

Adaptive Response Planning to Sea Level Rise in Florida and Implications for Comprehensive and Public-Facilities Planning

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Executive Summary
Adaptive Response Planning to Sea Level Rise in Florida
and Implications for Comprehensive and Public-Facilities Planning

There is substantial but not complete agreement in the international scientific community that rates of sea level rise have increased in response to post-industrial global climate change. There remains, however, considerable uncertainty about precisely how high sea level will rise by any particular point in time. Projections of global sea level rise between 1990 and 2100 presented by the Intergovernmental Panel on Climate Change (IPCC) in its *Climate Change 2007* report (Meehl et al., 2007) range from 0.6 to 2.6 feet.¹ Several scientists have warned that evidence of more rapid melting of the Greenland and West Antarctic ice sheets indicates that sea levels could be as much as 4.5 to 16.5 feet higher by 2100.

Regardless of the rate of sea level rise over the next few decades and the measures that may be taken to reduce greenhouse gas emissions, it is clear that the earth is already committed to millennia of sea level rise because of the lag in achieving temperature equilibrium between the atmosphere and the oceans. Authors of the IPCC's *Climate Change 2007: Impacts, Adaptation, and Vulnerability* (Parry et al., 2007) argue that "the long timescales of sea-level rise suggest that coastal management, including spatial planning, needs to take a long-term view on adaptation to sea-level rise and climate change, especially with long-life infrastructure . . ."

James Titus of the U.S. Environmental Protection Agency maintains that it is very likely that existing urban areas will choose to defend themselves against rising sea levels by constructing flood protection works or raising the base elevation of entire urban areas. Titus suggests that it is in areas that are not built out where other options may be feasible, but only if the planning is done now before capital investments are made in private development and public facilities and infrastructure.

Thus, while uncertainty remains about the magnitude and timing of sea level rise, development decisions that are being made today are committing public and private capital to land use patterns and associated infrastructure and facilities with design lives that reach well into the period of time when the impacts of sea level rise will be felt.² Large areas of Florida are vulnerable to increasing sea levels. Many of these areas are already developed. Thus there are likely to be substantial components of public infrastructure that already are vulnerable to sea level rise and will remain so because of their long design lives.

¹ These are estimates of "eustatic" sea level rise, i.e. the increase in the volume of the oceans that results primarily from the thermal expansion of sea water as heat is transferred from the atmosphere and from the melting of glaciers, ice caps, and the Greenland and West Antarctic ice sheets. Sea level rise experienced by an observer on land is referred to as "relative" sea level rise. This is a function of changes in eustatic sea level as well as shifts in the elevation of the land.

² The street and highway rights-of-way that are laid out for new development have expected operating lives of more than 100 years. Underlying water distribution and wastewater and storm water collection systems have design lives of 30 to 50 years or more. Sewage treatment and wastewater reclamation facilities have design lives close to 50 years. New bridges are built to last 75 years.

This report offers a snapshot of the status of adaptive response planning for sea level rise by comprehensive planning and infrastructure planning and management agencies in the state of Florida. We have focused our attention on three major elements of local infrastructure: (1) water supply systems that draw from aquifers or surface waters close to the coast; (2) centralized wastewater management systems located in low-lying areas near the coast, including those with surface water discharges of treated wastewater; and (3) highways, bridges, and causeways in coastal areas.

Through telephone interviews conducted primarily with local and regional planners, we have sought to determine the perceived importance of sea level rise as a planning issue, the efforts that are underway to address sea level rise, and the ways in which the State of Florida, in particular the Department of Community Affairs, can facilitate more effective adaptive response planning. We interviewed long-range comprehensive planners from 20 cities and counties in parts of the state that are most vulnerable to sea level rise. We also interviewed 13 water supply planners and 9 wastewater facility planning officials whose agencies serve those same areas of the state and whose existing facilities are likely to be vulnerable to sea level rise impacts. In addition, we interviewed long-range planners in 5 regional planning councils that participated in a recent sea level rise vulnerability project funded by the U.S. Environmental Protection Agency, as well as water supply planners in 4 water management districts and officials with the state Department of Environmental Protection and the state Department of Transportation officials.

We supplemented our interviews with a comprehensive literature review and interviews with state and national experts designed to answer the following questions: (1) How fast is sea level rising and is the rate increasing? (2) How high will sea level rise by 2050 and 2100? (3) What are the primary anticipated effects of sea level rise on public infrastructure systems? (4) What adaptive responses may be feasible? And (5) What initiatives are underway already to adapt to sea level rise? The full report provides detailed answers to these questions. Here we provide highlights of our findings plus our recommendations.

What Do We Know About Projected Sea Level Rise for Florida?

The public media, as well as other information sources accessible to public officials in Florida, are carrying mixed messages about rates of sea level rise, sea level rise projections, and the implications of these possible changes over the next 50 to 100 years. Almost all of the comprehensive planners and infrastructure planners and managers with whom we spoke expressed significant uncertainty over how high sea level will rise and when. We explicitly asked the local comprehensive planners how high they think sea level will be in their jurisdictions by 2100. Almost half (45%) said they had no idea.

The IPCC's technical report, *Climate Change 2007: The Physical Science Basis* (Solomon et al., 2007), offers the most up-to-date syntheses of scientific understanding about sea level rise rates and projections. The chapter on sea level observations (Bindoff et al., 2007), presents data which suggest that the rate of global eustatic sea level rise has

increased in recent decades from a long-term average over the 20th Century of 1.7 millimeters (0.07 inch) per year to 3.1 mm (0.12 in) per year for the period 1993 to 2003. There is uncertainty, however, over whether the recent rate is indicative of accelerating sea level rise or an artifact of the high variability in observed sea level measurements. As noted above, the 2007 IPCC report presents projections of global eustatic sea level rise between 1990 and 2100 that range from 0.6 to 2.6 feet. Some authors have argued that these are too conservative and that they neglect the potential for much higher sea level rise rates and outcomes suggested by recent observations of accelerated melting of the Greenland and West Antarctic ice sheets.

Potential Impacts of Rising Sea Level

Sea level rise will have four major impacts of concern to comprehensive planning and the planning and management of public infrastructure: (1) inundation and shoreline recession, (2) increased flooding from severe weather events, (3) saltwater contamination of ground water and surface water supplies, and (4) elevated water tables.

As sea level rises, the elevation of the mean high-tide line will move landward at a rate determined by the gradient of the local topography. Reported shoreline recession rates for Florida's sand beaches range from 100 to 2000 feet for every 1-foot rise in sea level. Historically, the average rate of shoreline recession in the state has been about 1.5 meters (4.9 feet) per year. If the upper bound of the sea level rise rates projected by the IPCC for the worst-case future greenhouse gas emission scenario is applied to this gradient, an annual shoreline recession rate of 9.7 meters (32.1 ft) per year would be anticipated by approximately 2095 from eustatic sea level rise alone. The mid-level IPCC scenario would result in a recession rate of 6.0 meters (19.8 feet) per year.

Infrastructure that lies in the path of shoreline recession may be adversely affected in several ways. Above-ground structures may initially be subject to intermittent flooding from spring high tides. This may cause short-term access problems at the least, as well as flood damage if facilities are not adequately flood proofed. Shoreline recession due to erosion may result in scouring and undermining of above-ground facilities, road bases, and bridge abutments. Buried storm water and sanitary sewers and water supply lines may be damaged where shoreline recession exposes them to currents and wave forces.

Altered hydraulic head differentials may negatively affect wastewater discharge ocean outfalls, gravity-flow storm sewers, ditches, and canals, and the effectiveness of tide gates in storm water drainage canals and mosquito control ditches.

Sea level rise also may interfere with navigation under bridges and may increase the exposure of bridges to saltwater spray with resultant increases in spalling of concrete and more rapid corrosion of steel bridge components and rebar in older bridges. Newer bridges, however, are being constructed with concrete formulations that better resist cracking and spalling as structures age, as well as epoxy-coated rebar that resists corrosion.

As sea level rises, the return frequencies of coastal floods of a given elevation will increase, i.e. higher floods will happen more often, and the boundaries of flood zones and hurricane storm surge vulnerability zones for storms of a given return frequency will move higher and further landward. Shoreline recession due to erosion will shift flood zones further landward. Facilities previously sited in what were considered to be safe areas, e.g. outside the FEMA 100-year floodplain, may experience floods formerly classified as 100-year events, and structures designed to withstand the force of storm waves and moving floodwaters of a given intensity will be more likely to be subjected to stronger forces. Bridges and causeways along hurricane evacuation routes will have to be closed sooner for a given storm intensity. Highways, bridges, and causeways will be flooded more frequently. As sea level rises, incidents such as the vertical displacement of segments of the I-10 bridges over Escambia Bay during Hurricane Ivan in 2004 and Lake Pontchartrain during Hurricane Katrina will occur more frequently as will erosion of bridge abutments from storm waves and storm currents.

As sea level rises and shorelines recede landward, saltwater intrusion into coastal surficial aquifers will increase. Communities that draw water from surficial aquifers in various parts of Florida have already experienced problems with saltwater intrusion from the sea due to excessive withdrawals. Sea level rise will exacerbate these problems. The “salt front” of the tidal saltwater wedge in coastal rivers also will move further upstream with the potential to affect both surface water intakes and well fields in aquifers that are recharged by river water. The distance will be a function of the river’s gradient as well as the amount of freshwater flow down the river and the tidal cycle. Changes in precipitation regimes that accompany global climate change may, therefore, either serve to exacerbate or ameliorate this impact.

Seven of the 13 local water supply planners with whom we spoke indicated that saltwater intrusion associated with a 6 to 18-inch rise in sea level over the next 50 years would likely pose a threat to some of their wells (and in one case a surface water supply). Two others reported that they already have saltwater intrusion problems.

Sea level rise also will cause increases in the elevation of fresh ground water that overlies saltwater in surficial aquifers in coastal areas. This may expose buried utility lines and pipelines to corrosion and may cause increased groundwater infiltration into sanitary and storm water sewers resulting in decreased capacity of wastewater treatment plants and storm water management facilities. Higher water tables also can affect the structural stability of buried pipelines as well as road bases and may result in the need for more frequent road resurfacing. Several of the local water supply and wastewater system planners and managers with whom we spoke foresaw potential impacts of a 6 to 18-inch rise in sea level over the next 50 years on water distribution pipelines or wastewater collection systems, including infiltration and flooding risks to lift stations.

Adaptive Response Options

Adaptive responses fall into three categories: protection, retreat, and accommodation. The physical measures that can be used to protect developed areas from erosion and

inundation include construction of flood protection works, beach nourishment, dune building, and marsh building. The protection afforded by built structures will be reduced as sea level rises. These will have to be modified or relocated as the oceans get deeper and the shoreline recedes. Where such structures are built and maintained, almost complete loss of coastal wetlands and beach and dune systems will ensue. Thus, in the process of protecting uplands, the natural protective systems may be lost. Beach nourishment can keep pace with sea level rise so long as affordable supplies of suitable beach sediment are available. However, at some point space must be allotted for the beach and dune system to move further landward as sea level rises. Doing so may necessitate retreat by upland land uses.

Well fields threatened by encroaching saltwater intrusion have been protected by reducing the permeability of sediments that lie between the sea and the well field and by enhancing freshwater recharge in the area that lies between the sea and the well field. Surface water supplies susceptible to salt front intrusion may be protected through the use of tide gates where these do not interfere with navigation.

The primary option for large-scale retreat involves what has been dubbed a “rolling easement” under which "human activities are required to yield the right of way to naturally migrating shorelines" (Titus, 2000). The concept is grounded on the Public Trust Doctrine and common law principles that stipulate that boundaries shift as land erodes. Several states reportedly have instituted such easements under which development permits are conditioned on relocation of a structure once it is threatened by a receding shoreline. While Florida law empowers the state Department of Environmental Protection to require the adjustment, alteration, or removal of any structure that intrudes onto sovereignty lands of the state below the mean high water line of any tidal water body, the agency has rarely if ever invoked this authority. The agency has, in a limited number of cases, written a rolling easement provision into the permit conditions for structures built in areas with extreme erosion hazards under the state’s Coastal Construction Control Line (CCCL) permit program.

While rolling easements may offer the means for incremental retreat one property parcel at a time, they beg the question of what to do with infrastructure threatened by inundation and shoreline recession. Well fields contaminated by saltwater intrusion may be abandoned where protection strategies are deemed to not be cost-effective. But other central facilities such as water treatment plants and wastewater treatment or reclamation plants cannot be easily relocated because their location is constrained by the collection or distribution systems they support. Road segments threatened by receding shorelines may be abandoned, but such a strategy also is likely to involve abandoning storm water, sewer, and water supply lines. This would likely be a very costly and disruptive venture that would deprive property owners on the landward side of the road of municipal services before their properties are subject to rolling easement provisions. Relocation of roads and underground utilities is likely to have limited application because of the very high costs of right-of-way acquisition in coastal areas.

Sea level rise can be accommodated by directing new development away from areas that are anticipated to be affected by inundation, shoreline recession, and advancing coastal flood boundaries. Setbacks can be employed to require that new structures be built back from the shore by some multiple of the annual average erosion rate. At present, major habitable structures built along Florida's sand shoreline must, as a general rule, be setback a distance equal to 30 times the average annual erosion rate at the site. However, the maximum landward extent of the setback is defined by the boundary of the CCCL permit jurisdiction line, which in turn is defined in terms of the erosion likely to occur from a 100-year storm. As sea level rises, the CCCL must be resurveyed to account for the landward migration of the 100-year event erosion line. At present there are no provisions for doing so.

A second option is to prohibit development in larger hazard zones that are and will be susceptible to both shoreline recession and coastal storm flooding. However, a recent assessment by Deyle, Chapin, and Baker of the effectiveness of Florida's mandate for local governments to adopt and implement policies to direct development away from coastal high hazard areas in the state suggests that this is not likely to be accomplished without radical changes in state and local land use policies and underlying federal and state laws. Notwithstanding the issue of political will, property rights law presents a formidable barrier to completely prohibiting development of such areas, while public funds for fee-simple acquisition are entirely inadequate to buy-out property owners.

New above-ground infrastructure can be designed to accommodate higher coastal flood elevations. New infrastructure also can be sited outside the bounds of advancing coastal flood boundaries, if official maps of hurricane storm surge zones and 100-year floodplains are developed to depict both contemporary and future boundaries. While FEMA's recently published guidelines for coastal flood hazard zone mapping along the Atlantic and Gulf Coasts encourage mapping partners to account for sea level rise (U.S. Federal Emergency Management Agency, 2007), none of the revised coastal maps of A-zones and V-zones produced under FEMA's Map Modernization project have done so as yet.

When we asked local water supply planners about adaptation options for increased saltwater intrusion they listed both retreat and accommodation strategies: (1) development of inland well fields or surface water sources, (2) development of deeper brackish aquifers with attendant desalination, (3) desalination of water from existing well fields as salt water intrusion occurs, (4) constructing tide gates in water supply canals to prevent salt front migration upstream, and (5) increased use of wastewater reclamation.

The wastewater system planners and managers with whom we spoke listed both accommodation and protection strategies: (1) sealing of manhole covers, (2) refurbishing sewers to reduce ground water infiltration, (3) relocation of some vacuum sewer collection pits and buffer tanks, and (4) elevation or flood proofing of components of existing sewage treatment or reclamation facilities.

Planning Responses to Sea Level Rise

While a substantial number of cities and states in the U.S. have developed or are developing climate action plans, most of these are focused almost entirely on mitigating greenhouse gas emissions. In Florida, Governor Crist's July 2007 executive order calls for the formation of an Action Team on Energy and Climate Change which is initially charged with developing an action plan to achieve targets for statewide greenhouse gas reductions. The Action Team's charge for its second year of work, however, includes development of climate change adaptation strategies.

Only a handful of state and local governments have begun to address adaptive response planning. In North Carolina, an initiative is underway by the state Division of Coastal Management to require all coastal counties to address the impact of sea level rise in their land use plans. A bill adopted by the California Assembly but not yet acted upon by the state Senate, would require local governments to address sea level rise when they revise their general plans. Preliminary recommendations forged by the Washington Climate Advisory Team Coastal and Infrastructure Preparation/Adaptation Working Group include suggestions that sea level rise be addressed in local capital facilities planning and that climate change and sea level rise implications be addressed under the state's Environmental Protection Act. The working group has formulated a number of other specific preliminary recommendations that address sea level rise and infrastructure. These are reported below in our full report.

Florida's Planning and Policy Framework for Addressing Sea Level Rise

The planning framework within which sea level rise adaptation could be addressed in Florida includes the provisions of state statutes and rules governing the future land use, infrastructure, and capital improvements sections of local comprehensive plans and those governing state, regional, and local planning of water supply and wastewater management systems, roads, bridges, and causeways. Our review of these planning frameworks reveals a set of consistent findings across these planning domains:

- (1) There are no explicit requirements that state, regional, or local planning entities address sea level rise in land use or infrastructure planning.
- (2) Statutory planning time frames are generally too short to directly encompass sea level rise impacts.
- (3) There are provisions within these planning frameworks, however, that offer appropriate contexts within which sea level rise adaptive response planning could be addressed.

The 10-year local comprehensive planning horizon stipulated in the state's Growth Management statute does not provide an explicit context for considering the implications of long-term gradual changes such as sea level rise for future land use or infrastructure planning. Most of the 20 coastal communities we surveyed do not prepare plans with planning horizons greater than the 10-year statutory minimum, although a few extend the planning horizon to 15 to 20 years. Exceptions include Collier County, which reported

that they extend the planning horizon for infrastructure to 25 years, and Hillsborough County, which reported that they have begun an effort that will employ a 50-year planning horizon.

Requirements for the Conservation Element of local comprehensive plans arguably could offer the context within which the expected impacts of climate change on coastal wetlands, water wells, beaches, shorelines, and floodplains might be addressed if a much longer planning horizon were stipulated. The statutory requirement for the Coastal Element to address "avoidance of irreversible and irretrievable loss of coastal zone resources" provides further leverage for considering the potential impacts of sea level rise, at least on natural systems.

The focus of the Capital Improvements Element on fiscally feasible, near-term capital improvements planning appears to be too short-range to be a feasible means for addressing sea level rise adaptation. The Infrastructure Element, however, which addresses sanitary sewers, solid waste, drainage, potable water, and natural groundwater aquifer recharge, does offer an appropriate opening through a requirement for an analysis of the problems and opportunities for facilities replacement and expansion and new facility siting. However, to do so requires a planning horizon greater than 10 years.

Florida statutes define a 20-year planning horizon for regional water supply planning and require coordination between the regional plans and local comprehensive plans. Regional water supply plans must be prepared by water management districts where a district determines that existing sources of water are not adequate to supply water for all existing and future reasonable-beneficial uses and to sustain the water resources and related natural systems for the 20-year planning period. Local government comprehensive plans must be "coordinated" with any applicable water management district's regional water supply plan, and the Future Land Use element of the local comprehensive plan must be based on the availability of local water supply. While water management districts have responsibility for regional-scale planning, the decisions to undertake specific water supply development projects rest with local governments and their water purveyors. Local governments and other water supply entities are not required to implement the specific water supply development projects for which they are designated in the regional plan. They may instead propose an alternative water supply development project sufficient to meet the needs identified by the district in the regional plan.

There is nothing in the statutory language that provides an explicit context for addressing the long-term implications of sea level rise on water supply sources or water supply infrastructure. Potential coastal and storm wave impacts are addressed by regulations issued by the state Department of Environmental Protection (DEP) that require that new and expanded public water systems be situated outside of 100-year floodplains and above the highest recorded high tide and that community water systems must be designed and constructed so that structures and equipment are protected from physical and wave damage from a 100-year storm.

The state's planning framework for wastewater management facilities is similar except that the planning horizon is 10 years rather than 20. Planning for new or expanded capacity is triggered when the 3-month average daily flow exceeds 50 percent of the permitted capacity of an existing treatment plant or reuse and disposal system. As with water supply systems, wastewater treatment plant structures and equipment must be protected from physical damage from a 100-year flood, but there are no explicit requirements that sea level rise be addressed in new facility or collection system planning.

The state DEP does not currently have any initiatives underway to directly address the implications of sea level rise for existing wastewater collection and treatment systems. The state officials with whom we spoke believe, however, that operation and maintenance performance reports required every 5 years should serve to detect problems that will become manifest as sea level rises such as increased ground water infiltration or reduced discharge capacity for ocean outfalls. Other regulations that require that collection, treatment, and discharge systems function as designed would provide the leverage for requiring corrective action. DEP's anti-degradation policy discourages the permitting of new or expanded surface water discharges (including ocean outfalls). The state also requires utilities requesting domestic wastewater plant construction or expansion to investigate the feasibility of implementing water reuse. Thus it is likely that the number of wastewater treatment plants with surface water discharges likely to be adversely affected by sea level rise will decline over time and that newer facilities will be less likely to be situated in low-lying coastal flood hazard zones that will be most susceptible to sea level rise impacts.

The general planning horizon for major transportation projects, including highways, bridges, and causeways, is generally 20 years, which coincides with the federally stipulated time frame for long-range transportation plans developed by metropolitan planning organizations and for long-range statewide transportation plans. The design and construction of roads, bridges, and causeways in Florida follow the state "Greenbook" published by the Florida Department of Transportation, and guidelines developed by the American Association of State Highway and Transportation Officials (AASHTO). The Greenbook and the AASHTO guidelines address scour of bridge abutments and piers but they do not address flooding or erosion design standards for roads. Road vulnerability to flooding is primarily addressed by the state's *Project Development and Environment Manual* (PDE) review procedures and criteria.

The *PDE Manual* requires completion of a risk evaluation for all encroachments within 100-year floodplains. These must consider both risks to highway users from flood hazards and risks to nearby property owners where the encroachment might exacerbate flood impacts. The risk analysis also must include probable flood-related costs for highway operation, maintenance, and repair during the service life of the facility. As with the siting guidelines governing other infrastructure in the state, sea level rise impacts are not explicitly addressed. While coastal erosion hazards also are not explicitly accounted for in the *PDE Manual*, state district engineers with whom we spoke indicated that they are taken into consideration in both siting and design.

What Florida Planners Have to Say

The perceived threat posed by sea level rise varied substantially among the local long-range planners we interviewed. Thirty percent felt that it may be a major threat, another 30 percent said moderate, and 15 percent said minimal or not at all. Twenty percent of our respondents said they were unsure or did not know.

We asked the local water supply and wastewater system planners and managers to assess the adequacy of their long-range planning processes for contending with two future sea level rise scenarios: (1) sea level rise of 3.5 inches in 30 years and 6 inches more in 50 years and (2) sea level rise of 11 inches in 30 years and 18 inches higher in 50 years. Most responded in terms of the threats they foresaw to their existing systems and, for the most part, were sanguine about their abilities to accommodate sea level rise impacts within the normal course of their system planning and maintenance processes. One of the local water supply planners suggested that recent state policy promoting the development of alternative water supplies, including reclamation of domestic wastewater for irrigation and development and treatment of brackish water supplies, would help to accommodate any impacts of sea level rise. Under the more extreme scenario, several local water supply and wastewater system planners and managers foresaw possible impacts of concern including saltwater intrusion into water supply sources, increased flood threats to existing treatment facilities, and impacts on underground water supply distribution systems and wastewater collection systems, including infiltration and lift station flooding.

With two exceptions, sea level rise is not explicitly addressed in long-range comprehensive planning in the 20 communities where we interviewed local planners. A number of the planners suggested, however, that the provisions governing development within coastal high hazard areas or FEMA flood hazard zones offer some policies that are pertinent to sea level rise vulnerability.

Collier County explicitly addresses sea level rise in its comprehensive plan through two policies in its Conservation and Coastal Element. One requires that the natural functions of developed coastal barriers and developed shorelines be restored and maintained and that in so-doing, development and redevelopment proposals must consider the implications of potential sea level rise. The other policy requires that shoreline development projects demonstrate that the project will remain fully functional for its intended use after a six-inch rise in sea level.

Miami-Dade County, which was one of the first local governments in the U.S. to develop a greenhouse gas reduction plan, created a Climate Change Advisory Task Force in 2006. Liaisons from 13 different county departments work with the Task Force, which has formed six committees. The Scientific and Technical Committee is charged with providing information on possible near-term and long-term impacts of climate change on the Miami-Dade region and strategies for adapting both the built and natural environments to unavoidable impacts. A Built Environment Committee is responsible for providing recommendations to the Task Force for adapting and adaptively managing the

existing and future built environment, including public and private buildings and infrastructure.

Most of the local water supply planners, and all of the wastewater system planners and managers, said that sea level rise is not explicitly accounted for in their long-range planning processes. As with the long-range comprehensive planners, several suggested that the measures they do take to protect against contemporary flood and hurricane hazards offer some protection against sea level rise. We received similar responses from state officials who oversee water supply, wastewater treatment, and state-funded transportation project planning.

We received more diverse answers from the five water management district water supply planners we interviewed. Sea level rise is not perceived to be an immediate concern for water supplies in the St. Johns River, Southwest Florida, and Northwest Florida districts. The South Florida Water Management District, on the other hand, reported that district staff prepared an analysis in 1998 that assessed the impacts of a 6-inch rise in sea level on the canals in the district that are used for storm water management, flood protection, aquifer recharge. They currently incorporate sea level rise scenarios developed by the U.S. Army Corps of Engineers in their hydrologic modeling of water supply alternatives.

Five of the regional planning councils (RPCs) in the state, as well as Walton County, participated in an EPA initiative to map land uses within the 5-foot and 10-foot contour intervals to identify areas that might be inundated by an astronomical high tide on top of a 5-foot rise in sea level. The resulting reports were published between 2003 and 2006. We interviewed the project managers for these studies to learn about how the studies had been used and what other initiatives, if any, the RPCs might have taken concerning sea level rise.

Two of the RPCs distributed their maps to local planning directors in their regions. The Treasure Coast RPC of its county planning department directors about the study. Some of the RPCs have posted the maps or reports on their website. Others have used the report as the basis for presentations to local planners and other local officials. It is interesting to note, however, that none of the local comprehensive planners or water supply or wastewater system planners or managers mentioned these studies during our interviews.

The Southwest Florida RPC, which was the lead agency for the EPA-funded initiative that produced these studies, has had some discussions with the EPA about possible follow-up projects including (1) an analysis of the impacts of sea level rise on wetlands and how and where they can migrate and (2) a cost/benefit analysis for holding back the sea in a specific location. The South Florida RPC has just completed a "Climate Change Community Toolbox" to assist local governments with planning for and adapting to climate change. The Toolbox includes a sea level rise atlas, three science-based plain language fact sheets on the impacts of climate change on Miami-Dade County, and a compendium of adaptation resources. The South Florida RPC is also working with local planning officials to launch a long-range regional plan to be called "Vision 2060" which will address climate change among other important issues.

Local planners responsible for major infrastructure systems seemed more convinced of the importance of accounting for sea level rise in their long-range planning than did local long-range comprehensive planners. Some of the local comprehensive planners went by the book saying that they would address it if it were added to the requirements under the 9J-5 *Florida Administrative Code* rules. Several said planning for sea level rise is important, but they felt it was not feasible for them to do so at the local level. These planners were from smaller coastal cities. A few others said they thought it should be addressed but they believed it was not on the agenda of important planning issues for their citizens or elected officials. Two others said they personally felt that other issues were more important in their communities. Two respondents suggested that sea level rise was perhaps not the domain of the comprehensive planners. One of these respondents suggested that the issue might better be addressed through the land development code.

Most of the local water supply planners and wastewater system planners and managers indicated that they thought that sea level rise ought to be accounted for in their long-range planning. However, several expressed uncertainty about when it would be appropriate to do so given the long time frame over which it is projected to occur. One water supply planner, from a Panhandle county with a secure inland water supply system, maintained that the threat was not significant enough to warrant attention at this time. One wastewater system manager suggested that the key question out to be whether new development should be permitted in areas likely to be vulnerable to sea level rise.

We received consistent responses from the local comprehensive planners and water supply and wastewater systems planners and managers when we asked about constraints that limit their agency's concern with sea level rise: (1) political climate or other pressing issues; (2) lack of adequate/credible information about potential impacts; (3) too long a time frame; (4) lack of state policy direction, and (5) lack of money and other resources.

The RPC planners generally echoed these points. Several noted that local governments will not be very interested until the state requires them to address sea level rise in their comprehensive plans. A particular constraint mentioned by one of the RPC planners is the lack of elevation data at a greater resolution than five feet, e.g. one-foot contour intervals, with which to do sea level rise vulnerability mapping. Such data are currently being compiled by the state Division of Emergency Management as part of an effort to update the regional hurricane evacuation studies for the state. LiDAR-based elevation mapping, at 1-foot and 2-foot contours for all areas of the state below 10 meters, is scheduled to be completed by September 2008.

When we asked the local comprehensive planners and infrastructure planners what resources might be made available from the state that would enhance their ability to account for the potential impacts of sea level rise in their long-range planning, they identified the following: (1) credible predictions of sea level rise scenarios for which planning would be appropriate coupled with information about likely impacts and best practices for adaptation; (2) public education that can serve to raise public awareness of the importance of dealing with potential sea level rise impacts now; (3) policy direction

as to how local governments should address sea level rise in comprehensive plans, water supply planning, and wastewater system planning; (4) training for local planners; and (5) funding to help defray the costs of conducting local vulnerability studies and assessments of practical adaptation options.

Suggestions from the RPC planners for initiatives by the state generated some additional ideas beyond those regularly suggested by the local planners: (1) use the 30-year erosion projection line as the basis for a rolling easement; (2) include sea level rise in state action plans, e.g. the Everglades Restoration Project, which uses only a 6-inch estimate over 100-years despite recommendations that a 2-foot rise be used; (3) provide information to local government concerning the impacts of sea level rise on wetland and wetland migration; (4) provide information on alternative means of protecting lands that local governments believe should be protected; (5) account for sea level rise when subsequent updates are done of the regional hurricane evacuation studies; (6) facilitate partnerships with universities to access and translate current science into effective policy; (7) provide funding to the RPCs to provide technical assistance to local governments with sea level rise adaptation; (8) provide public communication training to help RPC staff explain sea level rise and other climate change phenomena and issues effectively; and (9) develop best practices guidance for incorporating sea level rise into comprehensive plans.

Recommendations

The following recommendations are offered for consideration by the state Department of Community Affairs and the Division of Community Planning. Rationales for each recommendation are included in the full text.

1. Coordinate with the state Department of Environmental Protection (DEP) and the Florida Action Team on Energy and Climate Change to ensure that the Action Team's efforts to address climate change adaptation strategies in 2008 will provide useful guidance to local and regional land use and public infrastructure planning and management.
2. Coordinate with the state Division of Emergency Management (DEM) and the state Department of Environmental Protection (DEP) to make available to local, regional, and state agencies the best possible data for mapping sea level rise scenarios at 1-ft contour intervals based on DEM's current LiDAR-based contour mapping project.
3. Coordinate with the state Department of Environmental Protection (DEP), the state Division of Emergency Management (DEM), the Florida Action Team, and the Scientific and Technical Committee of the Miami-Dade Climate Change Advisory Task Force to provide up-to-date information on sea level rise vulnerability for local governments, regional planning councils, regional water management districts, state agencies, and other interested persons.

- a. Define a range of several (2-4) Florida-specific sea level rise scenarios and probabilities for 50-year and 100-year planning horizons based on the most recent report of the Intergovernmental Panel on Climate Change (IPCC) and other credible scientific reports. Over the short term, consider using the scenarios depicted by the South Florida Regional Planning Council for their Sea Level Rise Atlas, i.e. 1 ft, 2 ft, 3 ft, and 5ft.
 - b. Based on (a), produce maps at an appropriate scale for local planning, e.g. 1:2400, for each scenario and each planning horizon that depict the likely locations of the following:
 - mean high water line, seasonal high water line, or other appropriate sea level reference line
 - SLOSH storm-surge boundaries
 - c. Update (a) and (b) on a schedule coordinated with the release of the Intergovernmental Panel on Climate Change (IPCC) scientific assessments (approximately every 5 to 7 years).
4. In collaboration with the state Division of Emergency Management (DEM), coordinate with the Region IV Office of the Federal Emergency Management Agency (FEMA) to initiate explicit accounting for sea level rise in conducting the FEMA flood hazard map restudies for the coastal areas of Florida pursuant to the provisions of Appendix D of the 2007 *Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update*.
 5. Coordinate with the state Department of Environmental Protection (DEP), the Florida Action Team, and the Southwest Florida Regional Planning Council to provide best practices guidance for adaptive response planning for sea level rise impacts on land use and infrastructure.

Specific adaptive response planning issues that might be addressed include the following:

- a. Defining appropriate long-range planning horizons for regional and local water supplies, local wastewater and storm water management systems, state and local transportation infrastructure, and local land use planning.
- b. Identifying alternative adaptive strategies for the design of new water supply facilities, domestic wastewater collection and treatment systems, storm water management systems, and bridges and roads that account for potential sea level rise impacts over the next 75 to 100 years.
- c. Defining appropriate methods for assessing sea level rise-induced shifts in flooding and erosion hazards in planning corridors for new highways and in assessing major amendments to the Future Land Use Element and Future Land Use Map in local comprehensive plans.
- d. Identifying alternative strategies for long-term infrastructure maintenance, repair, protection, and relocation for existing water supply facilities, domestic wastewater collection and treatment systems, storm water management systems, and bridges and roads that account for impacts of

sea level rise-induced shifts in flooding and erosion hazards over the next 50 to 75 years.

- e. Identifying options for incorporating “rolling easements” in both state and local development permits for areas immediately adjacent to coastal waters of the state.
6. In collaboration with the state Department of Environmental Protection (DEP), the Governor’s Office, and the Florida Action Team fund pilot projects in several coastal communities in the state for conducting detailed sea level rise vulnerability assessments and adaption strategy assessments for existing public infrastructure systems.
 7. Coordinate with the state Department of Environmental Protection, the state Department of Transportation, the Governor’s Office, the Florida Action Team, and other agencies as appropriate, to consider legislation and/or rules that would:
 - a. Define appropriate long-range planning horizons for regional and local water supplies, local wastewater and storm water management systems, state and local transportation infrastructure, and local land use planning.
 - b. Require accounting for sea level rise-induced shifts in coastal flooding and erosion hazard boundaries in assessing corridors for new state highways and local highways funded with state monies and in major amendments to the Future Land Use Element and Future Land Use Map in local comp plans.
 - c. Require accounting for sea level rise-induced shifts in coastal flooding and erosion hazard boundaries in the siting and design of new water supply facilities, domestic wastewater collection and treatment systems, storm water management systems, and bridges and roads.
 - d. Require development of specific strategies for assuring proper functioning of water supply, wastewater and storm water management, and transportation infrastructure that account for the impacts of sea level rise-induced shifts in flooding and erosion hazards over the design life of the system. Special attention should be focused on water supply distribution systems and wastewater and storm water collection systems.
 - e. Require formal assessment of the impacts of major developments and infrastructure projects on the ability of coastal wetlands and beach and dune systems to adapt to sea level rise by migrating landward.
 - f. Direct the state Department of Environmental Protection to include “rolling easement” provisions in state CCCL permits and state permits for coastal armoring structures that require modification or relocation of structures that intrude onto sovereignty lands of the state below the mean high water line of any tidal water body.

Adaptive Response Planning to Sea Level Rise in Florida and Implications for Comprehensive and Public-Facilities Planning

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Introduction

Sea level has been on the rise since the last glacial period ended some 18,000 years ago (Hansom, 1988), in response to millennial cycles of climate variability driven by irregularities in the earth's orbit around the sun and shifts in the tilt of the earth's axis (Houghton, 2004). Since the onset of industrialization in the mid 1800s, increases in emissions of carbon dioxide and other greenhouse gases have contributed to additional warming of the earth's atmosphere on the order of approximately 0.6° C (Houghton, 2004).

Warming of the atmosphere results in several phenomena which contribute to an increase in the volume of the oceans resulting in what is referred to as eustatic sea level rise: (1) thermal expansion of water as heat is transferred to it from the atmosphere, (2) melting of continental and alpine glaciers and ice caps, and (3) melting of the Greenland and Antarctic ice sheets. Because of the long lag time in transferring heat from the atmosphere throughout the depths of the oceans, eustatic sea level rise would continue for thousands of years if atmospheric temperatures were to be stabilized (Alley et al., 2007).

Sea level rise experienced by an observer on land is referred to as relative sea level rise. This is a function of changes in eustatic sea level as well as shifts in the elevation of the land. In some areas, the land is rising as part of the very slow phenomenon of "glacial rebound" or in response to other tectonic changes in the earth's crust. In others, the land is subsiding, due to tectonic activity or other factors such as excessive ground water pumping and extraction of oil and gas. At the same time, the ocean bottom is rising and falling in different areas in response to related phenomena. Because most areas of Florida are geologically stable, observed sea level primarily reflects the forces that drive eustatic sea level.

As is detailed further below, there is substantial but not complete agreement in the international scientific community that rates of sea level rise have increased in response to post-industrial global climate change. There remains, however, considerable uncertainty about precisely how high sea level will rise by any particular point in time. Projections of sea level rise between 1990 and 2100 presented by the Intergovernmental Panel on Climate Change (IPCC) in its *Climate Change 2007* report range from 0.6 to 2.6 feet (Meehl et al., 2007). An early analysis by the U.S. Environmental Protection Agency (1989) estimated that a 2-foot rise in sea level would inundate an area equivalent to the states of Massachusetts and Delaware combined, close to 10,000 square miles of land.

Several scientists have warned that evidence of more rapid melting of the Greenland and West Antarctic ice sheets indicates that sea levels could be as much as 4.5 to 16.5 feet higher by 2100 (Hansen, 2007; Rahmstorf, 2007a).

Regardless of the rate of sea level rise over the next few decades and the measures that may be taken to reduce greenhouse gas emissions, it is clear that the earth is already committed to millennia of sea level rise because of the lag in achieving temperature equilibrium between the atmosphere and the oceans. Authors of the IPCC's 2007 report, *Climate Change 2007: Impacts, Adaptation, and Vulnerability*, (Parry et al., 2007, p. 346) argue that

[t]his raises long-term questions about . . . how best to approach coastal spatial planning. While shoreline management is starting to address such issues for the 21st century . . . the long timescales of sea-level rise suggest that coastal management, including spatial planning, needs to take a long-term view on adaptation to sea-level rise and climate change, especially with long-life infrastructure . . .

Fred Ludwig, in an article in the August/September 2007 issue of *Planning* entitled “Too Much Water or Too Little? Coping with the Inevitable” quotes James Titus of the U.S. Environmental Protection Agency as saying that it is very likely that existing urban areas will choose to defend themselves against rising sea levels by constructing flood protection works or raising the base elevation of entire urban areas (Ludwig, 2007, p. 30). Titus suggests that it is in areas that are not built out where other options may be feasible, but only if the planning is done now before capital investments are made in private development and public facilities and infrastructure.

Barnett and Beckman, in a second article in the August/September 2007 issue of *Planning*, echo the authors of the recent IPCC report on adaptation to climate change (Parry et al., 2007), calling for planning and engineering studies now to plan both for the inevitable sea level rise that will occur regardless of future efforts to mitigate greenhouse gas emissions as well as against plausible scenarios of more catastrophic sea level rise that could accompany complete melting of the Greenland and West Antarctic ice sheets. They say “There needs to be serious public discussion about protecting every coastal city: what it will cost and how these costs can be met” (Barnett and Beckman, 2007, p. 37).

Thus, while uncertainty remains about the magnitude and timing of sea level rise, development decisions that are being made today are committing public and private capital to land use patterns and associated infrastructure and facilities with design lives that reach well into the period of time when the impacts of sea level rise will be felt. The street and highway rights-of-way that are laid out for new development have expected operating lives of more than 100 years. Underlying water distribution and wastewater and storm water collection systems have design lives of 30 to 50 years or more. Sewage treatment and wastewater reclamation facilities have design lives close to 50 years. New bridges are built to last 75 years. In addition, elements of the natural infrastructure that helps to mitigate the vulnerability of human settlements to coastal storms, namely beach

and dune systems and coastal wetlands, will be altered as sea level rises. Efforts to protect the built environment from sea level rise may compromise the ability of these natural systems to adapt.

Large areas of Florida are vulnerable to increasing sea levels as shown in Figure 1, which depicts areas that would be inundated by a 1-meter (3.3 feet) rise. Many of these areas are already developed. Thus there are likely to be substantial components of public infrastructure that already are vulnerable to sea level rise.

This report offers a snapshot of the status of adaptive response planning for sea level rise by comprehensive planning and infrastructure planning and management agencies in the state of Florida. Through telephone interviews primarily with local and regional planners, we have sought to determine the perceived importance of sea level rise as a planning issue, the efforts that are underway to address sea level rise, and the ways in which the state, in particular the Department of Community Affairs, can facilitate more effective adaptive response planning.

We have focused our attention on three major elements of local infrastructure: (1) water supply systems that draw from aquifers or surface waters close to the coast; (2) centralized wastewater management systems located in low-lying areas near the coast, including those with surface water discharges of treated wastewater; and (3) highways, bridges, and causeways in coastal areas. We also briefly address storm water management systems in this analysis. However, we did not address them to the same degree as other infrastructure because the issues concerning these systems overlap considerably with those of wastewater management systems.

We supplemented our planner interviews with a comprehensive literature review and interviews with state and national experts designed to answer the following questions concerning sea level rise vulnerability and adaptation: (1) How fast is sea level rising and is the rate increasing? (2) How high will sea level rise by 2050 and 2100? (3) What are the primary anticipated effects of sea level rise on public infrastructure systems? (4) What adaptive responses may be feasible? (5) What initiatives are underway already to adapt to sea level rise?

We begin by describing the sample of jurisdictions and agencies with which we conducted interviews. We then address Florida's vulnerability to sea level rise in terms of both what the experts say and what our interviews tell us about the perceptions of long-range planners in the state. This is followed by an examination of the potential impacts of sea level rise on public infrastructure and possible adaptation options, drawn from our review of the literature and discussions with state, regional, and local experts and planners in the state.

We address existing and potential adaptation initiatives by presenting an overview of the manner in which sea level rise is being approached in other parts of the U.S. and the planning framework in Florida through which sea level rise adaptation could be addressed. We then report the results of our surveys with local and regional

comprehensive and infrastructure planners and describe a few specific sea level rise adaptation initiatives that have been taken in the state. We conclude with a series of recommendations for initiatives that we think merit consideration by the state Department of Community Affairs and other state agencies that can enhance the ability of local planners to effectively adapt to the impacts that sea level rise is likely to have on new and existing public infrastructure over the next 50 to 100 years.

Our Sample

We conducted interviews with long-range comprehensive planners from a sample of 20 cities and counties that are most vulnerable to sea level rise based on a map compiled by Weiss and Overpeck (2005) of areas of the state likely to be inundated by a 1-meter rise in sea level (see Figure 1). We also interviewed 13 water supply planners and 9 wastewater facility planning officials whose agencies serve those same areas of the state and whose existing facilities are likely to be vulnerable to sea level rise impacts. In addition, we interviewed long-range planners in 5 regional planning councils that participated in a recent sea level rise vulnerability project funded by the U.S. Environmental Protection Agency, as well as water supply planners in 4 water management districts and officials with the state Department of Environmental Protection who oversee wastewater management planning. Our inquiries concerning transportation infrastructure were focused on State Department of Transportation officials because of the major role played by the state in financing and overseeing both construction of new transportation infrastructure and major repair and reconstruction efforts for existing systems. Table 1 lists the local, regional, and state agencies with which we conducted interviews.

What Do We Know About Projected Sea Level Rise for Florida?

Almost all of the local comprehensive planners and water supply and wastewater facility planners with whom we spoke expressed significant uncertainty over how high sea level will rise and when. We explicitly asked the local comprehensive planners how high they think sea level will be in their jurisdictions by 2100. Almost half (45%) said they had no idea. Three of the eight respondents who offered an estimate said 1 to 3 feet, which is consistent with the predictions in the most recent reports from the IPCC – see below. Two estimated less than 1 foot; two said 4 to 5 feet; and one estimated more than 5 feet.

What Have Public Officials Been Hearing?

The public media, as well as other information sources accessible to public officials in Florida, are carrying mixed messages about rates of sea level rise, sea level rise projections, and the implications of these possible changes over the next 50 to 100 years. Underlying uncertainty about the factors that explain observed changes in sea level coupled with limited historic data and high inter-annual and decadal variations in tide gage data have resulted in divergent interpretations among scientists that have contributed to these mixed messages. In a few instances, media reports and public statements appear to have simply been incorrect.

Estimates of Sea Level Rise Rates

We have uncovered only one article in a major Florida newspaper over the past 5 years that explicitly discusses the current rate of sea level rise in Florida (see Table 2). That article (Ritchie, 2007) quotes Florida State University geologist Dr. Joseph Donoghue as saying that the rate is 2.0 millimeters per year (mm/yr). Donoghue is quoted as saying that there is no evidence of accelerated sea level rise. However, the other scientist interviewed, Dr. Stephen Leatherman, Director of the International Hurricane Research Center at Florida International University, reportedly maintained that there is evidence of acceleration in the rate of sea level rise over the past decade or so. The Florida Cabinet has heard several reports about changes in sea level from presenters at its two recent Climate Change Conversations. At the second Conversation, in June 2007, Dr. James O'Brien (2007), emeritus professor of meteorology at Florida State University, reported that tide gage data indicate a long-term average rate of global sea level rise of about 2.1 mm/yr, while recent satellite altimetry data (1993-2003) indicate a global rate of 3.0 mm/yr. O'Brien maintained, however, that there is no proof of accelerated sea level rise.

Future Sea Level Rise Projections

Recent newspaper articles that discuss likely future sea level conditions in Florida (Dean, 2006; Lollar, 2007; Mulkey, 2007a) have reported projections of global average increases in eustatic sea level due to climate change ranging from 0.6 to 20 feet by 2095 or 2100 (see Table 3). The Florida Cabinet has heard three apparently very different reports about projected sea levels from presenters at its two Climate Change Conversations. At the Conversation on April 3, 2007, Dr. Stephen Mulkey (2007b), Director of Research and Outreach/Extension for the University of Florida's School of Natural Resource and Environment, spoke in terms of 2 feet of eustatic sea level rise by 2100 based on the IPCC's *Climate Change 2007* report (Meehl et al., 2007). In the subsequent Cabinet Conversation, on June 12, 2007, Kellee James (2007), an economist with the Chicago Climate Exchange, presented information attributed to the IPCC, the State of Florida, and the Natural Resources Defense Council, claiming that sea level in Florida will rise by 2 to 10 feet over the next 50 years. In his presentation at the second Conversation, O'Brien (2007) maintained that it will take 484 years for sea level to rise 5 feet. This translates to about 1 foot of sea level rise by 2100.

Dr. Earnest Estevez at the Mote Marine Laboratory developed sea level rise projection estimates for Sarasota Bay for the Sarasota Bay National Estuary Program's 1992 *Framework for Action* (Roat et al., 1992). He estimated a maximum potential increase of 64 centimeters (2.1 feet) by 2115 relative to the 1992 mean higher high water line for the area based on the extant global projections available at that time adapted for Sarasota Bay.

According to Brandt Henningsen, Chief Environmental Scientist with the Southwest Florida Water Management District (personal communication, July 26, 2007), the U.S. Geological Survey office in St. Petersburg, Florida, developed an estimate of sea level

rise in about 1997 for use by the district in their Tampa Bay wetland restoration program. The USGS estimate was an increase of 1 to 1.5 feet over the next 100 years.

The South Florida Water Management District released a study in 1998 that assessed the impacts of possible sea level rise and associated saltwater intrusion on water resources in southeastern Florida (Trimble et al., 1998). This study, which was disseminated to county and regional planners, used a scenario of a 0.5-foot increase in sea level between 1995 and 2050 based on a U.S. Environmental Protection Agency (EPA) study authored by Titus and Narayanan (1995).

The Titus and Narayanan report also served as the basis for a series of studies completed more recently by several of the regional planning councils (RPCs) in the state (East Central Florida RPC, 2004; South Florida RPC, 2005; Southwest Florida RPC, no date; Tampa Bay RPC, 2006; Treasure Coast RPC, 2005), plus Walton County (Hudgens, 2003). The studies were undertaken with funding from EPA to “illustrate how communities expect to address the most fundamental question about sea level rise: Where will we retreat and where will we hold back the sea?” (Southwest Florida RPC, no date). The EPA’s objectives included both mitigation of the vulnerability of people and property to increased erosion and flooding and promoting strategies to ensure the long-term survival of coastal wetlands (Tampa Bay RPC, 2006, p. 3).

Each of the RPC studies contains a table of regional sea level rise projections relative to 1990 for the years 2025, 2050, 2075, 2100, 2150, and 2200 based on the methods set forth by Titus and Narayanan (1995). Estimates are presented for a range of probabilities between 90 and 1 percent. The range of estimates for 2100 is 26 to 117 centimeters (0.9 to 3.9 feet) for each of the regions. The mean estimate for 2100 is 51 to 52 centimeters (1.7 feet).

Following the reasoning of Titus and Narayanan, the studies used the 10-foot contour interval to depict areas likely to be flooded by astronomical high tides on top of a 5-foot rise in eustatic sea level. Most of the reports explain in the text that a 5-foot rise in sea level was projected by Titus and Narayanan to be likely over a period of 200 years; however, this time context is not explicit on the maps included in the reports. A standard set of assumptions was used to map likely response strategies (protection almost certain; protection reasonable likely; protection unlikely; or no protection) based on existing land uses (Tampa Bay RPC, 2006, pp. 33-35).

What Are the Experts Saying Now?

Mixed signals from the popular press and other informal sources reflect in part continuing scientific uncertainty about contemporary rates of sea level rise and the levels to which sea level will rise by specific points in time.

Estimates of Sea Level Rise Rates

The IPCC's fourth assessment report, *Climate Change 2007: The Physical Science Basis* reports that the rate of global eustatic sea level rise began to increase sometime after 1850 and appears to have increased further over the past decade or so. The rates reported in the report appear to support such a conclusion. However, scientists disagree as to whether or not the recent data are indicative of a significant trend of accelerated sea level rise.

In the IPCC chapter on sea level observations (Bindoff et al., 2007, p. 410), the IPCC reports a long-term average rate of global sea level rise of 1.7 millimeter (0.07 inch) per year for the 20th century (see Table 3). The observed rate for the period 1961 to 2003 is 1.8 mm (0.07 in) per year, while the observed rate for the period 1993 to 2003 is 3.1 mm (0.12 in) per year (p. 419). These estimates are derived from reconstructions using long-term, spatially-sparse, land-based tidal gage data and near-global satellite altimeter data available since 1992 (Bindoff et al., 2007, p. 411).

Scientists disagree as to whether or not the tide gage and satellite altimeter data show evidence of an actual acceleration in the rate of sea level rise. Walton (2006) cites conflicting findings from previous studies by a number of authors including Church and White (2006), Donnelly et al. (2004), and Douglas (1991). Psuty and Ofiara (2002, p. 153) found that an exponential curve provided a better fit to tide gage data for Atlantic City, New Jersey, than a straight line, concluding, therefore, that an acceleration in sea level rise was evident at that location. Walton (2006) makes a related argument from his time-series analyses of five tide gage stations in Florida over the period 1941 to 2005.

Bindoff et al. (2007) note, however, that no long-term acceleration of sea level has been identified using 20th century data alone because of high inter-annual and decadal variability. They also observe that the higher observed rate of sea level rise during 1993 to 2003 may "partly reflect" decadal variability rather than an acceleration in the rate of sea level rise (p. 420). FSU geology professor, Joseph Donoghue (personal communication, June 28, 2007), maintains that the time period represented by the altimeter data is too short to be interpreted as a long-range trend. He says that because of the very large inter-annual and decadal variation of tide gage sea level data it is possible to find an array of "trends" for different 10-12 year samples of data points. As shown in Figure 2, there is very substantial noise in the tide gage data. Donoghue (personal communication, September 10, 2007) reports that the long-term tide gage data for Florida are consistent with the observed long-term trend of a global eustatic sea level rise rate over the last century of 1.7 mm/yr. He notes that repeated leveling surveys, and more recently GPS surveys, tend to corroborate the observation that Florida's coast is mostly experiencing eustatic sea level rise with little movement of the land itself.

It is important to note that there is substantial regional variability in sea level observations. These are influenced by regional variations in sea water temperature and density, salinity, wind patterns, and ocean currents. According to Bindoff et al. (p. 409), sea level rise rates are several times greater than the global mean in some regions while in others, eustatic sea level is actually falling. As shown in Table 2, long-term data from tide

gages maintained by the National Oceanic and Atmospheric Administration, show long-term relative sea level rise rates between 1.53 mm (0.06 in) per year at Apalachicola and 2.43 mm (0.10 in) year at Mayport (Zervas, 2001).

Future Sea Level Rise Projections

As shown in Table 3, recently published projections of sea level rise by 2100 relative to approximately 2000 from credible scientific sources range from less than 1 foot to more than 15 feet. Some are based on analysis of current trends while others are derived from an array of scenarios based on different assumptions about future greenhouse gas emissions.

The IPCC *Physical Science Basis* chapter on global climate projections (Meehl et al., 2007, p. 820) presents estimated projections of mean global sea level rise rates as well as total mean global sea rise for a time period bounded by two time intervals: 1980-1999 to 2090-2099.¹ These estimates are based on a set of scenarios that encompass a range of possible greenhouse gas emissions ranging from best case (B1) to worst case (A1FI).² Scenario A1B represents an intermediate scenario.

The IPCC's projected rates of sea level rise for the 1980-1999 to 2090-2099 [~1990 to 2095] time period range from 1.5 to 9.7 mm (0.06 to 0.38 in) per year (see Table 2). The corresponding aggregate increases in sea level for the time period (see Table 3) range from 0.18 meter (0.6 foot) for the B1 scenario to 0.59 meter (1.9 feet) for the A1FI scenario. If recent melting rates of the Greenland and West Antarctica ice sheets increase linearly with global mean temperature, the upper bound of sea level rise could be as high as 0.28 meter (0.9 foot) to 0.79 meter (2.6 feet) by 2095.

In a recent article published in the journal *Science*, Stefan Rahmstorf, professor of physics of the oceans at Potsdam University, Germany, presents a semi-empirical analysis of the relationship between the magnitude of average atmospheric temperatures and the rate of sea-level rise (Rahmstorf, 2007a). Rahmstorf argues that sea level will rise as a response to an increase in temperature until a new equilibrium is reached. Paleoclimatic data indicate that the equilibrium level will be significantly higher and will take millennia to achieve. While there are uncertainties in how much sea level will rise, he maintains that a rise of as much as 1.4 meters (4.6 feet) by 2100 cannot be ruled out based simply on a continuation of the linear relationship between sea level rise and temperature observed in the 20th century. In a subsequent critique of the IPCC report, Rahmstorf (2007b) argues that adjustments for full ice sheet uncertainty and the effects of carbon cycle feedback on global temperature rise would add 0.35 meter to the Meehl et al. (2007) range of 0.18 to 0.59 meter yielding a sea level rise increase by 2095 of 0.53 meter (1.7 feet) to 0.94 meter (3.1 feet).

¹ The IPCC chose to use these time intervals to reflect uncertainties in the climate change models. Taking the midpoints of these intervals, the projections are roughly for the period 1990 to 2095 (Rahmstorf, 2007b).

² See Appendix A for a synopsis of the emissions scenarios.

Hansen (2007) criticizes the reticence of the IPCC report authors to fully address the implications of the apparent onset of disintegration of the Greenland and West Antarctic ice sheets. He argues that the sea level rise trend has become nonlinear and, as a result, linear extrapolations of observed rates of melting underestimate the likely magnitude of melting during the current century. Hanson maintains that the approximate 1 mm/yr increase in the observed rate of sea level rise over the past decade, i.e. the apparent increase from the satellite altimetry observations, is probably attributable to more than a doubling of the rate of ice sheet melting. He suggests that if the rate of ice sheet melting continues to double on an approximate 10-year basis that the amount of sea level rise by 2100 relative to 2000 could be as much as 5 meters (16.5 feet). However, he also concludes that it is now "impossible to accurately predict the sea level change on a specific date" because we have no valid predictive models for the melting process that is now taking place.

Recent formal analyses of contemporary rates of sea level rise in Florida are scarce. The only published analysis we have located is a recent article by Walton (2007) who employed exponential time-series analysis to model data from five tide gage stations in Florida to account for a possible acceleration trend in sea level rise. His results predict increases in relative sea level between 2006 and 2080 ranging from 0.25 meter (0.8 foot) to 0.35 meter (1.1 feet). As shown in Table 3, these estimates fall within the range of the IPCC's estimates without accelerated melting of the Greenland and West Antarctic ice sheets.

Potential Impacts of Rising Sea Level

Sea level rise will have four major impacts that are relevant to comprehensive planning in general and the planning and management of public infrastructure in particular: (1) inundation and shoreline recession, (2) increased flooding from severe weather events, (3) saltwater contamination of ground water and surface water supplies, and (4) elevated water tables.

Inundation and Shoreline Recession

The most obvious impact of sea level rise is simple inundation of previously dry land. Titus (1991) calculated that the U.S. could lose as much as 20,000 square kilometers (7,720 square miles) of dry land due to inundation from a 1-meter rise in sea level if shorelines were allowed to retreat naturally. He estimated that 70 percent of these losses would occur in the low-lying coastal plains of the southeast.

As sea level rises, the elevation of the mean high-tide line will move landward at a rate determined by the gradient of the local topography. Along sedimentary shorelines, the extent of shoreline recession will also be a function of erosion unless there is a sufficient influx of new sediment to offset the erosion losses (NRC, 1987, p. 49). Along the protected shores of ocean bays, where the shoreline typically consists of salt marshes or mangrove swamps, the shoreline typically recedes more slowly than along sandy beaches due to steeper gradients and lower wave energy. In these areas, which account for the

majority of coastal land below 1 meter in elevation (NRC, 1987, p. 64), inundation is the primary impact of sea level rise. Erosion is more limited, accounting for only about 1 percent of coastal wetland loss (NRC, 1987, p. 69), because of more cohesive sediments and the presence of dense wetland vegetation (NRC, 1987, p. 49).

The general rule-of-thumb for recession of sandy shorelines in the face of sea level rise was defined by Bruun (1962). The so-called Bruun Rule, is that sandy shorelines will erode landward a distance that is determined by the amount of sea level rise and the slope of the beach. While the Bruun Rule is an oversimplification of the complexities of shoreline recession (NRC, 1987, pp. 55-57), it does offer a basis upon which some generalizations can be made in the absence of detailed site-specific analyses.

The values of this recession factor vary substantially from one location to another. The public is hearing a wide variety of estimates about how far Florida beaches are likely to recede as sea level rises (see Table 4) ranging from 500 to 1,000 feet for every 1-foot rise in sea level (Dean, 2006; Lollar, 2007; Ritchie, 2007; Tasker, 2007).

Walton (2007) reports that the recession rate generally lies between 50 and 100 for the U.S., i.e. for a 1-foot rise in sea level, the shore will recede by 50 to 100 feet. Dr. Stephen Leatherman, Director of the International Hurricane Research Center at Florida International University, in a recent presentation to the Florida Cabinet (Leatherman, 2007), reported that the average recession factor is 78 for 5 locations on the east coast of the U.S.: Long Island, New Jersey, the Delmarva Peninsula, North Carolina, and South Carolina (see Table 4). In other words, a 1-foot rise in sea level would result in 78 feet of shoreline recession.

Titus et al. (2001) reported that the recession factor for Florida ranges between 100 and 1,000. Dr. Peter Howd of the U.S. Geological Survey is quoted in a recent article in the *New York Times* as saying that in much of Florida, the recession factor is only about 100 (Dean, 2006). On the other hand, Jeremy Weiss, a senior research specialist with the University of Arizona's Department of Geosciences, is quoted in an April 2007 article in the *Ft. Myers News Press* (Lollar, 2007) as saying that the range for southwest Florida is between 500 and 1,000. Tasker (2007) quotes Dr. Harold Wanless, a geologist at the University of Miami, as saying that the gradient on the Florida Keys and barrier islands such as Miami Beach may be as low as 1:2000.

Dr. Joseph Donoghue, professor of geology at Florida State University, reports that the average gradient in Florida is 1:1000 so that on average the shoreline recedes by 1.5 meters per year based on an average annual rate of sea level rise of 1.5 mm/yr (personal communication, June 28, 2007). If the upper bound of the sea level rise rates projected by Meehl et al. (2007) for the A1FI scenario is applied to this gradient, i.e. 9.7 mm/yr (see Table 2), an annual shoreline recession rate of 9.7 meters (32.1 ft) per year would be anticipated by approximately 2095 from eustatic sea level rise alone. The mid-level A1B scenario estimate of 6.0 mm/yr would result in a recession rate of 6.0 meters (19.8 feet) per year.

Nationwide, beach erosion rates are as high as 1 to 4 feet per year in many places (U.S. Federal Emergency Management Agency, 2000). In Florida, the state Department of Environmental Protection Bureau of Beaches and Coastal Systems (2007) has classified 387 of the state's 825 miles of sandy beaches (47%) as critically eroding.

Coastal wetland recession also varies with location. Wetlands naturally adapt to rising sea levels through accretion with sediment and biomass inputs (Nicholls and Leatherman, 1995, p. 238). Estuarine wetlands generally have been able to accrete at a rate equal to or greater than sea level along much of the east coast of the U.S., with the exception of Louisiana where rapid subsidence and a reduction in natural sediment inflow have contributed to substantial coastal wetland loss (NRC, 1987, pp. 66; 71). However, at some point the rate of sea level rise may exceed the ability of the wetland to keep pace. Wetlands that occur on the bay side of barrier islands may be able to keep pace with sea level rise if sufficient sediments are washed to the bay side by periodic overwash of beach sediments associated with major storm events (NRC, 1987, p. 65). However, if the barrier island has sufficiently high elevation or if human-made structures impede overwash, back-barrier wetlands may be inundated over the long term (NRC, 1987, p. 65). Titus (1991) estimated that 29 to 69 percent of wetlands along the east coast of the United States would be lost with a 1-meter rise in sea level if only currently developed areas are protected.

Sea level rise may interfere with navigation under bridges by diminishing the above-water clearance. Titus (2002, p. 3) argues, however, that this will not be a major issue for most large bridges over primary shipping lanes. In Florida, the design clearance for bridges over salt water is 12 feet which provides a margin to accommodate some sea level rise for most watercraft. Higher elevations of saltwater bodies will increase exposure of bridge decking, beams, trusses, and girders to saltwater spray from wind, waves, storms, and watercraft. This may promote spalling (flaking) of the concrete and more rapid corrosion of steel bridge components and the rebar in concrete components as the concrete cracks with age. Newer bridges, however, are being constructed with concrete formulations that better resist cracking and spalling as structures age and epoxy-coated rebar that resists corrosion. Bridges over non-navigable, freshwater are designed with a "drift clearance" of 2 feet. Where sea level rise affects these streams, vulnerability to blockage and structural damage from floating debris will increase.

Infrastructure that lies in the path of shoreline recession due to elevated sea level rise and erosion may be adversely affected in several ways. As the mean high tide line moves landward, above-ground structures such as wastewater treatment and reclamation facilities, water supply treatment facilities, and sewer lift stations may initially be subject to intermittent flooding from spring high tides. This may cause short-term access problems at the least, as well as flood damage if facilities are not adequately flood proofed. Shoreline recession due to erosion may result in scouring and undermining of above-ground facilities, road bases, and bridge abutments. Buried pipes, including storm water and sanitary sewers and water supply lines, may be damaged along sedimentary coasts where resultant shoreline erosion and recession expose them to currents and wave forces (NRC, 1987, p. 110).

Pumping rates for wastewater discharge pipes with subsurface outfalls may need to be increased to counter increased hydraulic head due to increased sea level (NRC, 1987, p. 110). Similarly, discharge rates from gravity-flow storm sewers, ditches, and canals will be reduced if outfalls are partially submerged because of the decreased hydraulic head due to higher tailwater levels (Titus et al., 1987). The capacity of such systems will be further reduced due to increased siltation at lower flow velocities. The effectiveness of tide gates in storm water drainage canals and mosquito control ditches may be compromised by small increases in sea level (NRC, 1987, p. 111).

Flooding from Severe Weather Events

As sea level rises, the return frequencies of coastal floods of a given elevation will increase, i.e. higher floods will happen more often, and the boundaries of flood zones for floods of a given return frequency will move higher and further landward. Shoreline recession due to erosion will further shift flood zones further landward.

Federal Emergency Management Agency (FEMA) 100-year flood boundaries, i.e. A-zones and V-zones, are often used to define areas within which infrastructure should not be built or areas within which infrastructure must be elevated or flood proofed. Sea level rise and shoreline recession will move the boundaries of the 100-year coastal storm floodplains higher and further landward. Similarly, hurricane storm surge vulnerability zones will move landward, so that areas previously landward of the Category 5 surge zone will be vulnerable to hurricane flooding and areas closer to the sea will be subject to higher intensity storm surges than at present. Possible increases in the intensity of hurricanes associated with climate change (Alley et al., 2007, p. 16) will increase the likelihood that these areas will be subject to higher storm surges as well as higher maximum sustained winds.

For example, Kirshen et al. (2004) estimated the impacts of sea level rise on the elevations of the 10-year, 100-year, and 500-year storms in Boston Harbor. A U.S. Army Corps of Engineers study conducted in 1993 (Weiner, 1993) had determined that the 10-year storm surge elevation in Boston Harbor was 2.8 meters, the 100-year elevation was 3.2 meters, and the 500-year elevation was 3.4 meters. Kirshen et al. (p. 55) estimated that at contemporary rates of relative sea level rise of 0.3 meter per century in Boston Harbor, the 10-year storm surge elevation would be equal to that of the 1993 100-year storm before the end of this century, and the 100-year storm surge elevation would equal that of the 500-year storm.

The primary implication here is that the level of flood protection previously afforded by the elevation or flood proofing of infrastructure will be reduced as sea level rises. Seawalls, bulkheads, revetments, and levees built to provide flood protection to public facilities and infrastructure will be over-topped more frequently. Drainage canals and ditches may be inundated for often resulting in longer delays in draining floodwaters from interior areas.

Furthermore, facilities previously sited in what were considered to be safe areas, e.g. outside the FEMA 100-year floodplain, may be exposed to floods with higher return frequencies, and structures designed to withstand the force of storm waves and moving floodwaters of a given intensity will be more likely to be subjected to stronger forces. Bridges and causeways along hurricane evacuation routes will have to be closed sooner for a given storm intensity. Highways, bridges, and causeways will be flooded more frequently. As sea level rises, incidents such as the vertical displacement of segments of the I-10 bridges over Escambia Bay during Hurricane Ivan in 2004 (see Figure 3) and Lake Pontchartrain during Hurricane Katrina (see Figure 4) will occur more frequently as will erosion of bridge abutments from storm waves and storm currents.

Saltwater Contamination of Ground Water and Surface Water Supplies

As sea level rises and shorelines recede landward, saltwater intrusion into coastal surficial aquifers also will increase (Jacoby, 1990, p. 316; NRC, 1987, p. 113). Communities that withdraw water from surficial aquifers in various parts of Florida, including the Biscayne Aquifer in southeastern Florida, the Floridan Aquifer along the northeastern coast, and the Tamiami Aquifer in southwestern Florida, have already experienced problems with saltwater intrusion from the sea due to excessive withdrawals (Shoemaker & Edwards, 2003; Sonenshein, 1995; Spechler, 2001).

The “salt front” of the tidal saltwater wedge in coastal rivers also will move further upstream as sea level rises (NRC, 1987, p. 115). The distance will be a function of the river’s gradient as well as the amount of freshwater flow down the river and the tidal cycle. Changes in precipitation regimes that accompany global climate change may, therefore, either serve to exacerbate or ameliorate this impact. Upstream extension of the salt front in coastal rivers will affect both surface water intakes and well fields in aquifers that are recharged by river water (Jacoby, 1990, p. 318; NRC, 1987, p. 115).

Hull and Titus (1986) estimated that a 2.4-foot rise in sea level in the Delaware estuary would push the 250 parts per million (ppm) isochlor of the Delaware River upstream an average distance of 7 miles. They also estimated that the sodium content of river water at one of Philadelphia’s intakes on the river would exceed the state standard of 50 ppm on 15 percent of the annual tidal cycles. Major (1992, p. 382) noted that upstream migration of the salt front in the Delaware River might require an increase in releases from the New York City water supply reservoirs in the Catskills.

Major also suggested that New York City’s Chelsea Pumping Station on the Hudson River, as well as the water supply for the City of Poughkeepsie, might be threatened by upstream migration of the salt front. Schwarz and Dillard (1990, p. 347) quoted a planner with the New York City Bureau of Water Supply as saying that the city’s emergency pumping station on the Hudson River at Hyde Park, more than 80 miles from the mouth of the river, should be moved immediately if sea level rise of 25 centimeters (10 inches) were imminent. At that time, the saltwater boundary of the river was reaching past the pumping station when high tides and low river flows coincided. Schwarz and Dillard (1990, p. 346) reported similar extant problems with high salinity at existing water supply

intakes for the City of New Orleans located on the Mississippi River. The managers with whom they talked also noted that corrosion of the city's cast iron water mains would become a problem at levels of increased salinity that would not affect potability.

The potential for salt front migration to affect water supplies in Florida is a function of both river gradients and rainfall volumes. Richard Verdi with the United States Geological Survey in Tallahassee (personal communication, August 7, 2007) indicated that the only river gradient data available for the state are those reported by Bridges (1982). Because that study was concerned with flood potential, most of the data points are several miles upstream from the mouths of the major rivers in the state. Thus the reported gradients are likely to be higher than those closer to the coast in some river basins. Table 5 presents data for some of the major rivers in the state including gradients in feet per mile and an estimate of how far upstream the salt front would move with a 3-foot rise in sea level if all other factors were held constant. The gradients range from 0.51 foot per mile on the Suwanee River near Wilcox to 5.51 feet per mile on the Perdido River near Barrineau Park. Estimated distances for salt front migration with a 3-foot rise in sea level range from 5.9 miles on the Suwanee to 0.5 mile on the Perdido based on those gradients.

Elevated Water Tables

Sea level rise also will cause increases in the elevation of fresh ground water that overlies saltwater in surficial aquifers in coastal areas. This may expose buried utility lines and pipelines to corrosion, especially where cast iron or concrete pipe is exposed to saltwater (NRC, 1987, p. 110). Higher water tables also may cause increased groundwater infiltration into sanitary and storm water sewers. Significant infiltration into sanitary sewers may impact the capacity of wastewater treatment plants, while infiltration into storm sewers may reduce the capacity of storm water detention, retention, or treatment facilities. Higher water tables also can lead to a reduction in the bearing capacity of some soils because of loss of friction between soil particles. This may affect the structural stability of road bases resulting in a need for more frequent resurfacing.

Sewers are routinely installed below the water table, however, prolonged exposure to groundwater infiltration can cause consolidation and weakened bearing strength of surrounding soils (Corbitt, 1990, p. 6.69) and result in cracks that progressively increase in size (Curran, 2006) and even displacement and structural failure of the pipe (*Illinois Municipal Review*, April 1993). The amount of infiltration is significantly affected by the hydraulic head due to the amount of groundwater that overlies the sewer (Hammer & Hammer, 2001, p. 356). Thus sewers originally laid above the water table may experience significant increases in infiltration where the water table rises partially or completely above the sewer line, especially if such sewers were not designed to withstand the hydraulic loads of overlying groundwater. In addition, sewers that were originally installed below the water table may experience increases in infiltration if sea level rise results in significantly increased water table elevations. Sewers constructed of light weight materials such as PVC plastic may be floated by rising groundwater tables if they

are not properly backfilled when installed so as to prevent this from happening (Lamson Vylon Pipe, 2007, p. 20).

Adaptive Response Options

Adaptive responses fall into three categories: protection, retreat, and accommodation. Titus (1991) suggests that choices among these options will be based on an evaluation of the value of the land and the built environment to be protected compared to the costs of protection. Titus predicts that highly developed coastlines will be protected from sea level rise with a combination of hard and soft engineering measures. In areas that are considered to be too expensive to adequately protect, Titus suggests that the sea may be allowed to advance and accommodation strategies such as raising the land or structures will be implemented. Areas that are not heavily developed but that have other intrinsic value (such as barrier islands for their aesthetic value) may be protected. Retreat strategies are likely to be limited to less developed areas, without significant investments in infrastructure, and natural areas such as coastal wetlands that are capable of naturally adapting to sea level rise if not constrained by topography or the built environment.

In this section we briefly summarize some of the strategies that have been proposed for adapting land use patterns and public facilities and infrastructure to advancing sea levels, shoreline recession, and the associated impacts of increased flooding, contamination of ground and surface water, and elevated water tables.

Protection

The physical measures that can be used to protect developed areas from erosion and inundation include construction of offshore breakwaters, perched beaches, revetments, dikes, floodwalls, seawalls, bulkheads, and dams, as well as beach nourishment, dune building, and marsh building (Sorensen, Wesiman & Lennon, 1984). Beach nourishment can keep pace with sea level rise so long as affordable supplies of suitable beach sediment are available. However, at some point space must be allotted for the beach and dune system to move further landward to maintain a beach slope that is in equilibrium with sea level and the local wave environment. Doing so may necessitate retreat by upland land uses (see below). The protection afforded by built structures will be reduced as sea level rises. These will have to be modified or relocated as the oceans get deeper. Breakwaters, for example will have to be elevated to keep pace with sea level rise. As the shoreline inevitably recedes due to inundation, if not erosion, breakwaters also will have to be moved further landward. Only dikes and levees that completely contain an area, as have been constructed in The Netherlands, have the long-term capacity to provide protection against large increases in sea level. Titus (2002, p. 8) notes, however, that building dikes also requires the reconfiguration of storm water drainage systems including the use of check-valves and pumps to discharge rainwater at levels above the streets.

Where such structures are built, almost complete loss of coastal wetlands and beach and dune systems will ensue (Titus, 2000, p. 733). Thus, in the process of protecting uplands,

the natural protective systems may be lost. According to Titus (2000), most states allow for the protection (armoring) of bay shores but not open-ocean shores. This is due to the public's desire for beach access and subsequent opposition to anything that would limit that access. Also, many state policies designed to protect ocean shores take migrating shores into account whereas policies designed to protect wetlands and bays generally do not include the concept of migrating wetlands. In fact, the Army Corps of Engineers issued Nationwide Permit No. 13 in 1996 (reviewed in 2007), which permits bank stabilization activities necessary to prevent erosion. While there are some restrictions on the extent to which stabilization measures can go, Titus argues that this permit essentially provides no allowance for the migration of wetlands.

Titus and Narayanan (1995, p. 140) report that the California Bay Area Conservation and Development Commission adopted a requirement in 1987 that all newly reclaimed land in San Francisco Bay be filled an additional 12 inches higher to account for accelerating rates of sea level rise. Nichols and Leatherman (1995) report that new seawalls in Great Britain and The Netherlands were being designed 0.25 to 0.66 meter higher to account for anticipated sea level rise within the 50 to 100-year design lives of the structures. The USACE redesign of the New Orleans levees reportedly will be designed to accommodate expected sea level rise over the next 50 years, the expected design life of the new levees (Ludwig, 2007, p. 31).

Well fields threatened by encroaching saltwater intrusion have been protected by reducing the permeability of sediments that lie between the sea and the well field, e.g. through installation of bentonite slurry walls and by enhancing freshwater recharge in the area that lies between the sea and the well field through the use of canals or injection wells (NRC, 1987). A 1998 study conducted by the South Florida Water Management District (Trimble et al., 1998) determined that water levels in coastal canals would need to be raised to provide additional recharge of the Biscayne Aquifer to offset saltwater intrusion from sea level. Doing so, however, would reduce the storm water drainage capacity of the canals. Surface water supplies susceptible to salt front intrusion may be protected through the use of tide gates where these do not interfere with navigation. Such structures are currently used in Hillsborough County, Florida, to protect two surface water supplies from incoming tides.

Retreat

The primary option for large-scale retreat involves what Titus (2000, p. 737) refers to as a "rolling easement" under which "human activities are required to yield the right of way to naturally migrating shorelines." The concept is grounded on the Public Trust Doctrine, which dictates that the intertidal zone should remain in public hands, and the Law of Erosion, which stipulates that boundaries shift as land erodes. Texas, as well as Maine, Rhode Island, and South Carolina reportedly have instituted such rolling easements under which development permits are conditioned on relocation of a structure once it is threatened by a receding shoreline (Titus, 2000; U.S. Environmental Protection Agency, 2006). However, it is important to recognize that these doctrines vary substantially among the common laws of the individual states. They may provide the basis for leaving

coastal property owners to their own devices if the state can effectively prohibit property owners from building seawalls or other obstructions to shoreline recession. However, under some state statutes and common laws, government compensation may be necessary if the state precludes a property owner from protecting their property.

While Florida law (Fla. Stat. ch. 161.061(1) (2007)) empowers the state Department of Environmental Protection to require the adjustment, alteration, or removal of any structure that intrudes onto sovereignty lands of the state below the mean high water line of any tidal water body, the agency has rarely if ever invoked this authority. The agency has, in a limited number of cases, written a rolling easement provision into the permit conditions for structures built in areas with extreme erosion hazards under the state's Coastal Construction Control Line (CCCL) permit program.

While rolling easements may offer the means for incremental retreat one property parcel at a time, they beg the question of what to do with infrastructure threatened by inundation and shoreline recession. Well fields contaminated by saltwater intrusion may be abandoned where protection strategies are deemed to not be cost-effective. But other central facilities such as water treatment plants and wastewater treatment or reclamation plants cannot be easily relocated because their location is constrained by the collection or distribution systems they support. Road segments threatened by receding shorelines may be abandoned, but such a strategy also is likely to involve abandoning storm water, sewer, and water supply lines. This would likely be a very costly and disruptive venture that would deprive property owners on the landward side of the road of municipal services before their properties are subject to the rolling easement provisions. Relocation of roads and underground utilities is likely to have limited application because of the very high costs of right-of-way acquisition in coastal areas.

Benefit-cost analyses conducted for two sections of U.S. 98 in the Florida panhandle that are subject to chronic damage from hurricane-caused erosion showed that periodic repair and replacement would be more efficient than relocation. A proposal to relocate portions of a county road in Indian River County, Florida, after sustaining damage from both Hurricane Francis and Hurricane Jean in 2004, was rejected because of right-of-way costs and the delays that relocation would entail. The state decided instead to armor 13 miles of the road. Similar cost constraints are likely to constrain the relocation of buried sewers and water lines.

As noted above, Titus (1991) anticipates that retreat strategies will primarily be confined to minimally developed and natural areas where the costs of protection will not be warranted and where there remains the potential for natural coastal ecosystems to adapt naturally. In these areas, it may be feasible for government to acquire land from property owners as shoreline recession makes continued occupation impossible without armoring.

Accommodation

New development can be directed away from areas that are anticipated to be affected by inundation, shoreline recession, and advancing coastal flood boundaries. Setbacks can be

employed to require that new structures be built back from the shore by some multiple of the annual average erosion rate. However, the multipliers currently used, for example 30 in Florida and North Carolina, do not provide long-term accommodation for the amount of shoreline recession likely to occur as sea level rises over the next 50 to 100 years. Furthermore, if the rate of sea level rise accelerates appreciable over the next few decades, the 30-year erosion rate of today will be an underestimate. At present, major habitable structures built along Florida's sand shoreline must, as a general rule, be setback a distance equal to 30 times the average annual erosion rate at the site (Fla. Stat. ch. 161.053(6) (2007)). However, the maximum landward extent of the setback is defined by the boundary of the CCCL permit jurisdiction line, which in turn is defined in terms of the erosion likely to occur from a 100-year storm (Fla. Admin. Code 62B-33.024(2)(e) (2007)). As sea level rises, the CCCL must be resurveyed to account for the landward migration of the 100-year event erosion line. At present there are no provisions for doing so.

A second, related option, is to prohibit development in larger hazard zones that are and will be susceptible to both shoreline recession and coastal storm flooding. However, a recent assessment of the effectiveness of Florida's mandate for local governments to adopt and implement policies to direct development away from coastal high hazard areas in the state (Chapin, Deyle, and Baker, under review; Deyle, Chapin, and Baker, under review) suggests that this is not likely to be accomplished without radical changes in state and local land use policies and underlying federal and state laws. Property rights law presents a formidable barrier to completely prohibiting development of such areas, while public funds for fee-simple acquisition are entirely inadequate to buy-out property owners.

New above-ground infrastructure can be designed to accommodate higher coastal flood elevations. Nicholls and Leatherman (1995, pp. 240-241) report several examples of decisions to increase the base elevation of infrastructure facilities to account for anticipated sea level rise. They cite Smith and Mueller-Vollmer (1993) as reporting that the Massachusetts Water Resources Authority designed the Deer Island sewage treatment plant with an additional 0.46 m of height so as to maintain gravity flows at higher sea levels without the capital and operating costs of additional pumping. Major (1992, p. 382) cites a report by Hurwitz (1987) that an outflow pipe for the Third City Tunnel of the New York City water supply system on the Roosevelt Island was redesigned to explicitly account for anticipated long-term rise in sea level.

New infrastructure also can be sited outside the bounds of advancing coastal flood boundaries, if official maps of hurricane storm surge zones and 100-year floodplains are developed to depict both contemporary and future boundaries. According to Mark Viera with the Federal Emergency Management Agency Region IV Office in Atlanta (personal communication, August 13, 2007), FEMA's Map Modernization project has not yet produced revised coastal maps of A-zones and V-zones that account for anticipated sea level rise. Map updating to date has focused on non-coastal areas where much of the emphasis has been on simply digitizing older paper maps rather than conducting formal restudies that reassess where flood hazard boundaries should be drawn. Map updating in

coastal areas is slated to begin in 2009 or 2010. According to Viera, these will be formal restudies. The agency's recently published guidelines for coastal flood hazard zone mapping along the Atlantic and Gulf Coasts (U.S. Federal Emergency Management Agency, 2007) do encourage "mapping partners"³ to account for sea level rise: "mapping partners should consider the impacts of sea-level rise on floodplain boundary delineations . . . [within] "the probable lifetime of a particular [flood] study" (pp. D.2.4-25 and D.2.4-26). Viera anticipates that additional guidance may be forthcoming once the post-Katrina remapping is finished in coastal Louisiana and Mississippi.

Accommodation strategies for existing infrastructure include elevation and flood proofing for above-ground facilities. Elevation of major existing facilities such as wastewater or water supply treatment plants is unlikely to be cost-effective. Base elevations may be increased when facilities are upgraded or replaced onsite, but this may not be possible for wastewater treatment or reclamation facilities served by gravity sewers unless pump stations are added to lift incoming sewage to the treatment facility grade. Bridges can be rebuilt with higher elevations. However, doing so may necessitate acquisition of additional right-of-way for extended approaches.

Titus (2002, p. 6) observes that roads are typically constructed at lower elevation than surrounding land for drainage purposes and, therefore, are more susceptible to flooding. He suggests that while major elevation of roads will require additional fill and reconstruction of the entire roadbed, small increments in elevation to reduce flooding can be accomplished on local streets by paving over existing pavement. This strategy does not, however, account for the structural destabilization of the roadbed where rising sea level also results in elevated water tables. Titus predicts that many low-lying communities will accommodate larger increments of sea level rise through incremental elevation of the land with fill.⁴ He suggests that doing so will also provide adaptation for roads.

Elevation of the ground surface will not address the impacts of rising sea levels on underground infrastructure. Sewer wet wells may need to be raised or otherwise protected against buoyancy resulting from elevated water tables. Manhole covers may need to be sealed to reduce inflow from street flooding. Accommodation strategies for increased infiltration and other impacts on underground sanitary and storm sewers associated with higher water tables include complete replacement of the sewer pipe, replacement of sewer bedding material, grouting of pipe cracks and/or surrounding soil, and lining with a smaller-diameter polyethylene plastic pipe (Corbitt, 1990, p. 6.69). Replacement is typically more expensive and time-consuming resulting in service disruptions and often interfering with surface transportation along sewer rights-of-way.

Titus et al. (1987, p. 219-220) identify three major accommodation strategies for storm water drainage systems in coastal areas aside from the option of tolerating more frequent flooding:

³ "Mapping partners" are the consultants who actually perform the remapping studies.

⁴ Titus (2002, p. 6) reports that eight New Jersey communities on barrier islands have signed agreements with EPA pledging to adapt to rising sea level by gradually elevating the land and structures upon it.

- (1) enhancement of gravity drainage through installation of large diameter pipes and widened drainage ditches to counteract the reduced head that results from higher tailwater elevations;
- (2) installation of forced drainage systems in low-lying areas where gravity drainage is no longer possible and increased pumping capacity for existing forced drainage systems to counteract higher tailwater elevations; and
- (3) delay of peak discharges and reduction of peak discharge volumes by enhancing storm water detention at upstream locations within drainage basins and incorporating other measures that enhance onsite detention and retention and infiltration of runoff such as use of porous pavements, roof-top detention, grassed waterways, etc.

Advancing salt fronts in tidally-influenced surface water supplies have been routinely managed through supplemental releases from upstream reservoirs (U.S. Environmental Protection Agency, 2006). However, maintaining sufficient quantities of water in storage to accommodate such releases may run counter to flood protection needs.

Accommodation options for saltwater intrusion into water supply well fields are well established because a number of coastal communities have already encountered the problem from excessive withdrawal rates. They include (1) reducing withdrawal rates by drawing more from alternative sources and promoting conservation and (2) the use of desalination (NRC, 1987, p.113; Sorensen et al., 1984). A number of water utilities in southern and southwestern Florida and the Tampa Bay area already employ desalination to treat water from deeper brackish aquifers and brackish surface waters including the cities of Ft. Myers, Ft. Pierce, and others are investigating the option of doing so. The Tampa Bay desalination plants treats water drawn from the bay, and other communities in the state, including Miami-Dade County, Ft. Myers, Ft. Lauderdale, and Port Everglades are assessing the feasibility of desalination of seawater (Ludwig, 2007; Southwest Florida Water Management District, 2006; Water Quality and Health Council, 2007). In areas such as the Florida Panhandle, where alternative surface water supplies are available, and northeastern Florida, where the Floridan Aquifer has low dissolved solids, desalination is considered to be less cost-effective.⁵

The Costs of Protection and Accommodation

The costs of protecting developed areas will be high and must be weighed against the economic value of the land and its improvements. Titus (1991) estimated that the cost of protecting developed shores along sheltered waters of the U.S. for a 1-meter rise in sea level would be approximately \$22.07 billion (in the southeast alone, \$8.91 billion). Protecting the open coast from 1 meter of sea level rise by elevating roads, structures, and beaches could range from \$7.8 billion along the Atlantic Coast to \$51.6 billion along the Gulf Coast, not including the cost of sand for renourishing beaches. The authors qualify

⁵ In a study of residential water rates in Florida, Whitcomb (2005) reported a range between \$1.00 and \$1.96 per thousand gallons (TG) in five communities in north central and northwestern Florida (mean = \$1.45/TG) and a range between \$2.27 and \$10.31/TG in 9 communities in the Tampa Bay and southeastern areas of the state (mean = \$5.12/TG).

this projection as too low because it ignores all of the impacts that could not be readily quantified.

Other estimates of the cost of protecting the shores of the U.S. have been made using different assumptions. In a study by Yohe et al. (1996) cited by Titus (2000), the authors estimated that the cost would only be \$45 billion to protect the U.S. shoreline if protection were confined to those areas where the value of the land and its improvements justify the protection. This cost could be further reduced to \$36 billion if landowners understood the need to abandon the shoreline well before the need arose and were, therefore, prepared for retreat. Walsh et al. (2004, p. 593) argue that protection and accommodation are likely to be cost-effective in the medium-term (decades) but that eventually managed retreat will probably be necessary.

Planning Responses to Sea Level Rise

Titus (2000) suggests that because sea level rise is such a long term problem it is possible that we do not need to prepare for it immediately. However, he maintains that it should be considered in the cycle of capital improvements, especially if the money spent on improvements could earn more money if invested somewhere else. There are two exceptions to this concept. One is the “retrofit penalty,” where if one is building a system anyway it may be cheaper and easier to build it with sea level rise in mind instead of having to retrofit the structure later. The other is where there could be incidental benefit for incorporating sea level rise into planning from the beginning. For example, if a community were to build a flood control structure for what will be a common flood height in the future, building it now would also mitigate the smaller floods that happen in the meantime. However, Titus also states that while engineering decisions can be put off into the future, land use decisions should not be delayed; communities need to decide how to deal with land as the shoreline recedes.

Our interviews with local, regional, and state long-range planners and infrastructure managers reveal that, with few exceptions, sea level rise is not on the menu of immediate concerns nor is it likely to be dealt with explicitly within the planning timeframes and processes that are currently in place for comprehensive and infrastructure planning.

In the following sections we present an overview of the manner in which sea level rise adaptation planning is being approached in other parts of the U.S. and Florida's recently convened Action Team on Energy and Climate Change. We then summarize the frameworks that govern long-range comprehensive planning and infrastructure planning at the local and regional levels in Florida for land use, water supply, wastewater, and transportation facilities. In addition we report the findings from our surveys of local, regional, and state officials concerning these processes and conclude with a description of the small number of initiatives that have been begun to address sea level rise adaptive planning in Florida.

What is Happening in Other States and Communities in the U.S.?

The Pew Center on Global Climate Change released a report in August 2007 that provides an overview of climate change adaptation initiatives by state and local governments in the U.S. (Pew Center on Global Climate Change, 2007). They note that while 35 states have prepared or are in the process of preparing climate action plans concerned with mitigating greenhouse gas emissions, only 6 states (Arizona, California, Maryland, North Carolina, Oregon, and Washington) explicitly do or will address climate change adaptation in those plans. The initiatives in Arizona, Maryland, and Oregon have just begun, however, the Oregon Climate Change Integration Group has made some preliminary recommendations (Abbott & Dempsey, 2007):

- Appoint a special committee to evaluate the current understanding of climate change science relative to the state's emission reductions goals on a schedule coordinated with the release of the Intergovernmental Panel on Climate Change (IPCC) scientific assessments.
- Dedicate funding to establish a climate change research center through the Oregon University System focusing on both adaptation and mitigation strategies for natural and human systems.
- Dedicate funding to establish an ongoing education, communication, and outreach program on climate change to assure that investments in research and policy measures are translated into on-the-ground results.
- Establish and fund a program of technical assistance to assist local governments to devise climate change action plans.

The preliminary adaptation assessment completed in California does not explicitly address sea level rise impacts on infrastructure or long-range land use planning. However, a bill passed by the California Assembly in June 2007, AB 1066, would require the Governor's Office of Planning and Research to develop guidelines on planning for sea level rise for use by local governments when updating their general plans (Douglas & Christie, 2007). The bill also would require the state Ocean Protection Council to convene an interagency task force to gather existing information on sea level rise projections to inform the guidelines.

In North Carolina, an initiative is underway by the state Division of Coastal Management to require all coastal counties to address the impact of sea level rise in their land use plans (North Carolina Climate Action Plan Advisory Group, 2007).

The Washington Climate Advisory Team (CAT) includes a Coastal and Infrastructure Preparation/Adaptation Working Group, which is in the process of developing its recommendations for the CAT. One of its draft high-priority recommendations for immediate implementation is to require inclusion of a climate change element in local comprehensive plans that explicitly addresses sea level rise (Washington Climate Advisory Team Coastal and Infrastructure Preparation/Adaptation Working Group, 2007). They would also recommend that sea level rise be addressed in local capital facilities planning under the auspices of the state's Growth Management Act and that

climate change and sea level rise implications be addressed in environmental impact assessments prepared under the State Environmental Protection Act. Other specific preliminary recommendations that address sea level rise and infrastructure include the following:

- Avoid non-essential coastal armoring.
- Include sea level rise in the design of all coastal state facility construction/major repair projects and encourage this for local government projects.
- Require all state infrastructure funding programs to include consideration of climate change and sea level rise in funding and design.
- Improve near-shore elevation data control points to provide accurate elevation benchmarks to support mapping and monitoring of sea level in all coastal areas.
- Develop state-issued sea level rise benchmarks and risk reduction guidelines for public facility planning including validation of projections and identification of tiers of recommendations based on level of risk over time for different types of facilities.
- Assess vulnerability of existing infrastructure (storm water systems, sanitary sewer, coastal groundwater supplies, septic systems) to saltwater intrusion and design retrofit programs.
- Raise the awareness of utility operators to the potential vulnerability of infrastructure and encourage them to include adaptive improvements (e.g. tide gates) into their capital facilities plans.
- Consider sea level rise in habitat restoration and large-scale mitigation and acquisition proposals so as to enhance the resiliency of the restored/mitigated habitat.
- Consider near-shore areas adjacent to vulnerable coastal habitats for preservation/conservation easement/purchase [presumably to allow landward migration of coastal ecosystems as sea level rises].
- Consider habitat reclamation opportunities in long-term management of armored/diked shorelines as part of response to sea level rise.
- Develop science-based sea level rise and erosion vulnerability maps for all coastal areas.
- Conduct a formal legal analysis of sea level rise and property rights/regulation/public access issues.
- Develop a public education program directed to the general public, decision makers, and local government officials.

The Pew Center (2007) reports that while hundreds of cities in the U.S. are developing climate action plans, as is the case with the states, most are focused on greenhouse gas emission reduction only. They observe, however, that a few are taking action to address specific impacts associated with sea level rise including saltwater intrusion into ground water supplies, protecting infrastructure and communities from flooding and more severe hurricanes, and preparing for water shortages. Several notable initiatives include those by King County, Washington, the City of New York, and the City of Seattle plus the Climate Resilient Communities campaign recently launched by the International Council for Local Environmental Initiatives (ICLEI).

The Pew Center highlights the King County, Washington, *Climate Plan* as exemplary for its attention to adaptation to climate change (King County, Washington, 2007). It contains a few specific references to sea level rise and infrastructure:

- King County will collaborate with climate scientists and the Federal Emergency Management Agency to evaluate and plan for the potential impacts of coastal flooding associated with sea level rise paying particular attention to the impacts of climate change on shoreline erosion.
- The county's Historic Preservation Program will identify historic buildings, cultural properties, and archaeological sites that are vulnerable to damage caused by climate change impacts.
- The county's the Wastewater Treatment Division will determine which of its facilities are most vulnerable to climate change impacts, including sea level rise, and will develop a series of climate change response strategies to maximize flexibility to respond to changed conditions and assumptions.
- The county's County Road Services Division will incorporate climate change impacts information into construction, operation and maintenance of infrastructure projects.

The City of New York's recently published plan for 2030, *PlaNYC: A Greener, Greater New York*, addresses climate change adaptation in several ways. It calls for the creation of an inter-governmental task force to supplement work begun in 2004 by the city's Department of Environmental Protection that was focused on the city's water infrastructure. The expanded task force will "create an inventory of existing at-risk infrastructure, analyze and prioritize the components of each system, develop adaptation strategies, and design guidelines for new infrastructure" (City of New York, 2007, p. 138).

Seattle's 2006 action plan reports that the Climate Impacts Group at the University of Washington has estimated that sea level will rise in Puget Sound by 1.3 feet by 2050 due to anticipated changes in wind and current patterns in the Pacific Ocean (City of Seattle, 2006). The plan calls for the Office of Sustainability and Environment to convene an interdepartmental team to prioritize adaptation issues and recommend specific strategies, actions, and timing to the Mayor.

The International Council for Local Environmental Initiatives (ICLEI) is an association of more than 630 cities, towns, counties, and their associations, and national and regional local government organizations committed to sustainable development. Cities for Climate Protection® (CCP) is ICLEI's flagship program designed to educate and empower local governments worldwide to take action on climate change. Miami-Dade County was one of the founding participants of CCP. Other Florida participants include Alachua, Broward, Hillsborough, and Orange counties and the cities of Gainesville, Miami Beach, Riviera Beach, and Tampa.

In 2005 ICLEI launched its Climate Resilient Communities campaign to help local governments in the U.S. improve their resiliency to climate disruptions and catastrophes from global warming. "The program helps local governments develop tools to assess their vulnerabilities and prepare their communities for the impacts and costs associated with predicted global climate change" (International Council for Local Environmental Initiatives, 2007). The program is based on five milestones:

- (1) conduct a climate resiliency study,
- (2) prioritize areas for action and set goals,
- (3) develop a climate resilient action plan,
- (4) implement the plan, and
- (5) monitor and reevaluate.

ICLEI is collaborating with King County, Washington, and the Climate Impacts Group at the University of Washington to create a Climate Adaptation guidebook that is due to be released in 2007. The guidebook will be used as a primary education and outreach tool, and the adaptation protocols it describes will be pilot-tested in four US communities: Miami-Dade County, Florida; Keene, New Hampshire; Homer, Alaska; and Ft. Collins, Colorado.

Florida's Action Team on Energy and Climate Change

On July 13, 2007, Florida Governor Charlie Crist signed an executive order calling for the formation of an Action Team on Energy and Climate Change. The Team, which met first on August 29, 2007, is charged with developing an action plan to achieve targets for statewide greenhouse gas reductions. The state Department of Environmental Protection (DEP) is serving as the lead agency for climate change activities. DEP is working to provide "sound science-based information to raise awareness among citizens and stakeholders and inform state level policymaking as well as provide staff support to the Governor's Action Team on Energy and Climate Change" (Florida Department of Environmental Protection, 2007a). The Action Team's initial report, scheduled for November 1, 2007, is to be focused on reducing greenhouse gas emissions. The Team's second, report, scheduled for November 1, 2008, is to also address adaptation strategies.

Florida's Planning and Policy Framework for Addressing Sea Level Rise

The planning framework within which sea level rise adaptation could be addressed in Florida includes the provisions of state statutes and rules governing the future land use, infrastructure, and capital improvements sections of local comprehensive plans and those governing state, regional, and local planning of water supply and wastewater management systems, roads, bridges, and causeways. The following overview of these planning frameworks reveals a set of consistent findings across these planning domains:

- (1) There are no explicit requirements that state, regional, or local planning entities address sea level rise in land use or infrastructure planning.

- (2) Statutory planning time frames are generally too short to directly encompass sea level rise impacts.
- (3) There are provisions within these planning frameworks, however, that offer appropriate contexts within which sea level rise adaptive response planning could be addressed.

Local Comprehensive Planning Requirements

The local comprehensive planning horizons stipulated in the state's Growth Management statute (Fla. Stat. ch. 163 (2007)) do not provide an explicit context for considering the implications of long-term gradual changes such as sea level rise for future land use or infrastructure planning.

Local comprehensive plans in Florida are required to encompass two planning horizons: a 5-year period after plan adoption and a second period covering at least 10 years (Fla. Stat. ch. 163.3177(5)(a) (2007)). Local governments are encouraged to develop a community vision that provides for sustainable growth, recognizes its fiscal constraints, and protects its natural resources. Such a community vision must depict the desired land use patterns and character of the community during a 10-year planning timeframe (Fla. Stat. ch. 163.3177(13) (2007)). A separate Future Land Use Element designates the proposed future general distribution, location, and extent of land uses in the community over the 10-year planning horizon (Fla. Stat. ch. 163.3177(6)(a) (2007)).

Most of the 20 coastal communities we surveyed do not prepare plans with planning horizons greater than the 10-year minimum required under state statute, although a few extend the planning horizon to 15 to 20 years. Collier County reported that they extend the planning horizon for infrastructure to 25 years, and Hillsborough County reported that they have begun an effort that will employ a 50-year planning horizon.

Requirements for a separate Conservation Element (Fla. Stat. ch. 163.3177(6)(d) (2007)), which addresses the conservation, use, and protection of natural resources in the area, including ". . . wetlands, waterwells, estuarine marshes, . . . beaches, shores, flood plains, rivers, bays, lakes, harbors, . . . fisheries and wildlife, [and] marine habitat . . ." arguably could offer the context within which the expected impacts of climate change might be addressed if a much longer planning horizon were stipulated. The statutory requirement for the Coastal Element to address "avoidance of irreversible and irretrievable loss of coastal zone resources" (Fla. Stat. ch. 163.3177(6)(g)1.d. (2007)) provides further leverage for considering the potential impacts of sea level rise, at least on natural systems.

Infrastructure planning is governed by two required local comprehensive plan elements: (1) a Capital Improvements Element and (2) a general sanitary sewer, solid waste, drainage, potable water, and natural groundwater aquifer recharge element (referred to hereafter as the Infrastructure Element) (Fla. Stat. ch. 163.3177(3)(a)1. and (6)(c) (2007)).

The focus of the Capital Improvements Element on fiscally feasible near-term capital improvements planning appears to be too short-range to be a feasible means for addressing sea level rise adaptation. The state purpose of the element is to outline the principles for construction, extension, or increase in the capacity of public facilities, as well as the principles for correcting existing public facility deficiencies, which are necessary to implement the comprehensive plan (Fla. Stat. ch. 163.3177(3)(a)1. (2007)). It must include a “financially feasible 5-year schedule of capital improvements” (Fla. Stat. ch. 163.3177(3)(b)1. (2007)). Local governments that elect to designate an urban service boundary must adopt a 10-year financially feasible facilities plan (Fla. Stat. ch. 163.3177(14) (2007)). Local governments that choose to adopt a long-term concurrency management system under Chapter 163.3180(9) *Florida Statutes*. must also adopt a long-term capital improvements schedule covering up to a 10-year or 15-year period (Fla. Stat. ch. 163.3177(3)(d) (2007)).

The Infrastructure Element is intended to indicate ways to provide for the future potable water, drainage, sanitary sewer, solid waste, and aquifer recharge protection needs for the area (Fla. Stat. ch. 163.3177(6)(c) (2007)). It must describe the problems and needs and the general facilities that will be required for solution of the problems and needs over the two planning periods encompassed by the comprehensive plan, i.e. 5 years and at least 10 years. The more detailed requirements set forth in the *Florida Administrative Code* dictate that facility needs for the two planning periods are to be “based on the projected demand at current local level of service standards for the facility, resulting from development permitted by local government, the projected population, land use distributions as indicated in the future land use element, and available surplus capacity identified” (Fla. Admin. Code 9J-5.011(1)(f) (2007)). The Infrastructure Element also must include an analysis of the problems and opportunities for facilities replacement and expansion and new facility siting. This appears to be the logical place to address the potential impacts of sea level rise on infrastructure, but to do so requires a planning horizon greater than 10 years.

Parallel requirements are included in the directives contained in the section of the *Florida Administrative Code* concerning the Coastal Element, which must be included in the plans of coastal communities in the state. Analyses are required of the demand upon, capacity of, and area served by existing infrastructure within the coastal planning area as well as estimates of future needs (Fla. Admin. Code 9J-5.012(2)(h) (2007)). Coastal communities with deepwater ports are required to include a Deepwater Port Master Plan in their comprehensive plans. These also have 5 to 10-year planning horizons including a plan for future port expansion for an initial 5-year period and in-water facility maintenance for at least a 10-year period (Fla. Admin. Code 9J-5.012(5)(d) (2007)). The port master plans also must assess the impact of port expansion and maintenance on coastal natural resources and land use and infrastructure of adjacent areas. This would be the appropriate place to address SLR for ports.

Water Supply Planning

Florida statutes define a 20-year planning horizon for regional water supply planning and require coordination between the regional plans and local comprehensive plans. While water management districts have responsibility for regional-scale planning, the decisions to undertake specific water supply development projects rest with local governments and their water purveyors. There is nothing in the statutory language that provides an explicit context for addressing the long-term implications of sea level rise on water supply sources or water supply infrastructure.

The need for major water supply infrastructure in Florida is primarily identified through the preparation of district water management plans by each of the state's regional water management districts pursuant to Chapter 373.036(2) *Florida Statutes*. The district plans cover at least a 20-year time period and must be updated at least every 5 years. The major elements of these plans include the following:

- established minimum ground water levels and surface water flows,
- identification of one or more water supply planning regions within the district,
- technical data required to assist local governments in preparing the water supply sections of their comprehensive plans,
- a district-wide water supply assessment report that determines the adequacy of existing and anticipated water supply sources and conservation efforts for meeting the needs of all existing and reasonably anticipated legal water uses, and
- any completed regional water supply plans.

Specific considerations that must be reflected in the district water management plans include, among others:

- attainment of maximum reasonable-beneficial use of water resources,
- maximizing economic development of water resources consistent with other uses,
- managing water resources for environmental protection, drainage, flood control, and water storage,
- prevention of uneconomical or unreasonable uses, and
- preservation and enhancement of water quality.

Regional water supply plans must be prepared by water management districts pursuant to Chapter 373.0361 *Florida Statutes* where a district "determines that existing sources of water [within a designated water supply region] are not adequate to supply water for all existing and future reasonable-beneficial uses and to sustain the water resources and related natural systems for the planning period." The regional plan includes a quantification of the water supply needs of the region for at least a 20-year period based on a 1-in-10-year drought scenario plus a list of specific water supply development⁶ and

⁶ "Water supply development" means the planning, design, construction, operation, and maintenance of public or private facilities for water collection, production, treatment, transmission, or distribution for sale, resale, or end use (Fla. Stat. ch. 373.019(24) (2007)).

water resource development⁷ project options and the local governments and other water supply entities that should implement each project option. The plan also must address how the project options will prevent the loss of natural resources and avoid greater future expenditures for water resource or water supply development.

Water management districts also are required to complete consolidated district annual reports pursuant to Chapter 373.036(7) *Florida Statutes* or they may substitute an annual strategic plan which replaces both the district water management plan and the consolidated annual report. The annual report is required to include, among other elements, a 5-year capital improvements plan (pursuant to Chapter 373.536(6)(a)3 *Florida Statutes*); an annual 5-year work program (pursuant to Chapter 373.536(6)(a)4 *Florida Statutes*); and an alternative water supplies annual report that describes all alternative water supply projects funded that year and the quantity of new water provided (pursuant to Chapter 373.1961(3)(n) *Florida Statutes*).

When a regional water supply plan is undertaken by a water management district, local governments within the water supply planning region may prepare their own water supply assessments which then must be considered by the district in preparing the regional plan. Local governments and other water supply entities are not required to implement the specific water supply development projects for which they are designated in the regional plan (Fla. Stat. ch. 373.0361(6) (2007)). They may instead propose an alternative water supply development project sufficient to meet the needs identified by the district in the regional plan (Fla. Stat. ch. 373.0361(7)(b) (2007)).

Local government comprehensive plans must be “coordinated” with any applicable water management district's regional water supply plan through the inclusion of a specific policy statement that addresses such coordination (Fla. Stat. ch. 163.3177(4)(a) (2007)). The Future Land Use element of the local comprehensive plan must be based on the availability of local water supply (Fla. Stat. ch. 163.3177(6)(a) (2007)). Within 18 months after the applicable water management district governing board approves an updated regional water supply plan, a local government must amend the Infrastructure Elements of its comprehensive plan to incorporate the alternative water supply project or projects selected by the local government from those identified in the regional water supply plan pursuant to Chapter 373.0361(2)(a) *Florida Statutes* or proposed by the local government under Chapter 373.0361(7)(b) *Florida Statutes*. The element also must include “a work plan, covering at least a 10 year planning period, for building public, private, and regional water supply facilities, including development of alternative water supplies, which are identified in the element as necessary to serve existing and new development. The work plan shall be updated, at a minimum, every 5 years within 18

⁷ "Water resource development" means the formulation and implementation of regional water resource management strategies, including the collection and evaluation of surface water and groundwater data; structural and nonstructural programs to protect and manage water resources; the development of regional water resource implementation programs; the construction, operation, and maintenance of major public works facilities to provide for flood control, surface and underground water storage, and groundwater recharge augmentation; and related technical assistance to local governments and to government-owned and privately owned water utilities (Fla. Stat. ch. 373.019(22) (2007)).

months after the governing board of a water management district approves an updated regional water supply plan” (Fla. Stat. ch. 163.3177(6)(c) (2007)).

State regulations promulgated by the State Department of Environmental Protection require that all components of new or expanded water supply systems be situated outside of 100-year floodplains and above the highest recorded high tide (Fla. Admin. Code 62-555.310 (2007)). New wells are to be located in areas free from or least subject to inundation from surface drainage and flood water (Fla. Admin. Code 62-555.312 (2007)). Community water systems must be designed and constructed so that structures and equipment are protected from physical and wave damage from a 100-year storm and they must remain fully operational and accessible when exposed to flooding and wave action from a 25-year storm (Fla. Admin. Code 62-555.320 (2007)).

Wastewater Planning

State law dictates a 10-year planning horizon for wastewater treatment facilities. Sea level rise is not explicitly addressed in regulations governing either the siting of new facilities or the operation and maintenance of existing facilities. Provisions governing the siting and design of new facilities explicitly require that treatment facilities be capable of withstanding the impacts of a 100-year flood. Officials in the state Department of Environmental Protection (DEP) who oversee the permitting of such facilities believe that other regulations should assure that both treatment facilities and collection and disposal systems are operated and maintained so as to adapt to the potential impacts of sea level rise.

There are more than 3,000 permitted, domestic and industrial wastewater treatment facilities in Florida, not including subsurface wastewater disposal systems, i.e. septic tanks. A little less than three-quarters of the individually permitted wastewater facilities in Florida are classified as domestic (municipal) wastewater facilities. These are principally designed to collect and treat sanitary wastewater or sewage from dwellings or homes, businesses, and institutions. The remaining individually permitted facilities are classified as industrial wastewater facilities.

Fewer than 25 percent of the permitted domestic and industrial wastewater treatment facilities discharge to surface waters of the state (Florida Department of Environmental Protection, 2007b). The remaining facilities discharge solely to groundwater through land-application, beneficial reuse of reclaimed water, or deep well injection. Those that do discharge to surface waters (slightly more than 200 domestic wastewater facilities) are subject to the state’s National Pollutant Discharge Elimination System (NPDES) permitting requirements. Approximately 110 of these facilities discharge to coastal rivers or streams likely to be affected by rising sea level. Only 6 discharge directly to the Atlantic Ocean. None discharge directly into the Gulf of Mexico or Florida Bay. Many of the NPDES facilities also discharge to groundwater.

The planning horizon for domestic wastewater management systems is essentially 10 years. As reported above, the state’s laws governing the Infrastructure Element of local

comprehensive plans requires a description of the facilities that will be needed to meet a community's infrastructure problems and needs over both 5-year and 10-year planning periods. Once the 3-month average daily flow exceeds 50 percent of the permitted capacity of an existing treatment plant or reuse and disposal system, the permit holder is required to submit a capacity analysis report to DEP (Fla. Admin. Code 62-600.405 (2007)). The capacity analysis report is required to include flow projections, based on local population growth rates and water usage rates, for at least the next 10 years; an estimate of the time required for the three-month average daily flow to reach the permitted capacity; recommendations for expansions; and a detailed schedule showing dates for planning, design, permit application submittal, start of construction, and placing new or expanded facilities into operation.

State regulations issued by the Florida Department of Environmental Protection (DEP) which govern the siting of new wastewater treatment facilities do not explicitly address the potential impacts of sea level rise. However, per Chapter 62-620 *Florida Administrative Code*, an applicant to the State Department of Environmental Protection for a permit for a domestic wastewater facility must provide a preliminary design report containing among other things a site plan showing operations and unit processes, 100-year and 25-year flood elevations; approximate finish elevations for all major treatment units, pumping stations, and sanitary manholes; and a storm water management plan (Florida Department of Environmental Protection, 2001). Section 62.600.400(2)(c) *Florida Administrative Code* specifically requires the applicant to assess the potential for damage or interruption of operation because of flooding, including potential wave action, when siting new treatment plants and expansions of existing plants at inland or coastal locations. The treatment plant structures essential for the purpose of treating, stabilizing, conveying, or holding incompletely treated waste and electrical and mechanical equipment must be protected from physical damage by the 100-year flood. The treatment plant also must be designed to remain fully operational and accessible during the 25-year flood.⁸ Similar requirements apply to the siting of sewage pump stations (Fla. Admin. Code 62.604.400(2)(e) (2007)). As noted above, FEMA maps of 100-year floodplain boundaries do not currently reflect estimates of potential sea level rise. However, there is the potential for restudy maps to be developed over the next several years that do reflect the impacts of sea level rise on future floodplain boundaries.

DEP does not currently have any initiatives underway to directly address the implications of sea level rise for existing wastewater collection and treatment systems. They do, however, have several rule provisions that they believe should serve to detect problems that become manifest as sea level rises and that would require corrective action by system operators. In particular, the state's requirement that wastewater treatment facility permit holders submit operation and maintenance performance reports every 5 years (Fla. Admin. Code 62-600.735 (2007)) should provide a trigger for identifying excessive

⁸ Lesser flood levels may be designed for, if justified in the preliminary design report based on local conditions, water surface elevations, forces arising from water movement, wave heights, flood protection measures provided, and provisions for wastewater storage such that applicable water quality standards will be met; but in no case shall less than a 10-year flood be used.

collection system inflow that may result as ground water levels rise in response to rising sea level in low-lying coastal areas.

Another possible impact of sea level rise is reduced discharge flows from submerged treatment plant outfalls as the hydraulic head increases with higher sea levels. DEP requires the regular submission of operation and maintenance reports that include documenting discharge rates (Fla. Admin. Code 62-600.410 (2007)). The regulations specifically require that all wastewater treatment facilities and equipment to function as intended. If discharge rates were compromised, facilities might need to install larger pumps to deal with the increased hydraulic head. This rule also would require that corrective action be taken if a treatment facility or portions of the collection system were compromised by flooding or erosion.

At present there are only six municipal domestic wastewater treatment systems with ocean effluent outfalls (Koopman, Heany, Cakir, Rembold, Indeglia, & Kini, 2006). All six are in Palm Beach, Broward, and Miami-Dade counties. While the state does not have formal rules that explicitly require that such facilities be phased out, they have several initiatives in place that are designed to encourage the phasing out of all surface discharges of treated wastewater. These are motivated by two concerns: (1) water supply shortages in many parts of the state and (2) concerns with the effects of nutrient enrichment from treated wastewater effluent. DEP's anti-degradation policy discourages the permitting of new or expanded surface water discharges (including ocean outfalls). The state also requires utilities requesting domestic wastewater plant construction or expansion to investigate the feasibility of implementing water reuse.

Transportation Planning

The Florida state highway system consists of approximately 12,000 miles of highways. About 4,000 miles of this system constitute the Strategic Intermodal System, which is managed directly by the state Department of Transportation (DOT). The remaining 8,000 miles are managed by local governments. All local transportation projects for communities situated within the boundaries of one of the state's 26 Metropolitan Planning Organizations (MPOs) that are funded with state or federal monies must be included in the MPO's 20-year Long-Range Transportation Plan. The same planning horizon also is stipulated for long-range statewide transportation plans (23 CFR 450.104).

The design and construction of roads, bridges, and causeways in Florida follow the state "Greenbook" (Florida Department of Transportation, 2005) and guidelines developed by the American Association of State Highway and Transportation Officials (AASHTO, 2002). The Greenbook includes scour design standards for hydraulic loads on bridge substructure for 100-year flood events but does not address flooding or erosion design standards for roads. The AASHTO guidelines recommend providing structural protection of bridge piers and abutments against scour. State DOT officials with whom we spoke indicated that bridge abutment design to minimize erosion and scour damage is based primarily on best professional judgment. Bridge superstructure components are designed to minimize damage from storm surge and waves but no explicit standards have been

published. A study is underway to estimate the magnitude of such hurricane loadings and their probabilities for major rivers, streams, and bays in the state.

Local and state projects funded with state or federal monies also must comply with the state's *Project Development and Environment Manual* (PDE) review procedures and criteria, which address natural hazards and the environmental impacts of transportation projects including highways, bridges, and causeways. Section 24-2.3 of the *PDE Manual* (Florida Department of Transportation, 1998) requires completion of a risk evaluation for all encroachments within 100-year floodplains. These must consider both risks to highway users from flood hazards and risks to nearby property owners where the encroachment might exacerbate flood impacts. The risk analysis also must include probable flood related costs for highway operation, maintenance, and repair during the service life of the facility. Twenty years is the typical time frame for defining the service life of the capacity of a highway. However, the service life of the right-of-way and roadbed is more on the order of 75 years. Coastal erosion hazards are not explicitly addressed in the *PDE Manual*, but discussions with state district project environmental engineers indicated that such hazards are routinely considered.

Section 18-2.3 of the *PDE Manual* (Florida Department of Transportation, 1999) requires determining the significance of the effects of alternative corridor options on wetland stability and quality, including both short-term and long-term effects. However, discussions with state district project environmental engineers revealed that these assessments do not consider the effects of transportation projects on the long-term ability of wetlands to adapt to sea level rise.

What Florida Planners Have to Say

Here we summarize our findings from our interviews with local long-range comprehensive planners, regional and local water supply planners, and local wastewater systems planners.

Local Comprehensive Planners

We interviewed long-range planners in 20 coastal jurisdictions in the state (see Table 1). We asked these planners about their perceptions of the threats posed to their communities by sea level rise without specifying any detailed projections. Thirty percent felt that it may be a major threat, another 30 percent said moderate, and 15 percent said minimal or not at all. Twenty percent of our respondents said they were unsure or did not know.

As reported above in the discussion of sea level rise projections, we also asked each planner how high they thought sea level would rise by 2100. Nearly half (45%) said they had no idea, while another 15 percent offered no response. Another 15 percent gave answers that fall within the range of projections made in the most recent IPCC report, i.e. 1-3 feet.

We also asked the planners what their impressions are of the distance inland the shoreline would move in their communities with a 1-foot rise in sea level. As reported above, the expert answers are fairly diverse ranging from 100 to 2,000 feet (see Table 4), so it is not surprising that the planners had diverse perceptions as well. However, more than half (53%) said they did not know and another 10% did not respond. Only one of the respondents guessed that the distance might be as high as 100 feet. When asked about vulnerable areas of their communities most referred either to coastal flood-hazard zones or coastal high hazard areas as the most vulnerable locations. Thus while they may have no good handle on how far landward sea level rise may reach, they do have a sense for the most vulnerable areas within their communities.

We received a range of responses to our question about whether or not sea level rise vulnerability is an issue that should be addressed in the long-range planning that these local planners do. Some went by the book saying that they would address it if it were added to the requirements under the 9J-5 rules. Several said yes, but they felt it was not feasible for them to do so at the local level. A few others said they thought it should be addressed but they believed it was not on the agenda of important planning issues for their citizens or elected officials. Two others said they personally felt that other issues were more important in their communities. Two respondents suggested that sea level rise was perhaps not the domain of the comprehensive planners. One of these respondents suggested that the issue might better be addressed through the land development code. Miami-Dade County has recently formed a Climate Change Task Force which will address sea level rise along with other climate change impacts (see details below).

We formally asked the planners if the potential impacts of sea level rise are addressed in their plans. A number of the respondents suggested that the provisions governing development within coastal high hazard areas or FEMA flood hazard zones offer some policies that are pertinent to sea level rise vulnerability. Only Collier County said that their plan actually does so.

The Conservation and Coastal Element of Collier County's comprehensive plan includes several policies that explicitly or implicitly address accommodation of sea level rise (Collier County, Florida, 2007). Objective 10.4 requires that the natural functions of developed coastal barriers and developed shorelines, including beach and dune systems, be restored and maintained. Policy 10.4.13 requires that in so-doing, development and redevelopment proposals must consider the implications of potential sea level rise. Policy 10.6.2 explicitly requires that a specific sea level rise scenario be accounted for in preparing EISs for shoreline development projects. In particular, proposals for such projects must demonstrate that the project will remain fully functional for its intended use after a six-inch rise in sea level.

A third section of this element of the county's comprehensive plan includes an objective that the long-range planner suggested implies accounting for sea level rise. Objective 12.2 stipulates that the county "shall ensure that publicly funded buildings and publicly funded development activities are carried out in a manner that demonstrates best practice to minimize the loss of life, property, and re-building cost from the affects from

hurricanes, flooding, natural and technological disaster events." Included among the listed best practices are requirements that (a) construction be sited "above the floodplain" and (b) "beach and dune restoration, re-nourishment, or emergency protective actions" [be taken] to minimize the loss of structures from future events."

The planners listed the following as constraints that limit their agency's concern with sea level rise: (1) political climate or other pressing issues (n=10); (2) lack of adequate information about potential impacts (n=8); and (3) too long a time frame (n=2).

When asked what resources might be made available from the state that would enhance their ability to account for the potential impacts of sea level rise in their long-range planning, the planners we interviewed listed the following: (1) credible predictions of sea level rise scenarios for which planning would be appropriate coupled with information about likely impacts and best practices for adaptation (n=18); (2) public education that can serve to raise public awareness of the importance of dealing with potential sea level rise impacts now (n=3); (3) policy direction as to how local governments should address sea level rise in comprehensive plans (n=5); and (4) funding to help defray the costs of conducting local vulnerability studies and assessments of practical adaptation options.

Regional and Local Water Supply Planners

We interviewed water supply planners both with the regional water management districts and with local water supply utilities because of the integrated nature of water supply planning in the state. As noted above, the water management districts prepare long-range regional plans that identify water supply project needs. However, it is up to local governments and their water suppliers to take the initiative for specific water supply projects.

As shown in Table 1, we interviewed water supply planners with four of the state's five water management districts (WMDs): Northwest Florida, St. Johns River, South Florida, and Southwest Florida. We excluded the Suwannee River Water Management District because there are no major coastal cities within that district. The extent of long-range planning reported by those whom we interviewed ranged from none to 20, 30, and 50 years. At the Southwest Florida WMD, where some plans extend out to 50 years, the analyses for the last 30 years consist simply of demand projections.

Local water supply planners indicated that their long-range planning time horizon extends from 20 to 40 years or more. The average for the 13 local water purveyors with whom we spoke was 23 years. We also asked the local planners about the lead times for developing different types of water supply facilities. They reported that new well fields require 2 to 10 years to plan and develop, new surface water sources 4 to 10 years, and desalination plants 2 to 10 years. Seven of the 13 local water purveyors we interviewed reported that they currently use or are planning desalination plants for treating brackish ground water or surface water supplies. Tampa Bay Water, which provides water to six local governments in the Tampa Bay area (Hillsborough County, Pasco County, Pinellas

County, City of New Port Richey, City of St. Petersburg, and City of Tampa), operates the largest seawater desalination plant in the U.S.

Three of the four WMD water supply planners reported that saltwater intrusion is an existing direct threat to water supply in some or all of the coastal areas within their regions. The St. Johns River WMD planner reported that saltwater intrusion was primarily a concern in terms of wetland ecosystem health rather than water supply quality. Seven of the 13 local water supply planners with whom we spoke indicated that saltwater intrusion associated with a 6 to 18-inch rise in sea level over the next 50 years would likely pose a threat to some of their wells (and in one case a surface water supply). Two others reported that they already have saltwater intrusion problems. The protracted drought that has affected south Florida since November 2005, the third worst on record as of April 2007, has raised concerns about the potential for further saltwater intrusion (Florida Department of Environmental Protection et al., 2007).

We also asked local water supply planners about adaptation options for accommodating increased saltwater intrusion. The tactics listed include (1) development of inland well fields or surface water sources, (2) development of deeper brackish aquifers with attendant desalination, (3) desalination of water from existing well fields as salt water intrusion occurs, (4) constructing tide gates in water supply canals to prevent salt front migration upstream, and (5) increased use of wastewater reclamation.

We asked the local water supply planners if their current water supply planning processes could accommodate two different sea level rise scenarios: (1) sea level rise of 3.5 inches in 30 years and 6 inches more in 50 years and (2) sea level rise of 11 inches in 30 years and 18 inches higher in 50 years. Twelve of the 13 local planners reported that they either foresaw no threat to their water supply infrastructure from the first scenario (n=9) or that the existing water supply planning process ought to be able to accommodate any possible impacts (n=3). One suggested that some adaptation measures might be necessary but that recent state policy promoting the development of alternative water supplies, including reclamation of domestic wastewater for irrigation and development and treatment of brackish water supplies, would help to accommodate any impacts of sea level rise. Under the more extreme scenario, three of the local water planners still foresaw no threat and three anticipated that the current planning process could accommodate possible impacts. Three planners said they thought that saltwater intrusion might become a limiting factor under such conditions, and two of them expressed concern for portions of their water line systems. Two others thought there might be some problems but did not elaborate.

We received diverse answers when we asked the WMD planners about the extent to which sea level rise is currently accounted for in long-range planning. Sea level rise is not perceived to be an immediate concern for water supplies in the St. Johns River WMD. The planners we interviewed with the Southwest Florida WMD and the Northwest Florida WMD also reported that other concerns are a greater priority for water supply planning in their districts.

The Southwest Florida WMD indicated that they account for sea level rise both through their ongoing water quality monitoring of coastal aquifers and through their rules governing water supply development. They do not, however, have any ongoing assessments of sea level rise in the water supply section of the district.

The Northwest Florida WMD reported that they account for sea level rise indirectly in their long-range planning through the strategy in their Regional Water Supply Plan to develop inland sources for serving coastal water supply needs. This strategy has been in place since the 1980s because of saltwater intrusion problems caused by excessive ground water withdrawals. They also suggested that the district's efforts to protect natural wetlands and floodplains provide a margin of flexibility for these natural systems to adapt to sea level rise.

The South Florida WMD, on the other hand, reported that district staff prepared an analysis in 1998 (Trimble et al., 1998) that assessed the impacts of a 6-inch rise in sea level on the canals in the district that are used for storm water management and flood protection as well as for recharging the shallow Biscayne Aquifer. They currently incorporate sea level rise scenarios developed by the U.S. Army Corps of Engineers in their hydrologic modeling of water supply alternatives. They work with a projected rise of 0.8 feet (9.6 inches) for 2050.

Most of the local water supply planners said that sea level rise is not explicitly accounted for in their long-range planning processes (n=9) or that it is indirectly accounted for (n=2). Only two reported explicit consideration of sea level rise at this time. When asked about the factors that limit their agencies' current concerns with sea level rise, four said lack of credible information and three said the planning horizon is too short. Others listed (a) lack of state policy direction, (b) too many other priorities, and (c) lack of money and other resources.

Eight of the 13 local water supply planners we interviewed said they thought that sea level rise should be explicitly accounted for in their long-range water supply planning. Three said they felt that the problem was too long-range or too uncertain. One planner, from a Panhandle County with a secure inland water supply system, maintained that the threat was not significant enough to warrant attention at this time.

We received responses similar to those from the local comprehensive planners when we asked what resources might be made available from the state that would enhance the ability of regional or local water planning agencies to account for the potential impacts of sea level rise in their long-range planning: (1) official documentation of the rate of sea level rise occurring in Florida; (2) formal policy direction regarding how sea level rise should be addressed in water supply planning; (3) training for water supply planners; (4) more fiscal resources; and (5) public education to create awareness of the nature of the problem and its importance.

Local Wastewater System Planners

We interviewed wastewater utility managers in 9 coastal communities (see Table 1) following a protocol similar to that administered to the local water supply planners. Planning horizons tend to be shorter for local wastewater systems than for water supply system, with a range of 5 to 20 years and a mean of 13. As noted above, state rules require that capacity analysis reports be based on local population growth rates and water usage rates, for at least the next 10 years. These reports must be filed with DEP when the 3-month average daily flow exceeds 50 percent of the permitted capacity of an existing treatment plant or reuse and disposal system.

All but one of the 9 communities with which we spoke (Apalachicola) were in the process of planning for or constructing new or expanded wastewater treatment or wastewater reclamation facilities. The primary reasons for the new or expanded facilities include increased demand and a need to provide more effective nutrient removal or otherwise reduce discharges to surface water bodies.

As we did with the local water supply planners, we asked the local wastewater system managers if their current planning processes could accommodate two different sea level rise scenarios: (1) sea level rise of 3.5 inches in 30 years and 6 inches more in 50 years and (2) sea level rise of 11 inches in 30 years and 18 inches higher in 50 years. Responses from the wastewater manager were nearly identical for both scenarios. Four of the 9 managers felt that the existing planning process could accommodate either scenario or that they posed no threat to their existing systems. Three managers expressed concern with possible impacts on their collection systems, including increased infiltration. One community of the three communities uses vacuum sewers, rather than gravity or force-main sewers, which has collection pits and buffer tanks located close the shore. One other respondent thought that some adaptive changes might be needed with one or more of their treatment or reclamation facilities. Two of the respondents observed that with the higher sea level rise scenario measures would have to be taken to protect existing treatment or reclamation facilities because the costs of relocation would be prohibitively high.

Specific adaptive strategies that might be employed for existing facilities if the more extreme scenario were to materialize include sealing of manhole covers, refurbishing sewers to reduce ground water infiltration, relocation of some vacuum sewer collection pits and buffer tanks, and elevation or flood proofing of components of existing sewage treatment or reclamation facilities.

As was the case with the local water supply planners, none of the local wastewater system managers said that sea level rise had been explicitly considered in the planning or design of their systems. Several noted, however, that measures they do take to protect against contemporary flood and hurricane hazards offer some protection against sea level rise.

Most of the wastewater system managers indicated that they thought that sea level rise ought to be accounted for in their long-range planning, but several expressed uncertainty about when it would be appropriate to do so given the long time frame over which it is projected to occur. One manager suggested that the key question ought to be whether new development should be permitted in areas likely to be vulnerable to sea level rise.

As with the comprehensive planners and water supply planners, the factors noted as most limiting the concern of the wastewater managers' agencies with sea level rise included scientific uncertainty, the long time horizon, lack of political urgency, and fiscal and staffing constraints. State resources that could enhance adaptive planning include reliable information about where and when and how high sea level will rise, funds to defray the costs of planning and implementing adaptation strategies, and training.

Florida Adaptation Initiatives

Initiatives by Florida public agencies to address adaptive planning for sea level rise have been limited to date. Most notable have been the scenario-based assessments of likely adaptation approaches that have been undertaken by five of the regional planning councils under a contract between the U.S. Environmental Protection Agency and the Southwest Florida RPC, plus two recent initiatives by the South Florida RPC, and Miami-Dade County's recently-formed Climate Change Advisory Task Force. Each of these is briefly described below.

Regional Planning Councils

As reported in the discussion of sea level rise projections, five of the regional planning councils (RPCs) in the state, as well as Walton County, participated in an EPA initiative to map land uses within the 5-foot and 10-foot contour intervals to identify areas that might be inundated by an astronomical high tide on top of a 5-foot rise in sea level. The resulting reports were published between 2003 and 2006: Hudgens (2003), East Central Florida RPC (2004), South Florida RPC (2005), Treasure Coast RPC (2005), Tampa Bay RPC (2006) and Southwest Florida RPC (no date). We interviewed the project managers for these studies to learn about how the studies had been used and what other initiatives, if any, the RPCs might have taken concerning sea level rise.

The Tampa Bay RPC reviewed the study and maps with its Regional Planning Advisory Committee. It also distributed draft maps to all of the local planning directors in the region. The Treasure Coast RPC distributed its study to the county planning directors in its region and met with each of the departments about the study. Some of the RPCs have posted the maps or reports on their website. Others have used the report as the basis for presentations to local planners and other local officials. The Southwest Florida RPC intends to include the maps in its next regional policy plan. It is interesting to note that none of the local comprehensive planners or water supply or wastewater system managers mentioned these studies during our interviews.

The Southwest Florida RPC, which was the lead agency for the EPA-funded initiative that produced these studies, has had some discussions with the EPA about possible follow-up projects including (1) an analysis of the impacts of sea level rise on wetlands and how and where they can migrate and (2) a cost/benefit analysis for holding back the sea in a specific location.

The South Florida RPC has just completed a project funded by the state Department of Community Affairs to produce a "Climate Change Community Toolbox" to assist local governments with planning for and adapting to climate change. This project is linked to Miami-Dade County's Climate Change Advisory Task Force (see below). The Toolbox includes three main components: (1) a sea level rise atlas based on recent LiDAR mapping that depicts areas likely to be inundated by sea level rises of 1, 2, 3, and 5 feet above mean sea level; (2) three science-based plain language fact sheets describing the impacts of climate change on Miami-Dade County's (a) economy, (b) community, and (c) environment; and (3) a compendium of adaptation resources.

The South Florida RPC is also working with local planning officials to launch a long-range regional plan to be called "Vision 2060" which will address climate change among other important issues. One motivation is pressure on Miami-Dade County from the state Departments of Community Affairs and Environmental Protection, as well as the South Florida Water Management District, to develop adequate plans for water and sewer services as a condition to further growth.

We asked the RPC planners about constraints to taking further sea level rise adaptive planning initiatives. Several noted that local governments will not be very interested until the state requires them to address sea level rise in their comprehensive plans. As with the other planners we interviewed, several mentioned the disjunction between the standard planning cycle and the time period over which sea level rise will play out. They also mentioned the oft-repeated concern with scientific uncertainty. Another important constraint is the lack of elevation data at a greater resolution than five feet, e.g. one-foot contours.⁹

Suggestions from the RPC planners for initiatives by the state generated some additional ideas beyond those regularly suggested by the local planners: (1) use the 30-year erosion projection line as the basis for a rolling easement; (2) include sea level rise in state action plans, e.g. the Everglades Restoration Project, which uses only a 6-inch estimate over 100-years despite recommendations that a 2-foot rise be used; (3) provide information to local government concerning the impacts of sea level rise on wetland and wetland migration; (4) provide information on alternative means of protecting lands that local

⁹ The Florida Department of Community Affairs Division of Emergency Management is in the process of completing a project to provide LiDAR-based contour mapping of coastal areas that are likely to be inundated by hurricane storm surge to be used for conducting new SLOSH model mapping of surge zones. The project includes collection of new LiDAR data and processing and/or improvement of existing LiDAR data. The final composite product based on new and existing compatible LiDAR data will include maps of both 1-foot and 2-foot elevation contours (Florida Division of Emergency Management, 2007, p. 26). The LiDAR mapping is scheduled to be completed in September 2008 with the new SLOSH model runs to be completed soon thereafter.

governments believe should be protected; (5) account for sea level rise when subsequent updates are done of the regional hurricane evacuation studies; (6) facilitate partnerships with universities to access and translate current science into effective policy; (7) provide funding to the RPCs to provide technical assistance to local governments with sea level rise adaptation; (8) provide public communication training to help RPC staff explain sea level rise and other climate change phenomena and issues effectively; (9) develop best practices guidance for incorporating sea level rise into comprehensive plans.

Southwest Florida Water Management District Wetland Restoration Program

The Southwest Florida Water Management District has been involved in a program to restore wetland habitat in the Tampa Bay ecosystem since 1971 (Henningsen, 2003) which is currently an integral part of the Surface Water Improvement (SWIM) Program for the Bay as well as the management plan for the Tampa Bay Estuary Program. Both management plans are designed for a 100-year time frame, hence accounting for sea level rise is very relevant. Wetland restoration designs since the early 1990s have included high-marsh components to provide the means for low marsh habitats to migrate landward as sea level rises. The program has used a 12 to 18 inch sea level rise scenario over 100 years developed for the district by the St. Petersburg office of the U.S. Geological Survey.

Miami-Dade County

Miami-Dade County was one of the first local governments in the U.S. to develop a greenhouse gas reduction plan with its *Long-Term Urban CO₂ Reduction Plan* adopted in 1993. More recently, the County Commission created a Climate Change Advisory Task Force in April 2006. The Task Force was first convened in February 2007 and issued its first report to the County Commission on July 10, 2007. Liaisons from 13 different county departments work with the Task Force, which has formed six committees.

The Scientific and Technical Committee is charged with providing the Task Force with the best possible information on possible near-term and long-term impacts of climate change on the Miami-Dade region, strategies to mitigate those impacts through greenhouse gas emission reduction, and strategies for adapting both the built and natural environments to unavoidable impacts.

A Built Environment Committee has separate responsibilities for providing recommendations to the Task Force for adapting and adaptively managing the existing and future built environment, including public and private buildings and infrastructure. This committee is to develop standards and strategies for the resiliency of the built environment, prevention of adverse consequences, and response and recovery from future conditions and events. Miami-Dade County also is a founding member of the International Council for Local Environmental Initiatives (ICLEI) and one of four cities participating in ICLEI's pilot Cities for Climate Protection Campaign (see description above).

Recommendations

The following recommendations are offered for consideration by the state Department of Community Affairs and the Division of Community Planning.

1. Coordinate with the state Department of Environmental Protection (DEP) and the Florida Action Team on Energy and Climate Change to ensure that the Action Team's efforts to address climate change adaptation strategies in 2008 will provide useful guidance to local and regional land use and public infrastructure planning and management.

Possible models to consider include the Coastal and Infrastructure Preparation/Adaptation Working Group of the Washington Climate Advisory Team, the Scientific and Technical Committee of the Miami-Dade Climate Change Advisory Task Force, and the adaptation elements of the King County, Washington, *Climate Plan*. Many of the following recommendations could conceivably fall within the purview of the Action Team's adaptation initiative.

2. Coordinate with the state Division of Emergency Management (DEM) and the state Department of Environmental Protection (DEP) to make available to local, regional, and state agencies the best possible data for mapping sea level rise scenarios at 1-ft contour intervals based on DEM's current LiDAR-based contour mapping project.

The sea level rise studies recently published by several of the state's regional planning councils are of limited utility because they are based on 5-ft and 10-ft contour interval data. The current LiDAR-based mapping project being conducted by DEM and scheduled to be completed in September 2008 will include LiDAR based mapping of both 1-ft and 2-ft contours. However, the landward limit of the new LiDAR data that are being collected for this project does not extend sufficiently high in elevation in all parts of the state to encompass all areas that may be inundated by sea level rise at the upper end of the possible 2100 scenarios that are being utilized by many sea level rise planners, i.e. 3 feet and 5 feet NGVD.

3. Coordinate with the state Department of Environmental Protection (DEP), the state Division of Emergency Management (DEM), the Florida Action Team, and the Scientific and Technical Committee of the Miami-Dade Climate Change Advisory Task Force to provide up-to-date information on sea level rise vulnerability for local governments, regional planning councils, regional water management districts, state agencies, and other interested persons.
 - a. Define a range of several (2-4) Florida-specific sea level rise scenarios and probabilities for 50-year and 100-year planning horizons based on the most recent report of the Intergovernmental Panel on Climate Change (IPCC) and other credible scientific reports. Over the short term, consider

using the scenarios depicted by the South Florida Regional Planning Council for their Sea Level Rise Atlas, i.e. 1 ft, 2 ft, 3 ft, and 5ft.

- b. Based on (a), produce maps at an appropriate scale for local planning, e.g. 1:2400, for each scenario and each planning horizon that depict the likely locations of the following:
 - mean high water line, seasonal high water line, or other appropriate sea level reference line
 - SLOSH storm-surge boundaries
- c. Update (a) and (b) on a schedule coordinated with the release of the Intergovernmental Panel on Climate Change (IPCC) scientific assessments (approximately every 5 to 7 years).

The single greatest constraint to adaptive planning for sea level rise that was identified by the local and regional planners with whom we spoke was the uncertainty about future sea level rise scenarios and impacts and the lack of credible information with which to address this uncertainty. A single, state-wide effort that builds on the initial efforts of the Miami-Dade Climate Change Advisory Task Force would offer the means to address this constraint.

4. In collaboration with the state Division of Emergency Management (DEM), coordinate with the Region IV Office of the Federal Emergency Management Agency (FEMA) to initiate explicit accounting for sea level rise in conducting the FEMA flood hazard map restudies for the coastal areas of Florida pursuant to the provisions of Appendix D of the 2007 *Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update*.

The FEMA 100-year flood boundaries are the primary referent employed in state statutes and rules for regulating the siting and flood protection of state infrastructure and other land uses. Taking advantage of the provisions of FEMA's map modernization project guidance to account for sea level rise in the forthcoming restudies is an important opportunity for accommodating sea level rise within the confines of existing policies and procedures.

5. Coordinate with the state Department of Environmental Protection (DEP), the Florida Action Team, and the Southwest Florida Regional Planning Council to provide best practices guidance for adaptive response planning for sea level rise impacts on land use and infrastructure.

Specific adaptive response planning issues that might be addressed include the following:

- a. Defining appropriate long-range planning horizons for regional and local water supplies, local wastewater and storm water management systems, state and local transportation infrastructure, and local land use planning.
- b. Identifying alternative adaptive strategies for the design of new water supply facilities, domestic wastewater collection and treatment systems,

storm water management systems, and bridges and roads that account for potential sea level rise impacts over the next 75 to 100 years.

- c. Defining appropriate methods for assessing sea level rise-induced shifts in flooding and erosion hazards in planning corridors for new highways and in assessing major amendments to the Future Land Use Element and Future Land Use Map in local comprehensive plans.
- d. Identifying alternative strategies for long-term infrastructure maintenance, repair, protection, and relocation for existing water supply facilities, domestic wastewater collection and treatment systems, storm water management systems, and bridges and roads that account for impacts of sea level rise-induced shifts in flooding and erosion hazards over the next 50 to 75 years.
- e. Identifying options for incorporating “rolling easements” in both state and local development permits for areas immediately adjacent to coastal waters of the state.

One of the other major resources that local planners told us they need is a set of guidelines for effective adaptive response planning, including policies and strategies for protection, accommodation, and retreat. The "Climate Change Community Toolbox" recently developed by the Southwest Florida Regional Planning Council, as well as similar products under development through the Climate Resilient Communities campaign of the International Council for Local Environmental Initiatives (ICLEI) and other state and local governments in the country, can serve as the foundation for best practices guidance to Florida communities and regional and state agencies. It is important that such guidance be formulated in the context of the specific sea level rise vulnerabilities of Florida's coastal communities and the existing policy framework that governs land use and infrastructure planning and management in the state.

6. In collaboration with the state Department of Environmental Protection (DEP), the Governor's Office, and the Florida Action Team fund pilot projects in several coastal communities in the state for conducting detailed sea level rise vulnerability assessments and adaption strategy assessments for existing public infrastructure systems.

While the initiatives being taken by the Miami-Dade Climate Change Advisory Task Force will likely provide one such pilot study it is important that analogous studies be conducted in other coastal communities in the state that do not have the unique hydrologic infrastructure system of the Central and South Florida Project.

7. Coordinate with the state Department of Environmental Protection, the state Department of Transportation, the Governor's Office, the Florida Action Team, and other agencies as appropriate, to consider legislation and/or rules that would:

- a. Define appropriate long-range planning horizons for regional and local water supplies, local wastewater and storm water management systems, state and local transportation infrastructure, and local land use planning.
- b. Require accounting for sea level rise-induced shifts in coastal flooding and erosion hazard boundaries in assessing corridors for new state highways and local highways funded with state monies and in major amendments to the Future Land Use Element and Future Land Use Map in local comp plans.
- c. Require accounting for sea level rise-induced shifts in coastal flooding and erosion hazard boundaries in the siting and design of new water supply facilities, domestic wastewater collection and treatment systems, storm water management systems, and bridges and roads.
- d. Require development of specific strategies for assuring proper functioning of water supply, wastewater and storm water management, and transportation infrastructure that account for the impacts of sea level rise-induced shifts in flooding and erosion hazards over the design life of the system. Special attention should be focused on water supply distribution systems and wastewater and storm water collection systems.
- e. Require formal assessment of the impacts of major developments and infrastructure projects on the ability of coastal wetlands and beach and dune systems to adapt to sea level rise by migrating landward.
- f. Direct the state Department of Environmental Protection to include “rolling easement” provisions in state CCCL permits and state permits for coastal armoring structures that require modification or relocation of structures that intrude onto sovereignty lands of the state below the mean high water line of any tidal water body.

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Appendix A
SRES Scenarios Employed by the
Intergovernmental Panel on Climate Change

The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)*

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis:

- A1FI - fossil intensive
- A1T - non-fossil energy sources
- A1B - a balance across all sources, where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

B1. The B1 storyline and scenario family describes a convergent world with the same global population as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

* Excerpted from Alley et al. (2007).

Table 1: Sample of Local, Regional, and State Agencies Interviewed

Jurisdiction/Agency	Comprehensive Planning	Water Supply	Wastewater Systems	Transportation Planning
Local Governments				
Charlotte County	X			
Collier County	X	X		
Hillsborough County	X	X		
Lee County	X	X	X	
Miami-Dade County	X	X		
Santa Rosa County	X	X		
Walton County			X	
Apalachicola	X		X	
Boca Raton		X		
Ft. Lauderdale	X			
Ft. Myers	X	X	X	
Ft. Pierce	X	X	X	
Ft. Walton Beach	X	X		
Jacksonville/Duval County	X	X	X	
Key West	X			
Melbourne	X		X	
Naples	X	X	X	
Panama City	X			
Pensacola	X		X	
Pompano Beach	X			
Punta Gorda		X		
St. Augustine	X			
Tampa	X			
Regional Planning Councils				
East Central	X			
South Florida	X			
Southwest Florida	X			
Tampa Bay	X			
Treasure Coast	X			
Water Management Districts				
Northwest Florida		X		
St. Johns		X		
South Florida		X		
Southwest Florida		X		
State Agencies				
Dept of Transportation				X

Table 2: How Fast is Sea Level Rising?

Date	Source	Author	Authority	Location	Time Period	SLR Rate (mm/yr)	Accelerating?
Estimates from Popular Press and Other Informal Sources							
2007, June	<i>Tallahassee Democrat</i>	Ritchie	Leatherman	Florida	n/a	n/a	Yes
2007, June	<i>Tallahassee Democrat</i>	Ritchie	Donoghue	Global and Florida	Current	2	No
2007, June	Florida Cabinet Climate Change Conversation	O'Brien	Author	Global	Tide gage data (long term)	2.1 (relative)	No
2007, June	Florida Cabinet Climate Change Conversation	O'Brien	Author	Global	Altimeter data (1993-2003)	3.1 (eustatic)	No
Estimates from Peer-Reviewed and Other Scientific Sources							
2007, May	IPCC <i>Physical Science Basis*</i>	Meehl et al.	Authors	Global projected	1980-1999 to 2090-2099	1.5 to 9.7 (eustatic)	Yes
2007, May	IPCC <i>Physical Science Basis*</i>	Bindoff et al.	Authors	Global	1993-2003	3.1 ±0.7 (eustatic)	Yes
2007, May	IPCC <i>Physical Science Basis*</i>	Bindoff et al.	Authors	Global	1961-2003	1.8 ±0.5 (eustatic)	n/a
2007, May	IPCC <i>Physical Science Basis*</i>	Bindoff et al.	Authors	Global	20 th Century	1.7 ±0.5 (eustatic)	n/a
2005, July	<i>Proceedings 14th Biennial Coastal Zone Conference</i>	Stolz & Gill	Authors	Florida east coast	Tide gages	1-3 (relative)	n/a
2001	tidesandcurrents.noaa.gov/sltrends	NOAA	Zervas (2001)	Mayport, FL	Tide gages	2.43 (relative)	n/a
2001	tidesandcurrents.noaa.gov/sltrends	NOAA	Zervas (2001)	St. Petersburg, FL	Tide gages	2.40 (relative)	n/a
2001	tidesandcurrents.noaa.gov/sltrends	NOAA	Zervas (2001)	Miami Bch, FL	Tide gages	2.39 (relative)	n/a

2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Ft. Myers, FL	Tide gages	2.29 (relative)	n/a
2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Key West, FL	Tide gages	2.27 (relative)	n/a
2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Pensacola, FL	Tide gages	2.14 (relative)	n/a
2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Naples, FL	Tide gages	2.08 (relative)	n/a
2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Fernandina Bch, FL	Tide gages	2.04 (relative)	n/a
2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Cedar Key, FL	Tide gages	1.87 (relative)	n/a
2001	tidesandcurrents.noaa.gov/ sltrends	NOAA	Zervas (2001)	Apalachicola, FL	Tide gages	1.53 (relative)	n/a

* Peer-reviewed sources and/or authorities.

Table 3: How High Will Sea Level Rise Over the Next 100 Years?

Date	Source	Author	Authority	Location	Time Period	SLR Rise (ft)
Estimates from Popular Press and Other Informal Sources						
2007, April	<i>The Stuart News</i>	Kirley (2007a)	National Academy of Sciences	Global	2007 to 2107	1
2007, June	Florida Cabinet Climate Change Conversation	O'Brien	Author	Global	2007 to 2100	1
2006, June	<i>New York Times</i>	Dean	Church et al. (2001)*	Global	1990 to 2100	1.7
2007, February	<i>The Gainesville Sun</i>	Mulkey (2007a)	Alley et al. (2007)*	Global	[~1990 to 2095]	0.6 - 1.9
2007, April	Florida Cabinet Climate Change Conversation	Mulkey (2007b)	Alley et al. (2007)*	Global	~1990 to 2095	2
2007, April	<i>The Stuart News</i>	Kirley (2007b)	Treasure Coast Regional Planning Council	Global	2007 to 2107	0.8 - 3.8
2007, April	Florida Cabinet Climate Change Conversation	James	Alley et al. (2007)*	Global	2006 to 2056	2 - 10
2007, April	<i>Ft. Myers News Press</i>	Lollar	Weiss and others at U. of Arizona	Global	[2007] to 2100	2 - 20
Estimates from Peer-Reviewed and Other Scientific Sources						
2007	<i>Ocean Engineering*</i>	Walton	Author	Florida (5 tide gage stations)	2006 to 2080	0.8 - 1.1
2007, May	<i>IPCC Physical Science Basis*</i>	Meehl et al.	Authors	Global	1980-1999 to 2090-2099 [~1990 to 2095]	0.6 - 1.9
2007, May	<i>IPCC Physical Science Basis*</i>	Meehl et al.	Authors	Global with accelerated ice	1980-1999 to 2090-2099	0.9 - 2.6

				sheet melting	[~1990 to 2095]	
2007, March	www.realclimate.org	Rahmstorf (2007b)	Author	Global	~1990 to 2095	1.7 - 3.1
2005, December	<i>Sea Level Rise in the Treasure Coast Region</i>	Treasure Coast Florida RPC**	Titus & Narayanan (1995)	SE Florida	1990 to 2100	0.9 - 3.9
2007, January	<i>Science</i> *	Rahmstorf (2007a)	Author	Global	2006[?] to 2100	1.6 - 4.6
2007, June	<i>Environmental Research Letters</i> *	Hansen	Author	Global with accelerated ice sheet melting	2000 to 2100	Up to 16.5

* Peer-reviewed sources and/or authorities.

** Similar estimates reported in East Central Florida RPC (2004), South Florida RPC (2005), Southwest Florida RPC (no date), and Tampa Bay RPC (2006).

Table 4: How Fast Will the Shoreline Retreat as Sea Level Rises?

Date	Source	Author	Authority	Location	Shoreline Retreat (ft) per Foot of SLR
2007, April	Florida Cabinet Climate Change Conversation	Leatherman	Author	Long Island, NJ, Delmarva, NC, SC	78
2007	<i>Ocean Engineering*</i>	Walton	Author	US	50-100
1962	<i>Jrnl Waterway, Port, Coastal & Ocean Engrng*</i>	Bruun	Author	SE Florida	100
2006, June	<i>New York Times</i>	Dean	Howd	Florida	100
2007, June	<i>Tallahassee Democrat</i>	Ritchie	Donoghue	Florida	960
1991	<i>Coastal Management*</i>	Titus et al.	Author	Florida	100-1000
2007, April	<i>Ft. Myers News Press</i>	Lollar	Weiss and others	SW Florida	500 - 1000
2007, June	personal communication	Donoghue	Author	Florida	1000
2007, April	<i>The Miami Herald</i>	Tasker	Wanless	Florida Keys, Barrier Islands	200-2000

* Peer-reviewed sources and/or authorities.

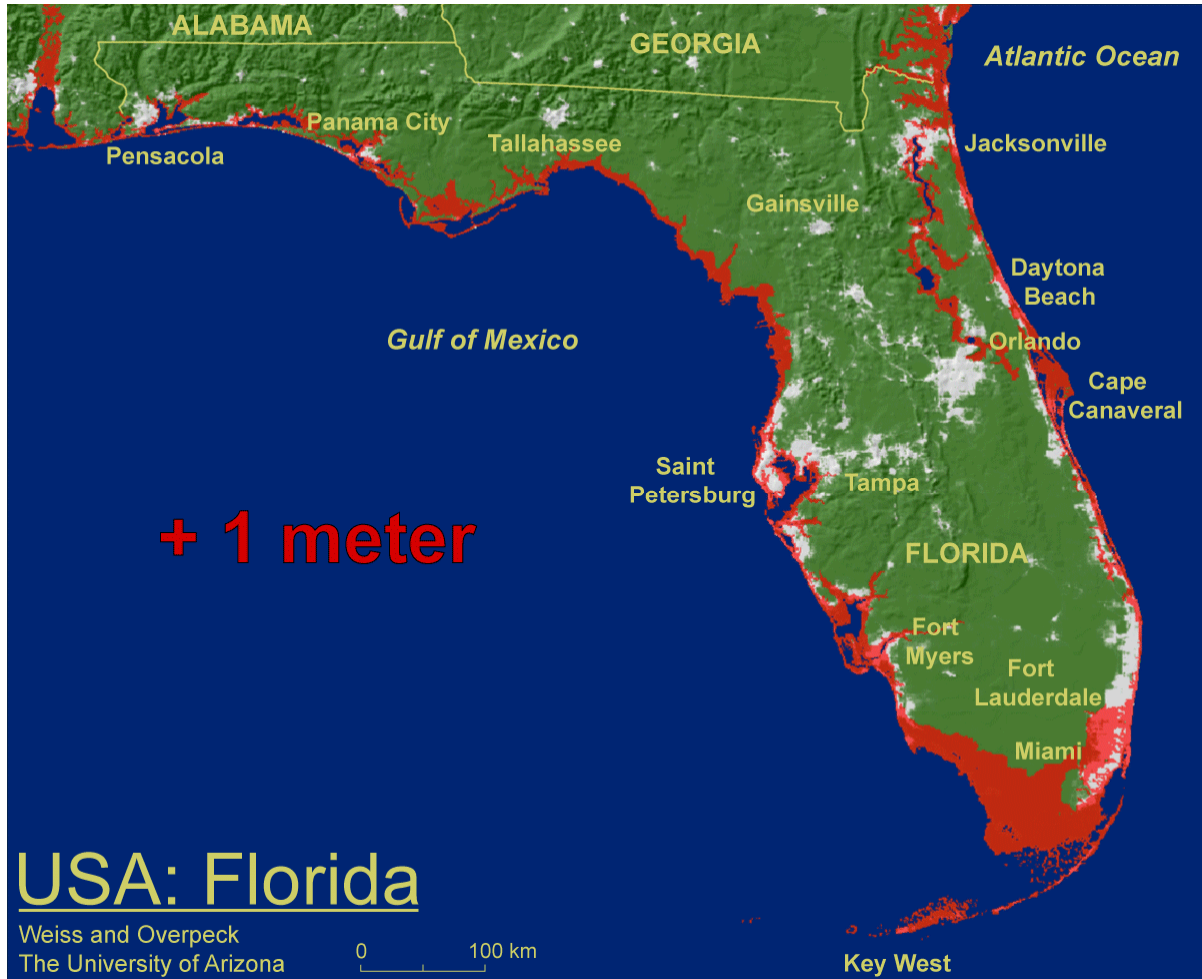
Table 5: River Gradients and Estimated Salt Front Migration for Major Florida Rivers

River and Sample Location*	Measured Gradient (ft/mi)	Estimated Salt Front Migration with 3-Foot Sea Level Rise (mi)
Ortega River near Jacksonville	2.41	3.0
Drainage canal tributary to St. Lucie Canal	1.68	1.8
Shell Creek near Punta Gorda	2.44	1.2
Cypress Creek near Sulphur Springs	2.10	1.4
Suwanee River near Wilcox	0.51	5.9
Choctowatchee River near Bruce	1.72	1.7
Yellow River at Milligan	3.31	0.9
Blackwater River near Baker	3.59	0.8
Escambia River near Century	2.17	1.4
Perdido River near Barrineau Park	5.51	0.5

* No data available for areas south of Lake Okeechobee or the lower reaches of the Caloosahatchee River.

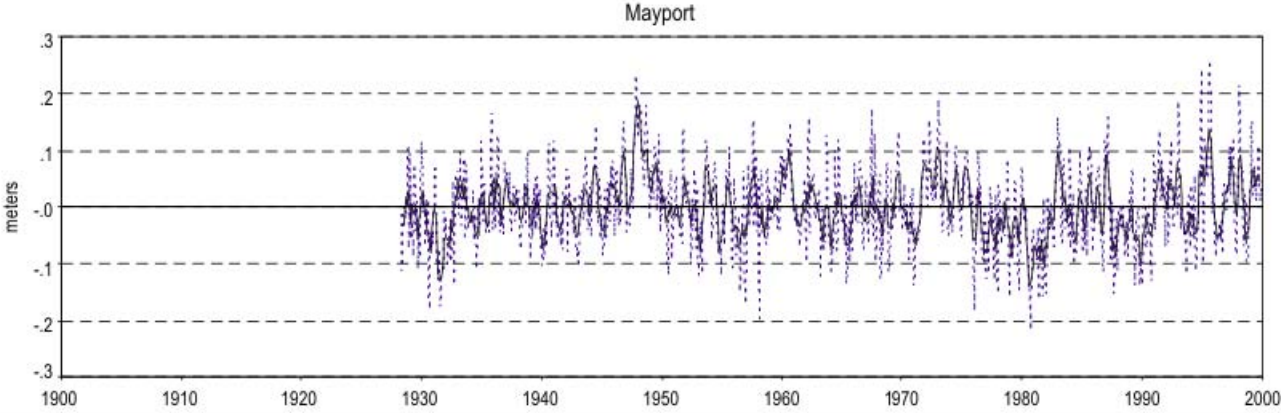
Source: Bridges (1982).

Figure 1: Areas of Florida Likely to be Inundated by a 1 Meter Rise in Sea Level



Source: Weiss and Overpeck (2005).

Figure 2: Interannual variation of mean sea level for all data to 1999 for Mayport, Florida



Source: Zervas (2001).

Figure 3: I-10 Bridge over Escambia Bay, Florida after Hurricane Ivan, 2004



Source: www.govanleave.com/ivan/ (2004).

Figure 4: I-10 Bridge over Lake Pontchartrain, Louisiana, after Hurricane Katrina, 2005



Source: www.zavadil.com/katrina/katrina.htm (2007).