

Sinking Assets: A Decision Framework and Strategies for Adaptation to Sea Level Rise in Florida

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Abstract

This paper provides an overarching view of the nexus between planning, design, and law as they relate to adaptation to sea level rise in Florida. It introduces a decision-making framework that can be used to define and evaluate potential adaptive responses and makes policy recommendations to further adaptive response planning for sea level rise in Florida. Though precise estimates are not possible, sea levels along the Florida coast could rise anywhere from 30 to 75 inches (75-190 cm) by the year 2100 relative to 1990. While sea level rise is incremental, the rate at which it is occurring is accelerating. The extent of the impacts caused by this are uncertain, but it is known that at a minimum, elevated water tables, changes in erosion and accretion patterns, more extensive coastal flooding, and saltwater intrusion will occur. The associated effects on human development and ecosystems will be gradual, but punctuated by coastal storm events which are likely to be more intense as a result of climate change. When tipping points for infrastructure and natural systems are reached, the effects may be dramatic. It is therefore essential to have a decision-making framework that facilitates structured evaluation of adaptive planning, design, and policy options at a site-specific level, that enables human and ecosystem adaptation to sea level rise, and that reflects local planning goals and objectives, sea level rise vulnerability, and ecological and economic conditions.

Keywords: sea level rise, Florida, adaptation, climate, planning, design, law

1.0 Introduction

This paper provides an overarching view of the nexus between planning, design, and law as they relate to adaptation to sea level rise in Florida. It introduces a decision-making framework that can be used at a local and site-specific level to define and evaluate potential adaptive responses, examines property law as a potential constraint, and makes policy recommendations to further adaptive response planning for sea level rise in Florida.

Though precise estimates are not possible, sea levels along the Florida coast could rise anywhere from 30 to 75 inches (75-190 cm) by the year 2100 relative to 1990 (Vermeer and Rahmstorf 2009). While sea level rise is incremental, the rate at which it is occurring is accelerating. The extent of the impacts caused by this are uncertain, but it is known that at a minimum, elevated water tables, changes in erosion and accretion patterns, more extensive coastal flooding, and saltwater intrusion will occur impacting both human and natural systems (Field et al. 2007; Titus and Anderson et al. 2009).

As a result of these impacts, human development in Florida will suffer. Higher coastal water tables may expose below-ground structures and facilities to corrosion, groundwater infiltration, and structural destabilization (Corbitt 1990; Curran 2006). Road pavement may be destabilized as road bases become saturated (National Research Council 2008). The return frequencies of coastal floods of a given elevation will increase, and the boundaries of flood zones and hurricane storm surge vulnerability zones will move higher and further landward (Gill, Marcy, and Johnson 2009; Kleinosky, Yarnal, and Fisher 2006). Above-ground structures will initially be subject to more frequent intermittent flooding from spring high tides. Increased sea levels will decrease or eliminate the vertical drop from gravity stormwater systems into drainage areas, resulting in exacerbated flooding of developed areas (Obeysekera et al. in this special issue; Titus and Craghan 2009). Shoreline recession due to erosion will shift flood zones further landward and also may result in scouring and undermining of above-ground structures, including sea walls, revetments, and bulkheads built to protect upland development from waves and storm surge. Saltwater intrusion, which is already a problem in Florida, will be exacerbated and more widespread (Shoemaker and

Edwards, 2003; Sonenshein, 1995; Spechler, 2001). 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 recharged by rivers and streams (Hull and Titus 1986; Major 1992; Titus et al. 1991). Sea level rise also may interfere with navigation under bridges (Gill, Wright, Titus, Kafalenos, Wright 2009).

It is still unclear to what extent specific ecosystems will be affected by sea level rise, but degradation is likely in many cases, with potential widespread shifts occurring in habitat and species distribution (Cahoon et al. 2009; De Guenni et al. 2005; Field et al. 2007; Maschinski et al. in this special issue; Mulkey 2007; Saha and Bradley et al. in this special issue; Saha and Ross et al. in this special issue). Contemporary land use changes as well as adaptive responses taken as sea level rise advances will further constrain the ability of shoreline ecosystems to adapt. As the BP oil spill has made clearer than ever, Florida’s coastal ecosystems are vital to our economy, way of life, and future. Yet landward shifts in the coastline may result in the loss of important coastal ecosystems as beaches and estuaries are squeezed between coastal armoring and rising seas, leading to a loss of coastal and marine resources along with the tourism, commercial/recreational fishing, and other activities dependent on coastal and marine resources. Thus, while our main focus remains on the adaptation of human development to sea level rise, ecosystems must also be considered due to their importance to human populations and as well as their intrinsic value.

Adaptation to sea level rise may occur through three basic types of responses: *protection, accommodation, and retreat*. Which of these responses is chosen will depend on (a) vulnerability of the coastal shoreline, (b) urban system value, and (c) natural system value. Unfortunately, land use changes and economic investment in coastal development occurring today are committing coastal communities, including both private and public assets, to future sea level rise vulnerability. Thus, *it is essential that sound adaptive response planning and design practices begin as soon as possible*. However, at present Florida’s statutes fail to address sea level rise and the need for adaptation (Deyle et al. 2007), and

constitutional and statutory takings law often act as *de facto* constraints to adaptive response planning (Echeverria and Hansen-Young, undated).

Adaptive response planning is not a simple process. State and local decision makers cannot afford to wait, yet they also must confront tradeoffs between short-term opportunity costs and long-term mitigation costs. They must contend with several dimensions of uncertainty: (a) What are the likely impacts of sea level rise within their region and where and when will these changes occur? (b) How much will adaptive response strategies cost over what period of time? (c) How will natural systems respond? (d) What legal constraints may arise in efforts to employ adaptive response policies? Uncertainty about the exact timing and amount of sea level rise does not necessarily counsel no action since the risk of harm is so great, and a pure “no regrets today” approach has the potential to result in regrets for our successors. It is therefore essential to have a decision-making framework that facilitates structured evaluation of adaptive planning, design, and policy options at a site-specific level, that enables human and ecosystem adaptation to sea level rise, and that reflects local planning goals and objectives, sea level rise vulnerability, and ecological and economic conditions.

2.0 Florida’s planning, regulatory, and design contexts for adaptive response measures

Highly concentrated coastal populations, varied shoreline conditions, and sensitive ecosystems complicate adaptive response planning in Florida. Legislative and political hurdles also need to be overcome, yet there are several constructs already in place that can be used to enable adaptive response planning. Federal, state, and local regulations and programs impact development and land use; any one of these levels can be used to pro-actively promote adaptive response to sea level rise or, when misused or poorly applied, may increase the risk to people, property, and ecosystems. To create a foundation for informed decision making, we briefly summarize the federal policy context that may influence adaptive response in Florida. This is followed by an overview of the state planning, regulatory, and design contexts that form the current framework for adaptive response planning in Florida.

2.1 Federal law context

The federal government directly regulates coastal land use through provisions of the Clean Water Act that govern dredging and filling of wetlands and other coastal waters (Clean Water Act Section, §404(b); 33 U.S.C. §1344(b)). State and local wetland and nearshore waters regulations must be no less stringent than those promulgated by the federal government. The National Flood Insurance Program (NFIP) sets a floor for regulating development within floodplains by only allowing for issuance of flood insurance policies in jurisdictions that meet minimum federal policy requirements. The desire of the electorate to have access to such flood insurance has led to almost uniform adoption of the minimum requirements (National Oceanic and Atmospheric Administration and Association of Flood Plain Managers 2007). While the NFIP has been subjected to decades of criticism as a subsidy that promotes development in unsafe areas (see for example Ruppert 2008), the 100-year floodplains delineated under the act are one of the most commonly accepted demarcations of hazardous areas in the U.S. In Florida, these have been used in a variety of state and local regulatory settings including regulating the siting of state and local infrastructure (Deyle et al. 2007; Fla. Admin. Code 9J-5.003(47)). Similarly, the “coastal building zone” under the state’s Coastal Zone Protection Act is defined in part by maps created for the NFIP (Fla. Stat. ch. 161.54(1) (2009)). While federal guidance on mapping such areas does allow for considering the effects of sea level rise on coastal floodplain boundaries (Federal Emergency Management Agency 2007), no such adjustments have been made yet in updating NFIP flood maps.

The federal government could exercise positive influence for adaptive response planning through the Coastal Zone Management Act (CZMA) (16 U.S.C. §§ 1451-1456 (2007)). The CZMA encourages states to develop coastal management plans that, among other things set broad priorities for uses within the coastal zone and provide the framework for regulating land uses within the coastal zone and studying coastal erosion and ways to control it. The CZMA has exhorted states for two decades to address the impacts of sea level rise (16 U.S.C. § 1451(l); 16 U.S.C. § 1452(2)(B); 16 U.S.C. § 1452(2)(K); 16 U.S.C. § 1456b(a)(2)), but addressing sea level rise is not mandatory. Florida’s coastal management plan, comprised of twenty-four different state statutes, has been approved even though

Florida statutes only once make mention of sea level rise. This single reference does little to control, limit, or inform local planning and development in the face of sea level rise.¹

Though federal policies form an essential component in supporting adaptive response planning, land use is predominantly the domain of states rather than the federal government, and Florida, like most other states, delegates much of the responsibility for land use regulation to local governments. State and local regulations governing design and development, coupled with investments in public facilities and infrastructure, play an integral role in defining development patterns and the vulnerability of the built environment to flooding and erosion. Thus, although Florida's policy framework governing coastal development contains no explicit provisions addressing sea level rise, several state policy instruments exist that could provide the foundation for supporting sound adaptive response planning. These include the State Comprehensive Plan and its application through the state's review of Developments of Regional Impact (DRIs), state standards for public infrastructure, statutes and regulations governing the content of local comprehensive plans, and state laws regulating construction of habitable structures seaward of the Coastal Construction Control Line (CCCL), development in wetlands, and storm water management. The following section focuses on Florida's planning and land use laws as an important framework for adaptive response planning policies. Subsequent sections address the state's direct regulation of coastal development, wetlands, and storm water management, and the design and development context within which adaptive response planning occurs.

2.2 State planning context

Florida has one of the country's most comprehensive and complex statutory frameworks governing land use and infrastructure planning. The State Comprehensive Plan is designed to provide "long-range policy guidance for the

¹ Fla. Stat. ch. 259.105(17)(d) (2009). This statute, on land acquisition under the Florida Forever Program, indicates that the program should include a climate change category list of lands that contribute to the aims of the program and may qualify as, among other things, helping "adapt to the effects of sea-level rise."

orderly social, economic, and physical growth of the state” (Fla. Stat. ch. 187.101 (2009)). Local comprehensive plans, and by extension, local development orders, are required to be generally consistent with the policies of the state plan as are Developments of Regional Impacts (DRIs) that may affect interests in more than one county. The state also dictates in substantial detail the required scope of local comprehensive plans governing land use, conservation, and infrastructure within coastal areas. State laws and regulations set pertinent planning requirements and design and performance standards for roads, bridges, wastewater treatment facilities, and public water supplies. Each of these policy elements is briefly summarized below.

The State Comprehensive Plan does not explicitly address sea level rise. It does, however, include policies that call for considering the impacts of flooding in land use planning and regulation and avoiding transportation improvement that subsidize development in coastal high-hazard areas (Fla. Stat. ch. 187.201(15)(b)6 and (19)(b)12 (2009)). Local comprehensive plans, as well as local development orders issued for DRIs, must be consistent with the policies of the State Comprehensive Plan (Fla. Stat. ch. 380.06 (2009)). Thus, these policies offer a potential framework for inserting sea level rise adaptive response policies into the state’s processes for reviewing local comprehensive plans and DRI development orders.

Further potential for addressing sea level rise in land use planning and regulation occurs in state “uniform standard rules” governing review of DRIs in coastal areas on emergency shelter capacity and evacuation route capacity (Fla. Admin. Code 9J-2.0256 (2009)) within the “hurricane vulnerability zone” (HVZ) and the “high hazard hurricane evacuation area” (HHHEA). The regulations define the HVZ and the HHHEA as the category 3 and category 1 hurricane evacuation zones respectively, but as currently written, the rules do not accommodate the effects of sea level rise on the boundaries of those evacuation zones.

Florida’s statutory planning horizons for major infrastructure systems range from 10 years for wastewater treatment facilities (Fla. Admin. Code 62-600.405 (2009)) to 20 years for regional water supply plans (Fla. Stat. ch. 373.036(2)

(2009)). Regional long-range transportation plans are required by federal law to plan for 20-year time frames as well (23 CFR 450.104 (2009)). There is nothing in the state statutory language that provides an explicit context for addressing the long-term implications of sea level rise on water supply sources or infrastructure, or wastewater treatment facilities, other than requirements concerned with vulnerability to flooding.

Potential coastal flooding 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 (Fla. Admin. Code 62-555.310 (2009)). Community water systems (Fla. Admin. Code 62-555.320 (2009)), as well as wastewater treatment plant structures and equipment (Fla. Admin. Code 62.600.400(2)(c) (2009)), must be designed and constructed so that structures and equipment are protected from physical and wave damage from a 100-year storm. Road vulnerability to flooding is primarily addressed by the state's *Project Development and Environment Manual* (Florida Department of Transportation 1998) review procedures and criteria which require completion of a risk evaluation for all highway project 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. Again, none of these contains any provisions to account for sea level rise.

Florida's Growth Management statute (Fla. Stat. ch. 163.3164 et seq. (2009)) and accompanying regulations (Fla. Admin. Code 9J-5 (2009)) spell out the requirements for local government comprehensive plans. The 10-year local comprehensive planning horizon stipulated in the statute (Fla. Stat. ch. 163.3177(5)(a) (2009)) does not provide an explicit temporal context for considering the implications of long-term gradual changes such as sea level rise for future land use or infrastructure planning. A targeted survey of twenty coastal communities by Deyle et al. (2007) revealed that most coastal communities do not prepare plans with planning horizons greater than the 10-year statutory minimum,

although a few extend the planning horizon from 15 years to as many as 25 and 50 years.

Requirements for the Conservation Element of local comprehensive plans (Fla. Stat. ch. 163.3177(6)(d) (2009)) 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 by the state. 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. (2009)) provides further leverage for considering the potential impacts of sea level rise, at least on natural systems.

State regulations include several requirements for the Coastal Element that concern the "coastal high hazard area" (CHHA) defined as the category 1 hurricane storm surge zone. The Coastal Element must identify infrastructure located within the CHHA and assess the potential for relocating threatened infrastructure located therein (Fla. Admin. Code 9J-5.012(2)(e)3 (2009)). It also must include objectives that limit public expenditures that subsidize development in the CHHA and that direct development away from it (Fla. Admin. Code 9J-5.012(3)(b)5&6 (2009)). As with other defined areas, this one does not account for the changes due to sea level rise.

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 (Fla. Stat. ch. 163.3177(3) (2009)). 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 (Fla. Stat. ch. 163.3177(6)(c) (2009)). However, to do so requires a planning horizon greater than 10 years.

In summary, our review of these planning frameworks reveals a set of consistent findings across the different dimensions of coastal planning in the state:

- (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) However, there are existing provisions within these planning frameworks through which sea level rise adaptive response planning could be addressed.

2.3 State regulatory context

2.3.1 Coastal development regulation context

Regulation in coastal areas in Florida varies according to the type of coastline. Florida's non-sandy, vegetative shorelines fronting the Gulf of Mexico or Atlantic have no particular setbacks for construction (Fla. Stat. ch.161.052(5) (2009)). On Florida's sandy beaches fronting the Gulf or Atlantic, Florida statutes state an intent to preserve and protect Florida's sandy beaches from "imprudent construction" which can harm the beach-dune system, endanger property, and interfere with public beach access. This is supposed to be accomplished in part through the Coastal Construction Control Line (CCCL) program, which regulates the areas on the Gulf and Atlantic coasts seaward of a line where the beach-dune system is subject to extreme impacts from a 100-year storm (Fla. Stat. ch. 161.053 (2009)). However, due to many exceptions and weaknesses in the CCCL program, it has failed to adequately achieve its lofty goals (Ruppert et al. 2008).

The CCCL program does not currently consider sea level rise in its criteria for siting major habitable structures such as houses, businesses, condos, or hotels. State law requires that major habitable structures built along the state's sandy shorelines must, as a general rule subject to various exceptions, be set back a distance equal to 30 times the average annual erosion rate at the site—the 30-year erosion projection line (Fla. Stat. ch. 161.053(6) (2009)). While the CCCL must be resurveyed to account for the landward migration of the CCCL, the static 30-year multiplier does not account for likely accelerated rates of sea level rise and accompanying increases in erosion rates. At present the state's Department of Environmental Protection has no plans for making such adjustments. The only

mention of sea level rise in current CCCL regulations refers to coastal armoring (Fla. Admin. Code 62B-41.005(7)(c) (2009)). The regulation specifies only that sea level rise must be “considered” in reviewing applications for armoring, but it does not indicate how or to what ends.

The CCCL does present options for accommodating sea level rise in the state’s direct regulation of coastal construction. The statutory directives for surveying the CCCL and delineating the 30-year erosion setback could require formal adjustment in those boundaries that account for projected sea level rise over a specified time horizon. Similarly, the rules governing regulation of coastal armoring could provide more explicit direction as to how sea level rise should be “considered,” whether by requiring construction of a higher seawall or by requiring protection for lateral public access that could be harmed by the proposed armoring. For example, the state has the authority to protect lateral public access across sandy beaches by exacting a lateral easement on private property in exchange for the armoring permit (e.g. Fla. Stat. ch. 161.041 and ch. 161.053(5)(e) (2009)).

2.3.2 Wetland regulation context

Florida’s environmental resource permit program regulates development in, on, and over coastal “jurisdictional” wetlands. The applicable statute requires that activities within such wetlands must not “adversely affect” “conservation of fish and wildlife, including endangered or threatened species, or their habitats” or “fishing or recreational values or marine productivity in the vicinity of the activity” (Fla. Stat. ch. 373.414(1)(a) (2009)). The statute also recognizes that coastal armoring such as seawalls and bulkheads can have negative environmental impacts (Fla. Stat. ch. 373.414(5)(a) (2009)), and thus the state restricts the construction of seawalls *within* wetlands. While not explicitly acknowledging the impacts of rising sea levels on coastal wetlands, these restrictions may serve to reduce the harmful effects of seawalls that impede the ability of wetlands to migrate landward as sea level rises (Fla. Stat. ch. 373.414(5)(b) (2009)). The regulations do not, however, apply to land uses on adjacent uplands (Fla. Admin. Code 62-340.200 (2009)). Thus the state has no direct regulatory leverage, under

this part of the program, over upland activities that may impair the ability of wetlands to migrate landward as sea level rises.

2.3.3 Stormwater regulation context

Florida's environmental resource permit program also regulates stormwater management associated with many development activities (Fla. Stat. ch. 373.413 (2009)). The permitting program addresses water quality and water quantity issues through design standards for stormwater systems. Stormwater regulations do not currently consider how increased sea levels may decrease the effectiveness of stormwater management systems. However, the water management districts which primarily manage these programs are beginning to see the importance of sea level rise impacts on the long-term effectiveness of stormwater drainage to prevent flooding (Obeysekera, Park, Barnes, Dessalegne-Agaze, Trimble, and Said in this special issue).

2.4 Design and development context

Sound design² and development practices have an essential role to play in adaptive response planning to sea level rise because, at the end of the day, they encompass in large part the actual “on the ground” responses by communities and landowners to sea level rise and climate change issues. Due to the likely impacts of sea level rise in coastal areas, vulnerability should be considered when choosing and developing a new site, planning large-scale infrastructure projects, as well as when redeveloping urban areas, retrofitting existing structures, and managing properties. Design strategies, ranging from shoreline stabilization, flood-proofing, and elevation, to measures that facilitate future reconstruction and relocation, can be chosen to balance vulnerability costs, long-term private and public development investment benefits, and minimize ecological impacts.

As a first step in adaptive response planning, sea level rise vulnerability and total financial investment over the “design lives” of infrastructure projects, buildings, and landscapes need to be carefully considered when defining design criteria or

² In this paper, “design” refers to site planning, landscape design, engineering, and architectural design occurring in the public and private sectors.

programmatic elements for a project. Even when a structure reaches the end of its design life, it is rarely simply demolished or abandoned. Rather, it is usually rebuilt or replaced because it is enmeshed in a matrix of other infrastructure not all of which reaches the end of its useful life at the same time. For example, street and highway rights-of-way that are laid out for new development have expected operating lives of more than 100 years. Road bed design lives range from 40 to 75 years, while 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. Therefore it is essential that new development be considered within the context of the infrastructure it will require immediately, and what development and infrastructure it will require and encourage later on.

Sound design and development practices are also an essential component in reducing the ecological impacts of sea level rise. Left alone, many coastal wetlands and some beach and dune ecosystems are capable of adapting to rising sea levels by migrating landward (Cahoon et al. 2009; Williams et al. 2009). Human development that alters topographic gradients, hydrology, and/or sediment supply regimes can interfere with this natural adaptive capacity. Construction of hard structures such as bulkheads, seawalls, revetments, and buildings can physically obstruct landward migration of coastal ecosystems. Thus, sea level rise and its impacts on natural systems should be considered in tandem with the environmental impacts of new development. The combination of sea level rise and development-induced stresses may have serious effects on natural systems, but these can be reduced with appropriate development strategies.

A variety of types and combinations of adaptive responses will be necessary to reduce negative impacts to ecological systems and human populations. In the following section we describe three basic types of adaptive response strategies and provide a few examples of each as a segue into reviewing potential legal constraints to adaptive response planning.

3.0 Adaptive response options

We classify adaptive response options into three basic strategies following Dronkers et al. (1990): (1) protect, (2) accommodate, and (3) retreat. We provide brief summaries of these strategies and examples of specific options here. More detailed descriptions and assessments are presented in Section 6.

Protection (or “stand and defend”) comprises physical structures that resist erosion and inundation including “hard engineered” structures (e.g. seawalls, bulkheads, and revetments) as well as “soft engineering” approaches such beach nourishment and dune and marsh building (living shorelines) so that existing human uses can continue and/or expand (see for example Sorensen, Wesiman, and Lennon 1984). These are typically applied to developed areas, but some of these measures may be applied to protect individual structures or facilities, e.g. a flood wall or levee constructed around a wastewater treatment facility. Titus and Hudgens et al. (2009) assume that protection will be the adaptive response of choice where important economic assets are at risk. In Florida, at least one community, Punta Gorda, is actively considering enhanced protection for its core urban area (Beever et al. 2009).

The other end of the scale comprises retreat, which includes actions to get people and their physical assets out of the way of advancing sea level rise and its attendant effects. As defined by Dronkers et al., retreat includes staying out of the way and not developing vacant land that lies in the path of advancing sea level. It also includes relocating or demolishing existing private structures, public facilities, and infrastructure when the effects of advancing sea levels are too costly to accommodate and/or when structures, such as sea walls, prevent natural systems, such as coastal wetlands and beach and dune systems, from migrating landward on their own.

One primary means for avoiding development of hazardous areas and inducing retreat in post-storm situations is down-zoning, i.e. changing existing zoning to restrict allowable land uses to those not vulnerable to flood damage. Governments can keep vulnerable land from being developed altogether by purchasing it in fee-simple or by purchasing certain development rights while allowing the owner to

retain title to the land under development restrictions. Other strategies can be used to minimize development within hazard zones such as cluster development outside of vulnerable areas, development setbacks, and buffers. Rolling easements, in which built structures are required to be moved landward as sea level advances, can be used to enable natural shoreline retreat, and ultimately enforce relocation if necessary.

It may not be realistic to expect property owners to voluntarily limit their investment in coastal development, particularly considering the current uncertainty about sea level rise projections (Gay and Estrada 2010).

Accommodation strategies comprise a middle ground of adaptive response strategies that allow coastal development to co-exist with the effects of advancing sea level rise for some period of time with no efforts taken to stop the advance or get out of the way. This involves design strategies to minimize the costs of sea level rise such as elevating and/or flood proofing structures and public facilities (see for example Nichols and Leatherman 1995) as well as large-scale elevation of land. From a landscape design perspective, planting salt-tolerant species or non-salt tolerant, but lower priced and shorter-lived plants, such as annuals, would offer an accommodation option in areas likely to experience saltwater intrusion and flooding (Volk 2008).

Combinations of protection, accommodation, and retreat strategies may ultimately comprise the most appropriate response in many situations. For example, in an area where coastal storm flooding and/or sea level inundation are expected within the design life of a building, the local building code could require that structures be designed with the habitable floor levels above flood waters and with pier foundations to possibly allow the structure to be moved while reducing relocation/reconstruction costs should the site become uninhabitable due to sea level rise. As part of this approach, modular structures could be designed that would allow property owners to more easily disassemble and relocate their structures if necessary.

In areas likely to experience shoreline retreat from sea level rise, regulatory programs might require private waterfront developments to set aside an

alongshore buffer with a living shoreline as part of the overall site plan, better enabling upland ecosystem retreat, and potentially reducing hazards to structures by creating a storm buffer. Deep and narrow lots with structures sited on the upland ends could be required to enable shorelines to retreat, reduce erosion threats to structures, and minimize the need for protective structures such as sea walls.

Where they occur, most current responses to sea level rise in Florida consist of local government and agency adaptation planning endeavors such as the City of Punta Gorda Adaptation Plan (Beever et al.). The authors were unable to identify any specific development proposals implementing adaptive response planning measures in Florida. There are, however, developed areas where strategies such as cluster development and alongshore buffers have been used that can be applied to adaptive response planning. For example, the well-known New Urbanist community of Rosemary Beach was developed landward of the CCCL with limited disturbance of the dune system. However, adaptation within this community will still be difficult due to the permanent nature of the buildings, the proximity of dense development to the dunes, and the high property values that will encourage traditional protective measures if sea level rise causes the shoreline and dunes to retreat inland.

4.0 Legal limitations on adaptive response options

Adaptive policy responses to sea level rise, including those discussed above and others assessed in Section 6, could be subject to challenge under limitations on the regulation of private property in the United States and Florida. This sub-section briefly describes these potential limitations and how adaptive response options can be tailored to address these limitations.

4.1. US constitutional takings

The United States Constitution states that “private property [shall not] be taken for public use, without just compensation” (U.S. Const. amend. V.). For more than one-hundred twenty-five years, this meant that government could not physically invade a property owner’s land or premises or take title to it without paying. This

changed radically in 1922 when the U.S. Supreme Court created “regulatory takings” by concluding that a regulation that goes “too far” constitutes a prohibited “taking” of property (*Pennsylvania Coal Co. v. Mahon*, 260 U.S. 393, 415 (1922)). Almost a century of subsequent law has done little to make clearer when a regulation goes “too far.”

In 1992 in the *Lucas* case (*Lucas v. South Carolina Coastal Council*, 505 U.S. 1003 (1992)), the U.S. Supreme Court concluded that a regulation that deprives a property owner all economically viable use of land automatically constitutes a taking of property. However, the court indicated that this would seldom be the case since property usually retains some value. Usually, when a property owner challenges a regulation as a taking, courts will apply the test from the *Penn Central* case of 1978 (*Penn Central Trans. Co. v. City of New York*, 438 U.S. 104 (1978)). This three-part test examines the nature of the government regulatory action, the economic impact of the regulation, and whether the property owner had reasonable, investment-backed expectations in the prohibited use. This inquiry is very fact intensive and case specific, so the outcome is rather unpredictable as there are no set rules for how to weight the multiple facts a court may consider.

This uncertainty leads to problems for both property owners and regulators who are not clear about what rights they do and do not have. This, in turn, may lead cash-strapped, risk-averse local and state government regulators to not risk litigation due to regulations that protect the public, the treasury, and environmental resources from the impacts of sea level rise. Such a risk-averse stance may, if publicly known, ironically encourage property owners to file or threaten to file takings cases in attempts to pressure regulators to not adopt or not to apply regulations. Nonetheless, under the U.S. Constitution, the authority of regulators to address concerns with sea level rise arguably remains expansive since the U.S. Supreme Court has noted that landowners “may reasonably expect or anticipate” changes in property rights from time to time (*Stop the Beach Nourishment v. Fla. Dept. of Env’tl. Prot.*, 560 U.S. ___, No. 08-1151 (2010) (Kennedy, J., concurring); *Lucas v. South Carolina Coastal Com’n.*, 505 U.S. 1003, 1027 (1992)), that coastal areas present unique concerns (*Lucas*, 505 U.S. at

1035 (Kennedy, J., concurring)), and “changed circumstances or new knowledge may make what was previously permissible no longer so.” (*Lucas v. South Carolina Coastal Com’n.*, 505 U.S. 1003, 1035 (1992) (Kennedy, J., concurring)). Sea level rise should qualify as changed circumstances and new knowledge since, although nine inches of rise have been measured in Florida over the past 90-100 years, the causes and effects of future accelerated sea level rise are only now beginning to be understood and appreciated and have still not been incorporated into our legal structure.

Local governments may mitigate the impact of regulations for adaptive response planning through the planning tool of transfer of development rights (TDR).³ Constitutional takings law has had occasion to consider transfer of development rights in the context of a takings claim; in the case of *Penn Central*, the U.S. Supreme Court stated that a possibility of transferring and selling development rights is clearly valuable and counts to mitigate any financial burden that a zoning change creates for a property owner. (*Penn Central Transp. Co. v. City of New York*, 438 U.S. 104, 137 (1978)). Surprisingly, in the 1997 case of *Suitum v. Tahoe Regional Planning Agency*, the Court cast a shadow on the seeming clarity of the importance of TDRs as a way to mitigate the financial burden of regulation. In *Suitum* the U.S. Supreme Court said it was not asked to rule upon, nor would it rule upon, whether any value that may inhere in TDR credits counts towards determination of whether a taking has occurred or whether a taking that was found to have occurred has been compensated via the TDR credit’s value (*Suitum v. Tahoe Reg’l. Planning Council*, 520 U.S. 725, 728 (1997)). Despite the 1997 statement in *Suitum*, the value of TDR credits arguably still mitigates the economic impact of any restrictions forming part of a TDR program.

4.2 Florida constitutional takings limitations

Prior to moving to federal courts for a takings claim based on state law, a property owner must exhaust state remedies for the claim. *Williamson Cty. Reg’l. Planning Comm’n. v. Hamilton Bank of Johnson City*, 473 U.S. 172, 193-94 (1985).

³ A transfer of development rights

Florida's protection of private property comes in part through the constitutional protections afforded by the Florida Constitution in article X, section 6.

While Florida case law under its constitutional protections was very different from protections under the U.S. Constitution forty years ago, during the past several decades Florida law has evolved to virtually mirror U.S. Constitutional takings law. (*Joint Ventures, Inc. v. DOT*, 563 So. 2d 622 (1990); *Tampa-Hillsborough Cty. Expressway Auth. v. A.G.W.S. Corp.*, 640 So. 2d 54, 58 (1994); *Certain Interested Underwriters at Lloyd's of London v. City of St. Petersburg*, 864 So. 2d 1145 (Fla. 2d DCA, 2003) (utilizing interchangeably federal and state cases to describe Florida takings law); *Keshbro, Inc. v. City of Miami*, 801 So. 2d 864 (Fla. 2001) (same); *Agripost, Inc. v. Metro. Miami-Dade County*, 845 So. 2d 918 (Fla. 3d DCA 2003), review denied by 859 So. 2d 513 (Fla. 2003)).

Still, some differences do exist. One distinction relates to the need for a "public purpose" for the physical taking of property. In the case of *Kelo* (*Kelo v. City of New London*, 546 U.S. 807 (U.S. 2005)), the U.S. Supreme Court defined this broadly enough to include taking property and transferring it to another private party as part of the local government's redevelopment plan. In reaction to the *Kelo* case, Florida voters in 2006 approved an amendment to the Florida Constitution's property protections. This states that "private property taken by eminent domain . . . may not be conveyed to a natural person or a private entity except as provided by a general law passed by a three-fifths majority of the . . . the Legislature." Fla. Const. art. X, §6(c). This limitation could, for example, affect local government efforts to take vulnerable property by eminent domain and then resell that property with development restrictions and/or a rolling easement.

Florida case law follows federal constitutional takings law and treats the use of transfer of development rights as a way to mitigate the financial impact of regulations or zoning and as a way to avoid eliminating all beneficial economic use (*see, e.g. Shands v. City of Marathon*, 999 So. 2d 718 (3d DCA 2008)).

4.3 Florida statutory takings

Florida also has additional protections for private property in state statutes. The Bert J. Harris, Jr., Private Property Protection Act (Fla. Stat. ch. 70.001 (2009)) creates a cause of action for property owners whose property has been “inordinately burdened” by laws or regulations enacted after 1995.

If a property owner brings suit under the Bert Harris Act, the property owner must demonstrate that the regulation imposes an “inordinate burden” on the property. The statute describes two types of “inordinate burdens.” The first directly restricts or limits the use of real property such that the owner is permanently unable to attain “reasonable investment-backed expectations” for an existing use or a vested right to a specific use of the property as a whole. The second inordinate burden is one in which the owner is left with “unreasonable existing or vested uses.” The term “existing uses” includes either “an actual, present use or activity on the real property” *or* land uses which are “reasonably foreseeable, nonspeculative, . . . *suitable for the subject real property* and compatible with adjacent land uses, *and* which have created an existing fair market value in the property greater than the fair market value of the actual present use or activity” (Fla. Stat. ch. 70.001(3)(b) (2009)) (emphasis added). Note that under this definition, an “existing use” is not a protected use unless *all* of the conditions are fulfilled. Thus, if faced with a claim of an inordinate burden to an existing use, the government may argue that a proposed use is not a protected “existing use” if the property is not “suitable” for the proposed use due to the threat of sea level rise.

The authors are not aware of any Florida cases in which a regulator has presented the argument that property is not protected under Bert Harris because the property is not “suitable” for the proposed use. While it is not clear whether such an argument applied in the context of sea level rise would protect new regulations to promote adaptive response planning, the language of the Bert Harris Act allows such an argument.

Should a claimant under the Bert Harris Act prevail, the claimant can receive the difference in the value of the property before the challenged regulation and after,

which could be a substantial sum.⁴ In addition, even if the claimant loses, many local governments are so strapped for funds that they shy away from even a threat of litigation under the Bert Harris Act.⁵ State or local efforts to promote adaptation to sea level rise may be more effective if the state addresses the Bert Harris Act more directly through a statutory exemption to Bert Harris claims.⁶

4.4 Avoiding takings challenges in adaptive response planning

Adaptive response strategies should be designed to minimize interference with private property rights while also ensuring that the costs of private choices to locate development in hazardous areas—in loss of ecosystems, wildlife, money, infrastructure, beach access, or other metrics—are born by the private actors that benefit from their decisions to site in hazardous areas rather than by the general public. This section summarizes the potential for takings claims related to several key adaptive response strategies.

Hard engineering protective strategies are usually the preferred option of the property owner and thus not challenged when allowed; however, hard armoring damages important natural resources such as beaches and wetlands. Some local governments in Florida already have strict limits on shoreline armoring.⁷ Refusal to allow armoring is typically not a taking of property as there is no inherent right to armor property in Florida.⁸

“Soft” armoring through beach nourishment has been used for decades in large part because it avoids the difficult tensions between private property and protection of the public resource of the beach. Even beach nourishment, however, can give rise to a takings claim; the United States Supreme Court recently ruled

⁴ For example, a September 2004 ruling in Collier County awarded plaintiffs \$375 million.

⁵ Anecdotal evidence of this “chilling” effect of the Bert Harris Act on regulations are legion. The only attempt at systematic review of the impacts of Bert Harris known to the authors is by Echeverria and Hansen-Young (undated).

⁶ An exemption to the Bert Harris Act is not without precedent; Florida Statute section 373.414(18) contains an exemption to the Bert Harris Act.

⁷ One example is Sarasota County’s code section 54-721, which does all but ban coastal armoring in the county.

⁸ Several Florida local governments already have strict limitations on armoring. For example, Sarasota County has implemented strict limitations on allowable coastal armoring. Sarasota County, Florida, Code of Ordinances, Chapter 54, Article XXII, Sections 54-721 through 54-729.

that a Florida statute, which declares all new beach area created through nourishment is the property of the state, does not constitute a taking of the property rights of the affected property owners (*Stop the Beach Nourishment v. Florida DEP*, 560 U.S. ___, (2010), No. 08-1151). After this claim first arose, and prior to the Supreme Court's final ruling, Florida's Legislature passed a law that if a beach nourishment project results in a taking, the *increase* in land value due to better storm and erosion protection from the additional sand will be subtracted from any payment for a taking (Fla. Stat. ch. 161.141; 2007 Laws of Florida ch. 2007-99, section 3).

Elevating development presents a way to avoid or minimize flooding. Elevation may occur through elevation of buildings on pilings, or it may occur through elevation of ground level through the use of fill, thus raising buildings and roads. Elevating new or substantially rebuilt structures via use of pilings presents very few takings issues as this has long been an accepted requirement in many flood-prone areas. Elevation through fill may also present few takings problems when it is only applied to new development on an area-wide scale. Applying an elevation requirement to existing structures, existing neighborhoods, or to generally raise land or to raise public roads and infrastructure may result in constitutional or Bert Harris claims since government is liable if its direction of water onto property denies the property owner beneficial use of the property (*Drake v. Walton County*, 6 So. 3d 717, 720-21 (1st DCA 2009); *Thompson v. Nassau County*, 343 So. 2d 965, 966 (1st DCA 1977)). This could occur when a government elevates a road and changes drainage patterns that result in flooding land (*Kendry v. State Road Dep't*, 213 So. 2d 23 (4th DCA 1968)). Private parcels using fill to elevate and causing increased flooding on adjacent parcels may also be held liable under nuisance law, even if elevation of the property is required by law. (*Westland Skating Center, Inc. v. Gus Machado Buick, Inc.*, 542 So. 2d 959, 962-63 (Fla. 1989)). Potentially the only way to avoid legal wrangling over flooding and drainage might be to elevate entire areas at once.

Regardless of the type of local government regulation used, if changes to the local code may be reasonably construed as simply clarifications of clearly-applicable comprehensive plan requirements that pre-date enactment of the 1995 Bert Harris

Act, such clarification is likely not subject to a Bert Harris claim since the property owner could not have had an expectation to greater development than the comprehensive plan allowed Palm Beach Polo, Inc. v. Village of Wellington, 918 So.2d 988 (Fla. 4th DCA, 2006); (Citrus County v. Halls River Development, Inc., 8 So.3d 413 (Fla. 5th DCA, 2009)).

5.0 Adaptive decision-making framework

While the exact parameters of how deep the water will be where and when remain uncertain, the longevity of urban land use patterns and the design lives of private structures and public facilities dictate that land use changes and economic investment in coastal development occurring in Florida today are committing coastal communities to future sea level rise vulnerability. In addition to increasing the economic costs of adaptation, these changes will constrain the set of adaptive responses that are possible as the impacts of sea level rise manifest themselves. Contemporary land use changes, as well as adaptive responses taken as sea levels rise, also will constrain the ability of natural systems to adapt.

In light of the uncertainty of sea level rise predictions and the potentially complex interactions of contemporary land use decisions and future adaptive response options, a logical and flexible method of making decisions is needed for state and local officials about what, if any, adaptive response initiatives should be taken now. Several researchers have developed criteria and decision-making frameworks for assessing the relative merits of alternative adaptive responses to climate change in general and sea level rise in particular.

The predominant quantitative approach has been inter-temporal benefit-cost (net present value) analysis (Adger et al. 2007; Patt et al. 2010; Stern 2007). Less rigorous, pragmatic approaches have applied a net benefits conceptual framework for making rough assessments of adaptive response decision alternatives. Titus and Hudgens et al. (2009) apply a simple heuristic approach based on existing and planned development intensity to assign one of two alternative sea level rise adaptive response strategies - retreat or protect - to coastal uplands along the Atlantic coast of the US. They posit that the likelihood of protection against sea level rise will increase as the mix of existing and planned land use shifts from

areas dedicated to conservation and “vacant” land (e.g. agriculture or forestry) to increasing levels of development intensity.

Van Raalten et al. (2009) follow a similar approach in an adaptive response alternatives analysis for San Francisco Bay in which they reduce the adaptive response decision framework to a four-cell “Strategy Development Method” (SDM) matrix based on two primary values ascribed to a specific geographic area: (1) economic importance and intensity of existing development (high/low) and (2) natural hydrological and ecosystem dynamics (high-natural/low-altered).

Many researchers recognize that uncertainty and decision makers’ views of risk are an important element of adaptive response decision making (Patt et al. 2010; Stern 2007). Titus and Neumann (2009) take decision makers’ tolerance for uncertainty into account along with several more explicit net benefits criteria: (1) the magnitude of near-term impacts that would be mitigated by an adaptive response initiative, (2) the opportunity costs of the initiative, (3) the long-term consequences of acting or failing to act, (4) the sensitivity of the consequences to sea level rise, and (5) the consequences of deferring adaptation decisions.

We describe here a possible approach for evaluating adaptive response alternatives for the State of Florida that builds on those of Titus and his colleagues and van Raalten et al. We take a goals achievement approach (Hill 1968) where, rather than attempting to quantify net benefits, the decision maker simply examines the ability of adaptive response alternatives to meet a set of goals. We include explicit criteria for vulnerability to capture one of the dimensions of uncertainty inherent in assessing the costs of sea level rise impacts.

Our decision-making framework involves a four-step process that may be followed by government officials responsible for land use and infrastructure planning:

1. Define sea level rise adaptive response goals
2. Define applicable coastal shoreline typologies
3. Identify appropriate adaptive response options

4. Evaluate potential options for each shoreline type against the adaptive response goals.

We present below a possible goals framework and a coastal shoreline typology that reflects the important attributes of Florida's coast. In section 6 we apply this framework to illustrate how public decision makers might approach questions of adaptive response to sea level rise in Florida.

5.1 Goals framework for assessing sea level rise adaptive response options

We adopt a risk-averse approach grounded in a benefit-cost conceptual framework that includes the following goals:

1. Minimize risk to human development
2. Minimize public sector capital and operating costs
3. Minimize opportunity costs
4. Minimize legal challenges, i.e. account for federal and state constitutional and state statutory constraints
5. Maximize political feasibility viz-a-viz costs, property rights, etc.
6. Mitigate environmental stresses including climate change
7. Minimize interference with ecological adaptation
8. Maximize long-term adaptability of land uses, structures, and landscapes.

The first six goals are typical of evaluation frameworks that address environmental as well as economic benefits and costs. We include the seventh to explicitly address the potential for development decisions to impede natural adaptive responses to changing sea level. The eighth reflects the fact that the earth is already committed to centuries or more of sea level rise, regardless of the measures that may be taken to reduce greenhouse gas emissions (Wigley 2005). As a result, each adaptive planning measure has design limits that will be surpassed at some point in the future as sea level continues to advance. How much and how fast sea level rises will determine when those design limits are reached and, therefore, the longevity of the adaptation. These uncertainties, coupled with others about possible interactions between specific adaptive responses and the

abilities of natural systems to adapt, serve to emphasize the importance of maximizing the long-term adaptability of land uses, structures, and landscapes.

5.2 Coastal shoreline typologies

Table 1 shows our modification of the van Raalton et al. (2009) SDM typology. We include shoreline vulnerability in addition to urban economic value and natural system value. The coastal shoreline vulnerability dimension accounts for the variation in coastal geologic substrates, topographic gradients, and wave energy encountered in different areas of Florida. We base the urban system value on the sunk cost of private and/or public structures and importance to existing and future local and regional economies. We define natural system value in terms of natural and altered systems, but further differentiate those that harbor species of concern or that have important economic value.

Dimension	Scale		
	High	Moderate	Low
Coastal shoreline vulnerability	High wave energy + high erosion vulnerability	High wave energy + low erosion vulnerability	Low wave energy + low or no erosion vulnerability
		OR low wave energy + high to moderate erosion vulnerability	
	AND/OR high inundation/flood exposure	AND/OR moderate inundation/flood exposure	AND/OR low inundation/flood exposure
Urban system value	Significant private and/or public sunk assets and important to current local and regional economies and culture	Substantial private and/or public sunk assets, important to local economy and culture and/or with substantial potential to become important to local and regional economies and culture	Few or no private and/or public sunk assets, lower economic potential, and low cultural value
Natural system value	Threatened or endangered species habitat and/or high recreational or economic value ecosystems, e.g. beaches, coastal wetlands that support fisheries	Other valuable coastal natural systems	Altered coastal ecosystems that do not give substantial support to recreational or commercial interests

Table 1 Coastal shoreline typology

High wave energy = National Flood Insurance Program V-zone

Low wave energy = National Flood Insurance Program A-zone

High erosion vulnerability = sedimentary substrate (sand beach and dune system)

Moderate erosion vulnerability = wetland (salt marsh or mangrove) substrate

Low erosion vulnerability = consolidated substrate, e.g. Florida Keys

No erosion vulnerability = armored shoreline (seawalls, bulkheads, revetments, etc.)

High inundation/flood exposure = Areas <3 feet above mean high water, or other factors *

Moderate inundation/flood exposure = Areas >3 feet and <5 feet above mean high water, or other factors*

Low inundation/flood exposure = Areas >5 above*

*Based on land updated NFIP maps, storm surge projections, and local sea level rise inundation maps and time frame projections. These may vary based on site-specific characteristics. For example, lands particularly subject to storm surge may be "high inundation" even though they are more than 3 feet above MHW. Similarly, areas not at great risk of storm surge may be "low inundation" at elevations lower than 5 feet above MHW.

6.0 Assessment and application of adaptive response options

In this section we illustrate how the adaptive decision-making framework can be applied to assess a set of adaptive response options using a weighted goals achievement matrix. We describe a sample set of adaptive response options which we evaluate against the illustrative set of goals identified in section 5.1 for the Florida shoreline typologies defined in section 5.2. Local or state governments can readily modify this framework with their own sets of strategies, options, goals, and local conditions.

Table 2 provides brief descriptions of a sample array of adaptive response options for each of the three strategies described in section 3: protection, accommodation, and retreat. Table 3 provides an illustration of how a decision maker might weight each of the goals identified in section 5.1 to reflect different combinations of the three-dimensional Florida shoreline typology described in section 5.2. The general approach we take is to assign equal weights to the goals to “minimize legal challenges” and “maximize political feasibility.” We have raised the weights for “minimize risks to human development” and “minimize opportunity costs” for situations where the urban system value is high and the natural system value is low and followed the reverse strategy where urban system value is low and natural system value is high. Where shoreline vulnerability is low we have raised the weight for “minimize capital and operating costs” and reduced the weight for “maximize long-term adaptability.”

Adaptive Response Strategy	Response Option	Description
Protect – hard engineering	Shore armoring	Seawalls, bulkheads, and revetments constructed parallel to the shore to protect upland embankments or structures from wave damage and erosion.
	Dikes	A linear earthen structure along a sea or river designed to protect lands from flooding (Voigt 1998).
	Storm surge barriers	Construction of mechanical barriers to prevent flooding of a partially enclosed body of water such as a bay or river from extremely high tides and storm surge.
Protect – soft engineering	Beach nourishment	“[R]eplenishing a beach by artificial means; e.g., by the deposition of dredged materials, also called beach replenishment or beach feeding” (Voigt 1998).
	Living shorelines	“[P]rotection, restoration, or enhancement of vegetated shoreline habitats. . . through . . . placement of plants, stone, sand fill and other structural and organic materials.” (Center for Coastal Resources Management 2010)
Accommodate	Elevated structures	Elevating structures above a specified flood level using fill, pilings, or a perimeter wall (FEMA 2009), both for flood protection, and potentially for easier relocation if necessary.
	Dry floodproofing	Permanent and temporary measures applied to a structure that prevent damage from flooding by making a building substantially impermeable to floodwaters (FEMA 2009).
	Landfill	Large-scale elevation of land areas by placement of fill to raise the base elevation above a specified flood level.
Retreat	Prohibit development plus TDR	Zoning of properties vulnerable to coastal erosion and flooding so as to prohibit development and allowing transfer of development rights (TDR) from those properties to others determined to be more suitable for development.
	Prohibit development plus acquisition	Zoning of properties vulnerable to coastal erosion and flooding so as to prohibit development and fee-simple acquisition of those properties to maintain their undeveloped status.
	Restrictive easements	The voluntary donation or sale to a second party of the development rights of all or a portion of a private property parcel thereby limiting the types of uses while the land remains privately owned.
	Cluster development	A land development technique that groups or “clusters” development more densely within certain portions of the developable property, and maintains the remainder of the property in open space, conservation, or a similar use.
	Post-disaster down-zoning plus TDR	Zoning of properties damaged by storm-induced erosion and/or flooding so as to prohibit redevelopment and allowing transfer of development rights (TDR) from those properties to other less vulnerable properties.
	Post-disaster down-zoning plus acquisition	Zoning of properties damaged by storm-induced erosion and/or flooding so as to prohibit redevelopment and fee-simple purchase of those properties to maintain their undeveloped status.
	Managed realignment	“[D]eliberate breaching, or removal, of existing seawalls, embankments or dikes in order to allow the waters of adjacent coasts, estuaries or rivers to inundate the land behind” (ABP Marine Environmental Research Ltd 2010).
	Decommission/relocate existing infrastructure	Discontinuing use of and/or moving infrastructure away from the coastal hazard zone before or after it is threatened or damaged.
	Rolling easement exaction	A legal construct where shoreline hardening structures are prohibited and the definition of public lands as being below the mean high water line is enforced.

Table 2: Sample adaptive response options for sea level rise

Scenario	Goal Weights								Totals
	Minimize Risk to Human Development	Minimize Capital and Operating Costs	Minimize Opportunity Costs	Minimize Interference with Ecological Adaptation	Maximize Long-Term Adaptability	Minimize Legal Challenges	Maximize Political Feasibility	Mitigate Environmental Stresses	
High-high-low									
Shoreline vulnerability = high Urban system value = high Natural system value = low	20.0	12.5	20.0	5.0	12.5	12.5	12.5	5.0	100.0
High-low-high									
Shoreline vulnerability = high Urban system value = low Natural system value = high	5.0	12.5	5.0	20.0	12.5	12.5	12.5	20.0	100.0
Low-high-low									
Shoreline vulnerability = low Urban system value = high Natural system value = low	20.0	20.0	20.0	5.0	5.0	12.5	12.5	5.0	100.0
Low-low-high									
Shoreline vulnerability = low Urban system value = low Natural system value = high	5.0	20.0	5.0	20.0	5.0	12.5	12.5	20.0	100.0

Table 3 Assigning weights to sea level rise response goals

Tables 4 and 5 illustrate how the weighted goals achievement matrix might be applied. We have scored each adaptive response option based on our knowledge of these systems and pertinent literature (for a recent general overview of most of these options see Titus and Craghan (2009)). The scores can be adjusted as new knowledge becomes available, but they should be held constant for different scenarios. Table 4 illustrates what the aggregate scores would be for each strategy with uniform weights for each goal. Table 5 shows how those scores would change with *different* weights for each goal as shown in Table 3. The Table 5 scores are arrived at by multiplying the weight times the values (the number between -3 to +3 indicated by +/- for each goal in Table 4), and adding to find a total for each strategy. That total is shown in Table 5 for each shoreline type. The scores for individual options vary significantly among the scenarios. This illustrates both the sensitivity of the framework to the goal weights and the importance of devising decision frameworks that are sensitive to variations in shoreline vulnerability, urban value, and natural system value. Brief explanations of the scoring of the individual options in Table 4 follow.

	Goals								
Adaptive Response Strategies and Potential Options	Minimize Risk to Human Development	Minimize Capital and Operating Costs	Minimize Opportunity Costs	Minimize Interference with Ecological Adaptation	Maximize Long-Term Adaptability	Minimize Legal Challenges	Maximize Political Feasibility	Mitigate Environmental Stresses	Totals
Goal weights	12.5	12.5	12.5	12.5	12.5	12.5	12.5	12.5	100
Protect									
Shore armoring	+++	---	+++	---	--	++	+/-	--	-25
Dikes	+++	---	+++	---	--	++	+/-	--	-25
Storm surge barriers	+++	--	+++	+/-	--	++	+/-	--	25
Beach nourishment	++	--	+	-	++	+	+/-	+	50
Living shorelines	+	++	++	++	+++	++	++	+++	213
Accommodate									
Elevating structures	+++	--	++	+/-	+	+-	+/-	+++	113
Floodproofing structures	++	--	++	+/-	+	++	+/-	+++	100
Elevating developed areas	+++	--	+++	--	--	++	++	--	25
Retreat									
Prohibit development plus TDR	+++	++	--	+++	++	++	+/-	+++	163
Prohibit development plus acquisition	+++	--	---	+++	++	+/-	+/-	+++	75
Restrictive easements	+++	+	--	+++	++	+/-	+/-	+++	125
Cluster development	++	++	+/-	++	+	++	++	+	150
Post-disaster down-zoning plus TDR	+++	++	--	+++	++	++	---	+++	125
Post-disaster down-zoning plus acquisition	+++	--	---	+++	++	+/-	---	+++	38
Managed realignment	+/-	+++	---	+++	++	++	++	+++	150
Decommission/relocate existing infrastructure	+/-	---	---	+	+	+/-	+/-	+	-38
Rolling easement exaction	++	+	+	+	+	+/-	+/-	++	100

Table 4: Illustration of adaptive response weighted goals achievement matrix

Rating scale:

- +++ highly positive impact on goal = 3
- ++ moderately positive impact = 2
- + somewhat positive impact = 1
- highly negative impact = -3
- moderately negative impact = -2
- somewhat negative impact = -1
- +/- neutral or uncertain impact on goal = 0

	Scenarios			
	High-High-Low	High-Low-High	Low-High-Low	Low-Low-High
Adaptive Response Strategies and Potential Options	Shoreline vulnerability = high Urban system value = high Natural system value = low	Shoreline vulnerability = high Urban system value = low Natural system value = high	Shoreline vulnerability = low Urban system value = high Natural system value = low	Shoreline vulnerability = low Urban system value = low Natural system value = high
Protect				
Shore armoring	58	-108	50	-115
Dikes	58	-108	50	-115
Storm surge barriers	85	-35	85	-35
Beach nourishment	28	-3	-3	-33
Living shorelines	198	228	190	220
Accommodate				
Elevation	128	98	105	75
Floodproofing	108	93	85	70
Landfill	100	-50	100	-50
Retreat				
Prohibit development plus TDR	125	200	125	200
Prohibit development plus acquisition	30	120	0	90
Restrictive easements	88	163	80	155
Cluster development	143	158	150	165
Post-disaster down-zoning plus TDR	88	163	88	163
Post-disaster down-zoning plus acquisition	-8	83	-38	53
Managed realignment	83	218	90	225
Decommission/relocate existing infrastructure	-75	0	-105	-30
Rolling easement exaction	100	100	100	100

Table 5: Illustration of effects of different weighting schemes on adaptive response option scores

Protection strategies minimize opportunity costs by allowing development of vulnerable lands for some periods of time, but those benefits are offset to some extent by their high capital and repair and replacement costs. Hard engineered structures, such as shore armoring (see generally Nordstrom 2000), dikes, and storm surge barriers (Tam 2009), are rated highly for minimizing risk to human development because they can be designed to withstand high waves and storm surges. They are, however, very expensive to construct (Beever et al. 2009) and will eventually incur costs for repair and/or replacement due to advancing shore erosion and reduced effectiveness as sea level rises. Shore armoring and dikes can prevent landward migration of beach and dune systems and/or coastal wetlands as sea level rises. Seawalls also can exacerbate erosion both in front of and adjacent to the structure. These structures therefore present impediments to ecological adaptation and potentially lateral public access on the beach. The sunk capital costs in hard engineered structures limit long-term adaptability of human systems because of the very high costs of repair, replacement, and/or relocation due to advancing erosion and/or sea level rise. Legal challenges are likely minimal except where structures such as seawalls are opposed by neighboring property owners or environmental advocates or where the structures will adversely affect neighboring properties. Political feasibility will likely depend on who pays for the structures and the relative political strength of pro and con advocates. Hard engineered structures typically alter the natural environments in which they are placed, e.g. the use of cut-and-fill associated with bulkheads in coastal wetlands, interference of storm surge barriers with the hydrologic, sediment, and salinity regimes of coastal wetlands and coastal river floodplains, and complete isolation of floodplain wetlands from natural hydrologic regimes by dikes. Hard engineered structures also require the use of considerable quantities of energy and raw materials in construction with the associated carbon footprints. Therefore we rank them as contributing substantially to additional environmental stresses.

“Soft” engineered approaches such as nourishment and living shorelines often provide lower levels of protection, may have lower capital costs, with fewer direct adverse impacts on natural systems and greater long-term flexibility for both natural and human systems to adapt to sea level rise and changing shorelines (see

generally National Research Council 1995). Beach nourishment benefits can be short-lived if a project area is hit by a severe storm, potentially requiring expensive subsequent renourishment. Nonetheless, nourishment is often sought because it helps preserve the recreational, tourism, and ecosystem function of the beach. Recent litigation in Florida concerning publicly-funded beach nourishment indicated that Florida's beach nourishment program does not run afoul of constitutional property protections (*Stop the Beach Renourishment, Inc. v. Florida Department of Environmental Protection*, 560 U. S. ____, No. 08-1151 (2010)). Another soft-engineering approach, living shoreline construction, is less expensive and has fewer adverse impacts on natural systems—indeed it is sometimes done for habitat restoration as much as for property protection. However, living shorelines may provide lower levels of protection and only be useful on low-energy shorelines. Living shorelines required by regulators could potentially raise legal concerns if the living shoreline were to grow tall enough to interfere with the riparian right to a view of the water (*Padgett v. Central & Southern Florida Flood Control Dist.*, 178 So. 2d 900, 904 (2d DCA 1965)). The view consideration is unlikely to arise in northern areas of Florida, but living shorelines including mangroves in southern Florida could lead to such issues.

Accommodation strategies allow continued use of coastal areas for some period of time with no efforts taken to stop the advance of sea level rise or get out of the way. In particular we focus on the accommodation options of elevation, floodproofing, and landfill. A fourth option, floating structures, has deliberately been excluded from this paper because of its unlikely feasibility in Florida due to the extent of high energy shorelines and statewide storm vulnerability, although there may be limited situations where it is appropriate. The accommodation options of elevating and floodproofing structures may be imposed upon the private sector through building codes and may be employed directly by governments for public facilities and infrastructure. Elevation includes 1) elevating the structure only, such as by use of pilings, and 2) elevating the structure and potentially surrounding land by use of fill. Elevating and floodproofing structures can provide significant levels of protection from storm flooding, but may offer incomplete protection against long-term inundation from rising sea levels unless surrounding developed land and infrastructure are also

elevated. In addition, elevation may not be feasible for many existing slab on grade and masonry structures. Direct costs may be borne by the private sector where elevating or floodproofing structures is required through building codes, but effectiveness hinges on adequate enforcement (Mileti 1999), while large-scale elevation of land may require government or taxpayer financing through a special improvement district. Capital costs for elevating and floodproofing *public* facilities and infrastructure can be substantial, and elevating entire developed areas will be very expensive. The question for policy makers in these situations should be whether the benefit to the public outweighs the costs of accommodation measures. These options do limit opportunity costs by allowing productive use of vulnerable land for some period of time.

Floodproofing, and elevating structures or entire areas, present less of a barrier to ecological adaptation and shoreline retreat than hard-engineered structures, but eventually the elevated land or structure may impede the landward migration of natural systems as sea level rises. Additionally, in the process of construction, large-scale elevation by landfill may significantly alter natural habitat and drainage patterns and will have a higher carbon footprint from consumption of energy and materials.

The potential for legal challenges for elevation and floodproofing approaches varies. Floodproofing, when made a condition of a building permit, presents little problem as this has been done for many years without significant challenges. Structural elevation requirements present little room for challenge as well when accomplished by elevating on pilings as this is a common remedy in areas prone to flooding. The more challenging situations involve elevating individual structures or entire areas by fill, and potential for takings claims exists in these cases (see section 4.4). In general, the political feasibility of accommodation strategies will be affected by the costs associated with complying with elevation or floodproofing standards on private property and, perhaps, the associated tax burdens of expensive public sector accommodation measures, including costs associated with legal claims.

Retreat options are generally viewed as carrying substantial opportunity costs, especially where development is altogether prohibited on vacant land in vulnerable areas or where existing development is abandoned in post-disaster settings (May and Deyle, 1998). Most retreat measures provide significant reductions in risk to human development by moving people and their property out of harm's way. Public sector costs are confined primarily to the costs of administering regulations and associated programs with the exception of measures that involve the purchase of property or development rights (i.e. restrictive easements) and the costs of decommissioning or relocating existing public facilities and infrastructure. Most of these measures minimize interference with ecological adaptation by getting out of the way well in advance of the need for natural systems to migrate landwards as sea level rises. The effectiveness with which ecological adaptation is facilitated by relocating existing infrastructure and imposing rolling easements will depend on the thresholds employed to initiate relocation. All retreat options enable future adaptability of human systems because the measures can be altered without significant costs as new knowledge becomes available. Policies that prohibit development in hazardous areas or that prevent redevelopment of hazardous areas after major storms have a high potential to run afoul of federal and state constitutional and statutory constraints on regulatory takings of private property. Those measures are described in Table 2 as being accompanied by one of two compensatory mechanisms so as to minimize legal challenges: use of transfer of development rights (TDR) or fee-simple purchase of the affected property. The political feasibility of various retreat options is likely to vary. As a general rule, there is considerable political resistance in Florida to restrictions on building in hazardous coastal areas (Deyle, Chapin, and Baker 2008), while efforts to restrict redevelopment after disasters also are often met by strong local political opposition (Smith and Deyle 1998). All of the retreat options are likely to have minimal ecological impacts.

7.0 Conclusions and recommendations

The relentless rise in sea level, and the acceleration in its rate, present important challenges in contemporary planning, law, and design practice. Sound adaptive response planning is essential due to the longevity of urban development patterns and the sunk costs of private and public capital that are invested in development.

Adaptive response options span a broad range from protection to accommodation to retreat with a diverse array of implications for balancing present and future benefits and costs. Because the uncertainties that attend the timing and magnitude of sea level rise for any particular location make it impractical to conduct formal net present value analysis, public decision makers need a flexible yet logical decision-making framework to assess the pros and cons of alternative adaptive response options now.

The approach we outline here accounts for the differential vulnerability of Florida's coastal urban and natural environments to the impacts of rising sea levels. Our approach differs from others by employing a weighted goals-achievement matrix which defines the decision criteria used to assess adaptive response options. We illustrate how this evaluation method can be applied to a set of adaptive response policy goals and how sensitive evaluations using such a matrix can be to the weights applied by a decision-making body. We make a case for including a decision-making goal that accounts for the effects of adaptive response, or lack thereof, on the ability of coastal ecosystems to adapt on their own to accelerating sea level rise. We also argue the importance of including a goal to maximize the long-term adaptability of land uses, structures, and landscapes.

No less important than having a decision-making framework for assessing adaptive response options is having the legal authority to implement the full array of possible response policies and programs. Florida comprehensive planning law and other state and local regulatory programs currently offer some justification for state or local government agencies that wish to proactively plan for sea level rise impacts and a framework to enforce design and development practices in line with adaptive planning goals. However, the authority for state agencies to directly incorporate sea level rise into regulatory and other programs may be limited due to Florida's strict approach to allowing agencies to create regulations—agencies are limited to creating only regulations specifically authorized by statute as opposed to those only “reasonably related to the purpose” of statutory law (Fla. Stat. ch. 120.52(8) (2009)). This potential limitation on agency ability to incorporate sea level rise into agency programs may be more imagined than real,

but even if it were not to actually prohibit agency rule making, it may still serve as a potential excuse for inaction if an agency does not have sufficient political support to confront the difficult issues raised by sea level rise.

Local governments do not suffer from this problem since local governments in Florida have “home rule” authority which essentially grants them power to enact any law or regulation for protection of the health or welfare of the public as long as the law is not preempted or prohibited by state or federal law. Nonetheless, in the realm of land use planning and regulation, many local governments look to the state for direction, particularly in a regulatory domain such as sea level rise that is viewed with skepticism by some (Deyle et al. 2007).

Still, changes in state laws and regulations could clarify the authority of state agencies to incorporate sea level rise—or require that they do—and push hesitant or reluctant local governments to do the same. Such changes should provide the maximum amount of protection from the potential liability of takings claims as possible as state and local agencies seek to protect life, property, and welfare from the harms associated with sea level rise.

Any local or state agency using its regulatory authority to incorporate sea level rise into planning and development regulations, may also need to contend with potential constitutional or statutory takings claims. Thus, adaptive response planning must be carefully designed to minimize interference with existing private property rights.

Based on the forgoing, we recommend consideration of the following planning actions and changes to state and local laws and regulations to promote adaptive response planning:

- Develop a coordinated information-sharing network of local governments, private organizations, and state agencies to address adaptive response planning to sea level rise. Allocate funding for and disseminate information essential to local government planning efforts. This may include the following objectives:

- Define a range of several 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 to be used by local governments, regional planning councils, regional water management districts, state agencies.
- Make available to local, regional, and state agencies the best possible data for mapping sea level rise scenarios based on the Florida Division of Emergency Management's recently-completed LiDAR-based mapping project.
- Define appropriate long-range planning horizons for regional and local water supplies, local wastewater and stormwater management systems, state and local transportation infrastructure, and local land use planning that incorporate state sea level rise scenarios.
- Incorporate sea level rise adaptive response planning goals and policies into the State Comprehensive Plan, building and expanding on the existing land use and infrastructure related policies, and as a guide for local comprehensive plans.
- Require sea level rise adaptive response planning to be integrated into local government planning devices such as comprehensive plans, zoning, and future land use maps, beginning with requirements for the Conservation, Coastal, and Infrastructure elements of local comprehensive plans. This may include the following objectives:
 - Provide technical assistance to local governments in adding adaptive planning requirements to their land development regulations, development review processes, and objectives for projects receiving local government funding.
 - Require accounting for sea level rise vulnerability in the siting and design of public facilities, infrastructure funded with state monies, and in major amendments to the Future Land Use Element and Future Land Use Map in local comprehensive plans.
 - Require development of specific strategies for assuring proper functioning of public facilities and infrastructure for one or more specified sea level rise scenarios.

- Require 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.
- Incorporate sea level rise into Florida's Environmental Resource Permit program by:
 - Increasing the ability of the program to regulate upland development likely to adversely affect wetland migration inland in response to sea level rise.
 - Incorporating sea level rise scenarios into evaluation of the ability of proposed stormwater systems to manage flooding and protect water quality.
- Initiate explicit accounting for sea level rise in conducting FEMA flood hazard map restudies for the coastal areas of Florida.
- Require that CCCL permits for habitable structures are conditioned on the granting of a deed restriction that will not allow armoring and establishment of a "rolling easement" that assures the ability of natural coastal ecosystems to migrate.⁹
- Integrate sea level rise adaptive response planning into continuing education and licensure requirements for appropriate design, planning, engineering, and legal professionals, as well as state university degree programs.

As the BP oil spill has made very clear, much of the welfare of Florida and other coastal states rests on their coasts and ocean areas and the tourism and recreational/commercial fishing they support. Yet many coastal areas, the people who inhabit them, and the economic well being of their communities face unprecedented challenges in adapting to sea level rise. Local government responsibilities to protect life and property as well as to responsibly manage local natural and financial resources dictate the necessity for adaptive response planning. The existing tools and decision framework described above offer a starting point for local governments in Florida, while the recommended policy changes could improve the ability of state and local governments to protect people, property, and ecosystems through adaptive response planning.

Our intent is to further the conversation about what is possible and what is desirable in responding to sea level rise through land use and infrastructure planning and development management. While the visions for future growth a development should be created at the local level and should arise from the local community, states still have a role to play in technical and financial assistance, adopting laws promoting and/or requiring local action, and promoting flexibility in the tools chosen so as to account for the uncertainties associated with sea level rise and its impacts.

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⁹ Additional recommendations are available in Ruppert et al. 2008

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