on federally held student loans. This payment pause for federal student loan borrowers has been extended multiple times by executive orders during the COVID-19 pandemic through all of 2021 and into 2022. (See U.S. Department of Education at https://studentaid.gov/announcements-events/coronavirus).

[55] Borrowers could be behind on payments for student loans or other types of debt for their own education. Although the federal student loan pause has been in effect since March 2020, findings from the 2020 survey did not show substantial improvement in student loan repayment status among borrowers. This could be due to the uncertainty regarding the policy and interpretation of the survey questions. Data from the Federal Reserve Bank of New York show a decline in student loan delinquency in 2020 and 2021 (Federal Reserve Bank of New York, *Quarterly Report on Household Debt and Credit* (New York: FRB New York, November 2021), https://www.newyorkfed.org/medialibrary/interactives/householdcredit/data/pdf/HHDC_2021Q3.pdf).

[56] Currently enrolled students are frequently not required to make payments so are less likely to fall behind. Among those with less than an associate degree who are not currently enrolled, a larger 28 percent of borrowers are behind.

Table 22. Behind on student loan payments for own education (by parents' education, race/ethnicity, and institution type)
Percent

Characteristic	2019	2021	Change
Parents' education			
Parent has completed a bachelor's degree	9	8	−2
Neither parent has completed a bachelor's degree	22	15	−7
Race/ethnicity			
White	11	9	−2
Black	29	17	−12
Hispanic	24	18	−6
Institution type			
Public	15	11	−4
Private not-for-profit	11	7	−4
Private for-profit	27	23	−4

Note: Among adults with outstanding debt for their own education. Change reported may not match difference between the columns because of rounding.

Difficulties with repayment also vary by race and ethnicity. While Black and Hispanic borrowers were still disproportionately likely to be behind on their debt and were less likely to have completely paid off their student loan debts, these borrowers saw improvements in their repayment status. In 2021, 17 percent of Black borrowers and 18 percent of Hispanic borrowers reported being behind on their student loan debt, compared with 29 and 24 percent in 2019, respectively.

While the percentage of borrowers behind on payments declined over the prior two years, disparities in payment status persist based on the type of institution attended. Twenty-three percent of borrowers who attended for-profit institutions were behind on student loan payments, versus 11 percent who attended public institutions and 7 percent who attended private not-for-profit institutions.

Greater difficulties with loan repayment among attendees of for-profit institutions may partly reflect the lower returns on degrees from these institutions.[57] Indeed, when accounting for race and ethnicity, parents' education, level of institution (two year or four year), and institution selectivity, the relationship between for-profit institution attendance and being behind on student loan payments persists. This suggests that the high payment difficulty rates for attendees of for-profit institutions reflect characteristics of the schools and is not simply due to the characteristics of their students.

Although it is common to focus only on those with outstanding debt, many people who borrowed for their education had repaid their loans completely. Excluding these people who have paid off their debt could overstate difficulties with repayment. Indeed, the share of adults who were behind on their payments is much lower when accounting for all who ever borrowed, including those who had completely repaid that debt.

Among those who ever incurred debt for their education, 6 percent were behind on their payments at the time of the 2021 survey, 42 percent had outstanding debt and were current on their pay-

[57] See David J. Deming, Claudia Goldin, and Lawrence F. Katz, "The For-Profit Postsecondary School Sector: Nimble Critters or Agile Predators?" *Journal of Economic Perspectives* 26, no. 1 (Winter 2012): 139–64, https://www.aeaweb.org/articles?id=10.1257/jep.26.1.139, for a discussion of the rates of return by education sector.

ments, and 52 percent had completely paid off their loans. Nevertheless, the demographic and educational characteristics of those who fall behind on payments remain similar when also incorporating those who have paid off their loans.

Relation to Financial Well-Being

Consistent with the student loan payment relief and improvements in payment statuses, self-reported financial well-being among adults with outstanding debt has increased over the pandemic. Among all adults who went to college and had outstanding student loan debt, 73 percent were doing at least okay financially in 2021. This is up from 65 percent who were doing at least okay financially in 2019.

The improvement in financial well-being among student loan borrowers occurred among borrowers of all education levels. The 65 percent of borrowers with an associate degree who reported doing at least okay financially in 2021 was up 9 percentage points from the 56 percent who were doing at least okay in 2019 (table 23). Among borrowers with some college education but no associate degree, the improvement was 7 percentage points. Among those with at least a bachelor's degree, the improvement in financial well-being was 6 percentage points.

Table 23. At least doing okay financially (by education and debt status)
Percent

Characteristic	2019	2021	Change
Some college, no associate degree			
Never had debt	77	76	−1
Previously had debt, now repaid	71	74	3
Currently has debt	51	58	7
Associate degree			
Never had debt	85	83	−2
Previously had debt, now repaid	79	76	−3
Currently has debt	56	65	9
Bachelor's degree or more			
Never had debt	92	94	2
Previously had debt, now repaid	92	94	2
Currently has debt	75	81	6

Note: Among all adults who attended college.

In contrast, adults who attended college and either did not borrow or had already repaid their student loan debts did not exhibit similar improvements in financial well-being. For those with an associate degree who never borrowed, 83 percent were doing okay financially in 2021, as were 76 percent of those who borrowed and paid off their debt. Each of these were similar to or below the shares doing at least okay in 2019, standing in contrast to the improvements seen among those with outstanding loans. This suggests that the changes in student loan policies likely contributed to the increase in self-reported well-being among borrowers.

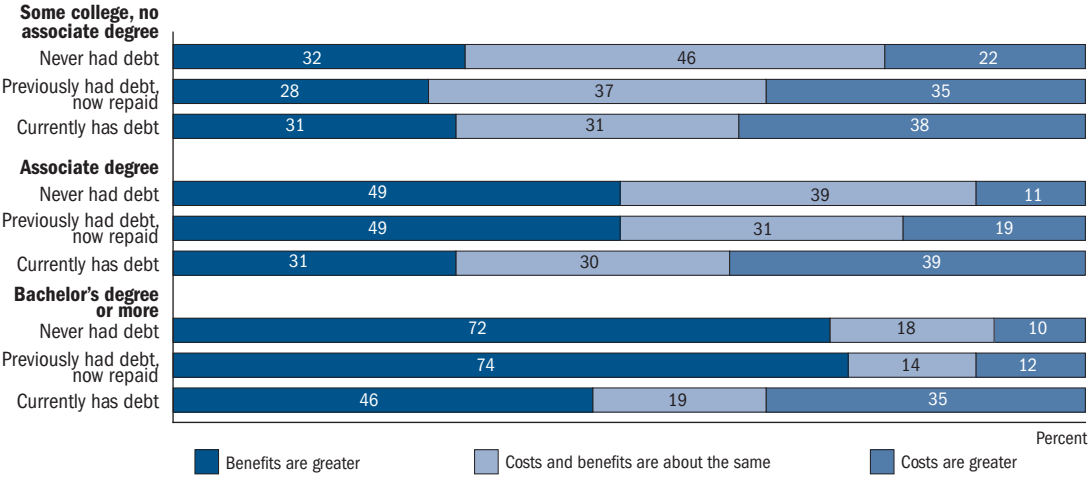
Relation to Self-Assessed Value of Higher Education

The self-assessed value of higher education was lower among those who had outstanding debt. Among borrowers with outstanding debt, 40 percent said the benefits of their education exceeded

the cost. This was below the 63 percent of borrowers who completely paid off their debt and 51 percent of those who went to college but never had debt.[58] Student loan borrowers with outstanding debt also were twice as likely as those who repaid their debt to say that the costs of their education outweigh the benefits.

These gaps in perceptions of one's higher education were particularly notable among those who completed a degree. Approximately 3 in 10 adults who attended college but did not complete an associate or bachelor's degree said that the benefits of their education exceeded the costs, regardless of their student loan status. However, substantial gaps in perceptions of higher education emerged for those who completed a degree. Just over 3 in 10 associate degree recipients with outstanding debt said that the benefits exceeded the costs, compared with half of those without outstanding debt. Among bachelor's degree recipients, the gap in perceptions between those with and without outstanding student loan debt is even greater (figure 41). This gap indicates the extent to which perceptions of higher education are linked to whether individuals had to borrow for their education, and whether the returns on their education were sufficient for them to repay their student loans.

Figure 41. Self-assessed value of higher education (by education and debt status)



Note: Among adults who attended college. Key identifies bars in order from left to right.

[58] Differences in the level of education within these debt status groups also contribute to the self-assessment of costs and benefits. Those with a bachelor's degree or higher make up 71 percent of those who attended college and previously had debt, compared with 42 percent of those who attended and never had debt.

Retirement and Investments

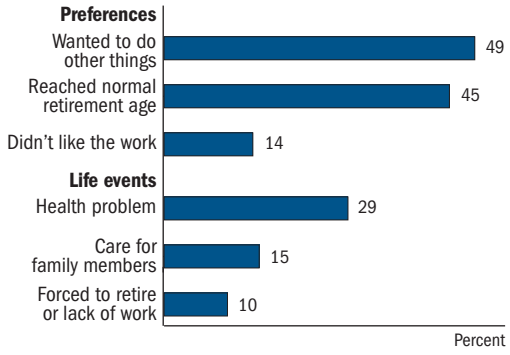
In 2021, retirees' descriptions of their reasons for retirement and their income sources were consistent with recent years. As was the case in 2020, a sizeable share of recent retirees said COVID-related factors affected the timing of their retirement decision. Among non-retirees, a higher share reported they felt like their retirement savings were on track, and a smaller share borrowed against or cashed out retirement savings, compared with 2020. Yet, differences by age and race or ethnicity in retirement preparedness among non-retirees remained similar to earlier years.

Current Retirees

Retirees represent a sizeable portion of the adult population. Twenty-seven percent of adults in 2021 considered themselves to be retired, even though some were still working in some capacity.[59] Fourteen percent of retirees had done some work for pay or profit in the prior month. Consequently, 4 percent of all adults considered themselves retired and were still working. Retirees with more education were slightly more likely to work in retirement.

In deciding when to retire, most retirees indicated that their preferences played a role, but life events contributed to the timing of retirement for a substantial share (figure 42). Forty-nine percent of retirees said a desire to do other things or to spend time with family was important for their decision to retire, and 45 percent said they retired because they reached a normal retirement age.

Figure 42. Reasons for the timing of retirement



Note: Among retirees. Respondents could select multiple answers.

Nonetheless, 29 percent said that a health problem was a factor in their decision to retire, and 15 percent said they retired to care for family members. One in 10 said they were forced to retire or that work was not available. Collectively, health problems, caring for family, and lack of work contributed to the timing of retirement for 45 percent of retirees.

[59] In this report, descriptions of current retirees include everyone who reported being retired, including those who also reported that they are working.

A sizeable share of recent retirees indicated that COVID-19 was a factor in their retirement decision. Twenty-five percent of adults who retired in the prior 12 months, and 15 percent of those who retired one to two years ago, said factors related to COVID-19 contributed to when they retired. Compared with other retirees, recent retirees whose retirement decision was related to COVID-19 were more likely to say they retired because they were forced to do so or work was not available. While the pandemic may be contributing to retirement decisions for some recent retirees, the share of adults who consider themselves to be retired has remained relatively consistent during the pandemic.[60]

Table 24. Sources of income in the prior 12 months among retirees (by age)
Percent

Source	Retirees age 65 and older	All retirees
Social Security	92	78
Pension	66	57
Interest, dividends, or rental income	49	43
Wages, salaries, or self-employment	25	32
Cash transfers other than Social Security	7	11

Note: Among retirees. Respondents could select multiple answers. Sources of income include the income of a spouse or partner.

Social Security remained the most common source of retirement income, but 79 percent of retirees had one or more sources of private income. This included 57 percent of retirees with income from a pension; 43 percent with interest, dividends, or rental income; and 32 percent with labor income (table 24).[61] Seventy-eight percent of retirees received income from Social Security in the prior 12 months, including 92 percent of retirees age 65 or older.

While retirees as a group report a generally high level of financial well-being and life satisfaction, those who were not married and those with a disability reported lower levels for these subjective measures (table 25).[62] In 2021, 81 percent of all retirees said they were doing at least okay financially, and 60 percent reported high levels of life satisfaction. On average, retirees who were not married were not doing as well, with just 68 percent saying that they were doing at least okay financially and 49 percent reporting high levels of life satisfaction. Retirees with a disability, regardless of their marital status, were less likely to report they were doing at least okay financially or that they had high levels of life satisfaction.

[60] Other recent data have shown an increase in retirements during the pandemic. In part, the difference in findings is because retirees in the SHED include some who are retired while also working in some capacity, as well as some who are retired but provide other reasons—such as health limitations—as the reason for not working. An alternative definition of retirement focuses only on older adults who are not working and who say the reason they are not working is because they are retired. By this measure in the SHED, 51 percent of adults age 55 or older were retired in 2021—a share that edged up over the course of the pandemic from 48 percent in 2019 and 49 percent in 2020—consistent with results from the Current Population Survey using a similar definition (Richard Fry, "Amid the Pandemic, a Rising Share of Older U.S. Adults Are Now Retired," web page, Pew Research Center 2021, https://www.pewresearch.org/fact-tank/2021/11/04/amid-the-pandemic-a-rising-share-of-older-u-s-adults-are-now-retired/).

[61] The type of pension was not specified, so pension income may include income from defined benefit plans, which pay a fixed monthly amount, and defined contribution plans, such as 401(k) and 403(b) plans.

[62] About one-third of retirees were not married, and about one-fourth of retirees had a disability.

Retirement Savings among Non-Retirees

Although three-fourths of non-retired adults had at least some retirement savings, about one-fourth did not have any (figure 43). This share has remained nearly unchanged since 2019. Among those with retirement savings, these savings were most frequently in defined contribution plans, such as a 401(k) or 403(b), with 55 percent of non-retired adults having money in such a plan. These accounts were more than twice as common as traditional defined benefit pension plans. Fifty-two percent of non-retirees had retirement savings outside of formal retirement accounts, up from 48 percent of non-retirees who reported having such accounts in 2020.

While most non-retired adults had some type of retirement savings, only 40 percent of non-retirees thought their retirement saving was on track. Still, the share of non-retirees who thought their retirement saving was on track increased in 2021, from 36 percent who thought their saving was on track in 2020 and 37 percent who thought their retirement savings were on track in 2019. Because retirement saving strategies differ by circumstances and age, survey respondents assessed whether or not they felt that they were on track, but they defined that for themselves.

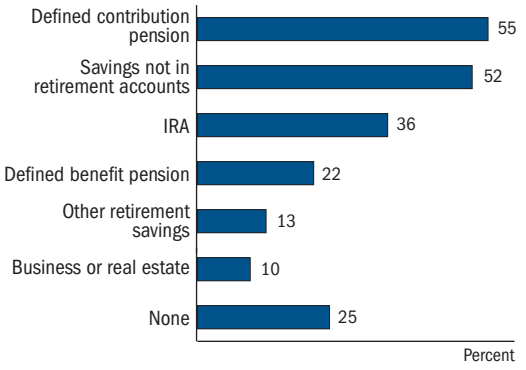
Table 25. Financial well-being and life satisfaction among retirees (by marital status and disability status)

Percent

Characteristic	At least doing okay financially	High life satisfaction
Married		
No disability	92	70
Disability	77	53
Overall	**88**	**65**
Not married		
No disability	75	54
Disability	58	40
Overall	**68**	**49**

Note: Among retirees.

Figure 43. Forms of retirement savings among non-retirees



Note: Among non-retirees. Respondents could select multiple answers.

Retirement savings and perceived preparedness differed across demographic groups. Younger adults were both less likely to have retirement savings and to view their savings as on track than older adults. Compared with all non-retirees, Black and Hispanic non-retirees were less likely to have retirement savings and to view their retirement savings as on track, while White and Asian non-retirees were more likely to have such savings and say they were on track (table 26).

Table 26. Retirement saving and self-assessed preparedness (by age, race/ethnicity, and disability status)
Percent

Characteristic	Any retirement savings	Retirement savings on track
Age		
18–29	62	30
30–44	75	39
45–59	84	45
60+	87	52
Race/ethnicity		
White	81	46
Black	64	26
Hispanic	61	25
Asian	85	52
Disability status		
No disability	79	43
Disability	49	17
Overall	**75**	**40**

Note: Among non-retirees.

The lower rates of savings among Black and Hispanic non-retirees partly reflect the fact that Black and Hispanic adults were, on average, younger than the non-retired population overall. Even within age cohorts, however, significant differences remained in retirement savings by race and ethnicity, consistent with patterns seen in previous years.

Non-retirees with a disability were also less likely to have retirement savings and to view their savings as on track. Among non-retirees with a disability, only 49 percent had retirement savings and 17 percent viewed their savings as on track. Adults with a disability have a lower rate of employment compared with adults without a disability. (See box 1 for more on the employment experiences of adults with a disability during the pandemic.) In addition, adults with a disability who receive means-tested benefits may face asset limits that would deter holding any savings they may have accrued.[63]

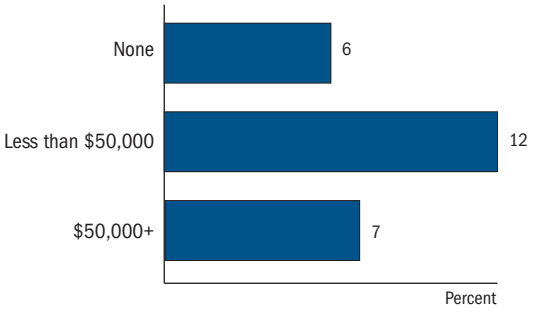
Occasionally, retirement savings can also act as a source of emergency funds for non-retirees who face economic hardships. Overall, 8 percent of non-retired adults tapped their retirement savings—a slight decrease from 2020. Yet, 14 percent of non-retired adults who had experienced a layoff in 2021 borrowed or cashed out funds from their retirement savings. Even so, some non-retirees who may have a need for a reserve fund to weather a hardship may not have retirement savings or may have already tapped such savings. Forty-three percent of non-retirees who experienced a layoff in the prior 12 months did not have self-directed retirement savings at the time of the survey, compared with 26 percent of non-retirees who did not experience a layoff.

Non-retirees with smaller account balances were more likely to have borrowed from, or cashed out, funds from their retirement accounts in the prior 12 months (figure 44). Twelve percent of those

[63] SSI and Social Security Disability Insurance (SSDI) are federal programs to support adults with a disability who meet medical and other requirements. SSI recipients must have limited income and resources, but SSDI recipients do not have to meet income and resource limits to qualify for benefits. See Social Security Administration, *Red Book: A Summary Guide to Employment Supports for Persons with Disabilities Under the Social Security Disability Insurance (SSDI) and Supplemental Security Income (SSI) Programs*, January 2020, https://www.ssa.gov/redbook/.

with account balances under $50,000 borrowed from, or cashed out, these accounts, compared with 7 percent of those with account values of $50,000 or more. While tapping retirement funds could result in smaller account balances, or the exhaustion of such reserves altogether, adults with lower income (and likely with lower account balances) were more likely to experience shocks that could prompt them to tap retirement reserves early.[64]

Figure 44. Borrowed from or cashed out retirement savings accounts in the prior 12 months (by amount of self-directed retirement savings)

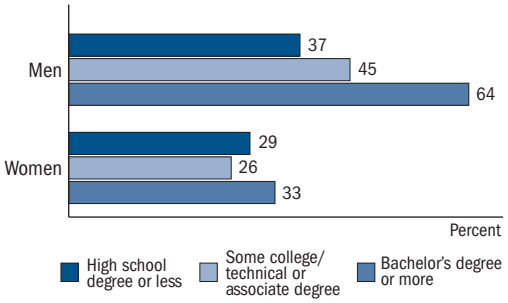


Note: Among non-retirees.

Self-directed retirement accounts frequently have complex rules on withdrawals and rely on individuals to have the skills and knowledge required to manage their own investments. Non-retirees with self-directed retirement savings varied in their comfort with making investment decisions for their accounts. Nearly 6 in 10 non-retirees with self-directed retirement savings expressed low levels of comfort in making investment decisions with their accounts.

Among those non-retirees with self-directed savings, a higher share of men were comfortable managing their retirement investments compared to women (figure 45). Sixty-four percent of men with a bachelor's degree were mostly or very comfortable making investment decisions, compared to 33 percent of women with this level of education who were mostly or very comfortable. In fact, the 33 percent of women with a bachelor's degree who were comfortable investing was similar to the 37 percent of men with a high school degree or less who expressed the same level of comfort.

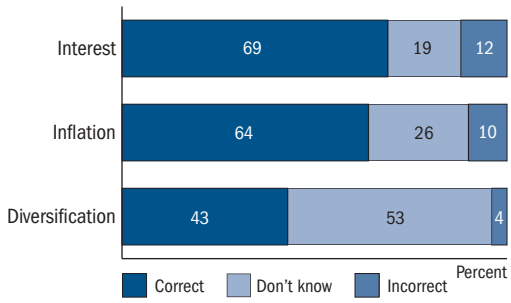
Figure 45. Mostly or very comfortable investing self-directed retirement savings (by gender and education)



Note: Among non-retirees with self-directed retirement savings. Key identifies bars in order from top to bottom.

[64] For more on early withdrawals and the relationship with economic shocks and income, see Robert Argento, Victoria L. Bryant, and John Sabelhaus, "Early Withdrawals from Retirement Accounts during the Great Recession," *Contemporary Economic Policy* 33, no. 1 (March 2013), https://www.researchgate.net/publication/254969212_Early_Withdrawals_from_Retirement_Accounts_during_the_Great_Recession.

Figure 46. Responses to financial literacy questions



Note: Among the one-half of respondents who were asked the questions including "Don't know" as an answer choice. Key identifies bars in order from left to right.

Financial Literacy and Experience with Investments

To get some sense of individuals' financial knowledge, respondents were asked three questions—on interest, inflation, and risk diversification, respectively—that are commonly used as measures of financial literacy (figure 46).[65]

Higher shares of adults provided correct answers to questions about interest and inflation than to the question on risk diversification. The average number of correct answers was 1.8 out of 3, and 34 percent of adults got all three correct.

Table 27. Financial literacy (by retirement savings and comfort investing)
Percent

Presence of retirement savings and level of investing comfort	Correct	Incorrect	Don't know/ Refused
Has self-directed retirement savings	67	7	26
Mostly or very comfortable investing	78	7	15
Not or slightly comfortable investing	59	8	33
No self-directed retirement savings	32	11	56
Retired	61	8	31
Overall	**59**	**8**	**33**

Note: Among the one-half of respondents who were asked the questions including "Don't know" as an answer choice.

Self-assessed comfort in managing investments was correlated with these measures of financial literacy. Among those with self-directed retirement accounts, on average, those who expressed comfort with managing their investments answered a larger share of questions correctly (78 percent) than those who expressed little or no comfort (59 percent) (table 27). Notably, the share of incorrect answers did not vary much with investment comfort. Instead, the number of "don't know" responses fell as investment comfort rose. Overall, however, non-retirees with such accounts still answered more financial literacy questions correctly, on average, than either non-retirees who did not have such accounts or people who were already retired.

[65] These questions were developed by Annamaria Lusardi and Olivia Mitchell (see "Financial Literacy around the World: An Overview," *Journal of Pension Economics and Finance* 10, no. 4 (2011): 497–508) and have been widely used to study financial literacy. In the 2021 SHED, half of the respondents received the questions and answer choices developed by Lusardi and Mitchell, and the results reported here reflect their responses. The other half of the respondents received the same questions without the "don't know" answer option. Full question wording is available in appendix A and results from the group who received the alternative formulation are included in appendix B of the appendixes to this report.

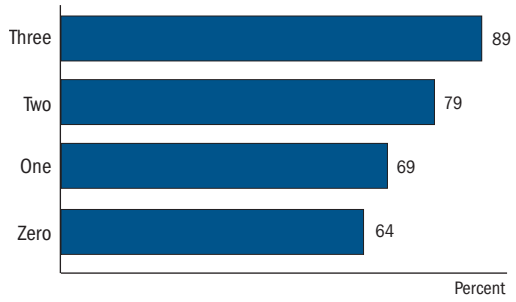
Gender differences in financial literacy mirrored differences in being comfortable with the investment decisions. Women, on average, answered a lower share of financial literacy questions correctly (52 percent) than men (66 percent). Women were also more likely to select "don't know" or to skip questions (39 percent) than men (26 percent). As a result, women, on average, had lower levels of financial literacy by this measure. Some evidence suggests that one driver of this gender difference may relate to different levels of experience with financial decisions.[66]

Financial knowledge appears to be correlated with experience with other investments as well. On average, people who own individual stock answered 77 percent of the financial literacy questions correctly. Those who have self-directed retirement savings, but no individual stocks, answered 59 percent correctly, and those with no self-directed retirement savings or stock holdings answered 32 percent correctly.

The high financial literacy scores among those who own individual stocks is particularly notable since one of the questions asks if owning individual stocks is riskier than owning a stock mutual fund. Sixty-three percent of stock owners correctly answered that it is riskier to own an individual stock, whereas just 33 percent of people who do not own individual stocks answered this question correctly. Consequently, many people who own individual stocks appear to be aware of this additional risk and either view the benefits as outweighing the risk or see the individual stocks as part of their broader investment portfolio.

Financial well-being is higher among people with higher rates of financial knowledge. Among those who answered all three of the financial literacy questions correctly, 89 percent were doing at least okay financially, whereas a lower 64 percent of those who did not answer any of the questions correctly were doing at least okay financially (figure 47). This positive relationship between financial well-being and financial literacy remains even when looking at people with the same level of education, although the magnitude of differences shrinks. Nevertheless, at least a portion of the increase in well-being with additional financial knowledge is likely attributable to other factors rather than to differences in financial knowledge alone.

Figure 47. At least doing okay financially (by number of financial literacy questions answered correctly)



Note: Among the one-half of respondents who were asked the questions including "Don't know" as an answer.

[66] Some of the gender gap in financial literacy may relate to specialization in financial tasks within a household, with women being less likely to handle the finances. Joanne Hsu finds that women's financial literacy increases after the death of a spouse (see "Aging and Strategic Learning: The Impact of Spousal Incentives on Financial Literacy," *Journal of Human Resources* 51(4) (Fall 2016): 1036–67).

Description of the Survey

The Survey of Household Economics and Decisionmaking was fielded from October 29 through November 22, 2021. This was the ninth year of the survey, conducted annually in the fourth quarter of each year since 2013.[67] Staff of the Federal Reserve Board wrote the survey questions in consultation with other Federal Reserve System staff, outside academics, and professional survey experts.

Ipsos, a private consumer research firm, administered the survey using its KnowledgePanel, a nationally representative probability-based online panel. Since 2009, Ipsos has selected respondents for KnowledgePanel based on address-based sampling (ABS). SHED respondents were then selected from this panel.

Survey Participation

Participation in the 2021 SHED depended on several separate decisions made by respondents. First, they agreed to participate in Ipsos' KnowledgePanel. According to Ipsos, 10.1 percent of individuals contacted to join KnowledgePanel agreed to join (study-specific recruitment rate). Next, they completed an initial demographic profile survey. Among those who agreed to join the panel, 61.3 percent completed the initial profile survey and became a panel member (study-specific profile rate). Finally, selected panel members agreed to complete the 2021 SHED.

Of the 18,322 panel members contacted to take the 2021 SHED, 11,965 participated and completed the survey, yielding a final-stage completion rate of 65.3 percent.[68] Taking all the stages of recruitment together, the cumulative response rate was 4.0 percent. After removing a small number of respondents because of high refusal rates or completing the survey too quickly, the final sample used in the report included 11,874 respondents.[69]

Targeted Outreach and Incentives

To increase survey participation and completion among hard-to-reach demographic groups, Board staff and Ipsos used a targeted communication plan with monetary incentives. The target groups—young adults ages 18 to 29; adults with less than a high school degree; adults with

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[67] Data and reports of survey findings from all past years are available at https://www.federalreserve.gov/consumerscommunities/shed.htm.

[68] Three hundred ninety-five respondents were not included in the analysis because they started, but did not complete, the survey (known as break-offs). The study break-off rate for the SHED was 3.2 percent.

[69] Of the 11,965 respondents who completed the survey, 91 were excluded from the analysis in this report because of either leaving responses to a large number of questions missing, completing the survey too quickly, or both.

household income under $50,000 who are under age 60; and those who are a race or ethnicity other than White, non-Hispanic—received additional email reminders and text messages during the field period, as well as additional monetary incentives.

All survey respondents not in a target group received a $5 incentive payment after survey completion. Respondents in the target groups received a $15 incentive. These targeted individuals also received additional follow-up emails during the field period to encourage completion. Additionally, the incentives offered to some targeted individuals increased to $25 during the field period to increase the incentive for completion.[70]

Survey Questionnaire

The 2021 survey took respondents 21.6 minutes (median time) to complete.

A priority in designing the survey questions was to understand how individuals and families—particularly those with low- to moderate-income—fared financially in 2021. The questions were intended to complement and augment the base of knowledge from other data sources, including the Board's Survey of Consumer Finances. In addition, some questions from other surveys were included to allow direct comparisons across datasets.[71] The full survey questionnaire can be found in appendix A of the appendixes to this report.

Survey Mode

While the sample was drawn using probability-based sampling methods, the SHED was administered to respondents entirely online. Online interviews are less costly than telephone or in-person interviews and can be an effective way to interview a representative population.[72] Ipsos' online panel offers some additional benefits. Their panel allows the same respondents to be re-interviewed in subsequent surveys with relative ease, as they can be easily contacted for several years.

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[70] All participants received a pre-notification email before the survey launch. They also received four email reminders during the three-week field period in addition to the initial survey invitation. Targeted respondents received two additional email reminders over this period. Three days before closing the survey, the email reminder to targeted adults increased the incentive for completing the survey from $15 to $25. Of the 5,733 respondents in a targeted group, 251 received the higher $25 incentive payment and the rest received the $15 incentive payment.

[71] For a comparison of results to select overlapping questions from the SHED and Census Bureau surveys, see Jeff Larrimore, Maximilian Schmeiser, and Sebastian Devlin-Foltz, "Should You Trust Things You Hear Online? Comparing SHED and Census Bureau Survey Results," Finance and Economics Discussion Series Notes (Washington: Board of Governors of the Federal Reserve System, October 15, 2015), https://doi.org/10.17016/2380-7172.1619.

[72] David S. Yeager et al., "Comparing the Accuracy of RDD Telephone Surveys and Internet Surveys Conducted with Probability and Non-Probability Samples," *Public Opinion Quarterly* 75, no. 4 (2011): 709–47.

Furthermore, internet panel surveys have numerous existing data points on respondents from previously administered surveys, including detailed demographic and economic information. This allows for the inclusion of additional information on respondents without increasing respondent burden.[73] The respondent burdens are further reduced by automatically skipping irrelevant questions based on responses to previous answers.

The "digital divide" and other differences in internet usage could bias participation in online surveys, so recruited panel members who did not have a computer or internet access were provided with a laptop and access to the internet to complete the surveys. Even so, individuals who complete an online survey may have greater comfort or familiarity with the internet and technology than the overall adult population, which has the potential to introduce bias in the characteristics of who responds.

Sampling and Weighting

The SHED sample was designed to be representative of adults age 18 and older living in the United States.

The Ipsos methodology for selecting a general population sample from KnowledgePanel ensured that the resulting sample behaved as an equal probability of selection method (EPSEM) sample. This methodology started by weighting the entire KnowledgePanel to the benchmarks in the latest March supplement of the Current Population Survey along several geo-demographic dimensions. This way, the weighted distribution of the KnowledgePanel matched that of U.S. adults. The geo-demographic dimensions used for weighting the entire KnowledgePanel included gender, age, race, ethnicity, education, census region, household income, homeownership status, and metropolitan area status.

Using the above weights as the measure of size (MOS) for each panel member, in the next step a probability proportional to size (PPS) procedure was used to select study specific samples. This methodology was designed to produce a sample with weights close to one, thereby reducing the reliance on post-stratification weights for obtaining a representative sample.

After the survey collection was complete, statisticians at Ipsos adjusted weights in a post-stratification process that corrected for any survey non-response as well as any non-coverage or under- and oversampling in the study design. The following variables were used for the adjustment of weights for this study: age, gender, race, ethnicity, census region, residence in a metropolitan area, education, and household income. Demographic and geographic distributions for the

[73] This approach also may allow for the retroactive linking of information learned about respondents from other data, as was done in 2021 to determine Asian respondents in earlier years of the survey.

noninstitutionalized, civilian population age 18 and older from the March Current Population Survey were the benchmarks in this adjustment. Household income benchmarks were obtained from the 2021 March Current Population Survey (CPS).

One feature of the SHED is that a subset of respondents also participated in prior waves of the survey. In 2021, about one-third of respondents had participated in the fall 2020 survey. Prior year case identifiers for these repeat respondents are available in the publicly available dataset, along with weights for this subset of respondents. These weights use a similar procedure as described above to ensure estimates based on the repeated sample are representative of the U.S. population.

Although weights allow the sample population to match the U.S. population (excluding those in the military or in institutions, such as prisons or nursing homes) based on observable characteristics, similar to all survey methods, it remains possible that non-coverage, non-response, or occasional disparities among recruited panel members result in differences between the sample population and the U.S. population. For example, address-based sampling likely misses homeless populations, and non-English speakers may not participate in surveys conducted in English.[74]

Despite an effort to select the sample such that the unweighted distribution of the sample more closely mirrored that of the U.S. adult population, the results indicate that weights remain necessary to accurately reflect the composition of the U.S. population. Consequently, all results presented in this report use the post-stratification weights produced by Ipsos for use with the survey.

Item Non-response and Imputation

Item non-response in the 2021 SHED was handled by imputation. Typically, less than 1 percent of observations were missing for each question.[75] As a result, population estimates were not sensitive to the imputation procedure and a simple regression approach was used.[76]

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[74] For example, while the survey was weighted to match the race and ethnicity of the entire U.S. adult population, there is evidence that the Hispanic population in the survey were somewhat more likely to speak English at home than the overall Hispanic population in the United States. In the 2021 SHED, the 60 percent of Hispanic adults who speak Spanish at home is below estimates from the 2019 American Community Survey. See table B16006 at https://data.census.gov. See the *Report on the Economic Well-Being of U.S. Households in 2017* for a comparison of results to select questions administered in Spanish and English at https://www.federalreserve.gov/publications/2018-economic-well-being-of-us-households-in-2017-preface.htm.

[75] Because item non-response is very low in the SHED, 2021 estimates are comparable with prior years where item non-response was handled differently.

[76] A logit regression was used for binary variables, a multinomial logit for categorical variables, an ordinal logit for ordered values, and a linear regression for continuous values. Typical predictors included income, education, race and ethnicity, age, gender, and metropolitan status, but varied depending on how well they predicted the variable of interest and item non-response. Additional predictors were included as appropriate.

The imputation procedure was carried out as follows:

1. Impute questions, like income and education, to be used in the imputation models throughout.
2. Continue at the beginning of the survey and impute missing values sequentially, question by question.

In some cases, the imputation for one question affected later questions by switching an observation from out-of-universe to in-universe or vice versa. These cases were handled by imputing the missing "downstream" question response or recoding it to missing, where appropriate.

Each variable in the publicly available SHED dataset has a corresponding imputation flag, 'var'_iflag, which is set to 1 if the observation was imputed and 0 otherwise.[77] For example, the first question of the survey about whether the respondent lived with their spouse or partner, L0_a, has a corresponding imputation flag of L0_a_iflag. This question had 31 missing values that were imputed, accounting for 0.3 percent of all observations.

[77] The survey data can be downloaded at https://www.federalreserve.gov/consumerscommunities/shed_data.htm.

Acknowledgments

This survey and report were prepared by the Consumer and Community Research Section of the Federal Reserve Board's Division of Consumer and Community Affairs (DCCA).

DCCA directs consumer- and community-related functions performed by the Board, including conducting research on financial services policies and practices and their implications for consumer financial stability, community development, and neighborhood stabilization.

DCCA staff members Alicia Lloro, Ellen Merry, Kenneth Brevoort, Kayla Jones, Jeff Larrimore, Jacob Lockwood, Anna Tranfaglia, Erin Troland, Douglas Webber, and Mike Zabek prepared this report. Federal Reserve staff members Laura Benedict, Andrea Brachtesende, David Buchholz, Ellen Levy, Madelyn Marchessault, Kirk Schwarzbach, and Pamela Wilson provided valuable feedback on the report. The authors would like to thank Eric Belsky, Anna Alvarez Boyd, Eileen Divringi, Dan Gorin, Simona Hannon, Geng Li, Tenisha Noel, Kamila Sommer, Sarah Stein, and Ann Thompson for their contributions to new survey questions. The authors would also like to thank Bob Torongo, Frances Barlas, Poom Nukulkij, and Alyssa Marciniak for their assistance fielding the survey.

If you have questions about the survey or this report, please email SHED@frb.gov.

Corrections

The Federal Reserve revised this report on August 22, 2022, to reflect corrected data described below.

On page 38, in the Health-Care Expenses section, figure 22, "Forms of medical treatment skipped because of cost during 2021," data were corrected for the entry "Dental care" from 13 percent to 17 percent and for the entry "Seeing a doctor or specialist" from 17 percent to 13 percent.

The Federal Reserve revised this report on February 2, 2023, to reflect the corrections described below.

On page 12, in the Overall Financial Well-Being section, in table 1, "At least doing okay financially (by demographic characteristics)," "LGBTQ+ status was first identifiable in the 2020 survey" was corrected to "LGBTQ+ status was first identifiable in the 2019 survey."

On page 54, in the Housing section, the title of figure 29 was corrected from "Distance to friends, families, and workplaces in 2020" to "Distance to friends, families, and workplaces after moves" and the bar lengths were adjusted to match the figure values.

On page 63, in the Education section, the bar lengths of figure 33, "Parent's views on precautions taken by child's school (by income and race/ethnicity)," were adjusted to match the figure values.

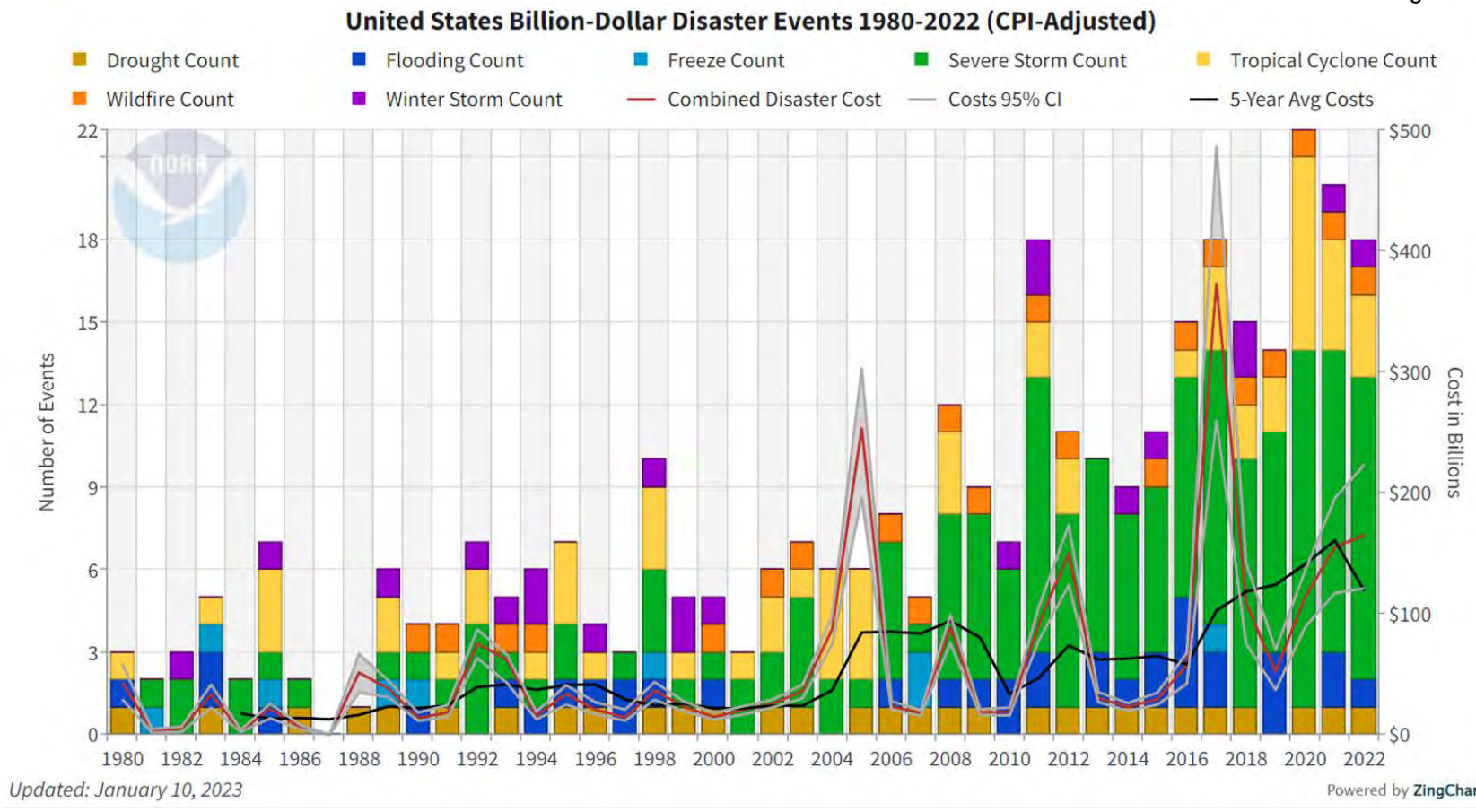
On page 71, in the Education section, the bar lengths of figure 39, "Acquired debt for own education, including repaid debt (by age and highest degree completed)," were adjusted to match the figure values.

On page 76, in the Education section, text in the footnote of figure 41, "Self-assessed value of higher education (by education and debt status)," was corrected from "Among adults ages who borrowed for their own education" to "Among adults who attended college."

On page 83, in the Retirement and Investments section, in figure 47, "At least doing okay financially (by number of financial literacy questions answered correctly)," the text "Key identifies bars in order from left to right" was removed from the footnote.

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United States Billion-Dollar Disaster Events 1980-2022 (CPI-Adjusted)
Drought Count
Flooding Count
Freeze Count
Severe Storm Count
Tropical Cyclone Count
Wildfire Count
Winter Storm Count
Combined Disaster Cost
Costs 95% CI
5-Year Avg Costs
Number of Events
Cost in Billions
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STATE OF MICHIGAN

BEFORE THE MICHIGAN PUBLIC SERVICE COMMISSION

In the matter of the application of **DTE ELECTRIC COMPANY** for authority to increase its rates, amend its rate schedules and rules governing the distribution and supply of electric energy, and for miscellaneous accounting authority	Case No. U-21534 ALJ Sally Wallace

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PROOF OF SERVICE

I, Mark N. Templeton, certify that an electronic copy of the Official Exhibits DAO-264 to DAO-277 sponsored by Arjun Makhijani (Part 8 of 10) on Behalf of Soulardarity and We Want Green, Too was served on the following on September 12, 2024.

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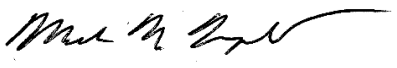
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The statements above are true to the best of my knowledge, information, and belief.

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Date: September 12, 2024

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