UNCW

UNIVERSITY OF NORTH CAROLINA WILMINGTON

ROSEMARY DEPAOLO
Chancellor

November 30, 2008

Erskine B. Bowles
President
The University of North Carolina
P.O. Box 2688
Chapel Hill, NC 27515

Dear Erskine,

The attached report on the effects of global warming on North Carolina is the product of substantial collaboration and consultation among our faculty. I was impressed at the attention and commitment all involved demonstrated in completing it. The UNCW Board of Trustees showed special interest and individual trustees have requested personal copies. Our faculty is currently planning a global warming learning community on campus, one of the first offshoots of the effort.

Because of UNCW's location and as a reflection of the coastal and oceanic emphasis of faculty research here, our report focuses on the maritime implications of global warming. I hope our report can serve as a call to action on this troubling, critical issue. UNCW is, of course, ready to support further UNC efforts in this regard.

Sincerely,

Rosemary DePaolo

cc: Norma Houston, Executive Director, UNC Tomorrow
/enclosure: UNCW Report on Effects of Global Warming on North Carolina

601 SOUTH COLLEGE ROAD · WILMINGTON, NORTH CAROLINA 28403-5931 · 910-962-3030 · FAX 910-962-4050 · depaolo@uncw.edu

The Potential Impacts of Climate Change on Coastal North Carolina

A Report by the Faculty of the University of North Carolina Wilmington

For
Erskine Bowles
President
The University of North Carolina
910 Raleigh Road
Chapel Hill, NC 27514

November 28, 2008

Authors and Contributors

Frederick M. Bingham, Ph.D.
Associate Professor
Department of Physics and Physical Oceanography
UNC Wilmington
Phone: 910-962-2383
Email: gingham@uncw.edu

Larwrence B. Cahoon, Ph.D.
Professor
Department of Biology and Marine Biology
UNC Wilmington
Phone: 910-962-3706
Email: cahoon@uncw.edu

William J. Cleary, Ph.D.
Professor
Department of Geography and Geology
UNC Wilmington
Phone: 910-962-2320
Email: clearyw@uncw.edu

Eleanor Krassen Covan, PhD
Professor of Gerontology and Sociology
University of North Carolina at Wilmington
601 S. College Road
Wilmington, NC 28403-5625
910-962-3435 (voice)
910-962-7906 (fax)

Robert Cutting, J.D.
Attorney/Associate Professor
Department of Environmental Studies
UNC Wilmington
Phone: (910) 962-3140
Fax: (910) 962-7634
Email: cutting@uncw.edu

Christopher F. Dumas, Ph.D.
Associate Professor
Department of Economics and Finance
UNC Wilmington
Phone: 910-962-4026
Email: dumasc@uncw.edu

Douglas W. Gamble, Ph.D
Associate Professor
Department of Geography and Geology
UNC Wilmington
Phone: 910-962-3778
Email: gambled@uncw.edu

Julie Lambert, Ph.D.
Assistant Professor
Watson School of Education
UNC-Wilmington
Phone:
Email:

Lynn Leonard, Ph.D.
Chair, Dept. Geography and Geology
UNC Wilmington
Phone: 910-962-2338
Email: lynnl@uncw.edu

Stephen L. McFarland, Ph.D.
Vice Provost
Academic Affairs
UNC Wilmington
Phone: 910-962-3137
Email: mcfarlands@uncw.edu

Dr. Martin H. Posey
Professor and Chair
Department of Biology and Marine Biology
UNC-Wilmington
Phone: 910-962-3471

Mr. Roger D. Shew
Lecturer
Department of Geography and Geology
UNC Wilmington
Phone: 910-962-7676
Email: shewr@uncw.edu

Stephen A. Skrabal, Ph.D.
Professor/Assistant Chair
Department of Chemistry and Biochemistry
UNC Wilmington
Phone: 910-962-7160
Email: skrabals@uncw.edu

Dr. Alina M. Szmant, Ph.D.
Coral Reef Research Group
Center for Marine Science
UNC-Wilmington
Tel: (910)962-2362
Fax: (910)962-2410
email: szmanta@uncw.edu

Craig R. Tobias, Ph.D.
Assistant Professor
Department of Geography and Geology
UNC Wilmington
Phone: 910-962-3874
Email: tobiasc@uncw.edu

Dr. Carmelo R. Tomas,
Associate Professor of Biology and Marine Biology
Center of Marine Science
UNC-Wilmington
Phone: (910) 962-2385
Email: tomasc@uncw.edu

Wm. David Webster, Ph.D.
Associate Dean
College of Arts and Sciences
UNC Wilmington
Wilmington, NC 28403-5912
webste@uncw.edu (email)
(910) 962-3756 (phone)

Acknowledgements

Other UNCW Faculty Consulted

G. Brooks Avery, Jr. (UNCW, Department of Chemistry and Biochemistry)

Dan Baden (UNCW, Director, Center for Marine Science)

Cathy Barlow (UNCW, Dean, Watson School of Education)

Amanda Boomershine (UNCW, foreign languages, re impacts on non-English speaking populations)

Bob Buerger (UNCW, Dept. Environmental Studies; re coastal recreation)

Raymond Burt (UNCW, Chair, Department of Foreign Languages and Literatures; re impacts on non-English speaking populations)

Jennifer Dorton (UNCW, CORMP, Center for Marine Science)

Jack Hall (UNCW, Chair, Dept. Environmental Studies)

Jim Herstine (UNCW, Dept. Health and Applied Human Science; re coastal recreation)

Mark Imperial (UNCW, MPA program)

Terry Kinney (UNCW, Chair, Dept. Health and Applied Human Science)

Lynn Leonard (UNCW, Chair, Dept. Geography and Geology)

Steve Meinhold (UNCW, ORSSP)

Martin Posey (UNCW, Chair, Department of Biology and Marine Biology)

James Reeves (UNCW, Chair, Department of Chemistry and Biochemistry)

Other Persons and Organizations Consulted

National Academy of Sciences

Mr. Reid Hawkins
National Weather Service
Weather Forecast Office -- Wilmington, NC

North Carolina Department of Agriculture

North Carolina Division of Marine Fisheries
Scott Crosson, Socio-Economist
Doug Mumford, Recreational Statistics

Dr. Daniel Phaneuf
Member, North Carolina Legislative Commission on Global Climate Change
Professor, Department of Agricultural and Resource Economics
North Carolina State University

North Carolina Rural Center

Michael P. Voiland, Ph.D.
Executive Director
North Carolina Sea Grant Program

Mr. Spencer Rogers
Coastal Engineering Extension Specialist
North Carolina Sea Grant Program
UNC-W Center for Marine Science

Dr. Ryan Boyles
North Carolina State Climatologist

NC Department of Transportation

Dr. Upton Hatch, Assoc. Dir.
North Carolina Water Resources Research Institute
NC State University
Raleigh, NC

Peter Robinson, Director
NOAA Southeast Regional Climate Center
UNC – Chapel Hill
pjr@email.unc.edu

Orrin H. Pilkey, Ph.D.
James B. Duke Professor of Earth Science, Emeritus
Division of Earth and Ocean Sciences
Nicholas School of the Environment and Earth Sciences
Duke University
Durham, NC

Contents

List of Tables

List of Figures

Executive Summary

At the request of University of North Carolina President Erskine Boles, this study investigates the potential impacts of climate change in coastal North Carolina from interstate I-95 eastward to the coast and the ocean off the North Carolina coast to the 200 mile limit of the United States' Exclusive Economic Zone. Potential climate impacts and options for mitigation and adaptation are assessed for the next one hundred years to 2100. No original data collection or analysis was conducted; findings reflect review and synthesis of existing information as of November 2008.

Physical Impacts of Climate Change:

- There is a high degree of scientific certainty that global average temperature is rising and will continue to rise.
- There is a high degree of scientific certainty that sea level is rising and will continue to rise due to thermal expansion of sea water. The current projected rate of sea level rise should be considered a conservative estimate because it does not include the effects of melting glaciers or water storage in reservoirs. The greatest threat to coastal North Carolina from climate change likely comes from sea level rise and its related impacts.
- There is a high degree of scientific certainty that increases in storm and hurricane intensity will occur. Changes in hurricane frequency cannot be confidently predicted at present. More intense storms generate larger and more powerful ocean waves. The combination of sea level rise and more powerful waves multiplies coastal erosion damage risks.
- Annual precipitation (total yearly rainfall) in coastal North Carolina is not currently predicted to change dramatically. However, the frequency of precipitation extremes or prolonged droughts may increase in the 50-yr time horizon, although predictions for the NC region show only moderate changes.
- All meteorological responses to climate change (precipitation, drought, hurricanes) are strongly modified by natural oscillations in the oceans and atmosphere (e.g. El Nino, the North Atlantic Oscillation). On decadal timescales these oscillations may act to intensify or moderate climate change effects.
- The salinization of coastal groundwater sources results from a combination of increased rates of human usage (both potable water and for industrial sources) and rising sea level. Increases in coastal population will exacerbate this problem.
- There are currently examples of groundwater flow reversal in the NC coastal plain resulting from pumping. Such reversal can increase the chances of groundwater salinization.
- Relative to other regions along the Atlantic coast, the NC coast is not currently experiencing large amounts of salt contamination of major municipal groundwater wells. One notable exception is Northeastern NC where salt water has intruded into the aquifer, and where groundwater is currently treated with reverse osmosis to ensure its potability.

Ecological Impacts of Climate Change

- Barrier island marshes are most impacted by storm overwash and restrictions on migration due to the location of the Intracoastal Waterway.
- Coastal wetlands serve as primary nursery areas for commercially important shellfish and finfish. Wetlands are subject to loss through sea level rise (physical and chemical effects) and from changes in storm intensity.
- Wetlands in brackish regions of estuaries will be most impacted by sea level rise. Accelerated decomposition of brackish wetlands due to increased salinity will result in the failure of some wetlands to keep pace with rising sea level.
- Chemical changes in wetlands during salinization are linked to increases in mercury conversion to its most toxic form (methylmercury).

Public Health Impacts

- Potential public health impacts of climate change include increases in heat stress-related illness and deaths, increased incidence of mosquito and tick-borne diseases such as malaria, dengue fever and Lyme disease, increased incidence of cholera and other water-borne diseases made more virulent by warmer temperatures, increased toxicity of air pollution such as ozone at higher air temperatures, increased levels of pollen, fungal spores, mold and other allergens, and increased rip current risk due to larger waves.

Economic and Social Impacts

- Coastal property vulnerable to sea level rise in just 4 NC counties is valued at about $7 billion. Property in Northeastern NC is more vulnerable because the ground is flatter. Work is underway to estimate impacts for all NC coastal counties.
- If no beach sand renourishment or other erosion management action is undertaken, sea level rise will overtake many NC beaches by 2080. Lost recreation value to local beach goers at southern NC beaches: $93 million a year by 2030, $223 million a year by 2080. Reduction in spending by non-local beach tourists: 16% decline by 2030, 48% decline by 2080. If erosion management action is undertaken, the costs are likely to increase dramatically as sea level rise and stronger storms increase erosion rates.
- Increased economic losses due to business interruption from more intense storms could reach several hundred million dollars per storm by 2080, with cumulative losses of several billion.
- More intense storms may increase the frequency of coastal evacuations and associated costs.
- In agriculture, changes in climate could drive changes in crop mix, increase pest problems, increase irrigation needs and waste runoff problems, and increase heat stress problems for livestock. Storm damage assessments indicate that more intense storms would cause significantly more crop damage.
- In forestry, more intense storms will likely cause additional forest damage, and warmer temperatures may increase forest pest problems.

- More extreme precipitation events will likely cause larger peak flows, leading to more storm water management problems (flooding, line breaks, etc.)
- Sea level rise and extreme precipitation events will likely increase the costs of transportation infrastructure repair and relocation.
- Warmer temperatures, droughts, and stronger storms may increase damage from lightning strikes and wildfires.

Recommendations

- Maintain and expand current meteorologic data stations. Efforts should be made in conjunction with partners in adjacent states since weather and climate does not recognize borders and must be modeled regionally.
- Evaluate and develop agricultural contingency plans in response to plausible changes in rainfall or drought frequency. Strategies should include water management in conjunction with human demand for potable water and crop management strategies to smooth out swings in agricultural productivity.
- Re-evaluate current coastal zone management plans, at the local and state level. Issues to be considered should include but not be limited to: 1) rebuilding in high risk coastal zones post hurricanes; 2) contingencies for re-establishing inlets closed by overwash from coastal storms; 3) cost-sharing analysis between local, state, and federal agencies for post hurricane rebuilding of infrastructure.
- Continue to support NC's coastal ocean monitoring systems and their coordination with other regional networks. The data that these programs gather are essential for understanding coastal hurricane dynamics and predicting the role of regional ocean-atmosphere oscillations on climate change impacts.
- Expand the NC-DNR groundwater salt monitoring network spatially and temporally, and combine network data with monitoring data collected at municipal wells.
- Require that an assessment of potential aquifer salinization be performed as part of the permitting process for installation and operation of new / existing large industrial and municipal production wells.
- Through collaboration between the US Geological Survey and the NC university system, adapt existing aquifer salinization models (e.g. USGS SUTRA) and conduct salinization simulations for the major coastal populations relying on groundwater for drinking water. These simulations will be invaluable for identifying sensitive regions and planning for subsequent allocation of resources for desalinization. Dare County can be used as an economic model for cost analysis.
- Improve understanding of the effects of climate change on sensitive tidal marshes and wetlands vegetation and associated nutrient cycling (carbon, nitrogen, phosphorus) and heavy metal (particularly mercury) transformations.
- Limit emissions of mercury near coastal wetlands, marshes, and swamps because the environmental conditions there promote the formation of methylmercury, a toxic and bioaccumulative mercury species.
- An improved surveillance infrastructure is needed to assess the effects of climate change on the frequency and extent of harmful algae blooms. Presently the DENR water

quality division has only one person to observe these species. Testing for algal toxins, a function of NC DHHS, is done by contract through University or private laboratories on an as needed basis. There are not enough trained people to maintain surveillance or to respond to events including coastal fish kills of unknown origin. Support a sustained workforce, sufficient professional training, and an integrated system for identifying and managing harmful algae bloom events.

- The main research needs for predicting health effects of extreme weather events center on improving regional data and projections of the future frequency and severity of extreme weather events. In addition, Greenough et al. (2001) noted a need for more epidemiology studies of the long-term impacts of extreme events and more accurate assessments of vulnerable populations and adaptation strategies.
- Further research is needed on strategies to prevent heat-stress related deaths, including better public early warning systems.
- There is a need to better understand the population dynamics of disease vectors such as mosquitoes, ticks, and rodents under climate change conditions and the transmission of vector-borne diseases to humans.
- Additional research is needed to clarify the relationships among water- and food-borne illnesses and specific pathogens to better understand the associations between these illnesses and ambient temperature.
- There is a need to better understand potential increases in pollen, mold spores and other allergens and effects on humans under climate change conditions.
- Develop contingency plans for potential increases in lightning activity and wildfires caused by warming, drought, and storm intensification.
- Re-evaluate current coastal zone management plans in light of rising sea level, increasing erosion, and increasing coastal populations and property values. In particular, a public discussion of beach erosion management alternatives should be initiated to clarify issues of public and private rights, responsibilities, and cost burden. Location-specific studies of the comparative costs of alternative beach management policies under conditions of sea level rise and increased erosion should be conducted.
- Re-evaluate coastal building codes and zoning requirements in light of rising sea level and stronger storms. Effective adaptation to sea level rise must include development of a flexible coastal building and development code that allows for an increase in both mean high tide and storm surge over the next 25 years.
- Develop contingency plans for coastal industries vulnerable to sea level rise and storm intensification: real estate, transport, agriculture, forestry, fisheries, water supply, and storm water mgmt.
- With the potential increases in sea level, coastal erosion and storm surge flooding, and storm severity, it is critical to raise public awareness about the potential increase in frequency and severity of these damaging events and to increase education about insurance options and benefits. Efforts to educate the public about wind damage insurance, flood insurance, business interruption insurance, and crop insurance should be redoubled.
- Investigate state/local options for using financial market instruments, in addition to reinsurance and disaster reserve funds, to hedge storm/hurricane risk.

- Anticipate the need for NC greenhouse gas reductions as part of national goals; identify cost-effective regional options and plan for contingencies.
- Develop and expand university and community college faculty expertise related to climate change, adaptation strategies, and greenhouse gas mitigation technologies.
- Increase efforts to educate the public about climate change and its potential impacts; train teachers to educate NC students about climate change.

I. Introduction

Background and Committee Charge

On July 23, 2008, North Carolina Senator and President Pro Tempore Marc Basnight requested that Mr. Erskine Bowles, President of the University of North Carolina, have the University's research scientists at the system's constituent campuses submit a report on global warming, including its causes, the timetable of expected effects or results, and what North Carolina and our nation as a whole can do to prevent global warming or mitigate further effects of it. Senator Basnight requested that the researchers at each campus not consult with scientists at other campuses, but submit reports that are a result of their individual research and analyses. The Senator asked that the report describe both current conditions and where we could be in 50 years. Faculty are not expected to conduct new research on the issue, but instead, are requested to prepare a report addressing the issue based on existing expertise.

Later in July 2008, President Bowles asked each UNC campus to prepare a report, have it reviewed by the campus' board of trustees, and submit the report to UNC General Administration by November 30, 2008.

On August 6, 2008, UNCW Provost Dr. Brian Chapman charged a committee of UNCW faculty to prepare a report that would "critically examine the potential effects of global warming on North Carolina" from a regional perspective. The charge asked that the committee consider potential physical, ecological and economic impacts on the Atlantic Ocean and the coastal zone of North Carolina. The report should consider changes in temperature, sea levels, precipitation patterns and amounts, agricultural yields, species extinctions, the intensity of regional extreme weather events, disease vectors, and especially economic activity.

The National Conference of State Legislatures recently issued a series of reports on the potential impacts of climate change on state economies (NCSL 2008). The North Carolina report found "In coming decades, a changing climate is expected to increase economic impacts on North Carolina and the nation. The most recent climate modeling predicts warmer temperatures, higher sea levels and more precipitation for North Carolina, and that these changes may be more pronounced if global emissions of greenhouse gases are not reduced."

The North Carolina Legislative Committee on Global Climate Change has issued an interim report calling for additional research, but it is still studying the issue and has not produced a final report.

Report Outline

I. Introduction
II. Potential Impacts of Climate Change on Coastal North Carolina
  a. Physical
  b. Ecological
  c. Public Health
  d. Economic and Social
III. Mitigation and Adaption Options
  a. Mitigation
  b. Short Run Adaption
  c. Long Run Adaption
IV. Climate Change Education and Outreach at UNCW
V. Conclusions
VI. Recommendations
VII. References

Project Scope

In light of the project completion timeline and UNCW's commitment to regional engagement, the UNCW faculty committee decided to limit the scope to coastal North Carolina. We consider the potential impacts of climate change in a geographic area consisting of the terrestrial region of North Carolina from interstate I-95 eastward to the coast and the ocean off the North Carolina coast to the 200 mile limit of the United States' Exclusive Economic Zone. North Carolina has statutory authority to influence management decisions affecting ocean resources out to the 200 nautical mile Exclusive Economic Zone boundary, as provided in the "consistency provision" of the Coastal Zone Management Act. That authority has been exercised in oil and gas exploration issues, among others. We consider potential climate impacts and options for mitigation and adaptation over the next one hundred years. The committee decided to broaden the project scope in one respect; we consider the effects of *climate change*, rather than simply *global warming*, which is just one aspect of climate change.

Climate Change— Current International and United States Assessment

The most commonly cited sources on climate change are the Intergovernmental Panel on Climate Change (IPCC) assessment reports. The IPCC is a scientific intergovernmental body set up by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). The IPCC was established to provide decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC states:

> *Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage.*
> (http://www.ipcc.ch/about/index.htm, accessed November 7, 2008)

Since 1990, four assessment reports have been completed, and each subsequent report reviews the latest findings in global change science. The most current report, the Fourth Assessment Report (AR4) was published in 2007. The completion of these reports can be characterized as the pinnacle of scientific research, in that a critical review of research creates and provides the consensus and agreement of the international climate change expert community. Thus, the report itself offers the acceptance or rejection of hypotheses concerning climate change.

In addition to the IPCC reports, the United States has also developed reports on climate change using climate change experts from the National Academy of Sciences (NAS) and the National Oceanic and Atmospheric Administration (NOAA) Program on Climate Change. These reports represent a very similar process to the IPCC in that it is a critical review of existing climate change knowledge by a variety of experts. Overall, there is much agreement between the three reports, indicating national and international agreement on the existence of climate change, projections for the future, and potential mitigation activities.

IPCC Report

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) indicates global warming (a positive linear increase in mean global temperature) of 0.74°C since 1906 (IPCC, 2007; http://www.ipcc.ch/). Further, 11 of the last 12 years in the instrumental record of global surface temperatures (since 1850) rank among the 12 warmest years on record, and the linear warming trend over the last 50 years is nearly twice that of the last 100 years. In short, global warming is unequivocal and warming is expected at 0.6 to 4.0°C over the next 100 years. Warming air causes ocean water to warm and expand, which in turn causes sea level to rise. Current IPCC predictions (from 2007's AR4) of sea level rise range from the current rate of approximately 18 cm/century to 60 cm/century by 2100. However, these predictions do not include the effects of accelerated continental ice sheet melting and ice loss to the oceans, as these processes were not amenable to reasonably constrained quantitative forecasts at the time. Actual rates of sea level rise are certainly going to be higher than the lower estimate of 18 cm/century. A recent study indicates that we have underestimated past sea level rise as well, as water reservoir construction during the 20th century masked what would have been an additional 3 cm rise in sea level (Chao et al. 2008). Recent analysis of ice movement rates in Greenland suggests an upper bound on likely sea level rise driven by this source on the order of 80 cm by 2100, but the analysis assumes no strong positive feedbacks in factors affecting ice melt rates (Pfefer et al. 2008). This paper does not address other ice sheets (WAIS, EAIS) or other ice loss mechanisms, such as accelerated melt. The conclusion is that sea level rise projections for coastal NC of 18-50 cm are well within what is possible when we add glacial melting. The impact of a warming climate on global precipitation patterns is complex with much regional variability. However, it is very likely that more frequent heavy rain events will separate periods of extreme heat and heat waves. In regard to tropical cyclones, storms are likely to become more intense with heavier precipitation and larger peak wind speeds, but there is less confidence about changes in the frequency of tropical systems. That is, the number of storms may not increase, but the storms will likely become stronger.

U.S. Climate Change Science Program Report

Work is currently in progress under the auspices of the U.S. Climate Change Science Program (CCSP) to produce a major report on global climate change impacts on the United States for release at the end of 2008 (www.climatescience.gov). According to the CCSP, this product is intended to be an integrated summary of the CCSP's synthesis and assessment products, the recent IPCC AR4 report, and other recent results that have appeared in the scientific literature. The CCSP is aiming for a single coherent analysis of the current understanding of climate change science, a summary of the contributions of the CCSP, and the identification of important gaps in the science. Drafts of this report indicate similar concerns voiced in the IPCC AR4: climate change is more evident and occurring faster than projected, sea-level rise and increased storm surge is of great concern to US coastal regions, and the confluence of social and physical factors are increasing the vulnerability of the U.S to negative impacts of climate change.

National Academy of Sciences 2008 Update

The latest report of the United States National Academy of Science (NAS) concerning climate change also supports the findings of the IPCC AR4 and the US CCSP (NAS 2008). The report indicates that the earth is warming due to human activities such as the release of greenhouse gases, aerosols, soot, and changes in global land cover. Further, the report indicates that climate change will result in a wide variety of impacts on ecosystems and human systems. Specifically, polar-regions are already experiencing major changes with rapid decreases in Arctic sea ice and glaciers. The NAS identifies the increasing need for energy as the single greatest challenge to slowing climate change.

II. Potential Impacts of Climate Change on Coastal North Carolina

The greatest shortcomings of the IPCC, NAS, and NOAA reports and of climate change science in general, are that they are based upon global and continental-scale climate models. Given the poor spatial resolution and limited data available for climate models, it is very difficult to precisely downscale global projections to a local or regional scale. Consequently, the confidence in local or regional impacts of climate change is much lower than on the global scale and there is less certainty as to potential outcomes of climate change for a specific location. However, predictions for coastal North Carolina can still be provided in the descriptive form as opposed to a precise numeric prediction, providing important and relevant information that allows the residents and governments of North Carolina to prepare for future impacts of climate change.

II a. Physical Impacts - Weather, Climate, and Oceans

Meteorological and coastal ocean responses to climate change act as the drivers for resultant ecosystem, public health, and economic impacts in coastal North Carolina. The drivers and responses are inherently subject to different levels of certainty / scientific consensus and severity of risk. Of most concern to North Carolina is the very high confidence of the IPCC that "coastal communities and habitats [in North America] will be increasingly stressed by climate change impacts interacting with development and pollution" (Field et al., 2007: 619). The rise in sea level along the coast (and the rate of change will increase in the future) will be exacerbated by the impacts of progressive inundation, storm-surge flooding, and shoreline erosion. Storm impacts, both tropical and winter storms, are likely to be severe, especially along the Gulf and Atlantic coasts. Population growth and the rising value of infrastructure in coastal areas increases vulnerability to climate variability and future climate change (Field et al., 2007). Further, given predictions of increased frequency of droughts, it is likely further stress will be placed upon freshwater supply resources already impacted by recent extreme drought. Most if not all trends used as metrics of global change show acceleration and rates of change at the high end of forecast model predictions.

Meteorological Impacts

North America and North Carolina are likely to warm, with annual mean warming in most areas to exceed global mean warming (Christensen et al. 2007). However, within the United States, North Carolina appears to be relatively more resistant to the impacts of warming in comparison with other states (Figure 1); the Southwestern states appear most vulnerable to warming impacts. The impact of climate warming on precipitation in North Carolina and the southeastern United States varies throughout the year (Mearns et al 2003). Models indicate a 20-30% decrease in summer rain, a 25-35% increase in spring precipitation, and a 20% decrease in winter. Patterns for precipitation in fall are complicated by an inability of current models to accurately incorporate tropical storms in analysis. Predicting the net effect of the changing hydrologic cycle on the water budgets at regional – local scales remains a challenge (Boyles and Raman, 2003).

Thus physical responses to change in NC weather and climate (e.g. water supply, agricultural production) are somewhat uncertain, but possess a high level of risk particularly with regard to public health and economic productivity.

Coastal North Carolina is impacted frequently by tropical or extra-tropical coastal storms. Some analyses suggest that increase hurricane activity, frequency of landfalls, and/or storm intensity has been realized in the Atlantic Ocean over the past century (Emanuel 2005a, 2005b). Two recent studies (Komar and Allan 2008; Bromirski and Kossin 2008) provide analyses of hurricane-associated wave heights along the U.S. Atlantic and Gulf coasts during the last several decades, based on reliable data sets. Concomitant with a measured increase in North Atlantic Ocean average tropical storm intensity, duration and power (a function of size, duration and strength of wind fields), there were more and larger waves, which have power that scales as an approximate cube of wave height (i.e., a wave two-times higher has power eight-times larger). The relationship between hurricanes and global warming over the 20th century is a controversial topic (Pielke et al. 2005; Trenberth and Shea 2006, Landsea 2005, and Pielke 2005), but there is increasing agreement within the scientific community of the likelihood that greenhouse warming will cause hurricanes in the coming century to be more intense on average and have higher rainfall rates than present-day hurricanes (http://www.gfdl.noaa.gov/~tk/glob_warm_hurr.html). Pielke et al (2005) have discussed the distinction between event risk, vulnerability and outcome risk. Event risk is the probability of a particular event occurring. Vulnerability is the impact that event could have if it occurred. Outcome risk is the combination of event risk and vulnerability and can be used to characterize the need for preparation for such an event. For example, when we drive, the probability of getting into a crash is small, but we still wear seatbelts because our vulnerability to injury in case of a crash is large, with a major potential impact. So, even if the link between increased hurricane intensity is not clear at this point, the potential impact of such an increase is quite large and North Carolina should be preparing for it.

The combination of storm events and sea level rise may cause storm surges along the mid-Atlantic coast to exceed100 yr coastal floods 3 or 4 times more frequently by the end of the 21st century (Najjar et al. 2000).

An increase in hurricane intensity and storm surge represent both a growing consensus among climate change scientists and a high level of risk to public health, ecosystem resources, and economic productivity.

Sea Level Rise (SLR) Impacts

Most of the excess heat associated with global warming (~80%) has gone into the ocean. Thus, the North Atlantic Ocean is getting warmer at a rate of about 0.3-0.5 degC/century (Levitus et al. 2000, Trenberth and Shea 2006). Warming results in thermal expansion of sea water and is the major reason why sea level rose at an average rate of about 18 cm/century since from 1961 to 2003. It is important to note that sea level rise appears to be accelerating, rising at a rate of about 31 cm/century over the last ten years of this period (1993 to 2003). Current IPCC predictions (from 2007's AR4) of sea level rise range from the current rate of approximately 18 cm/century to 60 cm/century by 2100 (Figure 2).

Recent geological investigations of historic relative sea level rise in North America (e.g., Maine and Connecticut) have identified accelerated rates beginning in the late 1800's and early 1900's. Kemp et al. (2008) investigate the rate of relative sea level rise in North Carolina based on foraminifera preserved in salt-marsh sediments on Roanoke Island, North Carolina. The authors' results suggest that in North Carolina the onset of rapid relative sea level rise began earlier (at the beginning of the 1800's) and has featured two distinct accelerations: an increase at the start of the 1800's from 8.0 +/- 0.4 cm/century to 15 cm/century (+/-1.6 cm/century) and a second acceleration around 1900 to 43 cm/century. This rate has been reconciled with the available tide gauge record data. Local rates of relative sea level rise for the NC coast are highest along the northeast coastline and less so in the Cape Fear region due to small variations in land elevation changes along the NC coast. In the northern region of the state, rates of sea level rise are up to 40 cm per century, decreasing somewhat to 32 cm per century in the southern coastal region (Figure 3).

The current global predictions of sea level rise extant now are likely to be conservative, as they have not fully integrated the possibility of rapid ice sheet melt, which is not yet wholly amenable to reasonable modeling. There are some indicators that Greenland might melt very quickly, but this melt rate remains a wildcard. Pfefer et al. (2008) estimate how fast glaciers on Greenland would have to move seaward in order to drive 2 and 5 m rises in sea level by 2100, as some forecasts have warned. Given the physical limitations on glacial movements, a rise of as much as 80 cm is plausible, but not more, in that time frame. The IPCC estimates cited in the article gave ranges lower than 80 cm by 2100, with the caveat that dynamic effects of glacial movement could not be factored in. The West Antarctic Ice Sheet has shown signs of increased melting in the last 5 years and may well be a major source of sea level rise in coming decades (Rignot et al, 2008, Vaughn and Blankenship, 2007). Although model predictions indicated that The Antarctic at least initially should be gaining mass through increased snowfall caused by the warming ocean, this appears not to be the case. Field observations in the next few years will determine whether this melting will be a continuing trend.

The conclusion is that sea level rise projections like those we have considered for coastal NC (13-50 cm) are well within what is possible when we add in the glacial movement source.

One of the most important applied problems in coastal geology today is determining the physical response of the coastline to sea-level rise. Prediction of shoreline retreat and land loss rates is critical to the planning of future coastal zone management strategies, and assessing biological impacts due to habitat changes or destruction. Thieler and Hammar-Klose (1999) developed a coastal vulnerability index for the U.S. Geological Survey. The components of the vulnerability index are presented in Figure 4, and the vulnerability rankings for the North Carolina coast are presented in Figure 5. The average slope of the lower coastal plain of North Carolina is of the order of 1:2000 which indicates that the potential for SLR-induced shoreline erosion is high. Over 5000 km^2 of land are below 1-m elevation (relative to NAVD 88) and rates of sea level rise in this region are approximately double the global average due to local isostatic subsidence (Douglas and Peltier 2002, Poulter and Halpin, forthcoming).

Currently, barrier island thinning, caused by erosion on both the ocean and sound sides, is a global phenomenon on coastal plain barrier islands. This includes most of the barrier islands in NC that are not stabilized in one fashion or another. Most likely this is a response to SLR and is the means by which the islands prepare themselves for SLR. For actual migration an island must be a few 10s to hundreds of meters wide (e.g. Masonboro Island).

While current distribution of barrier islands and lagoons along the NC coast are in part a function on rising sea level, specific barrier islands dynamics (i.e. patterns of migration, erosion, deposition, storms) are typically dominated by local factors such as shore orientation, longshore current patterns, and sediment supply. As such, the response of these systems to rising sea level should be considered on local scales and all islands will not likely respond in identical fashions. Some of the current information about shoreline changes in SE NC is flawed. Using the NC DCM's long-term erosion rates (end-point data) is not the best approach. Furthermore the changes along the barriers will not follow a straight-line "depletion" curve. Inlets and their associated shoals, particularly the ebb deltas will play significant roles in how the barriers will respond to changes in the adjacent estuaries. As sea level rises the tidal prism will increase and in turn so will the nature of the inlets and their influence on the adjacent oceanfront shorelines. This is particularly true for the shorter barriers such as Sunset Beach and Hutaff Island. The spatial and temporal changes will vary along the coast- some barriers will respond very quickly while others will lag behind. In order to better quantify the above changes existing models could be improved to better predict how various barriers will respond.

It is not just sea level rise that is the problem. Most coastal managers believe that long before areas are flooded they will have been impacted on by higher storm surges and storm wave activity, salinization of ground water (addressed in latter sections of this report), destruction of infrastructure and, on barrier islands, shoreline erosion.

Other impacts of sea level rise include an increase in the rate of loss of nourished beaches. This will necessitate placing sand on artificial beaches more frequently. In addition the rate of beach loss in front of seawalls, including sandbag walls, should be expected to increase as sea level rises.

For a number of reasons, holding the shoreline in place by the current widely applied method of beach nourishment will become economically difficult and perhaps impossible. Part of the problem is that when sea level rises another foot or so, the major coastal cities will require funding to defend or replace infrastructure and it is likely that barrier island recreational property will become lower priority for federal and even state funding. Because of this, it is important to maintain the possibility of retreating from the shoreline in response to sea level rise. Buildings can be moved or demolished to accomplish this, which has the advantage of preserving the beach which is so critical to the regional economy. Prohibition of the building of high rise structures on the immediate beach front could be one step in that direction. Because they are so costly to move, high rise buildings make a flexible response to sea level rise impossible.

Sea level rise is occurring now. Sea level will continue to rise with a high degree of certainty, as do the associated risks. Given recent increase in population along the NC coast, high vulnerability exists to coastal hazards associated with climate change.

Natural Climate Oscillations and Global Climate Change

North Carolina and the southeastern US are affected by a number of important kinds of natural variation as well. This variability can mask or hide the impact of anthropogenic climate change and make the interpretation of climate change more difficult. The interaction between natural variation and anthropogenic variations is still not well-understood (e.g. Kuzmina et al., 2005). Over the years, climatologists have characterized natural variability into a number of “modes” or large-scale patterns that influence global climate. The two most important of these modes for NC are those of El Nino – Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO). Both of these phenomena have extensive literature surrounding them (e.g. http://elnino.noaa.gov; Hurrell et al, 2001). ENSO originates in the tropical Pacific, but its reach is worldwide. It has a time scale of 3-7 years, and a known and documented effect on temperature, water resources and precipitation in the eastern US (Roswintiart, et al., 1998; http://www.coaps.fsu.edu/lib/booklet/). The NAO is mainly confined to the North Atlantic and Arctic and has a 10-20 year time scale. Its impact on the climate of NC or the eastern US has not been as well-documented, but it almost certainly exists. These oscillations can have large decadal-scale impacts on coastal storm frequency and intensity, temperature, droughts, precipitation intensity, flooding, etc.

There is a high degree of certainty that El Nino and NAO are having an impact on the NC climate.

Potential Climate Implications of Methane Gas Hydrate Deposit Utilization

There are substantial clathrate (also termed methane gas hydrate) deposits off the North and South Carolina coast on the Blake Plateau, a portion of the continental slope lying partially within the U.S. Exclusive Economic Zone. These deposits are claimed to hold the energy equivalent of Saudi Arabia, although the actual amounts are not clearly established (Milkov 2004), and the technology for extracting them is not yet fully developed. Methane burns cleanly, and is found inside the territory of the U.S., so economic and political pressure to extract it will likely rise. Methane gas hydrates are also found in many other places in the world. There may be widespread interest in developing these energy resources.

Methane is a powerful greenhouse gas (23 times more powerful than CO2), so extracting significant quantities of these resources in an inefficient, "leaky" manner could hasten deterioration of the climate. Methane gas hydrates are also concentrated in some kinds of permafrost, where recent research indicates that they appear to be destabilizing and degassing methane at potentially dangerous rates (Mrasek 2008). This is a potentially powerful positive feedback in the climate system, and could accelerate global warming.

II b. Ecological Impacts

Response of Coastal Wetlands to Sea Level Rise

Coastal wetlands link terrestrial and freshwater habitats with the sea. Marshes improve water quality by acting as nutrient transformers and trapping sediment; stabilize shorelines, attenuate storm surges, provide critical habitat for estuarine organisms, act as nursery areas for commercially important species, accrete sediments, and provide recreational opportunities for people. Sea level rise and the potential increase in coastal storm frequency / intensity associated with climate change directly impact the sustainability of coastal wetlands. Marshes build through sediment trapping and the balance between plant production and decomposition. For example, Moorhead and Brinson (1995) find that vertical accretion of peat is largely responsible for landscape features in the wetlands of the Albemarle-Pamlico peninsula. All of these processes are coupled tightly to sea level, and the erosion and accretion-related aspects of storm events (Morris et al. 2002; Cahoon 2006).

As sea level rises mainland marshes (those fringing estuaries and the mainland shoreline of barrier island lagoons), and marshes located on the back edge of barrier islands must accrete vertically and migrate landward. Vertical accretion that keeps pace with sea level rise (SLR) can only occur provided that the combined effect of sediment trapping and net marsh productivity exceeds SLR. For different marsh systems, there is a threshold level of SLR, below which marshes keep pace and exhibit long-term sustainability. For most Southeastern USA salt marshes, the current rate of SLR is about a factor of 3 below the threshold, but should be considered on a marsh by marsh basis (Morris et al. 2002). Therefore, when considering the slow steady march of SLR, current evidence on geologic and decadal timescales suggests many of the true salt-water marshes in NC can keep pace. However, Moorhead and Brinson (1995) find that if the rate of sea-level rise increases, vertical accretion rates of peat will not prevent submergence of extensive areas of wetlands in the Albemarle-Pamlico peninsula area. Furthermore, vertical accretion can be reversed by storm effects that erode the seaward edge of mainland marshes or lay down thick washover deposits onto barrier island marshes. Total marsh area is maintained in mainland marshes by horizontal marsh migration into the upland (now becoming intertidal due to SLR), and barrier island marshes migrate horizontally into the lagoon following storm washover (Gardner and Porter 2001). Mainland marsh migration is constrained geologically by the slope of the upland, consequently the loss of marsh area may be more pronounced in these types of systems, particularly in more brackish (upstream) estuarine areas where the shoreline is steeper. Mainland marsh migration is further limited by human modifications to the shoreline (e.g. bulkheads; Michener et al. 1997). Further up estuaries the mainland marshes have evolved under brackish conditions. Sea-level rise combined with salinity encroachment upstream subjects these systems to enhanced decomposition. This salinity-induced loss of wetland biomass is described elsewhere in this report and may be the primary determinant of wetland sustainability in the brackish regions of NC estuaries.

For barrier islands, provided that storm intensity and frequency (Emanuel 2005, Emanuel et al. 2008) is not too great, marshes will recolonize barrier island washover fans and migrate with the barrier island complex, landward. Under this low storm frequency / intensity scenario, the spatial distribution of barrier island marshes may change but total marsh area may be relatively unimpacted. We are aware of no threshold for relating storm effects to barrier island marsh loss. Migration of the barrier island marshes in response to SLR and storm washover is constrained by the Intracoastal Waterway (ICW), which will be maintained (i.e. periodically dredged) to ensure safety of navigation. Once migration reaches the ICW loss of barrier island marsh area will occur. Barrier island marsh habitats seaward of, but in closest proximity to, the ICW are the most susceptible to climate change. Several UNCW researchers in collaboration with other scientists at the University of South Carolina, NOAA, and the US Army Corps of Engineers are actively investigating wetland response to sea level rise in NC. Focused areas of research include: ground-truthing model estimates of marsh accretion and erosion, wave impacts on marsh sustainability, and connections between changes in the hydrologic cycle and wetland-estuary nutrient exchange.

As shown in Figure 6, extensive low-lying areas along the Outer Banks and smaller regions in the Cape Fear watershed are susceptible to saltwater inundation given a sea level rise of 31 cm (1 ft). A majority of the low-lying areas are concentrated in the Albemarle-Pamlico estuarine complex, including the Outer Banks, in the northern half of the state. Most of the potentially susceptible areas in the southern part of the state are in the Cape Fear watershed. Most of these areas include tidal wetlands and marshes.

Effects of Salinity Intrusion on Estuarine and Coastal Sediments

A number of studies, including several recent investigations carried out at UNCW, have established that significant biogeochemical changes (i.e., influenced by both biology and chemistry) will occur as tidal freshwater wetlands are progressively inundated by saltier water as a result of sea level rise. Organic matter, contained in biomass of vegetative and microbial origin, is predominantly decomposed by anaerobic (not involving oxygen) respiration, since oxygen is usually absent in saturated sediments and soils due to depletion by aerobic respiration. In freshwater wetland sediments, the dominant process by which organic matter is degraded is methanogenesis, in which a potent greenhouse gas, methane (CH4), is released to the sediment, water, and eventually, to the atmosphere. As sulfate ion (the third most abundant ion, by mass, in seawater) is introduced into these environments through salinity intrusion, the dominant organic matter decomposition process shifts from methanogenesis to sulfate reduction. End-products of sulfate reduction include sulfide and carbon dioxide (CO2). Sulfide in the form of hydrogen sulfide gas has a characteristic “rotten egg” odor and is one of the sulfur compounds that give saltwater marshes their distinctive smell. Although it is produced by a natural process, sulfide is quite toxic to some vegetation and organisms which are not adapted to live in its presence (Chambers et al. 1998; Wang and Chapman 1999; Pezeshki 2001). As previously freshwater regions are slowly converted to brackish environments, significant changes in vegetation types and distributions may occur, as discussed elsewhere in this report. For example, Chambers et al. (1998) suggest that the primarily freshwater tidal plant *Phragmites australis* (an invasive species non-native to North America), which is poorly adapted to high sulfide conditions, may give way to the more sulfide-tolerant salt marsh species, *Spartina alterniflora*.

Previous studies have demonstrated that sulfate reduction is about twice as efficient in decomposing organic matter relative to methanogenesis (Crill and Martens 1987; Sexton 2002). Hence, another potential impact in inundated coastlands is enhanced decomposition of organic matter in wetlands and marshes. The increased release of nutrients from the decomposing organic matter could further enhance organic matter degradation, possibly leading to loss of wetland soil carbon and mass (Morris and Bradley 1999). The associated reduced sediment volume may compromise the ability of wetlands and marshes to maintain elevation with rising sea level (Morris and Bradley 1999). Moorhead and Brinson (1995) have pointed out the probable inability of peat-dominated wetlands in the Pamlico-Albemarle system to keep up with rising sea level; this situation may be exacerbated by enhanced decomposition rates associated with sulfate reduction accompanying salt water intrusion. This hypothesis is supported in another way by experiments by Mendelssohn and Kuhn (2003) who found that addition of sediment to submerging salt marsh improved plant vigor and growth through many factors. In a rising sea level scenario, if sediment cannot be deposited rapidly enough to replace that which is submerged, deleterious effects on plant growth might be expected. This enhanced decomposition of brackish wetlands in the presence of higher salinity may supersede the responses of marshes to the physical rise in sea level discussed elsewhere in this report.

In addition to possible loss of wetlands mass, there are other environmental changes that might result from the geochemical changes accompanying salinity intrusion. These include: (1) slightly reduced emission of the greenhouse gas, methane, to the atmosphere, from decreased methanogenesis (Weston et al., 2006); (2) slightly increased emission of the less potent greenhouse gas, carbon dioxide, into the atmosphere, from increased sulfate reduction (Weston et al., 2006); (3) increased nutrient release from wetland sediments, due to loss of adsorptive mineral matter (Mendelssohn and Kuhn, 2003); (4) changes in other biogeochemical pathways by which organic matter is decomposed (Canavan et al., 2006; Lancaster, 2008; Vinson et al., 2008).

Another concern with rising sea level in wetlands and coastal environments is the possibility that the sulfate reducing conditions associated salinity intrusion will produce conditions that are relatively more conducive to the mercury methylation. Distributions and behavior of mercury in the environment are of great concern because of the toxicity and biomagnification potential of methylmercury, the chemical form of mercury found mainly in humans, fish, and other organisms. In North Carolina, as in many locales throughout the world, significant Hg releases occur through various point sources, including electric utility plants, industrial boilers, medical, hazardous, and municipal waste incineration, and manufacturing processes. Mercury contamination of valuable aquatic resources, from water to economically valuable fish, is a chronic problem in many parts of the industrialized world. In North Carolina, several watersheds and certain fisheries within them have documented mercury contamination, including some in the southeastern portion of the state. Previous studies have established that the transformation of mercury into methylmercury (in a process termed methylation) seems to be favored in sediments in which sulfate reduction is the dominant process of organic matter decomposition (Compeau and Barth, 1985; Gilmour et al., 1992). Recent studies at UNCW have established a link between salinity intrusion into predominantly freshwater wetlands, and enhanced mercury methylation.

Vinson (2008) performed sediment incubation experiments in Cape Fear and White Oak River sediments and found that increasing salinities of freshwater sediments due to sea level rise or human activities promotes sulfate reduction and associated methylmercury production. When oxygen conditions are reduced, as occurs during sulfate reduction in the presence of saltwater, iron and manganese oxyhydroxides can be chemically dissolved reduced and release methylmercury that is adsorbed to them to the overlying waters. Lancaster (2008) found that introduction of sulfate by increasing salinity in freshwater White Oak River sediments inhibited methanogenesis and drove the system to sulfate reduction. Increased degradation of organic matter after saltwater intrusion resulted in a greater net loss of carbon to the atmosphere. Most of the carbon flux into the atmosphere; however, was in the form of carbon dioxide instead of the highly potent greenhouse gas, methane. Addition of sulfate by saltwater addition to initially freshwater White Oak River sediments also resulted in an increase in methylmercury production. These studies suggest that wetland areas most sensitive to salinity intrusion may also be particularly effective at transforming mercury into the toxic and bioaccumulative form, methylmercury. An increase in coastal areas in which mercury methylation may occur could lead to enhanced bioaccumulation of methylmercury in fish and other economically important estuarine and marine species.

Another implication of salinity encroachment up NC estuaries is an apparent decreased capacity of the system to remove excess human-derived nutrient loads. Recent work performed in the Cape Fear River by graduate students at UNCW (Graham 2008, Dale, 2007) indicates that at higher salinities, sediment bacteria tend to retain and recycle inorganic nitrogen (the dominant form of nutrient pollution) rather than convert that inorganic nitrogen to harmless nitrogen gas. The net result of higher nutrient loads exported to the coast has been shown to result in increased incidence of coastal eutrophication and harmful algal blooms. This research is currently supported by NC Sea Grant and will yield improved tools for rapid detection of estuarine nutrient removal efficiency.

Impacts on Marine Invertebrates

Dr. Martin Posey and Troy Alphin of UNC-Wilmington's Department of Biology and Marine Biology work on benthic invertebrates in coastal systems - a key link in coastal food webs and organisms often used as indicators of environmental change because of their site fidelity and longer life spans compared to plankton (months to several years) (Posey et al. 2002, 2005, Burkholder et al. 2004, Mallin et al. 2002). There is very little published specifically on the effect of climate change on benthic invertebrates in southeastern North Carolina. However, our own long-term monitoring over the past 2 decades has indicated increasing numbers and persistence of species that normally occur in more southerly latitudes (e.g. Caribbean crabs, more southern bivalves, snails, and polychaete worms). We have also demonstrated clear impacts from chronic storm disturbances (see references below), which is a predicted consequence of global climate change from most climate models. Predicted effects of global climate change would be changing ecosystem structure related to changes in relative abundances of dominant fauna due to disturbance impacts from storms and changing temperature conditions (especially warmer winter temperatures). This in turn should have impacts on their prey and predators, which include many key fishery species. Changes in coastal geography, especially as it impacts the presence of lagoonal systems protected by barrier islands will also have major impacts since the highest abundances of most key benthic fauna occur in these protected nursery areas and these lagoonal/estuarine areas are also key for juveniles of many crabs, shrimp and finfish.

The recent increase in frequency of hurricanes, which may be a result of global climate change, seems to be at least partially responsible for some of the observed recent losses of benthic species (Durako et al. 2008). Hurricane-induced losses of benthic habitats may be direct, such as those due to wave effects, which erode sparse seagrass beds and may dislodge large sponges, or indirect, such as mortality due to reductions in salinity (physiological stress), sediment resuspension (light limitation), or nutrient increases (phytoplankton blooms leading to light limitation or sponge mortality). Anthropogenic activities that similarly affect water quality may exacerbate these indirect effects. Because of the exponential decrease in light with increasing depth, even small climate-change induced increases in sea level or anthropogenically-caused reductions in optical water quality could exacerbate benthic habitat losses in this region due primarily to light limitation because of the relatively high light requirements of seagrasses and symbiont-containing corals. Likewise, as evidenced by recent increases in coral bleaching, even small increases in water temperatures resulting from global warming may have negative effects on benthic species living near their upper thermal tolerance limits.

Impacts on Coral Reefs

Coral reefs and associated near-shore ecosystems are among the first marine ecosystems that showed evidence of effects of climate change, with then Senator Al Gore in 1991 labeling them as the “canaries in the minefield” for climate change (Gore 1992). Recent reports have documented major losses of live coral cover due to elevated seawater temperatures (e.g. Hoegh-Guldberg 1999; IPCC 2007), as well as concern over related ocean acidification on calcification rates on coral reefs (Hoegh-Guldberg et al 2007; ISRS 2008). Coral reefs world wide and especially in the Western Atlantic-Caribbean region have suffered increasing and dramatic changes in species abundance, diversity and habitat structure over the past two to three decades (Gardner et al 2003), much from elevated seawater temperatures, but also direct human impacts such as over fishing and siltation and pollution from poor land use. Physiological studies are on-going to understand how elevated temperatures stress or kill corals, and a model of how this happens at the molecular level is now available (DeSalvo et al 2008). Sponges are another prominent component of coral reef ecosystems that have been reported to bleach and die. The giant barrel sponge *Xestospongia muta,* a large and important Caribbean reef sponge, expresses hsp70 stress protein and dies when exposed to temperature increases of only a few degrees (Lopez-Legentil, et al. 2008). Therefore, rising sea water temperatures may also result in major declines of sponge populations in coral reef ecosystems. Although most of the studies to date concern corals and sponges in Florida, the Bahamas and the Caribbean, the work has broad implications for marine life off the coast of NC as well, which includes some of the same species of corals and sponges.

Impacts on Marine Mammals

The Marine Mammal Program within the Department of Biology and Marine Biology at UNC Wilmington undertakes two bio-monitoring programs within the state and mid-Atlantic region that provide long-term data sets to investigate the potential impacts of global climate change: (1) The program utilizes aerial surveys to document abundance and distribution patterns of marine mammals within our waters (e.g., Thayer et al. 2003). With North Carolinian and international collaborators, researchers investigate how these patterns correlate with environmental factors such as distance from shore, depth, and sea surface temperature. (2) The program responds to stranded marine mammals to investigate biology as well as to identify causes of mortality (Barco et al. 2008). These efforts have resulted in data sets that span longer than 10 years within the state and over 20 years within the region. Long-term data sets for large marine vertebrates are rare. This work has enhanced our ability to assess the health of, and to identify emerging diseases in, marine mammals within our State's waters.

The program's investigation of the thermal biology of cetaceans (whales, dolphins and porpoises), including the bottlenose dolphin, our local North Carolina marine mammal, can be used to predict how global climate change may impact the thermal physiology of this sentinel marine species (Meagher et al. 2008, Westgate et al. 2007, Dunkin et al. 2005, Torres et al. 2005). These studies have included a specific examination of how wild dolphins regulate their whole body temperature and heat loss across seasons as they experience typical annual changes in water temperature. These results are the first to establish such baseline data for any whale or dolphin species.

Impacts on Terrestrial Mammals

Climate change has significant impacts on several species of mammals, especially small mammals whose geographic distributions are limited by either the coldest temperatures during this year (January minima) or the warmest temperatures of the year (July maxima). The effects of global climate change on marine and terrestrial medium and large-sized mammals is minimal, as most have geographic distributions that range widely on the east coast of North America and the effects of climate change will be first seen at the northern and southern limits of their ranges. Likewise, the effects of global climate change on marine mammals will be less dramatic inasmuch as their aquatic environment is inherently much more stable than all terrestrial environments except caves.

Species of small mammals that are expanding their geographic distributions in North Carolina include the northern yellow bat and Brazilian free-tailed bat, and the nine-banded armadillo is now found in central South Carolina and will colonize North Carolina in the next fortnight or two. Also, as spruce-fir forests continue to retreat to higher elevations in the southern Appalachian Mountains, mammal species that inhabit the lowlands encroach higher on the mountains, thereby expanding their ranges attitudinally. This includes such species as the southern flying squirrel, eastern harvest mouse, and southeastern shrew. None of the aforementioned mammal species is considered imperiled.

Several species of small and medium-sized mammals are becoming less widespread in North Carolina. The snowshoe hare occurred in North Carolina in the last century but no longer occurs here, ostensibly due to climate change and the resulting change in flora. The fisher and porcupine inhabited North Carolina two centuries ago, but not in the last century. Also, as spruce-fir forests become increasingly more restricted to high elevations in the southern Appalachians, mammal species that inhabit the northern hardwood and spruce-fir forests are becoming less widespread. The northern flying squirrel, several species of shrews, the Appalachian cottontail, and perhaps the least weasel have geographic distributions that are shrinking in North Carolina. In addition, bats that hibernate are particularly affected by global warming, as temperatures in hibernacula are too warm for bats to stay in hibernation the entire winter, which depletes their fat reserves and they die. Many of these species are considered to be imperiled at the state or federal level. As a side note, North Carolina was warm enough during the last interglacial that a vampire bat occurred in North Carolina.

Impacts on Species Diversity and Extinction

Williams et al. (2007) find that key risks associated with projected climate trends for the 21st century include the prospects of future climate situations unlike any existing climates and the disappearance of some existing climates. Because climate is a primary control on species distributions and ecosystem processes, novel 21st-century climates may promote formation of novel species associations and other ecological surprises, whereas the disappearance of some extant climates increases risk of extinction for species with narrow geographic or climatic distributions and disruption of existing communities. Williams et al. consider the A2 and B1 emission scenarios produced for the fourth assessment report of the Intergovernmental Panel on Climate Change, with the goal of identifying regions projected to experience (*i*) high magnitudes of local climate change, (*ii*) development of novel 21st-century climates, and/or (*iii*) the disappearance of extant climates. Novel climates are projected to develop primarily in the tropics and subtropics, whereas disappearing climates are concentrated in tropical montane regions and the poleward portions of continents. Under the high-end A2 scenario, 12–39% and 10–48% of the Earth's terrestrial surface may respectively experience novel and disappearing climates by 2100 AD. Corresponding projections for the low-end B1 scenario are 4–20% and 4–20%. Dispersal limitations increase the risk that species will experience the loss of extant climates or the occurrence of novel climates. There is a close correspondence between regions with globally disappearing climates and previously identified biodiversity hotspots; for these regions, standard conservation solutions (e.g., assisted migration and networked reserves) may be insufficient to preserve biodiversity.

II c. Public Health Impacts

Human Disease

The Global Change Research Act, passed by the U.S. Congress in 1990, requires that periodic national assessments be conducted of the potential consequences of climate variability and change on the nation's health. The first U.S. National Assessment of the Potential Consequences of Climate Variability and Change was completed in 2000 (National Assessment Synthesis Team, U.S. Global Change Research Program 2001) and was the culmination of a national process of research, analysis, and dialogue about the coming changes in climate and their impacts, and what Americans can do to adapt to an uncertain and continuously changing climate. Patz et al. (2000) describe the conclusions of the National Assessment in the area of potential human health impacts in the Health Sector Assessment (HAS). The HSA focused on five categories of health outcomes: temperature-related morbidity and mortality, the health impacts of extreme weather events (e.g., storms and floods), health outcomes associated with air pollution, water- and food-borne diseases, vector- and rodent-borne diseases, and other diseases. The detailed results of the HAS were published in a series of papers released in 2001 (Bernard et al. 2001a,b, Greenough et al. 2001, Gubler et al. 2001, McGeehin and Mirabelli 2001, Rose et al. 2001). Ebi et al (2006) provide an update to the executive summary of the HSA. The following human health effects information was extracted and abbreviated from the Ebi et al (2006) report.

Temperature-related morbidity and mortality. Extreme heat waves during increasingly warm summers are expected to increase morbidity and mortality risks. For example, the extreme heat wave that struck Europe in 2003 caused approximately 35,000 deaths (Schar et al. 2004). As the U.S. population ages, it will become more vulnerable to heat-related health risks. On the other hand, some studies find that there has been a declining trend in heat-related deaths in U.S. cities from the 1960s through the 1990s, indicating that adaptive measures such as indoor cooling, heat response plans and urban planning can ameliorate some of the effects of extreme heat events on public health. Temperature and pollution levels are often highly correlated, and controls for each need to be incorporated into models to avoid overstating impacts of either factor.

Health effects related to extreme weather events. A large number of studies have examined the short- and long-term mental health effects of extreme events [e.g., increases in diagnoses of post-traumatic stress disorder (PTSD) following severe floods or hurricanes]. Although the existence of mental health impacts has been controversial, recent research appears to have confirmed that extreme events can increase PTSD.

Health effects related to air pollution. The net effects of climate warming on air pollution and human health are uncertain because of the complex interactions between meteorologic conditions, natural systems, and human activities that determine health impacts. For example, by linking output from climate models to air pollution models used to evaluate air quality compliance, some studies find that warming may increase ozone formation and peak ozone concentrations in Los Angeles and Sacramento, California. Other studies find both increased and decreased ozone concentrations, depending on the location and scenarios considered. The divergent results highlight some of the difficulties in projecting future pollutant concentrations under different climate change scenarios. There is general agreement that increased CO2 and higher temperatures will generally increase the growth rates of allergen-producing plants (e.g., ragweed) and the production of pollen. Increased allergen and pollen levels could increase the incidence and severity of asthma, which is already a serious public health issue in North Carolina, costing state residents an estimated $631 million in 2003 (Jensen 2006). Additional research is needed on specific meteorologic variables, meteorologic models that can estimate chemical and spatial relationships, and the future locations and types of pollution emissions.

Water- and food-borne diseases. An increase in the frequency and severity of extreme precipitation events caused by climate change would increase the risk of contamination events, which would increase the risk of water- and food-borne illnesses. For example, studies find that extreme precipitation events increase the loading of contaminants to waterways and could increase the risk of illness associated with *Cryptosporidium parvum* and salmonella.

Vector- and rodent-borne diseases. For mosquito-borne illnesses, increasing average temperatures may generally reduce the U.S. population's susceptibility to epidemics, assuming increased amounts of time would be spent indoors in air-conditioned environments. However, an increase in the frequency and severity of water-related extreme weather events (i.e., floods and hurricanes) could potentially increasing mosquito–human contact. There is a substantial literature relating weather and climate, but not climate change per se, to particular diseases. Because malaria and dengue fever have been the most extensively studied, these diseases are reviewed individually, followed by a brief summary of research on other diseases. Chan (1999) reviews a number of studies providing the following additional detail on malaria and dengue fever.

Malaria. Several associations between malaria and higher temperatures or climatic events have been reported in recent years in places such as Europe, Pakistan, Rwanda, Kenya and Colombia. Models have been used to explore malaria under climate change scenarios using a variety of approaches. Results suggest spreading of malaria to many currently non-malaria areas. Although one study found that under modified weather conditions malaria was not likely to spread beyond Florida in the United States, two other studies predicted that a global average 2°C rise in temperature could cause seasonal malaria to increase in some temperate regions as far north as northern Europe, suggesting that North Carolina is also at risk.

Dengue fever. Studies have found that higher temperatures increase the transmission efficiency of dengue virus by *Aedes* mosquitoes in the laboratory, and median temperature in the rainy season is the strongest predictor of dengue transmission in Mexico. Another study reported dengue fever climbing from 1,200 to 1,700 m above sea level in Mexico, in areas where the vector but not the disease had been previously present. Local climatic conditions were more important in predicting outbreaks than elevation per se, and the implication was that climate change may assist the spread of dengue into new susceptible areas. Another study examined the possibility for latitudinal spread of dengue by estimating the shift of 0°C isotherms (the minimal conditions for overwintering of eggs and larvae), and concluded that much of central and southern Europe could be at risk. Again, this suggests that North Carolina is also at risk for increasing dengue fever.

Other diseases. Cholera is typically a waterborne disease, with outbreaks often related to floods or droughts. When cholera cells emerge from dormancy, such as during increased water temperatures from El Niño events, they may attach themselves to zooplankton. Zooplankton blooms in warm nutrient-enriched waters has been hypothesized to concentrate the cholera pathogen in waters close to human settlements. The Centers for Disease Control and Prevention found an association between hurricanes, with their torrential rainfall, and leptospirosis, a bacterial disease characterized by a skin rash and flu-like symptoms, transmitted by rodents. Another study reported an association between the increased climate variability associated with the El Niño events and rodent-borne outbreaks of hantavirus. Two studies have concluded that climate variability and change could increase tick populations and the incidence of Lyme disease. Climate warming will likely increase health risks from increased fungal growth and fungal spores. Under warmer conditions, fungi could increase in number and could release mycotoxins with toxic, immunosuppressive, teratogenic, or carcinogenic compounds.

Harmful Algae Blooms

Warming of NC coastal waters, with eutrophication as a contributing factor, will directly affect the public health of state residents via an increase in the incidences of harmful algal blooms (HABs) (Smayda, 1997, Anderson , 1989; Hallegraeff, 1993; van Dolah, 2000). The increase in temperature allows a longer period of algal growth with amenable nutrient conditions in shallow lagoons, bays and estuaries. North Carolina has already been affected by “ex patriate” HABs. In the fall of 1987, Onslow Bay and coastal areas to the south were invaded by a toxic bloom of *Karenia brevis*, the Florida red tide organism (Tester et al., 1991), which lasted up to 4 months and caused the cessation of shellfish harvest (mostly oysters), and the cancellation of the regional Fall Oyster Festival. The state mobilized a testing and surveillance program using a model for bloom management from Florida, and was able to control the human exposure to sea food tainted by it. This species had not been reported in North Carolina previously and its introduction to our waters was attributed to transport of bloom populations from Florida to North Carolina via the Gulf Stream. Elevated temperatures in NC waters allowed *K. brevis* to survive longer and establish itself. Low winter temperatures prevented this species from establishing itself in NC waters, but as winter temperatures rise over coming decades, more frequent outbreaks could be expected. Surveys of Gulf Stream water and transported seaweed show a continuous presence of subtropical HAB species that could invade North Carolina coastal areas.

A ten year study of the New River Estuary (Jacksonville, NC) provided evidence for the presence of at least 18 toxic or potentially toxic species in that embayment (Tomas, 2002). The collaborative project between NC DENR, NCDHHS-CDC and UNCW (Tomas) has resulted in the identification of the highly toxic species, *Alexandrium peruvianum*, in 8 of the 10 years of study at the French’s Creek station near Camp Lejeune (Tomas et al, 2008). This is another toxic species previously unknown to our waters. The impact of this species on fishes and humans are unknown and should be followed with epidemiological investigations. Exposure of humans to these toxins will be a function of human recreational and commercial activities in coastal waters as well as consumption of contaminated seafood (oysters, clams, shrimp and crabs).

Most HABs occur during the summer and fall when previously unrecognized species persist throughout the warmer months. Extending the warm period further into fall offers an environment for a prolongation of those blooms. The prediction is that as coastal waters continue to remain warm longer, the HAB communities will fill ecological niches normally held by less invasive and beneficial species. HABs can also lead to hypoxia and anoxia (low oxygen stress) which will also hamper remediation methods to re-establish populations of species like oysters to stressed environments.

Some of the most potent HAB species belong to the freshwater Cyanobacteria or "blue green" algae, commonly observed as floating green mats in lakes, ponds and reservoirs. These can produce potent toxins that affect human liver, kidney and heart function. The toxins are absorbed through the skin or ingested in potable water. Increased warming will encourage cyanobacterial blooms and increased toxin release. This is of particular importance to our State's freshwater water supply since increasing HABs will influence large human populations relying on them for drinking water.

Warming coastal waters will also lead to an increase in prevalence of two oyster parasite infections, Dermo and MSX. The increased presence of these parasites will render a greater portion of the oyster population not suitable for human consumption. At present, there is no remedy to these parasites, and the situation may require as in Chesapeake Bay, the introduction of resistant foreign oyster populations, with grave implications to the native NC oysters.

II d. Economic and Social Impacts

Economists and other social scientists have been working hard to assess the potential economic and social impacts of global climate change for over 20 years (Darmstadter and Toman 1993, RFF 2001, Stern 2007). The work is both conceptually and practically difficult. Forecasting economic impacts is conceptually difficult because climate change involves nonlinear (i.e., "threshold" and "explosive") relationships among variables in the economy and the natural world (Darmstadter and Toman 1993). The work is practically difficult because the problem is global in scale, requiring the acquisition and assessment of data from many different countries with widely varying natural environments, economic systems, and especially data collection programs and the political will to cooperate.

A recent report by Bin et al. (2007) examines the potential economic impacts of climate change on North Carolina coastal resources. Coastal areas in the U.S. have seen growing populations and increased economic activity in recent years. Population in the coastal zone grew 37% between 1970 and 2000. The coastal zone contains only 4% of the U.S. land area, but the economic activity measured by employment and economic value added in the coastal zone contributed 11% to the U.S. economy in 2000 (Colgan 2004). Population growth has been accompanied by unparalleled growth in property values. The Heinz Center Report (2000a, 2000b) estimated that a typical coastal property is worth from 8% to 45% more than a comparable inland property. The relatively dense populations and valuable coastal properties are vulnerable to substantial risks including sea level rise, shoreline erosion, and storm damages. The authors consider three important sectors of the coastal economy: the impacts of sea-level rise on the coastal real estate market, the impacts of sea-level rise on coastal recreation and tourism, and the impacts of tropical storms and hurricanes on business activity.

Impacts on Coastal Property

Bin et al. (2007) estimated the potential impacts of sea level rise on property values in coastal North Carolina. Property impacts were assessed for four case study coastal counties (Bertie, Dare, Carteret and New Hanover), ranging from high-development to rural-economies and with shoreline dominated by estuarine to marine environments. The authors used high-resolution topographic LIDAR (Light Detection and Ranging) data to provide accurate inundation maps in order to identify all property that would be lost under different sea level rise scenarios if no adaptation activities are undertaken. The sea level rise scenarios considered were: an 11 centimeters (cm) increase in sea level by 2030 (2030-Low), a 16 cm increase by 2030 (2030-Mid), a 21 cm increase by 2030 (2030-High), a 26 cm increase by 2080 (2080-Low), a 46 cm increase by 2080 (2080-Mid), and an 81 cm increase by 2080 (2080-High). Data on property values came from the county tax offices which maintain property parcel records that include assessed value of property as well as lot size, total square footage, the year the structure was built, and other structural characteristics of the property. Spatial amenities such as ocean and sound/estuarine frontage, distance to nearest shoreline and elevation were also obtained using Geographic Information Systems (GIS). The baseline year is 2004, and all impacts are measured in 2004 U.S. dollars.

The Bin et al. study estimates the loss of property values due to sea level rise using a simulation approach within a hedonic property model framework (Palmquist 2004). In this approach, the property values are regressed on structural, location, and environmental attributes. Separate hedonic schedules are estimated for residential and non-residential properties. The estimated regression provides the relative importance of each property attribute in determining the property values.

Table 1 shows the distribution of current property values at risk from sea level rise. Displayed are the current (2004) property values that will be lost under the inundation scenarios. Overall, the northern part of the North Carolina coastline is comparatively more vulnerable to the effect of sea level rise than the southern part. Low-lying and heavily developed areas in the northern coastline of North Carolina are especially at high risk from sea level rise. The most significant loss is occurring in Dare County, followed by Carteret, New Hanover, and Bertie counties. For Dare County, the percentage of total property value lost ranges from 6% to 19%. Dense development along the Outer Banks in Dare County is subject to the most dynamic geological process in North Carolina. The loss in Carteret County ranges from 2% to 5% while New Hanover County has a relatively small loss from less than one percent to 1.5%. The loss in Bertie County is similar to that of New Hanover County in percentage terms.

Considering the four example coastal counties together (including the three most populous counties on the North Carolina coast), the present value of lost residential property value in 2080 is $3.2 billion discounted at a 2% discount rate. The present value of lost nonresidential property value in 2080 is $3.7 billion at a 2% discount rate.

The Bin et al. estimates do not consider the adaptation that coastal communities and property owners are likely to undertake as they observe sea level rise over time. Property owners may decide to relocate their communities in response to sea level rise or pursue beach sand renourishment. If so, property losses would be lower, but owners and/or government would bear adaptation costs. The Bin et al. estimates provide an assessment of the potential magnitude of losses without adaptation. Prevention of these losses is a measure of the potential benefits of adaptation activities. These benefits can be compared with the costs of adaptation activities to assess net benefits of proposed adaptation policies.

The Bin et al. results are likely conservative estimates of losses. The study focuses on the loss of property value from permanent inundation due to sea level rise. The impacts of temporary inundation caused by high tides and storms are not considered and occur much sooner in time than permanent flooding. Measuring the impacts of temporary flooding requires additional data such as the distribution of the partial damages due to storm surge, frequency and intensity of storms, and timing of storms. Flood insurance may change the estimated loss, although the insurance covers only the structures (not the land) and does not cover the loss due to sea level rise. Current flood insurance coverage under the National Flood Insurance Program is limited to $250,000 for a single family residence. The value of lost public infrastructure is another component that is not included in the Bin et al. study, although it is likely to be small relative to residential and commercial property losses. Wetlands account for a large portion of the land that would be inundated by sea level rise in coastal North Carolina. Wetlands provide a wide range of amenities such as habitat for fish and wildlife, flood protection, water quality improvement, opportunities for recreation, education and research, and aesthetic values. These functions and services are economically and ecologically valuable. Any losses of wetlands and associated function and service values due to climate change would not be captured by the losses of assessed residential and commercial property values.

Bin, Kruse and Landry (2008) find in a study of coastal North Carolina properties that location in a flood zone decreases property value and that larger flood probabilities have larger impacts on property values. The implication of this result is that increases in coastal flooding probabilities related to sea level rise and storm intensification can be expected to decrease property values of structures located in and near flood zones.

Impacts on Recreation and Tourism

The United States has 33,000 kilometers of eroding shoreline and 4300 kilometers of critically eroding shoreline (National Research Council 1995; U.S. Army Corps of Engineers, 1994). Sea level rise caused by climate change would likely increase beach erosion problems. The second component of the Bin et al. (2007) study provides estimates of the impacts of beach erosion due to sea level rise on coastal recreation and tourism in North Carolina. Bin et al. estimate the effects of sea-level rise on beach recreation at southern North Carolina Beaches (appropriate beach recreation data were not available for northern NC beaches) and recreational shore fishing along the entire NC coast. To estimate the recreational impacts of sea level rise current erosion rates are calculated for beaches and fishing locations and projected beach widths are modeled. Projected increases in erosion are estimated qualitatively for the years 2030 and 2080 by a local expert. These erosion rates are then mapped spatially to describe changes in beach width assuming no nourishment or barrier island migration (Table 2). Two sets of recreation data are used with the travel cost economic valuation method for recreation demand estimation. The first data set includes information on beach trips to southern North Carolina beaches. The second includes information on shore-based fishing trips for the entire North Carolina coast.

Bin et al. find that the lost recreation value of climate change-induced sea level rise to beach goers is $93 million in 2030 and $223 million in 2080 for the southern North Carolina beaches. For those households who only take day trips, 4.3% of recreation value is lost in 2030 and 11% is lost in 2080 relative to 2004 baseline values. For those households who take both day and overnight beach trips, 16% and 34% of recreation value is lost in 2030 and 2080, respectively. Beach trip spending by non-local North Carolina residents on hotels, restaurants, gas stations, etc., would also change significantly with climate change-induced sea level rise. Spending by those who only take day trips would fall by 2% in 2030 and 23% in 2080 compared to 2004. Those who take both day and overnight trips would spend 16% less in 2030 and 48% less in 2080. Turning to recreational shore fishing impacts, Bin et al. find that the aggregate annual reduction in shore angler recreation value due to sea level rise across all North Carolina beaches would be $14 million in 2030 and $17 million in 2080. This is a 3% reduction in 2030 and a 3.5% reduction in 2080 relative to 2004 baseline values. Angler spending would not change significantly as shore anglers move to other beaches or piers and bridges in response to sea level rise. Recreation value declines for the anglers themselves because these alternative fishing locations are less desirable. The coastal recreation and tourism analysis indicates that sea level rise may lead to substantial losses from reduced opportunities for beach trips and shore fishing trips without some type of mitigation. The present value of the lost recreation benefits due to sea level rise would be $3.5 billion when discounted at a 2% rate for the southern North Carolina beaches. The present value of the lost shore fishing benefits due to sea level rise would be $430 million using a 2% discount rate.

Impacts of Power Outages and other Business Interruption

The third component of the Bin et al. (2007) study estimates the impacts of increased storm severity on general “business interruption." The impacts of business interruption can be significant. For example, power outages result in an estimated cost of $80 billion per year in the U.S. (LaCommare and Eto 2004), and weather-related events account for 60 percent of customers affected by disturbances on the bulk power grid (North American Electric Reliability Council). Business interruption impacts depend on storm severity, date of storm strike, and the path of the storm across the state. As a case study, Bin et al. (2007) assess storm impacts by investigating projected climate-related increases in storm intensity for hurricane Fran, a category 3 storm that made landfall in North Carolina in 1996. Maximum wind speeds and wind gusts are calculated for each county along Fran's historical track, with and without the estimated impacts of climate change. The wind speeds are translated to equivalent hurricane categories, and hurricane categories are translated to days of business interruption by industry segment based on a survey of coastal NC businesses conducted by Burrus et al. (2002) (Table 3). Days of business interruption are then converted to economic impacts based on economic output per day by industry for each of the four case study counties. In these four counties alone, category 3 hurricanes similar to hurricane Fran would cause $34 million in additional business interruption losses per storm due to climate change by 2030, and $157 in additional business interruption losses per storm by 2080. If storm frequency is assumed to remain constant under climate change, the estimated cumulative impacts of climate change on business interruption in these four counties alone from 2004 to 2080 range from $373 million with no increase in coastal populations or income to $1.44 billion assuming coastal population and income increases as projected by the state of North Carolina. County-level cumulative loss estimates vary due to differences in population, industry structure, distance to the coast, etc., ranging from negligible impacts for Bertie County to $946 million for New Hanover County. None of these loss estimates includes losses from any category 4 or 5 hurricane strikes that might occur and have larger impacts due to climate change.

Impacts of Lightning Strikes

Lightning strikes cause billions of dollars of damage in the United States each year (Mills 2005). Climate change is expected to shift the distribution and frequency of lightning strikes (Reeve and Toumi 1999). The insurance industry has observed a notable increase in losses during periods of elevated temperatures (Figure 7) (Mills et al. 2002). North Carolina citizens and businesses may need to increase insurance protection to manage increased lightning risk, and insurance protection costs may increase due to higher premiums associated with increased risk.

Impacts of Wildfires

Wildfires cause billions of dollars of damage in the United States every year (Mills 2005). Fried et al. (2004) estimated the impact of climatic change on wildland fire and fire-suppression effectiveness in northern California. The warmer and windier conditions corresponding to a 2×CO_2 climate scenario produced fires that burned more intensely and spread faster in most locations. Despite enhancement of fire suppression efforts, the frequency of escaped fires doubled and the acreage burned by contained fires increased by 50 percent. On average, the average period of time between fires in grass and brush vegetation types was cut in half. The reported estimates reported represent a minimum expected change, or best-case forecast. In addition to the increased fire-suppression costs and timber costs, changes in fire severity of this magnitude would have widespread impacts on vegetation distribution, forest condition, and greatly increase the risk to property and human life. Increased wildfire could be a significant threat to pine forest regions of eastern North Carolina under drought conditions.

Impacts on Agriculture

Climate change may impact agriculture through warmer temperatures, more damaging storm winds, and more extreme rainfall events and flooding. The U.S. Department of Agriculture produces plant hardiness zone maps based on annual average minimum temperatures. These maps are used by farmers and horticulturalists to determine which plants are suitable for planting in various geographic regions of the U.S. From 1990 to 2006, the U.S.D.A. estimated that temperatures had warmed sufficiently to shift the plant hardiness zones northward, with the result that eastern North Carolina moved from a mix of zones 7 and 8 to entirely zone 8, the warmer zone (Figure 8). With continued warming, we may see additional shifts in climate zones and associated shifts in the crop and garden plants suitable for planting. A recent study by the American Enterprise Institute and the Brookings Institution estimated a potential 23 percent reduction in agricultural profits in North Carolina as a result of climate change (Deschenes and Greenstone 2006).

Although warm temperatures are necessary for growing crops, at higher temperatures crops may become stressed and growth may be negatively impacted, reducing crop yields. Schlenker and Roberts (2008) review the available information on the relationship between temperatures and growing conditions, identifying threshold temperatures at which crop yields decline rapidly. Their results imply that U.S. yields on corn, soybeans, and cotton are likely to decline by about 30–80% if the projected extent of warming occurs, with larger declines in yields expected in warmer (mostly southern) states than in cooler states.

Warmer temperatures may increase heat stress-related livestock deaths. North Carolina has multi-billion dollar poultry, egg, and hog industries, and heat stress can reduce the ability of these animals to gain weight and reproduce, in addition to direct mortality. For example, Adams et al. (1998) found that a 9 degree Fahrenheit increase in temperature reduces livestock yield in animal and dairy operation in the Appalachian region by about 10 percent. Livestock in the coastal plain are also susceptible to heat stress. Cooling technology could be used to reduce heat stress, but this would impose higher costs on agriculture and reduce profits.

Should climate change increase storm severity, stronger winds may inflict greater losses on agriculture by directly damaging crops in the field. The North Carolina Agricultural Statistics Service (NCASS) is a joint venture between the North Carolina Department of Agriculture & Consumer Services and the United States Department of Agriculture's National Agricultural Statistics Service. NCASS publishes current and historical statistics concerning agriculture in North Carolina (Murphy 2006). NCASS has produced County Damage Reports that provide estimates of crop and livestock losses due to tropical storms and hurricanes since 1996 (NCASS 2006).

Agricultural hurricane damage statistics for the case study counties considered in the Bin et al. report and statewide totals, 1996-2006, are presented in Table 4a. There is great variation in damage across counties for a given storm. This variation is due to differences in the types and intensity of crops and livestock raised across counties and differences in distances to the coast. Across storms, damages across counties differ for an additional reason—differences in storm tracks and landfall dates. Some storms cross counties that have large agricultural sectors, while other storms do not. Some storms make landfall at times when crops are more vulnerable to high winds and flood waters, other storms make landfall at times when crops are less vulnerable. Damages differ across years for a given county and hurricane category due to differences in the intensity of agriculture within a county over time and differences in agricultural commodity prices from year to year.

Despite the variation, some patterns emerge. In general, higher intensity storms produce greater damages. Damages for each county and statewide damages averaged across storms within each hurricane category are presented in Table 4b. As hurricanes increase in intensity, average damages rise. This pattern is not seen for every pair of hurricane categories for every county due to idiosyncrasies of the limited data set. Indeed, even for the statewide totals, average damages for a category 1 hurricane are lower than average damages for a tropical storm. However, the increases in average statewide damages between category 1 and category 2 hurricanes, and again between category 2 and category 3 hurricanes, are substantial.

Based on differences in average North Carolina crop and livestock damages from tropical storms and hurricanes between 1996 and 2006, it appears that a tropical storm or category 1 hurricane strike causes $30-$50 million (in 2004 dollars) in crop and livestock damage. A category 2 storm causes an average of $200 million in damage, or $150 million in incremental damage beyond the damage that would be caused by a category 1 hurricane strike. A category 3 storm causes an average of $800 million in damage, or $600 million in incremental damage beyond the damage that would be caused by a category 2 strike.

Climate change may also impact agriculture through more extreme rainfall events and associated flooding. Allan and Soden (2008) examine the predicted tendency for a warming atmosphere to hold more moisture and generate more extreme precipitation events. Observed amplification is found to be greater than predicted by modeling, suggesting that more extreme rainfalls may be more problematic than thought. This research was based on tropical zone studies, but in general wet regions, such as coastal NC, should see even wetter conditions (warmer water close by, warmer air, etc.) during warm seasons. Thus, we might reasonably expect to see more frequent extreme rain events in coastal NC. For example, Cahoon's (2008) analyses of Wilmington, NC, rainfall data show this tendency. With more extreme precipitation events, we would expect that hog lagoons and other outdoor waste holding systems would become more vulnerable to catastrophic rain events that will be hard to predict and almost impossible to handle with current design standards. Many waste spills owe directly to torrential rain events. Hog farmers will need to spray out more and keep lagoons lower, and that causes other troubles. Agricultural runoff will get worse – fertilizers, pesticides, and land-applied wastes will run off more vigorously in large rain events. Heavier rains also soak soils more thoroughly and bog equipment at planting and harvest times.

Impacts on Forestry

A recent review (Journal of Forestry 2008) of the potential impacts of climate change on forests notes that although increased temperatures and concentrations of carbon dioxide in the atmosphere may increase forest growth, increased pest infestations, decreased precipitation and increased wildfires may decrease forest production. In the south, increased damage from southern pine beetles could reach $500 million to $1 billion annually. The potential costs of increased fire fighting to combat wildfires could be substantial--in just the past 18 years, fire management expenses of the US Forest Service have increased from 13 to 45 percent of the agency's budget.

In a survey of 322 forest managers/users in the Mid-Atlantic region of the United States, DeWalle et al. (2003) found that climate change could have major effects on forest management because of the potential for increased frequency, duration, and/or severity of extreme weather events. In addition to direct loss of timber due to wind damage, survey respondents also mentioned the following impacts of extreme weather events: (1) depressed market prices following the event due to salvageable timber flooding the market, (2) delayed access to timber and delayed timber sales due to blocked roads and flooded areas, and (3) increased costs of road and facility maintenance.

Bin et al. (2007) found that, based on the limited data for North Carolina from hurricane Fran (category 3) and hurricane Isabel (category 2), the incremental forest damage associated with an increase in hurricane severity from category 2 to category 3 is substantial, on the order of 150% per storm event, or about $900 million.

Forests may also play a role in North Carolina's long-term greenhouse emissions reduction strategy. For example, studies suggest that the right forestry activities in the United States could increase carbon sequestration by 100–200 million tons/year, possibly doubling the amount of carbon annually sequestered by America’s forests (Bosworth et al. 2008).

Impacts of Fisheries

Bin et al. (2007) found that consistent time series data on the damages to commercial fishing operations caused by tropical storms and hurricanes do not currently exist for North Carolina. However, two recent case studies (Cheuvront 2005, Burgess 2006) indicate that commercial fisheries suffer economic losses primarily in the form of damaged fishing gear and reductions in the number of safe fishing days. In addition, there is some evidence that the populations of some target species may fall following hurricanes, further reducing the profitability of fishing. In addition, heavier rainfall events caused by climate change would likely increase polluted runoff to coastal streams and sounds, resulting in more frequent shellfish closures.

Impacts on Storm Water Management

Allan and Soden (2008) examine the predicted tendency for a warming atmosphere to hold more moisture and generate more extreme precipitation events. Observed amplification is found to be greater than predicted by modeling, suggesting that more extreme rainfalls may be more problematic than thought. This research was based on tropical zone studies, but in general wet regions, such as coastal NC, should see even wetter conditions (warmer water close by, warmer air, etc.) during warm seasons. Thus, we might reasonably expect to see more frequent extreme rain events in coastal NC. For example, Cahoon's (2008) analysis of Wilmington, NC, rainfall data indicates this tendency.

Potential consequences for urban storm water management are not trivial. Storm drain systems will be more frequently overwhelmed with street flooding a consequence. Storm water runoff management will become more difficult, as really big events overwhelm systems constructed to handle a “24 hr 25 year” event more often and generate significant loads of sediment and erosion damage as a result. Erosion problems in general will worsen, causing trouble at construction sites. Sewer systems with infiltration and inflow problems (I&), such as the City of Wilmington’s wretched system, will more frequently have large incursions of extra flow into system, with consequent treatment problems and violations. Costs to prevent this will be huge. Wilmington, NC, has a 2.5 million gallon per day I&I problem already in a system with 24 million gallons per day capacity.

Potential Impacts of Saltwater Intrusion on Water Resources

As sea level rises, the groundwater supplies of coastal communities could face greater threats from saltwater intrusion than previously thought, according to a new study from Ohio State University (Mizuno 2008). Based on the sea level rise predicted by the Intergovernmental Panel on Climate Change (IPCC), hydrologists simulated how saltwater will intrude into coastal fresh water aquifers. This new research shows that when saltwater and fresh water meet underground, they mix in complex ways, depending on the texture of the sand along the coastline. In some cases, a zone of mixed, or brackish, water can extend much further inland underground than previously thought. Brackish water is not safe to drink, because it causes dehydration. (Water that contains less than 250 milligrams of salt per liter is considered fresh water and is safe to drink.)

Fresh drinking water on the NC Coastal Plain is drawn from both surface water and groundwater sources. Coastal Plain water resources are limited at the upstream end by the balance between watershed recharge of fresh groundwater and water withdrawals in the Piedmont. At the downstream end the potability of the Coastal Plain water resources are constrained by rising sea level pushing salty surface water upstream in coastal rivers and by the intrusion of salty water into coastal aquifers. Depending on the mixing patterns of fresh and salt water in the subsurface, brackish groundwater may migrate far inland of the actual coastline. Salinity has been steadily encroaching upstream in the Cape Fear River as monitored by the Lower Cape Fear River Program. It is not known currently how much of the encroachment is due to decade-scale decrease in rainfall or withdrawals upstream (potable, agricultural, etc) upstream of Wilmington.

Salt intrusion into coastal drinking water aquifers depends on the geologic formation being used, pumping rate, recharge rate, sea level rise. Pre-colonial groundwater flow was seaward. Several areas of groundwater reversal (i.e. cones of depression) now exist along the eastern Piedmont and western Coastal Plain o NC. These act to intercept fresh groundwater that would normally help to keep rising seawater from intruding into the aquifer closer to the coastline (USGS HA 730-L). NC has the shallowest depth to salt water and the narrowest band of fresh groundwater along the Atlantic Coast (i.e. the smallest dimension of fresh groundwater resources). See Figures 9a and 9b reproduced from Barlow (2003).

NC DENR maintains a network of salt-water monitoring wells (around 100 that are sampled every 3-4 years for chloride.) Water that contains in excess of 250 mg salt per liter is not considered potable unless treated to remove that salt. Unlike Florida, New Jersey, Georgia, Long Island, NC has not seen major salt intrusion into potable water production wells that were not already brackish. Some intrusion has been observed in northeastern NC (Barlow and Wild 2002). Brackish groundwater resources are currently treated with reverse osmosis (e.g. Dare County / Outer Banks).

The potential for salt contamination of Coastal Plain groundwater resources is very real because of the relatively small volume of fresh groundwater available. This will be exacerbated by population growth in the Coastal Plain, SLR, and any extended droughts in the Coastal Plain and Piedmont (sources of aquifer recharge).

The NC DNR saltwater intrusion monitoring program will be ongoing and should be routinely assessed as climate change proceeds to evaluate the frequency of measurements and adequacy of spatial coverage. The Coastal Plain is wide in NC, and many of the major population centers are near its seaward edge. There is no other viable freshwater source other than groundwater. For groundwater that becomes saline, and for groundwater that is already saline, it will need to be treated (reverse osmosis) prior to distribution. This treatment represents additional costs at the local and state levels.

Impacts on Transportation Infrastructure

A recent U.S. Department of Transportation (2008) study uses multiple data sources to quantify the potential impact of sea level rise on land and transportation infrastructure in coastal areas of the eastern United States. The study provides several relevant pieces of information imperative to the security of our infrastructure, including: (1) digital elevation models (DEMs) to describe the elevation in the coastal areas and create tidal surfaces to describe the current sea water levels; (2) identification of land and transportation infrastructure that, without protection, will be inundated regularly by the ocean or will be at risk of periodic inundation due to storm surge; and (3) statistics that show the potential extent of inundated and at-risk land at given temporal intervals. This study offers maps and statistics for various levels of sea level rise from 6 cm to 59 cm. Maps show estimates of areas that, without protection, may regularly be inundated or may be at-risk of periodic inundation due to storm surge, under the methodologies used in this study. See Figure 10 for the North Carolina transportation infrastructure inundation map.

Potential Impacts of Increased Wave Height

Two recent studies (Komar and Allan 2008; Bromirski and Kossin 2008) of hurricane-associated wave heights along the U.S. Atlantic and Gulf coasts during the last several decades find that we are experiencing more and larger waves. Should climate change lead to more severe storms offshore, associated wave heights reaching shore would be larger. The immediate regional consequences of increased wave height include:

- More frequent and severe damage to beaches and coastal properties and infrastructure (such as Ocean Isle Beach's recent losses of houses and roads),
- Increased needs for shoreline protection and beach sand replenishment. Replenishment costs average about $10/cu yd for proximal sand resources and up to $30/cu yd for sand resources delivered by truck when proximal sources are unavailable or insufficient. Short-term demand for sand in coastal North Carolina has been estimated at up to 100 million cubic yards, with project costs in the billions of dollars. (Source: Draft report NC Ocean Policy Steering Committee)
- Damage to navigation systems (buoys, channel markers, and channels themselves [such as Carolina Beach Inlet]),
- Hazards to boaters. Larger waves force vessels to stay in port more often. Economic losses to commercial fishing, recreational boating interests, including private and charter fishing, scuba dive boats, etc.
- Rip currents associated with larger waves kill people and restrict use of the beach, as well as putting greater burden on first responders (lifeguards, paramedics, Coast Guard).
- Increased wave height and power will raise costs of any offshore energy development and cost more days of work offshore, as well as heightening risks of accidents. Consider the damage to energy infrastructure just done by Hurricanes Ike and Gustav.
- Losses to tourism focused on use of beach and boating will be substantial. Consider the economic impacts of fishing tournament cancellations.

Effects of Increased Storm Frequency or Intensity on Coastal Evacuation Costs

Emergency managers balance the benefits and costs of voluntary and mandatory evacuation orders when issuing orders prior to a hurricane. Should climate change result in increased hurricane frequency or intensity, managers will be faced with making evacuation decisions more frequently. Even if the storm is a "false alarm" and misses the evacuated region or weakens sufficiently to cause little material damage, there are still substantial costs associated with the evacuation events themselves. Whitehead (2003) examined hurricane evacuation cost as a function of storm intensity, behavior, and population with data from a survey of North Carolina residents who experienced 1998s Hurricane Bonnie. Whitehead used the evacuation predictions and estimates of household evacuation costs to estimate the aggregate opportunity costs of hurricane evacuations. Whitehead finds that hurricane evacuation costs for ocean counties in North Carolina range from about $1 million to $50 million depending on storm intensity and emergency management policy. With climate change, we may incur these costs more frequently. Although climate change may not lead to more storms, the storms we do have will likely become more severe, and so we may need to evacuate for a greater percentage of the storm events, leading to more frequent evacuations, even if the number of storms stays the same.

Potential Effects of Storm Intensification on Rip Current Risk

Rip currents are high velocity seaward-flowing currents originating within the surf zone. The number of deaths on United States beaches due to rip currents exceeds one hundred per year, and rip currents account for over eighty percent of rescues performed by beach lifeguards (Dumas et al. under review). Research to improve rip current forecasts continues. For example, in Daytona Beach, Florida, Engle et al. (2002) find that bigger waves with longer periods between crests and mid-low tidal stages are correlated with beach current rescues. Should climate change lead to more intense storms with bigger waves, rip current rescues and deaths may increase.

Climate Refugees and Immigration

A recent issue of the journal Science (p. 909, 15 August 2008) reviews a paper currently in press in *Geophysical Research Letters* on the relative responsiveness of different US regions to climate change (Figure 1). It finds that the southeastern US may be the region least impacted by climate change and the southwestern US may be the most impacted. In addition, the region of northern Mexico may be heavily impacted. As a result, North Carolina might receive influxes of “climate refugees” from more heavily impacted regions, such as immigrants from regions with climate-stressed agriculture, drought, or other dislocating factors, with corresponding increases in demands for social, economic, and ecosystem services.

Effects of Increased Storm Intensity or Frequency on Vulnerable Populations

The potential for climate change to increase storm intensity and evacuation frequency would likely have disproportionate effects on emergency service providers and vulnerable populations such as the elderly, the homeless, and low income residents without personal transportation or with medical problems. Consider a New Hanover County Department of Social Services social worker's description of the impacts of hurricanes on vulnerable populations:

> “Hurricanes hit the poorest people the hardest. The homeless flock to the shelters as soon as they open because they know they can get three hot meals and a cot, at least for a few days, and they have to get there first in order to get a cot at all. Then, when the storm passes and the shelters close, we have to send them back to where they were when they heard the shelters were opening. The poor elderly living in rented mobile homes go to the shelters because they're afraid to stay in a trailer. They have no renter's insurance because they can't afford it, so when they return to their home and everything is damaged, ruined, or gone, we try to help them relocate, try to find some furniture, assist financially,

> refer to other agencies, etc. Other poor people in rented trailers go to the shelters, and we do the same for them with priority given to those with children. Nursing home residents whose families don't come to deal with them, and people in residential treatment programs of various kinds who have been told they can't stay where they are, have to go to a shelter where they're suddenly around all kinds of people, many of whom are trying to get intoxicated any way they can. Of course, the people who are in the process of actually detoxing have a rough time. I know that sounds remote, but during [hurricane] Bertha, the Crisis Station actually sent all their detox patients to us, and they did not have fun. The domestic violence shelter sent their women and children to our shelters and with the press hawking all the hurricane shelters, the women get all freaked out, they're afraid their faces will be on TV, and some of them are in hiding. Most of the shelter population are the ones I've mentioned, because most of the people who live in low lying areas and mobile homes and have been told to evacuate usually have some friends and/or family who either live somewhere within driving distance away from the coast, or in a house which is not as vulnerable as where they are. Most houses in this county are just as safe as the shelters, which are, after all, just schools. There are no buildings, none, in this entire county which were built to withstand more than a Category 3 storm, there never have been, and the authorities have always known that, but continued to open shelters with some [recent hurricanes] Fran, Floyd, Hugo . . . . [Hurricane] Katrina changed that and for the first time this season, they have decided that if a Cat 4 or 5 is bearing down on us, the entire county will evacuate, like they do in Charleston and Savannah."

Dr. Ellie Covan, founding Director of the Gerontology Program at UNCW, has done research on the evacuation behavior of older men and women in Georgia and North Carolina. In an exploratory study designed to compare the characteristics, evacuation beliefs, risk factors, and health problems of older adults living in two Georgia counties and three North Carolina counties regarding willingness to evacuate in the event of a natural disaster, Dr. Covan found that one third of the elderly men said that they may or would not evacuate even after listening to news about the devastating impacts of Hurricane Katrina (Covan et al. 2001, Rosenkoetter et al. 2007).

An increase in hurricane intensity and evacuation frequency due to climate change would increase the need for additional emergency services to handle vulnerable populations during evacuations.

III. Mitigation and Adaptation Options

The potential costs of climate change can be ameliorated through *mitigation* (activities to prevent change or its associated costs) or *adaptation* (adjustments to lessen costs of unavoidable change). Adaption options include *short-run* options that can be completed relatively quickly with little irreversible commitment of infrastructure resources (e.g., insurance and financial options) and *long-run* options that take a long time to implement or involve irreversible commitment of infrastructure resources (e.g., highway relocation, home relocation, changing industry production processes, etc.).

As greenhouse gases emitted in one part of the world can affect the world as a whole, and because the global economy is increasingly interconnected, a solution to the problem of climate change will require global cooperation--efforts at the regional level are absolutely essential, but they are not enough (Bushnell et al. 2008). It is encouraging that the United States has reentered global discussions concerning global climate change and potential, globally coordinated, mitigation and adaptation options. As has been said of the recent financial system bailout package in the United States, although the costs of doing something may be significant, the costs of doing nothing may be much greater than the costs of doing something. As national policymakers consider national and international actions to combat climate change, the focus of this report will be on mitigation and adaptation options available to government, industry and households at the state and local level.

III a. Mitigation

Mitigation is defined here as actions that can be taken to prevent or reduce global climate change. As indicated by the data in Table 5 on the industry sector sources of greenhouse gases, actions taken to reduce greenhouse gas emissions will need to focus on the electricity, transportation and manufacturing sectors, although agriculture and forestry may be able to play a role by changing practices in ways that decrease emissions or increase the uptake and storage of greenhouse gasses. As indicated by the data in Table 6, although the United States is one of the largest greenhouse gas emitters, greenhouse gas reductions by the United States alone will not be sufficient to stop climate change; other countries must do their parts as well. The recent history and forecast of North Carolina greenhouse gas emissions by industry source/sector is shown in Figure 11. Obviously, any actions taken by North Carolina alone would be insufficient to prevent or modify global climate change substantially at the global scale. However, it would appear prudent for North Carolina to identify the actions that could be taken by the state to provide its appropriate share of mitigation activity in the most cost-effective manner, should the state be called upon to participate in any joint efforts to mitigate climate change at the national or international levels.

North Carolina Legislative Commission on Global Climate Change (LCGCC)

The 2005 Session of the North Carolina General Assembly (Session Law 2005-442, Senate Bill 1134) established the Legislative Commission on Global Climate Change (LCGCC) to "study issues related to global warming, the emerging carbon economy, and whether it is appropriate and desirable for the state to establish a global warming pollutant reduction goal, and, if the commission determines that the establishment of a goal is appropriate and desirable, to authorize the commission to develop a recommended goal." The commission has served as a forum for experts to present information to the state on global climate change science, economics, and potential mitigation and adaptation strategies.

North Carolina Climate Action Plan Advisory Group (CAPAG)

As part of the LCGCC process, the North Carolina Climate Action Plan Advisory Group (CAPAG) (http://www.ncclimatechange.us/), managed by the North Carolina Department of Environment and Natural Resources (http://daq.state.nc.us/monitor/eminv/gcc/) with input from the Center for Climate Strategies (http://www.climatestrategies.us/Faq.cfm), developed a list of greenhouse gas mitigation (reduction) options and recommendations for North Carolina (COPAG 2007). The options were ranked in terms of their ability to reduce greenhouse gases and in terms of their costs (COPAG 2008a, 2008b).

The CAPAG final recommendations included 56 options to mitigate North Carolina's release of greenhouse gasses. The 56 options fell into five broad categories: Energy Supply and Demand (ES), with 13 options, Transportation and Land Use (TLU), with 13 options, Residential, Commercial and Industrial Options (RCI), with 11 options, Agriculture, Forestry and Waste Management (AFW), with 13 options, and "Cross Cutting Issues" (options to improve coordination and administration) (CC), with 6 options. There was broad support within CAPAG for the recommended options, with 48 options being recommended by unanimous consent, and 8 being recommended by a supermajority.

The 56 options are described in greater detail in Table 7. The relative contributions of the options in terms of potential reductions in greenhouse gas emissions are presented in Figure 12. The financial benefit or cost of each option in dollars per metric ton of greenhouse gas emissions reduction is presented in Figure 13. Negative dollar amounts indicate net financial benefits (savings) of implementing the option. The incremental (marginal) costs of achieving target emissions reductions are presented in Figure 14 under the assumption that less costly options are implemented before more costly options.

If no mitigation options are implemented, CAPAG projects that North Carolina's emissions of carbon dioxide (CO_2), a primary greenhouse gas, would increase from about 205 million metric tons per year (MMT/yr) in 2008 to about 260 MMT/yr by 2020 (Figure 11). If all 56 recommended mitigation options were implemented, CAPAG estimates that North Carolina's emissions of CO_2 would gradually fall to about 140 MMT/yr by 2020, equivalent to North Carolina's annual emissions in 1990. Between 2008 and 2020, implementation of all 56 measures would eliminate 827 MMT of CO_2 in total. From year 2020 forward, implementation of all 56 measures would reduce CO_2 emissions by 120 MMT per year compared to what emissions levels would be without any mitigation. Although some of the 56 mitigation measures have net financial costs, surprisingly many have net financial benefits, and the present value in 2008 dollars of implementing all 56 measures is a *net benefit* of $5.12 billion for the state of North Carolina, its citizens and its industry.

III b. Short-Run Adaptation Options

Insurance Options

North Carolina ranks fourth in the nation in the number of recorded hurricane strikes, with 50 hurricanes making landfall from 1851-2006 (Blake et al. 2007). Insured losses from Hurricane Isabel in 2003 reached nearly $200 million (National Hurricane Center 2006). Increased real and perceived dangers of coastal flooding and erosion due to climate change could significantly increase the cost of insurance coverage for coastal residents, businesses and governments.

The Wharton Risk Management and Decision Processes Center (2008) recently completed a study of insurance and large-scale risks associated with natural disasters. The study found:

- There has been a major increase in the cost of natural disasters over the past 15 years.
- Property values at risk in hazard-prone areas in the U.S. have drastically increased in recent years.
- The impact of climate change on these increased losses is not clear, but is of growing concern.
- While catastrophes are often characterized as low-probability/high-consequence events, the data suggest that they are expected to occur with a much higher frequency than in the past. . . . Using Florida as an example, [computer modeling and actuarial analysis] revealed a 15 percent annual probability of an insured loss in the state of at least $10 billion, and a 5 percent annual probability that insured losses will exceed $25 billion.
- Insurance market regulation varies significantly across states.
- Due to the severe hurricanes in 2004 and 2005, the United States reinsurance market hardened in 2006. Premiums rose on average 76 percent between July 1, 2005 and June 30, 2006 but have fallen somewhat since that time as new reinsurers were attracted to the market by the higher premiums. Premiums are still considerably higher than they were at the beginning of 2005.
- There is a need to expand catastrophe risk securitization, as it still represents a small proportion of the capital in the global insurance market today.
- A wind insurance / flood insurance controversy emerged in the aftermath of Hurricane Katrina, creating further uncertainty related to the issues of insurer liability.
- Some people correctly understand risk and have adequate insurance coverage, but others do not. A key factor that explains these homeowners' decisions . . . is underestimation of risk. . . . Some families also face budget constraints which limit their interest and/or ability to voluntarily purchase adequate insurance . . . This behavior is especially likely in areas where property values have increased rapidly.
- Many people choose low deductibles on their homeowners policies.
- An analysis of several million homeowner insurance policies in four states reveals that a 10 percent increase in the average premium result in about 8.9 percent fewer homeowners buying insurance.

- There has been significant growth in residual market mechanisms that provide coverage to property owners who are not able to obtain insurance from private insurers.
- Strong building codes significantly reduces damage from hurricanes.
- Many homeowners to not voluntarily invest in mitigation measures (e.g., buying storm doors, roof anchors, etc.).

Along the North Carolina coast, flood insurance is provided by the National Flood Insurance Program (NFIP) and wind damage insurance is provided by the state-sponsored Beach Plan. Coastal residents who want to get a home mortgage loan from a bank are required to purchase NFIP flood insurance if they live in a flood hazard area. However, many residents drop the flood insurance after they obtain a loan, as maintenance of the insurance coverage has not been enforced by the banks or the government. Also, those who do not need a mortgage to purchase a home are not required to purchase flood insurance, and those who live outside flood hazard areas are not required to purchase flood insurance. As a result, many coastal residents are uninsured against flood losses. For example, Kriesel and Landry (2004) found that only 49 percent of a sample of eligible coastal properties participated in the NFIP flood insurance program. Perhaps coastal residents are doing other things to protect their property from flood damage? Based on the historical frequency of storm surge flooding and the costs of flood damage mitigation measures such as raising a house on pilings of fill dirt, elevating outdoor appliances, and building low flood walls or berms, it has not been cost effective for many coastal North Carolina residents to undertake flood mitigation activities (Burrus et al. 2001a, 2001b). However, sea level rise and storm intensification associated with climate change have the potential to greatly increase the frequency of coastal storm surge flooding. Flood losses may become more frequent and costly. The state could sponsor increased education programs to increase awareness of the increased likelihood of coastal flooding with climate change and the increased benefits of flood insurance coverage and flood damage mitigation activities. The state may also want to consider mechanisms to increase enforcement of flood insurance requirements tied to mortgage loans.

Keeler et al. (2003) point out that the National Flood Insurance Program does not technically cover erosion damage, just flood damage. The distinction is critical for the North Carolina coast under potential conditions of increased beach erosion due to sea level rise and storm intensification. Keeler et al. find that many coastal homeowners would be willing to purchase erosion insurance at prices in the range of current, subsidized, flood insurance premiums, but willingness to pay appeared to be less than the cost of unsubsidized erosion insurance. The State of North Carolina should work with the National Flood Insurance Program to clarify the issue of erosion coverage as soon as possible. If erosion is not covered, the state should make sure that the public is aware of the erosion risk and perhaps formulate an erosion insurance policy and plan.

Turning to wind damage insurance, the State of North Carolina sponsors a Beach Plan insurance program for coastal residents with subsidized premiums (the Beach Plan's independent actuaries estimate that Beach Plan rates would need to be increased by 76 percent to reach an appropriate level to cover the plans anticipated losses and expenses). The Beach Plan currently insures nearly $70 billion worth of property. Under the current system, if the Beach Plan does not have sufficient surplus, private insurance companies will be forced to pay for the difference in the form of assessments. A recent study by an actuarial firm (Watkins 2008) examined whether the state coastal insurance program known as the Beach Plan is adequately funded to withstand a significant storm. The study was commissioned by the Property Casualty Insurers Association of America. The study found that a once-in-50-year hurricane could cause enough property losses in coastal counties to force $1.4 billion in losses to be passed along to insurers across the state. The $1.4 billion dollar loss was based on a storm causing $2.9 billion in losses to homes and business insured by the Beach Plan. Reinsurance and a $535 million reserve would cover other losses. Losses by the plan would eventually be passed on to homeowner insurance policyholders around the state. If the losses were spread out to all policyholders in the state, a 50-year storm would translate into a 46 percent premium increase; a 100-year storm would mean a 92 percent premium increase, according to the study.

The potential costs of reimbursing coastal residents for wind-related losses could be reduced if residents would purchase structural mitigation devices, such as storm shutters, roof anchors, etc., for their houses. Research on coastal North Carolina residents (Burrus et al. 2002, 2007) indicates that many do not purchase structural mitigation features because (1) they underestimate the damage done by hurricane winds (even though residents do not appear to underestimate the probability of being struck by hurricanes) and (2) the costs of structural mitigation features are large relative to the costs of insuring against wind damage losses given the low deductibles of Beach Plan policies. Increasing or decreasing insurance premiums gives residents relatively little economic incentive to purchase mitigation devices, whereas residents would purchase more mitigation features if insurance deductibles were increased (Burrus et al. 2005).

Financial Derivative Market Options

The State of North Carolina should investigate the use of financial market derivative instruments to mitigate the potential costs of extreme weather events related to climate change. Examples include weather derivatives (Froot 1999) and disaster reserves (Wildasin 2008).

Beach Sand Renourishment

Beach sand nourishment or renourishment is the act of placing sand on an eroding beach in order to compensate for prior erosion and to slow current and future erosion (Jones and Mangun 2001). Beach sand renourishment is a common beach management strategy in the United States for sandy coastlines along the Atlantic coast and in the Gulf of Mexico (Trembanis and Pilkey 1998, Valverde et al. 1999). Beach nourishment has grown in importance as coastal government have banned beach "armoring," the use of sea walls, rip rap rock, jetties, groins, etc., to combat erosion. For example, in 1986 the State of North Carolina's Coastal Resources Commission issued regulations banning hard oceanfront structures. The North Carolina Legislature passed a law supporting the regulations in 2003 after they were challenged. From 1950-1993 the Federal government and its local government cost-sharing partners (65% federal, 35% local) spent an average of $34 million (1993 dollars) annually on beach sand nourishment (U.S. Army Corps of Engineers, 1994, 2004). At least $2.5 billion (2002 dollars) was spent on nourishment projects between 1950 and 2002 in the U.S., and the frequency of nourishment has increased dramatically in recent years with federal appropriations of $787 million from 1995-2002. To combat mounting federal costs, the Water Resources Development Act of 1999 (33 USC sec. 2213) increased the local cost share to 50% for all projects authorized after January 1, 2003.

Growing beach renourishment expenditures have aroused controversy, with some critics questioning whether the costs are worth the benefits (Bell 1986; National Research Council 1995; Pilkey and Dixon 1996). The continuation of multi-million dollar federal government cost-share subsidies of beach renourishment projects hinges on the results of cost-benefit studies. Although it is relatively straightforward to calculate the costs of beach renourishment projects (U.S. Army Corps of Engineers, 1994, 2004), measuring the benefits of renourishment projects is more difficult. There are several categories of potential beach nourishment benefits. First, beach nourishment protects beach-front buildings from potential erosion and storm damage. This category of beach nourishment benefit takes the form of "damage costs avoided." Several existing studies use standard hedonic valuation methods to estimate the property protection benefits of beach nourishment (e.g. Brown and Pollakowski 1977; Black et al. 1988; Kerns et al. 1980; Edwards and Gable 1991; Pompe and Rinehart 1995; Parsons and Powell 2001; and Landry et al. 2003).

A second category of potential beach nourishment benefits is enhanced recreation value. Beach recreationists may derive more enjoyment from a nourished beach with a wide, gentle slope and low crowding than they would from a narrow, eroded beach, typically with a high escarpment (sand cliff) and high crowding. Edwards and Gable (1991) used hedonic analysis to estimate the recreation benefits of beach nourishment that may accrue to the owners of beach property. Although researchers have used standard travel cost methodology (Hanemann 1978; Bockstael et al. 1987; Bell and Leeworthy 1990; and Parsons and Kealy 1992) to value beach recreation, "few, if any, travel cost models have been applied specifically to beach nourishment valuation problems" (National Research Council 1995). However, Parsons, Massey and Tomasi (1999) used the random utility model variant of the travel cost method to estimate the value of beach width at Delaware, Maryland, and New Jersey beaches and found that a beach width between 75 and 200 feet is preferred, with significant loss of recreation value as beach width falls to 75 feet. More recently, Bin et al. (2005) use the single-site travel cost method to estimate beachgoers' willingness to pay (WTP) for a beach trip in North Carolina but do not estimate the impact of nourishment or beach width on WTP. In addition to travel costs studies, several studies using contingent valuation (CV) methodology (Boyle 2003) have examined the incremental value attributable to beach nourishment . McConnell (1977) and Bell (1986) find that the economic value of beach recreation per person increases with increasing beach width. These authors attribute this result to the reduction in crowding associated with wider beaches. Shivlani et al. (2003) use CV to estimate recreationists' willingness to pay for beach nourishment in South Florida at $1.69 per visit but do not estimate changes in the number of visits or substitution between beach destinations. Landry et al. (2003) and Kriesel et al. (2004) use CV to examine the economic effects of three beach erosion management policies in Georgia and find that day users are willing to pay higher parking fees to maintain wider beaches via beach nourishment, on the order of $6-10 per day per household. Lindsay et al. (1992) use CV to decompose the factors affecting recreationists' willingness to pay for beach protection. Silberman et al. (1992) find using CV that both users and non-users of New Jersey beaches value non-eroded beaches. Using a choice-based conjoint survey, Huang et al. (2007) find that New Hampshire and Maine households are willing to pay higher license plate fees to preserve beaches through erosion control programs, but willingness to pay is lower if the programs have negative environmental or off-site erosion effects.

Although existing travel cost studies estimate the impacts of changing travel costs on beach visits, and although existing contingent valuation studies estimate the impact of changing beach width on beach recreation value for tourists already on the beach, only a few studies investigate the impacts of renourishment on both beach visits and value per visit. Silberman and Klock (1988) find that renourishment of New Jersey beaches in the mid-1980's increased tourist visits to the renourished beach while decreasing visits to nearby, substitute beaches. The net number of visits to all beaches increased with renourishment. WTP per beach trip increased by less than a dollar per trip. Indeed, Silberman and Klock note that "the change in visitation as a result of the beach renourishment project is substantially more important than the increase in [per person per day value] in estimation of recreation benefits [of renourishment]." Whitehead et al. (2008) study the potential effects of beach width on beach recreation demand in southern North Carolina using combined revealed and stated preference data to correct for hypothetical scenario bias in the survey data. They find that increased beach width increases both annual beach trips from 9 to 10 and increases beachgoers' WTP per trip by about $7.

Hamilton (2007) uses hedonic analysis to investigate the impacts of coastal characteristics on the price of coastal accommodations (hotels and bed and breakfasts) in the coastal Schleswig-Holstein district of Germany. Hamilton finds that an increase in the length of open coast increases the average price of accommodation, whereas an increase in the length of dike/seawall along the coast decreases the average price. However, beach sand area itself was not a significant determinant of accommodation price. Dumas, Chambers and Seel (2008) find that beach sand renourishment appears to modestly increase beach hotel occupancy rates and room prices in the southeastern United States.

Beach nourishment only defends the shoreline temporarily and must be re-implemented periodically. Smith et al. (2008) develop a linked economic and geomorphological model that explains this pattern and suggests what we might expect to see in the future if sea level continues to rise and beach erosion accelerates. The model generates both expected and surprising predictions. Specifically, Smith et al. find that communities will nourish more often if: 1) the baseline property values are higher; 2) unnourished beaches erode faster; 3) the economic value of beach width is higher; 4) fixed costs of nourishment are lower; or 5) the discount rate is higher. However, a higher cost of nourishment sand could result in either increased or decreased frequency of beach nourishment. It is thus possible that the demand for nourishment sand and the costs of nourishment could increase even as the per-unit cost of sand increases. This result is particularly striking in light of the scarcity of nourishment-quality sand and the possibility of greater scarcity in the future (Cleary et al. 2006, Finkl et al. 2007). Similarly, a higher erosion rate of nourishment sand could lead to either higher or lower optimal rates of nourishment. These latter results lead to new insights about linked economic and geomorphological models. Whether nourishment frequency increases or decreases hinges on whether the rate of foregone interest (financial capital depreciation) exceeds the rate of sand loss (erosion rate).

There may be ways to reduce the cost of beach sand renourishment through more coordinated management. Slott et al. (2008) couple a numerical model of coastline evolution and a cost-benefit model of beach nourishment, allowing adjacent communities to make dynamic nourishment decisions. Beach nourishment benefits adjacent communities both “updrift” and "downdrift." The total amount of money spent on nourishment activities can decrease by as much as 25% when adjacent communities both conduct on-going nourishment projects, as opposed to the case in which each community nourishes in isolation.

Extreme Heat Public Warning Systems

The state of North Carolina could implement a public health early warning system to reduce the impacts of extreme temperature events on vulnerable populations. The City of Philadelphia has such a system in place and could serve as a model (Acclimatise 2006).

III c. Long-Run Adaptation Options

Learning From Efforts in Other States

Several other states have begun to develop short and long-run plans for adapting to climate change. For example, a representative from the State of Maryland described Maryland's climate change adaptation plan before the North Carolina Legislative Commission on Climate Change in January 2008 (Aburn 2008). North Carolina should seek advice and "lessons learned" from other states' experience and research.

Coastal Building Code Modification

North Carolina has the second oldest hurricane-resistant building code in the nation and has periodically improved the code since the hurricanes of the 1950s (Rogers 2008). Building damage evaluations indicate that present state and national codes are adequate in most respects. The North Carolina piling foundation standards are better than the national standards. However, there are a variety of code issues that should be considered for improvement, in part due to local experience gained in the local hurricanes of the 1990s. There are also growing conflicts between the building code, floodplain regulations and Coastal Area Management Act regulations that should be sorted out for a more unified code. An ad hoc committee of those groups proved to be an effective method when the present foundation standards were developed.

Primary climate change interests with respect to coastal engineering and the North Carolina building code are sea-level rise, hurricane frequency and hurricane intensity, as they might affect recent historical records. Much of the perceived controversy over future climate change is a scientific debate over whether we can prove it is occurring or that it was man-induced. In the broader view the distinction may not matter. Climate and sea level have never been constants. The geologic record indicates sea level has been rising for 14,000 years. Tide gauges have recorded relative rates of rise in North Carolina of 1.0 to 1.5 feet over the last century. There is no science to suggest a reduction of those rates for the future — and there is growing evidence that the rates may accelerate in the future. The primary consequences are lowland inundation and shoreline erosion. Historical shoreline measurements indicate that most of the NC oceanfront is eroding. On the order of a 1 foot per year has likely been caused by sea-level rise. Erosion rates would increase if sea level rise accelerates. With or without climate change, shoreline erosion will be an issue for North Carolina, yet we have smaller oceanfront setbacks than many other states. Our setback is based on 30 years for buildings that have an average lifetime of 70 years.

The impact of climate change on hurricane frequency and severity is still appropriately under scientific debate. However, the same building code changes appropriate for climate change in a century are equally justified as necessary improvements and appropriate safety factors for hurricane or erosion that could occur tomorrow or next hurricane season. Incentive programs in the National Flood Insurance program already reward safer practices such as higher floor elevations and other damage reduction practices with premium reductions for owner or community practices above the minimum standards. Recent work with the wind-borne debris zone standard revisions in North Carolina suggest widespread support for incentives to encourage window protection in existing buildings through discounts in the Beach and FAIR Plan wind insurance premiums.

Improved Energy Efficiency of Buildings

A recent presentation by the Interim Director of Oak Ridge National Laboratory, U.S. Department of Energy, before the North Carolina Legislative Commission on Global Climate Change underscored the potential for improvements in the energy efficiency of buildings to save energy and reduce costs while reducing greenhouse gas emissions (Brown 2006). In the United States, 43 percent of the greenhouse gas emissions from burning fossil fuels support energy use in buildings. About half of this amount supports energy use in residential buildings and half in commercial and industrial buildings. About 70 percent of the energy used in residential buildings and 50 percent of the energy used in commercial buildings supports air heating and cooling, water heating, lighting, and refrigeration.

There are significant opportunities to reduce energy use, reduce greenhouse gas emissions, and reduce costs in these areas by making improvements to the stock of existing buildings. It is important to improve the energy efficiency of existing buildings because they are much less energy efficient compared to new buildings. For example, the energy used by a typical household refrigerator has been cut by 50 percent since the mid-1970's despite an increase in the average refrigerator size of about 20 percent. Replacing the nation's old refrigerators with current, efficient models could save the county an estimated $18 billion per year in reduced energy costs. Similarly, other new technologies and materials could increase energy efficiency, including: Sealing methods that address unseen air leaks, Electrochromic windows, Unconventional water heaters (solar, heat pumps, tankless…), Inexpensive nanocomposite materials for solar energy, Thermoelectric materials that transform heat into electricity, Abundant sensors dispersed to continuously optimize operations, Solid state lighting, and selective water sorbent technologies for geothermal heat pumps. The Energy Policy Act of 2005 authorized new energy efficiency standards for appliances and tax credits for homeowners to retrofit their homes and for home builders to incorporate higher efficiency appliances in new construction. State government can support energy efficiency by upgrading and enforcing State Residential Energy Codes, State Commercial Energy Codes, State Appliance Efficiency Standards, Green Building Standards for State Buildings, and State Energy Efficiency Resource Standards.

Beach Retreat

An alternative to beach sand renourishment as a strategy to combat increased beach erosion due to higher sea level and stronger storms is to gradually abandon beach front property to the sea, a strategy termed "beach retreat." Estimating the costs of beach retreat is difficult because it involves gathering large amounts of data on coastal properties, erosion rates, etc.

Parsons and Powell (2001) estimate the cost of beach retreat for Delaware's ocean beaches over 50 years. Delaware had spent $15-20 million per decade renourishing its 25 miles of beaches over several decades. The costs of beach retreat are categorized as: land loss, capital (structure) loss, proximity loss (loss in value of remaining and new structures due to being located farther from the migrating beach to avoid risk of loss), and transition loss (the cost of removing structures and infrastructure from the beach and moving it inland as the beach migrates; cost of moving a structure was estimated to be $25,000 per structure). As land erodes inland, the beach moves inland, and it is actually the land just inland of the migrating beach that is lost. The value of the ocean view is transferred to the next row of houses. Assuming historical erosion rates of about 3 feet/year, the cost of allowing the beach to erode over the period 2000-2049 was estimated to be $291 million in year 2000 dollars at a discount rate of 3 percent. Assuming renourishment costs of $20 million per decade over the same time period produces an estimate of $60 million in year 2000 dollars at the same discount rate. In this case, the cost of renourishment is less than the cost of beach retreat. However, should renourishment costs increase significantly, the cost comparison could reverse. Should erosion rates increase, both the costs of renourishment and the costs of beach retreat would increase, and which policy would be less costly would depend on multiple factors.

Landry et al. (2003) investigate beach erosion management alternatives for Tybee Island, Georgia. The historical erosion management policy was a combination of beach sand renourishment and shoreline armoring. Shoreline armoring is protecting beachfront property using "hard" structures such as seawalls, sandbags, rip-rap (rock piles), etc. The cost of building seawalls or bulkhead is commonly estimated at $1,190 per linear foot (Neumann et al. 2000). Landry et al. use economic simulations to calculate and compare the costs of renourishment, armoring, and beach retreat over a 25 time period. The status quo scenario is continued periodic beach renourishment with existing levels of beach armoring. It is assumed that status quo renourishment would cost $1 million per year on average. An alternative management scenario that removes armoring structures and increases renourishment frequency to maintain beach location results in increased recreational and beach front property value but also increased nourishment costs, resulting in a net gain of about $120 million over 25 years at a 4 percent discount rate. A "beach retreat" management scenario involved removing beach armoring, ceasing renourishment, and removing houses as the land eroded, which increased recreation value, reduced nourishment costs, and resulted in property value losses, resulting in a net gain of between $110 and $137 million over 25 years at a 4 percent discount rate, depending on assumptions. The authors conclude that the best erosion management strategy can vary depending on the economic and geologic parameters of the location.

Coastal Ocean Observation Systems

The Intergovernmental Panel on Climate Change (IPCC) recognizes that rising seas due to global warming may occur faster and more extensively than had been thought earlier. Such global changes complicate the tasks of separating natural and anthropogenic impacts, and underscore the need for long-term observations. Long-term research and monitoring is required to separate natural from human–induced changes, and scientifically determine linkages between cause and effect. Successful observation programs must monitor and study the coastal ocean at local and short-term scales within the context of large-scale and long-term patterns of change.

Since 1999, the Coastal Ocean Research and Monitoring Program (CORMP) at the University of North Carolina at Wilmington (UNCW) has conducted a comprehensive, long-term program of ocean observation and interdisciplinary studies in the coastal environment (Leonard 2008). CORMP is a comprehensive coastal ocean observing system that comprises a key component of NOAA's emerging Integrated Ocean Observing system (IOOS) in the southeast US region and is a founding member of the NOAA funded Carolinas RCOOS (Regional Coastal Ocean Observing System). The CORMP observing network fills a major gap in coastal observations along the Carolinas coasts and provides information that materially affects coastal management strategies, health and safety, business and commerce. The observing network is multi-faceted and consists of real-time oceanographic and meteorological platforms, regularly scheduled bi-monthly sampling cruises, and autonomous underwater vehicle surveys.

CORMP consists of four focus areas: Ocean Observations, Data Management, Ecosystem Research, and Outreach and Education that operate synergistically to provide a comprehensive and interoperable sub-regional observing system to: collect and disseminate physical and ecological data to establish baseline conditions; identify responses to stochastic events; validate existing and developing circulation, wave, and storm-surge models for the region; predict and verify long-term coastal ocean trends (oceanographic and climatological); and, to engage regional partners and end-users in the development and enhancement of products and services. CORMP observing activities directly support regionally important applications consistent with the following NOAA missions: Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management; Understand climate variability and change to enhance society's ability to plan and respond; and, Serve society's need for weather and water information.

Coastal ocean observation systems (COOS) are arrays of ocean instruments and associated data management and analysis programs that collect, manage and disseminate information on wave heights, water temperature, ocean currents, etc. COOS promote better measurement of changes in the coastal ocean that affect human activities in the coastal ocean and on shore. Dumas and Whitehead (2008) estimate the potential economics benefits of coastal ocean observation system equipment and data collection in the southeastern United States in eleven benefit categories: (1) maritime transportation, (2) commercial fishing, (3) recreational fishing and boating, (4) search and rescue operations, and (5) oil spill management and prevention, (6) hurricane evacuation warning systems, (7) beach recreation opportunities, (8) cruise line operations, and (9) beach erosion management.. Following a methodology used in similar studies of other U.S. coastal regions, we evaluate the impacts of conservative changes in economic activity in each benefit category. The annual economic benefit of COOS information is $170 million (2003 $), an estimate that falls between annual benefits of $33 million for the Gulf of Maine region and $381 million for the Gulf of Mexico. With climate change, COOS could become even more important. For example, if storms become more intense, COOS information could help us better predict erosion rates and hotspots, rip current risk, and the effects of dredging in inlets, waterways and ports.

River monitoring

The Lower Cape Fear River Program (http://www.uncwil.edu/cmsr/aquaticecology/LCFRP/) has monitored water quality and other features of this portion of the Cape Fear watershed since 1995. The dominant temporal features demonstrated in the resulting data base include seasonal changes in river discharge and the concentrations and distributions of water quality properties, inter-annual differences driven by droughts and wet periods, including the severe droughts of 2002 and 2007 and the heavy El Niño rains of early 1998, and the effects of hurricanes, notably Hurricanes Fran in 1996 and Floyd in 1999. Longer term trends that have been documented include slow but significant rises in nutrient loading, attributable to increases in source strengths in the basin, as well as increases in salinity associated with channel deepening. Changes in sea level and the frequency and intensity of rain fall events associated with climate change may affect North Carolina's river systems in several important ways, including the frequency and severity of flooding, the frequency and location of navigation/shipping hazards, municipal water supply, recreational and fishing opportunities, and fish and wildlife habitat. River monitoring programs are important for collecting the data necessary for anticipating, measuring, and adapting to the effects of climate change on North Carolina's coastal rivers and riverside communities.

Flood monitoring

Better understanding of the local relationships between rainfall, runoff and flooding may improve our ability to determine when a location will flood and better manage evacuation and other tropical cyclone mitigation. Gamble et al. (2008) are conducting a study to assess these relationships for Brunswick County, NC. Brunswick County experiences flooding along the main transportation network which can complicate and inhibit evacuation efforts for tropical cyclones. Future sea level rise and land use change may cause an increase in frequency of flooding events in Brunswick County especially along tidally influenced water ways. In order to develop better emergency response and mitigate impacts of tropical cyclones and sea level rise, Brunswick County Emergency Services (BCES), UNC Wilmington and the Renaissance Computing Institute (RENCI) has established a real time water level and weather monitoring system to assess flooding at key evacuation points across the county. Development of rainfall-runoff relationships for these locations has yet to be completed. Such a relationship will allow for the BCES to determine when a location will flood and better manage evacuation and other tropical cyclone mitigation efforts. Deliverables and expected results from this study include:

- Map of flood prone locations and contributing watersheds.
- Quantitative rainfall-runoff relationships used to predict water level.
- Guidelines for prediction of flooding in Brunswick County at monitored sites.
- Coarse characterization of potential increase in flood frequency due to future sea level rise and land use change.

IV. Climate Change Education at UNCW

Climate Change in the UNCW Curriculum

As of October 2008, the topic of global climate change was discussed in at least ninety-two courses and programs at UNC-Wilmington (Table 8), from the English department (ENG 313 Writing about Science), to History (HST 276 Introduction to the History of Science), to Biology, Physics, and Geology (BIO 478 Global Environmental Problems, PHY 420 Global Climate Change, GLY 420 Global Climate Change), to Environmental Studies, Political Science and Social Work (EVS 364 Environmental Policy, PLS 592 International Environmental Policy, SWK 106 Social Work and Global Visions), to Management, Marketing and Economics (MGT 455 Competitive Strategy, MKT 445 Marketing Strategy, ECN 325 Environmental Economics). The topic is covered from a wide variety of perspectives in both introductory and advanced courses.

For students considering climate change science as a career, the Department of Geography and Geology offers an opportunity for students to pursue a program of study that focuses upon climate science and global change studies. Courses in this program include Resources, Population and Environment, Regional and Environmental Planning, Principles of Hydrology, Introduction to Weather and Climate, Applied Climatology, Weather Analysis and Forecasting, and Environmental Geography. In addition, research opportunities exist for students through the Laboratory for Applied Climate Research (LACR). The primary objective of LACR is to involve students and university faculty in applied climatology field research of island and coastal environments. Through field research and frequent student-faculty interaction, an alternative to traditional classroom activities is offered, ultimately producing a unique, quality academic environment based upon experiential learning. LACR is equipped with-state-of-the-art meteorological field equipment and computing facilities. The equipment includes 2 Campbell Scientific Metdata1 weather stations, 2 Rainwise WS 2000 Wireless weather stations, 1 Davis Vantage Pro 2 weather station, multiple Davis tipping bucket rain gauges and data loggers, over 50 Onset temperature sensors and data loggers, sling psychrometers, infrared temperature guns, hand held anemometers, and stream discharge gages. To supplement data collected with this equipment, LACR also houses an extensive climate data library, including special collections of Caribbean climate data and tropical cave climate data. Computing resources associated with the laboratory including a Dell Precision 600 Workstation and software for statistical, meteorological, GIS, and remote sensing analysis. Over the past 10 years, 12+ students have served as research assistants on projects ranging from North Carolina coastal climatology, flooding in Brunswick county, and drought in the Caribbean. Support for these students comes from over $350,000 worth of grant funds from sources including NOAA, NSF, and the Association of American Geographers.

Promoting Climate Literacy for Future Teachers

Climate change has become an important global issue, and it is critical that teachers have an understanding of the fundamental science, the natural and human-induced factors affecting climate, and the potential consequences and solutions. Sally Ride, the first female astronaut, even proposes that climate change is the one issue that can once again ignite young students' interest in science, just as the launching of Sputnik did in the late 1950s and 1960s. However, research findings indicate that the greenhouse effect and the theory of global warming, fundamental to understanding climate change, are complex phenomena that students continue to express alternative conceptions even after instruction (Mason & Santi, 1998; Rye, Rubba, & Wiesenmayer, 1997). Common trends in the findings from several studies include elementary and secondary students confusing the greenhouse effect with ozone depletion or causally attributing the former to the latter, explaining the greenhouse effect on Earth as an environmental problem and not a natural phenomenon, attributing the greenhouse effect to specific gases over others, or describing consequences (e.g. increase in Earth's mean temperature and sea level rise) of the greenhouse effect (Koulaidis and Christidou, 1998, p. 560-561).

In the UNCW Watson School of Education, Education majors discuss climate change in Middle and Elementary School Science Methods classes, despite the fact that it is not a separate topic in the North Carolina Standard Course of Study by DPI (http://www.dpi.nc.us/curriculum/science/scos/2004/10unifying). In addition, about 50% of UNCW Education majors participate in Aquatic Wild workshops, where climate change is addressed by the workshop facilitator from the NC Wildlife Resources Commission. The Watson School has partnered with local public school educators to include discussion and hands-on activities related to climate change in the Junior Seahawk summer program in which UNCW Education majors help "at risk" kids. A proposal was submitted by Dr. Huber last year to the National Science Foundation entitled "34 Degrees North" to have UNCW Education students work with climate change in data collection using a comparison with our partner institution in South Africa collecting the same types of data.

Dr. Julie Lambert of the UNCW Watson School of Education has focused her research on identifying undergraduate education majors' pre- and post- knowledge and ideas about climate change before and after instruction that has been embedded in my elementary science methods courses. Dr. Lambert has developed several instructional lessons to incorporate in her teaching methods courses. Science methods courses typically focus on preparing teachers to effectively teach science; however, Dr. Lambert found that embedding an interdisciplinary theme, such as climate change, provides an opportunity to model inquiry-based science instruction while also reviewing fundamental science concepts from the earth, life and physical sciences. The instructional materials include a 25-page written guide for understanding science and climate change and several inquiry-based science lessons on the carbon cycle, photosynthesis and respiration, the greenhouse effect, heat transfer and ocean currents, the cause of the seasons, fossil fuels and the rock cycle, the water cycle, etc. In addition, the students have an assignment to 1) view and review the science in the movie, "An Inconvenient Truth," 2) respond to questions designed to guide them in their understanding of climate change, 3) analyze the document, Climate Literacy: The Essential Principles of Climate Sciences (http://climateliteracynow.org/), 4) construct a concept map to demonstrate their understanding of climate change, and 5) participate in a focus group interview at the end of the course. Feedback from the elementary methods students has been very positive, and Dr. Lambert has continued to revise the instructional materials for publication.

V. Conclusions

This study reviews the potential impacts of climate change in coastal North Carolina from interstate I-95 eastward to the coast and offshore to the 200 mile limit of the United States' Exclusive Economic Zone. The study considers impacts to year 2100. No original data collection or analysis was conducted; findings reflect review and synthesis of existing information as of November 2008.

Physical Impacts of Climate Change:

- There is a high degree of scientific certainty that global average temperature is rising and will continue to rise.
- There is a high degree of scientific certainty that sea level is rising and will continue to rise due to thermal expansion of sea water. The current projected rate of sea level rise should be considered a conservative estimate because it does not include the effects of melting glaciers or water storage in reservoirs. The greatest threat to coastal North Carolina from climate change likely comes from sea level rise and its related impacts.
- There is a high degree of scientific certainty that increases in storm and hurricane intensity will occur. Changes in hurricane frequency cannot be confidently predicted at present. More intense storms generate larger and more powerful ocean waves. The combination of sea level rise and more powerful waves multiplies coastal erosion damage risks.
- Annual precipitation (total yearly rainfall) in coastal North Carolina is not currently predicted to change dramatically. However, the frequency of precipitation extremes or prolonged droughts may increase in the 50-yr time horizon, although predictions for the NC region show only moderate changes.
- All meteorlogical responses to climate change (precipitation, drought, hurricanes) are strongly modified by natural oscillations in the oceans and atmosphere (e.g. El Nino, the North Atlantic Oscillation). On decadal timescales these oscillations may act to intensify or moderate climate change effects.
- The salinization of coastal groundwater sources results from a combination of increased rates of human usage (both potable water and for industrial sources) and from rising sea level. Increases in coastal population will exacerbate this problem.
- There are currently examples of groundwater flow reversal in the NC coastal plain resulting from pumping. Such reversal can increase the chances of groundwater salinization.
- Relative to other regions along the Atlantic coast, the NC coast is not currently experiencing large amounts of salt contamination of major municipal groundwater wells. One notable exception is Northeastern NC where salt water has intruded into the aquifer, and where groundwater is currently treated with reverse osmosis to ensure its potability.

Ecological Impacts of Climate Change

- Barrier island marshes are most impacted by storm overwash and restrictions on migration due to the location of the Intracoastal Waterway.
- Coastal wetlands serve as primary nursery areas for commercially important shellfish and finfish. Wetlands are subject to loss through sea level rise (physical and chemical effects) and from changes in storm intensity.
- Wetlands in brackish regions of estuaries will be most impacted by sea level rise. Accelerated decomposition of brackish wetlands due to increased salinity will result in the failure of some wetlands to keep pace with rising sea level.
- Chemical changes in wetlands during salinization are linked to increases in mercury conversion to its most toxic form (methylmercury).

Public Health Impacts

- Potential public health impacts of climate change include increases in heat stress-related illness and deaths, increased incidence of mosquito and tick-borne diseases such as malaria, dengue fever and Lyme disease, increased incidence of cholera and other water-borne diseases made more virulent by warmer temperatures, increased toxicity of air pollution such as ozone at higher air temperatures, increased levels of pollen, fungal spores, mold and other allergens, and increased rip current risk due to larger waves.

Economic and Social Impacts

- Coastal property value vulnerable to sea level rise in just 4 NC counties is valued at about $7 billion. Property in Northeastern NC is more vulnerable because the ground is flatter. Work is underway to estimate impacts for all NC coastal counties.
- If no beach sand renourishment or other erosion management action is undertaken, sea level rise will overtake many NC beaches by 2080. Lost recreation value to local beach goers at southern NC beaches: $93 million a year by 2030, $223 million a year by 2080. Reduction in spending by non-local beach tourists: 16% decline by 2030, 48% decline by 2080. If erosion management action is undertaken, the costs are likely to increase dramatically as sea level rise and stronger storms increase erosion rates.

- Increased economic losses due to business interruption from more intense storms could reach several hundred million dollars per storm by 2080, with cumulative losses of several billion.

- More intense storms may increase the frequency of coastal evacuations and associated costs.

- In agriculture, changes in climate could drive changes in crop mix, increase pest problems, increase irrigation needs and waste runoff problems, and increase heat stress problems for livestock. Storm damage assessments indicate that more intense storms would cause significantly more crop damage.

- In forestry, more intense storms will likely cause additional forest damage, and warmer temperatures may increase forest pest problems.

- More extreme precipitation events will likely cause larger peak flows, leading to more storm water management problems (flooding, line breaks, etc.)

- Sea level rise and extreme precipitation events will likely increase the costs of transportation infrastructure repair and relocation.

- Warmer temperatures, droughts, and stronger storms may increase damage from lightning strikes and wildfires.

VI. Recommendations

- Maintain and expand current meteorologic data stations. Efforts should be made in conjunction with partners in adjacent states since weather and climate does not recognize borders and must be modeled regionally.

- Evaluate and develop agricultural contingency plans in response to plausible changes in rainfall or drought frequency. Strategies should include water management in conjunction with human demand for potable water and crop management strategies to smooth out swings in agricultural productivity.

- Re-evaluate current coastal zone management plans, at the local and state level. Issues to be considered should include but not be limited to: 1) rebuilding in high risk coastal zones post hurricanes; 2) contingencies for re-establishing inlets closed by overwash from coastal storms; 3) cost-sharing analysis between local , state, and federal agencies for post hurricane rebuilding of infrastructure.

- Continue to support NCs coastal ocean monitoring systems and their coordination with other regional networks. The data that these programs gather are essential for understanding coastal hurricane dynamics and predicting the role of regional ocean-atmosphere oscillations in climate change impacts.

- Spatially and temporally expand the NC-DNR groundwater salt monitoring network, and combine this data with monitoring conducted at municipal wells into a common database.

- Require that an assessment of potential aquifer salinization be performed as part of the permitting process for installation and operation of new / existing large industrial and municipal production wells.

- Through collaboration between the US Geological Survey and the NC university system, adapt existing aquifer salinization models (e.g. USGS SUTRA) and conduct salinization simulations for the major coastal populations relying on groundwater for drinking water. These simulations will be invaluable for identifying sensitive regions and planning for subsequent allocation of resources for desalinization. Dare County can be used as an economic model for cost analysis.

- There is a need to better understand the effects of climate change on sensitive tidal marshes and wetlands vegetation and associated nutrient cycling (carbon, nitrogen, phosphorus) and heavy metal (particularly mercury) transformations.

- Limit emissions of mercury near coastal wetlands, marshes, and swamps because the environmental conditions there promote the formation of methylmercury, a toxic and bioaccumulative mercury species.

- An improved surveillance infrastructure is needed to assess the effects of climate change on the frequency and extent of harmful algae blooms. Presently the DENR water quality division has only one person to observe these species. Testing for algal toxins, a function of NC DHHS, is done by contract through University or private laboratories on an as needed basis. There are not enough trained people to maintain surveillance or to respond to events including coastal fish kills of unknown origin. Support a sustained workforce, sufficient professional training, and an integrated system for identifying and managing harmful algae bloom events.

- The main research needs for predicting health effects of extreme weather events center on improving regional data and projections of the future frequency and severity of extreme weather events. In addition, Greenough et al. (2001) noted a need for more epidemiology studies of the long-term impacts of extreme events and more accurate assessments of vulnerable populations and adaptation strategies.

- Further research is needed on strategies to prevent heat-stress related deaths, including better public early warning systems.

- There is a need to better understand the population dynamics of disease vectors such as mosquitoes, ticks, and rodents under climate change conditions and the transmission of vector-borne diseases to humans.

- Additional research is needed to clarify the relationships among water- and food-borne illnesses and specific pathogens to better understand the associations between these illnesses and ambient temperature.

- There is a need to better understand potential increases in pollen, mold spores and other allergens and effects on humans under climate change conditions.

- Develop contingency plans for potential increases in lightning activity and wildfires caused by warming, drought, and storm intensification.

- Re-evaluate current coastal zone management plans in light of rising sea level, increasing erosion, and increasing coastal populations and property values. In particular, a public discussion of beach erosion management alternatives should be initiated to clarify issues of public and private rights, responsibilities, and cost burden. Location-specific studies of the comparative costs of alternative beach management policies under conditions of sea level rise and increased erosion should be conducted.

- Re-evaluate coastal building codes and zoning requirements in light of rising sea level and stronger storms. Effective adaptation to sea level rise must include development of a flexible coastal building and development code that allows for an increase in both mean high tide and storm surge over the next 25 years.

- Develop contingency plans for coastal industries vulnerable to sea level rise and storm intensification: real estate, transport, agriculture, forestry, fisheries, water supply, and storm water mgmt.

- With the potential increases in sea level, coastal erosion and storm surge flooding, and storm severity, it is critical to raise public awareness about the potential increase in frequency and severity of these damaging events and to increase education about insurance options and benefits. Efforts to educate the public about wind damage insurance, flood insurance, business interruption insurance, and crop insurance should be redoubled.

- Investigate state/local options for using financial market instruments, in addition to reinsurance and disaster reserve funds, to hedge storm/hurricane risk.
- Anticipate the need for NC greenhouse gas reductions as part of national goals; identify cost-effective regional options and plan for contingencies.
- Develop and expand university and community college faculty expertise related to climate change, adaptation strategies, and greenhouse gas mitigation technologies.
- Increase efforts to educate the public about climate change and its potential impacts; train teachers to educate NC students about climate change.

VII. References

Aburn, T. "Maryland's Climate Action Plan: Establishing Goals." Maryland Department of Energy. Presentation before the North Carolina Legislative Commission on Global Climate Change,Raleigh, NC. January 16, 2008. Available: http://www.ncleg.net/

Acclimatise. 2006. "Review of adaptation to climate risks by cities." London Climate Change Partnership. London, UK. Available: http://www.london.gov.uk/climatechange-partnership/adapting-jul06.jsp.

Adams, R., et al. 1998. "The Economic Effect of Climate Change on U.S. Agriculture." In: The Impacts of Climate Change on the U.S. Economy. R. Mendelsohn and J. Neumann, eds. Cambridge University Press. Cambridge, UK.

Allan, R.P., and B.J. Soden. 2008. Atmospheric warming and the amplification of precipitation extremes. Science 321: 1481-1484.

Anderson, D.M., 1989, Toxic algal blooms and red tides: a global perspective. In: Red Tides: Biology, Enviormental Sciences and Toxicology, (Okaichi, T., Anderson, D.M, Nemoto, T. eds) New York Elsevier.11-16.

Barco, S.G., Friedlaender, A.S., McLellan, W.A., Swingle, W.M., and D.A. Pabst. The phenology of strandings: twenty years of Tursiops truncatus strandings in Virginia, US. SEAMAMMS, Charleston, SC, March 28-30 2008.

Barlow, P.M. and E.C. Wild. 2002. Bibliography on the occurrence and intrusion of saltwater in aquifers along the Atlantic Coast of the United States. USGS Open File Report 02-235.

Barlow, P.M. 2003. Ground water in freshwater-saltwater environments of the Atlantic coast. USGS Circular #1262.

Baumert, K.A., T. Herzog, and J. Pershing. 2005. Navigating the numbers: Greenhouse gas data and international climate policy. World Resources Institute, Washington, DC.

Bell, F.W. 1986. Economic policy issues associated with beach renourishment. Policy Studies Review. 6:374-381.

Bell, Frederick W., and Vernon R. Leeworthy. 1990. Recreational Demand by Tourists for Saltwater Beach Days. *Journal of Environmental Economics and Management*. 18:189-205.

Bernard SM, Ebi KL. 2001a. Comments on the process and product of the health impacts assessment component of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States. Environ Health Perspect 109(suppl 2):177-184.

Bernard SM, Samet JM, Grambsch A, Ebi KL, Romieu I. 2001b. The potential impacts of climate variability and change on air pollution-related health effects in the United States. Environ Health Perspect 109(suppl 2):199-209.

Bin, O., C. Dumas, B. Poulter and J. Whitehead. "Measuring the Impacts of Climate Change on North Carolina Coastal Resources." National Commission on Energy Policy. Washington, DC. 2007.

Bin, O., J.B. Kruse, and C.E. Landry. 2008. Flood Hazards, Insurance Rates, and Amenities: Evidence from the Coastal Housing Market. Journal of Risk and Insurance. 75(1):63-82.

Bin, O., C.E. Landry, C.L. Ellis and H. Vogelsong. 2005. Some Consumer Surplus Estimates for North Carolina Beaches. *Marine Resource Economics*. 20:145-161.

Black, D.E., L.P. Donnalley and R.F. Settle. 1988. An Economic Analysis of Beach Renourishment for the State of Delaware. Delaware Department of Natural Resources and Environmental Control. Dover, DL.

Blake, E., E.N. Rappaport, and C.W. Landsea. 2007. The Deadliest, Costliest, and most Intense United States Tropical Cyclones from 1851 to 2006. National Weather Service and National Oceanic and Atmospheric Administration Technical Memo., National Hurricane Center. Miami, FL. Available: http://www.nhc.noaa.gov/pdf/NWS-TPC-5.pdf.

Bockstael, N.E., W.M. Hanemann, C.L. Kling. 1987. Modeling recreational demand in a multiple site framework. *Water Resources Research*. 23:951-960.

Bosworth, D., R. Birdsey, L. Joyce, and C. Millar. 2008. Climate Change and the Nation's Forests: Challenges and Opportunities. Journal of Forestry. June Issue:214-221.

Boyle, K.J. 2003. "Contingent Valuation in Practice." *A Primer on Nonmarket Valuation*. P.A. Champ, K.J. Boyle, and T.C. Brown, eds. pp. 111-170. London: Kluwer.

Boyles, Ryan P., and Sethu Raman. 2003. Analysis of climate trends in North Carolina (1949-1998). Environment International. 29:263-275.

Bromirski, P.D., and J.P. Kossin. 2008. Increasing hurricane wave power along the U.S. Atlantic and Gulf coasts. Journal of Geophysical Research. 113: C07012, doi:10.1029/2007JC004706

Brown, G., and K. Pollakowski. 1977. Economic valuation of shoreline. Review of Economics and Statistics. 59(3):272-278.

Burgess, Christine. Personal communication. Stock Assessment Scientist, North Carolina Division of Marine Fisheries. Morehead City, North Carolina. September 15, 2006.

Burkholder, J., D. Eggleston, H. Glasgow, C. Brownie, R. Reed, G. Janowitz, M. Posey, G. Melia, C. Kinder, R. Corbett, D. Toms, T. Alphin, N. Deamer and J. Springer. 2004. Comparative impacts of two major hurricane seasons on the Neuse River and western Pamlico Sound ecosystems. Proceedings of the National Academy of Science (PNAS) 101: 9291-0296.

Burrus, Robert T., Christopher F. Dumas, and J. Edward Graham. 2007. Homeowner Responses to Hurricane Risk Perceptions. Journal of Housing Research. Accepted for publication, in press.

Burrus, R.T., C.F. Dumas, and J.E. Graham. “Impacts of Insurance Deductibles and Hurricane Damage Perceptions on Mitigation Choices.” In: Economics and the Wind. Editors: B.T. Ewing, et.al.. Nova Science Publishers, Inc. New York. pp.115-123. 2005.

Burrus, R.T., C.F. Dumas and J.E. Graham. 2002. Catastrophic Risk, Homeowner Response, and Wealth-Maximizing Wind Damage Mitigation. Financial Services Review. 11:327-340.

Burrus, R.T., C.F. Dumas, C.H. Farrell and W.W. Hall. 2002. The Impacts of Low-Intensity Hurricanes on Regional Economic Activity. Natural Hazards Review. 3(3):118-125.

Burrus, R.T., C.F. Dumas, and J.E. Graham. “Hurricane Storm Surge: Cost-Effective Mitigation in Wilmington, North Carolina.” In: Facing Our Future: Hurricane Floyd and Recovery in the Coastal Plain. Editors: J.R. Maiolo, et.al. Coastal Carolina Press, pp. 109-117. 2001a.

Burrus, R.T., C.F. Dumas and J.E. Graham. 2001b. The Cost of Coastal Storm Surge Damage Reduction. Cost Engineering. 43(3):38-44.

Bushnell, J., C. Peterman, and C. Wolfram. 2008. Local Solutions to Global Problems: Climate Change Policies and Regulatory Jurisdiction. Review of Environmental Economics and Policy. 2(2):175-193.

Cahoon, L. 2008. Personal communication. Department of Biology and Marine Biology. University of North Carolina Wilmington. Wilmington, NC. September 19, 2008.

Cahoon, D.R. 2006. A review of major storm impacts on coastal wetland elevations. Estuaries and Coasts 29: 889-898.

Canavan, R.W. Slomp, C.P., Jourabchi, P., Van Cappellen, P., Laverman, A.M., and van den Berg, G.A. 2006. Organic matter mineralization in sediment of a coastal freshwater lake and response to salinization. Geochimica et Cosmochimica Acta 70, 2836-2855.

CAPAG. 2008a. "Draft Consolidated CAPAG Options--Presentation." Presentation on Global Climate Change Mitigation Options for North Carolina. Presentation to North Carolina Legislative Commission on Global Climate Change. North Carolina Climate Action Plan Advisory Group (CAPAG). North Carolina Department of Natural Resources and Center for Climate Strategies. Raleigh, NC. March 5. Available: http://www.ncleg.net/gascripts/DocumentSites/browseDocSite.asp?nID=14&sFolderName=\Meeting%20Documents\2007-2008%20Interim\5%20March%202008\Presentations

CAPAG. 2008b. "Draft Consolidated CAPAG Options--Table." Presentation on Global Climate Change Mitigation Options for North Carolina. Presentation to North Carolina Legislative Commission on Global Climate Change. North Carolina Climate Action Plan Advisory Group (CAPAG). North Carolina Department of Natural Resources and Center for Climate Strategies. Raleigh, NC. March 5. Available: http://www.ncleg.net/gascripts/DocumentSites/browseDocSite.asp?nID=14&sFolderName=\Meeting%20Documents\2007-2008%20Interim\5%20March%202008\Presentations

CAPAG. 2007. Presentation on Global Climate Change Mitigation Options for North Carolina. Presentation to North Carolina Legislative Commission on Global Climate Change. North Carolina Climate Action Plan Advisory Group (CAPAG). North Carolina Department of Natural Resources and Center for Climate Strategies. Raleigh, NC. October 23. Available:http://www.ncleg.net/gascripts/DocumentSites/browseDocSite.asp?nID=14&sFolderName=\Meeting%20Documents\2007-2008%20Interim\23%20October%202007\Presentations

Chambers, R.M., Mozdzer, T.J., and Ambrose, J.C. 1998. Effects of salinity and sulfide on the distribution of Phragmites australis and Spartina alterniflora in a tidal saltmarsh. Aquatic Botany 62,161-169

Chan, N Y, K L Ebi, F Smith, T F Wilson, and A E Smith, 1999. An integrated assessment framework for climate change and infectious diseases. Environmental Health Perspectives. 107(5): 329–337.

Chao, BF, YH Wu, and YS Li. 2008. Impact of artificial reservoir water impoundment on global sea level. Science. 320:209-212.

Cheuvront, Brian. "Lasting Impacts of Hurricanes on North Carolina's Commercial Fishermen – Follow Up Survey." North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries. Morehead City, North Carolina. February 2005.

Christensen, J.H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, A. Sarr and P. Whetton, 2007: Regional Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Cleary, W.J., Willson KT, Jackson CW. 2006. Shoreline restoration in high hazard zones: Southeastern north Carolina, USA. Journal of Coastal Research Sp. Iss. 39:884-889.

Colgan, C.S. 2004. "Living Near… And Making a Living From… The Nation's Coasts and Oceans." In Appendix C of *An Ocean Blueprint for the 21st Century: Final Report of the U.S. Commission on Ocean Policy* (www.oceancomission.gov)

Compeau, G.C., Bartha, E., 1985. Sulfate-reducing bacteria: principle methylators of mercury in anoxic estuarine sediment. Appl. Environ. Microbiol. 50, 498-502.

Covan, Eleanor Krassen, Marlene M. Rosenkoetter, Beth Richards, and Anita Lane. 2001. "The Impact of Hurricane Floyd on the Elderly Residing in Four Southeastern North Carolina Counties," in Facing Our Future: Hurricane Floyd and the Recovery in the Coastal Plain, John R. Maiolo, John C. Whitehead, Monica McGee, Lauriston King, Jeffery Johnson, Harold Stone, (Eds), Coastal Carolina Press. (pp. 213 – 233)

Crill, P. M., and C. S. Martens. 1987. Biogeochemical cycling in an organic-rich coastal marine basin .6. Temporal and spatial variations in sulfate reduction rates. Geochimica et Cosmochimica Acta 51, 1175-1186.

Cutting, R.H., and L.B. Cahoon. 2009. The "gift" that keeps on giving: Greenhouse gas emissions and the Common law, Vermont Environmental Law Journal 10(2).

Darmstadter, J., and M.A. Toman. 1993. Assessing Surprises and Nonlinearities in Greenhouse Warming. Resources for the Future. Washington, DC.

Desalvo M.K., C.R. Voolstra, S. Sunagawa, J.A. Schwarz, J.H. Stillman, M.A. Coffroth, A.M. Szmant and M. Medina. 2008. Differential gene expression during thermal stress and bleaching in the Caribbean coral Montastraea faveolata. Molecular Ecology published online.

Deschenes, O., and M. Greenstone. 2006. The Economic Impacts of Climate Change: Evidence from Agricultural Profits and Random Fluctuations in Weather. American Enterprise Institute--Brookings Joint Center for Regulatory Studies. Washington, DC.

DeWalle, D.R., A.R. Buda and A. Fisher. 2003. Weather and Forest Management in the Mid-Atlantic Region of the United States. Northern Journal of Applied Forestry. 20(2):61-70.

Douglas, B. C., and W. R. Peltier. 2002. The puzzle of global sea level rise. Physics Today 55:35-40.

Dumas, C.F., C. Chambers, and P. Seel. 2008. The Impact of Beach Nourishment on Beach Hotel Room Rentals. Presentation at Southern Economics Association annual conference. Washington, DC. November 21-23, 2008.

Dumas, Christopher F., and John C. Whitehead. 2008. The Potential Economic Benefits of Coastal Ocean Observing Systems: The Southeast Atlantic Region. Coastal Management. 36(2):146-164.

Dumas, Christopher, James Herstine, Douglas Gamble and Steven Meinhold. “Willingness to Pay for Rip Current Awareness and Education Programs.” Marine Resource Economics. Under review.

Dunkin, R.C., McLellan, W.A., Blum, J. and D.A. Pabst. 2005. Ontogenetic changes in the thermal properties of Atlantic bottlenose dolphin (Tursiops truncatus) blubber. Journal of Experimental Biology. 208:1469 -1480.

Durako, M. J., Hall. M. O., Butler, M.J., Behringer, D. C. 2008. Benthic Habitats. Invited talk for the Florida Bay Science Conference, Naples, FL, Dec 7-11, 2008.

Ebi, Kristie L., David M. Mills, Joel B. Smith, and Anne Grambsch. 2006. Climate Change and Human Health Impacts in the United States: An Update on the Results of the U.S. National Assessment. Environmental Health Perspectives. 114(9): 1318–1324.

Edwards, S.F., and F.J. Gable. 1991. Estimating the value of beach recreation from property values: An exploration with comparisons to nourishment costs. Ocean and Shoreline Management. 15:37-55.

Emanuel, Kerry. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature. 436:686-688.

Emanuel, Kerry. 2005. Emanuel replies. Nature. 438:E13.

Emanuel, K., Sundararajan, R., and J. Williams. 2008. Hurricanes and global warming – results from downscaling IPCC AR4 simulations. Bulletine of the American Meteorological Society, DOI: 10.1175/BAMS 89-3-347.

Engle, J., J. MacMahan, R.J. Thieke, D.M. Hanes and R.G. Dean. 2002. Formulation of a Rip Current Predictive Index Using Rescue Data. Proc. National Conf. on Beach Preservation Technology, FSBPA, January 23-25, 2002, Biloxi, MS. USA.

Feyen, J., C. Auer, K. Hess, E. Spargo, A. Wong, S. White, J. Sellars, and S. Gill. 2005. Prediction of Ecological Effects of Sea Level Rise in North Carolina through Coupled Hydrodynamic, Digital Elevation, and Habitat Models. Poster presentation at U.S. Climate Change Science Program (CCSP) workshop, Arlington, Virginia. November 14-16, 2005. Available: www.climatescience.gov/workshop2005/posters/P-CO2.3_Feyen.pdf

Finkl CW, Benedet L, Andrews JL, Suthard B, Locker SD. 2007. Sediment ridges on the west Florida inner continental shelf: Sand resources for beach nourishment. Journal of Coastal Research 23(1): 143-159

FHWA. 2008. Potential Impacts of Climate Change and Variability on Transportation Systems and Infrastructure – The Gulf Coast Study. U.S. Department of Transportation, Center for Climate Change and Environmental Forecasting. North Carolina Briefing, Mr. Mike Savonis, Team Leader for Air Quality, Federal Highway Administration. March 5, 2008.

Field, C.B., L.D. Mortsch, M. Brklacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, and M.J. Scott, 2007. North America. Climate Change 2007: Impacts, Adaption and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 617-652.

Fried, J. S., M. S. Torn, E. Mills. 2004. The Impact of Climate Change on Wildfire Severity: A Regional Forecast for Northern California. Climatic Change. 64: 169-191.

Froot, K.A. 1999. The Financing of Catastrophe Risk. National Bureau of Economic Research. University of Chicago Press. Chicago, IL.

Gamble, Douglas, Rob Mitchell, and Anthony Neri. 2008. Personal communication regarding "Assessment and Investigation of Current and Future Brunswick County Hydrologic Response to Heavy Precipitation" project. Department of Geology and Geography, University of North Carolina Wilmington. Wilmington, NC. September 15, 2008.

Gardner, L.R., and D.E. Porter. 2001. Stratigraphy and geologic history of a southeastern salt marsh basin, North Inlet, South Carolina. Wetlands Ecology and Management 9: 371-385.

Gardner TA, IM Cote, JA Gill, A Grant, AR Watkinson. 2003. Long-term, region-wide declines in Caribbean corals. Science 301: 958–960

Gilmour, C.C., Henry,E.A., Mitchell, R., 1992. Sulfate stimulation of mercury methylation in freshwater sediments. Environmetal Science and Technology 26, 2281-2287.

Gore, A. 1992. Earth in the balance: ecology and the human spirit. Houghton Mifflin Boston, 407 pp.

Greenough G, McGeehin M, Bernard SM, Trtanj J, Riad J, Engelberg D. 2001. The potential impacts of climate vari- ability and change on health impacts of extreme weather events in the United States. Environ Health Perspect 109(suppl 2):191-198.

Gubler DJ, Reiter P, Ebi KL, Yap W, Nasci R, Patz JA. 2001. Climate variability and change in the United States: poten- tial impacts on vector- and rodent-borne diseases. Environ Health Perspect 109(suppl 2):223-233.

Hallegraeff, G.M. 1993. A review of harmful algal blooms and their apparent global increase. Phycologia 32:79-99.

Hamilton, J.M. 2007. Coastal Landscape and the Hedonic Price of Accommodation. *Ecological Economics*. 62:594-602.

Hanemann, W.M. 1978. A methodological and empirical study of the recreation benefits from water quality improvement. Ph.D. dissertation. Harvard University.

Heinz Center for Science, Economics and Environment. 2000a. *The Hidden Costs of Coastal Hazards*. Island Press.

Heinz Center for Science, Economics and Environment. 2000b. Evaluation of Erosion Hazards Summary. Prepared for Federal Emergency Management Agency.

Hoegh-Guldberg O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar Freshwater Res 50: 839-866.

Hoegh-Guldberg O., Mumby P. J., Hooten A. J., Steneck R. S., Greenfield P., Gomez E., Harvell C. D., Sale P. F., Edwards A. J., Caldeira K., Knowlton N., Eakin C. M., Iglesias-Prieto R., Muthiga N., Bradbury R. H., Dubi A., Hatziolos M. E. (2007) Coral reefs under rapid climate change and ocean acidification. Science 318: 1737-1742.

Huang, J-C., P.J. Poor and M.Q. Zhao. 2007. Economic Valuation of Beach Erosion Control. *Marine Resource Economics*. 22:221-238.

Hurrell, James W., Yochanan Kushnir and Martin Yisbeck. 2001. The North Atlantic Oscillation. Science. 291(5504):603-605.

IPCC, 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M.

IPCC. 2007. Climate Change 2007: The Physical Basis. Contributions of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC Geneva, http://www.ipcc.ch/.http://www.ipcc.ch/, Geneva.

ISRS. 2008. Coral Reefs and Ocean Acidification. Briefing Paper 5, International Society for Reef Studies, 9 pp

Jensen, K. 2006. "Burden of Asthma in North Carolina, 2006." North Carolina Department of Health and Human Services. Raleigh, NC.

Jones, S.R., and W.R. Mangun. 2001. Beach Nourishment and Public Policy after Hurricane Floyd: Where do we go from here? *Ocean and Coastal Management*. 44:207-220.

Journal of Forestry. 2008. Potential Effects of Climate Change on Forests. Journal of Forestry. April/May: 129-131.

Keeler, A., W. Kriesel, and C. Landry. 2003. Expanding the National Flood Insurance Program to Cover Coastal Erosion Damage. Journal of Agricultural and Applied Economics. 35(3):639-647.

Kemp, Andrew, Benjamin Horton, Steven Culver, Reide Corbett, Orson Van de Plassche and Robin Edwards. Early Onset of Accelerated Relative Sea Level Rise in North Carolina, USA. Abstract. Geological Society of America annual conference. 2008.

Kerns, W.R., R.J. Byrne and C.H. Hobbs. 1980. An economic analysis strategy for management of shoreline erosion. Coastal Zone Management. 8:165-184.

Kerr, Richard A. 2008. Climate Change Hot Spots Mapped Across the United States. Science. 321:909.

Komar, P.D., and Allan, J.C., 2008. Increasing hurricane-generated wave heights along the U.S. East Coast and their climate controls. Journal of Coastal Research, 24(2), 479–488.

Koulaidis, V., & Christidou, V. (1998). Models of students’ thinking concerning the greenhouse effect and teaching implications. Science Education, 83(5), 559-576.

Kriesel, W., and C. Landry. 2004. Participation in the National Flood Insurance Program: An Empirical Analysis for Coastal Properties. Journal of Risk and Insurance. 71(3):405-420.

Kriesel, W., A. Keeler, and C. Landry. 2004. Financing Beach Improvements: Comparing Two Approaches on the Georgia Coast. *Coastal Management.* 32(4):433-447.

Kuzmina, S., et al. 2005. The North Atlantic Oscillation and greenhouse-gas forcing. Geophysical Research Letters 32:L04703, doi:10.1029/2004GL021064.

LaCommare, K., and J. Eto. 2004. ‘‘Understanding the cost of power interruptions to U.S. electricity consumers.’’ Lawrence Berkeley National Laboratory Report No. 55718. Berkeley, CA.

Lancaster, N.N.M. 2008. Effects of salinity on biogeochemical processes and methylmercury production in freshwater wetland sediments. M.S. thesis, University of North Carolina Wilmington.

Landry, C.E., A.G. Keeler and W. Kriesel. 2003. An Economic Evaluation of Beach Erosion Management Alternatives. Marine Resource Economics. 18:105-127.

Landsea, C.W. 2005. Hurricanes and global warming. Nature. 438:E11.

Leonard, Lynn. 2008. Personal communication. Chair, Dept. Geography and Geology, UNC Wilmington, Wilmington, NC.

Levitus, Sydney, John I. Antonov, Timothy P. Boyer and Cathy Stephens. 2000. Warming of the World Ocean. Science. 287(5461):2225-2229.

Lindsay, B.E., J.M. Halstead, H.C. Tupper, and J.J. Vaske. 1992. Factors Influencing the Willingness to Pay for Coastal Beach Recreation. *Coastal Management*. 20:291-302.

Lopez-Legentil, S., B. Song, S. McMurray, and J.R. Pawlik. 2008. Bleaching and stress in coral reef ecosystems: hsp70 expression by the giant barrel sponge Xestospongia muta. Molecular Ecology 17: 1840–1849.

Lower Cape Fear River Monitoring Program: Annual Reports (http://www.uncw.edu/cmsr/aquaticecology/LCFRP/index.htm).

Mallin, M., M.H. Posey, M.R. McIver, D.C. Parsons, S.H. Ensign and T.D. Alphin. 2002.Impacts and recovery from multiple hurricanes in a piedmont-coastal plain river system. BioScience. 52: 999-1010.

Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Mason, L., & Santi, M. (1998). Discussing the greenhouse effect: Children's collaborative discourse reasoning and conceptual change. Environmental Education Research, 4(1), 67-86.

McConnell, K.E. 1977. Congestion and Willingness to Pay: A Study of Beach Use. *Land Economics*. 53(2):185-195.

McGeehin MA, Mirabelli M. 2001. The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. Environ Health Perspect 109(suppl 2):185-189.

Meagher, E.M., McLellan, W.A., Westgate, A.J., Wells, R.S., Blum, J.E., Pabst, D.A. 2008. Seasonal patterns of heat loss in wild bottlenose dolphins (Tursiops truncatus). Journal of Comparative Physiology B. 178:529-543.

Mearns et al. 2003, Climate Scenarios for the Southeastern US Based on GCM and regional Model Simulations. Climatic Change. 60: 7-35.

Mendelssohn, I.A. and Kuhn, N.L., 2003. Sediment subsidy: effects on soil-plant responses in a rapidly submerging coastal salt marsh. Ecological Engineering 21, 115-128.

Michener, W.K., Blood, E.R., Bildstein, K.L., Brinson, M.M., and L.R. Gardner. 1997. Climate change, hurricanes, and tropical storms, and rising sea level in coastal wetlands. Ecological Applications 7: 770-801.

Milkov, A.V. 2004. Global estimates of hydrate-bound gas in marine sediments: how much is really out there? Earth-Science Review. 66:183–197 doi:10.1016/j.earscirev.2003.11.002

Mills, E., E. Lecomte, and A. Peara. 2002. Insurers in the Greenhouse. Journal of Insurance Regulation. 21(1):43-78.

Mills, E. 2005. Insurance in a Climate of Change. Science. 309:1040-1044.

Mizuno, J. 2008. Numerical analysis of potential losses of freshwater resources in coastal aquifers caused by global climate change using an appropriate boundary condition. Master of Science Thesis. Department of Geological Sciences, Ohio State University. Available: http://www.ohiolink.edu/etd/view.cgi?acc_num=osu1213328150

Moorhead and Brinson. 1995. Response of Wetlands to Rising Sea Level in the Lower Coastal Plain of NC, Ecological Applications. 5(1): 261-271

Morris, J. T., and P. M. Bradley. 1999. Effects of nutrient loading on the carbon balance of coastal wetland sediments. Limnology and Oceanography. 44: 699-702.

Morris, J.T., Sundareshwar, P.V., Nietch, C.T., Kjerfve, B., and D.R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. Ecology. 83: 2869-2877.

Mrasek, Volker. A Storehouse of Greenhouse Gases Is Opening in Siberia, *Spiegel International Online*, 17 April 2008.

Murphy, Robert M. Personal communication. Director, Agricultural Statistics Service, North Carolina Department of Agriculture & Consumer Services. Raleigh, North Carolina. September 12, 2006.

Najjar et al. 2000, The potential impacts of climate change on the mid-Atlantic coastal region, Climate Research 14:219-233

National Academy of Sciences. 2008. Understanding and Responding to Climate Change: Highlights of National Academy Reports—2008 Edition. National Academies Press. Washington, DC.

National Assessment Synthesis Team, U.S. Global Change Research Program. 2001. Potential consequences of climate variability and change for human health in the United States. In: Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Cambridge, UK: Cambridge University Press, 437-458.

National Hurricane Center. 2006. Tropical Cyclone Report: Hurricane Isabel. National Oceanic and Atmospheric Administration. Miami, FL.
Available: http://www.nhc.noaa.gov/2003isabel.shtml?.

National Oceanic and Atmospheric Administration (NOAA). 2006. Coastal Services Center, Beach Nourishment: A Guide for Local Government Officials, website, http://www.csc.noaa.gov/beachnourishment/html/human/socio/geodist.htm and http://www.csc.noaa.gov/beachnourishment/html/human/socio/change.htm, accessed November 26, 2006.

National Research Council. 1995. Beach Nourishment and Protection. Committee on Beach Nourishment and Protection, National Research Council. National Academy Press. Washington, DC.

NCASS. County Storm Damage Reports (various storms and years). Agricultural Statistics Service, North Carolina Department of Agriculture & Consumer Services. Raleigh, North Carolina. September 12, 2006. http://www.ncagr.com/paffairs/hurricane.htm

NCDOT. 2008. Efforts Underway in N. C. to Deal with Climate Change. North Carolina Department of Transportation, Environmental Planning and Policy Committee. Raleigh, NC. April 30, 2008.

NCSL. 2008. "North Carolina: Assessing the Costs of Climate Change." National Conference of State Legislatures. Washington, DC.
Available: http://www.ncsl.org/print/environ/ClimateChangeNC.pdf

Neumann, J.E., G. Yohe, R. Nicholls and M. Manion. 2000. Sea-level Rise & Global Climate Change: A Review of Impacts to U.S. Coasts. Pew Center on Global Climate Change. Arlington, VA.

North American Electric Reliability Council. Annual disturbance reports.
Available http://www.nerc.com.

Palmquist, R. "Property Value Models," in K-G Maler and J. Vincent, eds., Handbook of Environmental Economics, volume 2, North Holland, 2004.

Parsons, G.R., and M.J. Kealy. 1992. Randomly drawn opportunity sets in a random utility model of lake recreation. *Land Economics*. 68:93-106.

Parsons, G.R., D.M. Massey, and T. Tomasi. 1999. Familiar and Favorite Sites in a Random Utility Model of Beach Recreation. *Marine Resource Economics*. 14:299-316.

Parsons, G.R., and M. Powell. 2001. Measuring the Cost of Beach Retreat. Coastal Management. 29:91-103.

Patz JA, McGeehin MA, Bernard SM, Ebi KL, Epstein PR, Grambsch A, et al. 2000. Potential consequences of climate variability and change for human health in the United States. In: Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change (National Assessment Synthesis Team, eds). U.S. Global Change Research Program. Cambridge, UK:Cambridge University Press, 437-458.

Pezeshki, S.R. 2001. Wetland plant responses to soil flooding. Environmental and Experimental Botany 46, 299–312.

Pfefer, WT, JT Harper, and S O'Neel. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. Science 321:1340-1343.

Pilkey, Orrin H., and Katharine L. Dixon. The Corps and the Shore. Island Press. Washington, DC. 1996.

Pielke, R.A., Jr., C. Landsea, M. Mayfield, J. Laver and R. Pasch. 2005. Hurricanes and Global Warming. American Meteorological Society. 1571-1575.

Pielke, R.A., Jr. 2005. Are there trends in hurricane destruction? Nature. 438:E11.

Pompe, Jeffrey J., and James R. Rinehart. 1995. The Value of Beach Nourishment to Property Owners: Storm Damage Reduction Benefits. Review of Regional Studies. 25(3):271-285.

Posey, M.H., T.D. Alphin, H. Harwell and B. Allen. 2005. Importance of low salinity areas for juvenile blue crabs, Callinectes sapidus Rathbun, in river-dominated estuaries of southeastern United States. Journal of Experimental Marine Biology and Ecology. 319: 81-100.

Posey, M.H. and T.D. Alphin. 2002. Resilience and stability in an offshore benthic community: responses to sediment borrow activities and hurricane disturbance. Journal of Coastal Research. 18: 685-697.

Poulter, B., and P. N. Halpin. forthcoming. High-resolution raster modeling of coastal flooding from sea level rise: Effects of horizontal resolution and connectivity. International Journal of Geographic Information Science.

Reeve, N., and R. Toumi. 1999. Lightning activity as an indicator of climate change. Quarterly Journal of the Royal Meteorological Society. 125: 893-903.

RFF. 2001. Climate Change Economics and Policy. Michael A. Toman, ed. Resources for the Future. Washington, DC.

Rignot, Eric, et al. (2008). "Recent Antarctic Ice Mass Loss from Radar Interferometry and Regional Climate Modelling." Nature Geoscience 1: 106-110 [doi:10.1038/ngeo102].

Rogers, Spencer. 2008. Personal communication. Coastal Engineering Extension Specialist. North Carolina Sea Grant Program and UNC-W Center for Marine Science. Wilmington, NC.

Rose JB, Epstein PR, Lipp EK, Sherman BH, Bernard SM, Patz JA. 2001. Climate variability and change in the United States: potential impacts on water- and food-borne diseases caused by microbiologic agents. Environ Health Perspect 109(suppl 2):211-221.

Rosenkoetter, M., E. K. Covan, S. Bunting, B. Cobb, and E. Fugate-Whitlock. 2007. “Disaster Evacuation: An Exploratory Study of Older Men and Women in Georgia and North Carolina.” Journal of Gerontological Nursing, 33(12):46-54.

Roswintiarti, Orbita, Devdutta S. Niyogi and Sethu Raman. 1998. Teleconnections between tropical Pacific sea surface temperature anomalies and North Carolina precipitation anomalies during El Nino Events. Geophysical Research Letters. 25(22):4201-4204.

Rye, J. A., Rubba P. A., & Wiesenmayer, R. L. (1997). An investigation of middle school students’ alternative conceptions of global warming. International Journal of Science Education, 19, 527-551.

Schlenker,W., and M. Roberts. 2008. “Estimating the Impact of Climate Change on Crop Yields: The Importance of Nonlinear Temperature Effects.” National Bureau of Economic Research. Working Paper No. 13799. Cambridge, Massachusetts. Available: http://www.nber.org/

Science. 2008. Global Warming: Climate Change Hot Spots Mapped Across the United States. Science. Volume 321. August 15. p. 909.

Sexton, S.G., 2002. Rates of carbon remineralization in coastal wetland sediments under sulfate reducing and methanogenic conditions: Implications for sea-level rise. M.S. thesis, University of North Carolina Wilmington, 55 p.

Shivlani, J., D. Letson, and M. Theis. 2003. Visitor Preferences for Public Beach Amenities and Beach Restoration in South Florida. *Coastal Management*. 31(4):367-386.

Shumway, S.E., 1990. A review of the effects of algal blooms on shellfish aquaculture. Journal World Aquaculture Society 21:65-104.

Silberman, J., D.A. Gerlowski and N.A. Williams. 1992. Estimating existence value for users and nonusers of New Jersey beaches. *Land Economics*. 68(2):225-236.

Silberman, J., and M. Klock. 1988. The recreation benefits of beach renourishment. *Ocean and Shoreline Management*. 11:73-90.

Slott, J.M., M.D. Smith, and A.B. Murray. 2008. Synergies between Adjacent Beach-Nourishing Communities in a Morpho-Economic Coupled Coastline Model. Coastal Management, 36:1–18.

Smayda, T.J., 1997. Harmful algal blooms : their ecophysiology and general relevance to phytoplankton blooms in the sea. Limnology and Oceanography 42:1137-1153.

Smith, Martin D., Jordan M. Slott, Dylan McNamara, A. Brad Murray. 2008. Beach Nourishment as a Dynamic Capital Accumulation Problem. Forthcoming: Journal of Environmental Economics and Management.

Stern, Nicholas. 2007. The Economics of Climate Change. Cambridge University Press. New York.

Tester, P.A., Stumpf, R.P, Vukovitch, FM, Flowler, P.K. Turner, J.T. 1991. An expatriate red tide bloom: transport, distribution and persistance. Limnology and Oceanography 36:1053-1061.

Thayer, V. G., Read, A. J., Colby, D. R., Friedlaender, A. S., Hohn, A. A., McLellan, W. A., Pabst, D. A., Dearolf, J.L., Bowles, N. I., Russell, J. R. and K.A. Rittmaster. 2003. Reproductive seasonality of western Atlantic bottlenose dolphins off North Carolina, USA. Marine Mammal Science. 19(4):617-629.

Thieler, V., and Erika S. Hammar-Klose. National Assessment of Coastal Vulnerability to Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast. U.S. Geological Survey Open-File Report 99-593. Woods Hole, Massachusetts 1999.

Tomas, C.R. 2002. A survey of the harmful algal species of the Cape Fear and New River Estuaries, North Carolina. Report to the North Carolina Water Resource Research Institute. 67 pages.

Tomas, C.R., van Wagoner, R., Tatters, A..V. and Wright, J.L.C. 2008 *Alexandrium peruvianum* (Balech and Mendiola) Balech and Tangen, a new toxic species for coastal North Carolina. Harmful Algae (in review).

Torres, L.G., McLellan, W.A., Meagher, E.M., and D.A. Pabst. 2005. Seasonal distribution and relative abundance of bottlenose dolphins, Tursiops truncatus, along the US mid-Atlantic Coast. Journal of Cetacean Research and Management.7(2):153-161.

Trenberth, Kevin E., and Dennis J. Shea. 2006. Atlantic hurricanes and natural variability in 2005. Geophysical Research Letters. 33: L12704, doi:10.1029/2006GL026894.

Trembanis, A. C. and O. H. Pilkey, Summary of Beach Nourishment along the U.S. East Gulf of Mexico Shoreline, Journal of Coastal Research 14:407-417, 1998.

U.S. Army Corps of Engineers, 1994, "Shoreline Protection and Beach Erosion Control Study, Phase I: Cost Comparison of Shoreline Protection Projects of the U.S. Army Corps of Engineers," Water Resources Support Center, Washington, D.C., USA.

U.S. Army Corps of Engineers, 2004, "Economic and Environmental Planning and Guidance," Publication number ER 1105-2-100. Available: http://www.usace.army.mil/inet/usace-docs/eng-regs/er1105-2-100/

USGS HA 730-L. Ground water atlas of the United States: Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia.

U.S. Department of Transportation. The Potential Impacts of Global Sea Level Rise on Transportation Infrastructure, Phase 1 – Final Report for Washington, D.C., Maryland, North Carolina, and Virginia. August, 2008. Available: http://climate.dot.gov/publications/potential_impacts_of_global_sea_level_rise/index.html.

Valverde, H. R., A. C. Trembanis, and O. H. Pilkey, "Summary of Beach Nourishment Episodes on the U.S. East Coast Barrier Islands", Journal of Coastal Research 15:1100-1118, 1999.

Van Dolah, F.M. 2000. Marine algal toxins: origins, health effects, and their increased occurrence. Environmental Health Perspectives. 108(Suppl 1): 133–141.

Vaughn, D., Holt, J.W.and Blankenship, D.D., 2007, West Antarctic Links to sea level estimation: EOS, v 88,46, 13 Nov 2007.

Vinson, J. S. 2008. Role of oxygen and salinity on biogeochemical processes controlling mercury and methylmercury flux from estuarine sediments. M.S. thesis, University of North Carolina Wilmington, 106 p.

Wang, F. and Chapman, P.M. 1999. Biological implications of sulfide in sediment-a review focusing on sediment toxicity. Environmental Toxicology and Chemistry,18, 2526–2532.

Watkins, N. "Beach Plan Deficit: Cost to Policyholders and Taxpayers." Presentation before North Carolina Joint Select Study Committee on the Potential Impact of Major Hurricanes on the North Carolina Insurance Industry. October 16, 2008.

Westgate, A.J, McLellan, W. A., Wells, R. S., Scott, M.D., Meagher, E.M., and D.A. Pabst. 2007. A new device to remotely measure heat flux and skin temperature from free-swimming dolphins. Journal of Experimental Marine Biology and Ecology. 346:45-59.

Weston, N.B., Dixon, R.E. and Joye, S.B. 2006. Ramifications of increased salinity in tidal freshwater sediments: Geochemistry and microbial pathways of organic matter remineralization. Journal of Geophysical Research 111, G01009, doi:10.1029/2005JG000071

Wharton Risk Management and Decision Processes Center. 2008. Managing Large-Scale Risks in a New Era of Catastrophes: Insuring, Mitigating and Financing Recovery from Natural Disasters in the United States. March 2008. Available http://opim.wharton.upenn.edu/risk

Whitehead, John C., “One Million Dollars per Mile? The Opportunity Costs of Hurricane Evacuation,” Ocean and Coastal Management, 46(11-12), 1069-1083, 2003.

Whitehead, John C., Christopher F. Dumas, Jim Herstine, Jeffery Hill, Bob Buerger. Joint Estimation of Revealed and Stated Preference Data to Estimate the Benefits of Improved Beach Access and Increased Beach Width. Accepted for publication, in press: Marine Resource Economics.

Whitehead, J.C., C.F. Dumas, J. Herstine, J. Hill and B. Buerger. 2008. Valuing Beach Access and Width with Revealed and State Preference Data. *Marine Resource Economics*. 23:119-135.

Whitehead, John C., Jim Herstine, Christopher F. Dumas. Recreational Boater Willingness to Pay for an Atlantic Intracoastal Waterway Dredging and Maintenance Program. Under review, Coastal and Ocean Management.

Wildasin, David E. 2008. Disaster Policies: Some Implications for Public Finance in the U.S. Federation. Public Finance Review. 36(4):497-518.

Williams , John W. Stephen T. Jackson, and John E. Kutzbach. 2007. Projected distributions of novel and disappearing climates by 2100 AD. 5738–5742 Proceedings of the National Academy of Sciences. April 3, 2007 vol. 104 no. 14.

World Resources Institute. 2007. Climate Analysis Indicators Tool (CAIT) version 4.0. Available http://cait.wri.org.
.

Tables

Table 1. Potential Impacts of Sea Level Rise on Coastal Property in Four Example Counties (2004 $'s). Source: Bin et al. 2007.

Example County	Baseline Value and Number of Properties in 2004	Cumulative Estimated Impacts (Lost Value 2004 $'s, Number of Properties, and Percent of Value)					
		Year 2030			Year 2080		
		Low (11 cm) Sea Level Rise	Mid (16 cm) Sea Level Rise	High (21 cm) Sea Level Rise	Low (26 cm) Sea Level Rise	Mid (46 cm) Sea Level Rise	High (81 cm) Sea Level Rise
New Hanover							
Total	$16 billion	$80 million	$84 million	$89 million	$95 million	$123 million	$228 million
*(n)	85,786	495	516	544	574	680	1,063
**(%)		0.50%	0.52%	0.55%	0.59%	0.76%	1.41%
Resid.	$17 billion	$62 million	$66 million	$71 million	$73 million	$91 million	$167 million
(n)	74,984	345	360	385	403	476	773
(%)		0.53%	0.57%	0.60%	0.62%	0.78%	1.43%
Nonresid.	$4 billion	$18 million	$18 million	$18 million	$22 million	$32 million	$60 million
(n)	10,802	150	156	159	171	204	290
(%)		0.41%	0.41%	0.41%	0.50%	0.72%	1.35%
Dare							
Total	$19 billion	$1.1 billion	$1.2 billion	$1.3 billion	$1.6 billion	$2.2 billion	$3.5 billion
(n)	38,780	1,506	1,725	1,965	2,331	4,004	7,716
(%)		6.08%	6.61%	7.09%	8.63%	11.83%	18.86%
Resid.	$12 billion	$366 million	$411 million	$462 million	$522 million	$907 million	$1.8 billion
(n)	27,006	825	927	1,051	1,225	2,143	4,371
(%)		2.98%	3.35%	3.77%	4.25%	7.39%	14.69%
Nonresid.	$7 billion	$777 million	$831 million	$871 million	$1.1 billion	$1.3 billion	$1.7 billion
(n)	11,774	681	798	914	1,106	1,861	3,345
(%)		11.88%	12.71%	13.32%	16.85%	20.16%	26.66%
Carteret							
Total	$8 billion	$172 million	$176 million	$186 million	$202 million	$260 million	$433 million
(n)	55,509	1,077	1,140	1,225	1,322	1,977	3,890
(%)		2.09%	2.15%	2.26%	2.46%	3.17%	5.27%
Resid.	$6 billion	$43 million	$46 million	$49 million	$56 million	$92 million	$208 million
(n)	34,073	192	207	228	261	468	1,204
(%)		0.72%	0.76%	0.83%	0.94%	1.55%	3.49%
Nonresid.	$2 billion	$129 million	$131 million	$136 million	$146 million	$168 million	$225 million
(n)	21,436	885	933	997	1,061	1,509	2,686
(%)		5.73%	5.80%	6.04%	6.48%	7.45%	9.98%
Bertie							
Total	$1 billion	$5 million	$6 million	$7 million	$ 7 million	$8 million	$13 million
(n)	17,502	72	81	93	99	126	174
(%)		0.52%	0.61%	0.66%	0.67%	0.84%	1.26%
Resid.	$727 million	$3 million	$4 million	$4 million	$4 million	$5 million	$8 million
(n)	15,777	55	61	68	73	91	126
(%)		0.44%	0.51%	0.54%	0.56%	0.69%	1.05%
Nonresid.	$274 million	$2 million	$2 million	$3 million	$3 million	$3 million	$5 million
(n)	1,725	17	20	25	26	35	48
(%)		0.74%	0.85%	0.99%	0.99%	1.26%	1.79%

* The number of properties at risk. ** The percentage to the total property value at risk.

Table 2. Impacts of Sea Level Rise on Southern NC Beach Widths without Beach Sand Renourishment or Other Adaptation Activity. Source: Bin et al. 2007

County	Beach	2003	2030	2080
Carteret	Atlantic Beach	135	85	0
Carteret	Emerald Isle	130	80	0
Onslow-Pender	North Topsail Beach	82	32	0
Onslow-Pender	Topsail Beach	110	60	0
New Hanover	Wrightsville Beach	160	110	3
New Hanover	Carolina Beach	185	135	28
New Hanover	Kure Beach	130	80	0
New Hanover	Fort Fisher	400	350	243
Brunswick	Oak Island	120	70	0
Brunswick	Holden Beach	90	40	0

Table 3. Impact of Increasing Hurricane Intensity on Business Interruption Full Day Equivalents (FDEL). (Burrus et al. 2002)

Industry Sector Name	Hurricane Bertha (Cat 1) FDEL	Hurricane Bonnie (Cat 2) FDEL	Hurricane Fran (Cat 3) FDEL	Industry Average FDEL
Boat Building and Repairing	6.54	32.21	104.46	47.74
Amusement and Recreation Services	9.94	17.78	89.03	38.92
Food Stores	12.92	27.08	23.25	21.08
Social Services	0.00	6.25	51.75	19.33
New Residential Structures	12.96	6.33	34.25	17.85
Electrical Repair Service	1.00	4.00	42.50	15.83
Furniture & Home Furnishings Stores	8.58	4.92	31.58	15.03
Other Nonprofit Organizations	16.75	14.56	13.13	14.81
Real Estate	10.74	8.24	11.72	10.23
Miscellaneous Retail	8.02	4.19	14.27	8.83
Canvas Products	5.00	5.00	14.00	8.00
Credit Agencies	6.31	2.88	14.35	7.85
Radio and TV Broadcasting	2.00	8.75	12.38	7.71
Hotels and Lodging Places	0.83	0.60	21.35	7.59
. (other sectors omitted) :	. :	. :	. :	. :
Average over all industry sectors	3.75	4.66	12.61	7.01

Table 4a: North Carolina Agricultural Hurricane Damage Statistics. Source: NCASS 2006.

Storm Name	Date	Storm Category	Agriculture Sector Damages				
			Bertie (2004 $'s)	Carteret (2004 $'s)	Dare (2004 $'s)	New Hanover (2004 $'s)	NC Statewide Totals (2004 $'s)
Bertha	1996	Cat 2	$10,893,115	$4,091,257	$0	$233,075	$206,685,166
Fran	1996	Cat 3	$2,775,410	$2,436,815	$2,333,688	$1,117,130	$793,706,645
Bonnie	1998	Cat 2/(3)	$3,429,983	$7,715,530	$1,823,119	$624,400	$210,431,851
Dennis	1999	TS/Cat 1	$0	$6,880,463	$0	$21,678	$47,743,241
Floyd	1999	Cat (2)/3	$12,311,920	$8,807,432	$7,065,549	$169,465	$881,938,012
Irene	1999	Cat 1	$6,154,031	$0	$2,878,837	$0	$32,191,125
Bonnie/Charlie	2004	TS & TS	$582,414	$1,795,434	$0	$119,876	$56,512,720
Frances*	2004	TS	$0	$0	$0	$0	$54,913,000
Ivan*	2004	TS	$0	$0	$0	$0	$21,313,391
Ophelia	2005	Cat 1	$0	$2,111,824	$0	$0	$18,700,586
Tammy	2005	TS	$3,959,350	$196,712	$0	$0	$48,888,235
Ernesto	2006	TS	$0	$1,294,801	$0	$44,670	$55,685,149
Alberto*	2006	TS	NA	NA	NA	NA	NA

* Storm entered North Carolina from the West, causing little damage to coastal counties in the eastern, coastal portion of the state.
NA = not available.
TS = tropical storm.
TS/Cat 1 = storm intensity borderline between tropical storm / category 1, category 1 assumed based on damage.
2/(3) = storm intensity borderline between category 2 / category 3, category 2 assumed based on damage.
(2)/3 = storm intensity borderline between category 2 / category 3, category 3 assumed based on damage.

Table 4b. Average North Carolina Agricultural Hurricane Damage Statistics. Source: Bin et al. 2007.

Storm Category	Bertie (2004 $'s)	Carteret (2004 $'s)	Dare (2004 $'s)	New Hanover (2004 $'s)	NC Statewide Totals (2004 $'s)
Tropical Storm	$1,513,921	$1,095,649	$0	$54,849	$53,695,368
Category 1	$2,051,344	$2,997,429	$959,612	$7,226	$32,878,317
Category 2	$7,161,549	$5,903,393	$911,559	$428,738	$208,558,508
Category 3	$7,543,665	$5,622,123	$4,699,619	$643,298	$837,822,329

Table 5. Worldwide Greenhouse Gas Emissions by Economic Sector, 2000.
Source: World Resources Institute 2007.

Sector	$MtCO_2$ eq.	Percentage[a]
Energy	24,722.3	59.4
Electricity	10,276.9	24.7
Transportation	4,841.9	11.6
Manufacturing	4,317.7	10.4
Other fuel combustion	3,656.5	8.8
Fugitive emissions[b]	1,629.3	3.9
Land-use change and deforestation	7,618.6	18.3
Agriculture	5,603.2	13.5
Waste	1,465.7	3.5
Industrial processes	1,406.3	3.4
International bunker fuels[c]	824.3	2.0
Total	41,640.5	100.1

[a] Percentages add up to more than 100 due to rounding.
[b] NO_2 data not available. Fugitive emissions include the leaking of refrigerants from air-conditioning and refrigeration systems.
[c] Fuels used by aircraft and ships.

Table 6. Worldwide Greenhouse Gas Emissions by Country and Region, 2000.
Source: Baumert et al. 2005.

Country	$MtCO_2$ eq.	Percentage of world GHGs
1. United States	6,928	20.6
2. China	4,938	14.7
3. Russia	1,915	5.7
4. India	1,884	5.6
5. Japan	1,317	3.9
6. Germany	1,009	3.0
7. Brazil	851	2.5
8. Canada	680	2.0
9. United Kingdom	654	1.9
10. Italy	531	1.6
Top 10 countries	20,707	61.5
Rest of world	12,958	38.5
Developed countries	17,355	52
Undeveloped countries	16,310	48

Table 7. Recommended Greenhouse Gas Emissions Mitigation Options, NC Climate Plan Source: COPAG 2008b.

CAPAG Option Number	Option Description	Estimated Emissions Reductions and Net Benefit or Cost
Energy Supply and Demand		
RCI-1	Demand-Side Management for Residential, Commercial and Industrial Sectors	these options together account for 23.5% of total emissions reductions $4.4 billion total NPV *savings* 2007-2020
RCI-2 / ES-7	Expansion of Energy Efficiency Funds	
RCI-4	Market Transformation and Technology Development Program	
RCI-5	Improved Appliance and Equipment Efficiency Program	
RCI-6	Building Energy Codes	
RCI-7	"Beyond Code" Building Design Incentives and Targets, Incorporating Local Building Materials and Advanced Construction, and Bulk Purchasing Programs for Energy Efficiency or Other Equipment	
RCI-11	Residential, Commercial, and Industrial Energy and Emissions Technical Assistance and Recommended Measure Implementation	
ES-1	Incentives for centralized renewables	these options together account for 20.4% of total emissions reductions $3.3 billion total NPV *cost* 2007-2020
ES-2b	Environmental performance standard; renewable energy generation target only	
ES-4a	Cap-and-trade; electric sector only	
ES-5	Aligning environmental and profit incentives	
ES-6a	Integrated gasification combined cycle with/without carbon capture and storage -- replacement of new 800 MW coal unit	
ES-8	Waste to Energy	
ES-10 / RCI-9	Green Power Purchasing (required for state facilities)	
ES-3 / ES-9 / RCI-10	Distributed Renewable and Clean Fossil Fuel Power Generation	
AFW-9&10	Expanded Use of Forest Biomass & Better Forest Management	

AFW-5	Agricultural Biomass Feedstocks for Electricity/Steam Production	
Transportation and Land Use Efficiency		these options together account for 26.7% of total emissions reductions $4.8 billion total NPV *savings* 2007-2020
TLU-1a	Land Development Planning	
TLU-3a	Surcharges to Raise Revenue	
TLU-3b	Rebates / "Freebates" to Change Fleet Mix	
TLU-11	Pay-As-You-Drive Insurance	
TLU-1b / TLU-2	Multi-Modal Transportation and Promotion	
TLU-5	Tailpipe GHG Standards (e.g., California Clean Car)	
TLU-4 / TLU-8	Idle Reduction, Elimination Policies	
TLU-4	Truckstop Electrification	
TLU-9	Diesel Retrofits	
TLU-12	Advanced Technology Incentives	
Clean & Renewable Fuels		these options together account for 10.2% of total emissions reductions $0.5 billion total NPV *cost* 2007-2020
TLU-6,7,13	Biofuels Bundle	
TLU-7	Procure Efficient Fleets	
TLU-13	Buses-Clean Fuels	
AFW-2	Biodiesel Production	
AFW-6	Ethanol Production	
Agriculture and Forestry		these options together account for 9.7% of total emissions reductions $0.2 billion total NPV *cost* 2007-2020
AFW-4a	Preservation of Agricultural Lands	
AFW-4b	Preservation of Forested Lands	
AFW-8	Afforestation and/or Restoration of Nonforested Lands	
AFW-13	Urban Forestry	
AFW-3	Soil Carbon Management, including incentives for organic production methods	
Waste Management		these options together account for 3.5% of total emissions reductions $0.3 billion total NPV *cost* 2007-2020
AFW-12	Increased Recycling Infrastructure and Collection	
AFW-1	Manure Digesters & Energy Utilization	
AFW-11	Landfill Methane & Biogas Energy Programs	

Government Facilitation, Coordination, Education & Outreach		emissions reductions and costs of these options not quantified as part of COPAG's initial analysis
CC-4	State Climate Public Education and Outreach	
RCI-8	Education (Consumer, Primary/Secondary, Post-Secondary/Specialist, College and University)	
CC-1	GHG Inventories and Forecasts	
CC-2	State Greenhouse Gas Reporting	
CC-3	State Greenhouse Gas Registry	
CC-6	GHG Goals or Targets	
CC-5	State Climate Change Adaptation Strategy	

Table 8. UNC-Wilmington Courses Discussing Global Climate Change.

Course Call Number	**Course Name**	**Notes**
ANT 292	Exploring World Cultures: Environmental Justice Ethnography	
ANT 309	Environmental Anthropology	
BIO 150	Humans and Ecology	
BIO 357	Ichthyology	
BIO 358	Marine Mammals	
BIO 362	Marine Biology	
BIO 366	Ecology	
BIO 425	Microbiology	
BIO 434	Coastal Marine Ecology	
BIO 460	Limnology	
BIO 463	Coral Reef Ecology	
BIO 466	Conservation Biology	
BIO 478	Global Environmental Problems	
BIO 495	Senior Seminar	Various seminars deal with this topic (though not all)
BIO 534	Advanced Topics in Ecology	
BIO 560	Estuarine Biology	
BIO 564	Biological Oceanography	
BIO 568	River Ecology	
BIO 585	Special Topics in Advanced Biology	Various seminars deal with this topic (though not all)
BIO 601	Oceanography and Environmental Science	
BIO 602	Physiological Ecology of Temperature	
BUS 495	Business Ethics	Discussed environmental impact of business. May not be on global scale. Discussed around the 17th class of Fall 2007
CHM 101	General Chemistry	Topic referenced in several lectures.
EBD 380	Entrepreneurship	Discuss companies such as Terrapass and others who sell solar water heaters and how there is not strong demand for their products.
ECN 325	Environmental Economics	
ECN 330	Natural Resource Economics	
ECN 437	Development Economics	

ECN 525	Masters Environmental Economics	
ECN 530	Masters Natural Resource Economics	
ENG 101	College Writing and Reading I	Discussed topic once in class
ENG 103	Advanced College Writing and Reading	Topic students sometimes pick for research paper. Professor acknowledges it as obvious that it will happen so students are limited to discussing solutions that could slow the climate change, e.g., alternative fuels.
ENG 313	Writing about Science	Climate change discussed a number of times
EVS 195	Introduction to Environmental Studies	Discusses topic multiple times
EVS 205	Global Environmental Issues	Entire first half of course is exclusively on global climate change issues
EVS 210	Sustainable Society Issues	
EVS 360	Human Dimensions of Natural Resource Management	Discussed on and off throughout class
EVS 364	Environmental Policy	
EVS 430	Tropical Environmental Ecology	Discusses issue in relation to tropics multiple times
EVS 485	Natural Resources	
EVS 495	Seminar in Environmental Studies	Discussed regularly.
EVS 510	Graduate Intro. To Envir. Problems & Policy	
FIN 335	Principles of Financial Management	
FIN 430	Investment Management	Discussed informally and briefly as a current event topic
GGY 180	World Geography I	
GGY 181	World Geography II	
GGY 220	Cartography	
GGY 270	Principles of Land Use Planning	
GGY 340	Resources, Population, and Environment	
GGY 345	Geography of Food	
GGY 346	Geography of US Race Relations	
GGY 350	World Political Geography	
GGY 473	Regional and Environmental Land Use Planning	
GLY 101	Introduction to Geology	

GLY 120	Environmental Geology	
GLY 125	Natural Disasters	
GLY 135	Prehistoric Life	It is difficult to teach geology, Earth history, and evolution without considering climate change.
GLY 150	Intro to Oceanography	
GLY 172	The Earth Through Time	
GLY 240	Geology of North Carolina	
GLY 300	Honors Oceanography	
GLY 310	General Petrology	
GLY 420	Global Climate Change	
GLY 440/540	Regional Geology of North America	
GLY 441	Structural Geology	
GLY 495	Seminar in Geology	
GLY 550	Marine Geology	
GLY/EVS120	Environmental Geology	Lab and course
HON 210	Sustainable Society Issues	
HST 103	Global History since 1500	
HST 276	Introduction to the History of Science: Modern Science	
HST 456/533	American Environmental History	cross-list grad/undergrad seminar - Discussed topic for two class periods
MAT 561	Fluid Dynamics and Modeling of Ocean Circulations I	Fall semester of 2 semester course
MAT 561	Fluid Dynamics and Modeling of Ocean Circulations II	Spring semester of 2 semester course
MAT 592	Advance topics in applied mathematics	Professor last taught in Fall 2002
MGT 455	Competitive Strategy	One class on pro-active management of enviro. issues.
MKT 445	Marketing Strategy	Discuss measuring a firm's carbon footprint. Walmart has asked suppliers for their carbon footprints.
PHY 260	Introduction to Astronomy	Professor lectures about astronomical reasons for climate change - not human
PHY 420	Global Climate Change	
PLS 101	American National Government	
PLS 105	Not Listed	

PLS 111	Introduction to Global Politics	One session taught on climate change
PLS 543	Environmental Policy Analysis	
PLS 592	International Environmental Policy	Will be discussed in Spring 2008 class
QMM 280	Quantitative Statistics	Discussed for building climate related models
REC 292	Resort and Spa Management	
REC 351	Introduction to Travel and Tourism	
REC 352	Commercial Recreation and Tourism	
REC 380	Marketing for Recreation Services	
STT 501	Applied Statistical Methods	We considered the global temperature anomalies dataset from Goddard Institute for Space Sciences (http://data.giss.nasa.gov/gistemp/). We used R to plot the annual values over time, then discussed the plot and its implications.
SWK 106	Social Work and Global Visions	Discusses global climate change at great length and at almost every class session
UNCW	Ocean Odyssey Program	Implemented several seminars on global climate change the largest being the "Global Warming Conference" in June of 2007
UNCW	GLS Seminars	Three seminars where the topic was discussed

Figures

Figure 1. Relative Responsiveness of U.S. Geographic Regions to Global Warming. (More responsive areas are more vulnerable to negative impacts of climate change.) Source: Science. 2008. Global Warming: Climate Change Hot Spots Mapped Across the United States. Volume 321. August 15. p. 909.

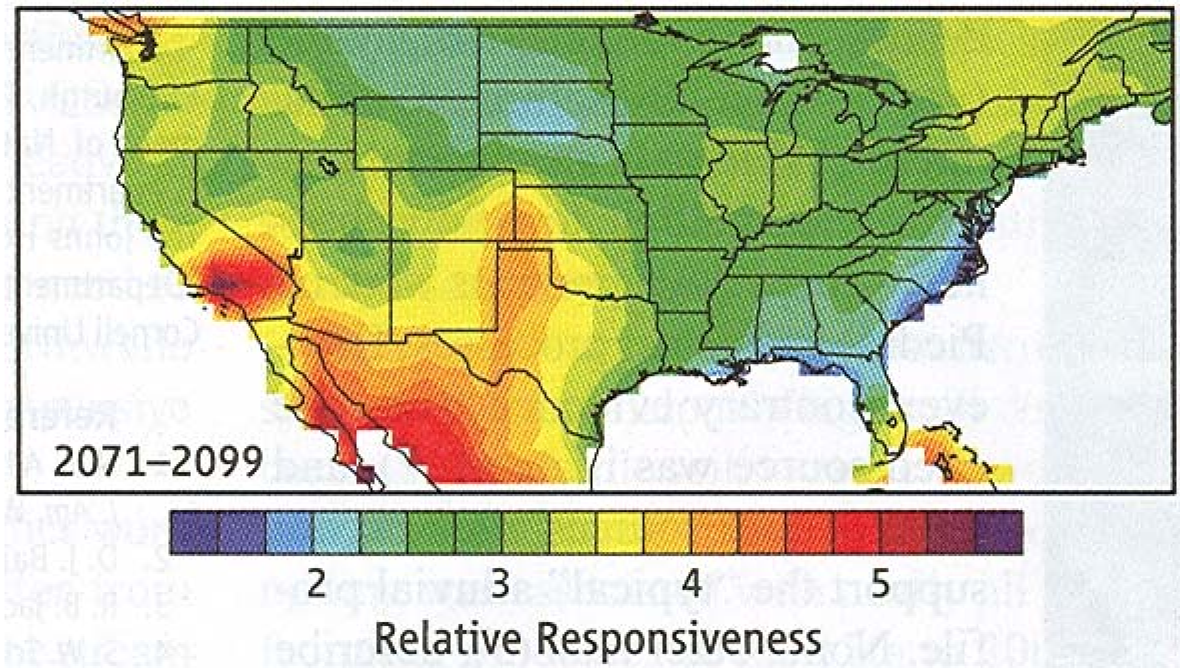


Figure 2. IPCC Global Sea Level Rise Projections. Source: IPCC 2007.

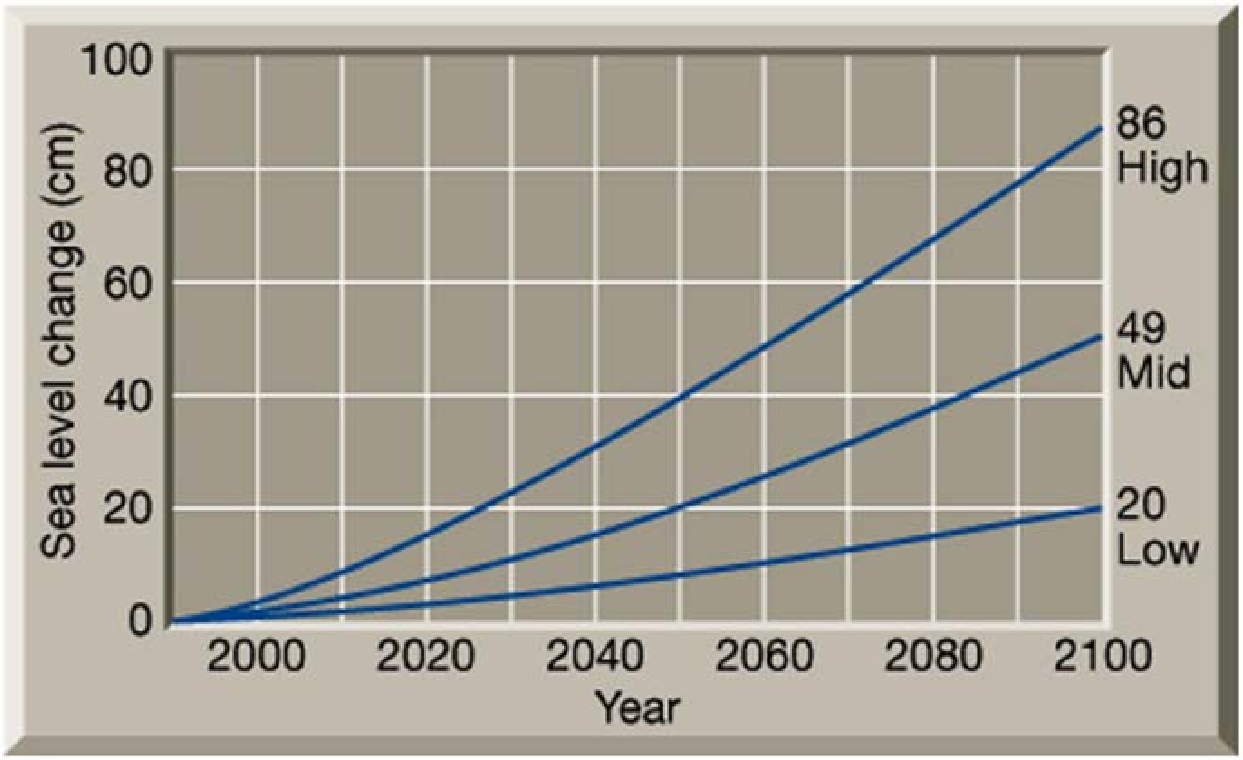


Figure 3: Observed rates of sea level rise along the North Carolina coast. From north to south, the gages are Hampton Roads, VA, Duck Pier, NC, and Charleston, SC. (Source: Permanent Service for Mean Sea Level, Proudman Oceanographic Laboratory, Liverpool, UK. http://www.pol.ac.uk/psmsl/)

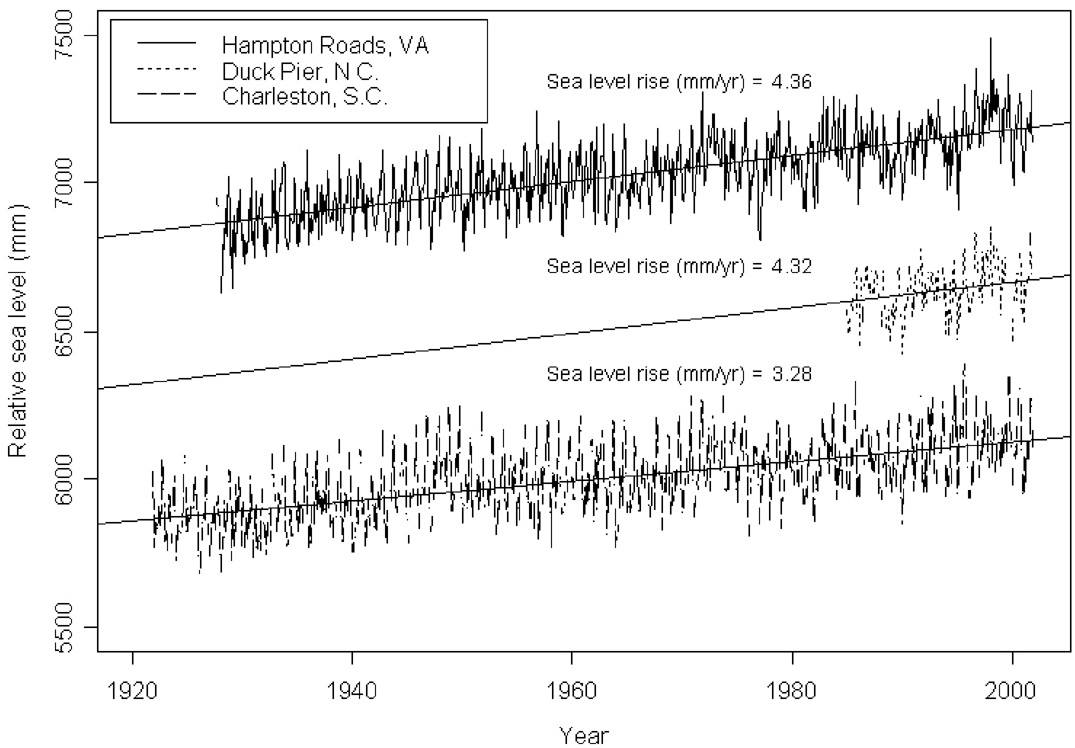


Figure 4. U.S. Geological Survey Coastal Vulnerability Index. Source: Thieler, V., and Erika S. Hammar-Klose. 1999.

	Ranking of coastal vulnerability index				
	Very low	Low	Moderate	High	Very high
VARIABLE	1	2	3	4	5
Geomorphology	Rocky, cliffed coasts Fiords Fiards	Medium cliffs Indented coasts	Low cliffs Glacial drift Alluvial plains	Cobble beaches Estuary Lagoon	Barrier beaches Sand Beaches Salt marsh Mud flats Deltas Mangrove Coral reefs
Coastal Slope (%)	> .2	.2 –.07	.07 –.04	.04 –.025	< .025
Relative sea-level change (mm/yr)	< 1.8	1.8 – 2.5	2.5 – 2.95	2.95 –3.16	> 3.16
Shoreline erosion/ accretion (m/yr)	>2.0 Accretion	1.0 –2.0	-1.0 – +1.0 Stable	-1.1– -2.0	< - 2.0 Erosion
Mean tide range (m)	> 6.0	4.1 – 6.0	2.0 – 4.0	1.0 –1.9	< 1.0
Mean wave height (m)	<.55	.55 –.85	.85 –1.05	1.05 –1.25	>1.25

Figure 5. Coastal Vulnerability Index Rankings for North and South Carolina Coasts. Source: Thieler, V., and Erika S. Hammar-Klose. 1999.

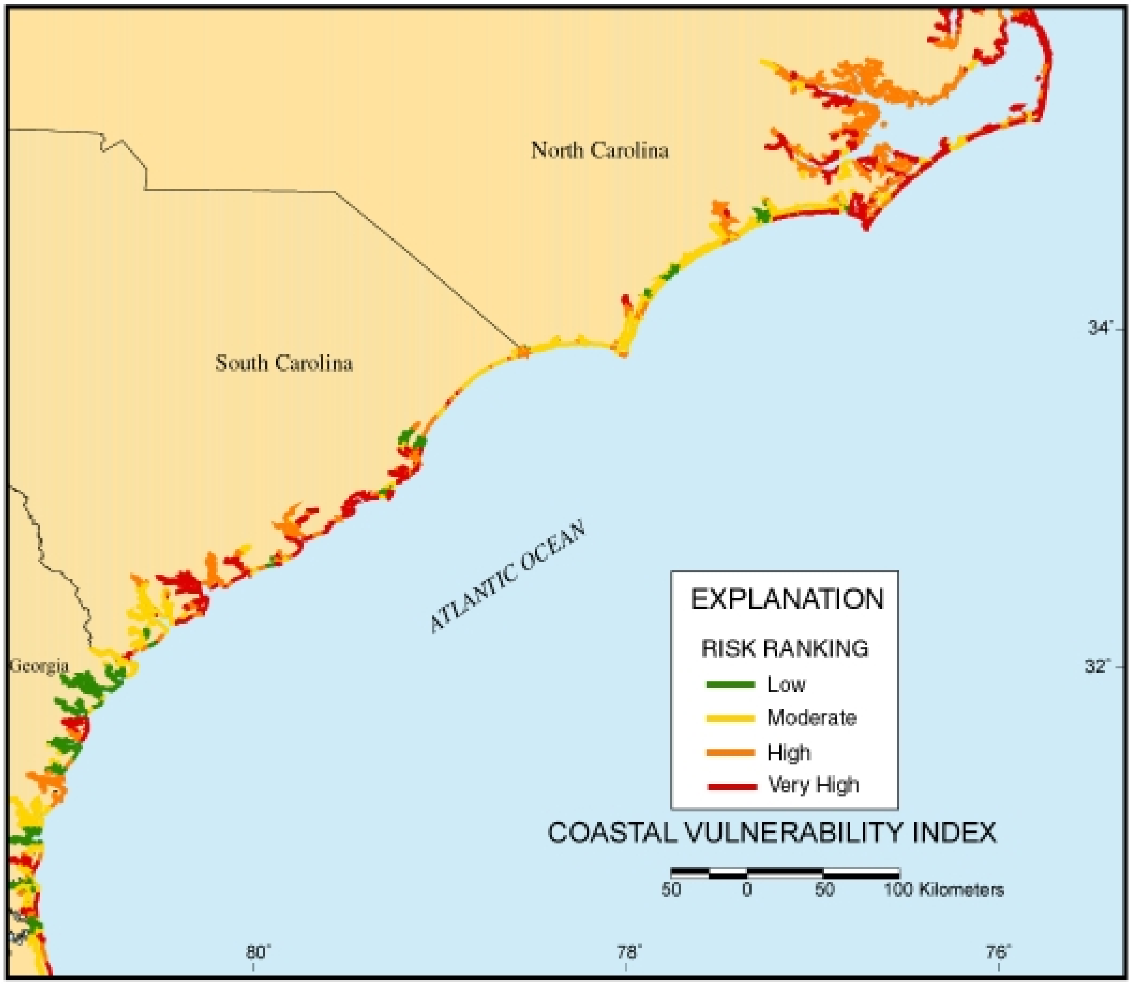


Figure 6. Areas of Coastal North Carolina at Risk for Inundation by Sea Level Rise. Source: Poulter, B., and P. N. Halpin. forthcoming.

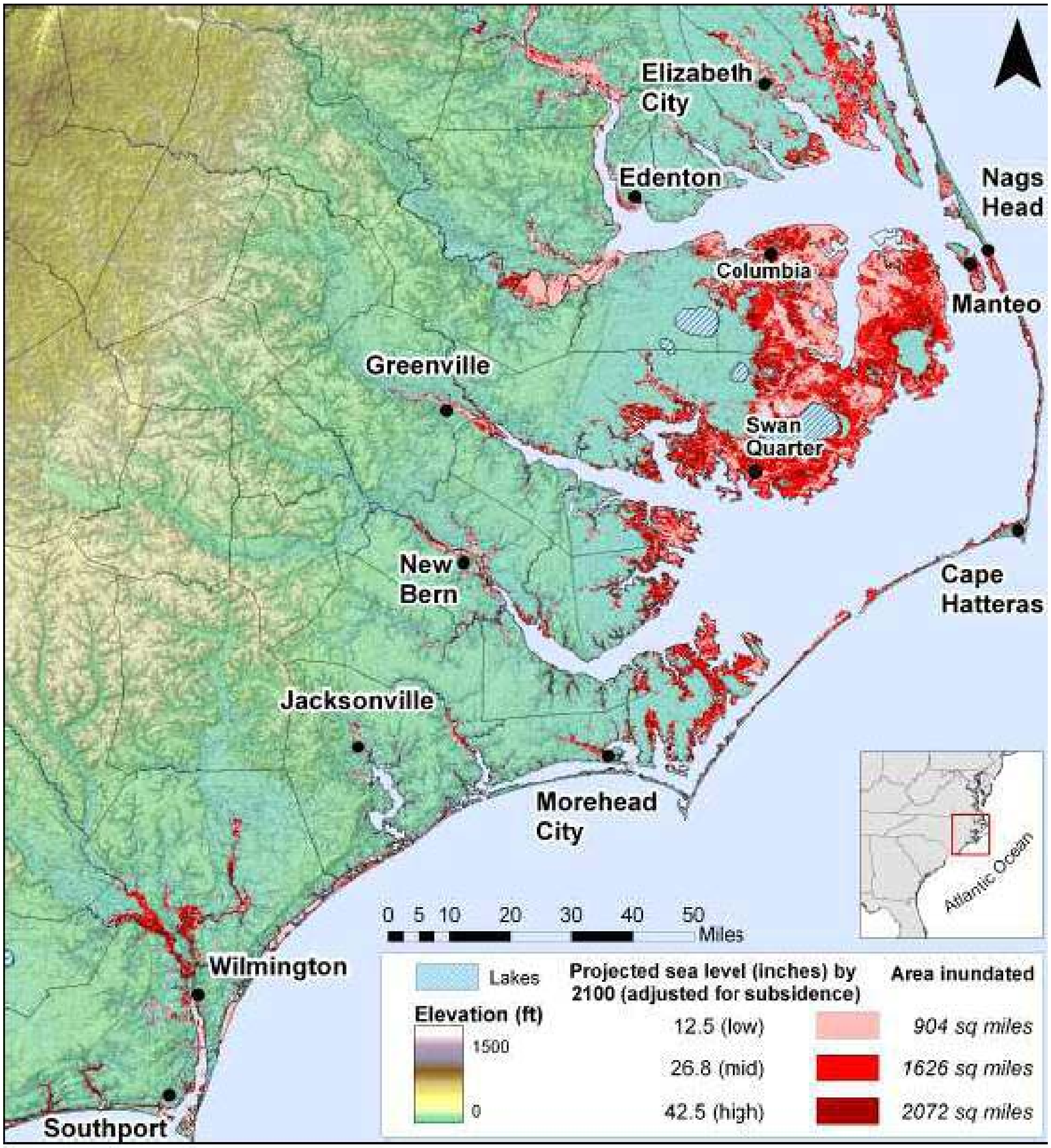


Figure 7. Impact of Higher Temperatures on U.S. Lightning-related Insurance Claims. Source: Mills et al. 2002.

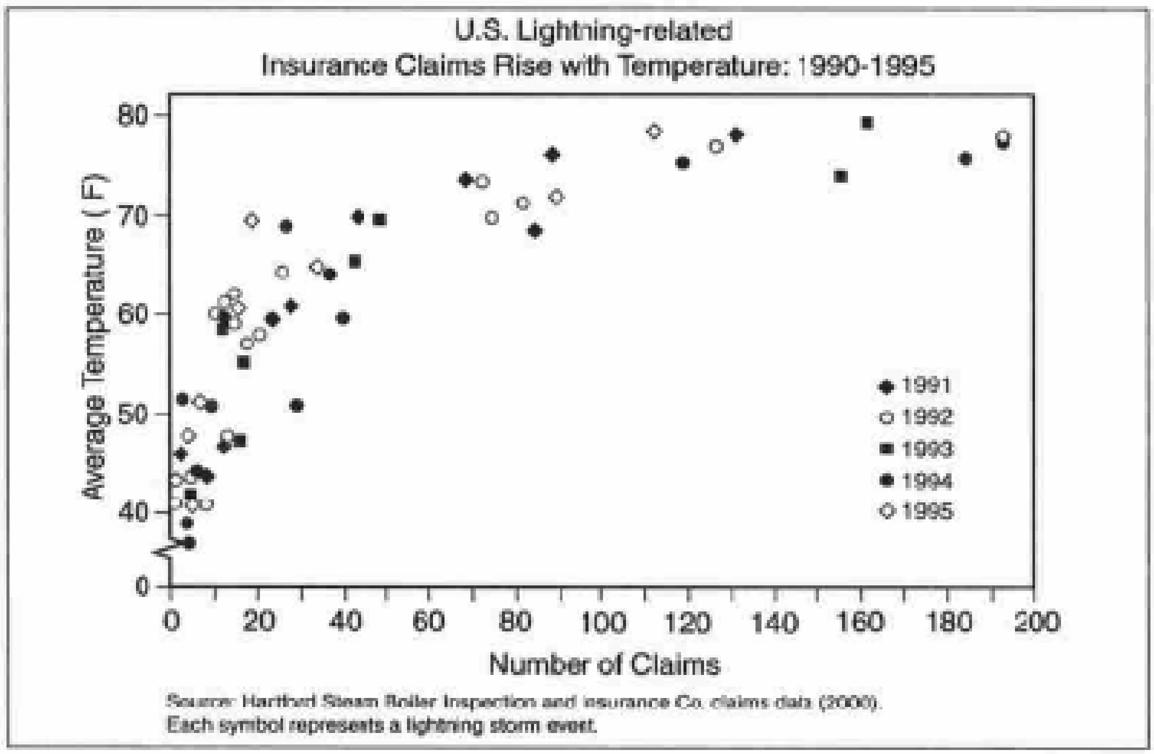


Figure 8. Recent Climate Warming Impacts on U.S. Agricultural Climate Zones. Source: U.S. Department of Agriculture.

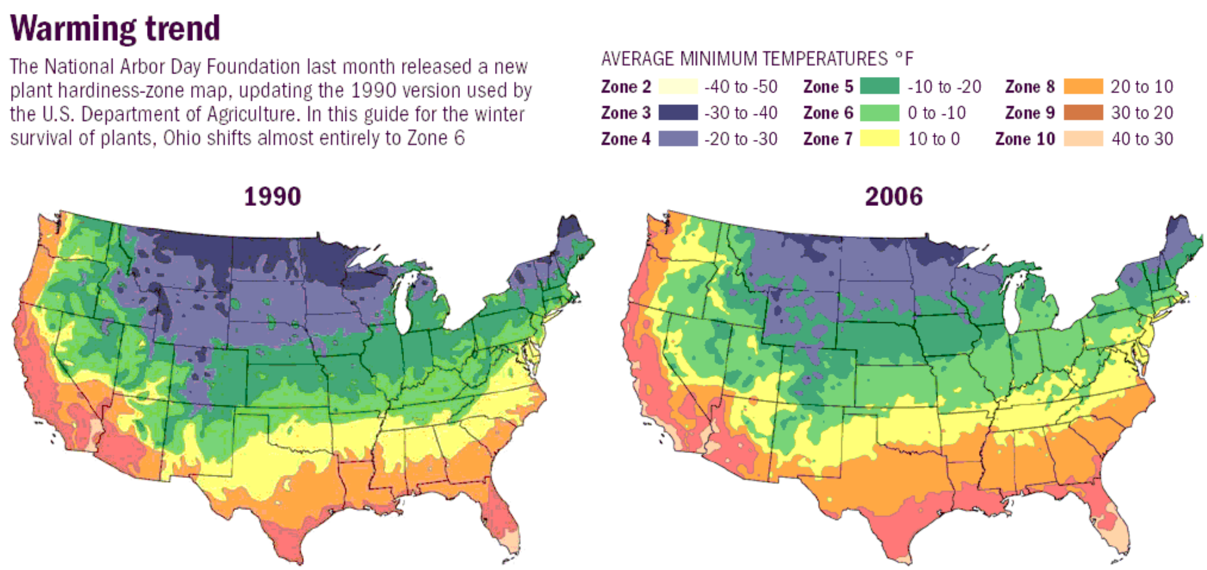


Figure 9a. Potential Impacts of Sea Level Rise on Coastal Groundwater Resources. Source: Barlow 2003, Figure 13.

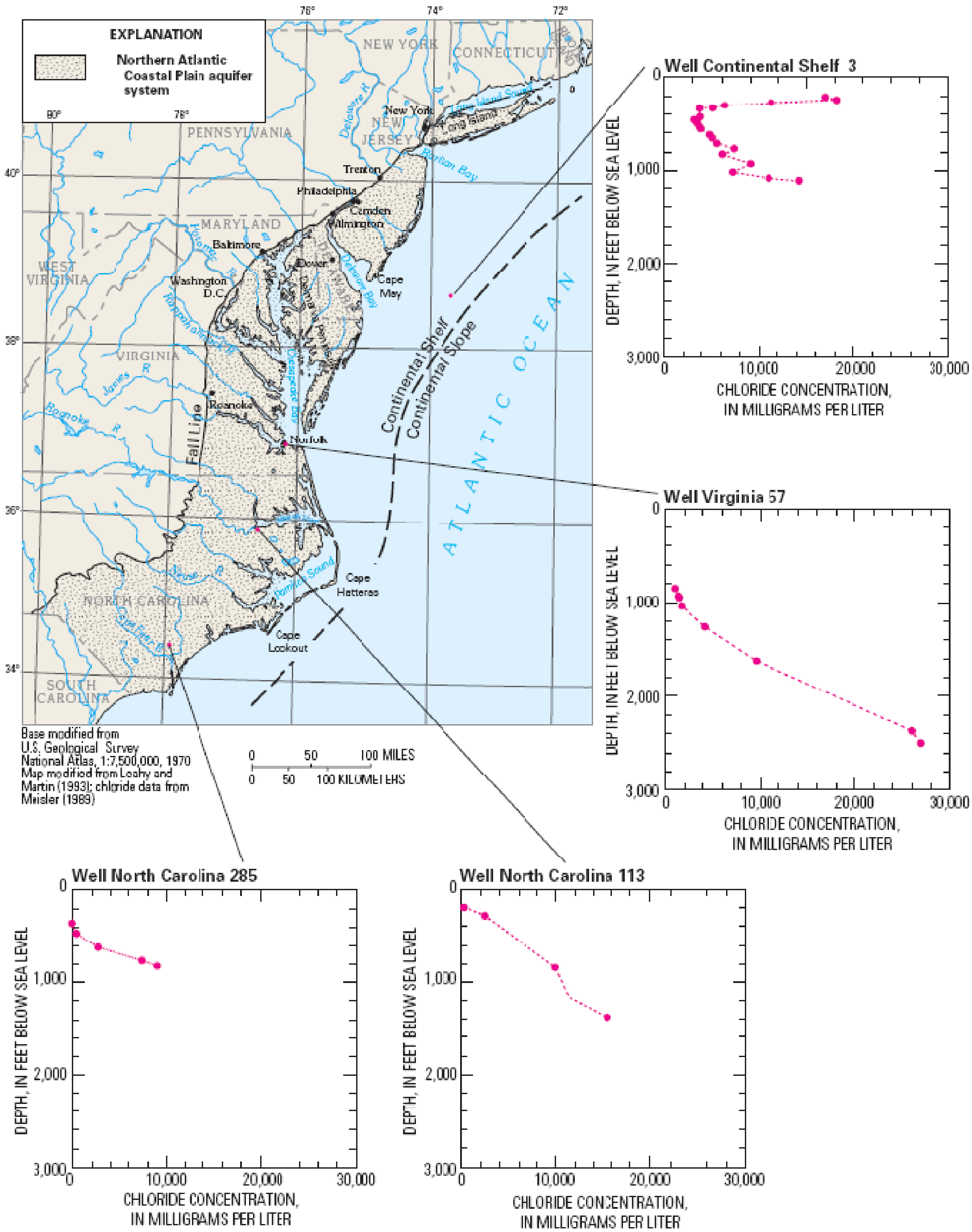


Figure 9b. Potential Impacts of Sea Level Rise on Coastal Groundwater Resources. Source: Barlow 2003, Figure 14.

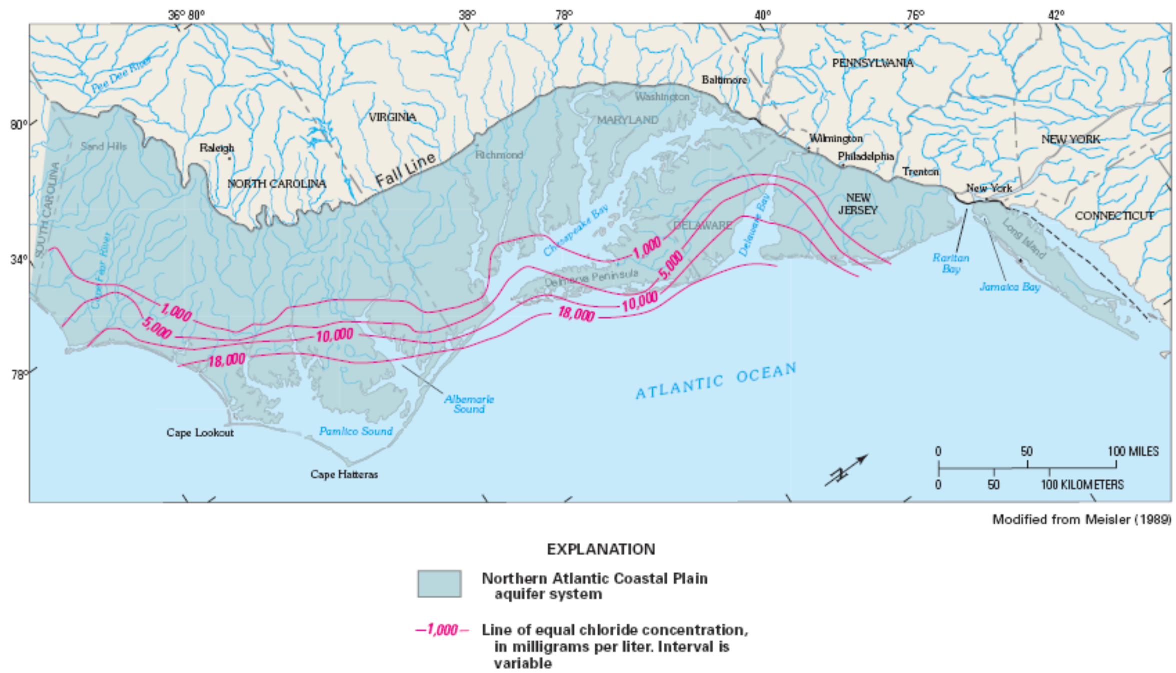


Figure 10. North Carolina Transportation Infrastructure Inundation Map (31 cm sea level rise scenario). Red = Interstate, Green = Other major highway, Crosshatch = railroad.
Source: U.S. Dept. Transportation. 2008.

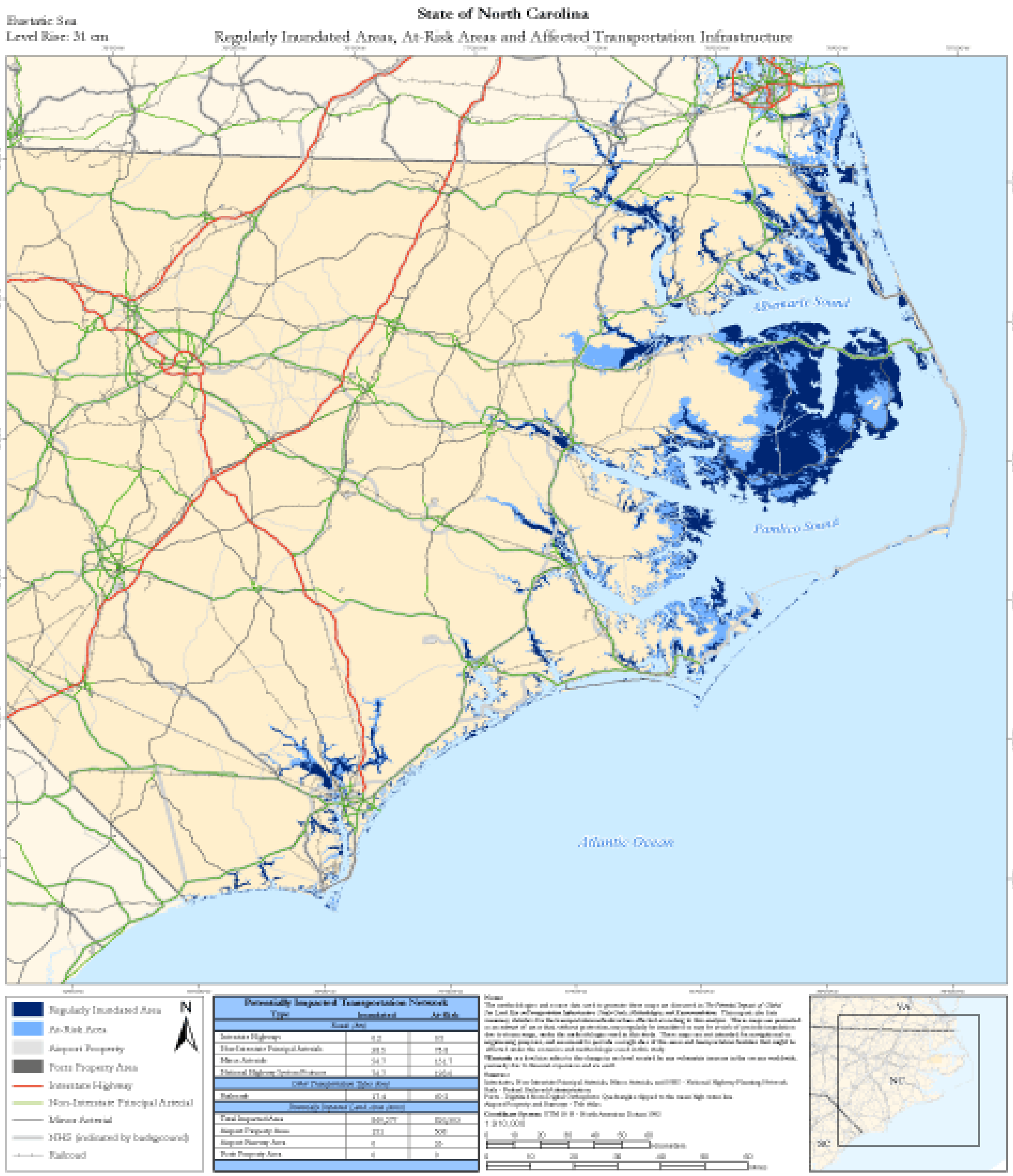


Figure 11. History and Forecast of North Carolina Greenhouse Gas Emissions by Source/Industry. (MMtCO2e = Millions of Metric Tons of Carbon Dioxide Gas Equivalents). Source: COPAG 2007.

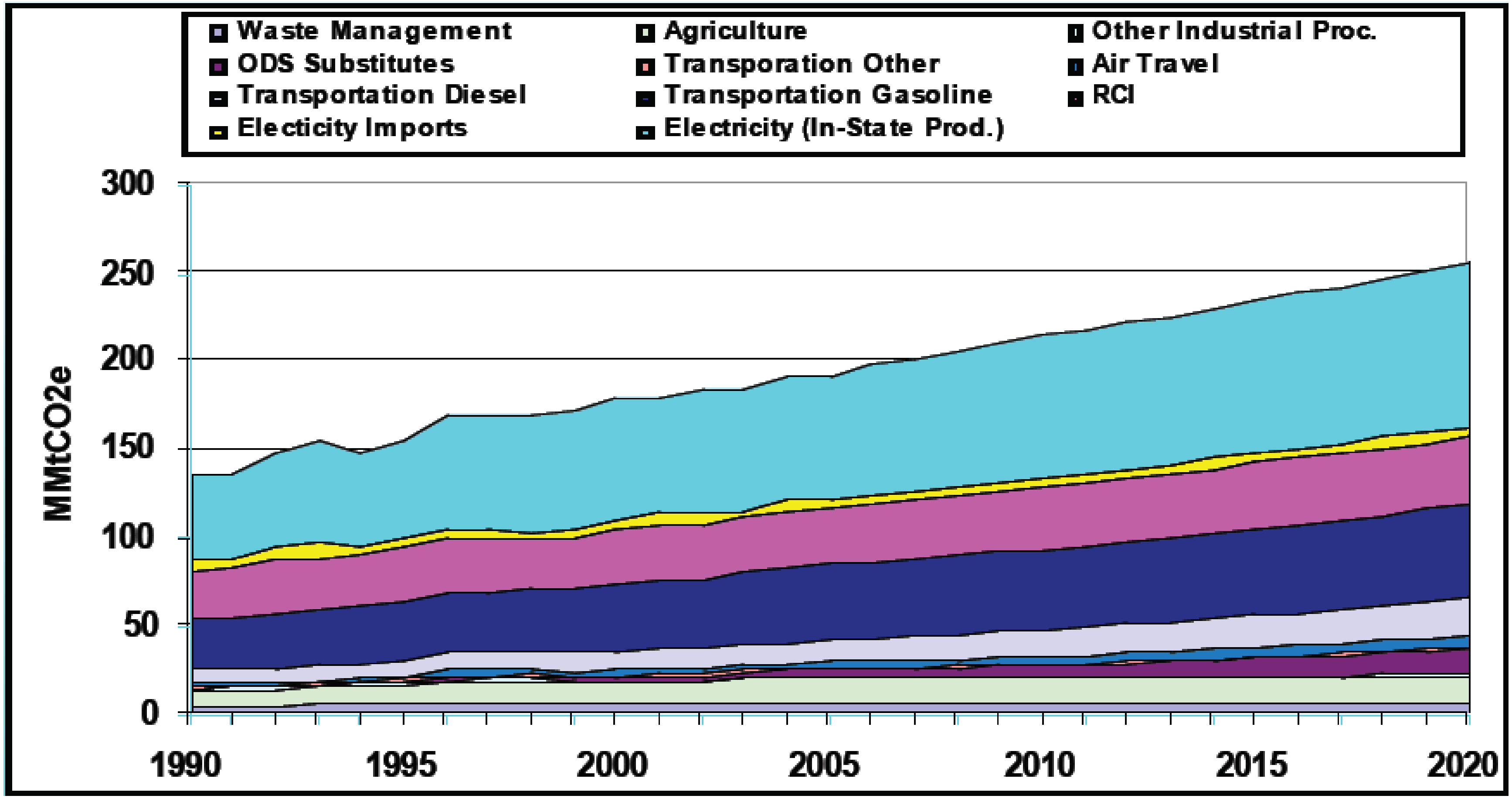


Figure 12. Relative Greenhouse Gas Reduction Potential in North Carolina for COPAG Options. (Millions of Metric Tons of Carbon Dioxide Gas Equivalents Reduced per Year). Source: COPAG 2008a.

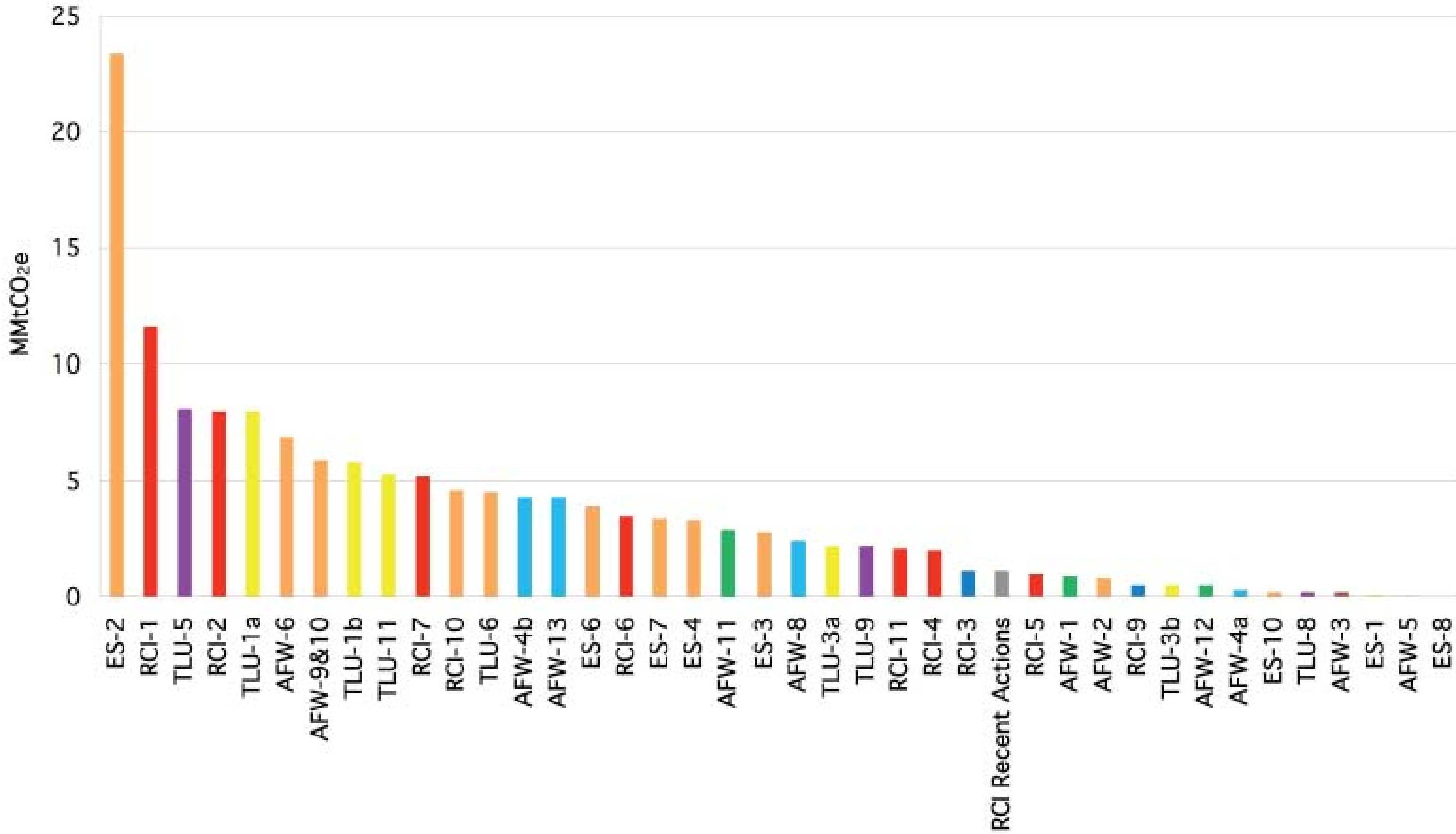


Figure 13. Relative Financial Savings or Cost of Greenhouse Gas Reduction Options for North Carolina.
(Dollars per Metric Ton of Carbon Dioxide Gas Equivalents Reduced; negative values indicate actions producing net savings.)
Source: COPAG 2008a.

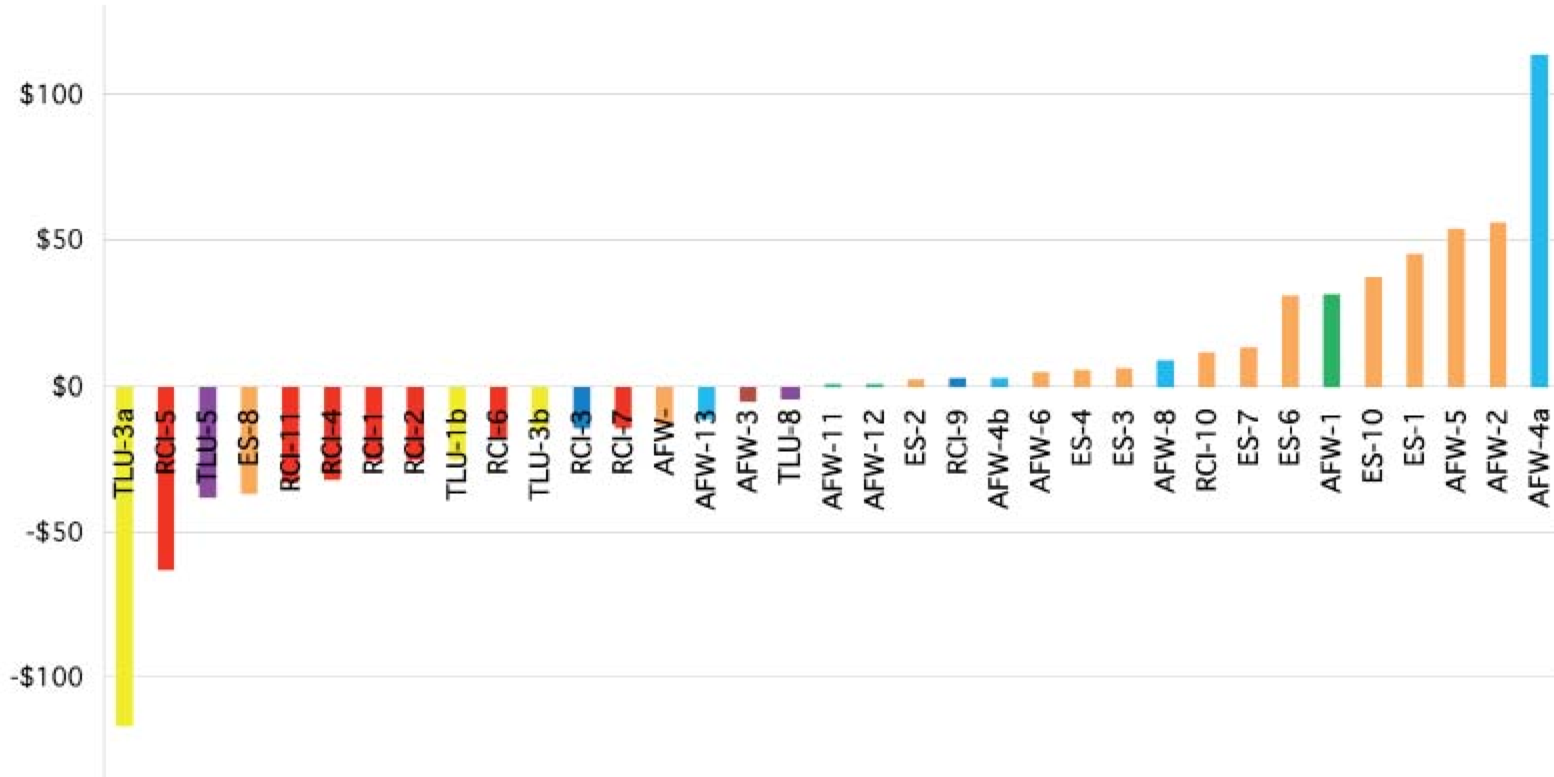
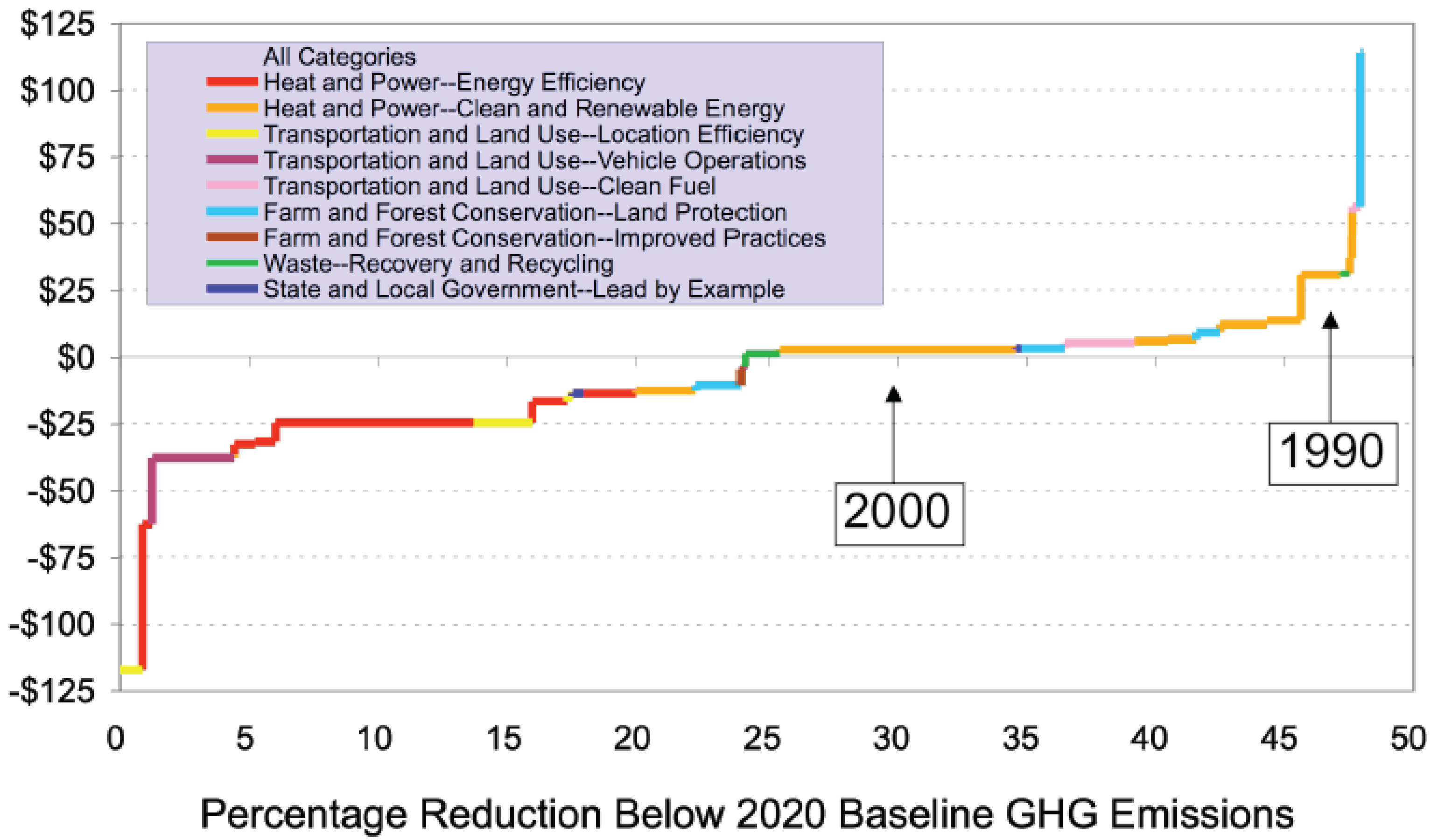


Figure 14. Incremental (Marginal) Cost per Metric Ton of Achieving Greenhouse Gas Reductions in North Carolina. Source: COPAG 2008a.



Notes: (1) negative costs indicate net financial savings of implementing option; (2) example--to achieve 1990 emissions level in 2020, a 47% reduction in emissions from unmitigated levels in 2020 would be required at a marginal cost of approximately $28 per ton.

Appendix

Letter from Senator Basnight.

NORTH CAROLINA GENERAL ASSEMBLY
PRESIDENT PRO TEMPORE
SENATOR MARC BASNIGHT
RALEIGH 27601-2808

July 23, 2008

Erskine Bowles
President
The University of North Carolina
910 Raleigh Road
Chapel Hill, N.C. 27514

Dear Erskine:

Global warming is an issue of utmost importance to our State and the world as a whole. As you know, there's a difference of opinion among the leading scientists about global warming and the risks it may pose to the environment. A few scientists believe that concerns over global warming are unwarranted while others worry that rising levels of carbon dioxide and methane could cause a widespread, significant change in the Earth's climate, including changes in precipitation and weather patterns, more intense and frequent tropical storms and hurricanes, and an increase in sea levels.

As a coastal state, North Carolina is very vulnerable to potential impacts of climate change. Sea level rise, stronger and more frequent tropical storms, and impacts to traditional fisheries are just a few of the potential impacts I have heard about that could have a great toll on our coastal areas. We are already facing great challenges in improving the health of our fisheries, protecting ocean and soundfront property from erosion, and ensuring the continuance of traditional recreational uses of our coastal areas. In addition, as a State in which farming is a major part of our economy, culture and history, the impact that a drought may have on our farmers and on our municipal water supplies is of grave concern. We must prepare ourselves for any new challenges we could face in the coming years because of global climate change.

Our outstanding University System is one of the strongest attributes of the State. We have the country's leading research scientists scattered Statewide, including experts in climate, geology, and marine science, many of whom are already studying global climate change and its potential effects. These experts can help us learn about where we stand with respect to global climate change, and where we could be in 50 years.

Please have the University's research scientists at the system's constituent campuses, where applicable, submit a report on global warming, including its causes, the timetable of expected effects or results, and what North Carolina and our nation as a whole can do to prevent global warming or mitigate further effects of it. Because scientists are influenced by the way they interpret data and by their broader views of the world, it is very important that the researchers at each campus do not consult with scientists at other campuses, but submit reports that are a result of their individual research and analyses. I also believe that each campus research team should submit its report to its chancellor for review, and that the report should be studied and openly discussed by each Board of Trustees at a regular meeting of the Board. After their review, the Trustees would formally transmit the report to the President's Office on or before December 15, 2008.

Thank you for your assistance with this matter. I look forward to reviewing the reports on global warming from our State's leading research scientists and to working on a way that North Carolina can do its part to mitigate the impact of global warming.

Sincerely,

Marc Basnight