FLORIDA AND CLIMATE CHANGE

THE COSTS OF INACTION

ELIZABETH A. STANTON
FRANK ACKERMAN

Tufts University
November 2007

EXECUTIVE SUMMARY

In July 2007, Governor Charlie Crist established greenhouse gas emission targets for the state of Florida, including an 80 percent reduction below 1990 levels by 2050. Although achieving this target will involve nontrivial expenditures, the *failure* to avert severe climate change would have even more severe consequences for Florida, in cold hard cash as well as human and ecological impacts.

Arguments against strong action to combat climate change often implicitly assume that inaction would be cost-free — that we can chose a future without significant impacts from climate change even if emissions of carbon dioxide and other greenhouse gases continue to grow unchecked. But the overwhelming scientific consensus now holds that this rosy assumption is simply wrong, and that the more greenhouse gases are released, the worse the consequences will be.

The stakes are high, the risks of disastrous climate impacts are all too real, and waiting for more information is likely to mean waiting until it is too late to protect ourselves and our descendants. If a bad outcome is a real risk — and run-away greenhouse gas emissions lead to a very bad outcome indeed — isn't it worth buying insurance against it? We buy fire insurance for our homes, even though any one family is statistically unlikely to have a fire next year. Young adults often buy life insurance, out of concern for their families, even though they are very unlikely to die next year. Taking action to reduce greenhouse gas emissions and control climate change is life insurance for the planet, and for the species that happen to live here, *Homo sapiens* included.

This report examines the potential costs to Florida if greenhouse gas emissions continue unchecked. To do so, we compare an optimistic scenario and a pessimistic one. Under the optimistic scenario — called "rapid stabilization" — the world begins taking action in the very near future and greatly reduces emissions by mid-century with additional decreases through the end of the century. Under the pessimistic scenario — called "business-as-usual" — greenhouse gas emissions continue to skyrocket throughout the 21st century. The business-as-usual scenario is based largely on the 2007 report of the Intergovernmental Panel on Climate Change (IPCC), a panel of more than 2,000 scientists whose consensus findings are approved by all participating governments, including the United States.

The cost of inaction — the difference between these two scenarios — is the human, economic, and environmental damage that may be avoidable with vigorous, timely actions to reduce greenhouse gas emissions. Many of these costs do not have dollar-and-cents price tags; increased deaths due to more intense hurricanes,[1] or the destruction of irreplaceable ecosystems by sea-level rise or temperature increases, transcend monetary calculation. Lives, and ways of life, are at stake; the most important damages are priceless.

Other costs, which do have explicit price tags, will be enormous. Among the many climate damages discussed in this report, we have estimated monetary values for four major categories:

- loss of tourism revenue, if the more unpleasant climate of the business-as-usual case makes Florida no more attractive year-round than it is today in its slowest season (autumn);
- increased hurricane damages, due to the greater frequency of Category 4 and 5 storms predicted by many climate scientists;
- the value of residential real estate that is at risk from sea-level rise; and
- increased costs of electricity generation as temperatures and air-conditioning requirements rise.

For just these four categories — loss of tourism revenue, increased hurricane damages, at-risk residential real estate, and increased electricity costs — the annual costs of inaction are projected to total $92 billion by 2050 and $345 billion by 2100, figures that respectively would constitute 2.8 percent and 5.0 percent of the state's projected Gross State Product (see table ES-1). If estimates were included for other sectors such as agriculture, fisheries, insurances, transportation, and water systems — to say nothing of ecosystem damages — the totals would be even larger.

Table ES-1. The Costs of Inaction

in billions of 2006 dollars, except percentages

	2025	2050	2075	2100
Tourism	$9	$40	$88	$167
Hurricanes	$6	$25	$54	$104
Electricity	$1	$5	$10	$18
Real Estate	$11	$23	$33	$56
Summary: Costs of Inaction				
in billions of 2006 dollars	$27	$92	$184	$345
as % of projected Florida GSP	1.6%	2.8%	3.9%	5.0%

FLORIDA'S FUTURE CLIMATE

Florida's future climate depends on overall emissions of greenhouse gases today and in the decades to come, and — because carbon dioxide persists in the atmosphere for a century or more — on the impacts of accumulated past emissions. We compare two scenarios: an optimistic *rapid stabilization case* and a pessimistic *business-as-usual case*. Neither, of course, is absolutely certain to occur; predicting long-term climate outcomes is difficult, especially for an area as small as a single state. But an enormous amount is now known about the likely effects of climate change; it is far too late to wait for more information before taking action. Based on the current state of knowledge, our scenarios represent plausible extremes: what is expected to happen if the world succeeds in a robust program of climate mitigation, versus what is expected to happen if we do very little. The difference between the two is the avoidable damage to Florida. It can be seen as the benefits of mitigation, or, from an opposite perspective, the costs of inaction.

Figure ES-1. Two Future Climate Scenarios for Florida

Rapid Stabilization Case

Lowest emissions under discussion today

- ✓ 50% reduction in current global emissions by 2050
- ✓ 80% reduction in current U.S. emissions by 2050

Plus, good luck in the outcomes of uncertain climate impacts

- ✓ Precipitation remains constant
- ✓ Hurricane intensity remains constant

Business-as-Usual Case

Steadily increasing emissions throughout this century

- ✓ Modeled on the high-end of the likely range of the IPCC's A2 scenario

Plus, bad luck in the outcomes of uncertain climate impacts

- ✓ Precipitation patterns changes (less rain in Florida)
- ✓ Hurricane intensity increases

Table ES-2. Two Future Climate Scenarios for Florida

	2025	2050	2075	2100
Annual Average Temperature *(in degrees Fahrenheit above year 2000 temperature)*				
Rapid Stabilization Case	0.6	1.1	1.7	2.2
Business-as-Usual Case	2.4	4.9	7.3	9.7
Sea-Level Rise *(in inches above year 2000 elevation)*				
Rapid Stabilization Case	1.8	3.5	5.3	7.1
Business-as-Usual Case	11.3	22.6	34.0	45.3

RAPID STABILIZATION CASE

With immediate, large-scale reductions in greenhouse gas emissions, and some good luck in the outcome of uncertain climate impacts, it is still possible for changes in the world's climate to remain relatively small. To keep the global average temperature from exceeding 2°F above year 2000 levels — an important threshold to avoid melting of the Greenland ice sheet and other dangerous climate impacts — we must stabilize the atmospheric concentration of carbon dioxide at 450 parts per million (ppm) or lower. In order to stabilize at 450 ppm, global emissions must reach one-half their current levels by 2050 and one-quarter of current levels by 2100. Because the United States' one-twentieth of world population bears responsibility for a full one-fifth of these emissions, U.S. emissions would have to decline 80 percent by 2050 in order to meet these goals.

In the rapid stabilization case, climate change has only moderate effects. Florida's annual average temperature increases 1°F by 2050 and 2°F by 2100, while sea levels rise by 3.5 inches by 2050 and 7 inches by 2100.

The rapid stabilization case also assumes the best results of the uncertain impacts of extreme weather: precipitation levels remain at historical levels, and extreme heat waves continue to be rare, brief events with manageable impacts in Florida. The frequency and intensity of hurricanes also remain at their historical levels, implying that in the course of an average 100 years Floridians can expect 73 hurricanes, of which 24 will be Category 3 or higher, and one year with four or more hurricanes.

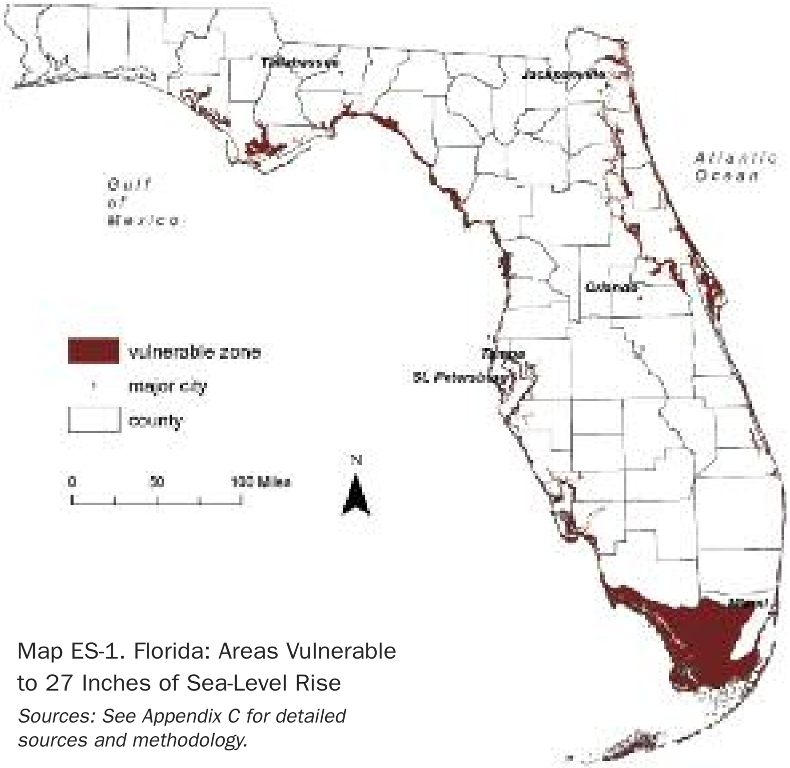
The rapid stabilization case is not a panacea. The state will still have to cope with its existing social and environmental problems, including water shortages, growing demands for electricity, the effects of hurricanes, the costs and constraints of Everglades restoration, and the impacts of ever-growing numbers of residents and visitors crowding into an already well-populated region. But at least climate change will not make these problems much worse — if we implement the rapid stabilization case by significantly reducing greenhouse gas emissions, starting soon and continuing throughout the century. Although Florida cannot itself ensure this outcome, its leadership can provide momentum toward the concerted actions that must be taken in the state, in the nation, and around the world.

BUSINESS-AS-USUAL CASE

And what if the world fails to achieve the needed reductions in emissions? The business-as-usual case assumes steadily increasing emissions, along with bad luck with the uncertain impacts of extreme weather. Specifically, it rests on the worst of what the IPCC calls its "likely" predictions for the A2 scenario, in which atmospheric concentrations of carbon dioxide exceed the critical 450 ppm threshold by 2030 and reach 850 ppm by 2100.

In the business-as-usual case, Florida's average annual temperatures will be 5°F higher than today in 2050 and 10°F higher in 2100. Sea-level rise will reach 23 inches by 2050, and 45 inches by 2100. The estimates for sea-level rise under the business-as-usual case diverge somewhat from the A2 scenario as presented in the most recent IPCC report, which — controversially — excludes some of the feedback mechanisms that could accelerate the melting of the Greenland and Antarctic ice sheets. This area of climate science has been developing rapidly, and the business-as-usual case estimates are based the most recent work of Stephan Rahmstorf, which appeared too late for inclusion in the IPCC report.

U.S. Geological Survey (USGS) maps and Geographic Information System (GIS) technology make it possible to show an approximation of Florida's coastline at 27 inches of sea-level rise, which is projected to be reached by around 2060 in the business-as-usual case. For simplicity, we refer to land area that would be inundated in Florida with 27 inches of sea-level rise as the year 2060 "vulnerable zone." Map ES-1, left, shows the entire state of Florida with the vulnerable zone in red. (More detailed maps are available in the main body of the report.)



Map ES-1. Florida: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: See Appendix C for detailed sources and methodology.

The vulnerable zone includes nine percent of Florida's current land area, or some 4,700 square miles. Absent successful steps to build up or otherwise protect them — which will be expensive and in some areas is likely impossible — these lands will be submerged at high tide. The vulnerable zone includes 99.6 percent, all but six square miles, of Monroe County (Florida's southwest tip and the Keys). It also includes 70 percent of Miami-Dade County, and 10 to 22 percent of 14 other counties. Almost one-tenth of Florida's current population, or 1.5 million people, live in this vulnerable zone; one-quarter of the affected population lives in Miami-Dade County.

The vulnerable zone also includes residential real estate now valued at over $130 billion, half of Florida's existing beaches, and 99 percent of its mangroves, as well as the following significant structures (among many others):

- 2 nuclear reactors;
- 3 prisons;
- 37 nursing homes;
- 68 hospitals;
- 74 airports;
- 82 low-income housing complexes;
- 115 solid waste disposal sites;
- 140 water treatment facilities;
- 171 assisted livings facilities;
- 247 gas stations
- 277 shopping centers;
- 334 public schools;
- 341 hazardous-material cleanup sites, including 5 Superfund sites;
- 1,025 churches, synagogues, and mosques;
- 1,362 hotels, motels, and inns; and
- 19,684 historic structures.

While efforts to protect at least some portions of the vulnerable zone will surely be taken, they may prove unavailing in some locales (and will be costly even where effective). As the Science and Technology Committee of the Miami-Dade County Climate Change Task Force recently noted, "the highly porous limestone and sand substrate of Miami-Dade County (which at present permits excellent drainage) will limit the effectiveness of widespread use of levees and dikes to wall off the encroaching sea."

Transportation infrastructure in Florida will be damaged by the effects of sea-level rise, particularly in combination with storm surges. Docks and jetties, for example, must be built at optimal heights relative to existing water levels, and rapid sea-level rise would force more frequent rebuilding. Roads, railroads, and airport runways in low-lying coastal areas all become more vulnerable to flooding as water levels rise, storm surges reach farther inward, and coastal erosion accelerates. Even roads further inland may be threatened, since road drainage systems become less effective as sea levels rise. Many roads are built lower than surrounding land to begin with, so reduced drainage capacity will increase their susceptibility to flooding during rainstorms.

Other important climate and environmental changes in the business-as-usual case include:

- **Hurricane intensity will increase**, with more Category 4 and 5 hurricanes occurring as sea-surface temperatures rise. Greater damages from more intense storms come on top of the more severe storm surges that will result from higher sea levels.
- **Rainfall will become more variable**, with longer dry spells, and will decrease by 10 percent overall, contributing to drought conditions.
- **Heat waves will become more severe and more common**, with new record temperatures and a gradual decline in nighttime cooling. The average "heat index" (temperature combined with humidity) in summer will 15–20 percent higher in much of the state. Miami will become several degrees hotter than today's Bangkok (probably the world's hottest, most humid major city at present), and daily highs in many Florida cities will exceed 90 degrees nearly two-thirds of the year.
- **Ocean temperature and acidity levels will increase**, causing coral bleaching and disease, with harmful effects on the many marine species that depend on coral ecosystems.

These effects will have significant impacts on Florida's industries and infrastructure.

Tourism, one of Florida's largest economic sectors, will be the hardest hit as much of the state's wealth of natural beauty — sandy beaches, the Everglades, the Keys — disappears under the waves. As noted in Table ES-1, costs of inaction are projected to total $9 billion by 2025, $40 billion by mid-century, and $167 at the end of the century.

Agriculture, forestry and fisheries will also suffer large losses. Well-known and economically important Florida products like orange juice and pink shrimp may become a thing of the past. And even as higher temperatures and more-irregular rainfall increase the demand for crop and livestock irrigation, freshwater supplies will become scarcer as saltwater intrusions contaminate them.

The **insurance industry** also will be affected by climate change, as it seeks to adjust to a new, riskier Florida. Florida's residents and businesses will continue to struggle to find affordable insurance coverage.

High temperatures will increase demands for **electricity**, primarily to supply air conditioning. The extra power plants and the electricity they generate are not cheap; the annual costs of inaction are $5 billion in 2050 and $18 billion in 2100, as reported in Table ES-1 above.

The same temperature increases will also degrade the performance of power stations and transmission lines, making them operate less efficiently; partly as a result, every additional degree Fahrenheit of warming will cost consumers an extra $3 billion per year by 2100.

Increased demand for electricity also has severe implications for water resources, as all coal, oil, gas, and nuclear power plants must be cooled by water.

The business-as-usual case will only intensify Florida's looming **water** crisis in other ways as well. Under hotter and drier conditions, agricultural and domestic users will need more water; the survival of irrigated winter agriculture in the state will be threatened. The one potentially vast source of fresh water, desalination of ocean water, is an expensive and technically complex process. The first large-scale facility to attempt ocean water desalination in the state, at Tampa Bay, has been plagued by technical delays and cost overruns. If enough desalination plants could be made available, the additional water needs under the business-as-usual case would add several billion dollars a year to the costs of inaction.

In both climate scenarios for Florida, climate change is likely to have important effects on the economic damages and deaths that result from **hurricanes**; in the business-as-usual case, these damages and deaths will be on a much larger scale. The cost of inaction attributable to greater hurricane damages, $25 billion by 2050 and $104 billion by 2100, as reported in Table ES-1, includes the effects of coastal development and higher population levels, sea-level rise as it impacts on storm surges, and greater storm intensity. In addition, the cost of inaction in the business-as-usual case includes an average of 19 additional deaths from hurricanes per year in 2050 and 37 additional deaths in 2100; these numbers are in addition to the deaths expected under the rapid stabilization case.

Finally, the business-as-usual case has important, and in some cases irreversible, impacts on priceless natural **ecosystems**. Hotter average temperatures, rising sea levels, changes in precipitation, increased storm damages, and increased ocean acidity and temperatures will all cause visible harm to well-known parks and other natural areas. Wholesale extinctions and ecosystem destruction are unavoidable in the business-as-usual future, and the strategy that could save the most species and ecosystems — allowing wetlands to migrate, taking over what are now dry lands — is extremely unlikely to occur, at least on a wide scale. Natural ecosystems in every corner of Florida will be affected.

And nowhere will the impacts be more devastating than in the **Everglades**. Rising sea levels under the business-as-usual case cause water to encroach 12 to 24 miles into the broad low-lying area of the Everglades, leaving the lower Everglades completely inundated. As large parts of the Everglades wetlands are converted into open water, nurseries and shelter for many fish and wildlife species will be lost. The 10°F increase in air temperature expected by 2100 will draw species northward out of the Everglades, but if current drylands are protected with seawalls this migration will be thwarted, and species will disappear from Florida, or in some cases become extinct.

These impacts on industry, infrastructure, and ecosystems — the cost of inaction — vastly outweigh expenditures on renewable energy, energy-efficient transportation and appliances, and other measures that are required to reduce emissions. If Florida makes the necessary efforts to achieve its ambitious target of 80 percent reduction in emissions by 2050, and the rest of the world follows suit with significant and immediate action, we can achieve the "rapid stabilization future." If, on the other hand, decisive climate action fails, we may well find ourselves living in the "business-as-usual future."

To reject a potential 10°F increase in temperature and 3 feet or more in sea-level rise this century, Floridians — and residents of other U.S. states and of other nations — must commit to beginning in the very near future to take steps to substantially reduce global greenhouse gas emissions. The only other available option is to place a very risky bet — that somehow, despite the most current scientific knowledge, business-as-usual emissions will not trigger a climate catastrophe. If we gamble and lose, we and our children cannot walk away from the consequences.

ACKNOWLEDGMENTS

This report was much more than a two-person job. We would like to thank

Muriel Calo, Abby Lindsay, Kimberly Lucas, Matt Riddle, Helen Scharber, and Jordan Winkler for their long hours of outstanding research assistance;
James Shyne and Barbara Parmenter for the GIS analysis and map creation;
Jeremy Fisher, Lucy Johnston, and Bruce Biewald at Synapse Energy Economics for the electricity system analysis;
University of Florida political scientist Walter (Tony) Rosenbaum for repeatedly helping us understand the state's many unique features, and UF botanist Stephen Mulkey for thoughtful comments;
Clare Kazanski and Jane Tenenbaum for design and production of the final report; and
Karen Florini at Environmental Defense, for first suggesting the project and supporting it throughout.

This study was supported by a grant from Environmental Defense. Opinions and conclusions expressed here, along with any errors that may remain, are the sole responsibility of the two authors.

Elizabeth A. Stanton
Frank Ackerman

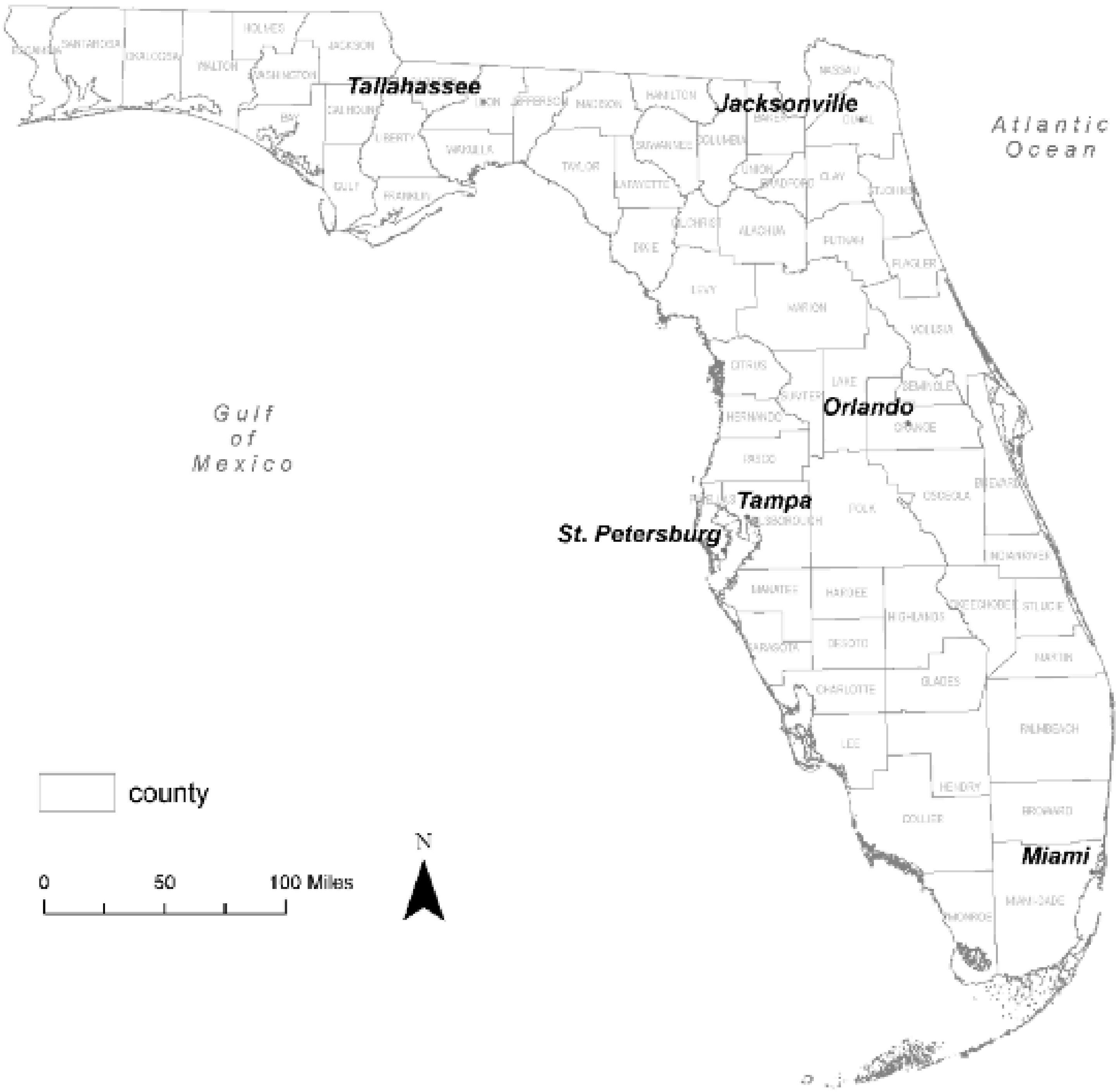
Global Development and Environment Institute, Tufts University
http://ase.tufts.edu/gdae/
and
Stockholm Environment Institute–US Center
http://www.sei-us.org

CONTENTS

List of Figures

List of Tables

List of Maps



Map 1. Florida Counties Boundaries.

I. INTRODUCTION

In July 2007, Governor Charlie Crist established greenhouse gas emission targets for the state of Florida.[2] Florida joins California, other states in the West and the Northeast, and countries around the world in supporting vigorous efforts to control climate change. In an era of droughts, heat waves, and violent storms, it is no longer possible to deny the reality of climate change, or the need for an effective response.[3]

Governor Crist's initiatives call for an 80 percent reduction in greenhouse gas emissions by 2050, an ambitious target that has been adopted by several other states and that is advocated by many scientists and civic groups.[4] Implementation of this target will require spending a noticeable amount of money. Indeed, opposition to climate policy increasingly focuses on the supposed damage to the economy that will result from reducing emissions.

But while doing something about climate change will have nontrivial costs, this report demonstrates that doing *nothing* about climate change will itself have immense costs — both monetarily and otherwise.

The stakes are high, the risks of disastrous climate impacts are all too real, and waiting for more information is likely to mean waiting until it is too late to protect ourselves and our descendants. If a bad outcome is a real risk — and run-away greenhouse gas emissions lead to a very bad outcome indeed — isn't it worth buying insurance against it? We buy fire insurance for our homes, even though any one family is statistically unlikely to have a fire next year. Young adults often buy life insurance, out of concern for their families, even though they are very unlikely to die next year. Taking action to reduce greenhouse gas emissions and control climate change is life insurance for the planet, and for the species that happen to live here, *Homo sapiens* included.

Florida's efforts at reining in greenhouse gas emissions are a forward-thinking, responsible contribution to resolving a global environmental crisis, but these actions are not enough to assure a stable climate for Florida. The effects of greenhouse gases are universal, like our shared atmosphere; it doesn't matter where they are emitted, the whole world feels the effects. Unfortunately, we cannot know how much climate-transforming carbon dioxide and other greenhouse gases will be emitted into the atmosphere in the coming decades. Neither can we be sure of the exact effects that these gases will have on the world's climate or ocean levels. Given a prediction about future emissions, climate scientists are able to forecast the range of probable climatic effects with some certainty, but exactly where we will fall in that range cannot be precisely specified.

UNDERSTANDING UNCERTAINTY IN CLIMATE PROJECTIONS

Does climate science now tell us that we are uncertain about what will happen next, or that things are certain to get worse? Unfortunately, the answer seems to be yes to both.

The problem is that different levels of uncertainty are involved. No one knows how to predict next year's weather, and the year-to-year variation is enormous: there could be many hurricanes, or almost none; unusually hot temperatures, or unusually mild; more rain than average, or less. But on average, scientists are increasingly certain that we are headed towards worsening conditions.

By way of analogy, imagine that you are drawing a card from a standard deck of 52 playing cards. You have no way to predict exactly what card you will draw, but you know a lot about the odds. There is exactly one chance in four of drawing a diamond, but any individual card may be a diamond, a club, a heart, or a spade. If you draw again and again, the average number on your cards (counting aces as one, and face cards as 11, 12, and 13) will be seven, but any individual draw could be much higher or lower than the average.

Now imagine that the dealer changes some cards in the deck after each draw. If the dealer removes all of the 6, 7, and 8 cards, the *average* number you draw will remain the same, but your chance of getting an extremely high or extremely low number in any one draw will increase. If instead the dealer adds extra cards with high numbers (face cards), the average number that you draw will increase.

Climate change is like drawing a card from a changing deck. There is no way of predicting the next card you will draw from a well-shuffled deck. But the message of climate science is that the deck of climate possibilities is changing in disturbing directions, both toward more variability and more extreme outcomes, and toward worsening averages. The same logic applies in reverse: reducing greenhouse gas emissions will not guarantee better weather next year, but it will ensure that in the future we and our descendents will be able to draw from a better deck.

Will social policy succeed in reining in the emission of greenhouse gases, not just in Florida, but around the world? Will we face good luck or bad in the uncertain impacts of climate change? Even as Florida does its part by reducing greenhouse emissions, it is still necessary for Floridians to prepare for an unknown future climate. This report describes two plausible climate futures: an optimistic scenario, called the rapid stabilization case, in which total world emissions of greenhouse gases are greatly reduced beginning in the near future, and a pessimistic scenario, called the business-as-usual case, in which global emissions steadily increase throughout the 21st century. The two scenarios also reflect differing assumptions about the consequences of those emission levels.

The cost of inaction — the difference between the best and worst likely climate change impacts — is the human, economic, and environmental damages that are avoidable with vigorous, timely actions to reduce greenhouse gas emissions. This cost vastly outweighs the expenditures on renewable energy, energy-efficient transportation and appliances, and other measures that are required to reduce emissions. If Florida makes the necessary efforts to achieve its ambitious target of 80 percent reduction in emissions by 2050, and the rest of the world follows suit with significant and immediate action, we can achieve the "rapid stabilization future." If, on the other hand, decisive climate action fails, we may well find ourselves living in the "business-as-usual future."

Read on for the details: the business-as-usual scenario described here is an offer you have to re-

fuse. To reject a potential 10°F increase in temperature and 3 feet or more in sea-level rise this century, Floridians — and residents of other U.S. states and of other nations — must commit to beginning in the very near future to take steps to substantially reduce global greenhouse emissions. The only other available option is to place a very risky bet — that somehow, despite the most current scientific knowledge, business-as-usual emissions will not trigger a climate catastrophe. If we gamble and lose, we and our children cannot walk away from the consequences.

II. FLORIDA'S FUTURE CLIMATE

Florida's future climate depends on overall emissions of greenhouse gases today and in the decades to come, and — because carbon dioxide persists in the atmosphere for a century or more — on the impacts of accumulated past emissions. We compare two scenarios: an optimistic rapid stabilization case and a pessimistic business-as-usual case. Neither, of course, is absolutely certain to occur; predicting long-term climate outcomes is difficult, especially for an area as small as a single state. But an enormous amount is now known about the likely effects of climate change; it is far too late to wait for more information before taking action. Based on the current state of knowledge, our scenarios represent plausible extremes: what is expected to happen if the world succeeds in a robust program of climate mitigation, versus what is expected to happen if we do very little. The difference between the two is the avoidable damage to Florida. It can be seen as the benefits of mitigation, or, from an opposite perspective, the costs of inaction.

The first climate future described in this report is the best that we can hope for: relatively small climate impacts that develop slowly. This scenario — the rapid stabilization case — is an optimistic estimate of what will happen if global emissions of greenhouse gases are cut in half by mid-century with further reductions thereafter. (Because cumulative per capita emissions in developed countries, particularly the U.S., vastly exceed those in the developing world, significantly greater reductions are needed from developed countries, on the order of 80 percent by 2050). The rapid stabilization case combines the lowest imaginable emissions with very good luck in uncertain climate impacts: By 2050, Florida's average annual temperature will rise just 1°F and sea-levels will rise a mere 3.5 inches.

The state will still have to cope with its existing environmental problems, including water shortages, Everglades restoration, and the impacts of ever-growing numbers of residents and visitors crowding into an already well-populated region. (Millions of people agree: Florida is a nice place to visit, and they *do* want to live there.) In this optimistic climate future, hurricanes continue

UNDERSTANDING THE COST OF INACTION

The *cost of inaction* is the damage that society can avoid by engaging in ambitious, large-scale reductions of greenhouse gas emissions, beginning in the near future and continuing throughout the century. In this report, we estimate the cost of inaction as the costs of the pessimistic “business-as-usual case” minus the costs of the optimistic “rapid stabilization case.”

The *rapid stabilization* scenario portrays the best future that we can hope for: greenhouse gas emissions are significantly reduced in the next 10 to 20 years, and continue a steady decline thereafter; as a result, the effects of climate change develop slowly and are relatively small. The rapid stabilization case, while not ideal, is a future that we can live with. Indeed, the moderate effects of climate change described in the rapid stabilization scenario are now all but unavoidable, given that many greenhouse gases persist in the atmosphere for decades and will continue to warm the planet.

In contrast, the *business-as-usual* scenario will be very hard to live with — but we and our children may be left with no other choice if greenhouse gas emissions continue to grow throughout the 21st century. In the business-as-usual future, the effects of climate change are very serious indeed: in Florida, a 10°F increase in the annual average temperature and 45 inches of sea-level rise.

The difference between these scenarios is the cost of inaction: the increased price that we will pay, and the damages that will occur, if we fail to quickly act to reduce greenhouse gas emissions, over and above the (much smaller) climate impacts that take place in the rapid stabilization scenario. The cost of inaction includes lost revenues of affected industries and the replacement of property damaged by rising waters and more intense storms. The business-as-usual scenario — and the costs that come with it — are still avoidable, but only with immediate action on a local, national, and global scale.

to strike the state at the same rate as in the past, and precipitation levels remain constant. It should be emphasized that this climate scenario is simply not possible absent significant reductions in greenhouse gas emissions, in the United States and around the world.

The second future climate scenario, or business-as-usual case, assumes emissions that continue to increase over time unchecked by public policy (often referred to as “business-as-usual” emissions), combined with bad luck in uncertain climate impacts. The business-as-usual case is represented by the high end of the “likely” range of the Intergovernmental Panel on Climate Change (IPCC) A2 scenario, which projects an increase in average annual temperature of 5°F and an increase in sea levels of 18 to 28 inches by 2050 in Florida.

The business-as-usual case goes beyond the IPCC’s A2 projections to incorporate unfortunate outcomes in the hardest-to-predict areas of climate science. Florida’s rainfall will decrease by 5 to 10 percent; hurricanes will be more intense and heat waves more common. In this pessimistic climate future, the challenges of Florida’s population and economic growth, and its current environmental problems, become far more difficult and expensive to address. Some of the costs have price tags attached, with meaningful monetary costs: loss of a fraction of tourism revenue, or of vulnerable beach front real estate, will cost the state many billions of dollars. Some of the costs are priceless, beyond monetary valuation: more deaths as a result of more powerful hurricanes, or the irreversible destruction of unique ecosystems.

It is important to note that this pessimistic future climate is by no means a worst possible case. Greenhouse gas emissions could increase even more quickly, as represented by the IPCC’s A1FI scenario. Nor is the high end of the IPCC’s “likely” range a worst-case: in IPCC terminology, the “likely” range extends from the 17th to the 83rd percentile, so 17 percent of the full range of A2 projections were even worse than the highest “likely” case. Instead, the business-as-usual case is offered as the probable outcome of current trends in emissions plus some bad luck in the way our climate responds to those emissions.

Both of these future climate scenarios use the same population and economic growth projections. Florida’s population was 17 million in 2005, or about 6 percent of the U.S. population. The U.S. Census Bureau forecasts that Florida’s population will grow 2 percent a year through 2030, reaching 29 million, and then 0.8 percent per year through 2050, reaching 33 million.[5] Given the difficulty of projecting population change more than a half century into the future, we make

Rapid Stabilization Case

Lowest emissions under discussion today
✓ 50% reduction in current global emissions by 2050
✓ 80% reduction in current U.S. emissions by 2050
Plus, good luck in the outcomes of uncertain climate impacts
✓ Precipitation remains constant
✓ Hurricane intensity remains constant

Business-as-Usual Case

Steadily increasing emissions throughout this century
✓ Modeled on the high-end of the likely range of the IPCC's A2 scenario
Plus, bad luck in the outcomes of uncertain climate impacts
✓ Precipitation patterns changes (less rain in Florida)
✓ Hurricane intensity increases

Figure 1. Two Future Climate Scenarios for Florida

the conservative assumption that Florida's population will remain constant at 33 million from 2050 to 2100. Still, this is almost twice the current population.

In 2005, Florida's Gross State Product (GSP, the state-level equivalent of GDP) was just under $7 billion, and GSP per capita (a figure often used as an estimate of the state's per capita income) was $40,000.[6] Based on long-run U.S. growth rates, we project that Florida's GSP per capita will increase at a rate of 2.2 percent through 2030, slightly lower than its current annual growth rate. From 2030 through 2100, we assume a reduction to a conservative 1.5 percent annual increase.[7] Using these projections, Florida's GSP per capita will be $73,000 in 2030 and $207,000 in 2100, both in 2006 dollars.

Growth at this pace will place significant strain on the environment, with or without additional climate impacts. In some Florida neighborhoods, real estate development already seems close to filling the available space for new residential construction, but millions of additional units will be needed state-wide to house the growing population of the next few decades. Fresh water supplies are already being used at or beyond a sustainable level, but more people moving to Florida means more demand for water. Rapid economic growth has meant increasing demands for electrical generation in Florida, a trend likely continue as the state economy races through the twenty-first century; the air-conditioning demands resulting from higher average temperatures will increase pressure on the state's electrical infrastructure.

Sustaining Florida's growth, in other words, will be an ongoing economic and environmental challenge, even in the optimistic rapid stabilization case. The business-as-usual case, adding even more serious climate constraints, will make these already challenging problems much more difficult and expensive to solve.

RAPID STABILIZATION CASE

With immediate, large-scale reductions in greenhouse gas emissions, and some good luck in the outcome of uncertain climate impacts, it is still possible for changes in the world's climate to remain relatively small. If we want a real chance of keeping the global average temperature from exceeding 2°F above year 2000 levels — an important threshold to prevent complete melting of the Greenland ice sheet and other dangerous climate impacts — we must stabilize the atmospheric concentration of carbon dioxide at 450ppm or lower.[8] In order to stabilize at 450ppm, global emissions of greenhouse gases must begin to decline by 2020, reaching one-half their current levels by 2050 and one-quarter of current levels by 2100. Because the United States' one-twentieth of world population bears responsibility for a full one-fifth of these emissions, U.S. emissions would have to decline 80 percent by 2050 in order to meet these goals (Chameides 2007). (Florida's objective of reducing greenhouse gas emissions 80 percent by 2050 is consistent with that goal.)

Of the six main scenarios that the IPCC describes as "equally probable"(Schenk and Lensink 2007), B1 has the lowest emissions, with atmospheric concentrations of carbon dioxide reaching 550 ppm in 2100. The concentration levels and temperatures of the rapid stabilization case are below the low end of the likely range presented in B1. Because there is no IPCC scenario as low as the rapid stabilization case, we have approximated the low end of the likely temperature range for atmospheric stabilization at 450 ppm of carbon dioxide using data from the Stern Review.[9]

Projected average annual temperature increases for Florida are reported in Table 1. In the rapid stabilization future, Florida's annual average temperature increases 1°F by 2050 and 2°F by 2100.

Table 1. Average Annual Temperature Increase: Rapid Stabilization Case

in degrees Fahrenheit above year 2000 temperature

	2025	2050	2075	2100
Florida	0.6	1.1	1.7	2.2
Global Mean	0.4	0.9	1.3	1.8

Source: IPCC Chapters 5, 10, and 11 (Intergovernmental Panel on Climate Change 2007b); Stern Review (Stern 2006); and authors' calculations.
Note: Florida data is the average of the U.S. East and Caribbean regions.

The concentration of greenhouse gases in the atmosphere will affect the climate of every city, state, and country somewhat differently. Florida's expected annual average temperature increase in the rapid stabilization case is very close to the global average, while most of the rest of the United States will experience larger temperature increases. (This is because climate change has a greater effect on temperatures closer to the poles, and less toward the equator.) The average annual temperatures that we report are an average of day and nighttime temperatures for every day of the year. A small change in annual average temperatures can mean a big difference to a local climate. Table 2 shows projected average annual temperatures for major Florida cities in the rapid stabilization case.

Table 2. Major Cities Average Annual Temperatures: Rapid Stabilization Case

in degrees Fahrenheit

Florida City	Historical	2025	2050	2075	2100
Pensacola	67.7	68.3	68.8	69.4	69.9
Jacksonville	68.0	68.6	69.1	69.7	70.2
Orlando	72.3	72.9	73.4	74.0	74.5
Tampa	72.3	72.9	73.4	74.0	74.5
Miami	75.9	76.5	77.0	77.6	78.1
Key West	77.8	78.4	78.9	79.5	80.0

Source: 2006 city temperatures from NOAA National Climatic Data Center (National Oceanic & Atmospheric Administration 2007b); annual average temperatures increase, IPCC Chapters 5, 10, and 11 (Intergovernmental Panel on Climate Change 2007b); Stern Review (Stern 2006); and authors' calculations.

In the best-case, rapid stabilization scenario, sea levels will still rise in the United States and around the world. Even if it were possible to stabilize the atmospheric concentration of carbon dioxide well below the target of 450 ppm, sea-levels would continue to rise gradually for centuries, because the ocean volume would continue to expand from the last 100 years of temperature increase (warmer water occupies more space than cooler water). The rapid stabilization case includes the IPCC's lowest projection for global mean sea-level rise, an increase of 3.5 inches by 2050 and 7 inches by 2100 (see Table 3).[10]

The rapid stabilization case also assumes the best results of the uncertain impacts of extreme weather: precipitation levels remain at historical levels, and extreme heat waves continue to be rare, brief events with manageable impacts in Florida. The frequency and intensity of hurricanes also remain at their historical levels. Over the last 156 years, 279 recorded hurricanes have hit the mainland United States, a little less than two hurricanes per year. If this long-term trend continues, the U.S. can expect 18 hurricanes per decade, of which 6 will be major hurricanes, reaching Category 3 or higher. Historically, four out of every ten U.S. hurricanes, and the same proportion of major hurricanes, make landfall in Florida (Blake et al. 2007).

Table 3. Annual Average Sea-Level Rise: Rapid Stabilization Case

in inches above year 2000 elevation

	2025	2050	2075	2100
Sea-Level Rise	1.8	3.5	5.3	7.1

Source: IPCC Chapters 5, 10, and 11 (Intergovernmental Panel on Climate Change 2007b).

These are long-term averages that do not reflect rare events like the 2004 and 2005 hurricane seasons. In each of those years, four hurricanes made landfall in Florida: Charley, Frances, Ivan, and Jeanne in 2004; and Dennis, Katrina (which hit the Florida panhandle), Rita and Wilma in 2005. Six of these hurricanes made their landfall in Florida at Category 3 or higher. There have been only 30 years since 1851 in which more than one hurricane struck Florida: and only two years, 2004 and 2005, when four hurricanes hit the state. Based on these trends, in the rapid stabilization future, in the course of an average 100 years Floridians will experience 73 hurricanes, of which 24 will be Category 3 or higher, and one year with four or more hurricanes.

BUSINESS-AS-USUAL CASE

Climatologists project a range of outcomes that could result from business-as-usual (meaning steadily increasing) emissions. The business-as-usual case is the worst of what the IPCC calls its "likely" projections for the A2 scenario. In this scenario, atmospheric concentrations of carbon dioxide exceed the critical 450 ppm threshold by 2030 and reach 850 ppm by 2100 (Intergovernmental Panel on Climate Change 2007b). In our business-as-usual case, the worst temperature and sea-level rise impacts likely to result from the A2 greenhouse gas concentrations are combined with pessimistic assumptions about the hardest-to-predict consequences of rising temperatures: more intense hurricanes, less rainfall, more severe heat waves, and large increases in ocean temperatures and acidification.

Temperatures rise

In the business-as-usual case, average annual temperatures increase four times as quickly as in the rapid stabilization case. Florida's annual average temperature will be 5°F higher than today in 2050 and 10°F higher in 2100. Table 4 and Table 5 show the progression of these temperatures over time. Even more important to Floridians than the change in *average* temperatures is the range of potential temperature extremes, which are much harder for climatologists to forecast. The most recent estimate of extreme temperatures for the United States was conducted in 2001 by the U.S. Global Change Research Program (USGCRP), using a scenario with slightly lower emissions than the IPCC A2. The USGCRP estimated that Florida's average July heat index (a measure of perceived heat, or temperature combined with humidity) will be an sizzling 15 to 20°F higher at the end of the century (U.S. Global Change Research Program 2001).

Table 4. Annual Average Temperature Increase: Business-As-Usual Case

in degrees Fahrenheit above year 2000 temperature

	2025	2050	2075	2100
Florida	2.4	4.9	7.3	9.7
Global mean	2.2	4.3	6.5	8.6

Source: IPCC Chapters 5, 10, and 11 (Intergovernmental Panel on Climate Change 2007b).
Note: Florida data is the average of the U.S. East and Caribbean regions.

Table 5. Major Cities Annual Average Temperatures: Business-As-Usual Case

in degrees Fahrenheit

Florida City	Historical	2025	2050	2075	2100
Pensacola	67.7	70.1	72.6	75.0	77.4
Jacksonville	68.0	70.4	72.9	75.3	77.7
Orlando	72.3	74.7	77.2	79.6	82.0
Tampa	72.3	74.7	77.2	79.6	82.0
Miami	75.9	78.3	80.8	83.2	85.6
Key West	77.8	80.2	82.7	85.1	87.5

Source: 2006 city temperatures from NOAA National Climatic Data Center (National Oceanic & Atmospheric Administration 2007b); annual average temperatures increase, IPCC Chapters 5, 10, and 11 f(Intergovernmental Panel on Climate Change 2007b).

To give these temperatures a context in which to understand them, Table 6 compares Florida cities' temperatures in the business-as-usual future to current temperatures in cities around the world. In 2100, Pensacola and Jacksonville climates will be as hot as that of today's Key West. A century from now, Orlando and Tampa will have the climate of today's Acapulco, Mexico, where the coldest month's average temperature is 79°F. Miami and Key West will have average annual temperatures several degrees hotter than Bangkok, Thailand's 83°F. Bangkok — perhaps the hottest, most humid major city in the world — has daytime temperatures that range from the high 80s to mid-90s throughout the year, while overnight lows range from the high 70s in the hottest months to the high 60s in the coolest months.[11] By 2100, Miami and Key West will be even hotter.

Or Key West would be that hot, if it were still above water. The business-as-usual case also includes rising sea levels.

Table 6. Major Cities Annual Average Temperatures in 2100: Business-As-Usual Case

in degrees Fahrenheit

	Historical Average	Predicted in 2100	Is like . . . today
Pensacola	67.7	77.4	Key West
Jacksonville	68.0	77.7	Key West
Orlando	72.3	82.0	Acapulco, Mexico
Tampa	72.3	82.0	Acapulco, Mexico
Miami	75.9	85.6	no comparable city
Key West	77.8	87.5	no comparable city

Source: Authors' calculations.

Sea-level rise

The estimates for sea-level rise under the business-as-usual case diverge somewhat from the A2 scenario as presented in the 2007 IPCC report. The authors of the IPCC 2007 made the controversial decision to exclude one of the many effects that combine to increase sea levels — the risk of accelerated melting of the Greenland and Antarctic ice sheets caused by feedback mechanisms such as the dynamic effects of meltwater on the structure of ice sheets. Without the effects of these feedback mechanisms on ice sheets, the high end of likely range of A2 sea-level rise is just 20 inches, down from approximately 28 inches in the IPCC 2001 report (Intergovernmental Panel on Climate Change 2001b).

Accelerated melting of ice sheets were excluded from the IPCC's projections not because they are thought to be unlikely or insignificant — on the contrary, these effects could raise sea-levels by hundreds of feet over the course of several millennia — but because they are extremely difficult to estimate.[12] Indeed, the actual amount of sea-level rise observed since 1990 has been at the very upper bound of prior IPCC projections that assumed high emissions, a strong response of temperature to emissions, *and* included an additional ad hoc amount of sea-level rise for "ice sheet uncertainty"(Rahmstorf 2007).

This area of climate science has been developing rapidly in the last year, but, unfortunately, the most recent advances were released too late for inclusion in the IPCC process (Kerr 2007a; b; Oppenheimer et al. 2007). A January 2007 article by Stephan Rahmstorf in the prestigious peer-reviewed journal *Science* proposes a new procedure for estimating melting ice sheets' difficult-to-predict contribution to sea-level rise (Rahmstorf 2007). For the A2 emissions scenario on which our business-as-usual case is based, Rahmstorf's estimates of 2100 sea-level rise range from 35 inches, the central estimate for the A2 scenario, up to 55 inches, Rahmstorf's high-end figure including an adjustment for statistical uncertainty. For purposes of this report, we use an intermediate value that is the average of his estimates, or 45 inches by 2100; we similarly interpolate an average of Rahmstorf's high and low values to provide estimates for dates earlier in the century (see Table 7).

Table 7. Annual Average Sea-Level Rise: Business-As-Usual Case

in inches above year 2000 elevation

	2025	2050	2075	2100
Sea-Level Rise —"most likely" estimate	8.9	17.7	26.6	35.4
Sea-Level Rise —"worst possible" estimate	13.8	27.6	41.3	55.1

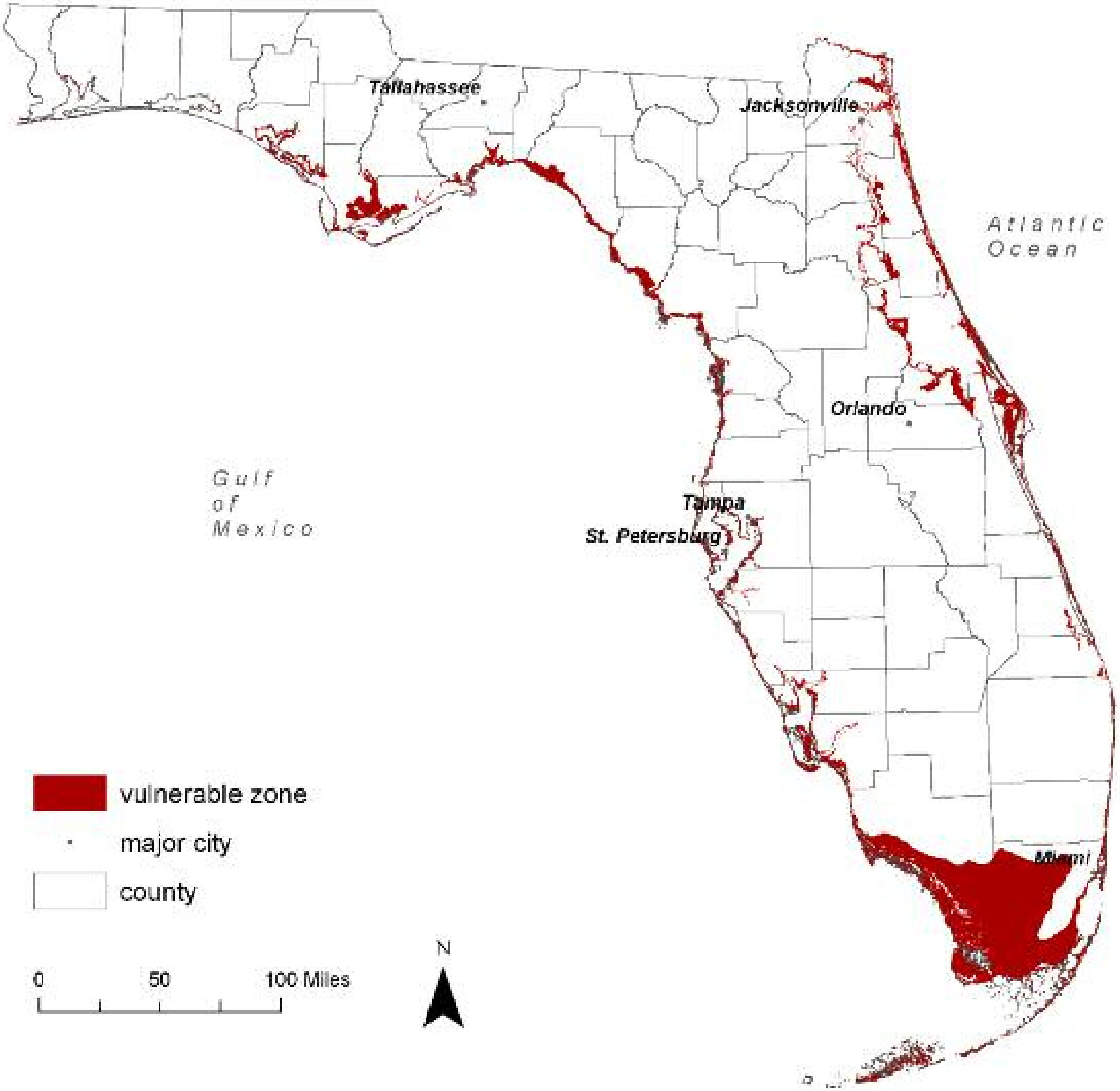
Source (Rahmstorf 2007); authors' calculations assuming a constant rate of change throughout the century.
Note: Slightly different amounts of sea-level rise are expected in different locations around the world. For Florida, sea-level rise is expected to be at approximately the global average; see IPCC Chapters 5, 10, and 11 (Intergovernmental Panel on Climate Change 2007b).

To quantify the area that may be affected by sea-level rise during the coming decades, we use U.S. Geological Survey (USGS) maps and Geographic Information System (GIS) technology that makes it possible to show a rough approximation of Florida's coastline at 27 inches of sea-level rise (see Appendix C for technical description of our GIS data). In the business-as-usual scenario using the Rahmstorf projections, this amount of sea-level increase would be reached by about 2060. We refer to land area that would be inundated in Florida with 27 inches of sea-level rise as the year 2060 "vulnerable zone."

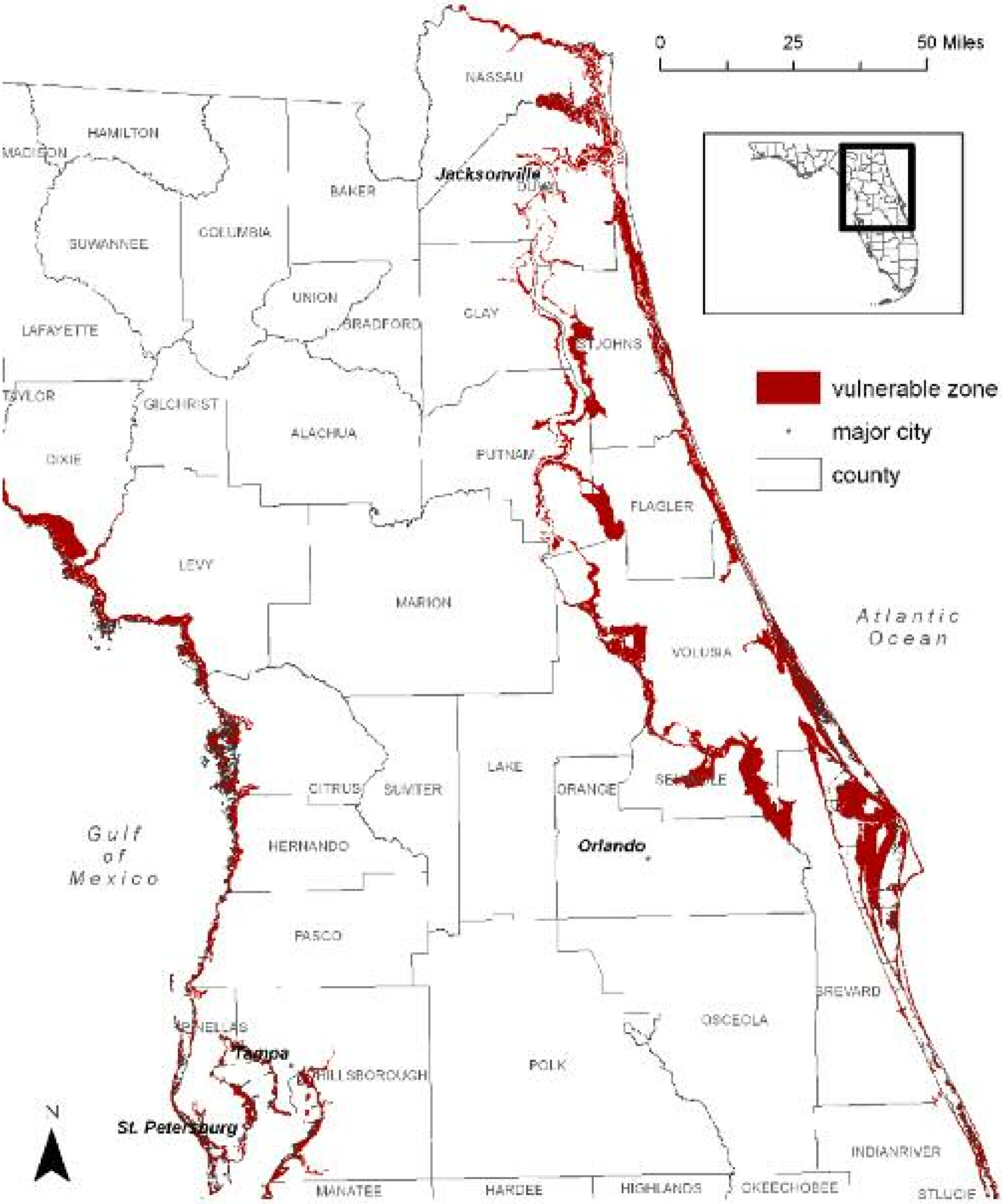
Note that while the exact *pace* of sea-level rise is not precisely quantifiable, it is virtually certain that this *amount* of sea-level rise will occur at some point if greenhouse gas emissions continue unchecked. In other words, the question is not whether Florida will need to cope with this much sea-level rise, but rather when it will need to do so.

Map 2, right, shows the entire state of Florida with the vulnerable zone in red. Map 3, Map 4, and Map 5 show the vulnerable zone for the North Peninsula, South Peninsula, and Panhandle areas of Florida in more detail. For example, if business-as-usual emissions continue, and nothing is done to build up or protect flooding lands, by 2060 nine percent of Florida's current land area — 4,700 square miles — will be in the zone vulnerable to sea-level rise, that is, submerged at high tide.

Even the best available elevation maps are limited by data collection errors and as yet unsurveyed changes in landscape. It should be emphasized that the exact borders of Florida's "vulnerable zone," that is, the area vulnerable to the first 27 inches of sea-level rise, cannot be known with certainty. The maps and data presented here are a best estimate based on the USGS dataset, and should be examined at a scale no smaller than the neighborhood or the small town. At the edges of the vulnerable zone, no map would be accurate enough to show whose backyard will be flooded.

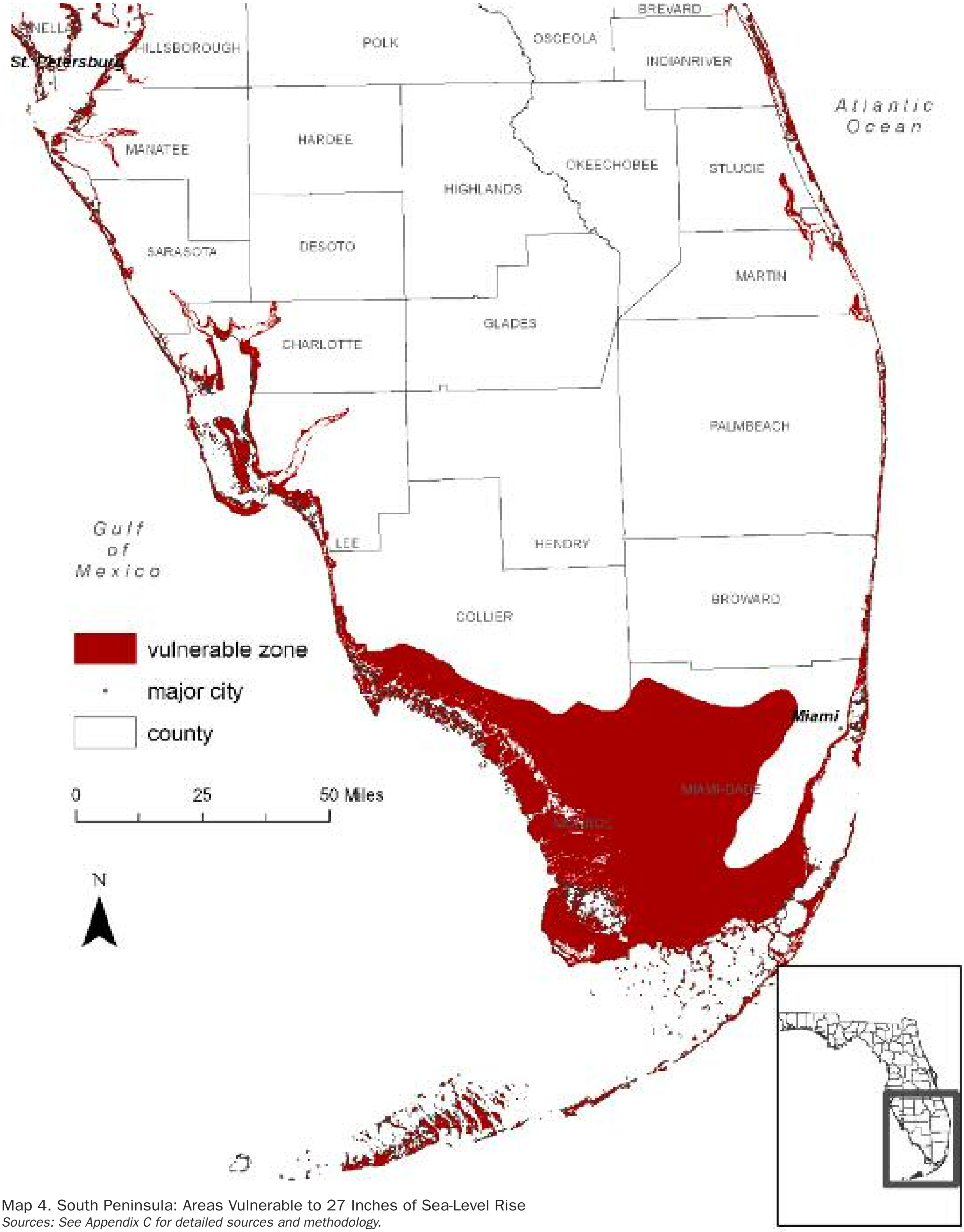


Map 2. Florida: Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.



Map 3. North Peninsula: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: See Appendix C for detailed sources and methodology.



Map 4. South Peninsula: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: See Appendix C for detailed sources and methodology.

Map 5. Panhandle: Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.

Of course, it is likely that adaptation measures will be taken to hold back the sea for many developed or otherwise valuable properties. But as the Science and Technology Committee of the Miami-Dade County Climate Change Task Force pointed out, "the highly porous limestone and sand substrate of Miami-Dade County (which at present permits excellent drainage) will limit the effectiveness of widespread use of levees and dikes to wall off the encroaching sea." (Miami-Dade County Climate Change Task Force 2007)

Coastal lands around the state are threatened by sea-level rise, including developed areas, natural ecosystems, and agricultural lands. Two-thirds of the total vulnerable land area is currently wetlands (marshes, tidal flats, swamps, mangroves, and wetland forests) that would be converted into open water, too deep for current vegetation to survive. For example, one-third of Florida's marshlands will be flooded, as will 99 percent of the state's mangroves. The 1,100 square miles of dryland in the vulnerable area consist primarily of developed land and dryland forest. In addition, more than half of Florida's beach land area will be flooded. Table 8 reports the amount of land area in the vulnerable zone by land use. (For a further breakdown of the vulnerable area by land cover and county, see Appendix A.)

While some areas of Florida will far more affected than others, 40 of the state's 67 counties have at least 1 square mile in the vulnerable zone, and 16 counties have at least 10 percent of their land in this category (see Table 9). In Monroe County — Florida's southwest tip and the Keys — 99.6 percent of land area will be under water by 2060; that's all but 6 square miles. So too will 70 percent of Miami-Dade County, and 20 percent of Franklin and Gulf Counties on the Florida panhandle.

Almost one-tenth of Florida's current population — 1.5 million people — live in this vulnerable zone; one-quarter of the affected population lives in Miami-Dade County. Thirty-three counties currently have 1,000 or more people living in the vulnerable zone. Table 10 lists the 10 counties that currently have more than 50,000 people living in the vulnerable zone. In Monroe County, only 4,000 people live in those 6 square miles of what will remain dry land after 27 inches of sea-level rise; the remaining 95 percent of the county's current population live in areas that will (absent successful countermeasures) be inundated by 2060.

Table 8. Selected Land Area Vulnerable to 27 Inches of Sea-Level Rise by Land Use

	Vulnerable Zone	
	square miles	percentage of vulnerable area (%)
Agriculture	52	1.2%
Developed	433	10.0%
Forest	409	9.5%
Mangroves	862	20.0%
Marsh and Tidal Flats	1,827	42.3%
Other Swamp and Forested Wetland	618	14.3%
Pasture	7	0.2%
Sandy Beach	29	0.7%
Scrub, Grasslands, Prairie, Sandhill	78	1.8%
TOTAL	4,315	100.0%

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Table 9. Land Area Vulnerable to 27 Inches of Sea-Level Rise by County

	Vulnerable Land Area (share of total land area)	Vulnerable Land Area (square miles)	Total Land Area (square miles)
Florida Total	**28.7%**	**4,048**	**14,080**
Monroe	99.6%	979	983
Miami-Dade	69.2%	1,354	1,956
Franklin	21.7%	118	544
Gulf	19.7%	109	555
Brevard	18.5%	187	1,009
Collier	18.2%	370	2,026
Pinellas	17.9%	50	280
St.Johns	17.5%	107	611
Volusia	16.6%	185	1,109
Lee	15.4%	124	804
Seminole	13.3%	41	307
Bay	11.6%	89	768
Duval	11.2%	87	776
Dixie	10.7%	75	704
Taylor	10.6%	111	1,042
Wakulla	10.5%	64	607

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

More than three-quarters of Florida's population, 444 people per square mile, live in coastal counties, while just 170 people per square mile live in inland counties, the differences partially due to large cities along the coast. In recent years, inland counties have been growing faster than shoreline counties; inland counties' population and housing stock grew 42 percent from 1990 to 2004 (Kildow 2006b; a). As sea-level rise increases, Florida's coastal population will move inland, increasing population density and transforming the landscape of the relatively rural and undeveloped interior of the state.

Sea-level rise may also have a less-obvious effect on Florida, by triggering a surge of "environmental refugees" from nearby Caribbean nations. Climate change has the potential to uproot people from their homes and their communities as villages and cities are flooded, and traditional livelihoods disrupted, especially in developing countries. Sea-level rise, desertification, greater variability in weather patterns, and unpredictable rainfall are expected to create environmental refugees around the world, and the Caribbean Basin is no exception (Bates 2002; Dlugolecki 2005; Salehyan 2005). According to a 1999 International Red Cross report, 50 million people worldwide may be displaced by the effects of climate change by 2010, making it a more significant source of refugees worldwide than violent conflict and political persecution (Roc 2006).

Table 10. Population Living in Areas Vulnerable to 27 Inches of Sea-Level Rise

	Vulnerable Population (share of total population)	Vulnerable Population	Total Population
Florida Total	**9.4%**	**1,503,153**	**15,982,378**
Miami-Dade	16.8%	379,511	2,253,362
Pinellas	16.5%	152,413	921,482
Volusia	20.8%	92,267	443,343
Brevard	18.7%	89,060	476,230
Monroe	94.9%	75,549	79,589
Duval	9.2%	71,843	778,879
Lee	15.7%	69,036	440,888
Palm Beach	6.1%	68,822	1,131,184
Broward	3.8%	60,920	1,623,018
Collier	22.3%	55,970	251,377

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Island nations in the Caribbean Sea would be devastated by 3 feet of sea-level rise, or more, in this century, together with higher temperatures, and more intense storms (Myers 1993; 2002; Intergovernmental Panel on Climate Change 2007b). In countries throughout the Caribbean, making a living will become harder. Most developing nations will find it difficult to pay for expensive adaptation measures like an extensive levee system, hurricane-rated construction methods, air conditioning, and an electrical system that can bear the power demands of an air conditioner in every home and business (Simms and Reid 2006). Florida's close proximity to a number of developing island nations could make it a desirable destination for environmental refugees from the Caribbean. Even if aggressive implementation of immigration controls limits the number of such refugees who actually settle in Florida, those measures themselves have serious social and ethical implications and are far from cost-free.

Greater hurricane intensity

In the business-as-usual scenario, hurricane intensity will increase, with more Category 4 and 5 hurricanes occurring as sea-level temperatures rise. Greater damages from more intense storms would come on top of the more severe storm surges that will result from higher sea levels (Henderson-Sellers et al. 1998; Scavia et al. 2002; Anthes et al. 2006; Webster et al. 2006; Intergovernmental Panel on Climate Change 2007b).

Tropical storms and hurricanes cause billions of dollars in economic damages and tens or even hundreds of deaths each year along the U.S. Atlantic and Gulf coasts. Tropical storms, as the name implies, develop over tropical or subtropical waters. To be officially classified as a hurricane, a tropical storm must exhibit wind speeds of at least 74 miles per hour. Hurricanes are categorized based on wind speed, so that a relatively mild Category 1 hurricane exhibits wind speeds of 74 to 95 miles per hour, while an extremely powerful Category 5 hurricane has wind speeds of at least 155 miles per hour (Williams and Duedall 1997; Blake et al. 2007).

Atlantic tropical storms do not develop spontaneously. Rather, they grow out of other disturbances, such as the "African waves" that generate storm-producing clouds, ultimately seeding the hurricanes that hit Florida. Sea-surface temperatures of at least 79°F are essential to the development of these smaller storms into hurricanes, but meeting the temperature threshold is not enough. Other atmospheric conditions, such as dry winds blowing off the Sahara or the extent of vertical wind shear — the difference between wind speed and direction near the ocean's surface and at 40,000 feet — can act to reduce the strength of Florida-bound hurricanes or quell them altogether (Nash 2006).

While climate change is popularly associated with more frequent and more intense hurricanes (Dean 2007a), within the scientific community there are two main schools of thought on this subject. One group emphasizes the role of warm sea-surface temperatures in the formation of hurricanes and points to observations of stronger storms over the last few decades as evidence that climate change is intensifying hurricanes. The other group emphasizes the many interacting factors responsible for hurricane formation and strength, saying that warm sea-surface temperatures alone do not create tropical storms.

The line of reasoning connecting global warming with hurricanes is straightforward; since hurricanes need a sea-surface temperature of at least 79°F to form, an increase of sea-surface temperatures above this threshold should result in more frequent and more intense hurricanes (Landsea et al. 1999). The argument that storms will become stronger as global temperatures increase is closely associated with the work of several climatologists, including Kerry Emanuel, who finds that rising sea-surface temperatures are correlated with increasing wind speeds of tropical storms and hurricanes since the 1970s, and Peter J. Webster, who documents an increase in the number and proportion of hurricanes reaching categories 4 and 5 since 1970 (Emanuel 2005; Webster et al. 2005).

Climatologist Kevin E. Trenberth reports similar findings in the July 2007 issue of *Scientific American,* and states that, "Challenges from other experts have led to modest revisions in the specific correlations but do not alter the overall conclusion [that the number of Category 4 and 5 hurricanes will rise with climate change]"(Trenberth 2007). While these scientists project increasing storm intensity with rising temperatures, they neither observe nor predict a greater total number of storms. Thus the average number of tropical storms that develops in the Atlantic each year would remain the same, but a greater percentage of these storms would become Category 4 or 5 hurricanes.

Scientists who take the opposing view acknowledge that sea-surface temperatures influence hurricane activity, but emphasize the role of many other atmospheric conditions in the development of tropical cyclones, such as the higher wind shears that may result from global warming and act to reduce storm intensity. In addition, since hurricane activity is known to follow multidecadal oscillations in which storm frequency and intensity rises and falls every 20 to 40 years, some climate scientists — including Christopher W. Landsea, Roger A. Pielke, and J. C. L. Chan — argue that Emanuel and Webster's findings are based on inappropriately small data sets (Landsea 2005; Pielke 2005; Chan 2006). Pielke also finds that past storm damages, when "normalized" for inflation and current levels of population and wealth, would have been as high or higher than the most damaging recent hurricanes (Pielke and Landsea 1998; Pielke 2005). Thus, he infers that increasing economic damages are likely due to more development and more wealth, not to more powerful storms.

Recent articles in the *New York Times* (Dean 2007a) and the *Smithsonian Magazine* (Nash 2006) present both sides of the debate. It is difficult to say how much of the scientific community falls into either camp, although the latest IPCC report calls increasing intensity of hurricanes "likely" as sea-surface temperatures increase (Intergovernmental Panel on Climate Change 2007b). A much greater consensus exists among climatologists regarding other types of future impacts on hurricanes. Even if climate change were to have no effect on storm intensity, hurricane damages are very likely to increase over time from two causes. First, increasing coastal development will lead to higher levels of damage from storms, both in economic and social terms. Second, higher sea levels, coastal erosion, and damage of natural shoreline protection such as beaches and wetlands will allow storm surges to reach farther inland, affecting areas that were previously relatively well protected (Anthes et al. 2006).

In our business-as-usual case, the total number of tropical storms stays the same as today (and the same as the rapid stabilization case), but storm intensity — and therefore the number of major hurricanes — increases. The hurricane impacts section, later in this report, includes estimates of likely hurricane damages and deaths in both scenarios.

Less rainfall, more drought

Florida's 2006 annual rainfall was 20 percent less than the historical average, and drought conditions continued through the first half of 2007. Across the state, rainfall for spring 2007 (March through May) averaged only 4.5 inches, compared to an average 10.4 inches of rainfall usually received in the spring (National Oceanic & Atmospheric Administration 2007b). As of mid-2007, water levels in Lake Okeechobee were at a record low (Florida Department of Agriculture and Consumer Services 2007d; Revkin 2007). The historical average annual rainfall for Florida is much greater than the 2006 level, because over the last century years of excessive rainfall have balanced out drought years (see Table 11).

Table 11. Florida State Average Rainfall

in inches, three-month totals

	Dec–Feb	Mar–May	Jun-Aug	Sept–Dec	Annual Total
Historical Average (1896–2006)	9	10	22	13	54
2006 Actual	9	5	19	10	43
High-impact case: 2100 predicted	8	9	20	12	49

Source NOAA National Climatic Data Center (National Oceanic & Atmospheric Administration 2007b).
Note: IPCC Chapters 10 and 11 (Intergovernmental Panel on Climate Change 2007b) project the upper range of precipitation decrease for Florida to be 10 percent. The 2100 projection shown here is a 10 percent reduction to the historical average.

In the business-as-usual case, precipitation levels decrease by 10 percent annually, contributing to drought conditions. This change may seem small, especially in comparison to the current drought, but this precipitation decrease is a projected average across many years. A decrease in rainfall of 10 percent represents a long-term tendency toward drought for Florida, year after year.

Not everyone agrees that Florida is headed for lower levels of rainfall, with or without climate change. What matters most, however, is not the annual total of precipitation, but the prevalence of drought. Paradoxically, increased rainfall could be accompanied by an increase in drought conditions: more rain could fall in hurricanes and sudden downpours, while hotter temperatures could lead to faster and more complete drying out between rainfalls. Most of the consequences of decreased rainfall discussed in this report are equally applicable to a scenario where total rainfall does not decline, but drought conditions increase.

In addition to obvious impacts on water supplies, persistent droughts also tend to exacerbate wildfires. In an average year, nearly 6,000 wildfires occur in Florida, burning 175,000 acres. Before 2007, the worst Florida fire season on record was 1998, when over 400,000 acres burned (Harrison 2004); as of mid-2007, more than 520,000 acres had burned. Most wildfires take place at the

end of the winter dry season, when both surface waters and underground aquifers are at their most depleted (Beckage and Platt 2003; Florida Department of Agriculture and Consumer Services 2007d).

Though this report does not include quantitative projections of future increases in wildfires associated with our business-as-usual scenario, an increase in drought conditions due to climate change would very likely increase the acreage burned by wildfires each year — and would likewise increase associated economic costs. The cost of wildfires can be substantial. According to a USDA study, the 1998 Florida wildfires cost at least $600 million, which included $12 million in destroyed houses, businesses, cars and boats; the cost of canceling the Daytona 500 and a steep decline in tourism; and a 100 percent increase in emergency-room visits for asthma and bronchitis. The study did not include lost worker productivity and wages, the indirect costs of road closures, or the loss of uninsured property (Butry et al. 2001).

More severe heat waves

In the business-as-usual case, heat waves become more severe and more common, with the chance of exceeding current record temperatures growing 100-fold by mid-century and a gradual disappearance of the cooling nighttime temperatures that dampen the health impacts of extremely high temperatures (Easterling et al. 1997; Kalkstein and Greene 1997; Easterling et al. 2000; Kalkstein 2000; U.S. Global Change Research Program 2001; Stott et al. 2004; Epstein and Mills 2005).

Unlike many other parts of the United States, incidents of multiple deaths in a heat wave are almost unheard of in Florida due to the prevalence of air conditioning in homes and businesses, as well as climate-appropriate architectural styles (Patton 2002). Deaths and illness from heat waves may stay at low historical levels even as Florida's average temperature and temperature extremes climb, but only if the state's air conditioning and electricity supply keep up with increasing temperatures and heat index values. Moreover, severe heat waves may well decrease the attractiveness of outdoor tourism attractions that play an important role in Florida's economy even in the summer months, such as going to the beach, fishing, scuba diving, and visiting theme parks.

Ocean warming and acidification

The world's oceans act as a massive heat sink, storing well over half of the energy from the sun that enters the global climate system. As the atmosphere warms, so do the oceans. In the business-as-usual scenario, with air temperatures increasing by 10°F, sea surface temperatures for Florida will increase by several degrees. This temperature increase will have a serious impact on many ocean species, and will further exacerbate stresses on Florida's coral reefs. Even moderate warming causes "bleaching" as the coral lose their colorful symbiotic algae; if the stress continues long enough, the reef will to start to die off.

Historically, large-scale coral bleaching has occurred in connection with extreme El Nino weather events. El Nino events occur when wind and ocean currents in the equatorial Pacific Ocean shift, resulting in a temporary increase in sea surface temperatures in certain areas. As a result of the 1998 El Nino — the largest in recorded history — 16 percent of the world's reefs were destroyed in less than 9 months. In some regions more than 95 percent of coral organisms were killed (Wilkinson 2000). In the Florida Keys, coral bleaching events have occurred several times in the past two decades. In 1997 and 1998, most likely in connection with the El Nino, large-scale bleaching occurred (Wilkinson 2004).[13]

It is clear from these El Nino-related bleaching events that corals are very sensitive to changes

in water temperature. Bleaching may occur with a temperature increase of just a few degrees. Under the business-as-usual scenario, sea surface temperatures are likely to rise by several degrees by 2100, surpassing the temperature limits of many of the coral species that inhabit the area. As bleaching events become more frequent and severe, the coral marine ecosystem supporting fisheries will be disrupted (National Wildlife Federation and Florida Wildlife Federation 2006). Globally, coral reefs support an estimated 0.5 to 2 million species of marine organisms, including 25 percent of all known marine fish species.

Independent of its warming-related impact, carbon dioxide (the most prevalent anthropogenic greenhouse gas) also affects coral reefs by decreasing the availability of dissolved calcium carbonate, the chemical building block for coral skeletons. Specifically, as atmospheric concentrations of carbon dioxide increase, more carbon dioxide dissolves into seawater, where it forms carbonic acid. Because calcium carbonate is alkaline, the carbonic acid tends to dissolve it. Already, global average surface ocean pH is 0.1 units lower than pre-industrial values (the more acidic the water, the lower the pH).

In the business-as-usual case, the Atlantic Ocean and Caribbean Sea will experience pH reductions of 0.35 over the next century. Because the pH scale is logarithmic (i.e., each full digit indicates a 10-fold change in acidity), this reflects more than a doubling of acidity. This increase in acidity will lead to reductions in calcification rates of coral and some other hard-shelled marine organisms (Gattuso et al. 1998; Kleypas et al. 1999; Caldeira and Wickett 2003). The effects of reduced calcification in coral are weaker skeletons, slower growth rates, and an increased susceptibility to erosion. Coral reefs that have seen physical damage, especially from human activities such as dredging, will be experience more severe effects (Kleypas et al. 1999).

Both warming and acidification will have detrimental effects on Florida's coral reefs. Bleaching events due to ocean warming are likely to gain the most attention as they produce the most visible destruction, whereas decreases in calcification occur over longer periods of time and are harder to observe. Both warming and acidity-related stresses increase vulnerability to coral diseases such as white and black band disease. Ultimately the overall damage will be a combination of both effects: warming episodes will lead to the expulsion of symbiotic algae and potential coral death, while acidification will hamper re-growth. In areas where physical damage from erosion or human activities has already increased vulnerability, the effects will be most pronounced.

Impacts from acidification are not limited to coral. Marine organisms that build calcium carbonate shells (called "bio-calcification"), including plankton, constitute much of the base of the entire marine food web. Loss of these organisms has the potential to disrupt the entire aquatic food chain, threatening not only invertebrates and fishes but also marine mammals and sharks. In addition, larger crustaceans (e.g., shrimp, lobsters, and crabs) and echinoderms (e.g., starfish, sea urchins, and sea cucumbers) will have increasing difficulty forming their own calcium-carbonate shells. For some organisms, extinction thresholds are likely to be crossed this century. The calcifying phytoplankton and zooplankton that are food for many larger marine species will also suffer with acidification (Intergovernmental Panel on Climate Change 2007b).

III. ECONOMIC IMPACTS: INDUSTRIES

Rapid growth in population and income per capita means that Florida business will be booming in the rapid stabilization case. With much more serious impacts from climate change in the business-as-usual case, some businesses will be unable to operate at their full capacity, while other industries may close up shop in Florida altogether. Tourism, one of Florida's largest economic sectors, will be the hardest hit as much of the state's wealth of natural beauty — sandy beaches, the Everglades, the Keys — disappears under the waves. Agriculture and fisheries will also suffer large losses. Well-known and economically important Florida products like orange juice and pink shrimp may become a thing of the past. The insurance industry also will be affected by climate change, as it seeks to adjust to a new, riskier Florida; Florida's residents and businesses will continue to struggle to find affordable insurance coverage.

TOURISM

Each year visitors make 85 million trips to Florida's scenic beaches, rich marine ecosystems and abundant amusement parks, staying for an average of five nights per trip. Of these trips to Florida, 78 million are taken by domestic U.S. travelers — an astounding one trip per year for every fourth U.S. resident — and 7 million trips by international visitors, one-third of whom are Canadian. A further 13 million Florida residents take recreational trips within Florida, and many more travel on business within the state, or participate in recreational activities near their homes (VISIT FLORIDA 2007a; b).

In 2006, almost a tenth of the state economy — 9.6 percent, or $65 billion, of Florida's gross state product (GSP) — came from tourism and recreation industries including restaurants and bars; arts, entertainment and recreation facilities; lodging; air transportation; and travel agencies.

An additional $4 billion was collected in sales tax on these purchases and $500 million in the "bed tax" charged by some counties on stays in hotels, motels, vacation rental condos, and campgrounds (VISIT FLORIDA 2007a; b).

Tourism projections: Rapid stabilization case

Tourism is the second biggest contributor to Florida's economy, after real estate. As GSP grows six-fold over the next century, we project that in the rapid stabilization case tourism and its associated taxes will remain a steady 9.6 percent of total GSP. Under these assumptions, Florida's tourism industry will bring in $317 billion in revenues in 2050. Today, approximately 980,000 people make their living in Florida's tourism and recreation sector, 6 percent of the state's population. If the same share of state residents is still employed in tourism in 2050, 1.9 million Floridians will draw paychecks from restaurants, amusement parts, hotels, airports, and travel agencies (VISIT FLORIDA 2007a; b). The gradual climate change under the rapid stabilization case should have little impact on tourism.

Tourism projections: Business-as-usual case

In the business-as-usual case, the future of Florida's tourism industry is clouded. Florida's average temperature increases 2.5°F by 2025, 5°F by 2050, and 10 °F by 2100. In January, warmer temperatures are unlikely to scare off many tourists, but in July and August — when the average high temperature on Miami Beach will rise from 87°F to 97°F over the next century, and the July heat index (temperature and humidity combined) will increase by 15 to 20°F — Florida's already hot and sticky weather is likely to lose some of its appeal for visitors.

Sea levels in 2050 will have risen by 23 inches, covering many of Florida's sandy beaches. In theory, these beaches could be "renourished" by adding massive amounts of sand to bring them up to their former elevation — the price-tag for this costly project is discussed below — or the new coastline could be converted to beach recreation use, but only if residential and commercial properties in the zone most vulnerable to sea-level rise are not "shored up" by sea-walls or levees. With 45 inches of sea-level rise over the next century, a Florida nearly devoid of beaches in 2100 is a very real possibility.

Many of the marine habitats that bring divers, snorkelers, sportfishers, birdwatchers and campers to Florida will also be destroyed or severely degraded over the course of the next century. Sea-level rise will drown the Everglades and with it the American crocodile, the Florida panther, and many other endangered species. As Florida's shallow mangrove swamps and seagrass beds become open water — unless wetland ecosystems are permitted to migrate inland by allowing Florida's dry lands to flood — manatees and other aquatic species that rely on wetlands for food, shelter and breeding grounds will die out. Similarly, Florida's coral reefs will bleach and die off as ocean temperature and acidity increases. Tourists are unlikely to come to Florida to see the dead or dying remnants of what are today unique treasures of the natural world.

Estimates of the direct impact of hurricane damage on Florida's economy are dealt with in a separate section of this report, but there are also important indirect effects on Florida's reputation as a vacation destination. As the intensity of storms increases in the business-as-usual case, fewer visitors are likely to plan trips to Florida, especially during the July-to-November hurricane season. The possibility of being caught in a storm or forced to evacuate to a storm shelter will become a greater concern for tourists as the effects of climate change are featured more frequently on the evening news.

Under these conditions, Florida's tourism industry is almost certain to suffer; the exact decline in future revenues and employment is, however, nearly impossible to estimate with any certainty.

The calculations that follow are, therefore, a rough estimate based on a broad interpretation of existing data.

Because Florida receives just 19 percent of its tourists in October through December, the fewest visitors of all four quarters, we infer that the lowest number of trips to Florida in any month is about 5 million (VISIT FLORIDA 2007a; b).[14] We take this to be the base rate for Florida's tourism at present; the rate that is insensitive to weather. Regardless of hurricanes and sweltering summers, at least 5 million people come to Florida each month. Some come for business, some to visit amusement parks (many of which are air conditioned, though outdoor areas, including lines, obviously are not), and some — despite rain, humidity, and scorching heat — to the beach. This projection implies that three-quarters of all tourists would still come to Florida despite the worst effects of climate change, while one-quarter would go elsewhere or stay home. We make the same assumption for Florida residents' share of tourism and recreation spending: for one out of four recreational activities that Florida families would have taken part it, they will instead choose to stay in their air conditioned homes.

We assume that under the business-as-usual case, tourism and recreational activities decline gradually to 75 percent of the rapid stabilization case level by 2100. Midway through that decline, in 2050, Florida's tourism industry will bring in $40 billion less in annual revenue and employ 1 million fewer people than it would in the rapid stabilization case, a loss of 1.2 percent of GSP. The annual cost of inaction reaches $167 billion in 2100 — 2.4 percent of GSP.

Table 12. Tourism Industry: Costs of Inaction

	2025	2050	2075	2100
Revenue (in billions of 2006 dollars)				
Rapid Stabilization Case	$161	$137	$460	$668
Business-As-Usual Case	$152	$277	$372	$501
Cost of Inaction	$9	$40	$88	$167
Revenue (as a percentage of GSP)				
Rapid Stabilization Case	9.6%	9.6%	9.6%	9.6%
Business-As-Usual Case	9.1%	8.4%	7.8%	7.2%
Cost of Inaction	0.5%	1.2%	1.8%	2.4%
Employment				
Rapid Stabilization Case	1,433,000	1,856,000	1,856,000	1,856,000
Business-As-Usual Case	928,000	860,000	797,000	738,000
Cost of Inaction	505,000	996,000	1,059,000	1,118,000

Source Authors' calculations.
Note: Employment numbers remain constant after 2050 because employment is assumed in these calculations to grow proportionally with population, and the conservative assumption that Florida's population will remain constant after 2050 is used throughout this report.

Two of the most likely strategies for partially mitigating this enormous loss to Florida's tourism industry are beach nourishment to protect existing beaches, and the facilitation of inland migration of sandy beaches and wetlands. Beach nourishment is widely recognized as a stopgap measure with many unfortunate side-effects. Sand and silt dredged from the ocean floor and placed on top of current beach ecosystems erode two to ten times more quickly than the original sand (Dixon 2007; Hauserman 2007; Skoloff 2007). The ecological costs of beach nourishment are also very high. Dredged material buries all beach fauna and flora, killing the existing ecosystem. The material used for beach nourishment is often unsuitable for the reintroduction of the same species, or of any species. Sea turtles, for example, have been unable to nest and lay eggs on several renourished beaches (Maurer et al. 1978; Lindquist and Manning 2001; Peterson and

Bishop 2005; Pilkey and Young 2005; Speybroeck et al. 2006).

With projected sea-level rise of 27 inches, 55 percent of Florida's 52 square miles of sandy beach will disappear under the waves by 2060. Florida spent an average of $29 million a year adding sand to eroding beaches from 2000 to 2004. More rapid sea-level rise in the business-as-usual case and more rapid erosion of dredged materials would require a far greater addition of sand in each year. Counteracting the effects of sea-level rise in 2060 by adding three cubic yards of sand to every square yard of beach would require 270 million cubic yards of sand at a cost of $2.4 billion.[15] This figure does not include normal erosion from waves, wind and rain.

And that's just for a one-time renourishment. On average, renourishment of beaches needs to take place every six to ten years. If the projected sea-level rise takes place at a constant pace and each square foot of beach, once nourished, must be nourished again every six years, the bottom line is $400 million per year in 2050, and $700 million in 2100. This calculation assumes an abundant supply of local sand. If sand is not available from sources nearby each beach needing nourishment, costs would be even higher to offset additional transportation expenses.

Building sandy beaches up to their former elevation would produce isolated sandy islands of beach that would be particularly vulnerable to constant wear by tide and wind. Even at the low estimate of the frequency of replenishment presented here, a cumulative 1.2 billion cubic yards of sand would be needed by 2050 and 4.4 billion cubic yards by 2100. This amount of sand is simply not available locally. Current nourishment efforts for many of Florida's beaches, especially those in the southeast, are already facing sand shortage and, in some cases, eroding beaches are not being replenished for want of sand (Powers 2005; Day 2007). Surely piling up sand where beaches once lay as floodwater rises all around is a losing proposition, but even if public money could be found to carry it out, reserves of nearby sand would soon be depleted, and the ever increasing cost of importing sand from out of state or out of the country is not included in the estimates presented here.

A second likely strategy for mitigating some of the losses to the tourism industry, and to irreplaceable natural ecosystems, is allowing dry lands adjacent to beaches and wetlands to be inundated. That is, to *not* protect valuable waterfront property, regardless of what has been built there. Even in our business-as-usual case, the pace of sea-level rise is slow enough for most ecosystems to migrate — growing on the inland side as dry land floods, and shrinking on the ocean side as beaches and wetlands become open water. The main obstacle to this conservation strategy is the existence of valuable dry land property on the inland edge of these ecosystems. A plan for adapting to climate change cannot both protect existing developed areas by building sea-walls and levees and at the same time allow wetland species to create new ecosystems.

Most of Florida's sandy beaches are directly adjacent to developed areas. Maintaining beaches by allowing their migration inland would require both costly beach nourishment to create sandy beaches on what is now concrete foundations, roads, and backyards. More consequentially, homes, businesses, and industrial sites would have to be abandoned to the waves.

AGRICULTURE

Florida's farmers and livestock producers contributed $4.5 billion to the state's economy, about 1 percent of GSP, and employed 62,000 workers, or 1 percent of the state's workforce, in 2005 (Bureau of Economic Analysis 2007; Bureau of Labor Statistics 2007).[16] Florida ranked fifth in the nation in sales of all crops and second in sales of fresh vegetables in 2004 (Florida Department of Agriculture and Consumer Services 2006b).

Table 13. Agricultural Sales and Employees, 2004

	Sales (millions of 2006$)	Employees
Greenhouse and nursery production	**1,738**	**23,487**
Fruit and tree nuts	**1,614**	**10,002**
Oranges	1,041	4,322
Other Citrus	284	1,718
Other	288	3,962
Animal production	**1,584**	**5,930**
Beef cattle	473	1,161
Dairy cattle and milk production	461	2,000
Other animal production	224	2,034
Vegetables and melons	**1,544**	**19,504**
Tomatoes	534	
Other	1,010	
Sugarcane	**587**	**2,141**
Other field crops	**165**	**1,394**
Total Agricultural Sector	**7,231**	**62,457**

Sources: Cash receipt figures from the Florida Agriculture Statistical Directory 2006 (Florida Department of Agriculture and Consumer Services 2006b); employment figures from Bureau of Labor Services, Quarterly Census of Employment and Wages (Bureau of Labor Statistics 2007).

Florida is well known for its $1.3 billion citrus industry, located primarily in the southern half of the state. Florida oranges, grapefruits, tangerines, and other citrus fruits accounted for more than half the total value of U.S. citrus production in 2004. Oranges alone brought in $1 billion in 2004, and in 2005, Florida employed 60 percent of all U.S. orange grove workers and 40 percent of all workers in the production of other citrus fruits (Florida Department of Agriculture and Consumer Services 2006b; Bureau of Labor Statistics 2007).

Florida's fresh vegetables and non-citrus fruits are also important to the U.S. food supply. In winter, farms lie dormant in most states, but Florida's mild climate allows produce to be grown year-round. Sales of vegetables and melons totaled $1.5 billion in 2004, employing 19,500 people (Bureau of Labor Statistics 2007). Florida ranks first in the country in sales of a host of vegetables and fruits, including fresh market tomatoes, bell peppers, cucumbers, squash, and watermelons. Florida's $830 million in tomato sales accounted for almost half of all fresh tomatoes sold in the United States in 2005 (Florida Department of Agriculture and Consumer Services 2006c).

Florida is also the nation's leading sugarcane producer with $550 million in sales, more than half of the U.S total for the crop in 2004. Florida's sugarcane is grown almost entirely in the warm climate and nitrogen-rich "muck" soils surrounding Lake Okeechobee in Palm Beach, Hendry, and Broward Counties (Mulkey et al. 2005; Florida Department of Agriculture and Consumer Services 2006b; Bureau of Labor Statistics 2007). Florida's greenhouse and nursery plants ranked second in the U.S. in 2005, with $1.9 billion in sales. Greenhouses and nurseries growing house-plants, hanging baskets, garden plants, fruit trees, and cut flowers employed over 23,000 people in 2004 (U.S. Department of Agriculture 2005; Florida Department of Agriculture and Consumer Services 2006c; Bureau of Labor Statistics 2007). Florida's 1.7 million head of cattle generated $473 million in cattle and calf sales and $461 million in dairy sales in 2004. Most of Florida's cattle are sold as calves that are shipped to other states to be raised as beef cattle, although in-state feedlots are expanding. Less than 10 percent of the cattle in Florida are dairy cows, producing milk mostly for in-state consumption (U.S. Department of Agriculture 2005; Bureau of Labor Statistics 2007; Florida Department of Agriculture and Consumer Services 2007b).

Agriculture projections: Rapid stabilization case

Despite its profitability and importance to the state and the nation, Florida's agriculture faces serious constraints even in the rapid stabilization case. There is little land remaining for expansion of agriculture; on the contrary, there is likely to be continued pressure on existing agricultural land from population growth and resulting residential development. Florida's citrus industry will continue to suffer from citrus canker, a bacterial disease that causes fruit and leaves to be shed prematurely. The citrus canker bacteria can be spread quite rapidly by wind-blown rain; hurricanes have transported the disease beyond the quarantine zones set up by farmers. The 2004 hurricanes led to the infection of 80,000 acres of commercial citrus; Hurricane Wilma in 2005 caused the disease to spread to an additional 168,000 to 220,000 acres (Schubert et al. 2001; Anderson et al. 2004; Florida Department of Agriculture and Consumer Services 2006a; d; 2007a).

Even greater pressure on agriculture will result from the scarcity of water in the state. Florida's agricultural sector is already heavily dependent on irrigation water: 80 percent of all farmed acres (excluding pasturelands) are irrigated (Marella 2004). In 2000, just under half of all freshwater withdrawals were used for agriculture (see the water system section, below). Citrus and sugarcane commanded 47 and 22 percent of agricultural water withdrawals, respectively; all vegetables, including tomatoes, used just over 10 percent; greenhouses and nurseries about 5 percent; and livestock less than 1 percent (Florida Department of Agriculture and Consumer Services 2003; Marella 2004).

Table 14. Acres of Irrigation by Crop Type, 2000

	Total Acreage	Irrigated Acreage	Water Use (million gallons per day)
Citrus	834,802	99%	1,825
Sugarcane	436,452	93%	857
Greenhouse and nursery	142580	96%	409
Vegetable Crops	239,674	88%	401
Field Crops	445,861	29%	148
Other Fruit Crops	28,955	66%	40
Livestock			32
Total Agricultural Sector	**2,139,774**	**80%**	**3,923**

Source U.S. Geological Survey Scientific Investigations Report 2004 (Marella 2004)
Note: Greenhouse and nursery combines four subcategories of "ornamentals and grasses": field grown, greenhouse grown, container grown, and sod, but excludes pasture hay and other crops and grasses that utilize reclaimed water. Agricultural sector total does not include pasture hay.

Total freshwater use for agriculture has trended upward in the past several decades, reaching an average of 2 billion gallons per day in 1970, 3 billion in 1980, 3.5 billion in 1990, and almost 4 billion in 2000 (Marella 2004). Furthermore, these averages mask large seasonal variations; farmers need water most at the driest times of the year, when surface water supplies are likely to be most limited. In 2000, irrigation required more than seven times as much water in April as in July (Marella 2004).

Growing demands for water for domestic and other purposes, combined with declining natural supplies and the potential requirements of Everglades restoration, could make it difficult to maintain even the current flow of irrigation water in the future (see water section). This is among the greatest challenges to sustainable development in Florida — even in the rapid stabilization case, where impacts develop relatively slowly.

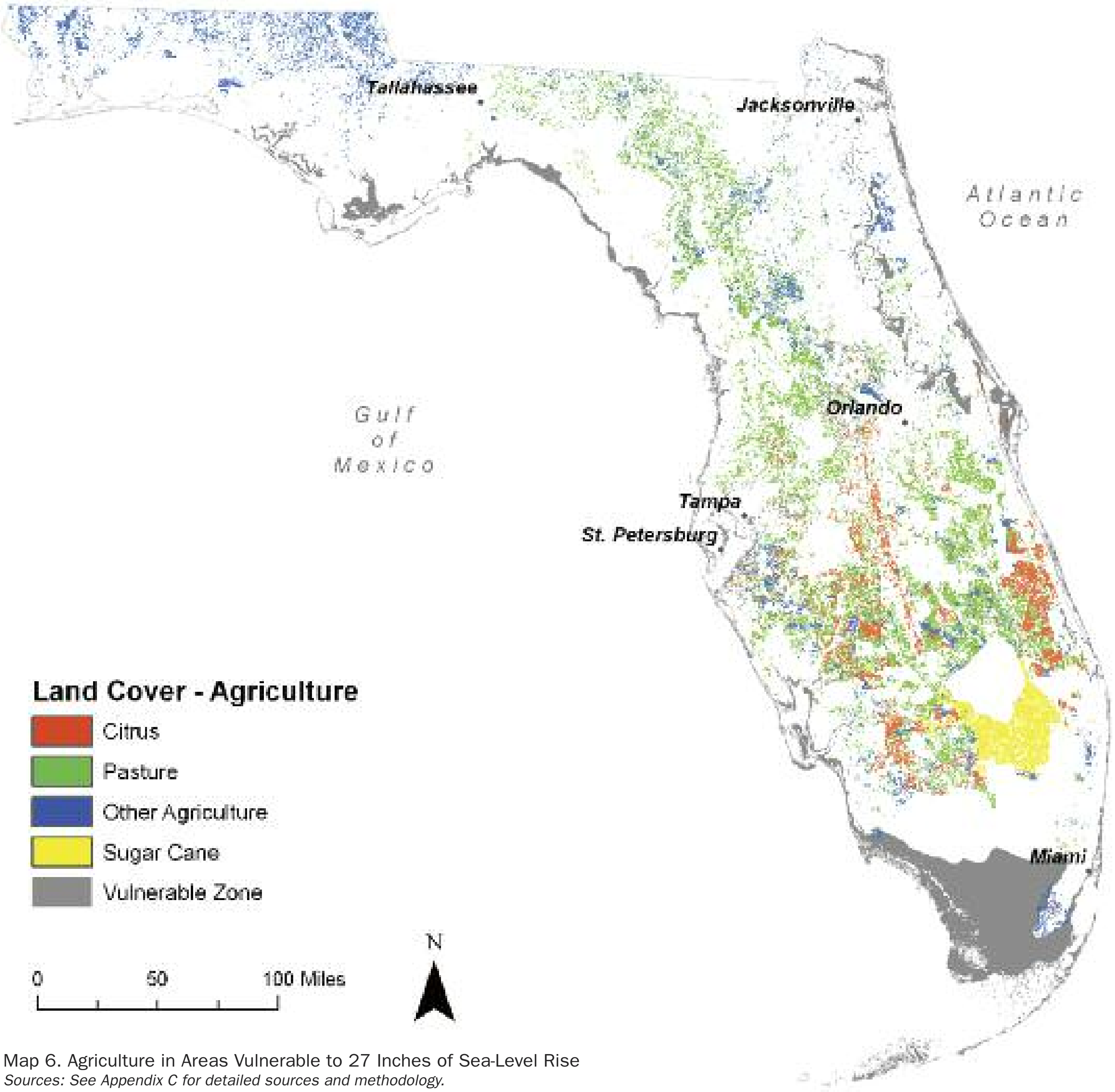
Agriculture projections: Business-as-usual case

In the business-as-usual case, Florida's climate changes much more quickly: the state will become hotter and drier, and hurricanes and other extreme weather events will become more frequent. Temperatures climb four times as quickly in the business-as-usual case; as a result, impacts that don't arise until 2100 in the rapid stabilization case become important by 2025 in the business-as-usual case.

The warmer weather and increased carbon dioxide levels that come with climate change could, at first, have some short-term benefits for Florida agriculture. Even in Florida, farmers can face heavy damages when temperatures dip below freezing, and these losses result in higher fruit and vegetable prices across the country. Rising temperatures would, on average, mean fewer winter freezes, a welcome change for many farmers. In addition, some types of plants can photosynthesize more productively when levels of carbon dioxide are somewhat higher than at present. All the major crops grown in Florida, except sugarcane, fall into this category. The magnitude of this effect, however, is uncertain and by the end of the century the business-as-usual scenario will have reached carbon dioxide levels well beyond those which have been tested on plants.

But reduced damages from freezing and benefits from carbon dioxide fertilization are not the only effects on agriculture in the business-as-usual case, and most of the other impacts are detrimental. As temperatures increase, citrus production in South Florida will begin to decline as periods of dormant growth, necessary to the fruit's development, are reduced (Environmental Protection Agency 1997). Optimal temperatures for citrus growth are 68-86°F; at higher temperatures, citrus trees cease to grow (Ackerman 1938; Morton 1987). Production of tomatoes, too, will begin to decrease before the end of the century, as Florida's climate moves above their mean daily optimal temperature range of 68-77°F (Sato et al. 2000; U.S. Global Change Research Program 2001; Lerner 2006). Sugarcane may also suffer a reduction in yield; it belongs to a class of plants that benefit little from higher levels of carbon dioxide in the air, and it will have to compete with carbon-loving weeds (Intergovernmental Panel on Climate Change 2007a). If farmers increase herbicide use as a result, their production costs will increase accordingly, as will the environmental impacts of herbicide use. Sugarcane will also grow more slowly in the hotter, business-as-usual climate; the optimal average growing temperature for sugarcane is 77–79°F (Vaclavicek 2004).

Even those agricultural commodities that thrive in higher temperatures and higher concentrations of carbon dioxide are at risk from other consequences of climate change, including the



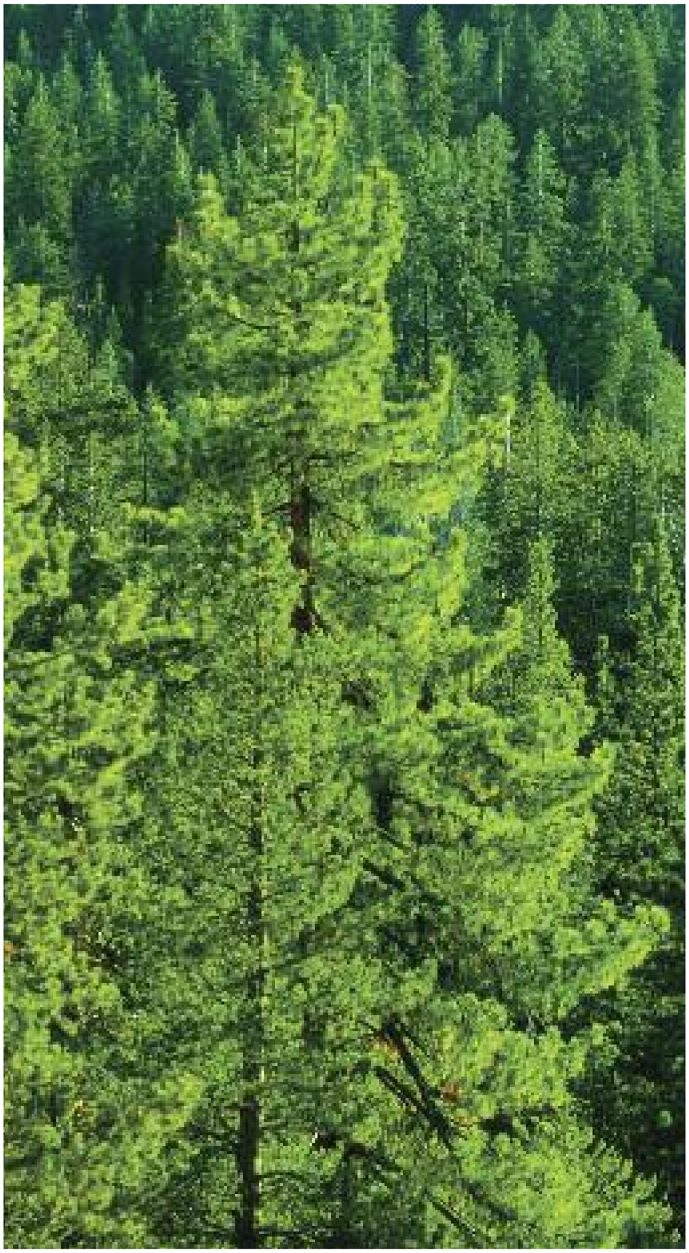
Map 6. Agriculture in Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.

northward shift of some pest insects and weed species (Intergovernmental Panel on Climate Change 2001a). Flooding from sea-level rise is another concern. With 27 inches of sea-level rise in 2060, 4,500 acres of current pasture, 7,000 acres of citrus groves and 26,000 acres of other farmlands will be inundated (see Map 6).

Florida also has a long history of severe crop damage from hurricanes, and more intense storms may cause still greater losses. The 2004 hurricane season, for example, caused extensive damage to citrus groves, decreasing yields by 17 percent in the following year. In Indian River County, where Hurricanes Francis and Jeanne both struck, citrus production dropped by 76 percent, and several other counties lost 40 to 50 percent of their crop (Florida Department of Agriculture and Consumer Services 2006b). Sugarcane is another vulnerable crop; flooding from hurricanes can easily damage sugarcane roots when moisture levels become too high (Natural Resources Defense Council and Florida Climate Alliance 2001).

Climate change's biggest threat to Florida agriculture, however, may be increased water requirements for irrigation of crops and for livestock, accompanied by a decreased supply of freshwater. In addition to the water problems discussed above, higher temperatures will result in greater irrigation needs, as more water is lost to increased evaporation from the soil and transpiration from plants, while 5 to 10 percent less rainfall reaches plants in our business-as-usual case. In a statistical analysis of USDA data, we found that Florida citrus and sugarcane require approximately 5 and 7 percent more water, respectively, for each degree (Fahrenheit) of mean temperature increase (U.S. Department of Agriculture 2003).[17]

FORESTRY



Forestry and forest product industries contributed approximately $3.5 billion to Florida's GSP and provided an estimated 30,000 jobs in 1997 (Hodges et al. 2005; U.S. Census Bureau 2007).[18] Florida's forestry industry output ranks 22nd in the nation, producing a wide variety of timber and related products, like paper, mulch, and plywood (Hodges and Mulkey 2003; Hodges et al. 2005; Florida Department of Agriculture and Consumer Services 2007c). Almost half of the state's land area is covered by forest, adding up to roughly 29,000 square mile, mostly in northern Florida (Natural Resources Defense Council and Florida Climate Alliance 2001; Florida Department of Agriculture and Consumer Services 2007c). Four-fifths of Florida's forested land is privately owned (Natural Resources Defense Council and Florida Climate Alliance 2001).

With climate change, the distribution of forest species will be affected. Many will experience increased productivity from higher levels of atmospheric carbon dioxide. For some species, temperatures will increase beyond their tolerance for survival. Higher temperatures will increase water stress from more evapotranspiration (water loss through leaves) and decreased soil moisture (Natural Resources Defense Council and Florida Climate Alliance 2001). Sea-level rise will threaten coastal and low-lying forests.

Each species has different tolerances for temperature and precipitation, and thus will respond differently to climatic variations. Tree species that currently coexist may migrate together to areas more closely matching their optimal climate, or the species composition of forests may change as some trees are able to migrate faster than others, or to tolerate a greater range of climatic conditions. In the northern and panhandle regions of the state, the current mixed conifer and hardwood forests are likely to shift northward out of the state as temperatures rise. This could make way for tropical evergreen broadleaf forests moving northward, or if drier conditions prevail, existing forests could be reduced and dry tropical savanna or pasture could take over. Another Florida ecosystem, the dry tropical savanna, could actually increase in forest density as it becomes more of a seasonal tropical forest (Environmental Protection Agency 1997).

Florida's loblolly-shortleaf pines and longleaf-slash pines will be adversely affected in the business-as-usual case as increases in temperatures surpass the upper limits of these species' optimal growth temperatures — 73 to 81°F (McNulty et al. 1996; Iverson and Prasad 2001). In contrast, oak trees, including oak-hickories and oak-pines, will be positively affected, as they thrive at higher temperatures (Iverson and Prasad 2001). Higher temperature, therefore, will lead to a replacement of loblolly-shortleaf pines with oak-pines in Florida (Iverson and Prasad 2001).

In general, the migration of forest ecosystems is not as simple as a uniform northward shift. Many forests will be unable to migrate because they are adjacent to developed or agricultural lands. Instead of moving with their accustomed climate, these forests will decline in health and productivity. Even where forests have the physical space to shift, there may be increased costs for the forestry industry as commercial forests move further away from current processing plants.

With less annual precipitation and a higher possibility of drought, forests will grow weaker. This added stress will make them more susceptible to pests and diseases. Due to their shorter life cycles and mobility, pests and diseases are likely to respond to the warmer temperatures by spreading their ranges and to do so at a quicker rate than trees can migrate.

FISHERIES

Florida's recreational fishing industry is of great importance to the state economy. Every year, more than 6.5 million people go on 27 million fishing trips in Florida, landing 187 million fish; another 90 million are captured in catch-and-release programs (Hauserman 2006). In 2005, anglers spent an estimated $4.6 billion in Florida on equipment, access fees, and other trip-related expenses, such as food and lodging; three-quarters of this was spent on saltwater fishing trips, the rest on freshwater fishing (Florida Fish and Wildlife Conservation Commission 2005a).[19] Florida has become a premiere fishing destination, accounting for more than 10 percent of total U.S. recreational fishing expenses (U.S. Fish & Wildlife Service 2007a). Popular year-round saltwater fishing destinations in Florida include Indian River Lagoon, Apalachicola Bay, Tampa Bay, and the Florida Keys. Fishers come in hopes of landing prized gamefish such as spotted seatrout, redfish (or red drum), snook, tarpon, and marlin. The most widely caught species in 2006 included herring, mullet, pinfish, blue runner, Spanish mackerel, kingfish, spotted seatrout, and gray snapper (National Oceanic & Atmospheric Administration 2007a). In addition, Florida is the top scuba diving destination in the U.S., and one of the five most popular diving sites in the world; coral reefs and the associated fish provide the major attraction for divers.

Commercial fishing also takes place in the state, although on a smaller scale. In 2005, the dockside value of fish caught in Florida totaled $174 million, just over 4 percent of the value of all U.S. seafood in 2005 (National Ocean Economics Program 2007b). There are probably several thousand people employed in commercial fishing, although the exact number is uncertain.[20] While at least 150 varieties of fish and shellfish are caught for sale, more than half of the commercial catch is shrimp, crab, and lobster, worth a total of $98 million in 2005 (National Oceanic & Atmospheric Administration 2007a). Florida shrimp, crab, and lobster represented about 11, 8 and 4 percent, respectively, of the value of the U.S. catch of those products in 2005. In particular, 95 percent of U.S. pink shrimp, 99 percent of Florida stone claw crab, and all Caribbean spiny lobster is Florida-caught (National Oceanic & Atmospheric Administration 2007a). Among finfish, the top four varieties in 2005 — grouper, snapper, mackerel, and mullet — brought in $45 million, or 27 percent of commercial fishing sales (National Oceanic & Atmospheric Administration 2007a). Moreover, some of these fish are found primarily in Florida: the state accounted for 86 percent of all U.S. grouper sales in 2005, and 62 percent of the mullet market.

Other fish-related industries, including seafood processing, seafood markets, and fish hatcheries and aquaculture, have a larger economic impact than commercial fishing, with an estimated combined contribution of $530 million to the state economy in 2004 (National Ocean Economics Program 2007a). The seafood markets and processing industries are not entirely dependent on Florida's own catch, since a large portion of seafood processed in Florida has been imported — over 80 percent by weight in 2004 (Kildow 2006b).

The impacts of climate change on recreational fishing are included in the discussion of tourism, so no separate estimates of losses are developed here to avoid double-counting. For the commercial fishing industry, there will be greater losses under the business-as-usual scenario, compared to the rapid stabilization scenario. The most important single variety, pink shrimp (comprising 15 percent of Florida's commercial fishing catch), is still imperfectly understood, but years of warm water temperatures and intense hurricanes have led to unusually low pink shrimp catches (Ehrhardt and Legault 1999). The business-as-usual scenario, of course, will make such conditions more common. In view of the small size of the commercial fishing industry, no estimate of the value of losses is calculated here. This does not mean, however, that climate change is irrelevant to fishing.

Overfishing has already led to declining fish populations in Florida, and climate change will exacerbate the problem by destroying crucial habitats (Florida Fish and Wildlife Conservation Commission 2005b; Schubert et al. 2006). In particular, climate change will have devastating effects on the coral reef and estuarine wetland ecosystems on which many fish species depend.

Coral reefs provide food, shelter, and breeding grounds to a number of recreationally and commercially important fish in Florida, including king and Spanish mackerel, red and yellowtail snapper, red grouper, and spiny Caribbean lobster (National Oceanic & Atmospheric Administration 2007a). In addition, larger species such as marlin are often attracted to the reefs to eat smaller reef-dwellers. As discussed above in the scenario section, warmer ocean temperatures and increased acidity, both resulting from climate change, will cause enormous, potentially fatal harm to coral reefs.[21]

Estuaries, which provide habitat to 70 percent of Florida's fish and shellfish species at some point in their life cycles, are severely threatened by climate change as well (Florida Department of Environmental Protection 2004a; Levina et al. 2007). Estuaries — areas where freshwater from the land mixes with seawater, such as river deltas and bays — host various types of wetlands along Florida's coast, including salt marshes, mangroves, and seagrass beds. Some important recreational fish, like the pinfish, spotted seatrout, and pompano, spend most of their lives in estuaries. Shellfish, like crabs, oysters, and shrimp, rely on the nutrients in freshwater for their growth, making the mix of fresh and saltwater in estuaries critical to their production (Florida Fish and Wildlife Conservation Commission). For many other fish, including those that spend their adult lives in the open sea, estuaries provide nursery grounds for their young. Mullet and grouper, for example, spawn offshore and let tides and currents carry their eggs to estuaries. Saltmarshes, seagrass beds, or mangrove roots then provide both food and protection from prey for the young fish.

Larger predators have difficulty passing through the closely knit grasses and roots, and in some cases cannot survive in the lower salinity water (Florida Department of Environmental Protection 2004b). Even fish that do not live in estuaries may be dependent on fish that do for food. Loss of estuarine habitats can cause ripple effects throughout the marine food chain (National Wildlife Federation and Florida Wildlife Federation 2006).

As sea levels rise, estuarine wetlands will be inundated and vegetated areas will be converted to open water (Levina et al. 2007). If sea levels rise gradually and coastal development does not prevent it, the wetlands and the species they support could migrate landward (Brooks et al. 2006). But rapid sea-level rise combined with structures built to protect human development, such as seawalls, prevent landward migration, causing estuarine habitats to be lost altogether. The 27 inches of sea-level rise projected in the business-as-usual scenario by 2060 is more than enough to turn most estuarine wetlands into open water.

More intense hurricanes also threaten to damage estuarine habitats. During Hurricane Andrew, large quantities of sediment from inland sources and coastal erosion were deposited in marshes, smothering vegetation (Scavia et al. 2002). The high winds of hurricanes also pose a direct threat to mangrove forests, knocking down taller trees and damaging others (Doyle et al. 2003).

INSURANCE

Insurance companies are, by their nature, gamblers, betting on what's going to happen to you. They make money if their guesses about the dangers you face are roughly correct, and the premiums they charge you are greater than the claims that you, on average, collect from them. They lose if they set their premiums so low that they are unable to pay their customers' claims, or so high that people stop buying insurance.

In Florida, selling property insurance means betting on the size of hurricane damages. The insurance industry has made mistakes in both directions, at times setting premiums too low to cover claims, and at other times charging more than their customers can afford. Under the best of circumstances — in the rapid stabilization scenario — hurricane damages will continue to vary widely from year to year, and the industry will need to take a long-term perspective to avoid bouncing between very low and very high rates.

Under the business-as-usual scenario, with about the same number of hurricanes but more of them reaching Category 4 or 5, damages will be higher on average, and also more variable from year to year. With greater uncertainty it will be easier for the industry to make a wrong bet, in either direction, and it will be harder for homeowners to pay the increased average cost of insurance. Greater and greater public subsidies will be required as private insurers raise their rates, or leave the market.

The challenge of making a multi-year gamble on hurricane damages seems to call for big businesses that can afford to take the long view. What has happened, though, is that many of the largest insurance firms in the country have folded their cards and left the riskiest parts of the Florida market after some of the memorable hurricanes of recent years. Smaller, state-based insurance firms, an increasingly important part of the industry, do not have the resources to provide adequate coverage for hurricane damages on their own. As a result, the state and federal governments have been drawn into subsidizing Florida property insurance. But even with the subsidies, homeowners who decided where to live, and how much house they could afford, at a time of much lower rates are now being squeezed by the drastic increase in premiums.

It looks like an attractive market: among U.S. states, Florida's property insurance industry is second only to California's in value of premiums sold (Florida Office of Insurance Regulation 2006). In Florida, property insurance is provided by leading private companies such as State Farm and Allstate, as well as smaller companies active only in Florida; by a state-created not-for-profit insurer called Citizens' Property Insurance Corporation; and by the federal government's National Flood Insurance Program (NFIP). Homeowners living on the coast often have one policy from a private insurer covering general threats such as theft or fire, another from Citizens to cover wind risk from hurricanes, and a third from NFIP for flood damage.

Before Hurricane Andrew hit in 1992, many property insurers, eager to increase their market shares, were charging rates that proved too low to pay for the claims filed after the storm. These low rates made high risk areas look misleadingly attractive and affordable, encouraging investment in real estate. (Many of the "investors" were middle-class households who could not afford to move again when rates went up.) As a result of Andrew, Florida insurers faced $15.5 billion in claims, and 12 insurance companies went bankrupt (Florida Office of Insurance Regulation 2006; Scott 2007). Premiums went up by an average of 82 percent across the state (Wilson 1997).

For the companies that remained in the state's insurance industry, the rate increases were enough to restore financial health. From 1996 to 2006, the loss ratio for Florida insurers was less than 70 percent of all premiums collected, meaning that insurers paid less than seventy cents in claims out of every dollar of premiums. Florida's loss ratio was only two percentage points higher than the average for all insurers nationwide (Florida Office of Insurance Regulation 2007a; Hundley 2007).

Insurance companies were somewhat better prepared for the massive storms of 2004 and 2005, although one large Florida-based insurer, Poe Financial Group, was bankrupted, and many other companies dropped their policies in vulnerable parts of Florida to limit their exposure to future storms. Rate increases after these storms roughly doubled the average premium charged across the state, according to a spokesperson for the Florida Office of Insurance Regulation (Kees 2007). These increases brought the loss ratio down to 45 percent in 2006, allowing insurers to rapidly recoup their losses from 2004 and 2005 (Florida Office of Insurance Regulation 2007b). But despite the higher rates, several of the larger insurance companies continued to move out of the Florida market: the two largest insurers, State Farm Group and Allstate Insurance Group, reduced their share of the market from 50.9 percent in 1992 to 29.9 percent in 2005 (Grace and Klein 2006). Although a few large national firms remain in Florida, 12 of the state's top 15 insurers sell only Florida residential property insurance (Florida Office of Insurance Regulation 2006).

For many Florida homeowners, this means that rates have skyrocketed in recent years. Stanley Dutton, a Florida resident who was profiled in *Newsweek,* said he was selling his house on Florida's panhandle after his premiums increased from $394 in 2000 to $5,479 in 2006 (Breslau 2007). *USA Today* reported in 2006 that Key West homeowner Teri Johnston's wind storm premium on her 1,500 square foot home had quadrupled since 2004 to $11,856, and that rate included an $18,000 deductible (Adams 2006). While these are extreme cases, the impact on the average homeowner has been hard enough.

The state government plays an active role in Florida insurance markets, and has expanded its involvement in response to recent hurricane activity. One key role of the state is to regulate insurers' activities to prevent sudden abandonment of policyholders or unfair premium hikes. All rate increases are subject to public hearings and require regulatory approval; companies wishing to cancel policies must provide 90 days' notice and some assurance that their withdrawal is "not hazardous to policyholders or the public" (Florida State Legislature 2006; Kees 2007). Companies have pursued a strategy of dropping the policyholders with the riskiest properties, which allows them to reduce their risk and improve their expected level of profitability without requiring state approval for rate increases (Grace and Klein 2006; Florida Office of Insurance Regulation 2007b).

The state has also played an ever-growing role as an insurer of last resort for homeowners who cannot find private insurance. Prior to Hurricane Andrew, the state acted as an insurer of last resort through the Florida Windstorm Underwriting Association (FWUA), but only to a limited set of customers. When thousands of customers were dropped after Andrew, a new insurer of last resort was set up called the Residential Property and Casualty Joint Underwriting Association (JUA), which grew to 936,000 policies in September of 1996, before shrinking again as new private insurers moved into the state (Wilson 1997). The FWUA and JUA merged in 2002 to become Citizens' Property Insurance Corporation, partly in response to private insurers' demands that the government assume some of their wind risk. After the 2004 and 2005 storms, many more customers were dropped by private insurers and picked up by Citizens, raising the number of its policy holders to over 1.3 million. In June 2007, a new bill was passed which freezes Citizens' rates until January 1, 2009 and allows policyholders of private companies to switch to Citizens if their private insurer charges 15 percent more than the state's rates. With these changes, the number of properties insured by Citizens is projected to reach 2 million by the end of 2007 (Liberto 2007).

The state increasingly has also taken on the role of providing reinsurance for private insurance companies. After the wave of bankruptcies following Hurricane Andrew, the state government set up the Florida Hurricane Catastrophe Fund, or CAT Fund for short, to provide a limited level of reinsurance to private insurers, which would cover a portion of their claims in the event of a hurricane. The rates charged were below private market rates for reinsurance, especially after the storms of 2005 nearly doubled private reinsurance rates (Florida Office of Insurance Regulation 2007a). In January 2007, the state injected more money into the CAT fund, expanding it from $16 billion to $28 billion, and required private insurers to purchase more reinsurance through them, and to pass on the savings to customers through lower rates (Florida Office of Insurance Regulation 2007a). The projected savings, however, did not materialize.

One impact of this expanded government role in insurance markets is that the state's potential liability in the event of a large hurricane has increased. In 2005, the state had to bail out Citizens, which had a $1.4 billion deficit; this was done through a combination of a charge on all insurance companies, which is passed on to policyholders, and a payment from the state budget of $750 million (Kees 2007). With the expansion of Citizens and the increase in subsidized reinsurance, the state could be left with an even larger bill in the event of another big storm.

All these changes have increased the amount that the state government effectively subsidizes property insurance rates. Citizens' rates may not appear artificially low to policyholders, but according to a spokesman for the organization, the rates necessary for the premiums of homeowners in high risk coastal areas to cover their own claims would be entirely prohibitive (Scott

2007). In addition, the federal government provides flood insurance through NFIP that is often pegged at rates too low to break even with claims. The nationwide effects of Hurricane Katrina left NFIP bankrupted 10 times over by the $16 billion it paid in flood claims.

In Florida's insurance industry, an already bad situation will be made much worse if climate impacts intensify. Under the rapid stabilization scenario, continuing the current frequency and intensity of storms, the industry might be able to muddle along with the current arrangements, premiums, and state and federal subsidies. Under the business-as-usual scenario, with more intense storms, as well as higher sea levels that will increase the height of storm surges, the insurance crisis will become more severe. Either premiums or subsidies, or likely both, will have to increase to cover the rising average costs of storm damages. As storms intensify, private firms are likely to continue withdrawing from the market for Florida property insurance, leaving the government — that is, the taxpayers — with an increasingly expensive drain on public resources.

The cost of hurricane damages, discussed later in this report, will be borne in large part by property owners, through increased premiums and/or reduced coverage, and by state and federal governments through subsidies to insurance companies. Increased insurance costs and increased storm damages will contribute to a decline in property values, worsening climate damages to the real estate industry. There is no way to predict the monetary cost of the business-as-usual scenario to the private insurance industry — except to note that even the least skillful gambler, after losing enough times in a row, will eventually leave the table.

IV. ECONOMIC IMPACTS: INFRASTRUCTURE

Even without climate change, Florida's public and private infrastructure will take an enormous amount of investment in order to keep up with a near doubling of population in the next 50 years. In the rapid stabilization case, the impacts of climate change for the 21st century are about the same as the changes during the 20th century. Almost all of Florida's infrastructure will be able to weather slowly rising temperatures and slowly rising seas with routine maintenance and new construction, activities that would be necessary regardless of a changing climate. In the business-as-usual case, however, Florida's infrastructure will suffer very serious damages. On top of the pressure of rapid growth, roads and power plants, schools and reservoirs, shopping malls and airports all will suffer damage from climate change. Nine percent of the state's current land area will be under water. Saltwater will also intrude into freshwater storage. High temperatures will increase demands for electricity. The costs of business-as-usual emissions will be high, and at times, Florida's infrastructure may fail to provide necessary services to state residents.

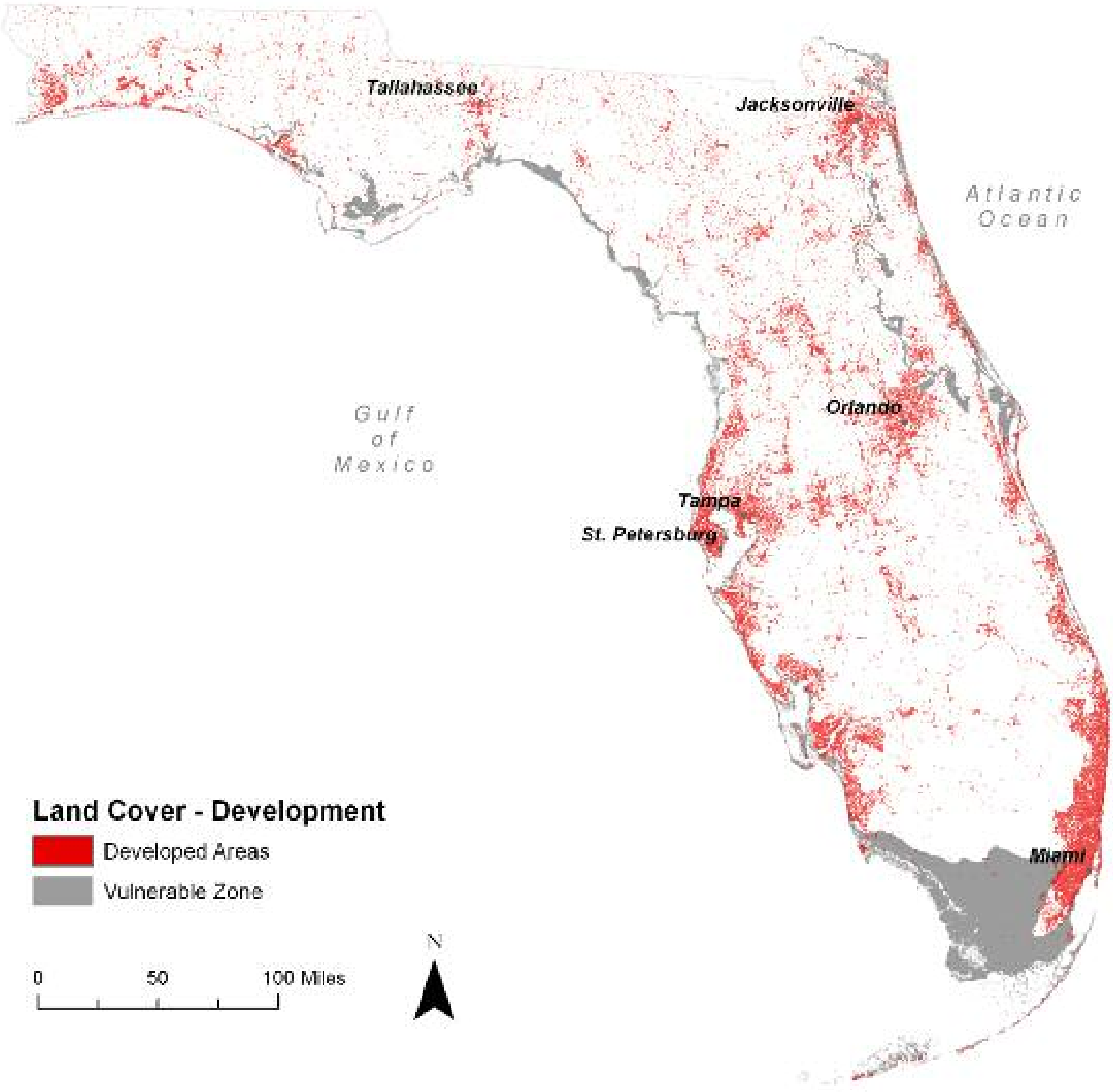
REAL ESTATE

The effects of climate change will have severe consequences for Florida's real estate. If nothing were done to hold back rising waters, sea-level rise would simply inundate many properties in low-lying, coastal areas. Even those properties that remained above water would be more likely to sustain storm damage, as encroachment of the sea allows storm surges to reach inland areas that were not previously affected. The land area vulnerable to inundation if sea levels were to rise 27 inches, as the business-as-usual scenario projects by 2060, currently contains over 900,000 housing units worth an estimated total of $130 billion.[22] This figure does not account for anticipated growth in population, incomes, and therefore in real estate as well, over coming decades; the value of vulnerable real estate in 2060 will be much larger.

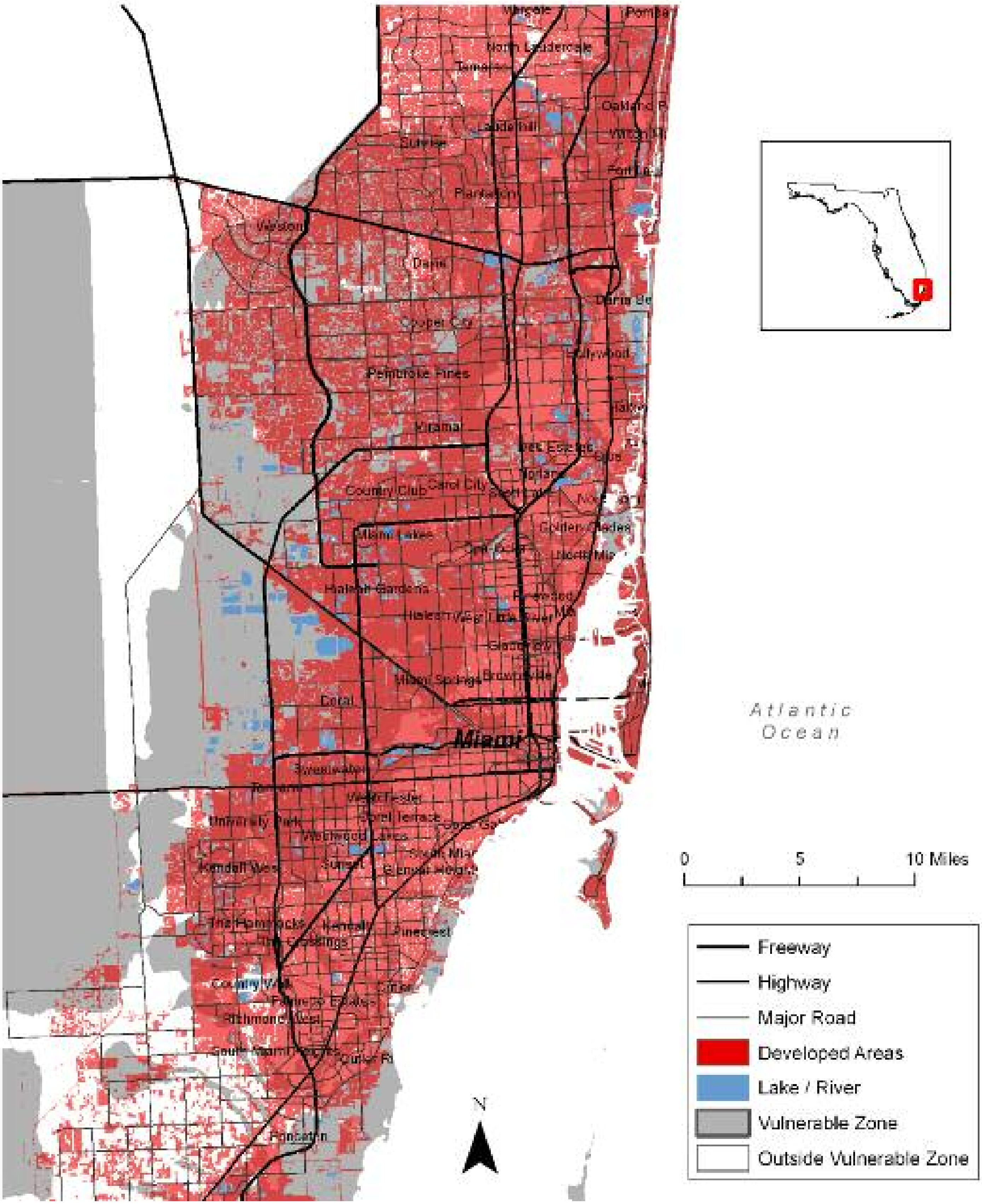
Table 15. Housing Units Currently in Areas Vulnerable to 27 Inches of Sea-Level Rise

	Number of housing units in vulnerable zone	County median value for owner-occupied homes (2006 dollars)	Value of real estate in vulnerable zone (million 2006 dollars)
All Florida	**916,861**	**$118,478**	**$129,117**
Miami-Dade	190,770	$145,171	$27,694
Monroe	48,973	$282,380	$13,829
Pinellas	97,457	$112,976	$11,010
Collier	47,473	$196,683	$9,337
Palm Beach	52,196	$158,283	$8,262
Broward	51,623	$150,556	$7,772
Lee	57,292	$132,176	$7,573
Volusia	52,689	$102,205	$5,385
Brevard	47,656	$110,517	$5,267
Sarasota	37,407	$100,800	$3,771
Manatee	25,723	$139,785	$3,596
St.Johns	22,493	$142,829	$3,213
Duval	30,555	$104,898	$3,205
Martin	17,702	$178,420	$3,158
St.Lucie	18,997	$140,371	$2,667
Bay	22,145	$109,463	$2,424
Charlotte	18,391	$113,561	$2,089
Hillsborough	16,650	$114,380	$1,904
Indian River	11,732	$121,756	$1,428
Flagler	8,262	$136,039	$1,124
Pasco	9,745	$93,190	$908
Nassau	3,662	$148,332	$543
Seminole	3,823	$124,098	$474
Clay	3,604	$126,907	$457
Escambia	3,640	$100,332	$365
Putnam	3,807	$80,195	$305
Franklin	2,008	$123,278	$248
Citrus	1,913	$98,810	$189
Wakulla	1,506	$112,624	$170
Hernando	1,647	$102,205	$168
Santa Rosa	746	$185,444	$138
Gulf	1,357	$90,380	$123
Walton	913	$112,859	$103
Lake	439	$117,776	$52
Taylor	663	$77,268	$51
Okaloosa	338	$118,478	$40
Levy	374	$88,741	$33
Dixie	389	$72,234	$28
Orange	102	$125,854	$13

Source Florida Geographic Data Library (University of Florida: GeoPlan 2007)



Map 7. Developed Land in Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.



Map 8. Miami/Fort Lauderdale: Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.

There are 6,400 square miles of developed area in Florida. Of this, 433 square miles, or 6.8 percent, are in the vulnerable area in the business-as-usual scenario. Miami-Dade County, the most populous county, will have almost 70 percent of its total land area flooded, including 73 square miles of residential neighborhoods, commercial districts, and industrial properties. In Monroe County, all of the Florida Keys will be under water in 2060 in the business-as-usual scenario.

In addition, to residential properties worth $130 billion, the vulnerable zone includes other valuable — and otherwise significant — facilities throughout the state:

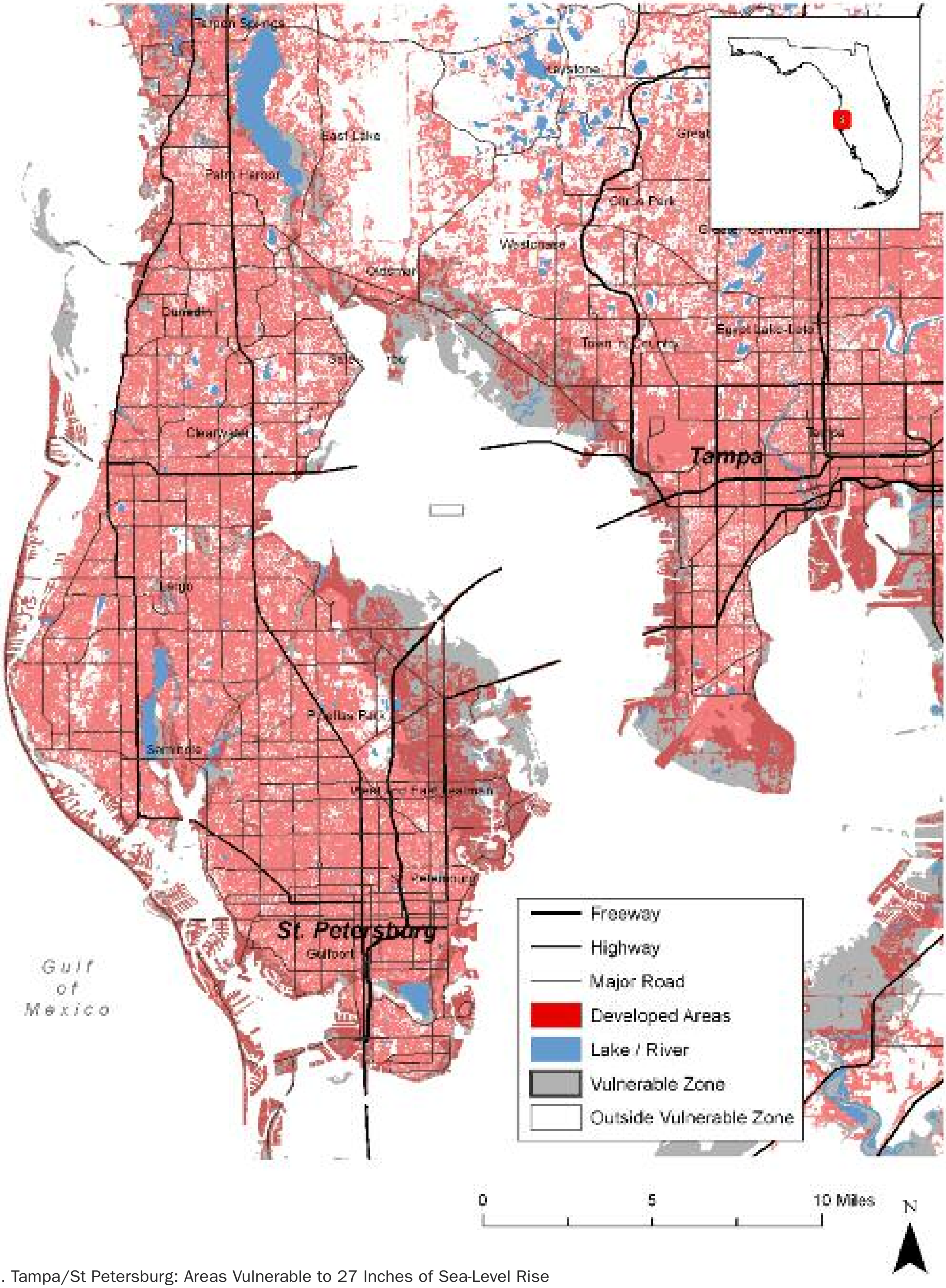
- 2 nuclear reactors;
- 3 prisons;
- 37 nursing homes;
- 68 hospitals;
- 74 airports;
- 82 low-income housing complexes;
- 115 solid waste disposal sites;
- 140 water treatment facilities;
- 171 assisted livings facilities;
- 247 gas stations
- 277 shopping centers;
- 334 public schools;
- 341 hazardous materials sites, including 5 superfund sites;
- 1,025 churches, synagogues, and mosques;
- 1,362 hotels, motels, and inns; and
- 19,684 historic structures.

More intense hurricanes, in addition to sea-level rise, will increase the likelihood of both flood and wind damage to properties throughout the state. The cost of insuring homes against wind damage has already risen so high that many private insurance companies are unwilling to sell coverage at any price, forcing residents to rely on Citizens, the state-created insurance company (Scott 2007). Post-storm flood damage is generally even costlier than damage from high winds, creating the need for both structural repair and replacement of the contents of homes and buildings. But even with insurance to cover damages, the costs of the time and stress involved in repairing a storm-damaged home are high. Mobile homes, which represent 12 percent of Florida residences, but even higher shares in some of the most vulnerable counties — 19 percent in Monroe, 20 percent in Franklin, and 25 percent in Gulf County — are at particular risk from the effects of stronger storms. While the values of these homes constitute only a small fraction of the value of all coastal real estate at risk from climate change, their residents may be least economically prepared to cope with damages.

With two simplifying assumptions, it is possible to estimate the value of real estate at risk from sea level rise. First, we assume that the value of real estate will grow uniformly in all parts of the state, in proportion to GSP, throughout this century. Second, we assume that the fraction of the state's residential property at risk is proportional to the extent of sea-level rise. Then, starting from the calculation of $130 billion of residential real estate, as of 2000, that would be vulnerable to 27 inches of sea-level rise, it is possible to project the effects of both scenarios through 2100. The results are shown in Table 16. The cost of inaction — that is, the annual increase in the value of residential real estate at risk of inundation — rises from $11 billion in 2025 to $56 billion in 2100, or almost 1 percent of GSP. And sea levels will continue to rise beyond 2100.

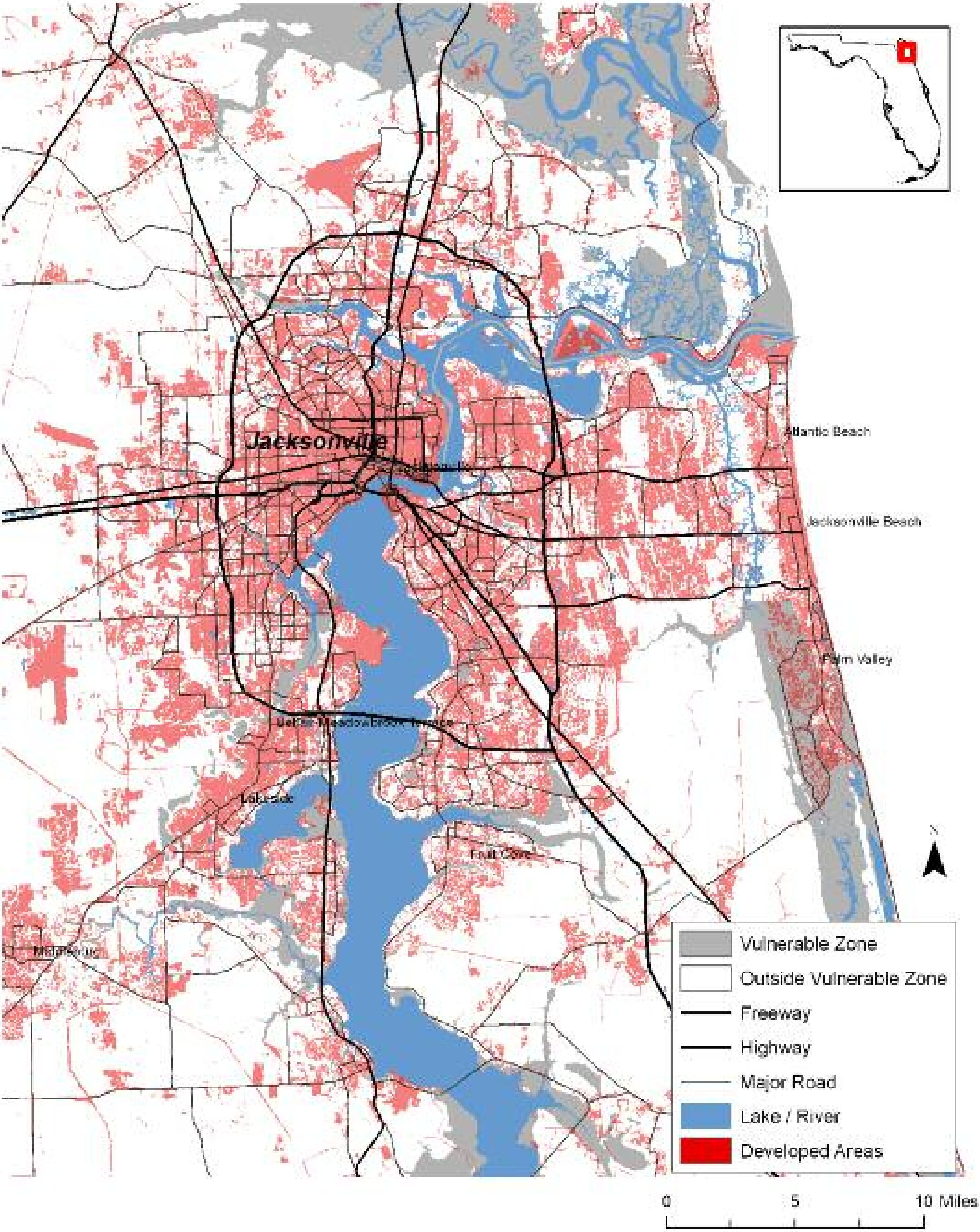
No one expects coastal property owners to wait passively for these damages to occur; those who can afford to do so will undoubtedly seek to protect their properties. But all the available methods for protection against sea-level rise are problematical and expensive. It is difficult to imagine any of them being used on a large enough scale to shelter all of Florida from the rising seas of the 21st century, under the business-as-usual case.

Elevating homes and other structures is one way to reduce the risk of flooding, if not hurricane-induced wind damage. A FEMA estimate of the cost of elevating a frame-construction house on a slab-on-grade foundation by two feet is $58 per square foot, after adjustment for inflation, with an added cost of $0.93 per square foot for each additional foot of elevation (Federal Emer-



Map 9. Tampa/St Petersburg: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: See Appendix C for detailed sources and methodology.



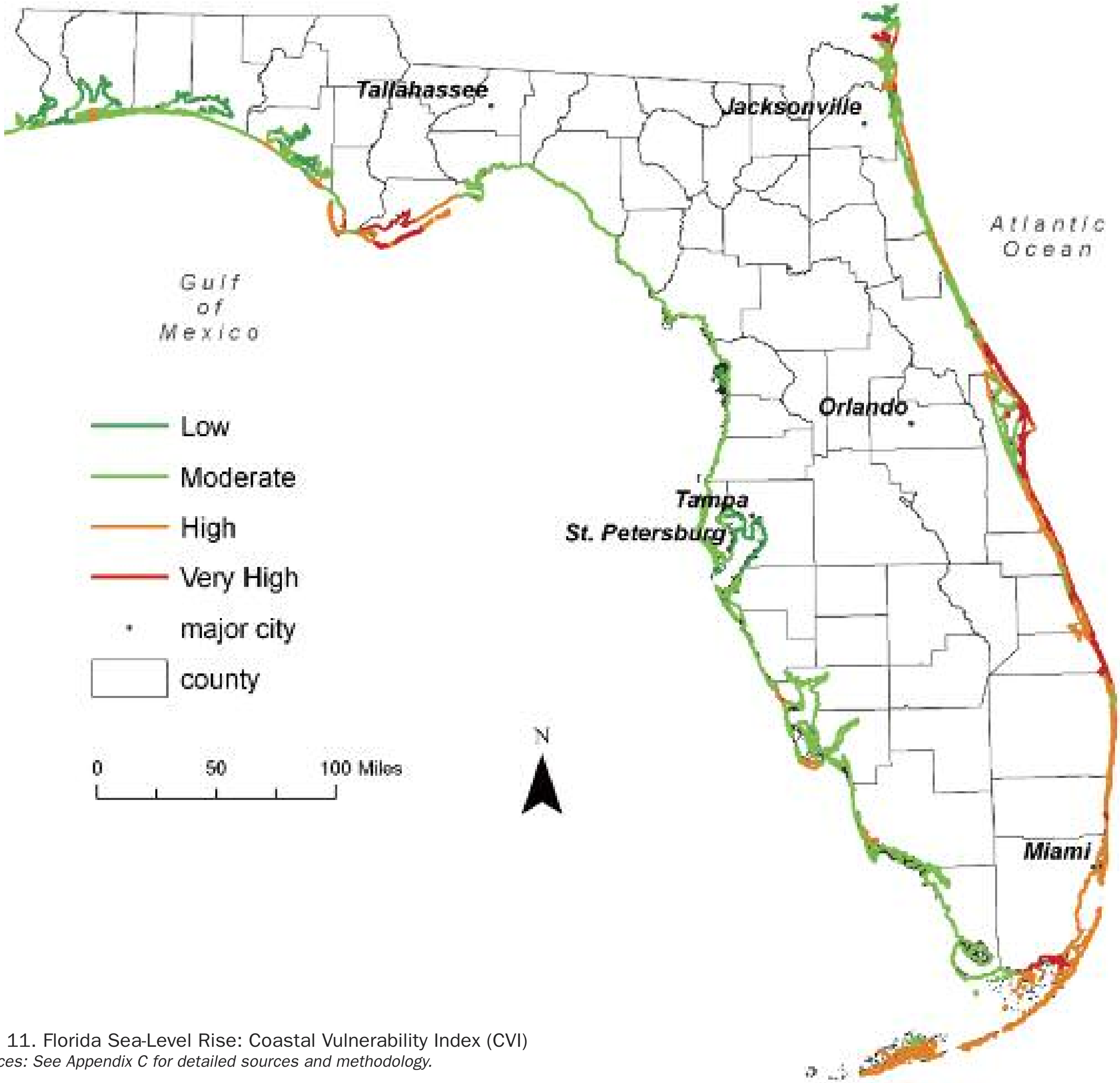
Map 10. Jacksonville: Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.

Table 16. Residential Real Estate at Risk from Sea-Level Rise, Without Adaptation

annual increases in value at risk

	2025	2050	2075	2100
Damages (in billions of 2006 dollars)				
Rapid Stablization Case	2	4	6	10
Business-as-Usual Case	13	27	39	66
Cost of inaction	11	23	33	56
Damages (as percent of GSP)				
Rapid Stablization Case	0.12%	0.13%	0.13%	0.15%
Business-as-Usual Case	0.79%	0.82%	0.81%	0.95%
Cost of inaction	0.67%	0.69%	0.68%	0.80%

Source: Authors' calculations.



Map 11. Florida Sea-Level Rise: Coastal Vulnerability Index (CVI)
Sources: See Appendix C for detailed sources and methodology.

gency Management Agency 1998). A house with a 1,000 square foot footprint would thus cost $58,000 to elevate by two feet. It is not clear whether building elevation is applicable to multistory structures; at the least, it is sure to be more expensive and difficult.

Another strategy for protecting real estate from climate change is to build seawalls to hold back rising waters. There are a number of ecological costs associated with building walls to hold back the sea, including accelerated beach erosion and disruption of nesting and breeding grounds for important species, such as sea turtles, and preventing the migration of displaced wetland species (National Oceanic & Atmospheric Administration 2000b). In order to prevent flooding to developed areas, some parts of the coast would require the installation of new seawalls. Estimates for building or retrofitting seawalls range widely, from $300 to $4,000 per linear foot (Yohe et al. 1999; U.S. Army Corps of Engineers 2000; Kirshen et al. 2004; Dean 2007b).

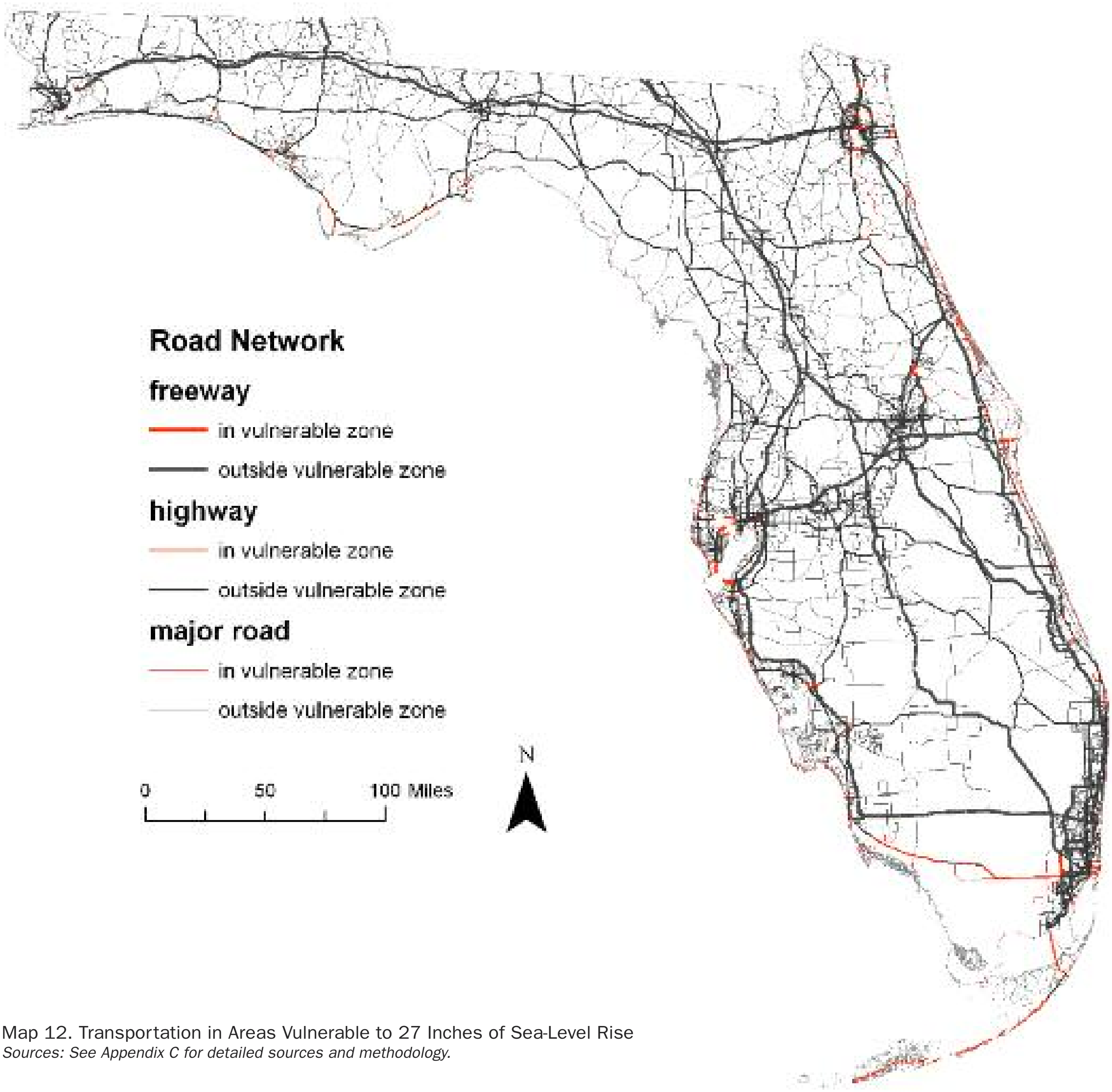
The United States Geological Survey (USGS) has created an index to rate the vulnerability of U.S. shoreline to sea-level rise, taking into consideration tides and erosion, as well as elevation (U.S. Geological Survey 2000). According to their assessment out of 4,000 miles of total Florida shoreline, 1,250 miles are in the "high" vulnerability category and 460 miles are in the "very high" category. If just these 1,700 miles of shoreline were protected with seawalls, and construction costs averaged $1,000 per linear foot (or a bit over $5 million per mile), the total cost would be just under $9 billion. The 4,000 total miles of shoreline assumed by USGS, however, do not take into account Florida's many channels and inlets, which make the actual coastline much longer. (Conversely, other estimates of the length of Florida's coast-line range down to 1,350 or fewer miles; the varying estimates reflect the different resolution at which the measurements are made.). The actual coastline length, when these features are accounted for, is 22,000 miles.[23] If seawalls were needed for 42 percent of Florida's actual coastline (the share of very high and high vulnerability coastline under the USGS definition), or 9,200 miles, the cost would be $49 billion. In other words, constructing seawalls sufficient for statewide protection would be an engineering megaproject, several times the size of the long-term Everglades restoration effort.

Yet another approach involves beach nourishment, bringing in sand as needed to replenish and raise coastal beaches (which as noted above can have major environmental impacts). A major analysis of the costs of protecting the US coastline from sea-level rise, conducted by EPA in 1989, relied heavily on restoring and building up beaches (Titus et al. 1991). The study projected that most of the sand would need to be dredged up more than five miles offshore. It estimated the cost of sand to protect Florida against 39 inches of sea-level rise (a level reached in 2087 in the business-as-usual case) would be between $6 billion and $30 billion in 2006 dollars, depending on assumptions about the quantity and cost of sand. As with statewide seawall construction, beach nourishment on this scale would be a mammoth engineering project, with uncertain environmental impacts of its own.

In short, while adaptation, including measures to protect the most valuable real estate, will undoubtedly reduce sea-level rise damages below the amounts shown in Table 16, there is no single, believable technology or strategy for protecting the vulnerable areas throughout the state.

TRANSPORTATION

Transportation infrastructure in Florida will be damaged by the effects of sea-level rise, particularly in combination with storm surge. Many types of transportation infrastructure, including port facilities, airport runways, railways, and especially roads, are at risk. Docks and jetties, for example, must be built at optimal heights relative to existing water levels, and more rapid sea-level rise may force more frequent rebuilding. Roads, railroads, and airport runways in low-lying coastal areas all become more vulnerable to flooding as water levels rise, storm surges reach farther inward, and coastal erosion accelerates. Even roads further inland may be threatened, since road drainage systems become less effective as sea levels rise. Many roads are built lower than surrounding land to begin with, so reduced drainage capacity will increase their susceptibility to flooding during rainstorms (Titus 2002).



Map 12. Transportation in Areas Vulnerable to 27 Inches of Sea-Level Rise
Sources: See Appendix C for detailed sources and methodology.

Table 17. Roads and Railroads in Areas Vulnerable to 27 Inches of Sea-Level Rise

	Limited Access Highways (miles)	Other Highways (miles)	Major Roads (miles)	Railroads (miles)
Florida Total	**75.5**	**390.8**	**1972.4**	**181.3**
Bay		8.4	43.1	3.6
Brevard	5.7	25.4	213.2	51.5
Broward		2.0	36.0	1.5
Charlotte	1.9	6.1	51.4	3.5
Citrus			12.7	
Clay		3.1	11.4	2.0
Collier		46.4	101.4	2.3
Dixie			20.1	
Duval	11.5	16.5	84.9	20.6
Escambia		1.0	70.0	5.4
Flagler		2.9	32.9	0.7
Franklin		17.4	76.5	2.1
Gulf		9.5	17.1	10.2
Hernando			10.5	
Hillsborough	6.6	9.8	13.6	15.2
Indian River		0.6	52.1	0.2
Lake			2.2	
Lee	1.4	3.5	97.5	1.5
Levy			3.8	
Manatee	8.8	3.3	40.6	2.8
Martin		2.6	43.3	4.5
Miami-Dade	14.0	55.6	211.9	8.2
Monroe		95.3	59.1	
Nassau	1.3	1.2	8.5	3.9
Okaloosa		0.2	0.1	
Orange		0.4		
Palm Beach		6.6	80.1	1.9
Pasco		0.7	10.8	
Pinellas	10.9	12.5	104.9	1.5
Putnam		5.4	10.6	3.6
Santa Rosa	0.9	0.7	3.5	0.6
Sarasota	0.1	12.0	44.2	
Seminole	6.7	0.4	14.2	2.4
St.Johns		3.2	128.8	4.7
St.Lucie		1.6	103.7	
Taylor			9.6	
Volusia	5.6	27.1	134.3	27.3
Wakulla		6.6	11.5	
Walton		2.5	2.0	

Sources: road network data from US Streets Dataset (Environmental Systems Research Institute 2005) and Rail Network dataset (Federal Railroad Administration and Research and Innovative Technology Administration's Bureau of Transportation Statistics 2006); vulnerable zones data from NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Note: Limited access highways are accessed via a ramp and/or numbered exits, like all Interstates and some intrastate highways.

One response to the threat of inundated transportation infrastructure is to simply elevate it to keep pace with the sea-level rise. While elevation may be less expensive than letting rising waters wash out entire highways, it does not come cheap. One estimate put the average cost of elevating roads at $2 million per mile (Dean 2007b). With over 2,400 miles of existing highway and other major roads at risk of inundation with 27 inches of sea-level rise, the cost of elevating just these roads sums to over $4.8 billion. This total does not take into account the millions of miles of city streets in Florida's vulnerable areas that would need to be elevated, nor does it consider the many additional miles and lanes of roads that will likely be built as Florida's population doubles over the next 50 years.

Elevating roads, however, may cause other problems. Streets are built lower than surrounding residential and commercial property so that water from the land can drain into the street. Elevating the roads can prevent this drainage. In such cases, it becomes necessary to raise surrounding lots along with the street, so that relative heights are preserved (Titus 2002).

ELECTRICITY

The electricity sector in Florida encompasses 138 power plants,[24] representing over 56 gigawatts (GW) of capacity. (A gigawatt is a million kilowatts.) The system relies heavily on power plants that burn natural gas (33 percent) and coal (29 percent); oil and nuclear power (12 percent each) make up the remainder of generation. [25] Planned new plants will primarily burn natural gas, and it is expected that oil plants will be converted to burning gas or phased out by 2015. The state's electricity market is growing rapidly, following the burgeoning population. Floridians were projected to draw a peak demand of nearly 47 GW in 2007, 3 percent higher than the peak of 2006 (North American Electric Reliability Corporation 2006). These increasing demands on the energy sector are expected to be strained by global climate change, at significant cost to Florida's consumers.

Florida's power plants are spread statewide, and some date back to the 1950s. Early power plants were built near the coastline; the size of new plants increased dramatically through the early 1980s, culminating with the large Turkey Point, Crystal River, and St. Lucie nuclear plants, and Manatee and Martin natural gas plants. From the mid-1980s, new plants were primarily smaller natural gas generators, concentrated in central Florida between Tampa and Orlando.[26] The transmission system reflects the location of power plants, with large lines extending down the center of eastern and western coastal counties. As coal plants have become less attractive politically, financially, and environmentally, the state has increased its reliance on natural gas plants, causing concern about the lack of diversity in Florida's energy portfolio (Platts 2007).

Florida's electricity market has been affected by rising gas and oil prices, which have caused electricity prices to jump from 6.9 to 8.8 cents per kilowatt-hour (kWh) between 2000 and 2005.[27] The U.S. Energy Information Administration (EIA) estimates that energy prices will stabilize at approximately 8.1 cents per kWh over the next two decades if oil prices settle at $60 a barrel (far below the price at the time of this writing). In short, Florida's electricity is expensive, and high energy prices can be expected well into the future, even without the added strain of climate change.

Among the impacts of climate change projected in the IPCC 2007 report, several will affect electricity demand, generation, and distribution capacity in Florida, including:

- Warmer and more frequent hot days and nights
- An increase in the frequency of heat waves
- More intense hurricanes
- Possible coastal flooding from storms surges and sea-level rise
- Changes in the availability of water

Generally, the energy sector is expected to be strained along three axes: temperature, demography, and topography.

- **Temperature:** While much of Florida experiences over a half year of comfortable temperatures between 70 and 85°F, the state has the warmest daily average temperatures in the nation, and summers are hot and humid (O'Brien and Zierden 2001). In 2005, 74 days had highs of 90°F or more, while winter highs dropped below 70°F on only 19 days. Already, these temperatures mean that air conditioners run through much of the year; as further discussed below, they also mean that power plants are using significant energy to cool equipment, and power lines are operating less efficiently than they would in a cooler climate. Rising temperatures will dramatically increase demand and further degrade system-wide efficiencies.
- **Demography:** The population of Florida is growing quickly, and aging even more rapidly. Currently 18 percent of residents are over 65, and this is expected to rise to 27 percent by 2030 (U.S. Census Bureau 2004a). An older population, highly dependent on air conditioning, will ensure that energy demand remains tightly coupled to temperature. With more frequent heat waves, there may be a need for costly emergency energy infrastructure to reduce heat-related injuries or illness. Without mitigation, the increasing number of Florida customers will stretch current infrastructure, particularly when power demands peak.
- **Topography:** Numerous power plants and transmission lines are close to the coastline, exposing significant energy infrastructure, and thus power system reliability, to storm damage in the near future, even without the more intense hurricanes that climate change may produce (Florida Public Service Commission 2006).

Electricity demand projections

In the rapid stabilization case, electricity demand will rise due to rapid demographic growth and increasing demands for electricity from residential and commercial consumers; climate change will play only a minor role. The Florida Public Service Commission recorded an increase in residential use per capita of 7 percent between 1995 and 2005, and has projected future increases of 0.84 percent per year (Murelio 2003). The EIA projects a 0.76 percent annual increase in commercial use per capita until 2030. Residential housing, amongst the fastest growing sectors in the state, will consume increasing electricity for lighting, air conditioning, and entertainment. The EIA estimates that after lighting, the largest use of residential electricity is for air conditioning, a factor which is expected to grow through 2030 at nearly 1 percent per year (Energy Information Administration 2007). Coupled with Florida's rapid demographic growth, the Florida Reliability Coordinating Council (FRCC) expects an annual compounded growth rate of 2.4 percent in summer peak demand and 2.8 percent in total state energy consumption between now and 2015.

Based on this picture of a rapidly growing state population and economy, we project average annual growth in electricity demand, from 2005 through 2100, of 1.54 percent — before considering any effects of temperature changes.

A review of Florida's electricity generation by hour indicates that it is closely correlated with temperature.[28] Generation rises at both low and high temperatures to meet heating and cooling demand, respectively, and is lowest at approximately 67 °F (see Figure 2). In 2005, 85 percent of the hours of the year were above 67°F, a percentage that will rise to 93 percent by 2050 and to 96 percent by 2100. All other things being equal, therefore, we would expect a steep increase in electricity demand in line with warming.

In the business-as-usual case, average annual temperatures rise over 9.7°F by 2100, causing a much more noticeable impact on the electricity system. On the one hand, this will ease the pres-

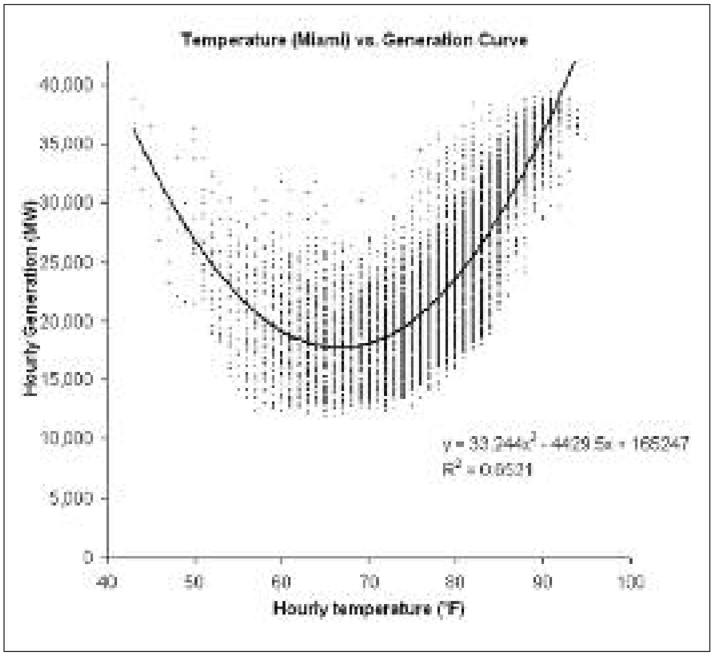


Figure 2. Hourly Fossil Generation in Florida versus Hourly Temperatures in Miami

Sources: Hourly power generation derived from 2005 Environmental Protection Agency (EPA) Clean Air Markets data for FRCC fossil units (Environmental Protection Agency 2007a); hourly temperature from Miami International Airport derived from National Oceanographic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) (National Oceanic & Atmospheric Administration 2007b).

Note: Each dot represents an hour of the year; vertical "lines" are multiple dots at the same temperature.

sure of winter demand for heating, a major factor in Florida's electricity use at present. In 2003, winter demand prompted the state to issue an advisory while local utilities asked consumers to conserve power (Murelio 2003). On the other hand, air conditioning demand on scorching days in the summer will quickly push up against the limits of system capacity. In 2005, 74 days had highs exceeding 90°F. This may climb to more than 90 days a year by 2020, 150 days by 2050, and nearly two-thirds of the year by 2100.

In the rapid stabilization case, where a temperature increase of only 2.2°F is expected by 2100, warming will add only 0.07 percent to electricity demand growth each year, for a combined annual growth rate of just over 1.6 percent. By 2100, we project Florida's total electricity demand will be about 4.5 times as large as in 2005.

For the business-as-usual case, we project that warming will add an average of 0.34 percent to the growth of electricity demand each year, for a combined annual growth rate of 1.88 percent. By 2100, we project Florida's total electricity demand will be about 5.9 times as large as in 2005. There is a large gap between the size of the electricity system in the two scenarios: by 2100 the difference between the two scenarios amounts to 1.4 times the amount of electricity the state produced in 2005.

Electricity supply projections

Unfortunately, the same high temperatures that cause electricity demand to spike also impair the efficiency of power system components, including central generating stations as well as transmission and distribution equipment.

- **Generators:** Due to their inability to cool components as quickly, thermal generators have lower efficiency at higher ambient temperatures. When air temperatures rise above design expectations, they are unable to produce as much power. For example, in gas turbines, performance decreases with increasing temperatures, and power output drops off significantly over 100°F. In Florida's current system, gas and oil systems lose approximately 1 percent efficiency for every 4°F temperature increase.[29] Florida relies heavily on seawater to cool power plants; increases in ocean temperature reduce the cooling efficiency, and thus impair generation efficiency. At a New York nuclear plant, generation efficiency drops rapidly if river water used for cooling rises above 50 to 60°F; output drops by as much as 2 to 4 percent when water temperatures reach 85°F (Powers 2003). While these declines in efficiency in may appear relatively small, the losses can have dramatic consequences across the system, particularly in heat waves when these resources are needed most urgently.
- **Transmission Lines:** When the amount of electricity carried over transmission lines increases (for example on a hot day when people are using air-conditioning), power lines heat up, stretch, and sag. An overloaded power line can sag so much that it comes in contact with a tree, or close to the ground, creating a short-circuit as electricity is discharged, and potentially leading to power outages. Higher ambient temperatures also decrease the maximum current carrying capacity of transmission and distribution lines.

The effect of high temperatures on power system components was highlighted during the widespread power system outages in the summer of 1999. On July 6th, a heat wave with sustained

temperatures of 100°F caused overloads and cable failures, knocking out power to 68,000 customers (U.S. Department of Energy 2000). Outages in New York City were due to heat-related failures in connections, cables and transformers. In the South Central region, power plants were not able to produce as much power as predicted, leading to system failures. Small inefficiencies at multiple power plants added up to losses equivalent to 500 megawatts.

To calculate costs for the two scenarios, we constructed a simple simulation of electricity demand and supply in Florida to 2100. The model accounts for changes in population, per capita demand, and temperature, but holds fuel prices and the cost of new power plants constant.[30] For the rapid stabilization scenario, the simulation assumes a slowly changing fuel mix, migrating towards increasing efficiency measures and use of renewable energy sources such as wind power, while phasing out oil and coal. With increasing petroleum scarcity, adoption of policies to reduce greenhouse-gas emissions, and resulting demand for better efficiency and widespread renewable energy sources, we can envision a cleaner portfolio with coal use falling steadily by 2100, and use of oil for electricity generation discontinued by 2050. In place of fossil fuels, the cleaner portfolio relies on rigorous new conservation measures that will reduce demand by 40 percent, along with expanded renewable electricity production, supplying 30 percent of electricity demand by 2100.

Such changes are entirely in line with Governor Crist's Executive Orders on climate change of July 2007; indeed, in order to meet the governor's targets for reduced greenhouse gas emissions, as set out in those orders, a massive shift to energy efficiency and renewable energy sources will be necessary. A June 2007 report from the American Council for an Energy-Efficient Economy (ACEEE) argues that Florida can afford to do even more than the cleaner portfolio used in our simulation (Eliot 2007).

For the business-as-usual case, on the other hand, we assumed that the state will satisfy the growing demand for electricity by maintaining the current fuel mix. In this scenario, Florida will need to build approximately five gas plants, four oil plants, and one coal plant in Florida *every year* for the foreseeable future. Even assuming that it was possible to obtain regulatory approval for all these facilities, and to site and construct them and the associated transmission lines, it is uncertain where adequate cooling water would be obtained (see discussion below). And the costs of securing those approvals, and siting and constructing those plants and transmission lines, would inevitably lead to price increases.

We estimate that in the business-as-usual case, the *annual* cost of power in Florida will rise to $43 billion in 2050 and to $78 billion by 2100 (see Table 18). A substantial portion of this growth can be attributed to booming population and energy demand, and is required even in the rapid stabilization case, but the difference between the two scenarios accounts for an added $18 billion a year by 2100. By the end of the century, every additional degree Fahrenheit of warming will cost electricity consumers an extra $3 billion per year.

According to the simulation, the increasing population and demand for power in the business-as-usual scenario will require an untenable 1500 new sources of generation, nearly 400 more than would be required in the rapid stabilization case.[31] Significant new construction may be required in any case to supply electricity for Florida's growing economy, but the costs will be much higher under business-as-usual than under the rapid stabilization scenario.

Table 18. Electricity Sector: Costs of Climate Change

in billions of 2006 dollars

	2025	2050	2075	2100
Rapid stabilization case	22.4	37.6	48.1	60.2
Business as usual case	23.5	42.5	58.4	78.2
Cost of inaction	1.1	4.9	10.3	18.1

Source Authors' calculations, see text.

In the business-as-usual scenario, the electric system has to adapt not only to gradual average temperature increases, but to increasing temperature variability as well, presenting additional challenges and expenses to the energy sector. Highly variable temperatures require a greater number of expensive peaking power plants to be online — that is, plants that sit idle most of the time, but provide enough electrical generation capacity to meet peak demand for cooling on hot summer afternoons. As a result, both the costs of generation and the overall size of the power grid in Florida will be larger than would be needed in the absence of climate change.

Vulnerability to extreme weather

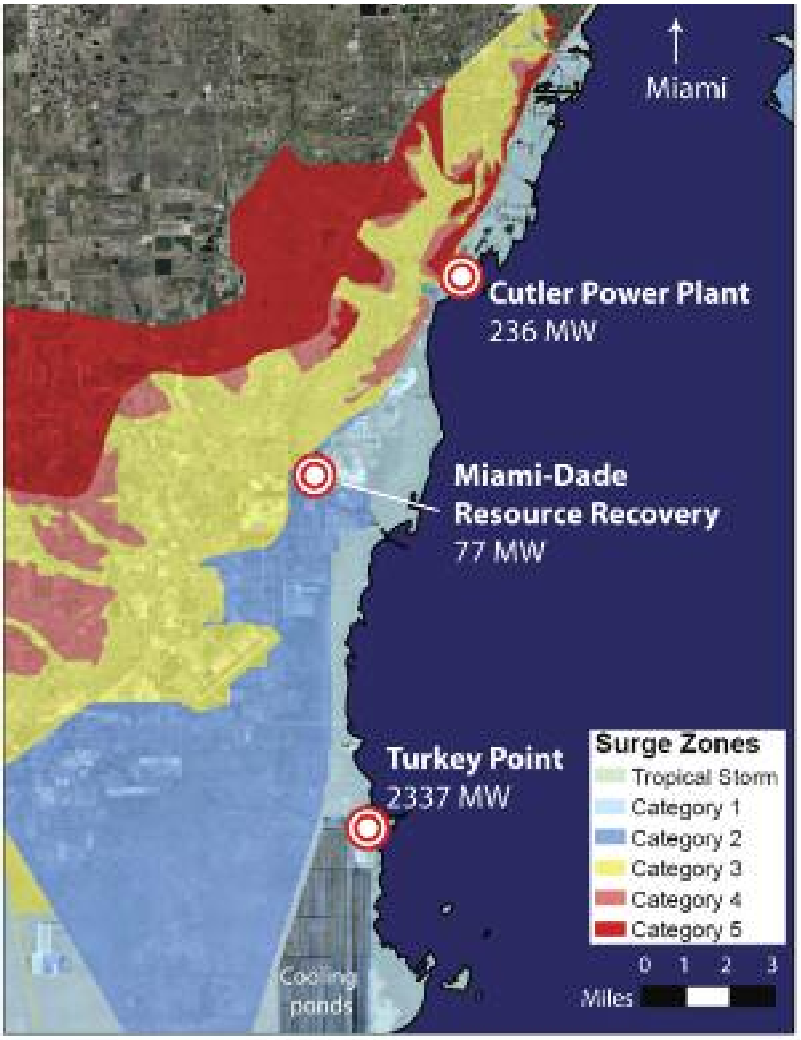
Not included in these figures are costs associated with the impacts of rising sea levels and more-intense hurricanes. Infrastructure vulnerability to storm damage has already been keenly felt in Florida during the 2004 and 2005 hurricane seasons. The four hurricanes that struck the state during each of those two years resulted in damage restoration costs for Florida's privately owned electric utilities of over $1.2 billion in 2004 and $0.9 billion in 2005 — to say nothing of the stresses on those utilities' customers from being with electricity for days or weeks at a time.

Table 19. Hurricane Impacts on Florida's Electric Utilities

	2004 Hurricanes				2005 Hurricanes			
	Charley	Frances	Ivan	Jeanne	Dennis	Katrina	Rita	Wilma
Hurricane category	4	2	3	3	3	2	2	3
Florida sustained winds (mph)	145	105	130	120	120	80	62	125
Number of Utility Restoration Personnel	19,860	21,172	6,430	27,320	5,353	14,820	546	19,121
Customer Power Outages (thousands)	1,800	4,500	400	3,500	500	1,200	25	3,551

Sources: Florida Division of Emergency Management, Hurricane Impact Report (Florida Division of Emergency Management 2004); Florida Division of Emergency Management, Draft Hurricane Impact Report (Florida Division of Emergency Management 2007).

Currently there are 15 plants, representing 22 percent of Florida's total generation capacity (13 GW) located in storm surge zones for Category 1 hurricanes, and up to 36 plants (over 37.8 percent of capacity) are vulnerable to Category 5 hurricanes. Some of Florida's largest coastal resources are also the most vulnerable, as estimated from the state's "surge zones" (Florida State Emergency Response Team 2006). In Miami-Dade County, the huge Turkey Point nuclear plant and two other significant power plants are well within the zone vulnerable to surges from even moderate storms (see Map 13). The surge zones shown in Map 13 are already vulnerable to storm surges under current conditions, and will be increasingly at risk from even the modest sea level rise in the rapid stabilization scenario. The business-as-usual scenario will bring much greater risks to these and adjacent areas, due to much greater sea level rise and increased intensity of storms.



Map 13. Principal Miami-area Power Plants at Risk from Storm Surges

Sources: See Appendix C for detailed sources and methodology.

Table 20. Statewide Energy Capacity Vulnerable to Hurricane Storm Surge

	Tropical Storm	Hurricane Category 1	2	3	4	5
Vulnerable plants	2	15	19	28	29	36
Capacity (GW)	3.1	12.7	14.7	16.9	16.9	22.4
% of state capacity	5.20%	21.50%	24.90%	28.60%	28.60%	37.80%

Sources: Storm surge zones from Florida Department of Community Affairs, Division of Emergency Management (Florida State Emergency Response Team 2006), power plant locations and data from 2006 EPA Emissions & Generation Resource Integrated Database (eGRID) (Environmental Protection Agency 2007b).

WATER SYSTEM

The recent record-breaking drought to the contrary, Florida is generally a wet state. It averages 54 inches of rainfall per year, a level matched only by a few other states in the Southeast, and by Hawaii. Huge aquifers can be found under all regions of the state, and many areas have abundant surface water as well. Indeed, most of south Florida was a vast wetland less than 100 years ago; agricultural and residential development was dependent on the massive drainage efforts of the first part of the twentieth century. Ironically, Florida succeeded all too well in getting rid of its former "excess" of water — leading to recent shortages, as well as a long and expensive process of environmental restoration.

The abundance of rainfall is deceptive. Precipitation is not evenly distributed throughout the year, but is heavily concentrated in the rainy season — for most of the state, June through September. In that hot, wet period, most of the rainfall, as much as 39 of the 54 inches, evaporates before it can be used. Demand for water, on the other hand, is highest during the dry months of the winter and spring, driven by the seasonal peak in tourism and by the profitability of irrigated winter agriculture.

In 2000, Florida used 12,000 million gallons per day (mgd) of salt water and 8,200 mgd of fresh water; the salt water is used almost exclusively for power plant cooling requirements (Marella 2004). Of the fresh water, 3,100 mgd came from surface water, and 5,100 from groundwater, or aquifers. Surface water is taken from a number of sources throughout the state, however, more than 40 percent of all surface water use occurs in Palm Beach and Hendry Counties, the two counties directly south of Lake Okeechobee. Most surface water, statewide, is used for irrigation.

Groundwater comes, above all, from the immense Floridan Aquifer that underlies the entire state. There were withdrawals from the Floridan Aquifer in all but one county in 2000, accounting for 62 percent of the state's groundwater supply (Marella 2004). Although reachable everywhere in the state, the Floridan Aquifer is of greatest use to central, northern, and northwestern Florida. In the south it is located much farther underground, and its water is more brackish. The Biscayne Aquifer, which lies above the Floridan Aquifer in the southeast, provided 17 percent of the state's groundwater, in Miami-Dade, Broward, and parts of Palm Beach County. Smaller aquifers elsewhere supplied the rest.

Reclaimed wastewater is a small but growing source, replacing about 200 mgd of fresh water in 2000. In addition, more than 100 desalination plants are in operation around the state, almost all used to reduce the salinity of brackish groundwater. Most are quite small, but there are a handful of 10-40 mgd plants (Florida Department of Environmental Protection 2007a). The first large-scale attempt at the more difficult and expensive task of desalination of ocean water, the new Tampa Bay facility, is discussed below.

As shown in Table 21, more than half of the fresh water used in Florida is for irrigation — including both agriculture and "recreational irrigation" of golf courses, sports fields, parks, cemeteries, and public spaces. (Related household uses, such as watering lawns, are included in "public supply" or "domestic self-supplied" water.)

Table 21. Water Use, 2000

	Fresh water (mgd)			Salt water (mgd)		
	Ground	Surface	Total	Ground	Surface	Total
Public supply	2,200	240	2,440	–	–	–
Domestic self-supplied	200	–	200	–	–	–
Commercial-industrial	430	130	560	–	–	–
Agricultural	1,990	1,930	3,920	–	–	–
Recreational irrigation	230	180	410	–	–	–
Power generation	30	630	660	–	11,950	11,950
TOTALS	**5,080**	**3,110**	**8,190**	**-**	**11,950**	**11,950**

Source: U.S. Geological Survey Scientific Investigations Report 2004 (Marella 2004)

In 2002, Florida had 2.31 million acres of harvested cropland, of which 1.70 million acres, or 74 percent, were irrigated.[32] The irrigated area represented 5 percent of the total land area of the state. Citrus fruits, sugar cane, greenhouse and nursery crops, and vegetables account for most of the irrigated area, and most of the irrigation water use, as shown in Table 14 (see agriculture section, above). Recreational irrigation, accounting for about 5 percent of all fresh water use, is primarily for golf course irrigation, although other uses are also included. Recreational use of fresh water has been growing rapidly in recent years (Marella 2004).

After irrigation, the largest category of water use is the public water supply, at 30 percent of the fresh water total. Per capita usage in 2000 amounted to 174 gallons per day for the population served by the public water supply (most but not all of the state), just below the national average of 180 gallons per day. Public supply includes some commercial, industrial, and public uses (e.g., firefighting), as well as household use. Florida's household use of public water supply averaged 106 gallons per person per day in 2000, down from 144 gallons per person per day in 1980 as a result of conservation efforts that have already been implemented (Marella 2004).

Water system projections: Rapid stabilization case

Even under the best of circumstances — under the rapid stabilization scenario, with minimal damages due to climate change — Florida's rapid economic and demographic growth is headed for a collision with the lack of additional water. The Department of Environmental Protection projects an increase in water requirements of 22 percent by 2025 (Florida Department of Environmental Protection 2007b). Looking farther ahead, if agricultural water use remains constant, since there is little land for agricultural expansion, and if all other water uses grow in proportion to population, then by 2050 the state would need 12,800 mgd of fresh water.[33] This is a 57 percent increase over water use in 2000, a quantity that appears to be impossible to provide from existing fresh-water sources. At the current cost of desalination, $3 per 1,000 gallons (see below), the additional water needed by 2050 would cost almost $6 billion per year — if it were available.

Groundwater supplies are already encountering limits. The water level in the Floridan Aquifer has been dropping for decades (Marella and Berndt 2005); it can no longer meet the growing needs of many parts of the state. Meanwhile, the state has turned down Miami-Dade County's request for a big increase in its withdrawals from the Biscayne Aquifer, which is also under stress; the county will instead be forced to invest in expensive alternatives such as a high-tech wastewater disinfection plant (Goodnough 2007). Surface water supplies are limited in most areas, and will be further constrained in south Florida by the long-term effort to restore the Everglades ecosystem.

Floridians, therefore, can look forward to more intensive conservation efforts, such as strict limits on lawn watering, combined with promotion of alternative vegetation that requires less water than a grassy lawn. Water constraints are a major threat to the future of Florida's agriculture, by far the biggest user of water. Even the new proposals for sugar cane-based bioethanol, designed to reduce greenhouse gas emissions, will require continuing massive flows of water for irrigation.

New water supplies will increasingly mean new investment in more expensive alternative sources. New reservoirs are being built wherever possible, including underground storage of fresh water in some cases. Wastewater treatment is a growth industry in the state. Many areas have access to brackish ground water, aquifers that are less salty than ocean water but too salty for untreated use. In order to use these inferior supplies, communities have to build and operate desalination plants.

While traditional ground and surface water supplies often cost less than $1 per 1,000 gallons, desalination of brackish water can cost up to $3 per 1,000 gallons.[34] And the drawbacks of desalination are not limited to cost alone. The process results in large volumes of waste water requiring disposal; with the reverse osmosis process, used in almost all existing plants, 100 gallons of brackish water is turned into about 75 gallons of potable water and 25 gallons of briny byproduct. The brine is often pumped underground, or mixed with other wastewater to dilute it (Reeves

2007). Desalination also requires large amounts of energy; reverse osmosis consists of forcing water, at very high pressure, through thousands of fine-mesh filters. Additional reliance on desalination would increase the demand for electricity, which in turn would increase the demand for cooling water for power plants.

The one truly abundant potential source of fresh water, desalination of sea water, is even more expensive and problematical. It has been implemented on a small scale in the southern Keys, but at a cost of $5 per thousand gallons, desalination remains more expensive than bringing in water from the mainland via pipeline (Reid 2007). Industry sources estimate the costs of ocean desalination at $3 to $8 per thousand gallons.[35] The state's first large-scale ocean desalination plant was built for Tampa Bay Water, a regional authority in one of the most water-scarce regions. It has been plagued by technical problems, multi-year delays, and cost overruns, reaching a cost of $158 million by the time it began operation in 2003. The plant hopes to reach its design capacity of 25 mgd of fresh water, with costs a little above $3 per thousand gallons, by the end of 2007 (Barnett 2007; Reid 2007). In view of the problems with the Tampa Bay plant, no one else in Florida is rushing to build a similar facility.

Although costs of ocean desalination have come down in recent years, there are a wide range of problems that limit the appeal of the process, even when it runs smoothly. Plant construction may degrade the shoreline environment; sea water intake may do further damage to the ocean floor; the discharge of very salty brine may harm the local ocean environment; chemicals used in pretreatment of sea water add contaminants to the waste water; and the plants require large amounts of energy (Yuhas and Daniels 2006). Both brine disposal and energy needs are much greater with ocean desalination than with brackish water plants.

Finally, while the Tampa Bay plant is large compared to previous desalination efforts, it is small compared to Florida's water needs. To meet the growth in the demand for water through 2050 (as projected above), 186 Tampa-sized plants would be needed — more than one new plant coming on line every three months, from now through 2050.

In short, there are no believable supply-side options for providing this much water; most of the gap will have to be filled by conservation and reduction in demand.

Water system projections: Business-as-usual case

Meeting Florida's water needs will be challenging, even in the absence of climatic change. The business-as-usual climate scenario will make a bad situation much worse, with average temperatures rising by 10°F, rainfall decreasing from 54 to 49 inches per year, and sea levels rising by almost four feet, over the course of the twenty-first century.

Hotter, drier conditions will increase the demand for water for irrigation and other outdoor uses, while at the same time decreasing supplies. Surface water flows will be diminished by the decreased rainfall and increased evaporation. Ground water supplies will also gradually diminish, as less rainfall and more evaporation means less water percolating down through the soil to recharge the aquifers. The decreased rainfall will not be uniform and predictable from year to year; rather, there will be more frequent droughts, resembling the conditions of 2001 and 2007. With water levels in Lake Okeechobee and elsewhere dropping under drought conditions, the water supplies for much of south Florida, and much of the state's agriculture, are at risk.

Rising sea levels will lead to increased salt water infiltration into aquifers, particularly since water levels in the aquifers are dropping and fresh water recharge is diminishing. Thus ground water supplies, which provide most of the state's drinking water, will tend to become brackish.

Rising sea levels will also block the traditional water flow through the Everglades ecosystem, which is slowly being reconstructed at great expense. By 2100, in the business-as-usual scenario, all of Monroe County and two-thirds of Miami-Dade County will be inundated; the southern Everglades, including the national park, will no longer be a fresh-water ecosystem. This change will be an ecological catastrophe for most of the species that now inhabit the southern Everglades. It will also have incalculable, but likely extremely disruptive, effects on fresh water flows throughout southern Florida, placing surface water supplies at risk.

This description of expected impacts makes it clear that climate change will cause expensive damages to Florida's water supply, but does not give rise to any precise dollar estimate. For an approximation of supply costs, suppose that climate change means that more of the demand for water has to be met at $3 per thousand gallons, a typical cost for desalination of brackish ground water, and also an optimistic cost for ocean desalination (the estimated costs at Tampa Bay, once it is running smoothly; or the low end of the desalination industry's cost projections).

Desalination is energy-intensive, so its cost will be even higher if electricity prices rise. At the present-day cost of $3 per thousand gallons, 1 mgd for a full year costs $1.1 million. Even under the rapid stabilization scenario, many parts of Florida may be facing costs of this magnitude for any future increases in water supply. The business-as-usual scenario will reduce the current supplies of fresh water, requiring more reliance on new supplies at $3 per thousand gallons. If the business-as-usual scenario means that an additional 50 percent of current surface water supplies had to be replaced (in addition to the new sources needed in the rapid stabilization case) at a cost of $3 per thousand gallons, the cost increase due to business-as-usual conditions would be $1.8 billion per year. The greater danger is that water will not be available even at this price, and that environmental damages resulting from sea-level rise, and from the operation of desalination plants, will cause incalculably larger harms.

V. IMPACTS OF HURRICANES

In both the rapid stabilization and business-as-usual future climate outlooks for Florida, climate change is likely to have important effects on the economic damages and deaths that result from hurricanes. In order to calculate Florida's hurricane-related costs over the next 100 years for each scenario, we took into account coastal development and higher population levels, sea-level rise as it impacts on storm surges, and (for the business-as-usual case only) greater storm intensity. The calculation is described here in general terms, and in more precise mathematical detail in Appendix B.

HURRICANE DAMAGE PROJECTIONS

We used hurricanes striking Florida from 1990 to 2006 as a baseline in estimating the average economic damages and number of deaths for different categories of hurricanes[36] (see Appendix D for details on Category 4 and 5 hurricanes striking Florida during this period). Based on hurricane trends over the last 150 years, Florida can expect to suffer four out of ten mainland U.S. hurricanes and two-thirds of all mainland U.S. Category 5 storms. In an average 100 years, that's 28 in Category 1, 21 in Category 2, 19 in Category 3, four in Category 4, and one or two Category 5 hurricanes. These probabilities were applied to the average damages and deaths established for each category in order to estimate the impacts of an "average hurricane year." Given no change to the frequency or intensity of hurricanes striking Florida, the expected impact from Florida's hurricanes in an average year is $3.7 billion (in 2006 dollars) and 8 deaths (at the 2006 level of population).[37]

Table 22. Hurricanes Striking Florida from 1990 to 2006

	Average Impacts 1990 to 2006		Annual	Impacts in an Average Year	
Hurricane Category	Damages (billions of 2006$)	Deaths (scaled to 2006)	Probability of Occurance	Damages (billions of 2006$)	Deaths (scaled to 2006)
1	$0.7	6	0.28	$0.2	2
2	$3.9	15	0.21	$0.8	3
3	$7.0	6	0.19	$1.3	1
4	$15.7	34	0.04	$0.6	1
5	$62.9	57	0.01	$0.8	1
Total			**0.72**	**$3.7**	**8**

Sources: The large majority of data were taken from (Blake et al. 2007; National Hurricane Center 2007); a few data points were added from (CNN 1998; National Climatic Data Center 2005; National Association of Insurance Commissioners 2007).

Note: Where discrepancies existed, the NHC(National Hurricane Center 2007) data were used. NAIC (National Association of Insurance Commissioners 2007) data — used for two data points — are insured damages only; following the convention documented in NHC (National Hurricane Center 2007), these insured damages were double to estimate total damages.

We consider three factors that may increase damages and deaths resulting from future hurricanes; each of these three factors is independent of the other two. The first is coastal development and population growth — the more property and people that are in the path of a hurricane, the higher the damages and deaths (Pielke and Landsea 1998). Second, as sea levels rise, even with the intensity of storms remaining stable, the same hurricane results in greater damages and deaths from storm surges, flooding, and erosion (Pielke Jr. and Pielke Sr. 1997). Third, hurricane intensity may increase as sea-surface temperatures rise; this assumption is used only for the business-as-usual case (Emanuel 2005; Webster et al. 2005; Intergovernmental Panel on Climate Change 2007b).

Florida's projected population level and per capita Gross State Product (GSP) — identical for the rapid stabilization and business-as-usual scenarios — were calculated for each year from 2010 to 2100.[38] Following Pielke and Landsea (1998) hurricane damages are assumed to be proportional to GSP; this logic is extended to treat hurricane deaths as proportional to state population.

The projected sea-level rise, above year 2000 levels, for Florida in the rapid stabilization and business-as-usual cases was calculated for each year. In the rapid stabilization case, sea-level rise reaches 7 inches in 2100, and for the business-as-usual case, 45 inches. Nordhaus (2006) estimates that for every meter of sea-level rise, economic damages from hurricanes double, controlling for other kinds of impacts.

Nordhaus (2006) also estimates the impact of increasing atmospheric carbon dioxide levels and sea-surface temperatures on storm intensity and economic damages. According to his calculations, every doubling of atmospheric carbon dioxide results in a doubling of hurricane damages — independent of the effects of sea-level rise. Projected carbon dioxide levels were calculated for the business-as-usual case for each year (the rapid stabilization case assumes that hurricane intensity will remain constant).

Combining these effects together, Florida's projected hurricane damages for the year 2050 is $24 billion and 18 deaths for the rapid stabilization case, and $49 billion — 1.5 percent of GSP — and 37 deaths in the business-as-usual case. The annual cost of inaction is $25 billion and 19 extra deaths in 2050 and $104 billion and 37 extra deaths in 2100.

Table 23: Hurricanes Striking Florida: Cost of Inaction

	2025	2050	2075	2100
Damages (in billions of 2006 dollars)				
Rapid Stabilization Case	$12	$24	$37	$55
Business-As-Usual Case	$18	$49	$90	$159
Cost of Inaction	*$6*	*$25*	*$54*	*$104*
Damages (as a percentage of GSP)				
Rapid Stabilization Case	0.7%	0.7%	0.8%	0.8%
Business-As-Usual Case	1.1%	1.5%	1.9%	2.3%
Cost of Inaction	*0.4%*	*0.7%*	*1.1%*	*1.5%*
Deaths				
Rapid Stabilization Case	14	18	19	20
Business-As-Usual Case	21	37	47	57
Cost of Inaction	*7*	*19*	*28*	*37*

Source: Authors' calculations.

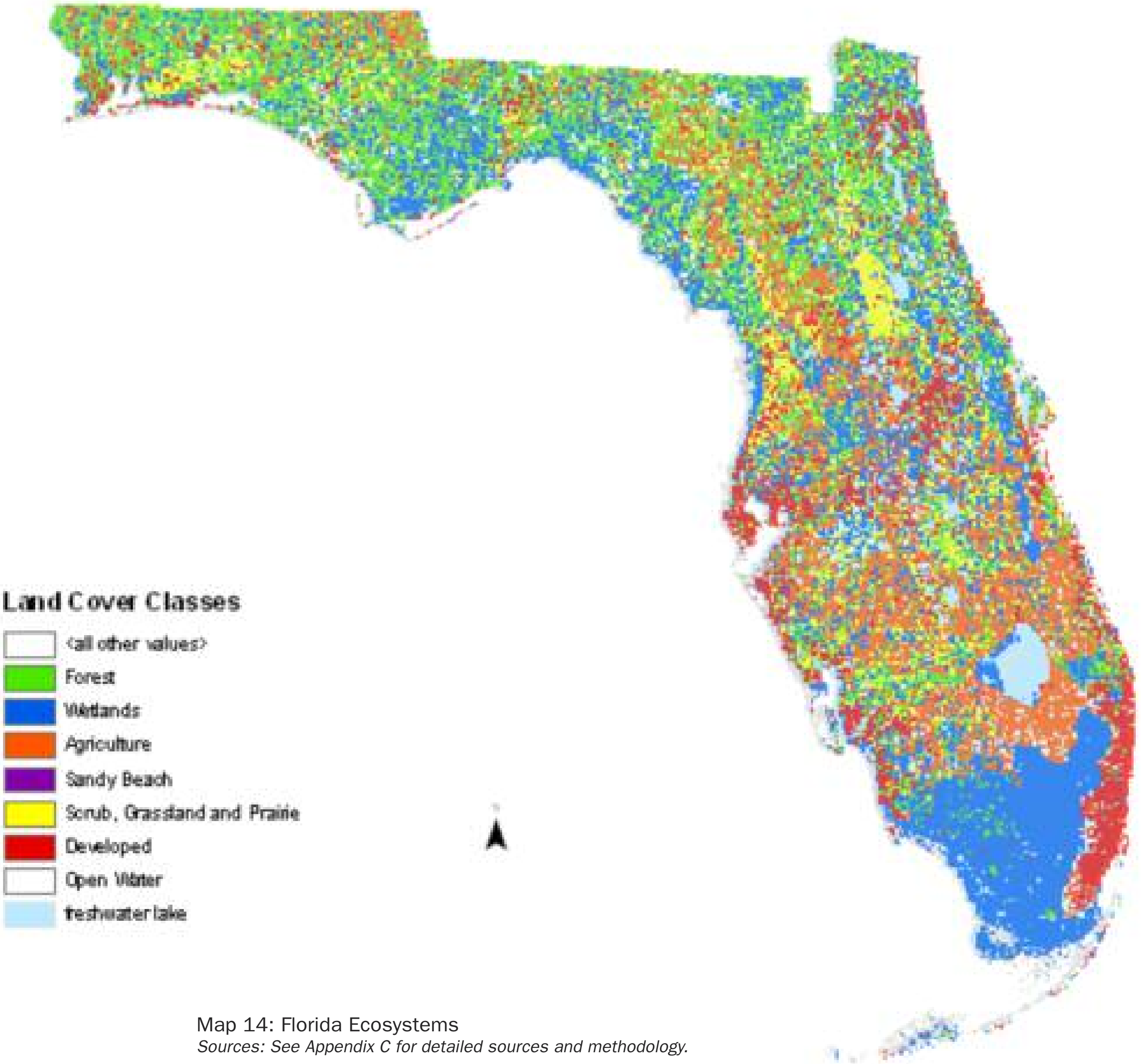
VI. ECOSYSTEMS

The economic damage that Florida will suffer in the business-as-usual case seems high enough even without any reckoning for the impacts of climate change on priceless natural ecosystems. Wholesale extinctions and ecosystem destruction are unavoidable in the business-as-usual future, and the strategy that could save the most species and ecosystems — allowing wetlands to migrate, taking over what are now dry lands — is extremely unlikely to occur, at least on a wide scale.

SEA-LEVEL RISE

Much of Florida's shoreline is made up of richly diverse coastal habitats, including estuaries, saltwater marshes, tidal flats, sandy beaches and barrier islands. All these habitats are at risk of disappearing under the waves as the seas around Florida rise 45 inches by 2100 in the business-as-usual case. Some of the species that live in these ecosystems may find it possible to migrate inland as waters rise, establishing new ecosystems along the new coastline. Many other species will be unable to adopt new territories, blocked by shoreline protections like seawalls, designed to maintain today's shoreline and land use.

Coastal estuaries will be among the ecosystems hardest hit by sea-level rise (Savarese et al. 2002; Intergovernmental Panel on Climate Change 2007b; Levina et al. 2007). These wetlands constitute one of Florida's most critical ecosystems. In estuaries, freshwater meets saltwater, creating a variety of habitats that can only exist in the resulting brackish water, such as mangroves swamps, saltwater marshes, tidal flats, seagrass beds, and oyster bars. Estuaries serve as nurseries and provide critical refuge and food sources for about 90 percent of Florida's most important recreational and commercial fish and shellfish species, as well as waterfowl and other wildlife. Wetlands also



Map 14: Florida Ecosystems
Sources: See Appendix C for detailed sources and methodology.

help filter pollutants, improving water quality; protect the coastline from storm surges and floods; and protect uplands from saltwater intrusion, among many other ecosystems functions that benefit human society (National Oceanic & Atmospheric Administration 2000a; National Wildlife Federation and Florida Wildlife Federation 2006).

Mangrove forests are an estuarine habitat that dominates much of southern Florida's subtropical coast. Many protected inner bays are mangrove-rimmed estuaries, a distinctive feature of the Everglades with its mixture of salt and freshwater. Fish such as snook and schoolmasters migrate in and out depending on the salinity of the water. Florida's mangrove forests are particularly important because they provide nurseries and shelter for many fish and wildlife species. Among the young protected

CASE STUDY: TEN THOUSAND ISLANDS

The Ten Thousand Island National Wildlife Refuge on the southwest coast of Florida is part of the largest expanse of mangrove forest in North America. The southern two-thirds of the 35,000 acre refuge protects mangrove habitat in the tidal fringes and numerous keys, while the northern third harbors saltwater marsh, ponds, and small coastal hammocks of coastal forest composed of oak, cabbage palms and tropical hardwoods.

Seagrass beds and mangrove swamps in the Ten Thousand Islands and Florida Bay serve as vital nursery grounds for roughly 200 species of marine fish, and the area is a critical refuge for dozens of bird species. Notable threatened and endangered species include West Indian manatee, bald eagle, peregrine falcon, wood stork, and the Atlantic loggerhead sea turtle. Estuarine wetlands like the Ten Thousand Islands are particularly sensitive to rising sea levels because of their low elevation (Savarese et al. 2002). As a result, the region's entire estuarine and wetland system could experience radical change in the next century, with the dramatic loss of pristine wetland ecosystems.

in this habitat are the gray snappers, an important commercial fish, and loggerhead turtles. The diversity of the mangrove ecosystem includes not only fish, invertebrates, amphibians, and reptiles, but also a variety of birds, such as egrets, roseate spoonbills, and the southern bald eagle, and mammals, such as manatees and an occasional bobcat or Florida panther. In recent years, as more of this habitat disappears, endangered species like the American crocodile will be increasingly threatened. Mangrove ecosystems protect the shoreline from erosion and dissipate the energy of storms, creating a natural barrier to storm surges from hurricanes (Savarese et al. 2002; Brooks et al. 2006).

Saltwater marshes, comprised mostly by grasses and other grass-like plants, occur in the zone between low and high tides. Most of Florida's saltmarshes occur on the Gulf Coast from Apalachicola to Tampa Bay to Cedar Key, and from Daytona Beach northward on the Atlantic Coast. They serve as natural filters and provide important habit for waterfowl and other wildlife (National Wildlife Federation and Florida Wildlife Federation 2006). The saltwater marshes create a safe nursery environment because larger fish cannot swim between the tightly packed grasses.

Tidal flats are areas of broad, flat land created by tides. They are generally composed of sandy or muddy soils and provide important sources of food for birds and other wildlife. They also play an important role in purifying pollutants that come from shore (National Wildlife Federation and Florida Wildlife Federation 2006). Many of the animal species that live in the tidal flats of Florida are similar to those that live in the mangrove ecosystem. Invertebrates like the queen conch, the Florida sea cucumber, and blue crab spend their lives in the mud while birds such as the yellow-crowned night-heron, Florida mottled duck, and marlin also make their home in tidal flats.

Estuaries, bays and other coastal and marine ecosystems already have been radically altered by human development, leading to significant declines in fish and wildlife populations. The construction of flood control and water diversion projects that alter natural freshwater flows into these ecosystems and raise nutrient concentrations and salinity have contributed to the loss of one-third of Florida's seagrass beds and half of its saltmarsh, mangrove and other wetland habitat. Across the United States, half of all estuaries now show significant levels of nitrate-driven eutrophication — increases in organic matter and a related depletion of oxygen in the water — leading to decreased water clarity, more frequent and harmful algae blooms and degraded sea grasses and corals (National Oceanic & Atmospheric Administration 2000a; Scavia et al. 2002; National Wildlife Federation and Florida Wildlife Federation 2006).

Rapid sea-level rise would further threaten estuarine habitats. Rising water levels would impact these critical ecosystems in two interconnected ways: inundation, as coastal wetlands become open water; and inability to migrate inland, due to barriers from human development and habitat fragmentation. The combined impact of inundation and impeded migration will be a substantial loss of coastal estuarine habitat. Historically, coastal wetland habitat such as mangroves have expanded inland or upward by accumulating sediment and peat in order to keep pace with sea-level rise (Michener et al. 1997; National Oceanic & Atmospheric Administration 2000a). In the absence of barriers to migration, wetlands will continue to encroach upslope and inland as soils are persistently inundated. Meanwhile, freshwater marsh and swamp habitats of the interior Everglades system and elsewhere will be displaced. Mangrove swamps, in turn, would be converted to shallow marine habitats in open water (National Oceanic & Atmospheric Administra-

CASE STUDY: FLORIDA’S SANDY BEACHES AND BARRIER ISLANDS

Many of Florida’s larger barrier islands are inhabited and are popular tourist destinations, such as Clearwater Beach and Treasure Island, in the Tampa Bay area, and Miami Beach, Sunny Isles Beach, and the Bay Harbor Islands in the Miami area. Further up the Gulf Coast, St. George’s Island and other barrier islands protect several parts of the panhandle. Under the business-as-usual scenario, the great majority of these islands will be completely inundated. Barrier islands face more complicated impacts from sea-level rise than ordinary coastlines because they tend migrate as sand is either eroded or accumulated. The protective buffer that these islands provide from storm surges also protects estuaries. Mudflats and marshlands mix with lagoons and bays, creating a variety of habitats for wildlife. When the lagoonal area between the islands shrinks and grows, and barrier islands shift their position, the salinity level of the water — a critical characteristics for many species — changes. The most vulnerable habitats are saltmarshes and tidal flats along the Gulf Coast and in South Florida, which contain a large portion of Florida’s wildlife diversity (National Wildlife Federation and Florida Wildlife Federation 2006).

tion 2000a; Scavia et al. 2002; Doyle et al. 2003; Lodge 2005; Brooks et al. 2006; National Wildlife Federation and Florida Wildlife Federation 2006; Levina et al. 2007). In Waccasassa Bay State Preserve on Florida’s Gulf coast, sea-level rise would increase saltmarsh, at the expense of coastal forests (Castaneda and Putz 2007), and in the Big Bend region of northwest Florida, large areas of marshland would be converted to open water as forest is converted to marsh. Some marshlands could migrate into forested zones, but overall, net terrestrial habitat would be lost to an open water environment (Doyle 1997).

SALTWATER INTRUSION

As sea levels rise, saltwater intrudes on freshwater stored underground in natural aquifers, threatening not only water supplies but also a number of ecosystems, including coastal freshwater lakes and low-lying coastal forests, where even minor intrusion of saltwater can have measurable impacts.

Already, native palms in the Waccasassa Bay State Preserve on Florida’s Gulf Coast and pine trees in the Keys have been damaged or are dying off from exposure to saltwater associated with sea-level rise (Ross et al. 1994). The regeneration of cabbage palm, red cedar and other coastal trees in the Big Bend region of the Florida Panhandle has also been hampered by saltwater intrusion (Williams et al. 1999). As sea-level rise continues, the species and landscape diversity of low-lying coastal areas and island ecosystems such as the Florida Keys and Big Bend will decline as diverse upland communities are replaced by mangroves.

HIGHER TEMPERATURES AND LESS RAINFALL

Higher average temperatures and lower precipitation rates under the business-as-usual scenario will have especially damaging effects on forested areas in the state’s temperate Panhandle and freshwater systems such as natural lakes, streams and wetlands in central and northern parts of the state. Studies modeling species loss in Florida show that biodiversity would be extremely susceptible to increasing temperatures (Dohrenwend and Harris 1975; Harris and Cropper 1992). A 3.5°F increase in temperature — a level reached by 2035 in the business-as-usual scenario — would lead to extensive loss of natural range by ecologically important temperate trees and shrubs; coupled with less rain, much of the state’s naturally forested areas would degrade to open scrub or dry grasslands (Box et al. 1999; Crumpacker et al. 2001).

Species at the southern end of their temperature limit will find it difficult to adapt to 10°F in

CASE STUDY: BIG BEND NATIONAL WILDLIFE REFUGE

The Big Bend coast of north and central Florida includes more than 120,000 acres of undisturbed coastal wetlands and saltmarshes that abut vast coastal forests, with a shallow surrounding seabed that stretches miles into the Gulf of Mexico. One-fifth of all estuarine wetlands along the U.S. coastline of the Gulf are in Florida's Big Bend, including five national wildlife refuges: wetlands in the Lower Suwannee Refuge; diverse beaches, coastal marshes and upland forests in the Cedar Keys Refuge; and prime estuarine habitat in Chassahowitzka Refuge. Big Bend is home to a diversity of wildlife, like the manatee, loggerhead sea turtle, white ibis, and black bear. The effects of rising sea levels and saltwater intrusion already can be observed at Big Bend in the stands of dead cabbage palms that populate the seaward edge of the saltmarshes (Williams et al. 1999). Other Big Bend tree species, like southern red cedar, live oak and sugarberry, have also proved vulnerable to salt exposure through tidal inundation. The retreat of coastal forest as sea levels rise may be hastened by the loss of saltwater marsh, which plays a buffering effect by filtering saltwater.

a century, and most of Florida's 119 native fish species could be eliminated from the state altogether (Mulholland et al. 1997; National Wildlife Federation and Florida Wildlife Federation 2006). At the same time, Florida's subtropical species, like mangroves and snook, could migrate northwards and inland with warmer temperatures, so long as human development and habitat fragmentation does not impede their expansion. Opportunistic non-native species, including introduced tropical fish and invasive plants such as the Australian pine tree and the Brazilian pepper shrub, are expected to expand their range as a result of higher temperatures, possibly suppressing native species in the process (Mulholland et al. 1997; National Wildlife Federation and Florida Wildlife Federation 2006).

Florida's temperate forests will face two different types of impacts: loss of species, and contraction of natural range. Forest ecosystems are expected to lose about one-third of their species in the northern peninsula, and one-fifth in the western Panhandle (Crumpacker et al. 2001). Reductions in geographical range compound the loss of biodiversity.

Florida's mixed conifer and hardwood forests, located in the panhandle and northern sections of the state, are expected to retreat northward to Georgia and Alabama (Environmental Protection Agency 1997). The natural distribution of woody plants in Florida is strongly controlled by climate factors — in particular by winter temperatures — and not soil type or precipitation levels. In general, the ranges for temperate woody species are expected to contract with warming and drying, while ranges for subtropical species will shift or expand northward, or inland, or both (Environmental Protection Agency 1997; Box et al. 1999). Woody species would experience range contractions of between 76 and 97 percent in the Florida Panhandle and between 30 and 65 percent in the upper peninsula by 2035 in our business-as-usual case. Even the 2°F increase that we forecast for 2020 is expected to reduce the range of some species. Shortleaf pine, American beech and black willow will suffer range reductions of 90 to 100 percent, while southern red oak, swamp chestnut oak and southern magnolia will lose 23 to 40 percent of their range.

CASE STUDY: OSCEOLA NATIONAL FOREST

Northeastern Florida's Osceola National Forest, 50 miles west of Jacksonville, contains two thousand acres of pine-flatwood forest and cypress-hardwood swamps. The Osceola is home to a rich ecosystem of diverse species including the endangered red-cockaded woodpecker and the alligator. In addition to playing a critical conservation role, these forested woodlands and swamps provide a wide range of valuable recreational activities for thousands of Florida residents and out-of-state visitors each year, including camping, hiking, swimming, fishing, and hunting. The Osceola will experience dramatic changes with global warming under the business-as-usual case, including a significant reduction in forested range and the loss of 55 percent of its species by 2030 (Crumpacker et al. 2001).

Species adapted to both temperate and sub-tropical climates, like the cabbage palmetto, will only experience a very slight increase in range, while subtropical native species currently endemic to southern Florida — Florida poison tree, pigeon-plum and Florida stranger fig — will experience large expansions in range if unimpeded by human development and other factors. Aggressive native, heat-tolerant plant species that already range throughout most of Florida — such as the saw palmetto and the southern bayberry — are likely to increase their density in response to warming and exert significant negative competitive pressure on other native species (Box et al. 1999).

CASE STUDY: OKEFENOKEE NATIONAL WILDLIFE REFUGE

Okefenokee National Wildlife Refuge, located in southeast Georgia and northern Florida, is North America's largest swamp, covering 438,000 acres. Most of the swamp is classified as a freshwater wetland, abutted by large tracts of riparian forest (mixed and pure cypress stands, blackgum forest, bay forest), swamp islands and prairie habitats. More than 200 species of birds have been identified in the refuge, including several endangered species such as the red-cockaded woodpecker, American bald eagle, and the wood stork. Rainfall plays a central role in the life of freshwater ecosystems. In Florida's Okefenokee Swamp, rain accounts for fully 95 percent of the water in the Swamp, with 80 percent returned to the atmosphere through evaporation and transpiration (U.S. Fish & Wildlife Service 2007b). The increasing frequency of droughts would affect the swamp's rich mosaic of vegetation and the density and distribution of its wildlife. Threatened and endangered species sheltered in the refuge would be hardest hit by such changes.

Freshwater ecosystems will also be affected in important ways by higher temperatures and less rainfall. Longer growing seasons, fewer and less severe freezes and higher temperatures year-round will reduce the habitat of cool-water species and encourage the expansion of subtropical species northward, including several exotic nuisance species currently confined to southern Florida. Reduced water quality due to lower concentrations of dissolved oxygen and increased drying of riparian wetland soils as a result of shorter flooding periods will have negative impacts on freshwater wetlands (Mulholland et al. 1997). Many native, temperate fish species will be lost and replaced with exotic subtropical species.

More intermittent rainfall and high summer temperatures will have significant impacts on streams and rivers, eventually lowering biodiversity in these critical ecosystems (Mulholland et al. 1997). Increased salinity and other downstream impacts on estuarine ecosystems are also expected (Scavia et al. 2002). Greater freshwater withdrawal to meet human needs will exacerbate the impact on freshwater and estuarine ecosystems. In north Florida, warm temperate lakes are projected to undergo substantial changes as warming shifts the conditions to a subtropical environment, increasing productivity and nutrient cycling rates as well as protozoa and bacteria populations. Subtropical blooms of blue-green algae and other exotics, now primarily confined to subtropical lakes, will expand northward (Mulholland et al. 1997).

SEVERE HURRICANES

Mangrove forests, freshwater marshes, and coral reefs are all vulnerable to hurricane damage. Since mangroves occupy intertidal coastal areas — between the high and low tide marks — they are particularly susceptible to hurricane winds and storm surges. Damage can range from defoliation to tree blowdowns. As hurricanes become more intense, studies indicate that mangrove trees will become shorter and forests will contain a higher proportion of red mangroves, which have a higher tolerance for salt water than other mangrove species (Doyle et al. 2003). Evidence from past hurricanes show that with extreme events some mangrove forests may be destroyed altogether, as happened in Hurricane Donna in 1960, which reached so far inland that what had been thriving mangrove forests were left without any vegetation.

Freshwater and brackish marshes are also impacted by hurricanes, with storm surges transporting unhealthy amounts of saltwater and sediment into these environments. During Hurricane Andrew, for example, storm surges dumped large quantities of sediment into low-salinity marshlands, smothering vegetation. Hurricane-induced erosion caused similar problems with the distribution of substrate and seaweed around the marshes, likewise suffocating plants. In freshwater marshes the introduction of too much additional saltwater caused salt burn of vegetation, harming or killing the plants by exceeding their salinity tolerance (Scavia et al. 2002). The salinity levels in fresh marshes can remain elevated for a year or more after hurricanes, resulting in long-term changes in plant communities (National Oceanic & Atmospheric Administration 2000a).

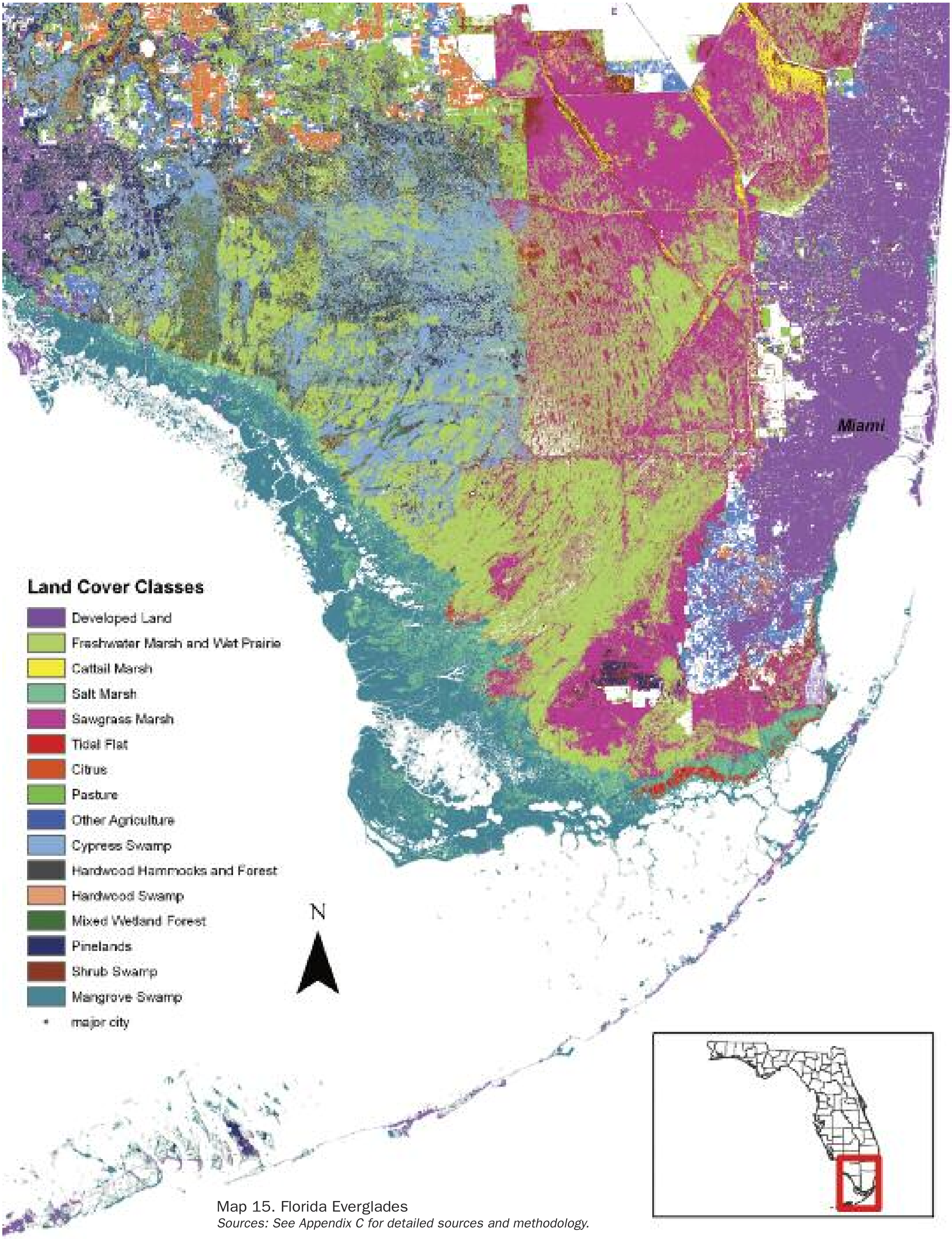
IRREVERSIBLE IMPACTS: THE EVERGLADES EXAMPLE

The irreversible ecosystem impacts of unconstrained climate change are best illustrated by the effects on Florida's signature ecosystem: the Everglades.

The Florida Everglades, in the southern tip of the state, is a United Nations' World Heritage Site and a unique treasure of the natural world. The Everglades encompasses a cornucopia of natural environments: freshwater marshes; wetland tree islands; cypress heads, domes, and dwarf cypress forests; tropical hardwood hammocks; pinelands; mangrove swamps and mangrove islands; coastal saline flats, prairies, and forests; tidal creeks and bays; and shallow, coastal marine waters (Lodge 2005). These diverse Everglades habitats sustain more than 11,000 species of seed-bearing plants — including 25 different orchids — 350 kinds of birds, 150 types of fish, and innumerable invertebrates (World Wildlife Fund 2007b).

The Everglades once spanned 4,000 square miles of South Florida, from the Kissimmee Chain of Lakes just south of Orlando, down the River of Grass all the way to Florida Bay and the Keys. After a long and sordid history of attempts to drain land, together with the installation of water-diverting structures, 70 percent of natural water flow through the Everglades has been diverted, and the Everglades is now half its original size. This unparalleled, and in hindsight ill-conceived, engineering project has affected the timing and distribution of the Everglades' freshwater: the current water cycle no longer meets needs of plants and animals that live there. Water quality has also deteriorated due to heavy loads of phosphorus, nitrogen, and mercury that flow from agricultural and urban sources. A Comprehensive Everglades Restoration Plan (CERP) is currently being implemented in an attempt to restore this ecosystem. Put in place by the Water Resources Development Act of 1992, CERP was approved by Congress in 1999. This program sets out to restore, preserve, and protect the Everglades while still providing flood protection and supplies of freshwater (Lodge 2005; World Wildlife Fund 2007a).

As sea levels rise, water may encroach 12 to 24 miles into the broad low-lying area of the Everglades, leaving the lower Everglades completely inundated. Currently, approximately one-third of the Everglades lies within the vulnerable zone, at risk from 27 inches of sea-level rise by 2060 in the business-as-usual case. The planned investment in Everglades' restoration is necessary to keep this ecosystem resilient enough to withstand global warming. If business-as-usual emissions continue, however, significant portions of the Everglades will be flooded and lost to the sea. As much



Map 15. Florida Everglades

Sources: See Appendix C for detailed sources and methodology.

of the Everglades' wetlands are converted into open water, nurseries and shelter for many fish and wildlife species will be lost. In addition, mangroves protect the shoreline from erosion and trap sediments and debris, and loss or migration of this ecosystem will greatly alter the Everglades' ecology (Natural Resources Defense Council and Florida Climate Alliance 2001; Titus and Richman 2001). The 10°F increase in air temperature expected by 2100 will draw species northward out of the Everglades, but if current drylands are protected with seawalls this migration will be thwarted, and species will disappear from Florida, or in some cases made extinct. More intense hurricanes will weaken the ecosystems within the Everglades and may render some species more vulnerable to pests or disease.

Florida is an important reservoir of biodiversity in the United States, with a rich mix of temperate and subtropical ecosystems. The Everglades is projected to lose one-quarter to one-third of its species richness due to climate change (Crumpacker et al. 2001). For example, the Everglades is the breeding ground for the endangered American Crocodile. As sea levels rise and temperatures increase, the northward shift of mangrove forests may disrupt crocodile breeding patterns and nesting areas for this species may become repeatedly flooded, increasing the mortality rate (U.S. National Park Service 1999; University of Florida: Florida Museum of Natural History 2002).

APPENDIX A. FLORIDA LANDCOVER BY COUNTY IN VULNERABLE ZONE

			AREA IN VULNERABLE ZONE BY LAND COVER (square miles)											
	Total Area (square miles)	Vulnerable Zone (square miles)	Developed	Bare Soil, Clearcut, or Extractive	Citrus	Pasture	Other Agriculture	Forest	Scrub, Grassland, Prairie, or Sandhill	Sandy Beach	Marsh and Tidal Flats	Mangroves	Swamp and Forested Wetland	Open Water
Miami-Dade	1983	1374	73	24	1	2	22	24	1	0	959	101	61	73
Monroe	1055	1051	29	0	0	0	0	26	0	1	323	493	76	102
Collier	2039	378	25	1	0	0	5	15	1	0	85	134	86	25
Volusia	1220	274	23	1	0	1	0	32	8	1	36	9	54	108
Brevard	1052	200	35	0	7	0	0	55	19	2	38	6	4	33
Duval	852	159	19	1	0	0	0	12	2	1	39	0	3	80
Stjohns	663	157	15	2	0	1	5	27	4	1	25	0	23	54
Lee	837	150	26	1	1	0	1	18	3	2	6	54	2	36
Franklin	552	126	4	1	0	0	0	24	3	5	28	0	48	13
Gulf	569	117	2	1	0	0	0	21	4	2	8	0	69	10
Putnam	827	117	6	1	0	0	4	12	2	0	0	0	26	65
Taylor	1050	113	1	3	0	0	0	18	2	0	37	0	45	6
Bay	773	90	18	2	0	0	0	30	7	4	12	0	12	7
Charlotte	726	85	13	0	0	0	0	3	2	0	11	24	1	31
Dixie	715	79	1	4	0	0	0	11	3	0	32	0	21	7
Wakulla	617	70	3	1	0	0	0	14	2	0	32	0	9	8
Seminole	345	68	2	0	1	1	0	5	1	0	13	0	15	29
Nassau	664	64	2	0	0	0	0	3	0	0	31	0	4	23
Levy	1137	63	0	0	0	0	0	4	0	0	43	0	3	12
Flagler	508	53	7	0	0	1	0	10	3	0	6	0	10	16
Pinellas	287	51	29	1	0	0	0	6	1	1	1	7	0	6
Manatee	762	42	10	0	0	1	1	3	1	0	3	7	1	14
Hillsborough	1070	39	13	0	0	0	0	3	1	0	5	9	1	6
Clay	644	39	3	0	0	0	0	4	0	0	0	0	6	25
Citrus	624	37	1	0	0	0	0	3	0	0	19	0	2	12
Martin	665	33	10	0	0	0	0	3	2	1	0	3	2	12
Stlucie	578	30	10	0	0	0	0	3	1	1	1	7	2	4
Sarasota	578	27	15	0	0	0	0	3	1	1	2	1	1	4
Palmbeach	2217	23	16	0	0	0	0	1	0	0	0	1	0	4
Lake	1157	21	0	0	0	0	0	1	0	0	0	0	16	3
Indianriver	514	20	7	0	0	0	0	2	0	1	1	5	1	2
Hernando	490	17	1	0	0	0	0	1	0	0	9	0	0	6
Broward	1219	15	11	0	0	0	0	0	0	0	0	1	0	2
Pasco	765	13	3	0	0	0	0	1	0	0	4	1	0	4
Orange	1003	10	0	0	0	0	0	0	0	0	6	0	3	1
Escambia	671	10	2	0	0	0	0	1	0	2	1	0	0	3
Santarosa	1024	7	1	0	0	0	0	1	0	0	3	0	0	2
Jefferson	612	6	0	0	0	0	0	0	0	0	5	0	0	1
Walton	1069	5	1	0	0	0	0	2	0	0	1	0	1	1
Liberty	843	5	0	0	0	0	0	1	0	0	0	0	4	0
Okaloosa	942	2	0	0	0	0	0	0	0	0	0	0	0	2
Marion	1662	1	0	0	0	0	0	0	0	0	0	0	1	0

APPENDIX B. HURRICANE DAMAGES METHODOLOGY

POPULATION AND DEVELOPMENT

Florida's projected population level and GSP (in 2006 dollars) were calculated for each year from 2010 to 2100. Following Pielke and Landsea (1998) hurricane damages are treated as proportional to GSP; in addition, this logic is expanded upon to treat hurricane deaths as proportional to state population. The resulting sets of population factors and development factors for each year are applied to the expected value of Florida's hurricane deaths and damages, respectively:

$$(1)\ \text{PopFactor}_{yr} = \frac{\text{Population}_{yr}}{\text{Population}_{2000}}$$

$$(2)\ \text{DevFactor}_{yr} = \frac{\text{Population}_{yr} * \text{PerCapitaGSP}_{yr}}{\text{Population}_{2000} * \text{PerCapitaGSP}_{2000}}$$

SEA-LEVEL RISE

The projected sea-level rise, above year 2000 levels, for Florida in the rapid stabilization and business-as-usual cases was calculated for each of the modeled years. In the rapid stabiliztaion case, sea-level rise reaches 180mm in 2100, and for the business-as-usual case, 1150mm. Nordhaus (2006) estimates that for every meter of sea-level rise, economic damages from hurricanes double, controlling for other kinds of impacts. To arrive at this estimate, Nordhaus constructs a geographic grid with elevations and capital stock values (assumed to be proportional to average income) for each cell. Using this grid, he models incremental sea-level rise and makes the assumption that damages are proportional to vulnerable capital stock. In modeling Florida impacts, Nordhaus' estimated impact is used both for economic damages, as he intended, and for hurricane deaths. Sea-level rise (SLR) factors, by year, for each of the two scenarios, are constructed based on this estimate:

$$(3)\ \text{RSSLRFactor}_{yr} = 1 + (\text{RSSLR}_{yr}) / 1000$$

$$(4)\ \text{BAUSLRFactor}_{yr} = 1 + (\text{BAUSLR}_{yr}) / 1000$$

STORM INTENSITY

Nordhaus (2006) also estimates the impact of increasing atmospheric CO_2 levels and sea-surface temperatures on storm intensity and economic damages. Based on a Monte Carlo (random) draw of storm frequency and intensity, Nordhaus estimates the expected damages from future hurricanes. He assumes that storm frequency will remain at the historical average, but maximum wind speeds will increase by 9 percent with a doubling of atmospheric CO_2. Using a regression analysis of past hurricanes, Nordhaus finds that hurricane power rises as the cube of maximum wind speed (a result confirmed by existing literature) and that hurricane damages rise as the cube of hurricane power. According to his calculations, every doubling of atmospheric CO_2 results in a doubling of hurricane damages — independent of the effects of sea-level rise. Again, Nordhaus estimate impacts are for economic damages, but are used here for deaths as well. Projected CO_2 levels were calculated for the business-as-usual case for all modeled years (the rapid stabilization case assumes that hurricane intensity will remain constant). Business-as-usual storm intensity (SI) factors for each year are as follows:

$$(5)\ \text{BAUSIFactor}_{yr} = \frac{\text{BAUCO2Concentration}_{yr}}{\text{BAUCO2Concentration}_{2000}}$$

COMBINED EFFECTS OF ALL IMPACTS

Future economic damages from Florida's hurricanes are calculated by adjusting the expected value (EV) of hurricane damages upwards, using the development factor, rapid stabilization or business-as-usual sea-level rise factor, and (for the business-as-usual case only) storm intensity factor:

$$(6)\ \text{RS-Damage}_{yr} = \text{EVDamage}_{yr} * \text{DevFactor}_{yr} * \text{RS-SLRFactoryr}$$

$$(7)\ \text{BAU-Damage}_{yr} = \text{EVDamage}_{yr} * \text{PopFactor}_{yr} * (\text{BAU-SLRFactor}_{yr} + \text{BAU-SIFactor}_{yr})$$

Future economic deaths from Florida's hurricanes are calculated by adjusting the expected value of hurricane deaths using the population factor, rapid stabilization or business-as-usual sea-level rise factor, and (for the business-as-usual case only) storm intensity factor:

$$(8)\ \text{RS-Deaths}_{yr} = \text{EVDeaths}_{yr} * \text{PopFactor}_{yr} * \text{RS-SLRFactor}_{yr}$$

$$(9)\ \text{BAU-Deaths}_{yr} = \text{EVDeaths}_{yr} * \text{PopFactor}_{yr} * (\text{BAU-SLRFactor}_{yr} + \text{BAU-SIFactor}_{yr})$$

APPENDIX C. GIS METHODOLOGY

Unless otherwise noted, all data used in this study were downloaded from the Florida Geographic Data Library (FGDL) website: http://www.fgdl.org/

ELEVATION MAPPING

To estimate the impact of sea-level rise on land area, populations, and public and private assets and infrastructure, we began with a 1:250,000 Digital Elevation Model (DEM) map of the State of Florida, and divided the state into "vulnerable" and "not vulnerable" zones demarcated by 1.5 meters of elevation and other factors described by Titus and Richman (2000) as corresponding to 27 inches of sea-level rise.[39] We used USGS 1:250,000 DEM (90m cells) for statewide elevation processing and analysis.

The data sets that went into this processing were:

- NOAA Medium Resolution Digital Vector Shoreline (Filename: allus80k.shp). Downloaded from the USGS Coastal and Marine Geology Program Internet Map Server — Atlantic and East Coast (http://coastalmap.marine.usgs.gov/regional/contusa/eastcoast/atlanticcoast/data.html). We clipped the allus80k.shp file to a smaller file that included the entire Florida coast plus additional margins to the north and west, to ensure that no coastline was left out. We then projected this clipped shoreline into the coordinate system used by the Florida Geographic Data Library.
- USGS 1:250,000 DIGITAL ELEVATION MODEL (Filename: USGSDEM). Downloaded from the Florida Geographic Data Library (http://www.fgdl.org/)
- HISTORIC AND PROJECTED POPULATIONS OF FLORIDA COUNTIES (Filename: CNTPOP_2004). Downloaded from the Florida Geographic Data Library (http://www.fgdl.org/)

The USGS DEM original elevation values ranged from 0–114 (meters). These were reclassified using the ArcGIS "reclass" function as follows:

0 = 0
1 = 1
2 = 2
3 = 3
4 – 114 = 4

We used the raster-mask environmental setting to mask out any cells falling outside of the *NOAA Medium Resolution Digital Vector Shoreline* polygon boundary. This was necessary in order to mask out zero elevation values in the DEM that were offshore. The result is a re-classed digital elevation model where the 0-3 elevation values match the original for those cells inside the NOAA shoreline; values from 4 meters and higher are all set to 4, and zero values outside the NOAA shoreline are set to NO DATA through the masking operation. The cell size remains 90 meters. All remaining data cells coded 0 or 1 were coded as being within the vulnerable zone ("in"). All remaining data cells coded as 3 or 4 were coded as being outside the vulnerable zone ("out"). We call this *vulnfin*.

RASTER TO VECTOR DATA CONVERSION

In order to overlay the vulnerable zone on other GIS layers, we converted the processed DEM data to a vector polygon data format. This inevitably results in some loss of spatial data accuracy, and at large scales ("zoomed in" to show small areas in detail) the data appears very pixilated and jagged. The result is v*uln_in_out_poly*.

DATA PROCESSING

The vulnerable zones polygon data layer was processed in three different ways, one for census data processing, a second way for all other facilities and infrastructure, and a third for land cover. These are described below.

Population analysis and demographic data processing

Our base data on populations and demographics are from the U.S. Census 2000's blkgrp2000_sum3 dataset, which we downloaded from FGDL.

Throughout our analysis, we assume that populations are homogenously distributed across each census block group. Thus, to estimate the population vulnerable to sea-level rise in a given block group, we multiply the percent land area vulnerable (i.e., total area less area covered by inland lakes and waterways) in that block group by the group's total population. This simplifying assumption was necessary because more detailed data on population density is not publicly available from the U.S. Census Bureau.

We used the following process to remove coastal and inland waterways from our demographic analysis:

1. For inland waters, we used the HYDROS data layer from FGDL and selected out codes for water and streams, exporting these to their own data layer, called *hydros_water_selected*.
2. We then used the ERASE function to erase *hydros_water_selected* from *blkgrp2000_sum3* to get each block group's dry area only. The resulting layer is called: *blockgrp2000_sum3_inlandwaters_erased*.
3. To eliminate coastal waters, we then clipped *blockgrp2000_sum3_inlandwaters_erased* by *countypop2004* to estimate only the dry-land areas of census block groups. The resulting layer is: *blockgrp2000_sum3_inlandwaters_erased_clipped_by_countypop2004*.
4. In the attribute table, we then calculated two new fields:
   a. area_dry = dry area (square meters)
   b. acres_dry = dry acres for each census block group.
5. The field "original acres" has the acres of the entire block before water and ocean were taken out.
6. We then used the "INTERSECT" operation with the *vuln_in_out_poly data set* to generate the vulnerable zone for each block group. The resulting layer is: *blockgrp2000_sum3_inlandwaters_erased_clipped_by_countypop2004_intersect_vuln_in_out_poly*.
7. We then created new attributes for this layer:
   a. vuln_zone: 0 and 1 = vulnerable area; 3 and above = not vulnerable)
   b. zone_area = area of each blockgroup_vulnerability zone in square meters
   c. zone_acres = area of each blockgroup_vulnerability zone in acres
   d. zone_fract = zone_area/area_dry. This can be used to allocate population and other raw numbers data to zones.

Because populations and assets are highly concentrated in urban areas, we used more detailed data from the National Elevation Dataset (NED) to generate elevation maps of the Jacksonville, Tampa Bay-St. Petersburg, Miami-Dade County, and Ft. Lauderdale areas. However, these were not used in the data extraction or analysis portion of the project, only for maps.

FACILITIES AND INFRASTRUCTURE

To process facilities and infrastructure, we intersected the *vuln_in_out_poly* data set with the FGDL's county boundary data set *(cntbnd)* and calculated a zone fraction for each IN and OUT based on recalculated areas. This data set was then used as the overlay data set for all facilities and infrastructure. Note that inland water bodies were not eliminated from this data layer.

All data related to facilities and infrastructure were downloaded from the Florida Geographic Data Library website, with the exception of roads data which came from StreetMap USA (ESRI). In our analysis of point data on facilities such as schools and medical centers, minor data loss was incurred when points fell on the border between two vulnerability zones. In most cases the number of points involved was negligible (5 religious centers lost from a population of 20,735; 5 lodging facilities lost out of 4650; 1 medical facility lost out of 13,381; 1 assisted rental home out of 1664), and in no case did it significantly effect our results.

LAND COVER

For calculating the various types of land cover square miles, we used the FGDL's Habitat and Landcover data set (GFCHAB_03). We reclassed the *vulnfin* raster data layer into 1=vulnerable and 0=not vulnerable, and then multiplied this through the landcover raster data set. The result was a landcover data set for covering only land cover in the vulnerable zones. From this we could calculate area for each land cover in the vulnerable zone.

COASTLINE ANALYSIS

We generated a map based on the U.S. Geological Survey's Coastline Vulnerability Index (CVI) data (http://woodshole.er.usgs.gov/project-pages/cvi/) and estimated the number miles of each class of coastline vulnerable to sea-level rise in each coastal county. Because shoreline data sets vary widely in scale, the estimated miles generated by GIS software from coastline data sets also varies widely.

MAP SOURCES

Map ES-1 and Map 2. Florida: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 3. North Peninsula: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 4. South Peninsula: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 5. Panhandle: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 6. Agriculture in Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 7. Developed Land in Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 8. Miami/Fort Lauderdale: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 9. Tampa/St Petersburg: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 10. Jacksonville: Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 11. Florida Sea-Level Rise: Coastal Vulnerability Index (CVI)

Source Coastal Vulnerability to Sea-Level Rise (Hammar-Klose and Theiler 2001).

Map 12. Transportation in Areas Vulnerable to 27 Inches of Sea-Level Rise

Sources: road network data from US Streets Dataset (Environmental Systems Research Institute 2005); vulnerable zones data from NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

Map 13. Principal Miami-area Power Plants at Risk from Storm Surges
Source Background map from Google Earth. For other data, see sources to Table 19.

Map 14. Ecosystems in Areas Vulnerable to 27 Inches of Sea-Level Rise
Source FDEP Ecological Regions dataset (Florida Department of Environmental Protection 2001).

Map 15. Florida Everglades
Source FDEP Ecological Regions dataset (Florida Department of Environmental Protection 2001).

APPENDIX D. PAST CATEGORY 4 AND 5 HURRICANES

The Saffir/Simpson categories rate storms from 1, the least powerful tropical storm to be rated a hurricane, to 5, storms with wind speeds of at least 155 mph. On August 25, 2005, Katrina first made landfall in southern Florida as a Category 1 hurricane, causing fatalities and significant economic damage. After reaching Category 5 intensity over the central Gulf of Mexico, Katrina weakened to Category 3 before striking Florida's northern Gulf coast, Mississippi, and Louisiana (National Hurricane Center 2007). Katrina has been billed as the costliest and the third deadliest hurricane to strike the United States with $144 billion (scaled to 2006 dollars) in damage costs and at least 1833 deaths. In Florida alone, damages reached $1.9 billion and 14 people were killed. Most destruction occurred when Katrina hit Louisiana and Mississippi, leaving coastal communities in these states in ruins. In Florida, heavy rains flooded some neighborhoods, primarily in Miami-Dade County, and structures were damaged by strong winds and tornadoes (National Hurricane Center 2007).

Only two storms in mainland U.S. history were responsible for more deaths than Katrina. By far the most deadly mainland U.S. storm was Texas' Galveston Hurricane of 1900, a Category 4 storm that caused an estimated 8,000 deaths and untold economic damage to what was then a port city of national importance. Despite warnings issued by the U.S. Weather Bureau, very few on the Texas coast sought shelter or evacuated. By the time the hurricane slammed into Galveston on September 8, 1900, it had winds of 135 mph and storm surges of 8 to 15 feet, which flooded the whole of Galveston Island. The surge knocked buildings off their foundations, destroying over 3,600 homes and the telegraph lines and bridges to the mainland (National Hurricane Center 2007).

The second deadliest storm, Florida's Lake Okeechobee storm of 1928, was a Category 4 hurricane that caused a storm surge on this large inland lake, flooding the surrounding countryside (Blake et al. 2007; National Hurricane Center 2007). The Lake Okeechobee hurricane roared ashore at Palm Beach on September 16, 1928 with 125 mph winds, after killing more than 1,000 people in Puerto Rico and Guadelupe. Lake Okeechobee lies 40 miles inland, but rain from the storm, coming at the end of a rainy summer, filled the lake to the brim and a storm surge broke the dike surrounding the lake in several places. Water flooded several hundred square miles of farmland below, sweeping away everything in its path and causing the deaths of almost two thousand people, three-quarters of whom were black migrant field workers (South Florida Sun-Sentinel 2007).

The most recent Category 4 storm to strike Florida was Hurricane Charley, which struck the southwestern coast with 150 mph winds on August 13, 2004. The National Hurricane Center issued warnings for the Florida Keys and Cape Sable area a day before Charley swept through, prompting a call for the evacuation of 1.9 million people along the Florida west coast, including 380,000 in the Tampa Bay area and 11,000 in the Keys. Strong waves and surges caused severe beach erosion and dune damage. On Captiva Island, off Florida's southwest coast, 6.5 foot storm surges caused erosion that produced a new quarter-mile inlet now known as Charley's cut. In Charlotte County, Charley damaged or destroyed thousands of homes, knocked down thousands of trees, and left more than 2 million people without power. Charley was responsible for 33 deaths in the United States and 5 in the Caribbean. Total estimated losses amount to $14 billion dollars, including destruction of as much as a quarter of the total citrus crop (National Hurricane Center 2007).

Only three Category 5 hurricanes have struck the continental United States in the 156 years for which detailed records exist. The 1935 "Labor Day" storm in the Florida Keys is the first Category 5 hurricane on record. The most intense hurricane ever to hit the United States, the Labor Day storm killed 408 people in the Keys, including 259 World War I veterans living in three Civilian Conservation Corps camps while they built the Overseas Highway. It also destroyed Henry Flagler's railroad, which connected Key West to the mainland, and is said to have cleared every tree and every building off Matecumbe Key (South Florida Sun-Sentinel 2007).

A second Category 5 storm, Hurricane Camille, made landfall on the Mississippi coast on August 17, 1969, ripping down power lines and pounding low-lying areas of southeastern Louisiana and Alabama with winds of 190 mph and a peak storm surge of 24 feet. Thousands were left homeless as Camille flattened nearly everything on the coast of Mississippi and caused additional deaths and flooding inland while crossing into Virginia. The combination of winds, surges, flash floods and rain caused 256 deaths, including 143 on the Gulf Coast (National Hurricane Center 2007; South Florida Sun-Sentinel 2007).

The final Category 5 hurricane is still well remembered by many Floridians. Hurricane Andrew made landfall on August 23, 1992 over the Turkey Point area south of Miami. The worst storm to hit Florida in recent memory, it forced 700,000 people in Southern Florida to be evacuated; a quarter million people were left homeless, and 44 lives were lost. The storm achieved hurricane strength over the Bahamas before sweeping over Southern Florida, where it caused storm surges of 17 feet on Biscayne Bay and led to sustained winds of 140 mph and peak gusts of 169 mph at Coral Gables (Pielke Jr. and Pielke Sr. 1997; South Florida Sun-Sentinel 2007). Communities south of Miami were devastated, with some described as "ground zero after a nuclear blast — minus the radiation."[40] Twelve percent of all homes in Dade Country were completely destroyed, including 90 percent of all the mobiles homes in southern Dade County. The storm nearly wiped out Florida's fruit tree nursery industry — with serious damage to 800 private tree nurseries — and led to major losses for many Dade County businesses. The Federal government poured in billions of dollars worth of aid, including tent cities for thousands, battlefield kitchens to feed 72,000 people, 600,000 ready-made meals from the Persian Gulf War, a field hospital, water, and blankets. Twenty-three thousand armed-services members were brought in to help with the largest relief effort Florida has ever seen. Estimates of the total damage suffered hover around $25 billion (in 1992 dollars — the same share of Florida's 2006 economy would have been $63 billion), half of which was issued by the insurance industry on private property claims. Andrew also tore through the Everglades National Forest, causing untold damage to its pristine wetland ecology (Pielke Jr. and Pielke Sr. 1997; Blake et al. 2007).

BIBLIOGRAPHY

Ackerman, E. A. (1938). "Influences of Climate on the Cultivation of Citrus Fruits." *Geographical Review* 28(2): 289–302.

Adams, M. (2006). A storm of trouble *USA Today*, 8 June 2006.

American Membrane Technology Association (2007). Membrane Desalination Costs, American Membrane Technology Association.

Anderson, P. K., A. A. Cunningham, N. G. Patel, et al. (2004). "Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers." *TRENDS in Ecology and Evolution* 19(10): 535–544.

Anthes, R. A., R. W. Corell, G. Holland, et al. (2006). "Hurricanes and Global Warming—Potential Linkages and Consequences." *Bulletin of the American Meteorological Society* 87(5): 623–628.

Barnett, C. (2007). Salty Solution?, *Florida Trend*, May 2007.

Bates, D. C. (2002). "Environmental Refugees? Classifying Human Migrations Caused by Environmental Change." *Population and Environment* 23(5): 465–477.

Beckage, B. and W. J. Platt (2003). "Predicting Severe Wildfire Years in the Florida Everglades." *Frontiers in Ecology and the Environment* 1(5): 235–239.

Bistyga, J. (2007). Personal communication with H. Scharber, 11 June 2007.

Blake, E. S., E. N. Rappaport and C. W. Landsea (2007). The Deadliest, Costliest, and Most Intense United States Tropical Cyclones from 1851 to 2006 (and other frequently requested hurricane facts). Miami, FL, NOAA: 1–45.

Box, E. O., D. W. Crumpacker and E. D. Hardin (1999). "Predicted Effects of Climatic Change on Distribution of Ecologically Important Native Tree and Shrub Species in Florida." *Climatic Change* 41(2): 213–248.

Breslau, K. (2007). The Insurance Climate Change, *Newsweek*, 27 Jan 2007.

Brooks, N., R. Nicholls and J. Hall (2006). Sea Level Rise: Coastal Impacts and Responses. Berlin, WBGU: 49.

Bureau of Economic Analysis (2007). Gross Domestic Product by State.

Bureau of Labor Statistics (2007). Quarterly Census of Employment and Wages.

Butry, D. T., D. E. Mercer, J. P. Prestemon, J. M. Pye and T. P. Holmes (2001). "What is the Price of Catastrophic Wildfire?" *Journal of Forestry* 99(11): 9–17.

Caldeira, K. and M. E. Wickett (2003). "Oceanography: Anthropogenic carbon and ocean pH." *Nature* 425(6956): 365–365.

Castaneda, H. and F. E. Putz (2007). "Predicting Sea-Level Rise Effects on a Nature Preserve on the Gulf Coast of Florida: a Landscape Perspective." *Florida Scientist*70(2): 166-175.

Chameides, B. (2007). "How Warm is Too Warm?, Worldwide Emissions Target, U.S. Emissions Target, Technologies to Get Us There." *Action Needed to Stop Global Warming (4-part series)*, 2007, from http://environmentaldefenseblogs.org/climate411/2007/03/07/tipping_point.

Chan, J. C. L. (2006). "Comment on ''Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment''." *Science* 311(5768): 1713b.

CNN (1998). Gulf Coast Damage Estimates Trickle in for Georges *CNN.com*, October 2, 1998.

Crumpacker, D. W., E. O. Box and E. D. Hardin (2001). "Implications of Climatic Warming for Conservation of Native Trees and Shrubs in Florida." *Conservation Biology* 15(4): 1008–1020.

Davis, C. (2004). New desalination technology taps waste heat from power plants *University of Florida News*.

Day, T. (2007). Personal communication with H. Scharber, 16 July 2007.

Dean, C. (2007a). Will Warming Lead to a Rise in Hurricanes? *New York Times,* May 29, 2007.

Dean, R. (2007b). Personal communication with F. Ackerman,

Dixon, C. (2007). Taming The Coast, *Popular Mechanics*, July 1, 2007.

Dlugolecki, A. (2005). The Economics of Climate Change: Evidence for the Stern Review.

Dohrenwend, R. E. and L. D. Harris (1975). A Climatic Change Impact Analysis of Peninsular Florida Life Zones. *Impacts of Climate Change on the Biosphere, Part 2: Climatic Impact, Climate Assessment Program*. Washington, D.C., U.S. Dept. of Transportation: 5/107-5/122.

Doyle, T. W. (1997). Predicting Coastal Flooding and Wetland Loss. U. F. 94–97. Lafayette, LA, US Department of the Interior, US Geological Survey.

Doyle, T. W., G. F. Girod and M. A. Books (2003). Modeling Mangrove Forest Migration Along the Southwest Coast of Florida Under Climate Change. *Integrated assessment of the climate change impacts on the Gulf Coast Region*. Z. H. Ning, R. E. Turner, T. Doyle and K. Abdollahi. Baton Rouge, GRCCC and LSU Graphic Services.

Easterling, D. R., B. Horton, P. D. Jones, et al. (1997). "Maximum and Minimum Temperature Trends for the Globe." *Science* 277: 364–367.

Easterling, D. R., G. A. Meehl, C. Parmesan, et al. (2000). "Climate Extremes: Observations, Modeling, and Impacts." *Science* 289: 2068–2074.

Ehrhardt, N. M. and C. M. Legault (1999). "Pink Shrimp, Farfantepenaeus duorarum, Recruitment Variability as an Indicator of Florida Bay Dynamics." *Estuaries* 22(2, Part B: Dedicated Issue: Florida Bay: A Dynamic Subtropical Estuary): 471–483.

Elgiston, H. (1992). Homestead: Ground zero. *Hurricane Andrew: path of destruction*. J. Macchio. Charleston SC, BD Publishing.

Eliot, R. N., et al. (2007). Potential for Energy Efficiency and Renewable Energy to Meet Florida's Growing Energy Demand. Washington, DC, American Council for an Energy-Efficient Economy: 106.

Emanuel, K. (2005). "Increasing destructiveness of tropical cyclones over the past 30 years." *Nature* 436: 686–688.

Energy Information Administration (2007). Annual Energy Outlook, Energy Information Administration.

Environmental Protection Agency (1997). Climate Change and Florida. Washington D.C., EPA, Office of Policy, Planning and Evaluation: 4.

Environmental Protection Agency (2007a). Clean Air Markets—Data and Maps, EPA.

Environmental Protection Agency (2007b). Emissions & Generation Resource Integrated Database, EPA.

Environmental Systems Research Institute (2005). Streetmap USA. *US Streets Dataset*, ESRI.

Epstein, P. and E. Mills (2005). Climate Change Futures: Health, Ecological and Economic Dimensions. Boston, MA, CHGE, Harvard Medical School.

Federal Emergency Management Agency (1998). Homeowner's Guide to Retrofitting: Six Ways to Protect Your House from Flooding. Washington, DC, Federal Emergency Management Agency: 173.

Federal Railroad Administration and Research and Innovative Technology Administration's Bureau of Transportation Statistics (2006). Rail Network dataset, Federal Railroad Administration (FRA), Research and Innovative Technology Administration's Bureau of Transportation Statistics (RITA/BTS).

Florida Department of Agriculture and Consumer Services (2003). Florida's Agricultural Water Policy: Ensuring Resource Availability. Tallahassee, Florida Department of Agriculture and Consumer Services: 40.

Florida Department of Agriculture and Consumer Services (2006a). Comprehensive Report on Citrus Canker Eradication Program in Florida Through 14 January 2006 Revised, Florida Department of Agriculture and Consumer Services—Division of Plant Industry.

Florida Department of Agriculture and Consumer Services (2006b). Florida Agriculture Statistical Directory. Tallahassee, Florida Department of Agriculture and Consumer Services: 178.

Florida Department of Agriculture and Consumer Services (2006c). Florida Agriculture Statistical Highlights. Tallahassee, Florida Department of Agriculture and Consumer Services.

Florida Department of Agriculture and Consumer Services. (2006d). "Press Release: USDA Determines Citrus Canker Eradication Not Feasible." Retrieved 4 September, 2007, from http://www.doacs.state.fl.us/press/2006/01112006_2.html.

Florida Department of Agriculture and Consumer Services. (2007a). "Citrus Canker Fact Sheet." Retrieved 4 September, 2007, from http://www.doacs.state.fl.us/pi/canker/faqs.html.

Florida Department of Agriculture and Consumer Services (2007b). Florida Cattle Industry Brochure. Tallahassee, Florida Department of Agriculture and Consumer Services: 2.

Florida Department of Agriculture and Consumer Services. (2007c). "Florida Wood Using Industry Directory." Retrieved 4 September, 2007, from http://flame.fl-dof.com/apps/wood_using.php.

Florida Department of Agriculture and Consumer Services (2007d). Wildfire report, July 10, 2007. Tallahassee, Florida Department of Agriculture and Consumer Services, Forestry Division.

Florida Department of Environmental Protection (2001). FDEP Ecological Regions dataset, 2001 edition, Florida Department of Environmental Protection.

Florida Department of Environmental Protection. (2004a, 15 June). "Estuaries." Retrieved 24 July, 2007, from http://www.dep.state.fl.us/coastal/habitats/estuaries.htm.

Florida Department of Environmental Protection. (2004b, 15 June). "Salt Marshes." Retrieved 25 July, 2007, from http://www.dep.state.fl.us/coastal/habitats/saltmarshes.htm.

Florida Department of Environmental Protection (2007a). Drinking Water Database, Florida DEP

Florida Department of Environmental Protection. (2007b, 31 May). "Drought Conditions." Retrieved 4 June, 2007, from http://www.dep.state.fl.us/drought/default.htm.

Florida Division of Emergency Management (2004). Hurricane Impact Report, A Summary, Florida Division of Emergency Management.

Florida Division of Emergency Management (2007). Draft Hurricane Impact Report, Florida Division of Emergency Management.

Florida Fish and Wildlife Conservation Commission Florida's Varied Marine Habitat. Tallahassee, Florida Fish and Wildlife Conservation Commission: 7.

Florida Fish and Wildlife Conservation Commission (2005a). Economics of Fish and Wildlife Recreation Tallahassee, Fish and Wildlife Conservation Comission.

Florida Fish and Wildlife Conservation Commission (2005b). Florida's Marine Fisheries: A Vision for the Future. Florida Fish and Wildlife Conservation Commission.

Florida Fish and Wildlife Conservation Commission (2007). Marine Fisheries Information System, Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute,.

Florida Office of Insurance Regulation (2006). An Overview of Florida's Insurance Market Trends. Tallahassee, Florida Office of Insurance Regulation: 46.

Florida Office of Insurance Regulation. (2007a). "Compare Homeowner's Insurance Rates." Retrieved 12 July, 2007, from http://www.shopandcomparerates.com/.

Florida Office of Insurance Regulation (2007b). Presumed Rating Factors. Tallahassee, Florida Office of Insurance Regulation: 25.

Florida Public Service Commission (2006). Energy generation by Fuel Type. *Review of 2006 Ten-Year Site Plants for Florida's Electric Utilities*, Florida Public Service Commission.

Florida State Emergency Response Team (2006). Florida's Storm Surge Zones, Evacuation Routes and Evacuation Zones, Florida State Emergency Response Team (SERT).

Florida State Legislature (2006). The 2006 Florida Statutes.

Gattuso, J. P., M. Frankignoulle, I. Bourge, S. Romaine and R. W. Buddemeier (1998). "Effect of calcium carbonate saturation of seawater on coral calcification." *Global and Planetary Change* 18(1–2): 37–46.

Goodnough, A. (2007). Florida Is Slow to See the Need to Save Water *New York Times*, 19 June 2007.

Grace, M. F. and R. W. Klein (2006). After the Storms: Property Insurance Markets in Florida, Georgia State Center for Risk Management and Insurance Research.

Hammar-Klose and E. R. Theiler (2001). Coastal Vulnerability to Sea-Level Rise: A Preliminary Database for the U.S. Atlantic, Pacific, and Gulf of Mexico Coasts, U.S. Geological Survey, Woods Hole Field Center.

Harris, L. D. and J. Cropper, W. P. (1992). Between the Devil and the Deep Blue Sea: Implications of Climate Change for Florida's Fauna. *Global Warming and Biological Diversity*. R. L. Peters and T. E. Lovejoy. New Haven, CT, Yale University Press: 309-324.

Harrison, M. (2004). "ENSO-Based Spatial Variability of Florida Wildlife Activity." *Southeastern Geographer* 44(2): 141–158.

Hauserman, J. (2007). The bottom line in the sand. *St. Petersburg Times*, January 28, 2007.

Henderson-Sellers, A., H. Zhang, G. Berz, et al. (1998). "Tropical Cyclones and Global Climate Change: A Post-IPCC Assessment." *Bulletin of the American Meteorological Society* 79(1).

Hoare, R. (2005, 5 January). "World Climate." 2007, from http://www.worldclimate.com/.

Hodges, A. W. and W. D. Mulkey (2003). Regional Impacts of Florida's Agricultural and Natural Resource Industries. Gainesville, FL, University of Florida: 20.

Hodges, A. W., W. D. Mulkey, J. R. Alavalapati, D. R. Carter and C. F. Kiker (2005). Economic Impacts of the Forest Industry in Florida, 2003: Final Report to the Florida Forestry Association. Gainesville, FL, University of Florida, IFAS: 47.

Hundley, K. (2007). Premium profits for insurers; As skies cleared, the coffers filled in 2006 for Florida's home insurers *St. Petersburg Times* 18 Mar 2007.

Intergovernmental Panel on Climate Change (2001a). *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge UK, Cambridge University Press.

Intergovernmental Panel on Climate Change (2001b). *Climate Change 2001: The Scientific Basis*. Cambridge, UK, Cambridge University Press.

Intergovernmental Panel on Climate Change (2007a). *Climate Change 2007: Summary for Policy Makers. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK, Cambridge University Press.

Intergovernmental Panel on Climate Change (2007b). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, U.K., Cambridge University Press.

Iverson, L. R. and A. M. Prasad (2001). "Potential Changes in Tree Species Richness and Forest Community Types Following Climate Change." *Ecosystems* 4(3): 186–199.

Kalkstein, L. (2000). "Saving lives during extreme weather in summer." *British Medical Journal* 321: 650–651.

Kalkstein, L. and J. S. Greene (1997). "An Evaluation of Climate/Mortality Relationships in Large U.S. Cities and the Possible Impacts of a Climate Change." *Environmental Health Perspectives* 105(1).

Kees, J. (2007). Personal communication with H. Scharber, 17 July 2007.

Kerr, R. A. (2007a). Pushing the Scary Side Of Global Warming, *Science*, June 8, 2007.

Kerr, R. A. (2007b). Scientists Tell Policymakers We're All Warming the World, *Science*, February 9, 2007.

Kildow, J. (2006a). Phase I: Facts and Figures: Florida's Ocean and Coastal Economies. Moss Landing, CA, National Ocean Economics Program.

Kildow, J. (2006b). Phase I: Florida's Ocean and Coastal Economies Report. Moss Landing, CA, National Ocean Economics Program.

Kirshen, P., M. Ruth, W. Anderson and T. R. Lakshmanan (2004). CLIMB Final Report: Infrastructure Systems, Services and Climate Change: Integrated Impacts and Response Strategies for the Boston Metropolitan Area. Boston, MA, Tufts University, University of Maryland, Boston University, and the Metropolitan Area Planning Council: 165.

Kleypas, J. A., R. W. Buddemeier, D. Archer, et al. (1999). "Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs." *Science* 284(5411): 118–120.

Landsea, C., R. A. Pielke, A. M. Mestas-Nuñez and J. A. Knaff (1999). "Atlantic Basin Hurricanes: Indices of Climatic Changes." *Climatic Change* 42(1): 89–129.

Landsea, C. W. (2005). "Meteorology: Hurricanes and Global Warming." *Nature* 438: E11–E12.

Lerner, B. R. (2006). Tomatoes Not Ripening?, *Purdue Yard & Garden News*, September 17.

Levina, E., J. S. Jacob, L. E. Ramos and I. Ortiz (2007). Policy Frameworks for Adaptation to Climate Change in Coastal Zones: The Case of the Gulf of Mexico. Paris, Organization for Economic Co-operation and Development: 69.

Liberto, J. (2007). Crist Freezes Rates for Citizens *St. Petersburg Times*, 27 June 2007.

Lindquist, N. and L. Manning (2001). Impacts of beach nourishment and beach scraping on critical habitat and productivity of surf fishes: Final Report to the NC Fisheries Resource Grant Program. Morehead City, NC.

Lodge, T. E. (2005). *The Everglades Handbook: Understanding the Ecosystem*. Boca Raton, CRC Press.

Marella, R. L. (2004). Water Withdrawals, Use, Discharge, and Trends in Florida, 2000: U.S. Geological Survey Scientific Investigations Report 2004–5151. Reston, VA, U.S. Department of the Interior, U.S. Geological Survey: 136.

Marella, R. L. and M. P. Berndt (2005). Water Withdrawals and Trends from the Floridan Aquifer System in the Southeastern United States, 1950–2000. U. G. Survey.

Maurer, D. L., R. T. Keck, J. C. Tinsman, et al. (1978). Vertical migration of benthos in simulated dredged material overburdens. *Vol. I: Marine benthos.* Washington, DC, US Army Corps of Engineers.

McNulty, S. G., J. M. Vose and W. T. Swank (1996). "Potential Climate Change Effects on Loblolly Pine Forest Productivity and Drainage across the Southern United States." *Ambio* 25(7).

Miami-Dade County Climate Change Task Force (2007). Statement on Sea Level in the Coming Century.

Michener, W. K., E. R. Blood, K. L. Bildstein, M. M. Brinson and L. R. Gardner (1997). "Climate Change, Hurricanes and Tropical Storms, and Rising Sea Level in Coastal Wetlands." *Ecological Applications* 7(3): 770–801.

Morgan, C. (2007). South Florida running out of sand. *Miami Herald*, 21 Mar 2007.

Morton, J. (1987). Orange. *Fruits of warm climates*. J. F. Morton. Miami, FL: 134-142.

Mulholland, P., R. Best, C. C. Coutant, et al. (1997). "Effects of Climate Change on Freshwater Ecosystems of the South-eastern United States and the Gulf Coast of Mexico." *Hydrological Processes* 11: 949–970.

Mulkey, W. D., A. W. Hodges, T. J. S. III, F. M. Roka and R. L. Degner (2005). Economic Impact of the C-43 Reservoir in Southwest Florida: Final Report. Gainesville, FL, University of Florida, Institute of Food and Agricultural Studies: 47.

Murelio, C. (2003). Winter Peak Records Break across Eastern U.S., *Energy Vortex*, 2007.

Myers, N. (1993). "Environmental Refugees in a Globally Warmed World." *Bioscience* 43(11): 752–761.

Myers, N. (2002). "Environmental Refugees: a growing phenonmenon of the 21st century." *The Royal Society* 357: 609–613.

Nash, J. M. (2006). Storm Warnings, *The Smithsonian*, September 2006.

National Association of Insurance Commissioners (2007). Katrina and Rita: Final Data Collection Summary, National Association of Insurance Commissioners: 33.

National Climatic Data Center. (2005). “Climate of 2005: Global Hazards and Significant Events.” 2007, from http://www.ncdc.noaa.gov/oa/climate/research/2005/jul/hazards.html.

National Hurricane Center (2007). NHC Archive of Hurricane Seasons. N. H. Center, NOAA.

National Ocean Economics Program (2007a). Coastal and Ocean Sector and Industry Data, National Ocean Economics Program.

National Ocean Economics Program. (2007b). “Fisheries Statistics.” Retrieved 27 July, 2007, from http://noep.mbari.org/LMR/fishSearch.asp.

National Oceanic & Atmospheric Administration (2000a). The Potential Consequences of Climate Variability and Change on Coastal Areas and Marine Resources. *Decision Analysis Series*. D. Boesch, J. Field and D. Scavla. Silver Spring, MD, NOAA Coastal Ocean Program.

National Oceanic & Atmospheric Administration (2000b). State, Territory, and Commonwealth Beach Nourishment Programs. Silver Spring, MD, National Oceanic and Atmospheric Administration.

National Oceanic & Atmospheric Administration (2007a). Fisheries Statistics Database, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Fisheries Statistics Division.

National Oceanic & Atmospheric Administration. (2007b). “National Climatic Data Center.” 2007, from http://www.ncdc.noaa.gov/oa/ncdc.html.

National Wildlife Federation and Florida Wildlife Federation (2006). An Unfavorable Tide: Global Warming, Coastal Habitats and Sportfishing in Florida. Reston, VA, National Wildlife Federation and Florida Wildlife Federation.

Natural Resources Defense Council and Florida Climate Alliance (2001). Feeling the Heat in Florida: Global Warming on the Local Level. New York Natural Resources Defense Council and the Florida Climate Alliance.

North American Electric Reliability Corporation (2006). 2006 Long-Term Reliability Assessment: The Reliability of the Bulk Power Systems In North America, North American Electric Reliability Corporation.

O’Brien, J. and D. Zierden (2001). Climate of Florida. NCDC, NOAA.

Oppenheimer, M., B. C. O’Neill, M. Webster and S. Agrawala (2007). CLIMATE CHANGE: The Limits of Consensus *Science*, September 14, 2007.

Patton, C. (2002). Heat can be overwhelming; so can its toll *The Florida-Times Union*, Aug. 30, 2002.

Peterson, C. H. and M. J. Bishop (2005). Assessing the Environmental Impacts of Beach Nourishment, *BioScience*, October 2005.

Pickett, P. (2007). Personal communication with H. Scharber, 17 July 2007.

Pielke Jr., R. A. and R. A. Pielke Sr. (1997). *Hurricanes: Their Nature and Impacts on Society*. Chichester, West Sussex UK, John Wiley & Sons.

Pielke, R. A. (2005). “Meteorology: Are there trends in hurricane destruction?” *Nature* 438: E13.

Pielke, R. A. and C. Landsea (1998). “Normalized Hurricane Damages in the United States: 1925–1995.” *Weather and Forecasting* 13: 621–631.

Pilkey, O. and R. S. Young (2005). “Will Hurricane Katrina Impact Shoreline Management? Here’s Why It Should.” *Journal of Coastal Research* 21(6): iii-ix.

Platts (2007). FRCC worries Florida may become too dependent on gas-fired power, 2007.

Powers, E. M. (2005). Florida Beach Restoration, *Southeast Construction*, August 2005.

Powers, W. (2003). Economic and environmental impacts associated with conversion of Indian Point Units 2 and 3 to a closed-loop condenser cooling water configuration. *Indian Point Fact Sheet,* New York State Department of Environmental Conservation.

Rahmstorf, S. (2007). A Semi-Empirical Approach to Projecting Future Sea-Level Rise, *Science*,

Reeves, T. (2007). In search of plentiful water for future *St. Petersburg Times (Florida),* July 5, 2007.

Reid, A. (2007). Seawater could help solve water woes, but at what price? *South Florida Sun-Sentinel*, July 24, 2007.

Revkin, A. C. (2007). Lake Okeechobee Drops to a Record Low. *The New York Times*, May 31 2007.

Roc, N. (2006). "Environmental refugees: a gathering storm." Retrieved June 12, 2007, from http://www.panosinst.org/productions/panoscope/nairobi-nov17.php.

Ross, M. S., J. J. O'Brien, L. d. Silveira and L. Sternberg (1994). "Sea-Level Rise and the Reduction in Pine Forests in the Florida Keys." *Ecological Applications*, 4(1): 144–156.

Salehyan, I. (2005). Refugees, Climate Change, and Instability. *Human Security and Climate Change Workshop*. San Diego, University of California-San Diego: 1–20.

Sato, S., M. M. Peet and J. F. Thomas (2000). "Physiological factors limit fruit set of tomato (Lycopersicon esculentum Mill.) under chronic, mild heat stress " *Plant, Cell & Environment* 23(7): 719-726.

Savarese, M., L. P. Tedesco, C. Mankiewicz and L. Shrake (2002). *Late Holocene Sea Level Rise in Southwest Florida: Implications for Estuarine Management and Coastal Evolution*. Fifteenth Keck Research Symposium in Geology Proceedings, Amherst College, Amherst, Massachusetts.

Scavia, D., J. Field, D. Boesch, et al. (2002). "Climate Change Impacts on U.S. Coastal and Marine Ecosystems." *Estuaries*25(2): 149–164.

Schenk, N. J. and S. M. Lensink (2007). "Communicating uncertainty in the IPCC's greenhouse gas emissions scenarios." *Climactic Change* 82: 293-308.

Schubert, R., H.-J. Schellnhuber, N. Buchmann, et al. (2006). The Future Oceans—Warming Up, Rising High, Turning Sour. Berlin, German Advisory Council on Global Change (WBGU).

Schubert, T. S., S. A. Rizvi, X. Sun, et al. (2001). "Meeting the Challenges of Eradicating Citrus Canker in Florida—Again." *Plant Disease* 85(4): 340–356.

Scott, R. (2007). Personal communication with H. Scharber, 18 July 2007.

Simms, A. and H. Reid (2006). Up in smoke? Latin America and the Caribbean: The threat from climate change to the environment and human development. The Working Group on Climate Change and Development. London, IIED and NEF: 1–44.

Skoloff, B. (2007). Crushed Glass to Be Spread on Beaches, ABC News.

South Florida Sun-Sentinel. (2007). "Hurricane Headquarters." Retrieved 7 June, 2007, from http://www.sun-sentinel.com/news/weather/hurricane/.

Speybroeck, J., D. Bonte, W. Courtens, et al. (2006). "Beach nourishment: an ecologically sound coastal defence alternative? A review." *Aquatic Conservation: Marine and Freshwater. Ecosystems* 16: 419–435.

Stern, N. (2006). *The Stern Review: The Economics of Climate Change.* London, HM Treasury.

Stott, P. A., D. A. Stone and M. R. Allen (2004). "Human contribution to the European heatwave of 2003." *Nature* 432(7017): 610–613.

Titus, J. (2002). Does Sea Level Rise Matter to Transportation Along the Atlantic Coast? *The Potential Impacts of Climate Change on Transportation*, U.S. Department of Transportation, Center for Climate Change and Environmental Forecasting.

Titus, J. G., R. A. Parke, S. P. Leatherman, et al. (1991). "Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea." *Coastal Management* 19: 171–204.

Titus, J. G. and C. Richman (2001). "Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf coasts." *Climate Research* 18: 205–228.

Trenberth, K. E. (2007). "Warmer Oceans, Stronger Hurricanes." *Scientific American* 297(1).

U.S. Army Corps of Engineers (2000). Lake Michigan Potential Damages Study—Task 3.3.2—Assess Costs of Higher and Lower Design Crest Elevations on Future Shore Protection. Detroit, U.S. Army Corps of Engineers: 23.

U.S. Census Bureau (2004a). State Interim Population Projections by Age and Sex: 2004 – 2030; Table 1: Interim Projections: Ranking of Census 2000 and Projected 2030 State Population and Change: 2000 to 2030. Washington DC, U.S. Census Bureau.

U.S. Census Bureau (2004b). U.S. Interim Projections by Age, Sex, Race, and Hispanic Origin; Table 1a. Projected Population of the United States, by Race and Hispanic Origin: 2000 to 2050, U.S. Census Bureau.

U.S. Census Bureau (2007). 2002 Economic Census, U.S. Census Bureau.

U.S. Department of Agriculture (2003). Florida Supplements to National Engineering Handbook, Part 652—Irrigation Guide. Washington, D.C., United States Department of Agriculture, Natural Resources Conservation Service.

U.S. Department of Agriculture (2005). Florida State Agriculture Overview—2005, United States Department of Agriculture: 2.

U.S. Department of Energy (2000). Interim report of the U.S. Department of Energy's Power Outage Study Team, US DoE, Office of Policy and International Affairs.

U.S. Fish & Wildlife Service (2007a). 2006 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation: National Overview. U. S. F. W. Service, U.S. Department of the Interior: 24.

U.S. Fish & Wildlife Service (2007b). Okefenokee at a Glance. U. S. F. W. Service, http://www.fws.gov/okefenokee/.

U.S. Geological Survey (2000). National Assessment of Coastal Vulnerability to Future Sea-Level Rise. Washington, D.C., United States Geological Survey: 2.

U.S. Geological Survey (2007). Coastal and Marine Geology Program Internet Map Server—Atlantic and East Coast USGS. 2007.

U.S. Global Change Research Program (2001). Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Washington D.C., National Assessment Synthesis Team, United States Global Change Research Program: Updated in 2004.

U.S. National Park Service. (1999). "Threatened and Endangered Species: Everglades National Park." Retrieved 31 July, 2007, from http://www.nps.gov/archive/ever/eco/toofew.htm.

UN Foundation and Sigma Xi (2007). Confronting Climate Change: Avoiding the Unmanagable and Managing the Unavoidable, 15th Session of the Commission on Sustainable Development.

University of Florida: Florida Museum of Natural History. (2002). "Crocodilians Natural History and Conservation." Retrieved 31 July, 2007, from http://www.flmnh.ufl.edu/cnhc/csp_cacu.htm.

University of Florida: GeoPlan (2007). Florida Geographic Data Library University of Florida. 2007.

Vaclavicek, A. (2004). SUGAR CANE: CULTIVATION, BREEDING, BIOTECHNOLOGY. *Student Preparation Seminars: Costa Rica 2004*, Centre for Agriculture in the Tropics and Subtropics, University of Hohenheim.

VISIT FLORIDA. (2007a). "Official Media Newsroom." Retrieved 12 June, 2007, from http://media.visitflorida.org/about/research/.

VISIT FLORIDA (2007b). Preliminary Visitor Estimates, Resident Pleasure Travel, and Industry Trend Indicators 2006Q4 and CY2006. Tallahassee, VISIT FLORIDA Research: 23.

Volusia County. (n.d.). "South Beaches Long-range Erosion Control Project." Retrieved 11 June, 2007, from http://www.volusia.org/portauthority/southecp.htm.

Webster, P. J., J. A. Curry, J. Liu and G. J. Holland (2006). "Response to Comment on 'Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment'." *Science* 311: 1713c.

Webster, P. J., G. J. Holland, J. A. Curry and H. R. Chang (2005). "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment." *Science* 309: 1844–1846.

Wilkinson, C. (2000). Status of Coral Reefs of the World: 2000. Townsville, Australia, Australian Institute of Marine Science.

Wilkinson, C. (2004). Status of coral reefs of the world: 2004. Townsville, Australia, Australian Institute of Marine Science.

Williams, J. M. and I. W. Duedall (1997). *Florida Hurricanes and Tropical Storms.* Gainesville, University of Florida Press.

Williams, K., K. C. Ewel, R. P. Stumpf, F. E. Putz and T. W. Workman (1999). "Sea-Level Rise and Coastal Forest Retreat on the West Coast of Florida, USA." *Ecology* 80(6): 2045-2063.

Wilson, C. (1997). Hurricane Andrew's Insurance Legacy Wearing Off *AP Business News,* February 27, 1997.

World Wildlife Fund. (2007a). "Everglades History." Retrieved 15 June, 2007, from http://www.worldwildlife.org/wildplaces/sfla/history.cfm.

World Wildlife Fund. (2007b). "South Florida: About the Region." Retrieved 30 July, 2007, from http://www.worldwildlife.org/wildplaces/sfla/about.cfm.

Yohe, G., J. Neumann and P. Marshall (1999). The economic damage induced by sea level rise in the United States. *The Impact of Climate Change on the United States Economy*. R. Mendelsohn and J. E. Neumann. Cambridge, Cambridge University Press: 178–208.

Yuhas, E. and T. Daniels (2006). "The US Freshwater Supply Shortage: Experiences with Desalination as Part of the Solution." *Journal of Enviromental Planning and Management* 49(4): 571–585.

NOTES

1 Throughout this report, "more intense" hurricanes refers to hurricanes of increased intensity, not of increased frequency.

2 On July 13, 2007, Florida Governor Crist issued Executive Order 07-127, which established statewide greenhouse gas emission reduction targets of 2000 levels by 2017, 1990 levels by 2025, and 80 percent below 1990 levels by 2050. http://www.flgov.com/pdfs/orders/07-127-emissions.pdf

3 This report makes no attempt to summarize the science of climate change. Good starting points are the Global Warming virtual exhibit by the U.S. National Academy of Science's Koshland Museum (http://www.koshland-science-museum.org/exhibitgcc/index.jsp) and the introductory page of the Real Climate web site http://www.realclimate.org/index.php/archives/2007/05/start-here/.

4 According to Environmental Defense' former Chief Scientist Bill Chameides (now Dean of the Nicholas Institute at Duke University), in order to meet these global goals U.S. emissions would have to decline by 10 to 30 percent of current levels by 2020 and 60 to 80 percent of current levels by 2050 (Chameides 2007).

5 The U.S. Census Bureau projects that national population levels will grow at an average of 0.8 percent annually through 2050. Florida's population is expected to grow more rapidly: 2 percent increase per year through 2030 (U.S. Census Bureau 2004a; b). The Census' state-level predictions end at 2030; we apply the projected U.S. rate of population growth thereafter.

6 All dollar figures adjusted for inflation using the Bureau of Labor Statistics' Consumer Price Index and reported as year 2006 dollars.

7 On average, U.S. GDP per capita has grown 2.2 percent annually since 1929, with the highest decadal growth rate in the 1940s — 4.1 percent per year — and the lowest growth rate in the 1950s — 1.7 percent per year. In the 1990s, U.S. GDP per capita grew by 2.0 percent per year, but the average annual growth rate since 2000 has been 0.9 percent. Florida's GSP per capita grew 2.5 percent from 1997 (the earliest data year available) to 2005, and 2.8 percent from 2000 to 2005.

8 An increase in global mean temperature of 2.3°F beyond year 2000 levels is considered an important tipping point. At greater increases in temperature, the Greenland Ice Sheet is very likely to melt entirely and irreversibly, causing 20 feet of sea-level rise over several centuries. Remaining below 2.3°F would require a stabilization of atmospheric carbon dioxide at 450ppm CO2 (or 500ppm CO2-equivalent including other greenhouse gases) (Intergovernmental Panel on Climate Change 2007b; UN Foundation and Sigma Xi 2007).

9 We used the average of Stern's (Stern 2006) 450ppm and 550ppm CO2-equivalent stabilization paths, as roughly equivalent to 450ppm CO2; Stern's emission scenarios included about 50 ppm CO2-equivalent of other greenhouse gases, so they correspond to 400 and 500 ppm of CO2 alone. The low end of the likely temperature range — or the 17th percentile — is a linear interpolation between the 5th and 50th percentiles. We assume 1.1°F in temperature increase from preindustrial times to year 2000. Stern's estimates are for global mean temperatures; we estimated regional U.S. temperatures using the same ratios of regional to global as the low end of the likely range of the IPCC's B1 scenario.

10 In the rapid stabilization case sea-level rise is primarily the result of thermal expansion, the slow expansion of the ocean as past temperature increases to surfaces waters very gradually warm the lower ocean. Thermal expansion from past emissions is now unavoidable. For this reason, we take the low end of the likely range for the IPCC's B1 scenario (Intergovernmental Panel on Climate Change 2007b) — 7 inches by 2100 — as a good approximation of sea-level rise in the rapid stabilization case. Slightly different amounts of sea-level rise are expected in different locations around the world. For Florida, sea-level rise is expected to be at approximately the global average; see IPCC (Intergovernmental Panel on Climate Change 2007b) Ch. 5, 10, and 11.

11 International temperatures are from the WorldClimate website (Hoare 2005).

12 When the IPCC's little-published estimate of sea-level rise from melting is combined with other more predictable, and better publicized, effects — like thermal expansion — the total sea-level rise for the high end of the A2 likely range increases from 20 inches to 25 inches by 2100 (Intergovernmental Panel on Climate Change 2007b).

13 Large numbers of coral were affected and many were likely killed, however. Due to a lack of appropriate monitoring, precise statistics are not known.

14 Monthly data on Florida's tourism is not available. October, November, and December each receive, on average, 6.3 percent of 85 million visitors, or 5.3 million people per month.

15 The authors' survey of recent beach nourishment projects in Florida shows that the average project places sand 9 feet deep at a cost of $9 per cubic yard (Powers 2005; Bistyga 2007; Day 2007; Morgan 2007; Pickett 2007; Volusia County n.d.).

16 All values in 2006 dollars. Sales are greater than the contribution to GSP, cited in the text; an industry's contribution to GSP is its sales, or cash receipts, less its purchases from other firms.

17 A Florida Irrigation Guide published by the USDA (U.S. Department of Agriculture 2003) gives estimates for the total water consumed (in inches) by region and type of plant for each month, along with the monthly mean temperature for the region. Citrus and sugarcane water consumption data by zone and month were each regressed on mean temperatures to find the percent water increase needed with a 1°F increase in temperature; r^2 values were above 0.90 in both cases.

18 All values in 2006 dollars.

19 All values in 2006 dollars.

20 According to official reports, there were only 428 people working in the fishing industry in 2005, but over 30,000 commercial fishing permits were sold to self-employed fishers (Bureau of Labor Statistics 2007; Florida Fish and Wildlife Conservation Commission 2007). With a total catch valued at $174 million, employment of only 428 commercial fishers would imply a catch of about $400,000 per person, which seems too high; on the other hand, 30,000 commercial fishers would average less than $6,000 each, which seems too low.

21 See also (Scavia et al. 2002).

22 The valuation of property is based on the 2000 Census: median owner-occupied property values by county, from the Census, were multiplied by the number of each county's housing units in the vulnerable zone, and then converted to 2006 dollars. Sources for vulnerable zone data: NOAA Medium Resolution Digital Vector Shoreline (U.S. Geological Survey 2007), USGS 1:250,000 Digital Elevation Model (University of Florida: GeoPlan 2007), and Historic and Projected Populations of Florida Counties (University of Florida: GeoPlan 2007).

23 Authors' calculation, from the GIS software and maps used in this report.

24 As of 2004: EPA eGRID (Environmental Protection Agency 2007b).

25 Percentages represent fuel use by total generation in 2005. Percentages do not add up to 100% because some generation is from non-qualified sources (Florida Public Service Commission 2006).

26 Environmental Protection Agency. *Emissions and Generation Resource Integrated Database (eGRID), 2006.* Available online at http://www.epa.gov/cleanenergy/egrid/index.htm

27 Energy Information Administration. *Electric Power Annual, 2006:* Table 4.5. Receipts, Average Cost, and Quality of Fossil Fuels for the Electric Power Industry, 1994 through 2005; available online at http://7www.eia.doe.gov/cneaf/electricity/epa/epat4p5.html; and 1990 - 2006 Average Price by State by Provider (EIA-861); available online at http://www.eia.doe.gov/cneaf/electricity/epa/average_price_state.xls

28 Hourly power generation derived from 2005 Environmental Protection Agency (EPA) Clean Air Markets data for FRCC fossil units (Environmental Protection Agency 2007a). Hourly temperature from Miami International Airport derived from National Oceanographic and Atmospheric Administration (NOAA) National Climate Data Center (NCDC) (National Oceanic & Atmospheric Administration 2007b).

29 Annual Energy Outlook 2007 (Energy Information Administration 2007): Table 39. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies.

30 Annual Energy Outlook 2007 (Energy Information Administration 2007): Table 6. Electric Power Delivered Fuel Prices and Quality for Coal, Petroleum, Natural Gas, 1990 through 2005 (n 2005 dollars); Table 39. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies.

31 Florida's current 138 power plants are comprised of 566 generators, which are clustered into plants. Of the 1500 generators, about 1000 are 50 MW wind projects, which could each be comprised of clusters of 15-30 turbines.

32 Calculated from US Agricultural Census, 2002. In addition, 120,000 acres of pasture and other farmland were irrigated, for a total irrigated farm area of 1.82 million acres.

33 Under the scenario assumptions, Florida's population is 2.09 times as large in 2050 as in 2000. As shown in Table 14, fresh water demand in 2000 was 3,920 mgd for agriculture and 4,270 mgd for all other uses. If the latter category is constant in per capita terms, it grows to 8,920 mgd by 2050.

34 In 2004 a University of Florida researcher announced a new technology which could reduce desalination costs from $3.00 to $2.50 per thousand gallons (Davis 2004). The American Membrane Technology Association, an industry group devoted to promoting desalination plants, estimates the costs of desalina-

tion of brackish water at $1.50 - $3.00 per thousand gallons (American Membrane Technology Association 2007).

35 American Membrane Technology Association (see previous note).

36 Data for Hurricane Jeanne (2004) was omitted because of large discrepancies between data sources.

37 For the purposes of these calculations, damages and deaths caused by each hurricane were scaled up to 2006 levels using Florida's gross state product (GSP) and Florida's population, respectively, as inflators.

38 All model inputs and results in 2006 dollars.

39 Titus and Richman 2001.

40 A quote attributed to a National Guardsman in (Pielke Jr. and Pielke Sr. 1997) and (Elgiston 1992).

PHOTO CREDITS

Cover:	(both photos) iStockphoto
page ii	iStockphoto
page 1	Photodisk
page 3	Photodisk
page 4	Hurricane George. © Weatherstock / Peter Arnold Inc.
page 19	Photodisk
page 20	Craig Quirolo, Reef Relief/ Marine Photobank
page 21	Photodisk
page 22	iStockphoto
page 24	iStockphoto
page 27	Photodisk
page 29	W. Cody/Corbis
page 30	Shutterstock
page 32	Shutterstock
page 33	Hurricane Katrina. Photodisk
page 36	Photodisk
page 44	iStockphoto
page 50	Photodisk
page 57	iStockphoto (top)
page 57	Photodisk (bottom)
page 60	©Tom Stack/Tom Stack & Associates
page 61	Photodisk
page 65	Photodisk
page 66	Photodisk
page 68	Photodisk

FLORIDA AND CLIMATE CHANGE

THE COSTS OF INACTION

ELIZABETH A. STANTON
FRANK ACKERMAN

Tufts University
Global Development and Environment Institute
and
Stockholm Environment Institute—US Center

November 2007