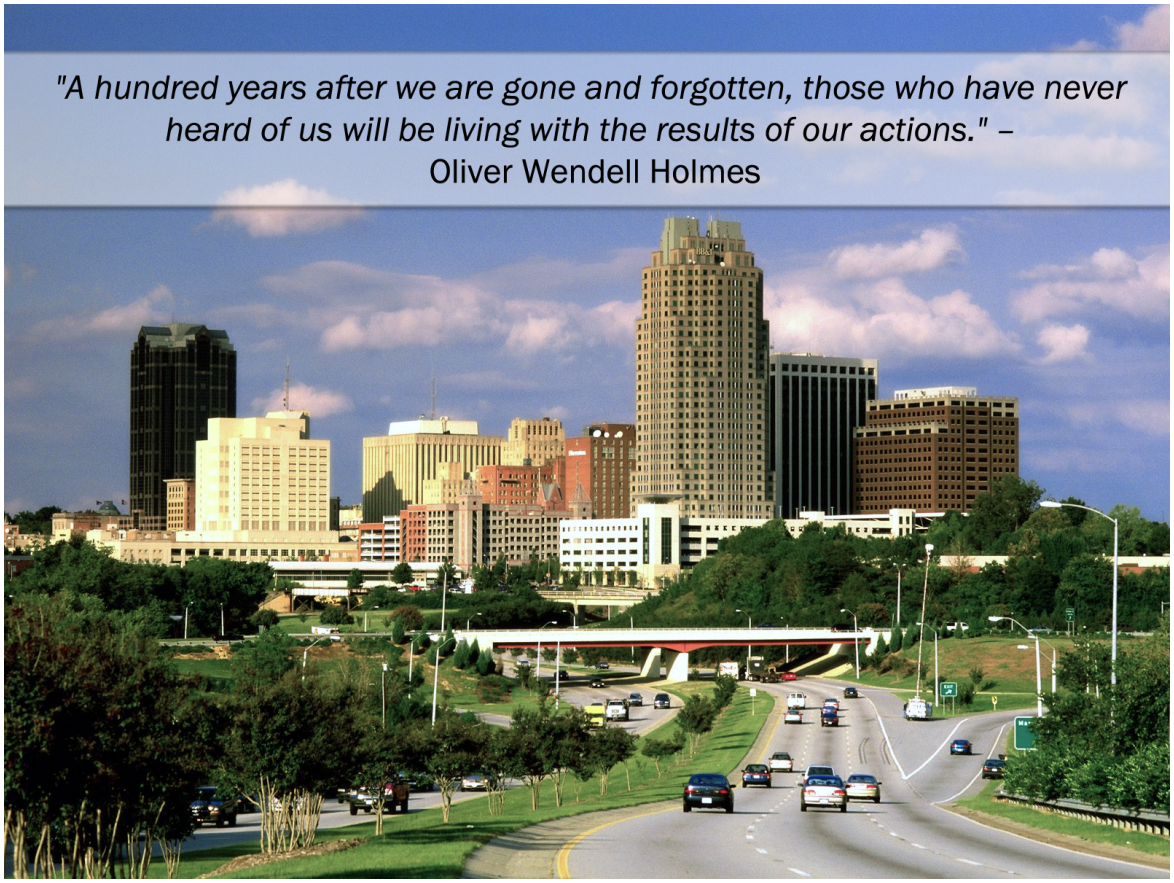
Adapting to Climate Change:

A handbook for local governments in North Carolina



June 2013

In 2050, over 14 million people are expected to be living in North Carolina:

they will be living with the consequences of decisions made today.

Adapting to Climate Change:
A handbook for local governments in North Carolina

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This document has benefited from the ideas, assessment, feedback and support from the Advisory Committee.

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Helpful Definitions

Adaptation	The process of adjustment to the actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.
Climate	Long-term average of weather conditions such as temperature, wind, rain and sunshine over an extended period of time.
Climate Change	A change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or variability of its properties and that persists for decades or longer.
Climate Impact	Any statistically observable change in climate that persists for decades or longer regardless of cause. A statistically observable change is any change in the mean and/or variability of climate conditions that can be identified using statistical tests.
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.
Exposure	The degree of climate stress on a system, which can include long term change in precipitation, temperature or other climate conditions as well as changes in variability. Exposure overlaps with community functions, human structures and populations to produce climate impacts.
Greenhouse Gas	Any gas that absorbs long wave, infrared radiation emitted by the earth. Examples include methane, nitrous oxide, ozone, water vapor, and carbon dioxide.
Natural Hazard	A naturally occurring event that may interact with humans, human activities or the built environment with potential negative effects to people and structures.
Prediction	When a projection is branded "most likely" it becomes a forecast or prediction[1].
Projection	Model-derived estimates of future climate conditions.
Resilience	The ability of a system and its component parts to anticipate, deflect, absorb, accommodate, or recover from the effects of a disruptive event without collapse.
Risk	The likelihood of adverse outcomes due to hazardous physical events interacting with vulnerable social conditions, as determined by the probability of the event and the associated consequences.
Vulnerability	The propensity or predisposition of a system to be adversely affected by natural hazards or climate impacts.
Weather	Short-term atmospheric conditions in a specific location during daily to weekly time periods.

I. Introduction

Since humans first walked the earth, they have been adapting to their environment and climatic conditions[1]. With much less powerful technology than we enjoy today, people have adapted well to their climate, settling everywhere from the arctic and tropical rainforests to the desert[2]. Examples of climate adaptation are all around us. Location of settlements, building construction, transportation systems, business models, agriculture, and recreational activities are all structured and designed to take climate into account[3]. Today we face new risks - increased storm intensity, higher temperatures, more frequent droughts, sea-level rise - but like our ancestors, we have the opportunity to protect ourselves and adapt to our changing climate[4].

This document is intended to provide local governments with information on how climate change might impact their communities, along with strategies that can be implemented to address the changing nature of those threats. We envision a North Carolina where water is used wisely and safe water sources are secure for every community; households and businesses are safe from flooding; and local responders are prepared to protect citizens in times of extreme heat, low air quality, and wildfires. Local governments do a number of things in their everyday activities that can help achieve this vision. Using existing authority and modifying policies and programs that are already in place, local governments can address many of the risks posed by a changing climate to create a more prosperous future.

A. Climate Change

Earth's climate has varied greatly in the past, but global temperatures have risen unusually quickly over the last few decades[5]. Atmosphere and ocean temperatures are higher on average than they have been in the past 500 years, and are likely higher than any other time in the last 1000 years. Global mean surface temperature has risen by approximately 1.3° Fahrenheit over the last century[6]. Eleven of the past twelve years (2000 – 2012) rank among the twelve warmest years on record of global surface temperature (since 1880). In the U.S. temperatures have increased about 1.5° Fahrenheit since 1895: more than 80% of that increase has occurred since 1980[7]. This warming pattern is an example of climate change.

Climate change refers to any statistically observable change in climate that persists for decades or longer regardless of cause. A statistically observable change is any change in the mean and/or variability of temperature, wind, sunshine, rain or other climate condition that can be identified by using statistical tests[8].

Weather is the set of meteorological conditions such as temperature, wind, rain, and sunshine at any particular time and place.

Climate, on the other hand, describes the long-term average of weather conditions such as temperature, wind, rain, and sunshine at a certain place[9]. Both weather and climate are location-specific but weather is time-specific, while climate is the average over an extended period of time. As Figure 1 shows, climate is a smoothed trend of weather events. Weather varies day to

day and some days, weeks or even seasons may not be representative of climate trends. Climate is what you plan for, but weather is what you get.

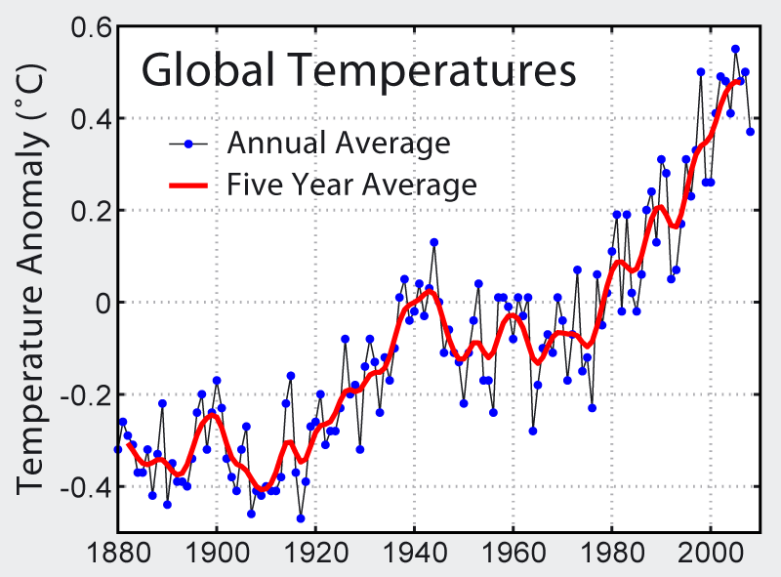

Figure 1.1 The record of global average temperatures compiled by NASA's Goddard Institute for Space Studies. The "zero" on this graph corresponds to the mean temperature from 1961-1990. The thicker red line represents five-year, average temperature; it shows less extreme fluctuations than the annual average[10].

Melting of snow and ice, changing weather patterns, and rising global-average sea level provide further evidence of the changing climate. Since the 1970's:

- Satellite data show arctic sea ice extent has decreased 2.7% every decade and is continuing to melt at accelerated rates[11].
- The area annually affected by drought has increased globally, correlating with significant changes in global precipitation patterns over the last century[12].
- The incidence of extreme high sea level has increased worldwide. Global average sea level has risen at an average rate of 0.07 inches/yr since 1961, but for the past two decades the rate has jumped to 0.12 inches/yr[13]; while these values may seem small, they indicate that the rate of sea level rise has almost doubled in the last forty years and may continue to rise at accelerated rates.

Evidence continues to accumulate that demonstrates climate change is occurring at an accelerated rate.

In addition to changes in average climate conditions, there has been an increase in climate variability worldwide over the last two decades[14]. Weather extremes are projected to occur more frequently, including more frequent wet and dry spells[15]. As the atmosphere warms, its water-holding capacity increases. As a result precipitation is expected to be concentrated in heavy rainfall events, separated by longer dry periods. This phenomenon has already been observed[16]. With the warming of the ocean, tropical storms are also expected to become more intense. These fluctuations and trends towards extremes alone stress human systems[17], necessitating a reevaluation of our development and environmental policies.

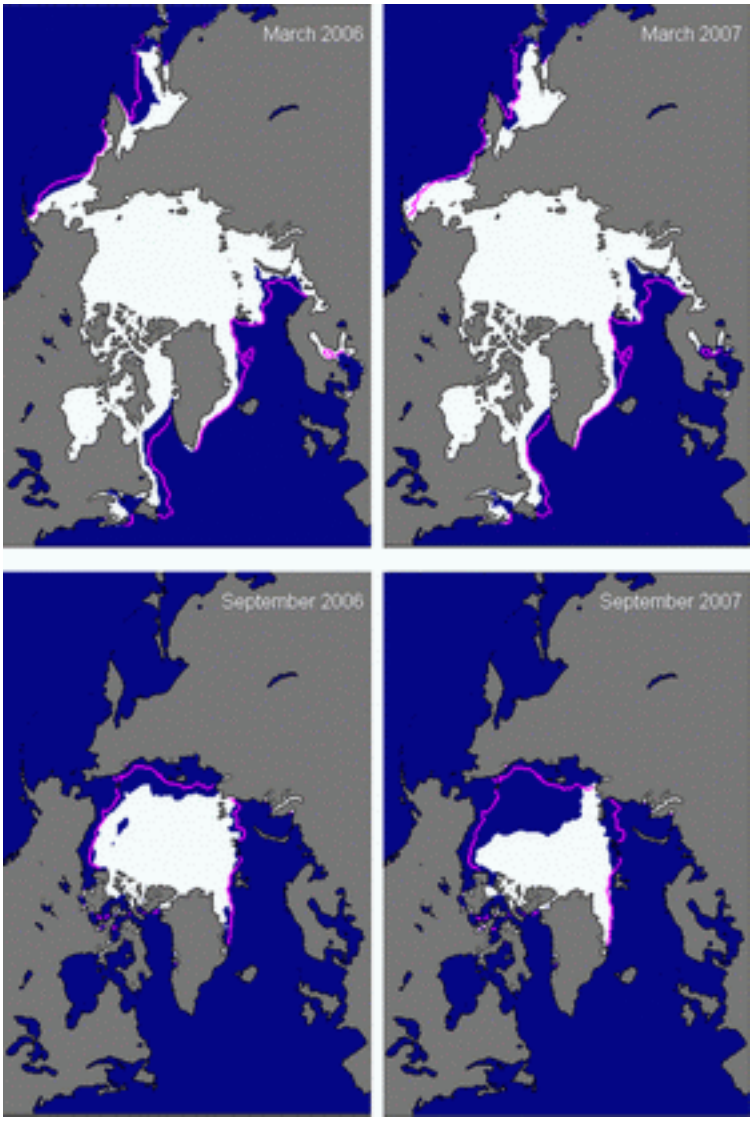

Figure 1.2 Sea ice extent in March and September 2006 and 2007, when the ice cover was at or near its maximum and minimum extent, respectively. The magenta line indicates the median maximum and minimum extent of the ice cover between 1979 and 2000. The March 2006 maximum extent and the September 2007 minimum extent established new records as the lowest extents for the period 1979-2007[18].

While the observed impacts of climate change - melting of snow and ice, rising sea level, and changing weather patterns - may seem distant, climate change will have drastic consequences in local communities everywhere. Under a "business as usual" scenario, people worldwide are very likely to experience greater poverty, hunger, disease, drought and flooding[19]. These consequences will cross national, state, and local boundaries affecting communities across the globe, the United States, and North Carolina.

Buildings, streets and other infrastructure are designed using assumptions about climate that are extrapolated from past trends. As climate changes, historic trends will become less accurate,

requiring adjustments to how infrastructure is designed and built. The efficiency and lifespan of old infrastructure will be compromised by the changing climate.

Costs of climate change will not only come in the form of infrastructure damage, but also from economic loss in the agriculture, health and tourism sectors. For example, higher temperatures and more frequent droughts in North Carolina are expected to decrease air quality and increase hospitalizations and costs of asthma[20]. In 2005 10.1% of adults and 17.8% of children in North Carolina reported being diagnosed with asthma[21]. Of these adults 32% reported having to miss work due to the disease and 47% of children have had to miss at least one day of school in the past year. Individuals with asthma also report high rates of hospitalization. In 2004 the cost of hospitalizations from asthma reached $88 million. In 2003 asthma is estimated to have cost North Carolina a total of $631 million; this figure includes the direct costs of physician visits, medication and hospital stays as well as indirect costs such as lost work days, school absenteeism, loss of productivity and lost earnings.[22].

In the winter of 2009 and 2010, the ski industry contributed $146 million to North Carolina's economy[23]. During low snow years, the number of visits to ski resorts drops on average by 43,855 (5%) trips and the revenue generated by the industry decreases by $2.7 million (10%)[24] on average. This loss in visits and revenue can cause significant economic loss for local governments in the form of reduced tax revenues and lost jobs. As climate changes, local governments may not be able to depend on traditional sources of revenue such as the ski industry. As with natural disasters, much of the burden of climate change will largely be carried by local governments and their taxpayers.

PROJECTIONS OF CLIMATE CHANGE

There are many ways to **project** climate change. One common approach is to evaluate the historic changes in temperature, rainfall, extreme events and other meteorological variables and extend the trends into the future. This linear approach can provide an idea of the direction of change, but there is no guarantee that the rate or magnitude of change of these variables will remain the same as the past, making accurate projections difficult.

An alternative approach, one that accounts for varying rates of change, is the use of computer modeling tools called General Circulation Models (GCMs). GCMs have the ability to account for the physics and chemistry of the earth system, as well as important climate feedbacks such as water vapor and methane release. Despite these advantages, GCMs are not perfect. GCMs produce climate projections for the whole globe, at low resolution; thus they do not model smaller local scale climate trends very well. Likewise, these models do not account for short-term climatic changes that occur in the real world such as El Nino events and the Atlantic Multidecadal Oscillation (that is related to hurricane activity in the Atlantic).

Making accurate projections is further complicated by the need to account for future human activities and emissions; for example, climate outcomes could be much different if new mitigation policy is adopted to curb GHG emissions than if we continue with business as usual. To account for this uncertainty in future emissions, the International Panel on Climate Change (IPCC) uses several scenarios representing different plausible assumptions of economic activity, emission regulations and technology[25]. Given the uncertainty of any given model, IPCC and

other large-scale assessment reports combine data from multiple GCMs to produce their **predictions**.

Models project current warming trends will continue and accelerate in the future. IPCC predicts that the earth's average temperature will rise about 5.4° F over the next century with a range of uncertainty from an increase of 2.0 to 11.5° F[26]. For comparison, the temperature has risen 9° F between the last ice age 10,000 years ago and the present, but the warming we are experiencing now is occurring over a much shorter timespan. Some experts have predicted that warming of 3.6° F will tip many earth systems over a threshold, causing widespread loss of Arctic sea ice, species extinctions and damage to infrastructure and agriculture[27].

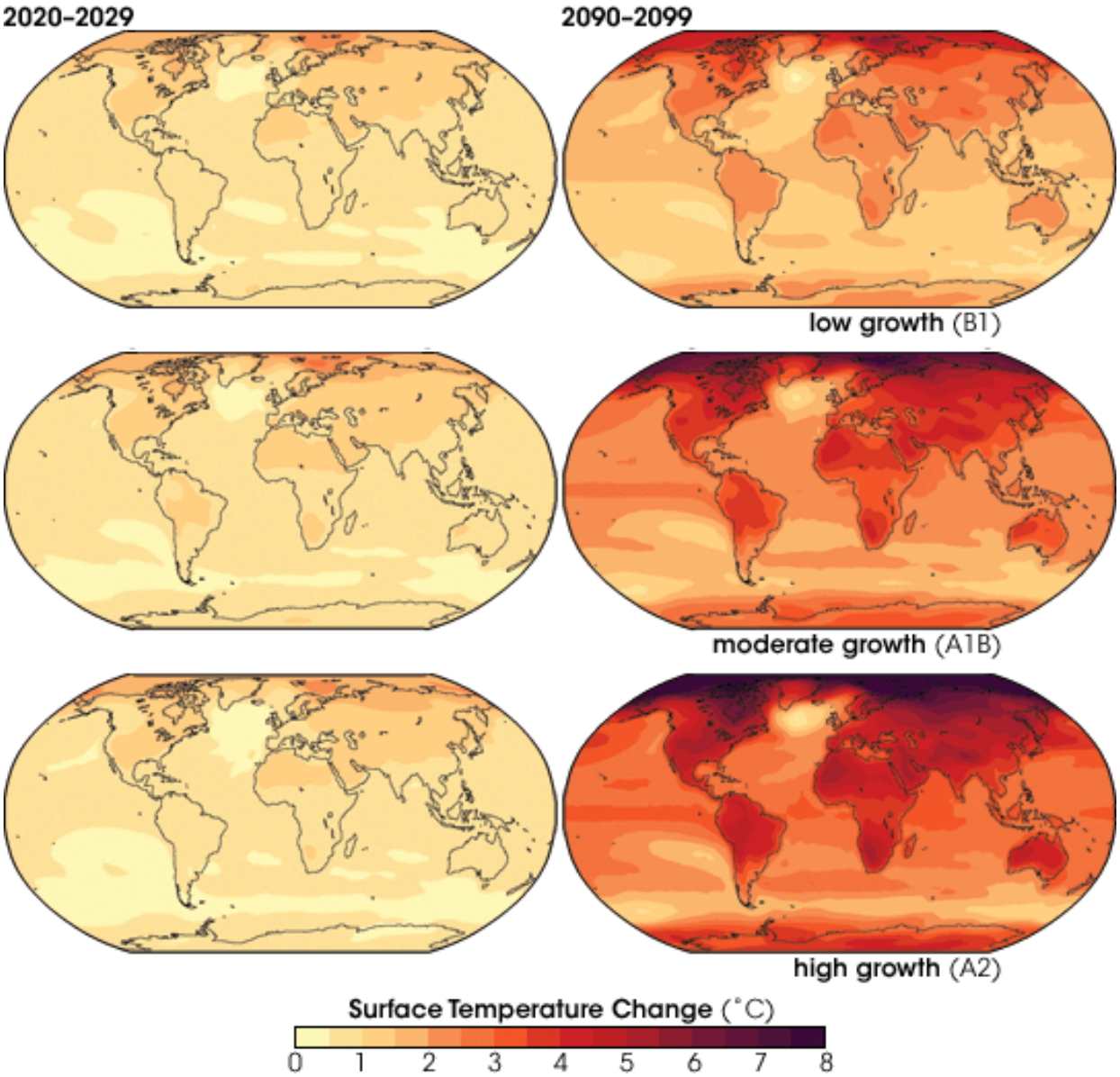

Figure 1.3 Average projected temperature change for three different IPPC growth and emission scenarios. Temperatures are relative to 1980 - 1999[28].

Climate models also project that wet regions of the world will become wetter and dry regions will become drier[29]. Globally, heat waves and heavy precipitation events will become more frequent and intense.

Climate models project smooth changes in climate, but the geological record shows that past changes in earth's climate can occur during punctuated events. These rapid changes are not completely understood, but suggest that future climate may be subject to punctuated change. Mechanisms that may lead to rapid changes may include changes in ocean circulation and release of greenhouse gases from the melting of permafrost[30].

Although climate projections are not perfect, they provide enough information to make sound policy decisions to manage risk of climate-related disasters[31]. In cases where there are threats of serious or irreversible damage, a lack of full scientific certainty should not postpone implementation of cost-efficient measures to prevent economic loss, environmental harm and loss of wellbeing[32].

"Although climate projections are not perfect, they provide enough information to make sound policy decisions to manage risk of climate-related disasters."

PROJECTIONS FOR NORTH CAROLINA

North Carolina experiences hurricanes, floods, droughts, heat waves, winter storms, cold spells, hail, high winds, lightning and tornadoes in any given year[33]. Although 2012 was not an extreme year, North Carolina broke 40 heat records, 4 snow records, 13 precipitation records and experienced 19 large wildfires in that year alone[34]. Since 2006 North Carolina has recorded the warmest month and the warmest summer, experienced the worst drought in 100 years, suffered the worst tornado outbreak, and been impacted by eight tropical cyclones (hurricanes, tropical storms, and tropical depressions). These events may be random occurrences of bad luck, or they may be reflections of a changing climate. In either case, North Carolina experiences its share of extreme events and will continue to experience them into the future. No model of future climate projects a reduction in these events, rather it is expected they will become more frequent and/or intense.

In North Carolina, climate change is expected to cause more extreme heat, rising sea levels, more intense hurricanes, and changing precipitation patterns causing more drought and heavy rainfalls[35].

Since the 1970s, North Carolina and the entire Southeast region of the U.S. have been undergoing a warming trend. Although the recent warming trend is not unprecedented to warming that occurred earlier in the temperature record, it is projected to continue into the future. Average temperatures in North Carolina are projected to increase by 4-5°F in the winter and 6-7° in the other seasons by 2100[36]. This rise in temperature means:

- More intense and frequent heat waves or consecutive high-temperate days, when temperatures do not cool off as much at night.
- An increased number of very hot days throughout the year.

- An increase in seasonal average temperatures. Future climate projections include shorter cool seasons and longer warm seasons, with an increase in average temperature during both.

Between 1993 and 2003 global, mean sea level rose by approximately 0.12 inches/year. Global sea-level rise is expected to accelerate in the future. The IPCC projects a 7 to 23 inch rise in global average sea level by 2100, but this projection does not include melting of ice. More recent research that accounts for ice melt projects a rise as large as 55 inches by 2100[37]. The change in sea level in North Carolina will result from the rise in global average levels, as well as local factors such as coastal slope, subsidence, shoreline erosion rates, and the shape of the coastline.

Data from the last half-century indicates that sea level has risen about 10 inches/century in North Carolina, but the rise is not consistent across the state. The coast north of Cape Hatteras, has experienced much greater sea-level rise. Many variables make North Carolina vulnerable to sea level rise including the coastal slope, geological makeup, erosion rates, and the shape of the coastline.

The minimum expected sea-level rise in North Carolina over the next century is 8 inches, which corresponds to a linear projection of current rates. Accelerated rates, however, are much more likely due to rising temperatures and melting ice at greater than historic trends. Accelerated rates of sea level rise may cause as much as 6.5-foot increase in sea level by 2100[38]. It is important to recognize forecasts of sea-level rise do not calculate sea level at specific points in time and that acceleration may not be constant over the next 90 years. Rather, rise in sea level may be discontinuous marked with sudden large changes, thus in 50 years we may have only experienced a small fraction of the rise that will occur by 2100.

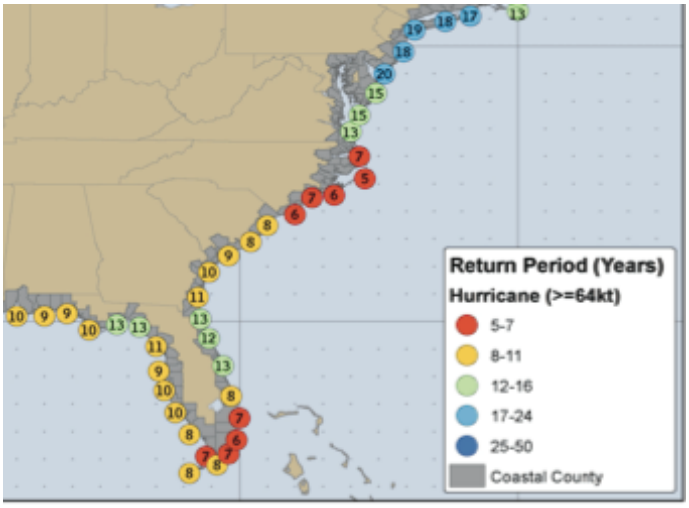

Figure 1.4 Return period (in years) of hurricanes passing within 50 nautical miles of various locations on the U.S. coast over the last 100 years[39].

On average, North Carolina can expect to receive a tropical storm or a hurricane once every 4 years[40]. During the 20th century (1901 – 2000), North Carolina experienced 81 direct hurricane and tropical storm landfalls[41]. In recent decades the intensity and destructive energy of

hurricanes in the Atlantic basin have increased and are likely to continue increasing[42]. Evidence continues to accumulate that higher water and air temperatures increase the intensity of hurricanes and tropical storms. Thus North Carolina can expect even more significant damage from hurricanes than it has experienced if nothing is done to mitigate impacts.

In the last 110 years, there has been little change in precipitation trends statewide; however, recent decades show an increase in variability between years[43]. Precipitation in North Carolina is projected to continue this recent trend of greater variability. Greater variability means that droughts, as well as more intense precipitation may become more frequent.

North Carolina is projected to endure more droughts like the 1998-2002 drought when the state experienced new low records for lake, reservoir and groundwater levels. Such droughts are expected to increase in both frequency and duration across the southeast region of the U.S. North Carolina can also expect a continuation of the recent increase in frequency of extreme precipitation events. Overall average annual precipitation is expected to increase as much as 6%[44], but this increase is expected to occur through fewer precipitation events that yield a higher amount of rain per event.

To summarize, North Carolina is projected to experience higher temperatures, rising sea levels, more intense hurricanes, more frequent drought and greater heavy precipitation. These climatic changes will have a significant toll on the state and local communities. Each condition and its expected impacts are discussed in greater detail in section II.

Five climate conditions most likely to impact North Carolina:

1. **More frequent and severe drought**
2. **More extreme heat**
3. **More intense hurricanes**
4. **Rising sea-level and accompanying storm surge**
5. **More intense heavy precipitation events**

CURRENT VULNERABILITY

The last section reviewed potential changes in hazard frequency and intensity due to climate change, but North Carolina is already vulnerable to climate impacts. Currently, North Carolina is ranked among the states with the highest number of billion dollar disasters. North Carolina experiences almost every kind of extreme weather from tornadoes to hurricanes, ice storms to wildfires:

- In 2002, drought caused a loss of $398 million in North Carolina's agricultural sector alone, and an additional $233 million loss in related industries[45]. In total 4,337 North Carolina jobs were affected by the drought.
- In 2003, Hurricane Isabel caused $200 million in insured property loss in North Carolina.
- During a drought in 2007, 340 water systems called for water restrictions affecting about five million residents.
- Every summer an average of twenty individuals die of heat stress.

The damage caused by recent extreme weather demonstrates the current cost of infrastructure, agricultural practices, land use choices, and behavior. As climate continues to change, extreme events are likely to become more frequent, intense and widespread, and the cost associated with them ever greater.

"As climate continues to change, extreme events are likely to become more frequent, intense and widespread, and the cost associated with them ever greater."

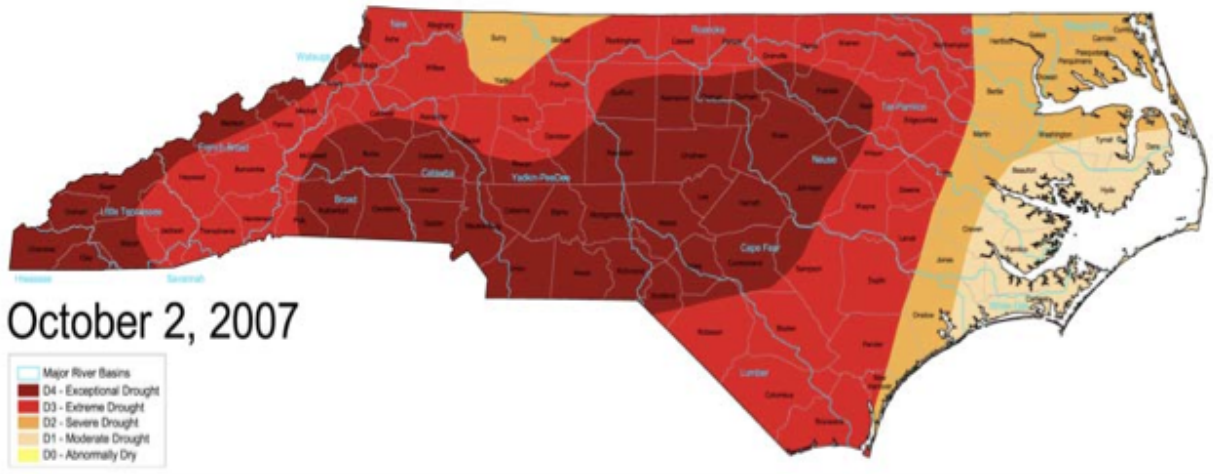

Figure 2. North Carolina's 2007 drought conditions that required over 340 public water systems to enact restrictions[46].

The impacts of any weather event occurs at the intersection of climate extremes, the built environment and human decisions. Losses from weather events today indicate the **vulnerability** of the built environment and the need to improve decision-making. With climate change, the frequency, intensity, spatial extent, duration and timing of extreme weather will change and may result in unprecedented extreme weather and climate events[47]. Events that occurred only once every 30 years on average may begin occurring every 4 to 5 years in the future[48].

There is little that can be done to prevent this increase in extremes, but there are opportunities to decrease community vulnerability and climate impacts and, in doing so, decrease losses from current and future disasters. While climate change may increase the frequency and intensity of hazards, the damage caused by those hazards cannot be attributed to climate change alone – good policy can reduce risk today and in the future.

B. What can be done?

Strategies and measures to limit the impact of climate change vary from simple to complex, from saving water and energy by turning off the faucet when you brush your teeth to international agreements to reduce greenhouse gas emissions[49]. Local governments have innumerable adaptation options from better sealing manholes, to relocating their sewer system, to guiding development out of hazardous areas. Not all options may be available to every community. Some

specific adaptation options may be unnecessary or too expensive for some municipalities, but action to reduce risk is within the reach of all communities.

Responses to climate change are generally divided into two categories: efforts to address the "cause" of human-induced climate change known as mitigation; and efforts to address the "symptoms" of climate change known as adaptation. Neither of these efforts pursued alone can help us avoid all climate change impacts: rather, mitigation and adaptation complement each other, and if pursued together, can significantly reduce the risks of climate change[50].

Climate change is like an imminent car crash:

Mitigation is the brakes – it will reduce the magnitude of the impact of climate change.

Adaptation is the airbag – it will soften the blow.

We need both to survive the crash intact!

(Source: Climate Wise. 2011. Integrated strategies for a Vibrant and Sustainable Fresno County. www.geosinstitute.org/images/stories/pdfs/Publications/ClimateWise/FresnoClimateWiseFinal.pdf)

Many adaptation actions also reduce greenhouse gas (GHG) emissions. Green roofs, for example, cool cities and retain water during storms (adaptation); they also increase the energy efficiency of buildings resulting in lower demand for fossil fuels and lower emission of green house gases (mitigation). Other adaptation strategies, however, may have negative ramifications for mitigation efforts. Therefore it is important to pursue these avenues in tandem.
Some may question why mitigation should be pursued at all if we can simply adapt as climate changes, but most adaptation measures become more costly and less effective as the magnitude of change gets larger[51]. If mitigation is not paired with adaptation and climate change continues

to accelerate, opportunities to adapt will be curtailed by the rapid pace and large scale of change[52].

Hazard Mitigation, Climate Mitigation and Climate Adaptation… A confusing world.

Climate mitigation aims to reduce the forcing that causes climate change while adaptation aims at reducing vulnerability to climate change. Hazard mitigation, focused on reducing vulnerability to natural hazards, shares many of the same characteristics of climate adaptation. Both are focused on identifying vulnerability to natural hazards and developing strategies to reduce that vulnerability, in fact, many of the strategies overlap between the two. So what's the difference? Climate adaptation requires a longer time frame and broader approach than is incorporated into the typical hazard mitigation plan.

To be eligible for certain types of state and federal disaster relief funds, all local governments must have a hazard mitigation plan. The hazard mitigation planning process presents an opportunity for communities to address climate adaptation, in their 2013 "Hazard Mitigation Planning Handbook" FEMA recognizes the opportunity to integrate hazard mitigation and adaptation.

MITIGATION

The Rio Accord, signed in 1992, defines mitigation as actions that promote the stabilization of greenhouse gas concentrations at a level that would prevent dangerous effects of climate change[53]. Signing countries, including the United States, agreed to several mitigation measures. Since then, mitigation has remained the predominant focus of international, national and local efforts to address climate change.

The Kyoto Protocol, signed in 1997, and the Copenhagen Agreement, signed in 2009, followed in the footsteps of the Rio Accord by establishing emission reduction targets for participating countries. Although the United States participated in both conferences, it failed to ratify the Kyoto Protocol. Consequently, national mitigation efforts in the U.S. have lagged behind those of other countries. Only recently, under President Obama, has national action been taken to reduce fossil fuel emissions. This action includes new EPA standards for automobile fuel efficiency, requiring permits for the largest stationary GHG emitters, mandatory reporting of greenhouse gas emissions from large emitters and the American Recovery and Reinvestment Act that funds state, local and tribal governments to reduce fossil fuel emissions, reduce energy use and improve energy efficiency.

Most mitigation efforts in the U.S. have emerged at the regional and state level. California has taken the lead by passing legislation to reduce state emissions to 1990 levels by 2020[54], establishing more stringent fuel emission standards for cars[55], mandating local land use plans to include GHG reduction strategies[56] and implementing a cap and trade program. Cap and trade programs set a total limit to emissions and then allocate those emissions to firms. Firms may then use their allotted emissions or sell them on an open market. The market system is intended to achieve the greatest reduction in emissions possible at the lowest cost to society because firms that can easily reduce their pollution will do so and sell their excess permits to those that have

greater difficulty. Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont established the Regional Greenhouse Gas Initiative (RGGI) in 2009, a cap and trade program for electric utilities. In addition, 36 states have created climate action plans that focus on mitigating climate change; two more are in the process of developing such a plan[57].

Local governments have also been taking strides to mitigate climate change, despite the lack of strong federal leadership. When the United States failed to ratify the Kyoto Protocol, the mayor of Seattle established the U.S. Conference of Mayors Climate Protection Agreement. By signing the agreement, mayors agree to strive for GHG reductions. Over 1,000 mayors have now signed the agreement including 43 from North Carolina[58]. In addition ICLEI Local Governments for Sustainability initiated a Cities for Climate Protection Campaign in 1993, which has now grown to include over 500 cities in the U.S and 9 in North Carolina. The Sierra Club also launched a Cool Cities campaign in 2005 to aid cities to mitigate climate change and includes 42 North Carolina cities[59].

ADAPTATION

Adaptation encompasses all methods to reduce the adverse effects of actual or expected climate on health and wellbeing, and also takes advantage of the opportunities that climate conditions provide. The concept of adaptation emerged in the Rio Protocol; however, it remained undefined and has received much less attention than mitigation. Not until Copenhagen did adaptation re-appear on the international scene with the establishment of a fund to subsidize adaptation[60].

Since then, much more effort has been given to adaptation at the national, regional and state level. Federal leadership, guidance, information and support are vital in fostering adaptation at state and local levels. In recent years the federal government has developed new adaptation initiatives and strategies such as[61]:

- Executive Order 13514 requires all federal agencies to develop recommendations for strengthening existing programs to adapt to climate change;
- The creation of the U.S. Interagency Climate Change Adaptation Task Force (ICCATF) was the principal party in developing national principles for adaptation and is leading to cross-cutting adaptation policies;
- The development of three cross-cutting adaptation strategies focused on integrating multiple levels of government efforts on adaptation in key sectors including freshwater resources, fish and wildlife, and ocean policy[62]; and
- A new decadal (2012-2021) research plan that intends to improve basic climate science, inform decisions, and improve assessments and communications[63].

A number of individual federal agencies have also taken action to promote, implement or support adaptation. These efforts are particularly important in fostering stewardship of public resources, building public awareness, providing usable information and projections, disseminating best practices, and ensuring the establishment of "flexible" federal policy[64]. The U.S. national security community has also come to view climate change as a threat to national security and is beginning to pursue adaptation[65].

Most state adaptation efforts have focused on preparing plans -14 states have completed climate adaptation plans, three are in the process of writing plans and eight others have made recommendations to create a statewide adaptation plan[66]. In addition many states have sector-specific plans that address a single service the government provides, such as transportation or water. These plans, as well as other state programs, serve to reduce state vulnerabilities, but they also serve an important role in national climate-related policy. State programs can encourage and incentivize local adaptation, serving as a laboratory for innovation and a model for federal programs. State action applies pressure to federal and private agencies to take further action[67].

To date, most adaptation has occurred at the local and regional level[68]. A recent survey of cities that are members of ICLEI-Local Governments for Sustainability found that about 175 cities are engaged in some form of adaptation planning[69]. Local adaptation is being pursued by municipalities of different sizes from a diverse geographic range. Leaders of climate adaptation such as Keene, New Hampshire; New York City, New York and Fresno County, California are now in the process of implementing their strategies. Efforts pursued at the local level encompass land use planning, provisions to protect infrastructure, new regulations on the construction of homes, road and bridges and new emergency measures to improve preparation, response and recovery[70].

Non-governmental and private institutions have also been significant actors in climate adaptation. Non-governmental organizations have provided assistance to local governments in the form of planning guidance, implementation tools, contexualized climate information, best practice exchange and helping to bridge the science-policy barrier[71]. A growing number of companies are also beginning to actively address risks of climate change. These efforts have been taken to protect core operations, value chains and broader networks from climate change impacts. For example, S.C. Johnson and Son is adjusting to potential climate-related disruptions by geographically diversifying its ingredient sourcing and operations to ensure business continuity[72].

C. Conclusion

THE CASE FOR ADAPTATION

Even if carbon dioxide emissions stopped today, climate change would continue and global temperatures would warm by about 1.1° F by 2100 due to greenhouse gases that have already been released[73]. We know that we are already committed to some warming, and we know this warming will affect many of the critical services and functions that local governments provide[74]. Some communities are already feeling the affects of climate change in the form of higher disaster costs and changing fauna and flora[75], but the high cost and damage of climate change are not inevitable. Adaptation provides an opportunity to reduce these risks.

"We know that we are already committed to some warming, and we know this warming will affect many of the critical services and functions that local governments provide."

The good news is that many adaptation actions have obvious immediate benefits as well as the long-term benefits and are worth pursuing in and of themselves[76]. Adaptation strategies are generally consistent with sound environmental practice, improve resource use today, and are appropriate responses to increase resilience against current natural hazards[77]. Many communities that created climate adaptation plans found that the strategies they recommend are consistent with the goals laid out in their other plans. Alexandria, Virginia found that many of their adaptation goals and actions overlapped with those already identified in the City's Environmental Action Plan[78]. Lewes, Delaware integrated climate adaptation into their hazard mitigation plan. In doing so, Lewes tied current hazards to long term climate trends and selected robust strategies that could address current hazards and long-term climate impacts. Like hazard mitigation planning, adaptation planning can be more cost effective than reactive action following change.

The costs of inaction are great and likely to grow in the future. Acting today will help prepare North Carolina's communities for these worsening impacts and provide time to achieve long-term goals of resilience.

Why make changes if the future is uncertain?

While the models agree that average temperature will increase, projections for other factors such as precipitation are less certain. Why would we invest time and resources into planning for such uncertainty? There are 3 main reasons:

1. Planning for continued historic conditions sets us up for failure. All of our current planning mechanisms use history to plan for the future – such as drought frequency and severity, dam stability, flood risk to communities, etc. Yet no climate models predict continued historic conditions. Relying on continued historical conditions for a community's needs, such as water for residents, winter chill for crops, or snow for recreation, will likely lead to failure.

2. We plan for uncertain conditions on a regular basis, and don't even realize it. Climate change is no different. Some examples include harvesting timber based on models of tree growth, planning new freeways based on 20---40 year projections of population growth and commute patterns, and buying fire insurance when we don't expect to have a fire. The severe potential cost of climate change (by some estimates, around 13% of national GDP by 2040) is so high that we would be prudent to plan proactively and reduce that risk.

3. Taking action makes the community more resilient and vibrant, regardless of the actual trajectory of climate change. Communities in North Carolina are already at risk of water shortages, flooding, heat mortality, and loss of agricultural and natural lands to development. By addressing these and other issues now, North Carolina residents' quality of life can be improved.

(Source: Climate Wise. 2011. Integrated strategies for a Vibrant and Sustainable Fresno County. www.geosinstitute.org/images/stories/pdfs/Publications/ClimateWise/FresnoClimateWiseFinal.pdf)

THE CASE FOR LOCAL ACTION

Because climate change is often viewed as a global phenomenon for which international treaties and national policy are the best actions, local governments may feel that climate change is not a local issue which they are responsible for, nor one which they have the ability to influence. However, the effects of climate change will be felt at the local level first. It is at the local level that streets and homes are flooded, asthma attacks occur, and crops are lost. It is also at the local level that potable water is supplied, wastewater is treated, development patterns are determined, building permits are issued and streets are built. During storms and drought, citizens turn to their local governments for solutions[79].

Local governments have the responsibility to protect their citizens. State and local governments have the authority to adopt laws to protect their citizens' safety, health, and general welfare. With this authority comes the responsibility to govern for the community's benefit. In light of climate change, this means taking steps to protect citizens from the risk of more intense hurricanes, the risk of higher temperatures, the loss of property from sea level rise and much more.

All levels of government, the private sector, and ordinary citizens can take action to reduce risk of climate change. Local governments are in a unique position to promote adaptation and reduce risk especially through land use planning, landscaping ordinances and infrastructure improvements, building codes, floodplain management, energy ordinances and more[80]. Local governments have the authority and a variety of tools to address many of these issues. In fact, through existing programs, local governments can take meaningful action to address climate change impacts.

Not only do local governments have the appropriate tools, they also have the necessary information and understanding of local issues. There are no one-size-fits-all adaptation programs. The impacts of climate change will differ based on the geographic region, scale of community and local capacity[81]. Local action can best address these differences in context and concerns.

Supreme Court Justice Oliver Wendell Holmes once said, "A hundred years after we are gone and forgotten, those who have never heard of us will be living with the results of our actions."[82] In 2050, over 14 million people are expected to be living in North Carolina: they will be living with the consequences of the decisions made today.

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II. Impacts and Strategies

Local governments already address many issues that may be associated with climate change such as water availability, storm damage, and public safety. Without concerted action, however, increased severity and frequency of climate impacts will take a greater and greater toll on communities' citizens and finances. This section reviews:

1. Major climate change exposure in North Carolina
    a. More frequent drought
    b. More extreme heat
    c. More intense hurricanes
    d. Increased intense precipitation
    e. Rising sea level and accompanying storm surge
2. Impacts on local governments
    a. Economic impacts
    b. Health impacts
    c. Environmental impacts
3. Possible strategies to lessen vulnerability
    a. Infrastructure strategies
    b. Land use strategies
    c. Natural resource strategies
    d. Education strategies

In this section the economic, public health and environmental impacts are described for each major climate exposure. While this structure is helpful to understand the potential cost of climate change, it is important to remember that many of the consequences of climate change have impacts across categories. For example, sea-level rise threatens saltwater marshes. This alone is an environmental impact, but it will also have economic and public health costs. Along with the loss of saltwater marsh comes the loss of the fisheries it supports and the storm protection it provides.

In addition, climate impacts interact to cause greater damage than they would alone. For example:

- Sea level rise increases the potential damage caused by hurricanes;
- Drought and increased temperatures together increase the likelihood of wildfires; and,
- Drought followed by heavy precipitation can pose serious water quality and flooding issues.

Strategies to address the impacts of climate change are grouped into four categories: Infrastructure, Land Use, Education, and Natural Resources.

- **Infrastructure strategies** involve changes or modifications of the basic physical systems of society to make both infrastructure itself, and the community that depends on it, more

resilient to impacts of climate change. These strategies include construction of new water storage systems, increased street maintenance, and raising wastewater treatment plants above flood levels and more.

- **Land use strategies** guide development and people out of harm's way, as well as improve design and location of development to better respond to climate change. Land use includes restrictions on development in flood zones, low impact design to improve management of stormwater, and urban landscaping to reduce summer temperatures.
- **Natural resource strategies** reduce consumption of raw resources and protect ecosystems that provide essential services. For example, techniques to reduce fresh water consumption and measures to protect coastal marshes that limit storm damage would both be considered natural resource strategies.
- **Education strategies** disseminate information about climate change impacts and adaptation measures to the general public and businesses. The success of many of the above strategies relies on the willing participation of community members; thus education strategies are central to effective adaptation. Business outreach is imperative to help community businesses learn about and address climate change impacts.

A. More Frequent Drought

Although North Carolina is a humid state, it does experience drought. Drought is defined as a period of time when precipitation deficits result in human-felt losses such as reduced agricultural production or shortages of freshwater supplies. Rapid population growth and development in North Carolina have exacerbated the region's demand for water and consequently increased the states' vulnerability to droughts. During the 1998-2002 drought, North Carolina experienced new record lows for lake, reservoir and groundwater levels. Unlike other hazards, drought can plague the area for weeks to years. In June 2012, heavy rains lifted the state completely out of drought for the first time since June 29, 2010[1]. Droughts are expected to increase in frequency and duration in the future.

Figure 2.1 Falls Lake during 2008 drought[2].

Economic Impacts

Droughts have the potential to cause widespread economic damage. The 2002 drought affected 4,337 jobs in North Carolina. The agricultural sector alone suffered $398 million in losses in 2002. Five years later, in 2007, another drought in North Carolina caused $500 million in agricultural damages[3]. Without adequate water, farmers can lose crops and livestock.

In 2012, the most severe and extensive drought in at least 55 years severely reduced national agricultural production. About 80% of agricultural land in the U.S. experienced drought in 2012 dramatically decreasing expected yields. Crop yields dropped 27% below expected levels. The decline in supply of corn and other commodities raised their cost to record highs. Corn prices rose to $6.95-8.25 a bushel, up from $6.22 a bushel the year before.

Poor quality of pasturelands and higher prices for feed will also increase the price of meat. Production of cattle, broiler chickens and hogs all decline with increasing drought[4]. When precipitation declines, agriculture is forced to rely more heavily on irrigation, increasing demand for water and producing potential conflicts over allocation of declining water supplies. Areas with large amounts of agriculture, such as the Piedmont and Coastal Plain regions, consequently will be more vulnerable to drought[5].

Reduced stream flow can also reduce the availability of electricity. Low stream flow will decrease power generation by hydropower. But it also reduces water available for energy plants to generate electricity and dispose of the heated cooling water safely. More than 80% of freshwater consumed in North Carolina is used for cooling power plants. On average, 500 gallons of water is needed to produce 1 megawatt-hour of electricity in a coal-fired power plant. Consequently drought has the potential to shut down coal and nuclear power plants[6].

Droughts also cause water emergencies triggered by water shortages in reservoirs, streams and wells. During the 2007-2008 drought in North Carolina, water-use restrictions were placed on 53% of public water systems, affecting five million people. At one point, 30 cities were at risk of having to ration water; some were within 100 days of exhausting their water supplies[7]. Lack of water has already become a constraint on many communities' growth restraining economic development and posing a major challenge to communities.

Health Impacts

The loss of electricity can pose a serious health threat. In the summer time, blackouts can cause heat stress, especially among the young and elderly. The loss of electricity can also have a domino effect, knocking out communication networks that can further increase individual risk by impeding the transmission of emergency information.

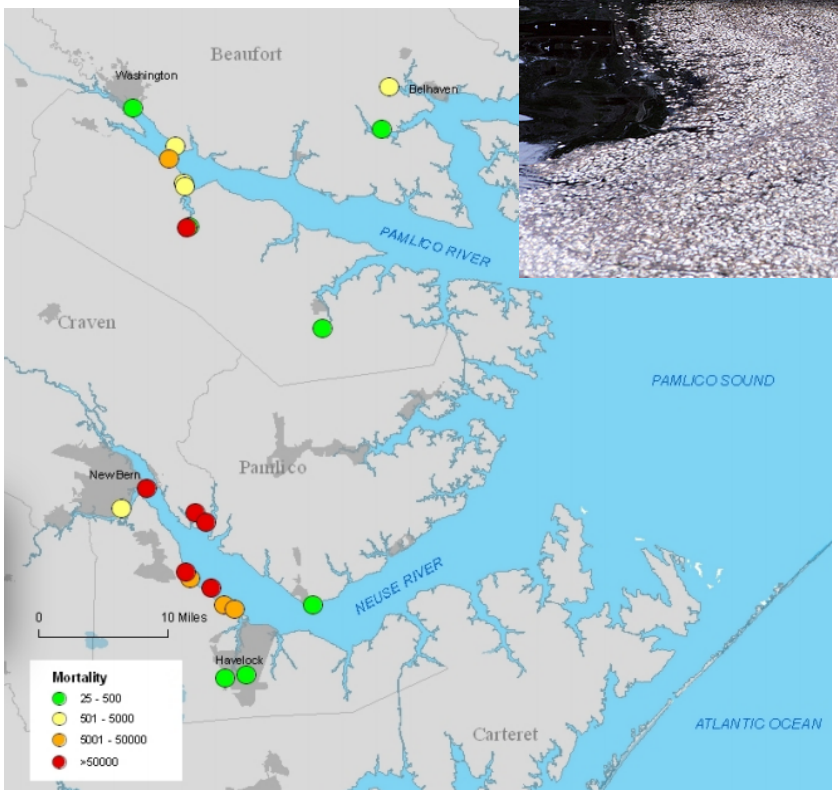
Droughts not only reduce water availability but also diminish water quality. During drought, contaminants build up on the ground and the next rainfall washes the contaminants into the water system. Filtration components in surface water treatment plants are designed on historic water quality data and may be clogged by high sediment flows following drought[8]. Drought also affects groundwater supplies, especially the supply of aquifers that exchange water with surface

systems. In coastal areas, the depletion of freshwater aquifers during drought can cause saltwater intrusion.

Infectious disease can be a direct consequence of drought[9]. Decreased rainfall can cause the contamination of ground and surface waters with viruses, protozoa and bacteria. Individuals that draw water from individual wells are at particularly high risk. Lower water flows and increased stagnation of waterways can also lead to the increase of mosquito populations and mosquito-carried disease.

In addition to these water-related health issues, droughts lead to decreased air quality. Reduced precipitation and dry soils result in more particulate matter in the air, increasing respiratory distress. This is especially important for communities that are not in attainment of national ambient air quality standards for particulate matter.

Environmental Impacts



Source: North Carolina Department of Environment and Natural Resources, Division of Water Quality. (2009). *North Carolina Division of Water Quality Annual Report of Fish Kill Events 2009*. Raleigh, NC.

Figure 2.2 In the above image, a photographer records the thousands of dead menhaden floating on the river surface. An estimated 200 million menhaden were killed due to anoxic conditions in the Neuse River in 40 days in 2009. This photo was taken outside New Bern near the Neuse River Bridge, the map to the left indicates locations and extent of fish kills in Pamlico Sound region in 2009.

Like the economy and humans, natural systems will be severely impacted by increased drought. As described previously, rain following droughts can wash excess sediments and toxins into waterways. The increase in pollutants and sediments can kill fish and other aquatic wildlife[10]. Reduced stream flow during droughts also increases water temperatures. As water temperature increases, it can hold less oxygen leading to anoxic conditions that can produce large fish kills. In 2009, poor water quality resulted in more than 33 fish kills (or events) in North Carolina, including the death of an estimated 200 million Menhaden within a 40-day period[11]. NOAA estimates that more than 95 percent of fish kills in North Carolina estuaries are due to low oxygen levels[12], which is further exacerbated by drought and high water temperatures.

Drought can also impact terrestrial systems by shifting species distributions, changing soil salinity levels and increasing the risk of wildfire. During the 2007-2008 drought, North Carolina fire fighters fought 7,200 wildfires, 30% more than a typical year. More acreage was burned than any other year in the past two decades[13].

Interacting Impacts

Dry conditions and high temperatures combine to increase the risk of wildfire. Droughts dry out vegetation that can be easily ignited, fuel fires and quickly spread fires. More people have become exposed to wildfire damage in recent years due to the expansion of the wildland-urban interface caused by homes being built in previously uninhabited forest areas. This expansion into forested areas is expected to continue and the risk of wildfire is projected to increase due to more frequent, intense droughts and rising temperatures.

Figure 2.3 Smoke emanating from the 2008 peat fire that burned 40,000 acres in Northeastern North Carolina photographed from space[14].

Wildfires also pose risks to communities' environment, economy and public health. Burning can damage the natural landscape and encourage the invasion of non-native species. Wildfires can damage homes and infrastructure. The pollution and reduced air quality produced by wildfires pose a serious health risk across a large geographic area. Figure 2.3 shows smoke from a wildfire being blown across eastern North Carolina.

Drought and heavy precipitation events also interact to reduce water quality. During dry periods pollutants can build up on roads and other impervious surfaces, when it rains these pollutants are washed into waterways. The pattern of long, dry periods interrupted by heavy precipitation can also increase sedimentation and runoff shifting stream hydrology to one typical of urban areas with low base flows and flash flooding.

In summary, drought can have many negative consequences for communities in North Carolina, including:

- **Agricultural losses and higher food prices;**
- **Electricity shortages;**
- **Water emergencies and limitations on growth;**
- **Reduced water and air quality;**
- **Outbreaks of infectious disease;**
- **Damage to aquatic ecosystems such as anoxic conditions and fish kills; and,**
- **Increased risk of wildfires.**

Drought Adaptation Strategies

Infrastructure Strategies

Most communities in North Carolina receive their drinking water from rivers as opposed to reservoirs, making them more susceptible to water shortages during drought[15]. One option is to build large engineering projects to ensure more stable water supplies. During high flows on the Tar River, Greenville extracts excess water from the river, treats it, and pumps it into an underground aquifer for later use. Reinfiltrating storm water runoff into groundwater has been pursued by a number of communities in the Sandhills and may be a promising option for rural areas where most people get water from private wells.

Alternatively, many cities are developing regional water systems that have more water sources to draw on in time of localized scarcity. In 2004, Statesville connected its water supply to nearby Salisbury to join the many cities that have linked to nearby systems with more stable supplies, including Cherryville, Concord, Kannapolis, Boone, Mars Hill and Blowing Rock[16]. As water becomes more scarce and expensive, it will become less practical for individual communities to act independently to meet their water needs. Local suppliers should collaborate at a regional level to address the water-supply issue[17].

When the construction phase was completed in 2011, Greenville Utilities pumped 60,000 gallons of water into the underground aquifer and recovered it shortly after demonstrating the potential of the first Aquifer Storage Recovery (ASR) project in North Carolina. ASR is the storing of treated drinking water in underground aquifers and sand deposits for use during periods of high demand and emergencies. The ASR project in Greenville can store more than 300 million gallons of treated drinking water at a fraction of the cost of storage in above ground tanks; and unlike above ground storage, water stored in ASR requires little additional treatment before use. ASR is expected to have significant economic benefits by helping meet peak demands and improving reliability of service in times of water emergencies. The same technology can also be used to prevent saltwater intrusion. Wilmington is currently in the process of implementing an ASR project to avoid expansion of their water treatment facility and the development of new raw water sources. While such large infrastructure projects may not be feasible for all communities, other strategies to increase infiltration and ground water levels can have similar benefits.

Greenville Utilities. (2012). Water Quality Report. Greenville Utilities. Retrieved from: http://www.guc.com/client_resources/publications/wqr2012.pdf

Land Use Strategies

Lengthening water delivery lines to reach new development can be costly for communities, as well as lead to greater water loss and energy expenditures on water delivery. By encouraging new development to take place in areas already developed, local governments can reduce water lost in transportation and also reduce wildfire risks.

Focusing new development in already developed areas or increasing density would slow the expansion of wildland-urban interface. Development can also be designed to reduce wildfire risk. Including fire safety measures in development ordinances such as the creation and maintenance of defensible space around homes by removing flammable vegetation, trimming trees, planting fire resistant plants and using non-flammable roofing material can reduce fire risk to homes. Fire departments and forest managers may also choose to manage vegetation and fuel loads to reduce the likelihood of large fires. These efforts should be paired with wildfire education to encourage citizen preparation and prevention.

Expansion into rural areas of Medina County, Ohio placed new demands on county water supplies. Some homebuilders initially wanted to develop large plots that would require filling in existing wetlands and natural floodplains. The building plans also required firefighting services to truck in large amounts of water in the event of an incident. A broad-based coalition that included the local government, county floodplain manager, planning commission, homebuilders association, and emergency manager came together to spearhead a process to promote development in the county while protecting water supplies and preserving wetlands and ponds. The partnership achieved a building standard that allowed builders to develop their desired housing design but also required them to build ponds and wetlands within each housing subdivision in an effort to sustain water supplies and allow for improved fire protection and floodplain management. The zoning and land use mitigation efforts promoted and protected the health, safety, and welfare of the residents by making the community less susceptible to flood and fire damage.

Source: FEMA. 2011. *A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action.*

Natural Resources Strategies

The City of Raleigh has permanent mandatory and voluntary water restrictions. Mandatory restrictions include: irrigation systems and water customers must reduce waste and application to impervious surfaces; restaurants should only serve potable water if requested; and hotels may only change linens when requested by guests. In addition to these mandatory restrictions, the city requests that customers irrigate less than one inch a week; water plants deeply and less frequently to encourage root growth; repair water leaks; and wash full loads in washing machines and dishwashers. Although these measures may seem simple water conservation will likely be a central component of ensuring an adequate water supply into the future. Currently 22 water supply systems have mandatory conservation measures and 68 have voluntary conservation measures; together these conservation measures encompass 45% of North Carolina's population[18].

Incentivizing the use of water saving technology and other best practices can further encourage water conservation. Building codes should be updated to permit waterless urinals and low flow plumbing fixtures. Cities should also update their landscape manual, if they have one, to reduce irrigation and encourage "water wise" landscaping. Incentives, such as rebates for rain barrels and high efficiency toilets, can also be implemented to reduce water demand.

Water reclamation and reuse is an additional opportunity to reduce water demand. Water reclamation refers to the use of treated wastewater for non-potable uses such as irrigation on agricultural fields and landscaping. While the initial investment in this technology may be expensive, it is a promising technique to reduce potable water demand. Communities can facilitate installation of water reclamation techniques as part of development and redevelopment projects.

Similarly gray water can reduce demand for drinking water by reusing water for non-potable purposes. Gray water is any water that has been used in a given building, except water from toilets. Gray water can be reused for other purposes on-site, especially landscape irrigation. Communities could evaluate and propose municipal building code amendments to incorporate single-source gray water "stub-outs" in new residential buildings and indoor reclaimed water in

new commercial buildings. Gray water "stub-outs" are plumbing that connects gray water sources like showers and sinks to a dead end outside the home. This dead end can later be connected to an irrigation or other gray water system.

In 2001, Cary became the first municipality in North Carolina to pump reclaimed water to homes and businesses for non-potable uses such as irrigation, industrial cooling, non-residential toilet flushing, dust control at construction sites and manufacturing processes. Reclaimed water is highly treated with biological nutrient removal, filtration processes, ultra-violet disinfection and hypochlorite treatment but rather than being discharged into streams it is diverted back to customers for reuse. On peak days, Cary delivers 1 million gallons of reclaimed water; in a summer month they pump up to 20 million gallons of reclaimed water to its customers. By reducing the amount of drinking water used for irrigation, manufacturing and other non-drinking uses, reclaimed water can lessen the demand on water treatment plants and natural sources of water. This extends the time before water treatment plants must be expanded and increases the reliability of drinking water supply.

Jordan, R. (2013). Reclaimed Water System. *Town of Cary*. Retrieved from http://www.townofcary.org/Departments/Public_Works_and_Utilities/Water/Reclaimed_Water_System.htm
image credit: http://www.brasfieldgorrie.com/

Water conservation measures have many co-benefits or advantages beyond reducing vulnerability to drought. Lower water consumption means cheaper water bills for consumers, as well as lower energy cost for water treatment and delivery. Reduced water demand also means a healthier natural environment. Due to these additional benefits, communities may choose to rank water conservation measures higher than other strategies.

While year round water conservation should serve a central role in addressing efficient use of natural resources, it is particularly important to be prepared for times of extreme water shortage. To prepare, communities should develop a water shortage response plan that identifies heightened conservation measures and alternative sources of water. In fact, all public and

privately owned water systems with 1,000 or more connections or serving more than 3,000 people in North Carolina must prepare a Water Shortage Response Plan as a part of their Local Water Supply Plan[19]. It is important that these plans are updated to recognize changing conditions.

Water shortages may lead power plants to reduce capacity or shut off. The loss of power, and air conditioning, may be a public health risk increasing emergency calls and admittance to hospitals. Police, fire and health services should be prepared to address power outages. To minimize outages it may also be important for cities to pursue strategies to reduce energy demand. Tools to reduce energy demands are further explored in the section on extreme heat.

Education Strategies

Education and outreach should be an integral part of all drought strategies. The public should be informed about their risks and strategies they can take as individuals. For example pamphlets with water conservation information could be distributed with water bills. Likewise, business outreach should be used to encourage businesses to decrease their water needs and demand. This information can help individuals lower their water bills as well as help the community reduce its vulnerability to drought.

Drought can have many negative consequences for communities in North Carolina, but there are a number of strategies to address vulnerability to drought including:

- **Developing water storage infrastructure;**
- **Creating regional water supply systems and collaboration;**
- **Water conservation through water use restrictions, incentivizing water saving technology, water reclamation and use of gray water;**
- **Development of water shortage response plans; and,**
- **Reduce risk of wildfires through smart land use and maintaining defensible space around buildings.**

While not all these strategies are available to every community, every community concerned about drought has options available to reduce their vulnerability. Specific actions to implement these strategies are listed in Appendix C.

B. More Extreme Heat

In North Carolina temperatures are expected to rise and extreme heat events are expected to become more prevalent. More extreme heat means:

- More intense and frequent heat waves or consecutive high-temperature days, when temperatures do not drop at night.
- An increased number of very hot days throughout the year.
- An increase in seasonal average temperatures. Future climate projections include shorter cool seasons and longer warm seasons, with an increase in average temperature during both.

Generally, heat waves have become more frequent across the U.S. A number of studies have linked the increased frequency and severity of heat waves to climate change[20]. This trend is expected to continue; heat events that once occurred every 20 years are expected to occur every

three or four years due to climate change[21]. The Southeast is expected to become the region of the U.S. with the highest heat index, a measure of comfort that combines heat and humidity. By the end of the century, North Carolina is expected to have about 120 days over 90°F every year. Higher temperatures and more frequent heat waves pose a serious threat to the economy, public health and the environment.

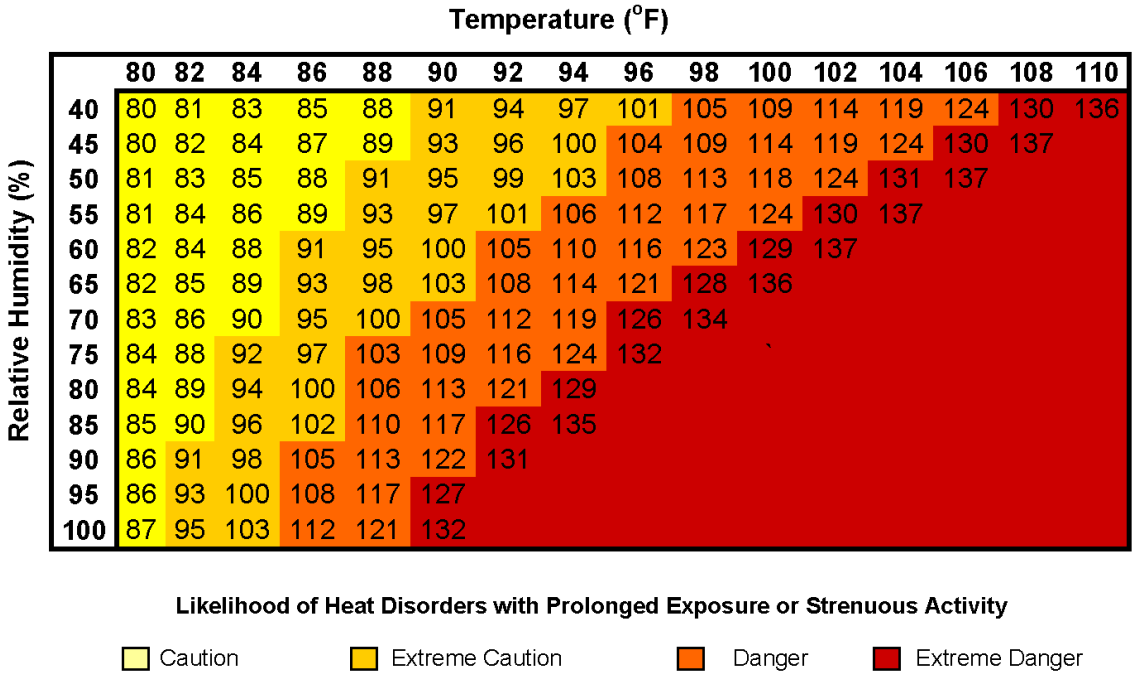


Figure 2.4 Heat index, a measure of comfort that combines heat and humidity provided by NOAA's National Weather Service[22].

Economic Impacts

Extreme heat has a multitude of economic impacts. Costs range from damage to infrastructure, to reduced tourism, to higher electricity demands, to agricultural loss.

Extreme heat can damage transportation infrastructure – degrading roads, buckling rail lines and reducing efficiency of airport runways. Transportation systems that are not designed for extreme heat may suffer severe damage. Expansion joints on bridges and highways are stressed and asphalt pavement deteriorates more rapidly at higher temperatures. In June 2012, during record heat, pavement on Interstate 440 buckled in Raleigh closing several lanes[23]. Moreover, maintenance may suffer because construction crews may have to operate on altered time schedules to avoid the hottest parts of the days and risk of heat stress.

Tourism is not only season dependent, but also climate dependent. Increased heat and humidity are likely to create unfavorable conditions for outside recreation and tourism activity.

Changes in temperature will also produce a change in electricity demand for heating and cooling. Higher temperatures in the summer will increase demand for air conditioning, electricity use and peak demand. Warming in the winter may reduce electricity demands for heating, but together,

there is an expected net gain in electricity demand. The increase in cooling needs over the past decade has outpaced the decrease in heating needs as seen Figure 2.3[24]. The amount of energy needed to cool (or warm) buildings is proportional to cooling or heating degree days, defined as the number of degrees that a day's average temperature is above or below 65° F.

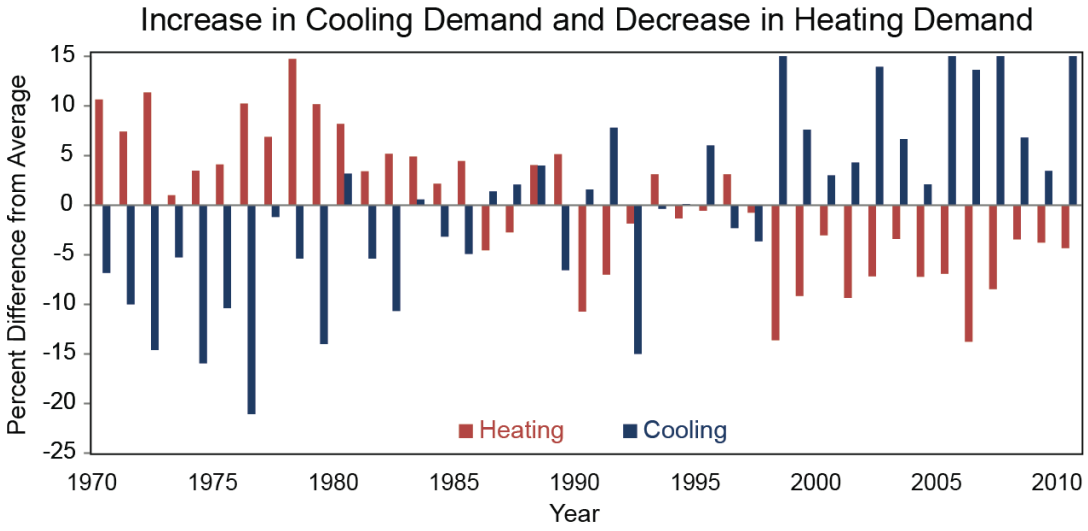


Figure 2.5 Percent more heating and cooling days, defined as days when average temperature is above or below 65° F, than the 1970-2000 average. Although the number of heating days across the U.S. has decreased, the increase in the number of cooling days has outpaced the reduction in heating days[25].

High temperatures can reduce agricultural productivity, especially the production of animal products. An increase in extreme heat will have a greater impact on livestock meat, milk, and egg production than an increase in average temperatures. At extreme temperatures, animals suffer heat stress and their internal temperature rises beyond the optimal range for production, and in some cases, health. Humidity further exacerbates the impact of high temperatures on animal health and performance. Reduced production due to heat can be costly; in 2011 heat-related loss of production exceeded $1 billion nationally[26].

Crops are also sensitive to increase in heat. The overall productivity of corn, soybeans, cotton, rice and peanuts across the south would likely decrease with a 2.2° F increase in temperature[27].

Public Health Impacts

Heat is the most deadly weather in the developed world. Every year there are about 700 deaths in the U.S. due to heat related illness, more than from floods, lightning and tornados combined. In the 1980's two severe heat waves killed up to 20,000 people in the U.S. In 1999 a drought and heat wave in the eastern part of the country claimed 502 lives, making it the deadliest weather event of the 1990's[28]. During a heat wave that struck Western Europe in 2003 over 35,000 people were killed by heat related conditions. For comparison, the death toll of hurricane Katrina was 1,836.

Deaths result from heat stroke, but also from cardiovascular, respiratory, and cerebrovascular disease[29]. Heat waves also cause a spike in hospital admissions for cardiovascular, kidney and respiratory disorders. Summer heat and extreme heat events are expected to become more frequent and intense, meaning greater hospitalizations can be expected. The Piedmont region is predicted to be the most impacted by increase in temperature extremes due to high populations[30]. Of the 2590 emergency visits for heat related illness (HRI) in the entire state, 2248 are from the Piedmont and Coastal Plain[31].

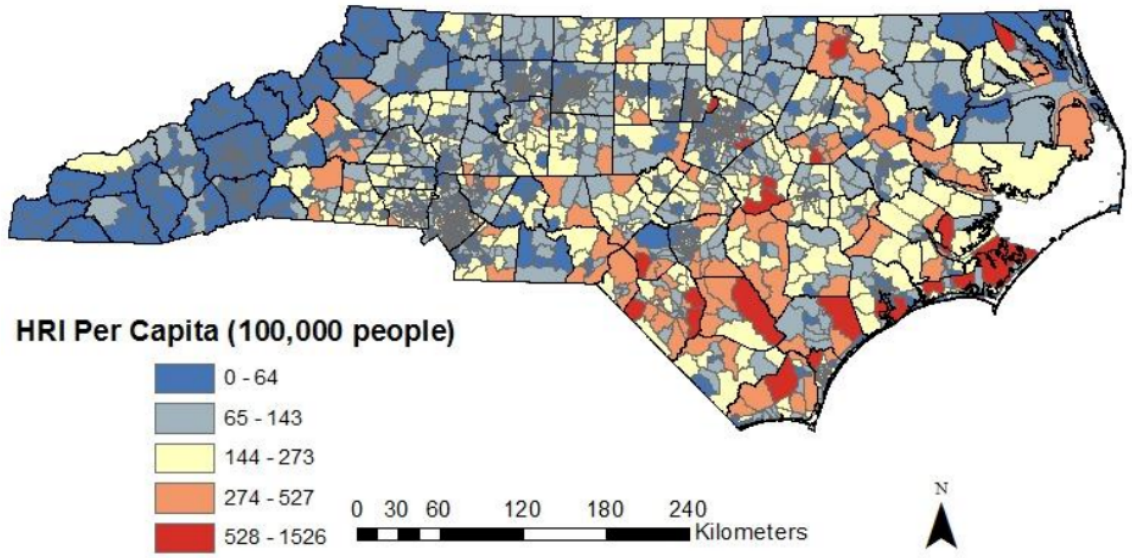


Figure 2.6 Emergency department heat related illness (HRI) admissions per 10,000 people 2007-2008[32].

Most hospital visits due to heat related illness occur in the summer months; 84% of HRI hospital visits occur June-August[33]. Heat waves dramatically increase hospital visits. In a study of heat related hospital visits in North Carolina, 27% of hospital visits occurred during heat waves that represent only 2% of days in the study period[34]. First responders should be prepared for the spike in emergency room visits during the summer months, and especially heat waves. Police and fire fighters must also be prepared for an increase in heat related 911 calls that spike in higher temperatures[35].

Heat waves can also cause increased mental illness. Research has demonstrated high levels of anxiety and post-traumatic stress disorder following heat waves and other disasters. Some patients with mental illness are especially susceptible to heat; dementia increases the risk for hospitalization and death during heat waves[36].

Air conditioning can reduce the risk that high temperatures and heat waves pose to citizens health, however, cooling buildings is a leading driver of demand for electricity. High demand for electricity during heat waves can result in brownouts and blackouts that can increase the risk of the entire service area. Brownouts refer to a drop in voltage; some brownouts are intentionally caused to reduce the electric loads in emergencies. In contrast blackouts are complete power

outages. High demand will also result in higher electricity prices disproportionately burdening the poor.

Higher temperatures pose an additional health threat by contributing to the formation of air pollutants and allergens like ground-level ozone. A rise in deaths due to ground-level ozone as well as an increase in hospital admissions and missed school days from asthma and respiratory illness is expected as temperatures rise with climate change[37].

Lastly, rising temperatures may result in an increase in infectious disease. The disease ecology of pathogens is complex, but frequently dependent on climate. In general, warmer temperatures increase the survivability of disease agents in the environment. Warmer temperatures in the winter when many pathogens are killed from the cold can allow an increase in pathogen populations. The survival of host organisms such as mosquitos and ticks may also contribute to disease risks[38].

While the health consequences of extreme heat will be far reaching, not all are equally vulnerable and some populations may be disproportionately burdened.

Urban areas are generally more vulnerable to heat due to higher temperatures in cities, but in North Carolina rural populations have been found to have higher incidence of heat related illness. Emergency department visit rates were 16% higher in rural than urban counties[39]. This relationship is in part driven by the correlation between agricultural labor and heat related illness. Agricultural laborers work outside in extreme heat conditions, North Carolina accounted for 57% of all heat related deaths of crop workers in the U.S. between 1992 and 2006[40].

Historically, heat waves have disproportionately affected the elderly and the poor. Of the 514 deaths during the July 1995 heat wave in Chicago, 72% percent of the deaths were among residents 65 years of age or older[41]. The elderly are vulnerable to heat stress because they cannot as efficiently regulate their body temperature. Similarly, people who are obese, have diabetes, heart disease and asthma are all more prone to heat stress.

In North Carolina, teenagers have also been found to have high rates of hospitalization. In fact, teenagers have the highest rates of emergency room visits due to heat related illness in the state.

Poverty may also increase individual's vulnerability by limiting their ability to protect themselves and respond to climate impacts. For example, low-income individuals may not have air conditioning or may not be able to afford to run their air conditioning increasing their vulnerability to heat stress. In North Carolina communities that had more residents living in mobile homes, a common proxy for rural poverty, had higher rates of heat-related emergency room admissions[42].

Many of the chronic illnesses that increase individuals' susceptibility to heat stress, such as cardiovascular and respiratory disease, are also more prevalent amongst low-income populations. When addressing heat, it is important to recognize social factors that influence vulnerability. These social factors should be considered when selecting avenues of communication, determining the location of cooling centers, and even identifying and prioritizing adaptation strategies.

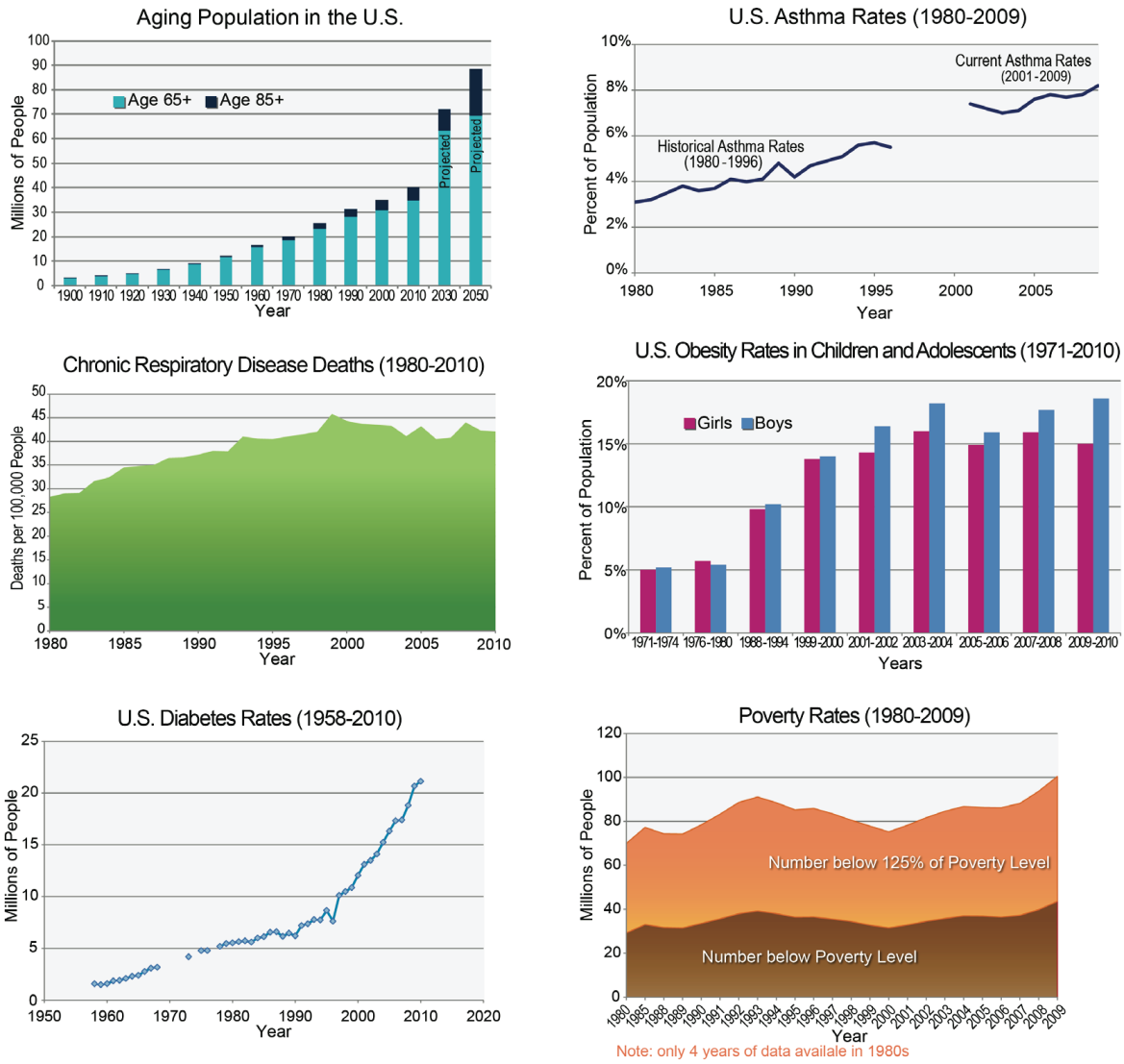


Figure 2.7 Health and social factors that increase vulnerability to climate change measured nationally. The elderly are more vulnerable to heat because they are less efficient at managing their body temperatures, but they are also more vulnerable to other climate change impacts such as hurricanes. Individuals suffering from chronic illness such as asthma, respiratory disease, obesity and diabetes are also more vulnerable to heat extremes. Likewise the poor and impoverished often lack the resources to reduce their exposure to climate impacts[43].

Environmental Impacts

Temperature is one of the key variables determining plant and animal ranges. As temperature rises, new species may invade and become established.

In aquatic ecosystems, higher air temperatures will lead to warmer water temperatures and lower dissolved oxygen levels in most streams and rivers. These changes cause a shift in species range

and distribution. Some sensitive species that are at the edge of their natural range, such as trout, may experience decline or extirpation (local extinction). Algal blooms are likely to get larger and exacerbate dissolved oxygen problems as well as produce fish kills.

Interacting Impacts

Rising temperatures and extreme heat will have dramatic impacts on the North Carolina economy, public health, and environment but will also interact to further other climate changes. Even in areas where precipitation is not expected to decrease, higher air temperatures are expected to promote drought. Higher temperatures cause increases in surface evaporation and loss of water from plants, leading to drier soil. As soil dries out, a larger proportion of the incoming heat from the sun goes into heating the soil and adjacent air rather than evaporating moisture, resulting in hotter summers under drier climatic conditions[44].

Heat can further intensify drought by increasing demand for water. High temperatures increase demand for air conditioning and electricity. To meet this demand, power-generating companies will increase water withdrawal and consumption. In fact, high water temperatures and low flow may suspend power plant production due to operational and environmental concerns. At the same time, high temperatures can increase irrigation demands, creating a water-use conflict.

High temperatures and dry conditions combine to increase the risk of wildfire. Wildfires also pose risks to communities' environment, economy and public health. Burning can damage the natural landscape and encourage the invasion of non-native species. Wildfires can damage homes and infrastructure. The pollution and reduced air quality produced by wildfires pose serious health risk.

In summary, extreme heat can have many negative consequences for communities in North Carolina, including:

- **Damage to transportation infrastructure;**
- **Reduced recreation and tourism;**
- **An increased demand for electricity;**
- **Reduced agricultural production;**
- **A spike in hospital visits and mortality during extreme heat events;**
- **Greater air pollution;**
- **Increased spread of infectious disease;**
- **An unequal distribution of impacts across the population;**
- **Invasive species and shifting animal and plant ranges; and,**
- **Reduced quality of aquatic ecosystems.**

Extreme Heat Adaptation Strategies:

Infrastructure Strategies

Infrastructure strategies to adapt to extreme heat are focused on creating infrastructure resistant to the damage caused by high temperatures. For example, high-temperature resistant paving materials could be used on highly travelled streets to prevent damage. Maintenance schedules may also be changed so streets are repaired more frequently to account for heat damage[45].

Using different materials may also reduce the risk of heat itself. Urbanized areas often experience significantly higher temperatures than surrounding rural areas as shown in Figure 2.8 - this phenomenon is called the urban heat island effect. Urban development uses materials such as concrete and asphalt that absorb, retain and emit heat more than surrounding areas. Using different materials can help reduce the urban heat island effect.

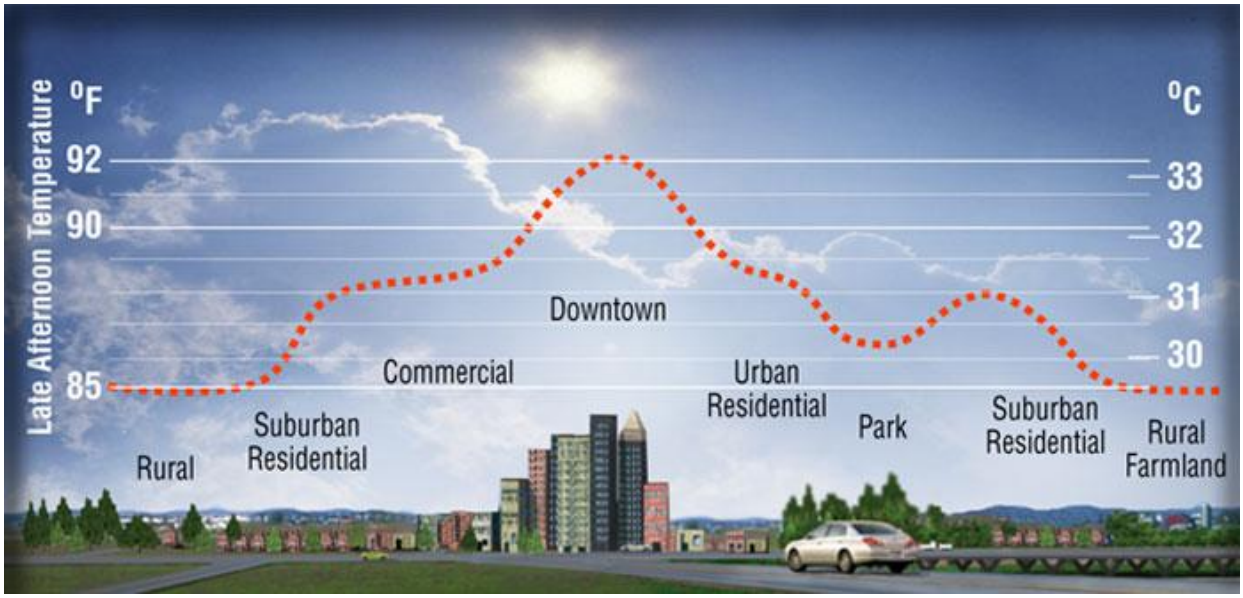


Figure 2.8 The urban heat island effect refers to the significant higher temperatures in urbanized areas than surrounding rural areas due to the materials used in urban development.

Cool pavements refer to paving materials that are more reflective, store less heat and have lower surface temperatures compared with conventional products. Using cool pavements can reduce ambient temperatures in urban areas and combat the urban heat island effect. Local governments may choose to perform pilot projects to evaluate "cool" pavement strategies to help inform creation of new policies. Ordinances can also be created to incorporate reflective or "cool paving" into municipal projects (parking lots and streets) and new private parking lot projects over a specific size.

Using alternative materials for roofing can also help reduce temperatures and heating demands. Cool roofs, which are made of highly reflective material that can remain 50 to 60°F cooler than traditional materials, can help reduce the heat island effect by lowering the ambient temperatures inside and outside of buildings. Local governments can use these materials on public buildings and encourage private buildings to do the same through energy and building codes. The City of Fayetteville, NC has installed cool roofs on its city hall and other public buildings, for example.

By lowering ambient temperatures, cool pavement and especially cool roofs have the potential to reduce energy demand and cost. One study found that cool roofs provide an average yearly savings of 50 cents a square foot, including the comparative cost of instillation, energy savings, and labor cost[46]. While this savings may seem small, a 2,000 square foot home could save $1,000 a year and $20,000 over the lifespan of the roof. These cost savings alone make cool roofs an attractive option.

Figure 2.9 The Joe and Joan Martin Center, a children's library, theater and community center located in Charlotte, was constructed with a cool roof. In 2006 it received a LEED-NC Silver rating and was awarded credits for reducing urban heat island effects[47].

Land Use Strategies

Landscaping ordinances and building codes can be updated to reduce the urban heat island effect, and as a result, decrease susceptibility to heat stress and energy use.

One method to reduce temperatures and energy demand is increasing urban tree cover and shade trees. Complete street standards that require tree plantings along roadways or requiring shaded parking lots are both effective tools for increasing trees in urban areas. Landscape ordinances can also be used to increase tree coverage, and specify tree species that will thrive in future climate conditions.

Gastonia, North Carolina has received multiple awards in recognition of its efforts to maintain trees throughout the city. The Keep Gastonia Beautiful Committee has forged a unique partnership with the city's electric department to replace trees interfering with power lines with more appropriate sized trees, plant new trees in areas without tree cover, and provide resources to residents to purchase trees. Gastonia also has a tree-planting program to replace trees lost during storms. In addition, the city has been recognized for its Arbor Day celebration, which includes many of the area schools, city leaders and staff and local citizens.

Source: "2011 Urban Forestry and Community Forestry Award Winners", North Carolina Forest Service, 2011. http://ncforestservice.gov/Urban/urban_awardwinners.htm

Increasing tree cover has multiple co-benefits and should be considered regardless of expected temperature changes. Tree planting and urban forests improve stormwater management by increasing water infiltration into the soil. Planting trees can also improve aesthetics and walkability. Complete streets lined with trees can make pedestrians feel more comfortable and increase the number of walking trips. Many cities across North Carolina are at the forefront of

the complete street movement including Charlotte, Asheville, Winston-Salem, Cary and Hickory. The North Carolina Department of Transportation has been an active partner in promoting complete streets through design standards and training[48].

Figure 2.10 A North Carolina example of street landscaping provided by DOT complete street program[49].

About 75% of electricity in the U.S. goes to heating, cooling and lighting buildings. Site planning and building design can reduce the amount of energy needed to cool and light buildings. Design standards may include southern orientation of structures to maximize daily light, shielding of windows to prevent summer overheating, thermal mass to retain coolness, and design for maximum natural summer ventilation[50].

Increasing insulation can also help reduce indoor temperatures in the summer and thereby decrease health risks associated with heat waves; it can also reduce energy demand for air conditioning. City and county governments can create programs to provide rebates to better insulate and weatherize old homes.

Education Strategies

Education about the risks of extreme heat and methods to avoid heat stress are some of the most effective strategies to reduce public health impacts of rising temperatures. Early warning systems of heat waves are very effective at protecting vulnerable populations and much less costly than treating individuals for heat stress and illness. Warnings of extreme heat, locations of cooling centers, and methods to stay healthy can be broadcast on local TV and radio stations.

Communities should also expand and enhance response to air quality hazards associated with high temperature days. On hot days local governments should try to encourage use of public transportation to improve air quality as well as provide information on how residents can produce less ozone.

Currituck County has a particularly informative heat education initiative. On the county website, information is provided about the symptoms of heat stroke and exhaustion, methods to treat heat stress, ways to plan for extreme heat and to protect individual property.

For more information see http://www.co.currituck.nc.us/Extreme-Heat.cfm

Local governments may also choose to provide information to their citizens about when to replace high energy-use appliances such as refrigerators, dishwashers, and water heaters. Where this information is already available, efforts should be made to increase its distribution and accessibility. Providing this information may help communities improve energy efficiency and reduce demand for electricity.

Other Strategies

With input from City agencies, especially the fire department, hospitals and community organizations, local communities should update their emergency response plan to address heat waves. The plan should identify populations that are most at risk and identify techniques to address their needs.

Hazard plans that incorporate heat waves should identify strategies to reduce risks of heat stress. For example communities may consider opening "cooling centers" during extreme heat events, providing information about cooling to residents, and encouraging people to check on their neighbors. Likewise, some counties provide air conditioning units to individuals with serious health problems. These programs should be expanded to incorporate more counties and more at risk populations. The state also runs a program, Operation Fan/ Heat Relief, which provides fans to the elderly[51].

Livestock can be protected from increases in heat extremes by providing partial or total shelter. Most hog and poultry livestock systems already are housed in structures where airflow and temperature can be controlled. The transition to more of these systems and the need to provide more cooling in the face of rising temperatures poses increased management and energy costs[52].

Extreme heat can have many negative consequences for communities in North Carolina, but there are a number of strategies to address vulnerability to extreme heat including:

- **Use different materials that are heat resistant or reduce ambient temperature;**
- **Change maintenance schedules to account for heat damage;**

- **Increase tree cover by updating landscape ordinances and complete street standards;**
- **Improve site planning and building design to lower energy demands;**
- **Educate citizens about heat risk and methods to avoid heat stress; and,**
- **Update emergency response plans to include extreme heat.**

While not all these strategies are available to every community, every community concerned about extreme heat has options available to reduce their vulnerability. Many of the strategies have additional benefits that may help achieve other community goals. Specific actions to implement these strategies are listed in Appendix C.

C. More Intense Hurricanes

Since the 1980s the strength and number of strong hurricanes in the North Atlantic has increased[53]. Rising ocean and air temperatures where hurricanes form result in greater evaporation that further fuels tropical storms. The intensity of hurricanes is projected to continue to increase, but the trend is more uncertain due to the complexity of hurricane formation. Climate models that utilize the best understanding of this complex process project further increases in the frequency and intensity of the strongest hurricanes. The link between hurricanes and ocean temperatures remains an active area of research[54].

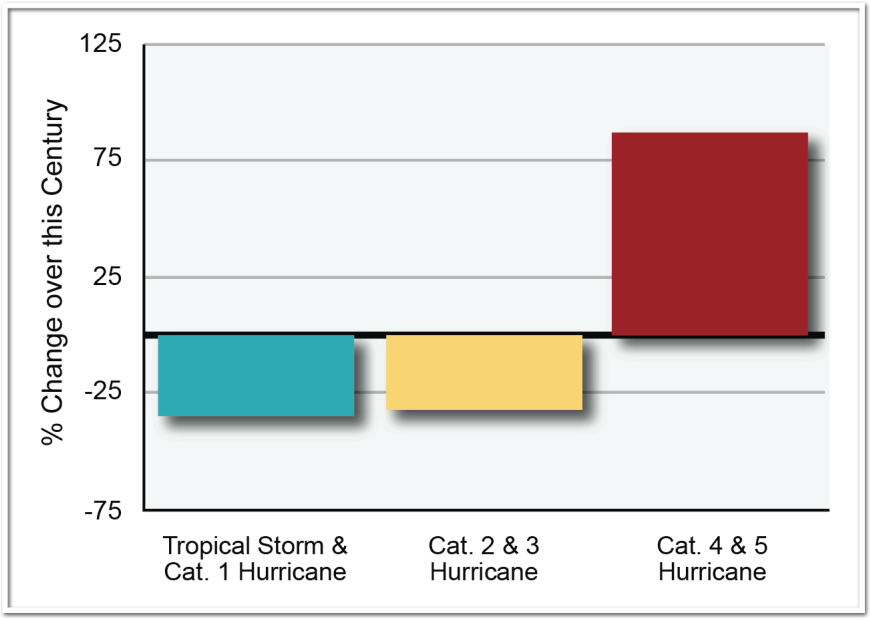


Figure 2.11 Projected changes in Atlantic hurricane frequency by category. By the end of this century (2100) the number of category 4 and 5 storms are expected to become more than 75% more frequent than today. Projected changes are for the period 2081-2100 compared with the period 2001- 2020[55].

Although category 3, 4 and 5 hurricanes account for only 20 percent of cyclone landfalls, they account for more than 70 percent of the hurricane-related damage in the U.S[56]. High category storms are characterized by strong winds that can down trees and damage roofing material; storm surge that can cause flooding along the coast and miles inland as well as structural damage by

battering waves and floating debris; and torrential rain that can cause extensive flooding. Hurricanes can also produce tornados.

Although coastal regions are generally most impacted by tropical storms, these storms have the potential to cause damage across the entire state. In fact, between 1970 and 1999, 63% of all tropical cyclone deaths occurred inland[57]. The most costly hurricanes in North Carolina, including Hurricanes Fran and Floyd, caused damage across the state from Dare to Guilford County. During Hurricane Floyd, the 15 to 20 inches of rainfall caused every river and stream in eastern North Carolina to flood causing damage in most counties in the state. In fact, President Clinton declared 66 of the 100 counties in North Carolina major disaster areas.

Economic Impacts

The worst natural economic disaster in North Carolina history was Hurricane Floyd that made landfall in September 1999. Agricultural damage in the form of lost crops, livestock and farm equipment exceeded $830 million. Tens of thousands of homes were damaged by falling trees and severe flooding resulting in $1.2 billion in property damage.

Figure 2.12 Hurricane Floyd caused extensive agricultural damage exceeded $830 million. Approximately 2.8 million poultry, 2,000 cattle, 250 horses and more than 30,500 hogs drowned in the extensive flooding[58].

Hurricanes cause serious infrastructure damage resulting in the shutdown of basic services like energy, water, and communications. The damage to basic infrastructure produces cost not only associated with replacing the physical system, but the lost revenue from inoperable systems. For example, when the I-35W bridge collapsed in 2007, the State of Minnesota estimated the economic cost of lost use at $0.4 million per day, while the replacement cost of the bridge was only $234 million[59]. In North Carolina, damage to coastal attractions, transportation, and accommodations can cause economic loss from declined tourism.

Hurricanes can also damage business by destroying property and inventory. Following Hurricane Fran, businesses in the Crabtree Valley Mall in Raleigh reported high losses. Over 12,000 businesses reported some kind of loss following Hurricane Floyd. Temporary closures result in lost revenue from which many businesses struggle to recover.

Public Health Impacts

There are direct and immediate health impacts of hurricanes. Falling trees, collapsing structures, and flooding can all cause death or injury. Hurricanes, however, also impact public health weeks and even years after the event.

The loss of one's home, possessions and community can cause severe stress and long-lasting mental health consequences. The most frequently reported condition was post-traumatic stress disorder (PTSD), followed by depression, and then other anxiety disorders but individuals also report chronic health problems and resource loss[60]. Many of these conditions improve over time, but in almost every study a minority of subjects continue to suffer long after the event. One study of 400 Dade County residents that were highly exposed to Hurricane Andrew found that 25% of the subjects met the diagnostic criteria for PTSD 6 months after the storm. Thirty months after the hurricane symptoms of depression and avoidance remained high[61].

The loss of critical services such as electricity, water, sewer and transportation can last for weeks. During Hurricane Floyd, more than 1.5 million homes and businesses lost power. Two weeks after the storm, nearly 8,000 still had no electricity[62]. The loss of these services can pose major health risks, including exposure to elements and increased illness due to contaminated water supplies and spoiled food. Damaged transportation infrastructure can make the delivery of safe water and food difficult.

Even though evacuees may be removed from direct impact of the hurricane, the provision of basic goods and medical attention can pose challenges.

Storm surge and flooding can cause pollutants to be washed into water supplies. During Hurricane Fran flooding caused hog waste lagoons to overflow their walls, contaminating floodwaters. Flooding of gas stations, and other sites that store toxic substances, can likewise cause water contamination.

Months after hurricanes, flood damage can pose a health risk in the form of mold damage that can cause severe respiratory disorders.

Environmental Impacts

Natural disturbances such as hurricanes are often essential to maintaining healthy natural systems. When left to their own devices, natural systems fully recover from these disturbances. However the increased intensity of hurricanes combined with human development can lead to ecosystem degradation and loss.

One of the greatest hurricane risks to the environment is water pollution. During hurricanes, storm surge and heavy precipitation can cause pollutants to overflow their storage and enter the environment. The pollutants can cause a variety of human health effects, as well as contaminating soils and waterways inhibiting recovery.

Natural ecosystems play a vital role in "buffering" the impacts of extreme events like hurricanes. Dunes, coastal wetlands, saltwater marshes, mangroves and reefs defend coastal ecosystems and infrastructure from storm surge. Reduction in wave damage provided by these ecosystems is

difficult to measure, but has been estimated as $3,332 per acre per year[63]. The loss of these systems can expose homes and infrastructure to greater wave action and damage.

Interacting Impacts

Rising sea levels are expected to increase the damage caused by hurricanes by magnifying storm surge. Hurricanes may also influence the rate of relative sea-level rise. Hurricanes can cause coastal erosion and flooding that changes the shape of the shoreline, and consequently sea level.

In summary, more intense hurricanes can have many negative consequences for communities in North Carolina, including:

- **Damage to critical infrastructure, homes and agriculture;**
- **Losses to local businesses, which may result in their failure;**
- **Death, injury, infectious disease and long-lasting mental health consequences;**
- **Reduced water quality; and,**
- **Degradation of natural systems and ecosystem services.**

Hurricane Adaptation Strategies

Infrastructure Strategies

It is almost always far less expensive to protect useful infrastructure than to wait for it to collapse. Cities should consider developing risk-based infrastructure decision-making criteria that consider shortened lifespan, damage and reduced efficiency of projects due to increased severe storms and climate change. Incorporating climate change into design of new infrastructure protects capital investments and public safety can reduce vulnerability.

Locating water and sewer treatment facilities outside of high-risk areas can reduce damage and long-term loss of services. Likewise, burying power lines to avoid disruptions from wind and rain as well as developing smart grids that limit widespread disruption of power supply can improve the delivery of electricity during storms and after. Connecting emergency centers with onsite renewable energy sources may also reduce susceptibility of these centers to lapses in conventional energy supply.

Building standards requiring more durable design can also reduce hurricane damage. Requiring hurricane straps that better secure roofs or increasing the required freeboard can reduce hurricane damage. Likewise, communities may consider codes, or lobbying state officials to improve state codes, that restrict the location of air conditioning units, utilities, and storage areas for hazardous materials to reduce damage and pollution.

Land use strategies

Avoiding high-risk areas or limiting the use of these areas is the most effective measure to reduce storm and flood damage. As climate and development patterns change, hazard areas will change too. Communities may consider redefining their flood and erosion hazard zones to match projected expansion of flooding frequency and extent, sea level rise and increased intensity of storms.

Development in hazardous zones can be limited through zoning, transfer of development rights, easements or buffer requirements; construction that does occur should be designed and built to be resistant to flood and wind damage. Some communities may even choose to remove existing infrastructure and structures from the flood and erosion zones. Buyouts following intense storms events are one approach that has been used in North Carolina to remove damaged property from hazardous zones.

When Hurricane Fran dropped 16 inches of rain in September of 1996, the Neuse River poured over its banks and flooded the town of Kinston. The flood damaged or destroyed over 400 homes. Kinston used the disaster as a window of opportunity to increase community safety, sustainability and resilience. Using FEMA flood buy-out funds they relocated 420 households from the floodplain to safe locations within the city boundary, revitalizing old neighborhoods and creating a more compact urban area. The city converted the floodplain to conservation area with funding from the North Carolina Clean Water Management Trust and created a regional park and greenway along the Neuse River. Although Kinston experienced heavy losses three years later during Hurricane Floyd, the buyout program reduced losses during the storm by $6.4 million. Following Hurricane Floyd, the city expanded the buyout program acquiring another 1210 homes.

Source: Godschalk, D. R. (2001). Natural Hazards, Smart Growth, and Creating Resilient and Sustainable Communities in Eastern North Carolina. In J. R. Maiolo, J. C. Whitehead, & M. McGee (Eds.), *Facing Our Future: Hurricane Floyd and Recovery in the Coastal Plain* (1st ed., pp. 271–282). Coastal Carolina Press.

Natural Resource Strategies

Natural ecosystems such as dunes, wetlands, oyster reefs, and mudflats reduce wave action and storm damage. As such, these ecosystems provide an important service that should be protected and restored. There are multiple tools to achieve coastal ecosystem protection including zoning and easements. The protection of these ecosystems has many additional benefits. The protected dunes and wetlands may serve as recreational areas or parks. Many of these ecosystems also provide other services such as water filtration, nurseries for juvenile fish or provision of food that can improve the coastal economy and health.

Communities may also consider collaboration with conservation and other local non-profits on restoration projects.

Education Strategies

Many of the deaths caused by hurricanes could be avoided by improving public information. Coastal communities at the highest risk of hurricane damage should inform their citizens about hurricane risk and encourage them to prepare for such disasters. Communities should also make evacuation plans and shelter information publicly available. Providing this information to tourists, that may not be familiar with hurricanes or the area, is particularly important.

Other Strategies

A strong hazard mitigation plan can address many of the risks posed by hurricanes and improve community preparedness. Such plans should identify multiple evacuation routes, and include

early warning systems and inter-jurisdictional coordination. Areas with high concentrations of vulnerable and special-needs populations should be identified and provided with necessary hazard services such as transportation during an evacuation.

Communities without a hazard mitigation plan should consider developing one, and those that already do have a plan may consider the increased intensity of hazards due to climate change in their updates. Communities should also consider participating in FEMA's Community Rating System to improve hazard preparedness.

Hurricanes can have many negative consequences for communities in North Carolina, but there are a number of strategies to address vulnerability to hurricanes including:

- **Protect critical infrastructure, consider a risk-based approach to decision-making that incorporates changing intensity and frequency of natural hazards;**
- **Improve building codes and standards;**
- **Limit development in high risk areas;**
- **Protect natural ecosystems that buffer impacts of natural hazards;**
- **Inform the public about hurricane risk and encourage them to plan accordingly;**
- **Prepare or strengthen a community hazard mitigation plan; and,**
- **Participating in FEMA's Community Rating System.**

While not all these strategies are available to every community, every community concerned about hurricanes has options available to reduce their vulnerability. Specific actions to implement these strategies are listed in Appendix C.

D. Increased Intense Precipitation

An increase in heavy precipitation events means not only an increase in the number of days with heavy precipitation but also an increase in the amount and rate of precipitation during events.

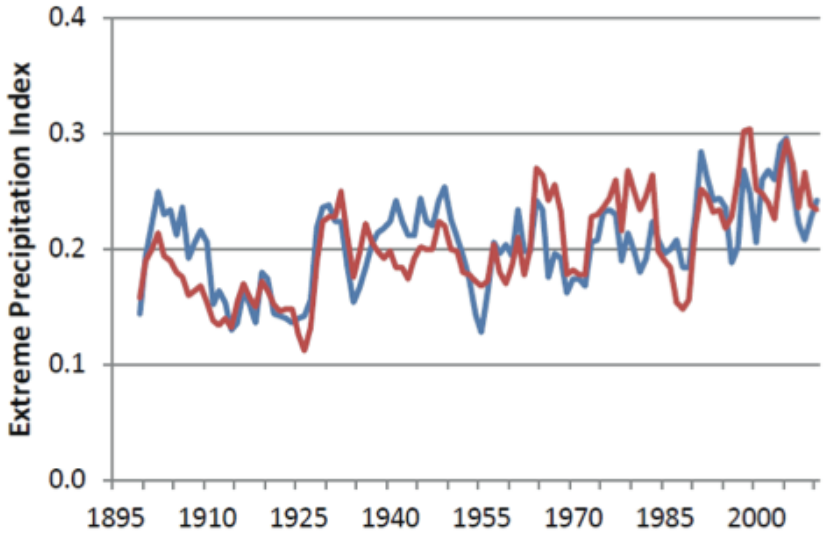


Figure 2.13 Change in extreme precipitation index since 1895 in the Southeast region. The red line indicates the occurrence of 1-day, 1 in 5 year extreme events and the blue indicates 5-day, 1 in 5 year extreme events using a precipitation 5-year running average.

Precipitation events are expected to become less frequent but more intense, leading to periods of drought punctuated by heavy downpours. Between 1958 and 2011 the amount of rain falling during very heavy events, defined as the heaviest 1% of all daily events, has increased by 26% in the Southeast. This trend is expected to increase into the future[64]. Extreme precipitation that historically occurred every 20 years may, in the next century, occur every 5 to 15 years[65].

The increase in heavy precipitation events will create a stream system more like an urbanized area that has low base flows but flash flood events. Heavy downpours can overwhelm stormwater infrastructure leading to flooding and erosion. Heavy rainfall can produce both short-lived flash floods and longer-duration river floods that can have tremendous impacts. Thunderstorms in the spring and summer can produce heavy rainfall in localized areas resulting in short-lived flash floods. In the winter, slow moving systems produce large areas of heavy rainfall that can contribute to river floods. All rivers are susceptible to flooding, which can result in increased waterborne disease, contaminated water supplies, and property and agricultural loss.

Economic Impacts

Much like hurricanes, heavy precipitation can cause costly damage to infrastructure as well as lost revenue from non-operating systems. In North Carolina, in fact, the most costly floods have been caused by hurricanes. Flooded transportation infrastructure can disrupt the mobility of people and goods. Infrastructure may also require maintenance or replacement following flooding.

Flooding can destroy crops or delay planting and harvesting, resulting in decreased profits. Increased precipitation will also increase soil erosion, impacting the quality of agricultural land and affecting water quality in steams and rivers.

Landslides can be triggered by intense precipitation, contributing to public safety concerns, loss of roadways and buildings and economic impacts.

Intense rainfall events may exceed the limits of dams and flood control structures, resulting in uncontrolled release of stored water and cascading flood events. Uncontrolled releases may also impact hydropower generation and the storage of potable water.

Public Health Impacts

Flooding can cause injury and death. Driving in floods is particularly high risk. The public health consequences of floods last long after high waters have subsided. The loss of one's home and property can be a stressful experience and can have long-term mental health consequences.

Perhaps most importantly, heavy precipitation events threaten the availability of clean water. Heavy rainfall can cause flooding of sewage systems, toxic waste facilities and livestock

Figure 2.14 Durham stormwater services tracks streams' physical and chemical traits in the city.

waste lagoons, contaminating drinking water sources. The change in stream hydrology to low base flow with short-lived peaks, also degrades water quality without extreme flooding. Precipitation, especially following dry periods, washes pollution and sediment into waterways. As a result of stream and river sediment, nitrogen and pollutant loads increase, threatening water supply sources.

The impact on groundwater is less clear. Change in development and precipitation patterns will likely produce more runoff and less infiltration into soils and aquifers. As a result groundwater supplies may decrease, but more research is required to fully understand the net influence of changing precipitation patterns.

Other public health concerns include the contamination of irrigation water that can contribute to food-borne disease. Flooding and standing water caused by heavy precipitation may also increase the prevalence of vector-borne diseases transmitted by mosquitos.

Environmental Impacts

Species and habitats in stream systems are impacted by the increase of stormwater runoff that carries with it sediments, nutrients and other contaminants. Changes in rainfall will also affect stream flow patterns, channel hydrodynamics, lake levels and the volume of groundwater recharge from aquifers which will alter the physical, chemical and biological structure of streams. One impact may be the increased frequency of anoxic conditions and fish kills in coastal rivers.

In summary, increased intense precipitation can have many negative consequences for communities in North Carolina, including:

- **Flooding and damage to infrastructure;**
- **Destroying crops, delaying planting and harvesting, and reducing agricultural land quality through increased erosion;**
- **Landslides;**
- **Threatening the availability of clean water and potentially reducing the availability of ground water supplies; and,**
- **Increasing vector borne disease and contaminating irrigation water.**

Increased Intense Precipitation Adaptation Strategies

Infrastructure Strategies

Changing precipitation and flood patterns should be considered in infrastructure decision-making. The siting and design decisions of new infrastructure should incorporate the increased heavy precipitation and corollary flooding. For example, combined sanitary and stormwater infrastructure should be phased out.

Improvements to infrastructure design can also make communities more resilient to the impacts of heavy precipitation. Design requirements for new or refurbished roadways to include different pitches combined with stormwater infrastructure can effectively remove water from roadways and bridges.

The use of different materials, such as permeable pavements, can reduce the impact of heavy precipitation events. Porous pavements permit water to flow into the soil beneath, increasing infiltration and reducing runoff. Public improvements to streets, parks and plazas can also be designed to divert urban runoff to bio-filtration systems such as greenscapes. Green roofs, which reduce the amount of stormwater runoff and delay the time at which runoff occurs, may also be considered. Green roofs have also been shown to lower heating and cooling costs, having the added benefit of reducing energy cost of buildings.

Simple improvements to existing infrastructure can also limit damage from heavy precipitation. For example, sealing manholes to prevent water from flowing into the sewer system can prevent sewer overflows that pose a public health and environmental risk.

Improvements to stormwater infrastructure may also be needed. Communities may choose to increase the capacity of stormwater collection systems such as increasing culvert size to accommodate projected changes in precipitation.

River Bend, a town in Craven County, experienced massive flood damage from Hurricane Fran in 1996. To prevent severe flooding from occurring again, River Bend received funds from FEMA's Hazard Mitigation Grant Program to improve its existing stormwater management system. The town increased the capacity of the piping system and installed additional pipes at flood sites, allowing more stormwater to flow out of the town and not back up on properties. Two sets of floodgates were installed, as were two detention ponds to catch the water as it flows through the area.

These infrastructural improvements to the stormwater management system have prevented flooding in River Bend during large tropical storms in 2010 and 2011. Although these improvements solved the major flooding problem, the town has committed $30,000 a year to stormwater management improvements.

FEMA. 2011. "Tested and Proven Success: Stormwater Improvement System Prevents Flooding". http://www.fema.gov/mitigationbp/bestPracticeDetail.do?mitssld=9111

Land Use Strategies

As precipitation and development patterns change, flood zones will change as well. Communities should consider redefining flood hazard zones to match projected expansion of flooding frequency and extent.

Development in flood zones should be limited; construction that does occur should be designed and built to be resistant to flood damage. Some communities may even choose to remove existing infrastructure and structures from the floodplain. Buyouts following flood events are one approach used in North Carolina to remove damaged property from the flood zone.

New development's contribution to flood potential should be limited. One approach to limiting development's impact on stormwater is low impact development, which captures stormwater and reuses it onsite. Landscaping, green roofs, site design and other best management practices can be used to reduce runoff and increase retention and infiltration. Communities may consider funding and implementing demonstration projects that provide examples of how these design features can be used.

Tropical Storm Jerry and the remnants of Hurricane Danny caused extensive flooding in the city of Charlotte and Mecklenburg County in 1995 and 1997 respectively. Neither flood resulted in a presidential declaration of disaster, but they did motivate the city and county government to reduce flood losses, improve water quality, and preserve the natural functions of the floodplain.

With the participation of a broad-based collection of interests, the city and county staff developed a strong stormwater management plan that focused on six strategies: (1) the establishment of new floodplain development standards; (2) the adoption of an enhanced flood warning system, (3) the creation of a drainage system maintenance plan, (4) the design of a public information campaign, (5) the formation of an interagency steering committee, and (6) the development and implementation of watershed-based hazard mitigation plans. For each strategy specific action-oriented tasks with time lines and parties responsible for their implementation were identified. An overriding theme of the document was the use of verifiable data to ground specific policy choices in sound fact base.

The new policies were based on the creation of new flood insurance rate maps that reflected the flood hazard conditions of the future, when all allowable development had occurred in the floodplain. The maps were based on existing zoning maps and estimates of future settlement patterns and land use. The new maps allowed for estimation of future impacts that factored in new development and increased impervious surfaces that cause changes in flood elevations. Under some future buildout scenarios the flood elevations increased by as much as eleven feet and expanded the floodway.

Concurrently, the county worked to create a stream buffer plan that identified buffer widths according to the acreage drained by each creek or stream in a series of watersheds. The larger the drainage area, the larger the buffer required, if the buffer area exceeded the mapped floodplain, new development was not allowed within the larger boundary. The plan improved water quality while also mitigating the impact of flooding. With the area along the creeks kept free of development, the existing vegetation was able to filter pollutants while the open space provided additional water storage.

Source: Smith, G. (2011). *Planning for post-disaster recovery: a review of the United States disaster assistance framework*. Fairfax, Va.: Public Entity Risk Institute.

Watershed and stormwater management plans can be particularly useful to limit the stormwater impact of future development and improve existing infrastructure.

Existing open space, from vacant land to underutilized parking lots, represents an opportunity to improve stormwater management.

Natural Resource Strategies

Maintaining the health and function of existing ecosystems can help manage stormwater. Natural buffers around streams and rivers reduce sediment and pollution levels in streams. Local governments may consider implementing a buffer requirement or seek conservation easements to protect these areas. Maintaining healthy riparian areas has positive benefits for water quality, and also reduces water temperatures, increases stream capacity and provides native plant and wildlife habitat. These buffers may also serve as recreational areas.

Communities should also consider expanding local tree planting efforts. Trees can store rainwater, reduce runoff and delay peak flows as well as reducing urban temperatures as discussed in the extreme heat section. A local government may consider implementing a landscape ordinance or complete street standards to increase tree plantings.

Protection of steep slopes may be another important step to limit the damage of heavy precipitation by reducing the chance of landslides. Communities may consider updating the grading ordinance, which provides guidance to developers and engineers by regulating grading, drainage, and erosion control on private and public property to prevent water pollution and sedimentation of water resources.

Other Strategies

Communities may consider establishing long-term dedicated funding mechanisms such as storm water utility fees or other taxes to improve and maintain stormwater infrastructure. To increase citizen participation in stormwater programs local governments may also provide incentives.

Increased intense precipitation can have many negative consequences for communities in North Carolina, but there are a number of strategies to address vulnerability to intense precipitation including:

- **Consider future precipitation and flooding patterns in infrastructure improvement, design, and development;**
- **Improve street, stormwater and other infrastructure to better manage high levels of precipitation;**
- **Redefine flood hazard zones to account for future projections;**
- **Limit development in flood prone areas;**
- **Encourage low impact development;**
- **Use existing open space and vacant lots to better manage stormwater;**
- **Protect stream buffers;**
- **Expand tree planting and urban forestry;**
- **Protect steep slopes from development; and,**
- **Create a stormwater management plan and consider providing long-term dedicated funding to stormwater management.**

While not all these strategies are available to every community, every community concerned about intense precipitation has options available to reduce their vulnerability. Many of the strategies have additional benefits that may help achieve other community goals. Specific actions to implement these strategies are listed in Appendix C.

E. Rising sea level and accompanying storm surge

Sea levels are rising globally due to the thermal expansion of the ocean as it warms and melting of ice and glaciers. As molecules warm, they move quicker and take up more space. You have probably experienced this phenomenon every winter when your car tires are not as inflated after a very cold night. Another easy way to visualize thermal expansion is to take an inflated balloon and hold it over a source of heat; you will see the balloon expand as the air molecules inside move more quickly. Today, the same thing is happening to our oceans at a much larger scale.

Global sea level has risen by about 8 inches over the last century. Proxy data has shown that this rate of sea-level rise is greater than any other period in the last 2000 years. Since 1992, the rate of sea-level rise as measured by satellites has been about twice the rate observed over the last century. In the next 100 years, sea level is projected to rise another 1 to 4 feet[66]. Rise at the higher end of existing predictions will threaten five million Americans that live within four feet elevation of local high tide.

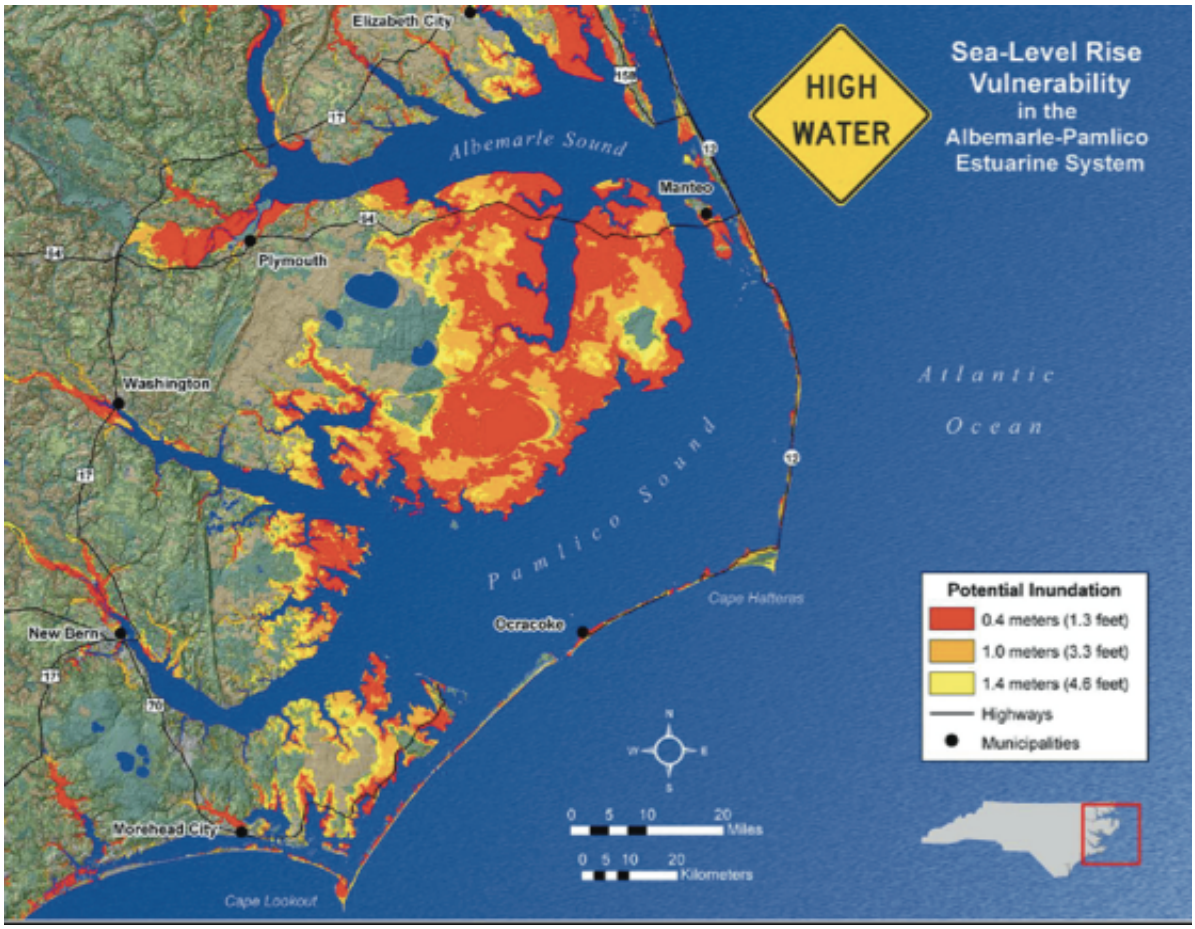


Figure 2.13 Map of areas in the Albemarle-Pamlico Estuarine System at risk of inundation under multiple sea-level rise projections[67].

The extent of sea-level rise realized by any community varies depending on local or relative sea-level rise. Relative sea-level rise is the combination of mean sea-level rise and a number of local

factors including vertical land movement (subsidence or uplift), changes in tidal ranges, changes in coastal currents, and changes in water temperature. For example, the stretch of coast from Cape Hatteras, NC to New Jersey has much higher rates of relative sea-level rise than most of the U.S. Atlantic coast[68]. As a result the coast north of Cape Hatteras will experience sea-level rise at up to double the rate of the southern shoreline in North Carolina[69].

If the rate of sea-level rise does not accelerate, coastal North Carolina can expect relative sea level to rise between eight and 15 inches by 2100. Increased rates of sea-level rise are much more likely; some models project a rise of up to 6.5 feet[70]. The North Carolina Coastal Resources Commission Science Panel recommended in 2010 that a rise of 1 meter (39 inches) be adopted as the anticipated sea-level rise for policy development and planning purposes. At this rate of sea-level rise, thousands of square miles of low lying land is at the risk of permanent and periodic inundation in North Carolina. Inundation of low-lying land is not the only impact of sea-level rise; coastal communities will confront saltwater intrusion, failure of septic tanks and die off of non salt-tolerant crops and plants.

It is important to understand that while the total expected rise in sea level by 2100 is about 1 meter, sea level will not rise at a constant rate. Rather it is highly likely that sea-level rise will be punctuated with flooding events that do not recede or increase sea level at a more rapid rate[71]. For example, tropical cyclones and their storm surge can push flooding further inland and result in severe coastal erosion that changes the shape of the shoreline and affective relative sea level. Consequently it is difficult to predict the sea level or the rate of rise for any given year[72]. Although projections are given only up to 2100, sea-level rise will continue past this date. Oceans take a very long time to respond to changes in Earth's surface temperature and therefore will continue to warm and rise for many centuries.

Figure 2.14 The 6-8 foot storm surge from Hurricane Irene caused extensive damage in North Carolina. N.C. 12 was over swept with waves cutting the roadway in five locations[73].

Sea-level rise also causes storm surges to be greater, extend farther inland and cause more damage. Although storm surge receives less publicity than hurricane winds and rain, it can cause significant damage as seawater is pushed inland, breaking down structures and carrying dangerous debris. Hurricane Irene provides a great example of how a large, low intensity storm can cause serious damage by storm surge. In North Carolina, the storm caused a 6-8 foot storm surge. North Carolina has 162,255 properties at risk of storm surge damage, and of these 48,164 are at extreme risk[74]. Rising sea levels will make homes and property already at risk of storm damage and coastal erosion increasingly vulnerable to loss. In addition, sea level rise will increase the 100-year floodplain by as much as 38% nationwide or by 7,000 square miles[75].

Economic Impacts

Sea-level rise and storm surge, combined with the pattern of heavy development in coastal areas, are already causing damage to infrastructure such as roads, buildings, ports and energy facilities[76]. Although coastal communities bear the majority of cost, some public infrastructure is replaced or repaired using state and federal tax dollars paid by all North Carolina residents. Since the early 1990's, taxpayers have spent more than $30 million repairing N.C. Highway 12, one of the most expensive and vulnerable roads in the state[77]. Some sections of the road have been fixed multiple times. To maintain N.C. 12 for the next 100 years is estimated to cost over $1 billion[78]. This sum will fall to N.C. taxpayers, but also U.S. taxpayers that pay for federal relief that contributes 80% of reconstruction cost following presidentially declared disasters like Hurricane Irene.

Event Date	Event	Cost
October 2007	Hurricane Noel	$33,000
October 2009 *	Tropical Depression Ida	$1,229,000
November 2009	Nor'easter	$377,000
September 2010	Hurricane Earl	$106,000
August 2011 *	Hurricane Irene	$12,079,000
October 2012	Hurricane Sandy	Estimated $10,000,000

Table 2.1 NC Highway 12 storm repairs in the last five years (* indicates federally declared disaster, Federal Highway Administration reimburses cost at about 80%).

In addition to the direct damage caused by sea-level rise and storm surge, economic impacts include a decline in tourism revenue. Nationwide, beach visits account for 200 million visitor days a year and amount to over $3 billion in revenue. In Dare County alone, tourists spend approximately $877 million dollars a year[79]. A rise in sea level could cause the retreat of beaches, damage infrastructure, and may dramatically impact the coastal tourist industry.

Rising sea levels can pose a serious threat to coastal agriculture in the form of salt-contaminated soils and saltwater intrusion. Increased salinity could cause the die-off of non-salt-tolerant crops. Fisheries may also suffer due to the loss of important ecosystems such as salt marshes that provide habitat for crustaceans and fish.

Health Impacts

Increase in flooding events and storm damage from sea-level rise pose a serious public safety risk. Such events not only put coastal inhabitants at risk of physical injury, hunger and sickness, but also may have long-term mental health consequences.

Saltwater intrusion is the result of seawater infiltrating freshwater aquifers. Some exchange between oceans and coastal aquifers occur naturally due to the increased mineral content, density and water pressure of saltwater. As sea level rises the ocean pressure becomes greater, resulting in greater infiltration of saltwater into freshwater aquifers. Pumping of freshwater for human needs lowers aquifer water pressure, creating a greater gradient between the ocean and aquifer pressure further exacerbating saltwater infiltration. Saltwater intrusion increases the cost of water filtration and may eventually completely contaminate water sources so they are no longer available for human consumption.

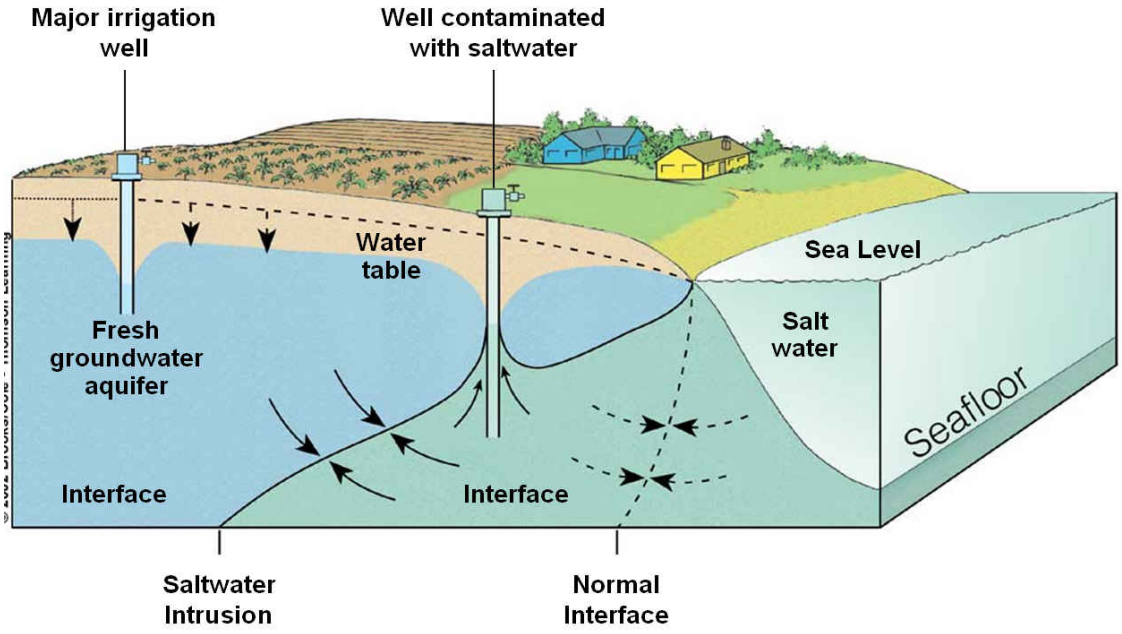


Figure 2.15 Some exchange between oceans and coastal aquifers occurs naturally, but rising sea levels and coastal pumping of freshwater aquifers changes the pressure gradient causing saltwater intrusion[80].

The same change in water pressure gradients that leads to saltwater intrusion can cause the failure of septic systems. As water tables rise, septic drainage fields no longer work effectively causing septic tanks to back up. Failure of septic systems poses yet another water quality issue and increases the potential for infectious disease.

Environmental Impacts

Coastal wetlands are at high risk due to the combined effects of sea-level rise and inland droughts that will reduce freshwater inflows. Damage to these ecosystems will be a blow to coastal biodiversity, but it also has serious implications for water quality and coastal fisheries. These ecosystems provide valuable services including water filtration, nutrient cycling, habitat

for juvenile fish, and wave attenuation[81]. Loss of saltwater marshes, as well as reefs and barrier islands will leave the coast more vulnerable to storms due to the loss of their wave attenuation. The value of coastal wetlands coastal protection has been estimated at $3,332 per acre, annually[82].

Saltwater intrusion can destroy freshwater wetlands, bays, and lakes. Coastal wetlands are particularly vulnerable to changes in salinity.

Marine systems will also feel the impacts of climate change: Aquatic community structure is largely dependent on water temperature and depth, both of which will be impacted. As sea level rises, ecosystems may not be able to move landward quickly enough to retain the appropriate depth, resulting in a change in ecosystem structure. This change in ecosystem structure may reduce the productivity of estuarine nursery areas, negatively impacting NC fisheries and the tourist industry.

Interacting Impacts

Changing precipitation patterns may exacerbate the effects of sea-level rise. A reduction in freshwater inflow paired with rising sea levels will speed the decline of coastal wetlands. Inflowing freshwater carries sediment that aids wetland accretion, changing inland precipitation patterns may increase wetland vulnerability.

In summary, sea-level rise can have many negative consequences for communities in North Carolina, including:

- **Damage to infrastructure;**
- **Decline in tourism;**
- **Damage to coastal agriculture and fisheries;**
- **Increased flooding related health risks;**
- **Saltwater intrusion and failure of septic systems; and,**
- **Loss of coastal ecosystems and their services.**

Sea-Level Rise Adaptation Strategies

Responses to sea-level rise have typically been categorized into three strategies: protection, accommodation and planned retreat.

Protection attempts to exclude the hazard by constructing barriers or reinforcing natural defenses through measures like beach nourishment and construction of sea walls. Protection is extremely costly, but may be feasible in the short-term and appropriate in highly developed locations. This strategy is criticized because it provides temporary protection to its design level and consequently is not a viable long-term option as conditions worsen. Additionally, protection measures have been known to encourage development in protected areas deemed “safe”, thus increasing the infrastructure and lives at risk if and when the capacity of structures is exceeded. Protection also comes at the tradeoff of losing natural systems such as marshes and beaches that are disrupted by engineering interventions.

Accommodation allows human and hazards to coexist (at least temporarily). Accommodation includes strategies such as elevated buildings, modification of drainage systems or altering land use.

Planned retreat attempts to remove human activity from hazardous areas with strategies such as restrictions on development and redevelopment.

Most communities could employ strategies from all three of these categories. For example a coastal community may renourish their beaches in the short term, but also require new buildings to be elevated, and develop a long-term strategy to discourage development in hazardous areas such as buyouts and prohibiting development in erosion zones.

Infrastructure Strategies

Communities can begin to integrate sea-level rise projections into new projects, infrastructure development and planning. Sea-level rise and its impacts should also be incorporated into water planning and wastewater management. Although a large degree of uncertainty exists concerning the extent and impacts of sea-level rise, response strategies can be effective and relatively painless if early action is taken.

Land Use Strategies

Post-disaster recovery plans can serve an important role in reducing coastal development in hazardous zones. By planning for redevelopment after major storm and flood events, communities can better reduce future risk by addressing the reconstruction of severely damaged homes and buildings in hazardous areas.

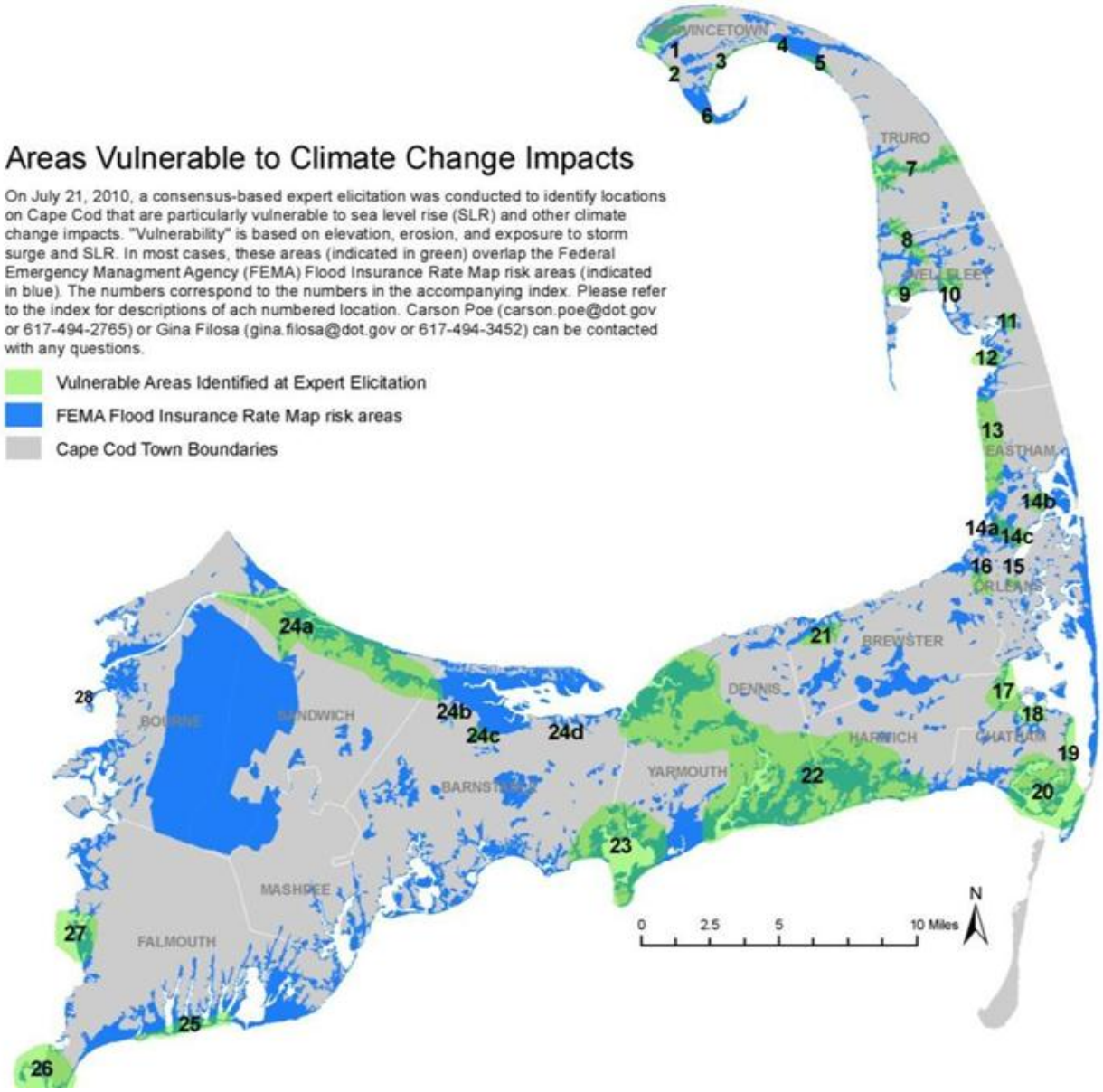
In their Coastal Area Management Act Core Land Use Plan, the Town of Duck, North Carolina states the following objectives that relate to sea-level rise adaptation: "Develop policies that minimize threats to life, property, and natural resources resulting from development located in or adjacent to hazard areas, such as those subject to erosion, high winds, storm surge, flooding, or sea level rise"; "develop location, density, and intensity criteria for new, existing development and redevelopment including public facilities and infrastructure so that they can better avoid or withstand natural hazards"; and to "develop, adopt, and enforce, and amend as necessary, a shoreline overlay zoning district to address development, redevelopment, and uses along shorelines and in adjacent waters." County ordinances also mandate a short-term moratorium on post-disaster reconstruction and enable a special reconstruction task force to identify opportunities to mitigate future damages through the management of reconstruction.

Natural Resources Strategies

Protection of natural ecosystems should also be prioritized. Intertidal flats, salt marshes, wetlands, oyster reefs and other coastal ecosystems provide extremely valuable ecosystem services including shoreline stabilization and wave attenuation that can reduce the impacts of storm surge. Additionally, these ecosystems provide water filtration and maintain fish and crustacean population on which local fisheries depend. Protection of these ecosystems may take many forms including buffers, conservation easements and overlay zoning. Communities may also consider partnering with local environmental groups to restore damaged ecosystems.

To address changing climate and rising sea levels Cape Cod, Massachusetts undertook a scenario planning process to guide future transportation and land use. The Interagency Transportation, Land Use and Climate Change Pilot Project lasted from 2010 to 2011 and produced 10 scenarios for 2030 varying in development intensity and transportation investment. These scenarios were used to develop action plans that account for vulnerability to sea level rise.

Source: Rasmussen, B., Morse, L., & Perlman, D. (2012, August). Climate Change Scenario Planning: The Cape Cod Pilot Project. *TR News*, *281*, 15–21.



Sea-level rise can have many negative consequences for communities in North Carolina, but there are a number of strategies to address vulnerability to sea-level rise including:

- **Post-disaster recovery planning;**
- **Protection of coastal ecosystems and their services; and,**

- **Integrate sea-level rise projections into infrastructure development and decision-making.**

While not all these strategies are available to every community, every community concerned about sea-level rise has options available to reduce their vulnerability. Specific actions to implement these strategies are listed in Appendix C.

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III. Taking Action

The first section of this handbook introduced the concept of climate change: it discussed expected ramifications of the changing climate, presented a case for adaptation and demonstrated the urgency of local action. The second section detailed the impacts of climate change in North Carolina and adaptation strategies to address these impacts. In this third, and final, section the adaptation planning process is presented.

First, we describe the several approaches that can be used to address climate change. Although adaptation can be integrated into many different types of plans, the process will remain the same. We describe the steps of the adaptation process next. Lastly we highlight the importance of monitoring and evaluation.

Most communities will find that the approach, process and strategies of climate adaptation are not new. Climate adaptation closely aligns with existing planning, policies and programs. Simply adjusting these existing plans, policies and programs to account for longer time frames and new motivations can produce significant progress toward climate change adaptation.

A. Approaches

Climate adaptation strategies can be implemented in a number of ways[1]:

- **Ad hoc** approach in which each department works independently to address climate impacts on a project-by-project basis;
- **Stand-alone adaptation plan** when an independent plan is produced to address climate impacts;
- **Hazard mitigation plans** can incorporate climate change impacts as long-term hazards. The Federal Emergency Management Agency (FEMA) recognized the opportunity to integrate climate change adaptation into hazard mitigation plans in the 2013 "Local Mitigation Planning Handbook"[2];
- **Sustainability** or **natural resource conservation plans** that identify environmental issues and policy strategies may naturally integrate climate change concerns;
- **Comprehensive plans** are far-reaching documents that document a community's development goals; these plans can include elements on land-use, transportation, utilities, education, economic development and hazards. Because climate change will influence all of these topics, climate change may be integrated into comprehensive plans.

Each of these approaches has strengths and weaknesses. Stand-alone adaptation plans may comprehensively address climate but be unconnected to other plans resulting in inconsistency and lack of implementation. Hazard mitigation plans are a strong approach to analyze climate impacts and address social and built-environment vulnerability but may overlook ecological system needs[3]. Sustainability and natural resource conservation plans may suffer from the reverse problem, excluding impacts on the built environment[4].

Just as not all strategies are suitable in every community context, not every approach is suitable in every situation. All approaches, however, have merit and communities should select the approaches that fit best for them. Where there is limited local support for direct climate change action due to political or economic concerns, a project-by-project or department-by-department approach may be best suited. If more resources can be dedicated to climate change action significant progress can be made through adjusting existing plans and programs to account for climate change[5]. When your community approaches renewal of its hazard mitigation plan, you may consider integrating climate change impacts and adaptation strategies into it.

Phoenix, Arizona has incorporated climate trends and variability into their Water Resource Plan. The plan takes a flexible approach to water management with four basic functions:

- Anticipating potential conditions affecting the timing and depth of water supply deficits such as climate variability, service area growth rates, and per-unit water use;
- Preparing near-term and long-term strategies for responding to deficits;
- Monitoring water supply and demand conditions including climate trends to identify trigger points; and
- Acting on pre-selected plan elements upon reaching trigger points to ensure sufficient implementation.

Phoenix has been partnering with universities and federal agencies in modeling the consequences of climate change on river flows and water resources. Where cyclical drought conditions are typically followed by periods of full reservoir recovery, a relatively permanent change in long term climate conditions could preclude such recovery creating "new normal" conditions. Some climate scenarios suggest reductions in long-term flows of 10 to 40 percent due to warmer, drier conditions. This shift could have profound implications for the volume and types of water supplies needed, demand management strategies, and for future infrastructure capacity. In effect, many trend-based factors utilized for decades in managing water resources may no longer be valid as historic patterns of wet and dry cycles may be affected by climate change. The plan attempts to identify these future scenarios and develop strategies to address potential water deficits. Phoenix's effort demonstrates an ad hoc approach in which impacts and strategies are considered for a single government function[6].

Lewes, Delaware integrated climate change adaptation into their hazard mitigation plan. The plan identifies how changing climate conditions – temperature increase, altered precipitation patterns and sea-level rise – are projected to influence current natural hazards. In assessing the city's vulnerability, a hazard mitigation approach focusing on exposure to flooding was paired with a climate change vulnerability assessment that evaluates exposure, sensitivity and adaptive capacity. Through the joint vulnerability assessment, Lewes identified two key vulnerabilities: (1) the water system that is threatened by

Figure 3.1 Flooded roadway in Lewes, Delaware caused by a nor'easter in 2008.

saltwater intrusion and destruction of water conveyance systems, and (2) the increased flooding of homes and city infrastructure. The plan recommends eight steps to improve resilience towards natural hazards and climate change including integrating hazard mitigation and climate change into the comprehensive plan[7].

Virginia Beach, Virginia addresses climate change in its comprehensive plan, and in doing so integrates climate mitigation and adaptation into transportation and land-use plans. The city was particularly concerned about the impact of sea-level rise, thus adaptation strategies focused on guiding development out of areas at risk of inundation to less vulnerable locations.

Multiple localities have developed stand-alone adaptation plans including King County, Washington; Chicago, Illinois; and New York City, New York. Although all these plans address climate adaptation, they take unique approaches. **King County, WA** uses a ***"Whole Organization Approach"*** in which climate change is embedded in the cost-benefit evaluations of all decisions made in the county[8]. In other words, each department is expected to consider climate change in their decision-making process. **New York City** in contrast takes a ***"Rational Process Approach"*** in which they conduct a vulnerability assessment and identify strategies to address identified vulnerabilities[9]. **Chicago** takes a similar approach, but rather than addressing all vulnerabilities focuses adaptive efforts on two key climate impacts: heat and precipitation. This tactic is termed the ***"Focused Approach"***. While these three examples are of major metropolitan areas, smaller local governments have also taken action.

Local governments have taken many different approaches to implementing climate adaptation. Local governments have multiple options and should select the ones best suited to their community.

B. Adaptation Process

Although communities may select different adaptation approaches, all climate adaptation will share a similar process. There are two basic products of adaptation planning - a vulnerability assessment and adaptation strategies[10]. The vulnerability assessment identifies what climate exposure and corollary climate impacts will affect the community. The adaptation strategies address the impacts identified in the vulnerability assessment. To produce these two products local governments should establish a planning process, assess vulnerability, create an adaptation strategy, and design a plan implementation and maintenance process. Box 3.1 provides an outline of the adaptation planning process, which is discussed in further detail below.

Establish the Planning Process

The adaptation planning process will largely be dependent on the approach a community chooses to pursue. If adaptation is being integrated into the hazard mitigation or comprehensive plan, the planning process will already be established. Likewise if an ad hoc approach is pursued the planning process may be modified to be opportunistic. Regardless of the approach taken, however, we urge communities to consider creating a climate change team or group that can help move adaptation forward and serve as a common source of information.

Box 3.1 Adaptation Process Outline

To produce the climate vulnerability assessment and adaptation strategies local governments should establish a planning process, assess vulnerability, create an adaptation strategy, and design a plan implementation and maintenance process

1. **Establish the Planning Process**
    - Step 1.1: Scope out Level of Effort and Responsibility
    - Step 1.2: Assess Resource Needs and Availability
    - Step 1.3: Assemble Planning Team and Establish Responsibilities
    - Step 1.4: Educate, Engage, and Involve Stakeholders
2. **Assess Vulnerability**
    - Step 2.1: Identify Climate Change Exposure
    - Step 2.2: Identify Community Sensitivity
    - Step 2.3: Assess Potential Impacts
    - Step 2.4: Consider Adaptive Capacities
    - Step 2.5: Develop Scenarios and Simulate Future Outcomes
    - Step 2.6: Summarize Vulnerability and Identify Focus Areas
3. **Create an Adaptation Strategy**
    - Step 3.1: Set Goals
    - Step 3.2: Identify Actions
    - Step 3.3: Evaluate, Select, and Prioritize Actions
    - Step 3.4: Write Action Plan
4. **Design a Plan Implementation and Maintenance Process**
    - Step 4.1: Adopt the Plan
    - Step 4.2: Implement the Plan
    - Step 4.3: Integrate Plan Findings into Other Planning Efforts and Programs
    - Step 4.4: Track, Evaluate, and Communicate Plan Progress
    - Step 4.5: Update the Plan

Assess Vulnerability

Your local hazard mitigation or natural resource plan most likely already identifies the major threats to your community, and provides a good starting point to assess climate change vulnerability[11].

Communities frequently struggle to identify expected climate exposure because most climate models are at the global or regional scale. To effectively begin planning for climate change, however, extremely localized projections are not needed. Local hazard mitigation plans identify the climate impacts most important to a community and regional climate change models can provide information about the changing frequency and intensity of these impacts. Almost every model predicts extreme events will become more frequent and/or intense.

The first step to assessing climate change vulnerability is to identify exposure or the climate change effects a community will experience. The second section of the handbook identifies five major climate change exposure in North Carolina, but these effects will not be distributed evenly across the state. Communities in the Piedmont will experience different exposure than coastal areas and vice versa.

Second, identify sensitivity of key community structures, functions, and populations that are susceptible to each climate change exposure. Climate change has the potential to have far reaching consequences on government functions and infrastructure. Many of the consequences may be unforeseen and unexpected. Appendix B, Climate Impacts, is intended to help communities think about the structures, populations, and functions that are sensitive to climate exposure.

Particular attention should be given to identifying populations vulnerable to climate change effects. Characteristics that influence social vulnerability include personal wealth, age, health, built environment, and more. Below is a list of populations vulnerable to climate change identified by the American Planning Association (2011):

- The elderly are less able to withstand stresses created by heat waves, air pollution and diseases, in addition to having greater potential mobility problems in avoiding storms and floods.
- Persons with disabilities and chronic illnesses are more susceptible to problems associated with climate change impacts due to health and mobility issues.
- Populations that are likely to be employed in outdoor settings, are more likely to be outdoors for recreation, or are homeless are more vulnerable to heat waves and air pollution.
- People living in high crime areas may refuse to open windows during heat waves or evacuate from their properties during storm events and floods due to crime concerns, enhancing their vulnerability.
- People living in substandard structures or mobile homes typically experience greater risk from storms and flooding and may have problems avoiding vector-borne diseases.
- Multifamily structures generally offer less opportunity for cross-ventilation than single-family dwellings, creating the potential for greater exposure to heat wave risk.

Table 3.1 Populations vulnerable to climate hazards[12].

Population	Heat Waves	Storms	Floods	Air Pollution	Diseases (Food & Water Borne)	Diseases (Vector Borne)
Persons over 65 (the elderly)	✓	✓	✓	✓	✓	✓
Persons 14 & under	✓	✓	✓	✓	✓	✓
Persons with disabilities or chronic illnesses	✓	✓	✓	✓	✓	✓
Linguistically isolated persons (non-English speaking or English as a second language - ESL)	✓	✓	✓	✓	✓	✓
Socially isolated persons, including the homeless	✓	✓	✓	✓	✓	✓
Single adults with children		✓	✓			
Transportation-challenged (no car or transit) persons		✓	✓			
Persons residing in high crime areas	✓	✓	✓			
Persons residing in mobile homes	✓	✓	✓	✓		✓
Persons with below median incomes	✓	✓	✓	✓		✓
Persons residing in substandard housing	✓	✓	✓	✓	✓	✓
Persons residing in multifamily structures	✓					

The third step is to identify the potential impacts that climate change exposure will have on the identified sensitive functions, structures and populations. How will an increase in extreme heat influence the delivery of energy (function), streets (structures) and the elderly (populations)? What will be the overall impacts of climate change on these functions, structures and populations?

Along with identifying exposure, sensitivity and potential impacts, adaptive capacity should be evaluated. Adaptive capacity includes the existing ability to address projected impacts. Many climate change impacts are not new and actions likely already exist to address many of the consequences of climate change.

Lastly, assessment should be adjusted to account for uncertainty, timing and different investment strategies. Strong climate adaptation planning considers not only a range of climate exposure but also a range of population growth and land use patterns. Communities should consider multiple future scenarios to identify the range of potential impacts and necessary strategies.

Create an Adaptation Strategy

The first step to developing an adaptation strategy is establishing goals. Goals should reflect the adaptive needs identified in the vulnerability assessment[13]. If a community projects impacts from increased frequency and intensity of heat waves but has no policy or actions in place to address this impact, it should establish goals to address increased heat waves. Goals should be clearly written, attainable and measurable[14].

After goals have been set, strategies should be identified. Since many of the consequences of climate change are not new, just exacerbated or accelerated, actions to address climate impacts may already exist and are being implemented outside the context of climate change[15]. Planning for climate change most likely will not require a new set of tools; rather it is only a matter of rethinking existing priorities[16]. As you begin considering strategies to address impacts, first evaluate your existing programs:

- Are there any existing actions that directly address expected climate change impacts?
- Are there any existing actions that indirectly address expected climate change impacts?
- Are the existing actions sufficient to meet expected climate change impacts?
- Are there any existing actions that could be modified or strengthened to help meet the adaptation goals?
- Are there any existing actions that are in direct conflict with the adaptation goals?

If new strategies must be developed, it is important to return to the vulnerability assessment to identify strategies that match the type and magnitude of impacts projected. Effort should be made to ensure adaptation strategies are flexible, cost effective, specific to the community's needs and integrative. Strategies selected will also vary based on the availability of financial, technical, and human resources available[17].

One approach to evaluating the acceptability of new strategies, identified by NOAA in its climate adaptation guide, is to weigh the **Social, Technical, Administrative, Political, Legal, Economic,** and **Environmental** (STAPLEE) opportunities and constraints of each action:

Social—The action should be socially acceptable.

- Will the proposed action disproportionately affect (positively or negatively) one segment of the population?
- Is the action compatible with present and future community values?

Technical—The action should be technically feasible, help to reduce losses in the long term, and have minimal cumulative and secondary impacts.

- How effective is the action in avoiding or reducing future losses?
- Will it create more problems than it solves?
- Does it solve the problem or only address a symptom?

Administrative—The action should be implementable. Can the local government meet the staffing and funding needs of the action or will it need outside assistance?

- Does the government have the capacity (staff, technical expertise, and funding) to implement and maintain the action, or can it be realistically obtained elsewhere?

Political—The action should be politically acceptable.

- Is there political support to implement and maintain this action?
- Is there a champion willing to help see the action to completion?
- Is there enough public support to ensure the success of the action?

Legal—The local government must have the legal authority to implement/enforce the action.

- Does the local government have the authority to implement/enforce the action?
- Are the proper laws and regulations in place to implement/enforce the action?
- Are there any potential legal consequences?
- Will the local government be liable for the action or lack of action?
- Is the action likely to be challenged by stakeholders who may be negatively affected?

Economic—The action should be cost- effective and be likely to pass a benefit-cost analysis.

- Are there currently sources of funds that can be used to implement the action?
- What benefits (market and nonmarket) will the action provide?
- Does the cost seem reasonable for the size of the problem and likely benefits?
- What burden will be placed on the tax base or local economy to implement this action?
- Does the action contribute to or detract from other community economic goals, such as capital improvements or economic development?
- What are the economic consequences of not implementing the action? It is important to remember that proactive planning can be more effective and less costly than responding reactively to climate change impacts as they occur[18].

Environmental—The action should meet statutory considerations and public desire for sustainable and environmentally healthy communities.

- How will the action affect the environment (land, water, protected species)?
- Will the action comply with state and federal environmental laws and regulations?
- Is the action consistent with environmental goals?

Once the appropriate adaptation strategies have been identified (using STAPLEE or a similar set of criteria) they should be prioritized for implementation. When prioritizing strategies, onset of the impact, flexibility, project cost effectiveness, co-benefits and feasibility should be considered.

Communities may choose to categorize strategies into win-win, no-regrets, low regrets and flexible adaptation options to better identify adaptation priorities:

- Win-win options—Actions that a community can take to address climate change that would likely be taken regardless of community concern for climate change. These actions

are cost-effective adaptation measures that also have other social, environmental, or economic benefits or co-benefits that make them attractive. For example, improving street design to include shade trees and incorporate stormwater management meets both adaptation and other community objectives. Improving street design can help reduce expected extreme heat and increased intense precipitation impacts. But improving street design might well be undertaken for numerous other reasons, such as to increase walking, reduce runoff or enhance aesthetics. Win-win options are measures that address climate impacts but also contribute to other social and environmental objectives.

- No-regrets options—Cost-effective adaptation measures that reduce risk to existing and future hazards. These actions are worthwhile whatever the extent of future climate change; they can be justified under current climate conditions and are also consistent with addressing risks associated with projected climate changes. These measures include mapping vulnerable populations.
- Low-regrets (or limited-regrets) options—Adaptation measures where the associated costs are relatively low and where the benefits, although mainly met under projected future climate change, may be relatively large. For example, warming temperatures will have economic development effects on communities whose economies are heavily dependent on tourism, such as coastal and mountain resort areas; such communities may want to pursue actions to minimize their economic vulnerability to climate change impacts. Low-regrets options are prudent actions to address climate impacts that are likely and pose particular threats for the community.
- Flexible adaptation options—Measures that are designed with the capacity to be modified at a future date as climate changes.

Some strategies will consistently be classified as win-win, for example conservation measures reduce costs, protect natural ecosystems, and reduce susceptibility to shortages caused by a changing climate. But the classification of most strategies will vary between communities. For example, a community that already suffers road damage from extreme heat may categorize using heat-resistant pavement a no-regrets option. Other communities that do not yet suffer road damage may classify the same strategy as low-regrets or flexible. In Appendix C adaptation actions are classified into win-win, no-regrets, low-regrets and flexible actions but the categorization may not be the same across communities.

Design a Plan Implementation and Maintenance Process

In order for adaptation strategies to be successfully implemented, a plan should describe the key mechanisms to carry out each strategy. For each strategy, the following information should be provided:

- Title
- Responsible Party
- Priority
- Funding Sources
- Goal(s) Addressed
- Objectives
- Evaluation Plan

After plans incorporating adaptation strategies are passed, they should be referenced during community decision-making. Clearly articulating the priority and goal(s) addressed will help ensure that strategies are implemented and guide future development. Including strong implementation and maintenance processes in adaptation plans will make them living documents that continue to be important after the planning process is complete.

Following the adoption of adaptation plans, other plans, ordinances and codes should be modified to ensure consistency. Adaptation strategies that affect land use should adjust the regulations governing these areas such as zoning codes. Adaptation strategies that require capital expenditures (e.g., relocating a wastewater treatment plant, building a cooling center, etc.), could be integrated into the community capital improvements plan (CIP). The CIP is an appropriate place to address priorities, funding, and scheduling of implementing adaptation strategies.

Monitoring and evaluation are particularly important in climate change adaptation because the science is still evolving. As better data and methods become available to identify localized climate change effects and predicted consequences, it is important to incorporate this improved knowledge. We encourage climate adaptation planning to be ongoing and flexible.
To support these efforts, consider:

- Hold regular meetings of the adaptation planning team or hold forums for climate change adaptation
- Continue outreach to community members and stakeholders
- Build and strengthen partnerships with neighboring jurisdictions, non-profits and the private sector

C. Monitoring and Evaluation

Due to the nature of climate change and our evolving understanding of climate, flexibility in policy is extremely important. Without appropriate monitoring and evaluation, however, it is impossible to know when or if new policies must be implemented or old ones adjusted. Phoenix, Arizona takes a very flexible approach in their water resource plan. Rather than projecting change and planning they ***anticipate*** many potential futures, ***prepare*** near-term and long-term strategies to address potential deficits, ***monitor*** conditions to identify trigger points, and when trigger points are reached ***act*** on pre-selected plan elements. Without careful monitoring of conditions, it would be impossible to determine when and what new strategies should be implemented. Consequently, we recommend that climate adaptation planning include strong monitoring framework; strategies should have clearly attached objectives that can be measured and a process to review progress. Many hazard mitigation and comprehensive plans have strong implementation sections that can serve as a guide, below is an excerpt from the Morrisville, North Carolina comprehensive plan.

Planning for adaptation to climate change differs from other planning in two key ways: the long-term nature of climate change, and the comprehensive approach that must be taken to address climate impacts. To successfully create long-term, all-inclusive plans it is essential to have an iterative process of planning, implementation, and monitoring, which feeds back in to planning and implementation.

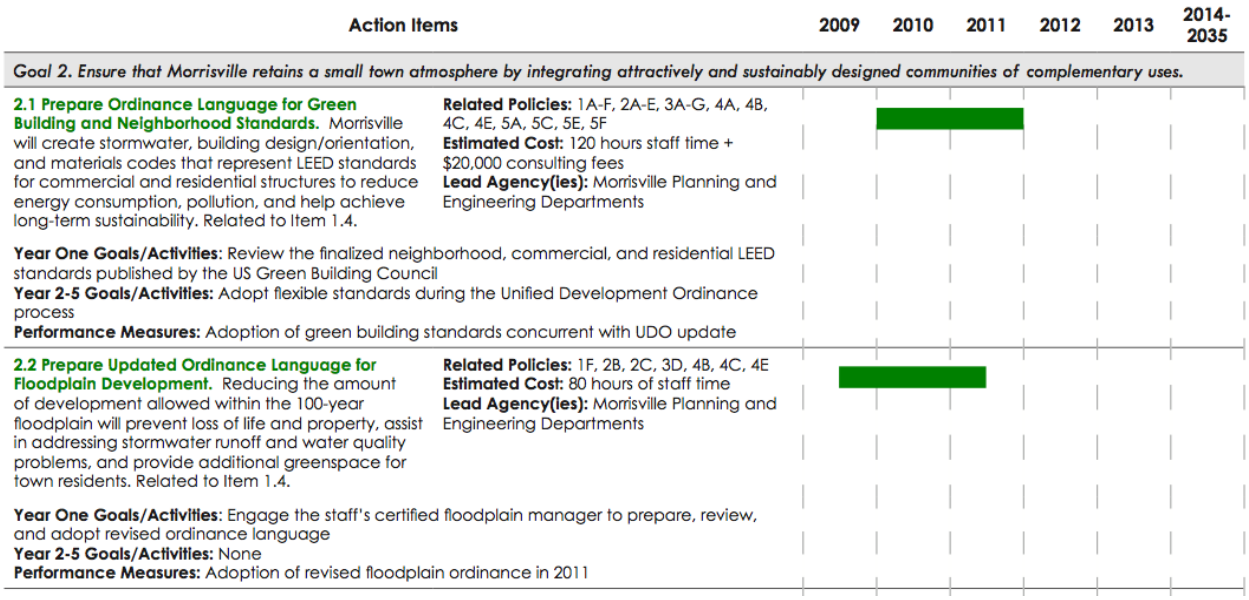

Figure 3.2 Excerpt from Morisville, North Carolina comprehensive plan, action items to achieve each goal are identified. For each action item, related policies, estimated cost, lead agency(ies), time frame, short-term objective, long-term objectives, and performance measures are listed.

D. Conclusion

Evidence continues to accumulate that climate change is occurring and that it will have negative consequences for communities across the globe. While climate change may seem daunting and distant, local governments can reduce their vulnerability. In fact, with small adjustments to existing programs, policies and plans local governments can take significant strides in addressing climate change. With the help of this handbook, North Carolina communities can begin to identify their vulnerabilities, actions already being taken, and new actionable strategies to further increase resilience.

While uncertainty does exist around climate impacts, local governments plan for uncertainty every day. Refusing to adapt or deferring action to wait and see is a choice that comes at a cost. Failing to address more frequent and intense extremes may come at the cost of more homes flooded, more asthma attacks, and more water shortages. You must ask yourself how risk adverse is my community?

Local governments have the authority, knowledge and tools to address climate change. There are opportunities, approaches and strategies available to every community to increase its resilience to climate change and create a more prosperous future.

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[17] National Oceanic and Atmospheric Administration, "Adapting to Climate Change: A Planning Guide for State Coastal Managers."
[18] Douglas Codiga and Kylie Wager, "Sea-Level Rise and Coastal Land Use in Hawai'i: A Policy Tool Kit for State and Local Governments" (Center for Island Climate Adaptation and Policy. Honolulu, HI., 2011), http://icap.seagrant.soest.hawaii.edu/icap-publications.

Appendix A: Additional Resources

Climate Change Science:

A review of basic climate science and how it should shape policy: http://downloads.globalchange.gov/Literacy/climate_literacy_lowres_english.pdf

The Intergovernmental panel on climate change has a wealth of information on their website: http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#.UaPOmCt4b68

The U.S. Global Change Research Program produces national climate change assessment reports that provide information about climate change across the U.S.: http://nca2009.globalchange.gov/

Climate Change Communication and Outreach:

A guide developed by ICLEI to help governments communicate climate change to citizens: http://www.icleiusa.org/action-center/engaging-your-community/ICLEI_Climate_Communication_Local_Governments.pdf

North Carolina Specific Climate Information:

The State Climate Office of North Carolina website provides data from local weather stations as well as information about climate change impacts in North Carolina: http://www.nc-climate.ncsu.edu/

The North Carolina Interagency Leadership Team created a document that reviews climate exposure in North Carolina, impacts on different sectors, and potential strategies to address impacts:https://connect.ncdot.gov/municipalities/InteragencyLeadership/Goals/Climate%20Ready%20North%20Carolina%20-%20Building%20a%20Resilient%20Future.pdf

The University of North Carolina at Chapel Hill Climate Change Committee Report draws on expertise of faculty members across the university to explore expected climate trends in North Carolina and their potential impacts: http://www.ie.unc.edu/PDF/Climate_Change_Report.pdf

Planning Process:

King County, Washington developed a handbook in collaboration of ICLEI for local, state and regional governments. Although the document focuses predominately on creating a stand-alone climate adaptation plan, it addresses the key steps in climate adaptation process: http://www.icleiusa.org/action-center/planning/adaptation-guidebook

The American Planning Association updated their climate change planning guide in 2011; the document provides sector-specific, mitigation and adaptation strategies. The descriptions of impacts are particularly helpful to further the discussion of broad impacts and comprehensive strategies: http://www.planning.org/policy/guides/pdf/climatechange.pdf

NOAA's "Adapting to Climate Change: A planning guide for state coastal managers" provides thorough coverage of the adaptation planning process. Although the many strategies identified are specific to state level officials, the planning process can be adopted at the local level: http://coastalmanagement.noaa.gov/climate/docs/adaptationguide.pdf

California's Adaptation Planning Guide also provides great step-by-step guidance to adaptation planning including vulnerability assessment and strategy selection: http://resources.ca.gov/climate_adaptation/docs/1APG_Planning_for_Adaptive_Communities.pdf

Examples of Climate Adaptation Plans:

The Pew Center provides information on existing state and local adaptation: http://www.c2es.org/publications/state-local-adaptation-planning

Lewes, Delaware integrated climate adaptation into their hazard mitigation plan: http://www.ci.lewes.de.us/pdfs/Lewes_Hazard_Mitigation_and_CLimate_Adaptation_Action_Plan_FinalDraft_8-2011.pdf

Virginia Beach, Virginia, addresses climate change in their comprehensive plan: http://www.vbgov.com/government/departments/planning/2009CompPlanProcess/Documents/cp-policy-document-web.pdf

Fresno County, California: http://www.lgc.org/adaptation/fresno/docs/Integrated_Strategies_for_Vibrant_Sustainable_Fresno_County_3011.pdf

A complete catalog of existing adaptation efforts can be found at Georgetown Law's Climate Center: http://www.georgetownclimate.org/adaptation/state-and-local-plans

Additional Resources:

Sector and impact specific resources, including other guidance documents and handbooks, are provided by Georgetown's Climate Center: http://www.georgetownclimate.org/adaptation/clearinghouse

APA's Green Communities Program provides multiple resources to address climate change and increase community sustainability: https://www.planning.org/nationalcenters/green/

Appendix B: Climate Impacts

This appendix is intended to help assess community vulnerability to climate change. The appendix includes four checklists: climate exposure, functions, structures, and populations. Together the four checklist will aid communities in the first two steps of a vulnerability assessment: identify exposure to climate change and identify sensitive functions. We hope the checklist will help begin the vulnerability assessment process and help identify the consequences of climate change, which can be far reaching, unforeseen and unexpected.

The climate exposure checklist includes primary and associated secondary impacts of climate change. Using data on current hazards and projected changes for the region, communities should select the most relevant primary and secondary impacts.

Climate Exposure

- ☐ More frequent drought
  - ☐ Wildfires
  - ☐ Water shortages
  - ☐ Reduced water and air quality
- ☐ More extreme heat
  - ☐ Air pollution
  - ☐ Heat waves
  - ☐ Reduced snow accumulation
- ☐ More intense hurricanes
  - ☐ Flooding
  - ☐ Reduced water quality
  - ☐ Coastal erosion
- ☐ Rising sea level
  - ☐ Saltwater intrusion
  - ☐ Flooding
  - ☐ Coastal erosion
- ☐ Intense precipitation
  - ☐ Flooding
  - ☐ Landslides
  - ☐ Reduced water quality

After completing the climate exposure checklist and identifying the primary and associated secondary impact that are most important to your community, sensitivity should be evaluated.

The functions, structures and populations checklists should help identify what aspects of the community will be affected by the projected exposure to climate change. While this list provides many functions, structures you should consider if any functions, structures and populations relevant to your community are not included such as the homeless population.

Functions

- ☐ Government continuity
- ☐ Water/sewer/solid waste
- ☐ Energy delivery
- ☐ Emergency services
- ☐ Public safety
- ☐ Public health
- ☐ Emotional and mental health
- ☐ Business continuity
- ☐ Housing access
- ☐ Employment and job access
- ☐ Food security
- ☐ Mobility/transportation/access
- ☐ Quality of life
- ☐ Social services
- ☐ Ecological function
- ☐ Tourism
- ☐ Recreation
- ☐ Agriculture, forest, and fishery productivity
- ☐ Industrial operations

Structures

- ☐ Residential
- ☐ Commercial
- ☐ Industrial
- ☐ Government
- ☐ Institutional (schools, churches, hospitals, prisons, etc.)
- ☐ Parks and open space
- ☐ Recreational facilities
- ☐ Transportation facilities and infrastructure
- ☐ Marine facilities
- ☐ Communication infrastructure
- ☐ Dikes and levees
- ☐ Water treatment plant and delivery infrastructure
- ☐ Wastewater treatment plant and collection infrastructure

Populations

- ☐ Seniors
- ☐ Children
- ☐ Individuals with disabilities
- ☐ Individuals with compromised immune systems
- ☐ Individuals who are chronically ill
- ☐ Individuals without access lifelines (e.g. car or transit, telephones)
- ☐ Non-white communities
- ☐ Low-income, unemployed, or underemployed communities
- ☐ Individuals with limited English skills
- ☐ Renters
- ☐ Students
- ☐ Seasonal residents
- ☐ Individuals uncertain about available resources because of citizenship status

Once sensitive functions, structures and populations have been identified potential impacts should be described. Description of impacts should include temporal extent, spatial extent, permanence and level of disturbance. After impacts are described, adaptive capacity should be assessed to identify what tools already exist to address the issue[1].

[1] "California Adaptation Planning Guide."

Appendix C: Adaptation Actions

This appendix includes sixty-four examples of adaptation actions that communities may consider implementing. Not all actions are appropriate for every community; rather a tailored program will have to be created to match each community's climate change vulnerabilities and capacity. To help identify appropriate actions the responsible government agency, the impacts addressed, and the action classification is identified for each action. Many of the actions will be familiar or similar to existing government programs, minor adjustments to existing programs and policy can significantly reduce vulnerability to climate change.

Government departments and their responsibilities vary across communities. Ten agencies are included as responsible agencies:

- Planning: agency that assists with managing growth, long-term planning for transportation and capital improvement, administering development regulations
- Public Works: agency responsible for street and sidewalk maintenance, stormwater management, animal control and upkeep of public property, some public works departments may also provide engineering and design services
- Emergency Management: agency responsible for developing emergency plans, addressing natural hazards, and managing emergency calls, most emergency management occurs on the county scale
- Fire Department: agency responsible for fire and first response, some fire departments may also shoulder responsibilities of emergency management
- Public Health: generally public health departments are responsible for health promotion programs, family health programs and some degree of environmental health monitoring, most public health departments are county wide
- Public Information: Agency responsible for communication and public affairs, this may also be termed human relations and include public GIS
- Public Utilities: Agency responsible for the provision of energy, water and sewer
- Finance: agency responsible for development and implementation of annual budgets as well as the necessary accounting for all government operations
- Parks and Recreation: Agency responsible for recreation and maintenance of park areas including natural areas
- Administration: Agency responsible for connecting departments, citizens and elected officials

Since government departments and their responsibilities vary, the listed agency may not be the appropriate lead agency in your community. However, it is likely there is an agency providing the listed function.

Many of the actions included address multiple climate change impacts; for example, one action may reduce risk of both heat and drought.

Actions may also be defined as win-win, no-regrets, low-regrets and flexible:

- Win-win options: Actions that address climate change that also have other social, environmental, or economic benefits or co-benefits.
- No-regrets options—Cost-effective adaptation measures that reduce risk to existing and future hazards. These actions are worthwhile whatever the extent of future climate change; they can be justified under current climate conditions and are also consistent with addressing risks associated with projected climate changes.
- Low-regrets (or limited-regrets) options—Adaptation measures where the associated costs are relatively low and where the benefits, although mainly met under projected future climate change, may be relatively large.
- Flexible adaptation options—Measures that are designed with the capacity to be modified at a future date as climate changes.

Some strategies will consistently be classified as win-win, for example conservation measures reduce costs, protect natural ecosystems, and reduce susceptibility to shortages caused by a changing climate. But the classification of most strategies will vary between communities. For example, a community that already suffers road damage from extreme heat may categorize using heat-resistant pavement a no-regrets option. Other communities that do not yet suffer road damage may classify the same strategy as low-regrets or flexible. Consequently, the classification provided may be different than how community chooses to categorize a given action.

Actions are categorized into Infrastructure, Land Use, Education, and Natural Resources adaptation actions to parallel the categorization of strategies in Section II.

Infrastructure Adaptation Actions

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Develop new risk based, decision-making process for the design and siting of new infrastructure.	Public Works, Public Utilities, Planning, Finance	X	X	X	X	X		X		

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Investigate the use of road surfaces that are more tolerant to changes in temperature on most heavily used roads.	Public Works	X							X	
Increase maintenance frequency of asphalt roads that may be adversely affected by high temperatures.	Public Works	X							X	X
Establish complete street standards to require tree plantings along roadways.	Planning, Public Works	X		X			X			
Perform a pilot project to evaluate "cool" pavement strategies to inform creation of new policies for municipal paving and capital improvement projects and private parking lots.	Public Works	X							X	
Change design requirements for new or refurbished roadways and bridges to include pitches combined with stormwater design to remove water from roadways and bridges.	Public Works, Planning			X	X			X		
Designate public buildings, such as libraries, as "cooling centers" that can be opened during extreme heat events.	Emergency Management	X						X		

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Connect emergency centers with onsite renewable energy sources to reduce susceptibility to lapses in conventional energy supply.	Emergency Management	X			X			X		
Identify areas that would allow for burial of existing power lines to avoid interruptions due to increased rain or wind events.	Planning, Public Utilities				X		X			
Design public improvements such as streets, parks and plazas for retention and infiltration of stormwater by diverting urban runoff to bio-filtration systems such as rain gardens.	Public Works, Parks and Recreation, Planning			X				X		
Use permeable surface wherever possible in public construction to reduce stormwater runoff and promote infiltration.	Public Works			X				X		
Establish long-term dedicated funding mechanisms such as storm water utility fees or other taxes to improve and maintain stormwater infrastructure.	Public Works, Public Utilities, Finance			X				X		

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Require developers of new buildings to build separate sanitary sewer and stormwater infrastructure as a condition of development approval.	Public Utilities, Public Works, Planning			X				X		
Increase capacity of stormwater collection systems to accommodate projected changes in precipitation.	Public Utilities			X				X		X
Integrate climate change scenarios into water supply systems.	Public Utilities		X						X	
Coordinate with regional water authorities on groundwater resources, surface water reservoirs, and water quality to ensure on going, high quality water supply.	Public Utilities		X				X			
Examine existing water supply systems to determine if they can be supplemented by: development of new sources of water, underground storage in aquifers during times of excess capacity, diversion of water from other uses, interconnectivity of regional	Public Utilities		X						X	

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
water systems, conservation, and new technology (reuse of gray water).										

Land Use Adaptation Actions

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Expand time horizons for comprehensive and land use planning.	Planning	X	X	X	X	X			X	
Require shaded parking lots as part of the approval process.	Planning	X		X			X			
Change existing codes to promote cool roofs made from more reflective materials	Planning	X					X			
Encourage adaptive reuse, redevelopment and brownfield development to protect open space that provides important services.	Planning		X	X		X	X			
Create incentives to reward low impact development such as a density bonus.	Planning		X	X	X	X	X			

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Revise storm water regulations and applicable municipal codes to efficiently manage higher concentrations of pollutants in urban runoff.	Public Works, Planning			X	X				X	
Update the grading ordinance, which provides guidance to developers and engineers by regulating grading, drainage, and erosion control on private and public property. To meet the ordinance's requirements, developers complete and submit a grading plan to demonstrate their compliance.	Planning, Public Works			X					X	
Encourage the use of passive systems in buildings for heating, cooling, ventilation, water delivery, and incorporate climate change preparation strategies into building design and construction	Planning,	X	X	X				X		
Update zoning ordinances to reflect expansion in flood hazard and erosion areas.	Planning, Emergency Management			X	X	X			X	

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Create a program to better insulate and weatherize old homes or provide information about state programs.	Planning	X			X		X			
Develop a vegetation and fuel management plan in areas designated as high fire hazard areas.	Fire Department	X	X					X		
Prohibit development in high-risk areas and provide incentives to concentrate development in low-risk areas.	Planning			X	X	X	X			
Utilize conservation areas and easements to preserve natural resources.										
Promote smaller single-family residential lots to reduce irrigation water demand.										

Natural Resources Adaptation Actions

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Update or create a landscape ordinance to increase tree cover and recommend trees that will thrive in future climate conditions	Planning	X		X			X			
Provide financial incentives for switching to more efficient processes and appliances.	Public Utilities	X	X				X			
Develop energy conservation incentives.	Planning	X	X				X			
Develop local water and energy conservation guidelines that are consistent with the building code.	Planning	X	X				X			
Prepare a stormwater plan that factors in projected climate changes.	Public Works, Planning			X	X				X	
Fund and implement demonstration projects that provide examples of how landscaping, green roofs, site design and other best management practices can be used to reduce runoff and increase retention and infiltration.	Planning, Public Works			X				X		

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Require development projects to complete a water conservation plan to outline their strategies for maximizing indoor and outdoor water efficiency.	Planning, Public Works		X						X	
Update the landscape manual to require new development and redevelopment projects to use landscaping that meets a designated water budget.	Planning, Public Works		X				X			
Create incentives to promote onsite water reuse such as a rebate for rain barrels.	Public Works, Public Utilities		X				X			
Propose and support building code amendments to incorporate single-source gray water “stub-outs” in new residential buildings and indoor recycled water in new commercial buildings.	Planning		X					X		
Continue source-water (well field) monitoring and protection programs to mitigate water supply loss due to groundwater contamination from pollutants and saltwater intrusion.	Public Utilities		X			X	X			

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Incorporate laws and regulations that require a percentage of pervious areas to capture and reuse rain water or increase infiltration.	Planning, Public Works			X				X		
Restore and expand riparian vegetation to increase shading, cool water temperatures, and provide cool refugia for wildlife	Parks and Recreation, Planning, Public Works	X		X			X			
Develop a comprehensive monitoring program of the biotic and abiotic environment. Establish early warning signs and track long-term changes in biological communities and processes. Key parameters may include: rate of sea-level rise; saltwater intrusion boundary; vegetation patterns; water temperature and pH; occurrence and range of invasive plant and animal species.	Park and Recreation, Planning, Public Works	X	X	X		X		X		
Identify and protect ecologically significant areas.	Parks and Recreation, Planning	X	X	X	X	X	X			

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Identify and map wetland, floodplain, and riparian ecosystems that play a vital role in flood control, groundwater recharge and water quality. Develop policies to protect and restore these areas.	Public Information, Planning, Parks and Recreation, Public Works		X	X		X	X			
Prioritize the conservation of key systems and corridors through land use planning, easements and habitat conservation plans. Funds should be leveraged by combining conservation projects with infrastructure and energy projects.	Planning, Parks and Recreation, Finance	X	X	X			X			
Utilize conservation areas and easements to preserve natural resources.	Planning		X	X	X	X	X			

Education and Outreach Adaptation Actions

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Increase public awareness about the public health risks associated with climate change and the need for emergency preparedness.	Public Health, Public Information, Emergency Management	X	X	X	X	X			X	
Create an early warning system for heat-waves and floods.	Emergency Management, Public Information, Public Health	X						X		
Enhance response to air quality hazards including encouraging use of public transportation on poor air quality days.	Emergency Management, Public Works, Public Information, Public Health	X	X				X			
Distribute educational materials about wildfire preparedness and prevention.	Fire Department, Emergency Management	X	X					X		
Provide local outreach and develop guidelines consistent with the building code to encourage green roofs.	Planning, Public Information	X		X			X			
Provide information for the public on when to replace high energy-use and high water-use appliances such as refrigerators, dishwashers, and water heaters.	Public Utilities, Public Information	X	X				X			

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Provide assistance and non-monetary incentives to help businesses manage climate change risks.	Economic Development	X	X	X	X				X	
Offer businesses free assistance to help them become more sustainable, lower their monthly utility costs and ultimately improve their bottom line.	Economic Development, Public Utilities	X	X				X			

Other Adaptation Actions

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
Update emergency response plan to address heat waves, identifying vulnerable populations.	Emergency Management, Fire Dept., Public Health	X						X		
Participate in the FEMA community rating system.	Emergency Management			X	X	X	X			
Identify multiple transportation routes for goods and evacuation during emergency situations.	Emergency Management, Public Works			X	X			X		
Update drought management plans to recognize changing conditions	Public Utilities, Planning, Emergency Management,		X					X		

Action	Responsible Agency	Impacts Addressed					Classification			
		Heat	Drought	Rain	Hurricane	Sea Level	Win-win	No-Regrets	Low-Regrets	Flexible
	Public Works									
Enhance monitoring of known diseases and potential diseases moving into the area.	Public Health	X	X	X	X			X		
Maintain a strong mosquito control program and be prepared to develop additional vector control programs as needed.	Public Health, Public Works	X		X	X			X		
Enhance community emergency planning for disease outbreaks and emerging public health threats.	Emergency Management, Public Health	X	X	X	X			X		
Work with groups like university extensions and the Farm Bureau to increase agriculture observation and monitoring, develop a climate information service, and estimates of weather and climate impacts on crop production.	Economic Development	X	X	X		X		X		
Map locations of vulnerable populations.	Planning, Public Health, Emergency Management	X	X	X	X	X		X		