an analysis of strategies for adaptation to sea level rise in florida

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AN ANALYSIS OF STRATEGIES FOR ADAPTATION TO SEA LEVEL RISE IN FLORIDA

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TABLE OF CONTENTS

Part 4: Bibliography and Research Appendices

PART ONE: INTRODUCTION

This paper examines strategies for adaptation to sea level rise in Florida. The majority of the scientific community now agrees that sea levels are rising at greater than historic rates due to anthropogenic climate change. Though precise estimates are not possible, the International Panel for Climate Change (IPCC) 2007 report projects a sea level rise of 7 to 23 inches by the year 2100. Other analysis predict a rise that could be closer to 36 inches. This rise in sea level will create a variety of issues including land use conflicts caused by seawater inundation, property loss and damage, saltwater intrusion into freshwater bodies, increased coastal erosion, and increases in storm surge. The Treasure Coast Regional Planning Council in a 2005 report summarizes the importance of planning for sea level rise in Florida by stating that, "the prospect of sea level rise is of particular concern to the State of Florida because of its expansive coastline, low elevations and flat topography, economic dependence of the tourism industry on beaches and coastal resources, and significant public and private investment in coastal areas" (TCRPC 2005). The necessity to respond to sea level rise in Florida is undeniable, and these responses must be guided by long range planning that addresses a variety of complex issues such as habitat conservation and working waterfront industries.

At risk development may respond to sea level rise through shoreline protection and hardening, adaptation and accommodation, or by retreating from the coastline. Discussion of how to respond to sea level rise has generally focused on the concept of managed retreat and associated policies. Managed retreat is essentially the act of moving development away from coastal hazards in a planned and controlled manner, and this document recommends managed retreat as basis for all responses to sea level rise. Discussions on managed retreat do not generally propose solutions for shoreline management that anticipate the inevitable coastal protection that will occur, particularly in areas of high density and high value development. Ecologically and financially sustainable shoreline management strategies that address coastal protection must be seriously explored. Realistic solutions to sea level rise also need to be explored from a design and graphic standpoint and applied to specific sites.

The purpose of this study is to explore ecologically and financially sustainable recommendations and strategies for coastal development response to rising sea levels in Florida. The focus is on the effects caused by inland sea water inundation with a secondary focus on shoreline erosion, and increased storm events. Managed retreat and shoreline protection strategies are graphically examined for various coastal conditions. Additional tools and information are outlined for the use of policy makers including information on policy options, goals and objectives, design guidelines for 'areas likely to be inundated', and step-by-step recommendations for response.

Anthropogenic Sea Level Rise and the Need for Adaptation

The majority of scientists agree that sea levels are rising due to anthropogenic global climate change. This is caused by both the thermal expansion of water and the melting of terrestrial glaciers and ice sheets inspired by the warming of the atmosphere (Hansen 2003). Changes in sea level are part of natural processes and have occurred throughout earth's history. However, the rate of sea level rise is projected to increase dramatically in the next century primarily due to historic and continuing greenhouse gas emissions from human activities. An immediate cease in greenhouse gas emissions would still not halt the processes of climate change and sea level rise. Many coastal ecosystems will have difficulty adapting to this rate of sea level rise, and coastal development will face increased hazards from flooding, erosion, and more numerous storm events. Therefore it is essential for the citizens and communities of Florida to determine methods of responding to sea level rise that maintain natural ecosystems, mitigate hazards, and preserve important resources and functions.

The International Panel for Climate Change (IPCC) projects a relative sea level rise of approximately 7 to 23 inches by 2100, though this will vary geographically. Based on more recent data and analysis, actual rise could be closer to 36 inches (Mulkey 2007: 9). Figure 1.1 shows what this means in terms of overall land inundation in Florida. A rise of three feet will inundate many of the most developed areas in the state with South Florida receiving the most far-reaching inundation.

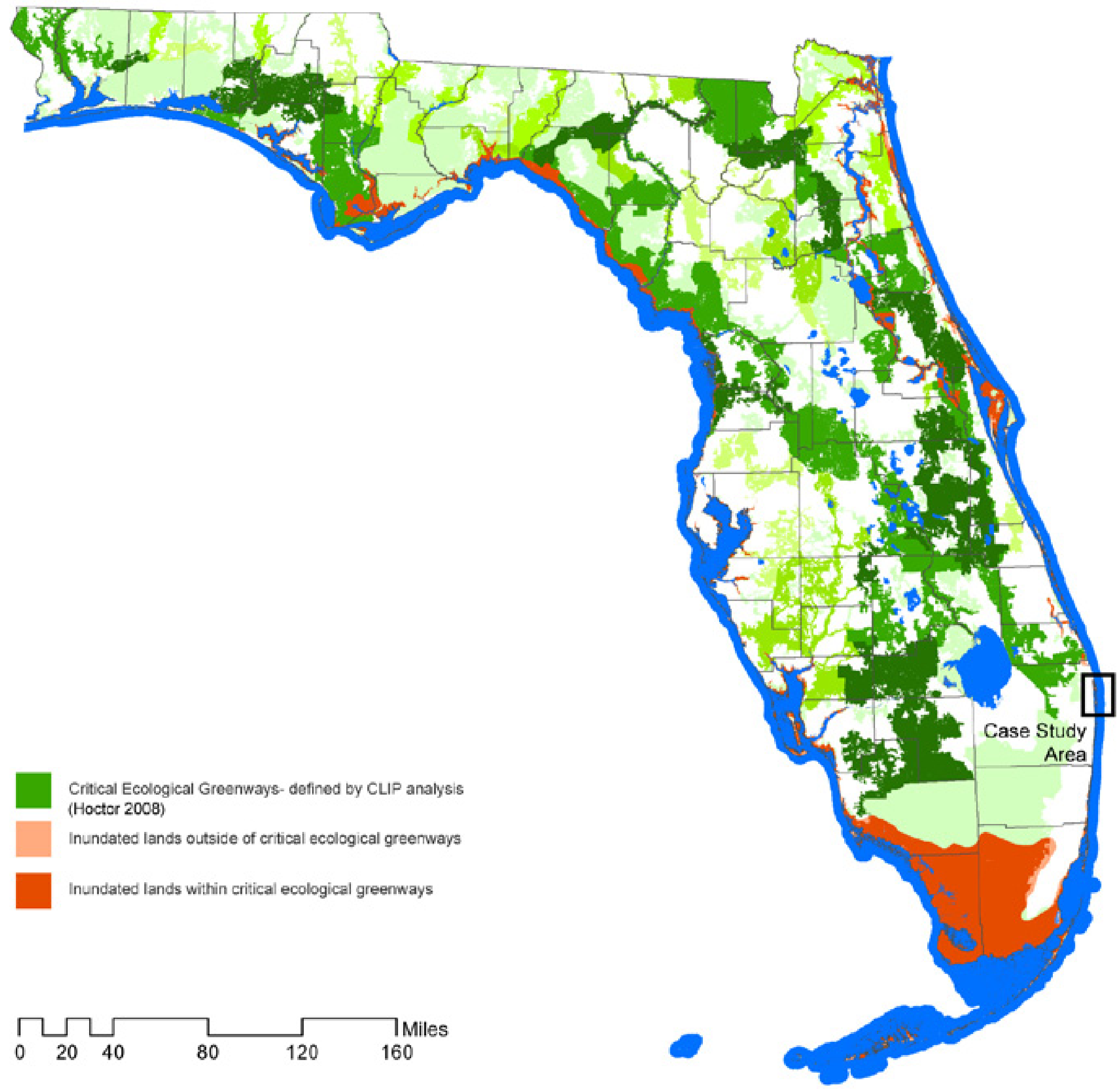
Sea level rise will have a variety of effects on coastal development. Inundation of uplands will create a variety of issues for developed areas including land use conflicts caused by property loss and inland development migration, saltwater intrusion into freshwater bodies, increased coastal erosion, and increases in the effects of storm surge. A rough estimate of the possible erosion caused by sea level rise is 100 to 1000 feet of inland erosion for each 1 foot rise in sea level (Titus 1989). Both coastal and inland developed areas will be at risk and required to respond to these issues.

The impacts of sea level rise on high density and value properties such as Miami Beach and Palm Beach are one of the most difficult conflicts to resolve. Retreat for these land uses is difficult as is ecologically and financially sustainable protection of coastal properties. Agricultural land uses will be impacted by land loss and saltwater intrusion. Water dependent land uses may experience increased competition for the use of coastal land if the amount of developable coastal land is decreased (Coburn 2008). Strategies for the relocation or protection of cultural resources will need to be devised, and in many situations cultural resources may be lost (Berenfeld 2008). The allocation of funds and resources for the protection or adaptation of these resources will need to be carefully assessed. Holistic waterfront planning will be essential that approaches response through inter-temporal and phased strategies. It will be important and difficult to balance public goals such as waterfront access, private property issues such as property loss, and conservation goals such as allowing for wetland retreat.

It is still unclear to what extent anthropogenic climate change will affect coastal ecosystems (Mulkey 2007), but, "in most if not all cases, global climate change impacts act in negative synergy with other threats... and can be the factor sending ecosystems over the threshold levels of stability and productivity" (De Guenni et al. 2005). A prominent example where sea level rise may cause major ecological changes is in the Everglades, and the goals of the Everglades restoration project should be carefully examined

Figure 1.1: Inundation caused by a One Meter Sea Level Rise
This map shows the inundation caused by a one meter rise in sea level, and the conflicts caused with Ecological Greenway priority lands.

Map Sources:
Hoctor 2008



with this in mind. The effects of sea level rise on ecosystems in Florida are already being seen in the deaths of Sabal Palm and other trees along the coast between Cedar Key and Homosassa Springs due to saltwater contamination of the soils. Coastal forest loss will probably increase as sea levels rise leaving shorelines more exposed to the effects of storms and erosion (Mulkey 2007). Proactive human intervention will be necessary to minimize ecosystem loss (Hansen 2003). One of the important ways for this to occur is through enabling ecosystem retreat by making lands available and prohibiting coastal protection.

There are several factors that exacerbate the issues caused by sea level rise. One of these is the state subsidization of coastal property insurance. The price associated with state sponsored coverage is below the true cost of the coverage. As a consequence, “owners of high risk properties with significant coastal exposure do not pay the true cost of the risks associated with those properties... and the below market prices associated with developing the coast will lead to overdevelopment of high-risk areas” (Jerry 2008). Overdevelopment and inflated property values in coastal areas will increase the cost of damage from storm events and other effects of sea level rise. This cost is shifted to the general taxpayer base because it is subsidized by the state.

Response to sea level rise can occur through protection, retreat, or accomodation, which allows for the use of vulnerable lands without preventing flooding or inundation (TCRPC 2005). High property values create the likelihood that owners will want to protect their property rather than retreating or accomodating inundation. This is the least ecologically and financially sustainable method of response, and coastal development will only experience increased hazards caused by sea level rise. This will compound the loss of property, insurance cost, and inland property owner tax burdens.

Discussion of how to respond to sea level rise has generally focused on the concept of managed retreat and associated policies. Neal et al. define managed retreat as, “the application of coastal zone management and mitigation tools designed to move existing and planned development out of the path of eroding coastlines and coastal hazards” (Neal et al. 2005, 602). It is essentially moving development out of harm’s way in a planned and controlled manner, and can be used as a proactive method of adapting human development to rising sea levels. This study recommends managed retreat as basis for all responses to sea level rise. Typical discussions on managed retreat do not provide solutions for the inevitable coastal protection that will occur in response to sea level rise, except to discuss ways of disallowing it. It is a reality that protection will occur (Titus 1991, TCRPC 2005). Serious discussion of strategies for protection must be explored that address ecologically and financially sustainable coastal management to the extent possible.

These strategies must also be holistically explored for specific sites from a design and graphic standpoint that includes consideration of sound waterfront design and management principles. The research defined few landscape architectural or architectural projects that realistically address sea level rise in this way. In their January 2008 article in the Harvard Design Magazine, “Design for Rising Sea Levels”, Jonathan Barnett and Kristina Hill write that, “As far as we can tell, most designers and planners aren’t thinking seriously about climate change in the U.S. unless they work closely with the insurance industry, which is dropping tens of thousands of East Coast customers and raising rates on the rest, in part as a result of climate predictions. Ecologists all over the world also know that it’s a very big deal. The World Bank knows. But building and landscape architects, engineers, and planners don’t seem to have connected the dots” (Barnett 2008).

They write that, “While some governments and their engineers are thinking in terms of enormous barriers, some architects have been thinking of altering buildings instead. The Rotterdam Architecture Biennale of 2005 brought together a cross section of architectural ideas in an exhibit specifically on water and cities. Using the past as a point of departure and displaying extreme real-world examples of constructed coastlines such as the Palm Jumeirah in Dubai, the exhibit was in some ways a valuable eye-opener. But when design concepts for dealing with climate change were requested from various practitioners around the world, the proposals that came back were more about shock than strategy. Perhaps that was the intent of the organizers. But the idea that glass-fronted buildings could and should detach from stilt-like supporting piers and float during floods won’t exactly appeal to insurance companies: Under what weather and terrain circumstances would floodwaters come without significant winds, waves, and debris? Architects, engineers, landscape architects, urban designers, and planners owe the public a serious discussion of how to deal concretely with the effects of sea-level rise up to at least 2060, as well as a look beyond to protections that would last until the end of the century” (Barnett 2008).

As stated by Dr. Stephen Mulkey in a 2007 report to the Century Commission for a Sustainable Florida, “Florida has yet to begin developing a portfolio of strategies for adaptation to climate change. While to some extent this depends on acquiring a better understanding of how Florida’s climate may change over the present century, lessons can be learned from cases where past climate change has resulted in changes in natural systems and human economies…Florida could develop a plan for strategic retreat from the coast, and develop proactive adaptive scenarios for preserving critically threatened coastal habitat and human infrastructure” (Mulkey 2007).

The purpose of this study is to explore ecologically and financially sustainable recommendations and strategies for coastal development response to rising sea levels in Florida. The Village of North Palm Beach and the adjacent barrier island form the study area, and retreat, adaptive, and protective response possibilities are examined. The focus is on defining methods of responding to sea inundation with a secondary focus on erosion and storm events, though the three are inextricably linked. Protective and managed retreat strategies are examined for various coastal conditions. Additional tools and information are outlined to inform policy makers including information on policy options, goals and objectives, design guidelines for ‘areas likely to be inundated’, and step by step recommendations for response.

The following section defines the basis for this research and the methodology used. *The overall project goal was to explore ecologically and financially sustainable design strategies for coastal development in response to rising sea levels.* **The bubble diagram in Figure 1.2 outlines the project research approach as well as directions for future research.** The following section will describe the approach that was developed and limitations and assumptions that were used.

Project Setup

Operational Definitions

- Ecological Sustainability: The level to which coastal management strategies support and maintain fully functional natural coastal processes and healthy riparian, littoral, and aquatic ecosystems.

- Financial Sustainability: The ability of governments and private land owners to fund and maintain coastal management strategies without undue financial costs over the life of the project. Undue financial costs could be defined by the value of the coastal management strategy as evaluated against alternative strategies and within the framework of a broader budget.

- High/Low Energy Shoreline: Defined by the amount of wave energy recieved along a shoreline.

- Protection: Shoreline stabilizing or hardening techniques such as seawalls and beach nourishment that attempt to maintain a static shoreline position.

- Accommodation: The use of strategies that allow for land use in areas vulnerable to coastal hazards to continue, but that do not attempt to prevent flooding or inundation using shoreline protection.

- Managed Retreat: Moving development out of the way of coastal hazards in a planned and controlled manner using techniques such as property abandonment, structure relocation, and hazard avoidance.

Assumptions

The project is founded on the assumption that based on scientific evidence sea levels are rising at rates that exceed historic sea level fluctuations. The inundation caused by sea level rise is permanent for all practical purposes and is treated as such in this paper. The necessity of planning, design, and policy actions that address sea level rise in Florida is discussed in Part 1, Study Area Overview.

Sea Level Rise Projections Used

Although accurate projections are not possible and actual changes will vary depending on location, the IPCC 2007 report projects a relative rise of 7 to 23 inches by 2100. However, projections vary, have generally increased over recent years, and are generally agreed to be imprecise. Based on more recent data and analysis, a actual rise could be closer to 36 inches, and this estimate was found in several sources through the course of research (Mulkey 2007: 9). For the purposes of the diagrams and maps in Part 3, a projection of 5 feet in 100 years was used. This was for several reasons including:

- It is slightly higher than most current sea level rise

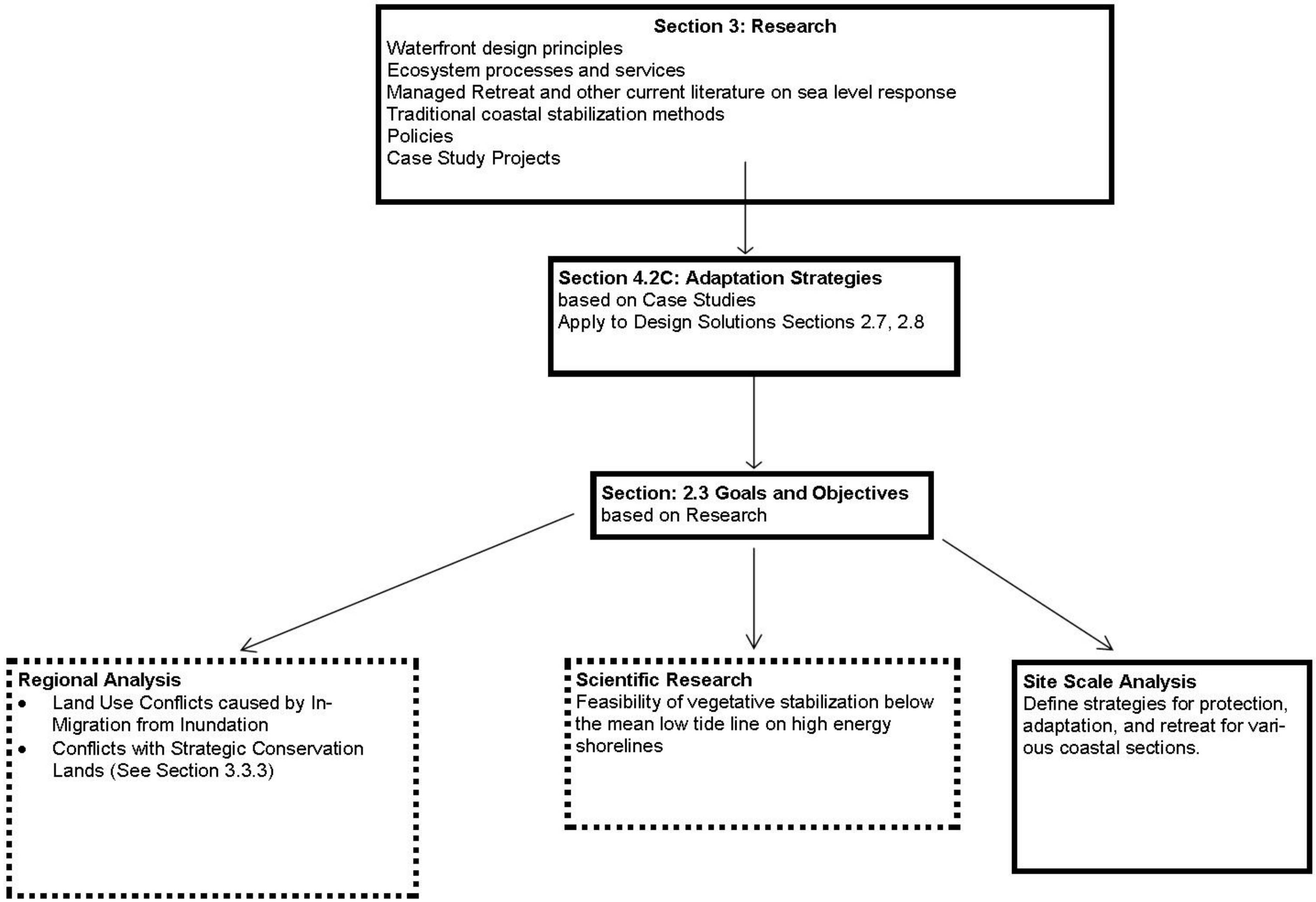


Figure 1.2: Research Process Diagram: Dashed boxes represent areas for potential continuing research

projections, so planning that addresses this level of rise will likely be adequate for lower levels that actually occur.

- A higher sea level rise estimate used for planning purposes can begin to address the effects of erosion, which will cause coastlines to recede in excess of the line established by inundation. This erosion will cause topographic maps to be less precise and reliable without regular revision. Therefore an estimate of 5 feet takes into account the additional intrusion of the sea caused by erosion, as well as the potential inaccuracy of topographic maps (Ellis 2008).
- The Treasure Coast Regional Planning Council sea level rise planning maps consider all land below the 10 foot contour in their studies. These maps were referenced in the conclusions for this paper, and the rational for their project setup was also considered appropriate for this study. This was because: 5’ contour information can be gathered statewide; existing tidal influences can extend almost to the 5’ contour, so the 10 foot contour would be approximately the highest elevation inundated by tides at a sea level rise of several feet thus taking into account long range projections; statewide most land below 5’ is already below the base flood elevation for a 100 year storm and will experience greater flooding due to sea level rise; and topographic contours are not completely accurate (TCRPC 2005).

- Sea level rise is unpredictable and estimates are not precise. Planning for a five foot rise begins to take into account the possibility of ice cap melting, though by no means does it address the full potential of sea level rise from ice melt (Tol 2005).

Project Focus

The research identified several major gaps in the work done on this topic to date, and these issues defined the scope and focus of this project. In a nutshell these gaps are design application and sustainable protection strategies.

- *Research identified few if any solutions to coastline protection from sea level rise that are ecologically and financially sustainable.* Of course there is a long history of engineered responses to coastal hazards. None of these provides an ecologically and financially sustainable solution to sea level rise inundation. However, there may exist other innovative solutions that can be adapted to respond to sea level rise, but due to time constraints these were not found.

- *Research identified few projects that address inundation due to sea level rise, in particular from a design point of view.* None of these projects are in Florida. There are projects that consider periodic flooding, which is not the same as designing solutions for permanent inundation. Information was also found to be lacking on design guidelines and direction for specific community action and use.

- *Graphic Illustration*: Proposed responses to sea level rise such as managed retreat are often presented in scholarly papers. Research indicates that these ideas have not been graphically illustrated and applied to a specific site, at least not within a publication that is readily available. This is particularly true in Florida.

It was determined that development responses to coastal hazards can be broken down into three basic categories: protection, accommodation, and retreat as defined above. *Based on these* *findings and the gaps in research to date, the following necessary products and recommendations were identified.*

Natural Coastal Condition

		Mangrove Swamp		Coastal Strand	Wetland	Inlet
		high % slope	low % slope			
Developed Condition	**Urban**					
	H Density			Fig 3.7, 3.12		
	M Density		Fig 3.10-11	Fig 3.7, 3.12	Fig 3.10-11	
	L Density			Fig 3.7, 3.12		
	Ag					
	Conservation		Fig 3.13		Fig 3.13	

Figure 1.3: Shoreline Types Matrix: This matrix identifies unique shoreline types each requiring a different approach towards adaptation. This matrix is by no means complete, but illustrates a basic process for identifying necessary strategies for adaptation.

	High Energy Shoreline	Low Energy Shoreline
Developed	Fig 3.7, 3.12	Fig 3.8-3.13
Undeveloped	Fig 3.7, 3.12	Fig 3.8-3.13

Figure 1.4: This matrix was developed from Figure 1.3 to identify in broader categories the major shoreline types requiring different methods of response.

- *It was determined that the primary project focus should be on identifying ecologically and financially sustainable solutions for coastline response to sea level rise and that all design solutions should be linked to policy solutions where possible.*

- It was determined that protective responses would receive additional focus and be graphically explored for a specific study area. This is not because these responses are necessarily appropriate but because they are inevitable. This research is included in Part 3, Protection.

- It was determined that a managed retreat strategy would be graphically explored for a specific study area from a design standpoint. This is because managed retreat is probably the best long-term response and has not to my knowledge been addressed in this manner for Florida. This is included in Part 3, Managed Retreat.

- It was determined that general design guidelines would be identified. This is because sea level rise response has not been addressed from a design point of view, particularly in a manner that can be used and adopted by communities in Florida. This is included in Part 3, Accommodation.

To this end, shoreline protection strategies are examined for various coastal conditions and a managed retreat strategy is diagrammed for a low energy coastline. Additional tools and information are outlined for the use of policy makers including information on policy options, goals and objectives, design guidelines for ‘areas likely to be inundated’, and step-by-step recommendations for response.

Limitations

The project scope was necessarily limited with regards to the effects of sea level rise. *The project focus was primarily on seawater inundation resulting from a relative rise in sea level*. *Possible related scenarios such as barrier island breaches and the effects from increased storm surge were not the focus.* Sea level rise will have many inland effects including erosion, inland seawater inundation, and saltwater intrusion into fresh water bodies, and causes, effects, and necessary responses to these are inextricably linked. The associated hazards of erosion and storms received secondary focus. This is for the following reasons:

- Erosion estimates are difficult, imprecise, and accurate estimates were not located for the study area. Erosion is also inextricably linked to seawater inundation and both can be considered with similar land planning measures.

- With regard to saltwater intrusion into freshwater bodies, inland seawater inundation has more obvious land use planning implications than saltwater intrusion. Though both are important issues, the focus of this paper was on planning and design issues and the choice was made to focus on seawater inundation.

- With regard to increased storm surge, time was not allocated to identify changes in storm surge caused by sea level rise, and such predictions may not exist. This is an important issue that should recieve focus, but due to time constraints, recieved secondary focus in this study.

Choice of Study Area

North Palm Beach was chosen as a study area. The study area also contains some areas outside and to the south of the Village of North Palm Beach, but the majority of the study area lies within the Village boundaries. The reasons for this choice are:

- North Palm Beach is an area that the author is familiar with, and therefore was able to make more informed recommendations. Time constraints also limited the practicality of an extensive site analysis in an area with which the author was not familiar.

- It possesses a variety of shoreline types including low energy developed coasts, low energy undeveloped coasts, high energy undeveloped coastlines, and high energy developed coastlines on the barrier islands. These basic categories of shoreline types are illustrated in Figures 1.3 and 1.4.

Research Methodology

Preliminary research was conducted on waterfront design principles, coastal ecosystems and processes, traditional engineering and development responses to coastal hazards, and managed retreat as a response to coastal hazards. Further research was then undertaken to locate real world or design projects (case study projects) addressing sea level rise and policy options for response.

Research on waterfront design principles was used to inform the illustrative managed retreat and protective response strategies. Principles were compiled from a variety of sources, commonalities were searched for, and these were combined into a composite list. There is no need to reinvent the wheel in this research; research on principles already defined by other cities and organizations as well as through consultation with planners and policy advisors was used to form these principles. This said, these principles are by no means all inclusive or completely applicable to all communities, and each community will have different issues and solutions for their waterfront. The implementation of managed retreat will increase the necessity for sound and holistic waterfront planning and design. New waterfronts will constantly be created and evolving over time due to new mean high water levels and shifting coastlines, and the development or non-development of these coastlines should be planned. Design principles such as public access and allowance for water-dependent uses will be more important than ever.

Coastal ecosystems and processes research was necessary for an understanding of the dynamics affecting coastal development, ecosystems, and their response to sea level rise. An attempt was made to focus on the responses of ecosystems to sea level rise and associated ecosystem services with the idea that these processes could inform development response strategies. The research showed that geographic and vegetative differences in coastlines would cause each coastline to respond differently to sea level rise, even between two coastlines that are seemingly identical. These variations create the necessity for varying human responses as well. The tables in Figures 1.3 and 1.4 were formed to help understand what land uses located in varying coastal conditions needed to be addressed. This may be adapted for individual use.

The research on traditional engineering and development responses focused on the pros and cons of these approaches. This research informed the writing of design guidelines for ‘‘areas likely to be inundated’’ and the analysis of protective responses.

Managed retreat as a response to sea level rise was researched. Particular focus was placed on identifying issues associated with its implementation. While the scope of this research could not allow complete analysis of solutions to these issues, some solutions and ideas are presented.

Research on policy options focused on addressing the issues associated with managed retreat. There are several options that can be used to address these issues, but based on the research, rolling easements as discussed in Part 4, Rolling Easements seem to be one of the most suitable options. Minimal focus was placed on inventing new public policies related to sea level rise because more qualified researchers have already investigated this topic. However, it was determined that graphic design application of these policies is lacking. It was also determined that recommendations should be made for an overall policy approach and that this approach should inform the strategies and recommendations in Part 3. The resulting design strategies reference or are linked to policy options.

Case study research was focused on projects that specifically address sea level rise. These are few, but particular focus was placed on identifying strategies to respond to seawater inundation. Projects that address erosion control and periodic inundation are also included with a brief commentary on potential issues or interesting solutions. These case study projects are included in Part 4, Appendix E.

Strategies and Recommendations Methodology

Focus and Considerations

The previously described research informed the recommendations and strategies included in Part 3. The following section describes the guiding considerations and overall focus of the strategies and recommendations in Part 3.

• The primary goal of all recommendations and strategies was to address financially and ecologically sustainable coastal management solutions. Potentially unsustainable elements of the recommendations and strategies are identified. Solutions that are primarily unsustainable are immediately discounted. The research identified financial and ecological sustainability as the primary challenges of traditional engineering responses to sea level rise.

• The focus of the recommendations and strategies was on solutions to sea level rise that can be functional and sustainable over the long and short term. Project phasing and adaptation were important components of the recommendations formed. Natural succession of plant and animal communities were part of this consideration.

• Research focus was placed on adaptable strategies that use natural or ecological systems to mitigate rising sea levels, and endeavor to maintain functional riparian and littoral zones, in part through the use of living shoreline principles. These include maintaining connections between riparian, intertidal and aquatic areas and endeavoring to maintain natural processes including tidal exchange, sediment flows, plant community transitions and groundwater flow. This approach is in contrast to traditional protective strategies such as sea walls and groins that will likely be ecologically and financially unsustainable in the face of sea level rise.

• Responses to sea level rise can be broken down into three main categories: protection, accommodation/adaptation, and retreat. The focus of the solutions developed was on protection and retreat. Accommodation or adaptive responses were assumed to be essential parts of either protection or retreat and were incorporated into all solutions. Accommodation was addressed primarily in the design guidelines in Part 3, Accommodation. Protective and managed retreat responses were diagrammed for North Palm Beach. With regard to protective responses, three primary coastal sections were examined: high energy/open coast shorelines such as barrier islands like Singer Island, low energy/sheltered coastlines such as along the Intracoastal Waterway, and wetland protection such as for the estuaries of MacArthur Beach State Park. As described in these sections, protection of conservation lands through hard or soft devices is not recommended, however there may be situations where this is appropriate.

• The concept of managed retreat has been chosen as a basis for all design recommendations where possible. There are a variety of ways that human development has traditionally responded to coastal hazards and changes including hard stabilization structures such as seawalls, soft stabilization methods such as beach renourishment, abandonment and rebuilding, and retreat. Managed retreat is essentially the process of moving development out of harm's way (away from areas of sea water intrusion) in a planned and controlled manner, and can be used as a proactive method of adapting human development to rising sea levels. Practically there are many reasons for using managed retreat as a basis for design and planning responses to sea level rise. These include less vulnerability to hazards over the long run, continuation of natural shoreline processes and beach preservation, and lower overall cost (Neal et. al. 2005). There may however be situations where managed retreat is not entirely feasible or desirable. In these situations other design strategies will be necessary.

• A final consideration in this document is that the perception of sea level rise as something by definition negative and detrimental to human society and natural systems needs to be reexamined. Sea level rise is inevitable and must be addressed as a process of change over time that requires response and adaptation with many costs but also some benefits. To achieve the most positive outcomes, these benefits must be creatively sought.

***Limitations*.**

The following section describes limitations placed on the scope of the recommendations and strategies. There are a variety of ways that development can respond to sea level rise that were not explored in this research.

Strategies that were not ecologically or financially sustainable were immediately discounted.

• One of these strategies deemed to be unsustainable is the possibility of building a lock across the Palm Beach and Jupiter Inlets converting the Lake Worth Lagoon into an inland water body. Regulated tidal exchange strategies could be used to maintain a level of tidal fluctuation. However, it is possible that the valuable estuaries and ecosystems within the lagoon would be eliminated because of limited tidal exchange and changes in salinity. The construction and maintenance of such locks would also be very expensive, and would not mitigate risks borne by barrier island development. Barrier island erosion and the potential for breach would still exist. If such a breach were to occur, the lock would be ineffective, and damage to coastal development would be very high if not already prepared for the possibility of a breach or higher waters.

• Adaptive strategies that are not part of an greater managed retreat plan were not explored because they are generally deemed to be financially and ecologically unsustainable. An example is allowing barrier island high rise development to remain, but discontinuing habitation of lower floors, and converting lower floor use to adaptable uses such as for parking. Such a strategy would have negative ecological effects if coastal protection is continued (as would be necessary to protect the foundations of the building). This strategy would ultimately place the building occupants at greater levels of risk, and the financial burden placed on the property owner would probably be great (adaptation of utilities, loss of revenue from rentable floor space, protection of the building shoreline erosion and storms). Another strategy not addressed because of its ecological and financial implications was raising of land through fill in order to elevated lands above sea level. This could be finanically feasible for a small site, but would be impractical at a large scale due to the amount of fill required. It would be difficult and expensive to adapt existing construction to a raise in elevation. Its ecological impacts would include covering terrestrial ecosystems with fill, which would likely kill many of the existing species, effects on the region where the sediment is taken, and interruption of drainage patterns.

• The focus of this study was on adaptation to inundation caused by sea level rise. Related considerations such as erosion, the effects of storms, and saltwater intrusion were considered but did not recieve primary focus. Major ecological or geological changes that could occur due to sea level rise were researched, but did not factor heavily into the strategies for adaptation. The difficulty of predicting these scenarios, the resulting difficulty of making a comprehensive study of them, and time constraints did not enable study and prediction of these possible scenarios. One of these scenarios is the possibility of a barrier island breach at MacArthur Beach State Park. If a breach were to occur, it could be allowed to remain in the State Park, but evacuation routes and particularly SR A1A would be repaired and protected (TCRPC 2005). This probabilty should be studied as it would change the ecology of the Lake Worth Cove, and would affect development response to sea level rise. For example, the protective strategies for low energy shorelines discussed in Part 3 may or may not be suitable for use in the Lake Worth Lagoon in the event of a barrier island breach. The change in wave energy affecting the shoreline would be a primary factor in this determination.

• It was not within the scope or ability of this research to conclusively recommend species suitable for ecosystem reestablishment. These recommendations should be made by shoreline ecologists and other researchers. However, some species are described within the recommendations and strategies based on research indicating their suitability.

Mapping and Diagramming Methodolgy

GIS and Adobe applications were used for producing the maps contained in this section. Topographic information was based on statewide topographic data , which is in five foot increments. Additional site information was based on GIS land use and land cover datasets as well as on-site data gathering. Maps produced by the Treasure Coast Regional Planning Council (Figure 1.8) provided a basis for assumptions of probable shoreline management responses. This information was used in Figure 3.5, which diagrams protection and adaptation potential for the study area. The tidal data for the site that was applied to many of the diagrams was gathered through on-site measurement and affirmed through research on tidal fluctuation data for the study area (Myers 1990, NOAA 2008). On-site measurement was essential in order to ascertain low and high tide levels relative to existing seawalls in the study area before shoreline diagrams could be made. These measurements were taken at 11:00 low tide on March 3, 2008. Tidal fluctuations are taken into account in all diagrams, with the exception of maps defining the study area because of the scale and less necessity. None of the maps incorporate erosion because accurate estimates were not located, particularly for the study area region. The use of a five foot sea level rise for mapping studies is slightly higher than most sea level rise projections, so can begin to address the additional level of shoreline retreat that might occur due to erosion. The recommendations and notes contained in the diagrams were produced through design and analysis based on considerable research. These recommendations have been loosely confirmed through consultation with a variety of researchers in the field, but should by no means be considered scientifically accurate or relied upon without additional research and consultation. An attempt was made to delineate between facts verified through other research and those determined through this research.

Integration of Ecological Sustainability

Ecological sustainability was integrated within the recommendations and strategies in Part 3 using principles of living shoreline restoration. In short, these are to maintain functional natural processes, and to support healthy coastal ecosystems. Natural processes that were considered include sediment flows, tidal exchange, and plant community transitions. Support of healthy ecosystems was considered in terms of both ecosystem restoration and management of existing ecosystems. The following discusses the integration of these components in terms of the three methods of response described in this paper: retreat, protection, and accomodation.

Retreat

Managed retreat is potentially the most ecologically sustainable method of response to sea level rise because it allows natural processes and ecosystem responses to sea level rise to take place unimpeded. The key elements that will allow this to happen are as follows, and these elements are incorporated in the recommendations and strategies discussing managed retreat in Part 3.

Shoreline protection policies must be discontinued, and development should adopt a policy of gradual retreat from the coast in keeping with sea level rise and coastal erosion. This can be implemented through rolling easement policies, and has already been addressed most notably in Texas through the Texas Open Beaches Act. These policies are assumed to be in place in the managed retreat strategies discussed in Part 3.

Additional components of ecologically sustainable managed retreat are addressed in Part 3. Of these, several of the primary recommendations are as follows. Certain lands would be zoned “Likely to be Inundated”, based on sea level rise and storm surge projections. The regulations within these lands would allow for creation and migration of an alongshore buffer for proactive ecosystem management, adaptation, and retreat. This buffer would allow for natural shoreline migration to occur while decreasing hazards to coastal development. Ecosystem and shoreline restoration would occur within this area where natural shorelines do not exist. Best management practices would have to be developed for the removal and reuse of structures inundated by shoreline retreat to mitigate ecological and other hazards. These and other policies are discussed in Part 3 and are important parts of ecologically sustainable managed retreat.

Protection

Shoreline protection is the least ecologically sustainable method of response to sea level rise. Since protective strategies were a primary focus of this study, methods were considered for minimizing their negative effects on coastal ecology but still allowing for shoreline protection from sea level rise. Some of the primary components of these strategies are as follows.

<u>Maintaining Functional Natural Processes</u>
None of the strategies proposed involves hard stabilization methods using materials such as concrete, rubble, or sandbags. This approach precluded the proposal of breakwaters, offshore barriers, seawalls, groins, sills, or dikes, particularly directly adjacent to the shoreline. In addition to a variety of financial and hazard related issues, hard stabilization causes beach loss and alters sedimentation patterns, so these methods were not proposed. Offshore shoreline protection was also avoided because its interference with sediment and tidal flows, affecting tidal ecosystems.

Maintaining Healthy Ecosystems

The maintenance of healthy ecosystems was approached in three ways: the maintenance of functional natural processes as described above, ecosystem reestablishment along developed shorelines, and existing ecosystem management through allowance for ecosystem retreat.

Ecosystem reestablishment and restoration were investigated for all protective strategies as methods of stabilizing shorelines and protecting development. It was determined that the feasibility of these methods varies depending on coastal conditions. Restoration of functional ecosystems is very difficult (Hansen 2003), but was set as a goal for shoreline protection strategies where possible to increase the level of ecological sustainability. The approach to this was as follows.

Only species that would occur in the study area naturally were examined for reestablishment. More in-depth research as to appropriate species for reestablishment needs to be conducted, as a variety of variables must be considered due to changes in shoreline conditions caused by sea level rise. This research was not possible due to time constraints and for this reason, recommendation of specific species is minimized. It was however possible to make general assumptions based on the existing natural communities in the area.

The natural shoreline conditions in which species native to the study area thrive were considered including shoreline gradient, tidal and salinity influx, and wave energy and erosion. An attempt was made to maintain these conditions within the strategies proposed, though this is by no means completely possible.

Plant community succession was assumed to occur over time in response to sea level rise, and this would hopefully occur in tandem with upland ecosystem retreat. Ecosystem retreat and succession are considered on a large scale in the managed retreat strategy with the proposal of an alongshore buffer and design guidelines for development and use of lands "Likely to be Inundated". These two elements are important in allowing ecosystems to retreat and succession to occur without total elimination of upland ecosystems. The consideration of succession and retreat are diagrammed on a smaller scale in the protection strategies in the strategies for protection of existing developed low energy shorelines (Figures 3.10-3.11). This strategy proposes the reestablishment of shoreline ecosystems along the protected shoreline and for the gradual removal of the hard protective structures (sea walls in this example). While maintaining the existing shoreline position, ecosystem retreat is allowed by beginning ecosystem reestablishment seaward of the line of protection. Land is created between the revegetated line and the line of protection through artificial fill (where sediment supply is low). Fill is added in keeping with the rate of sea level rise, allowing the established vegetation to retreat upland and inland, lowland succession to occur, and maintaining a vegetated riparian edge. This strategy also has a variety of pitfalls, which are discussed in Part 3.

Accommodation

Accommodation is addressed through design guidelines for 'areas likely to be inundated'. Maintenance of healthy ecosystems and functional natural processes is approached in much the same way as described above for protection and managed retreat. The guidelines are however founded on the principle of managed retreat and do not recommend protection. New construction is not recommended in areas where inundation is likely unless it can accomodate sea level rise in an ecologically and financially sustainable manner. Options that increase the ecological sustainability of land use in these areas include construction of relocation friendly buildings, non-permanent structures and land uses, or land uses that evolve as sea level rises. Accommodation does not imply permanent land use unless these uses allow natural shoreline processes to continue. It is through this approach that the adaptive methods discussed in Part 3 address ecological sustainability.

Integration of Financial Sustainability

There are many levels at which shoreline management strategies can be analyzed for their financial sustainability, but in this study, ecological aspects received greater focus than did financial aspects of coastal management. The following summarizes the financial considerations that were taken into account in the retreat, protection, and accommodation strategies included in this study.

Managed Retreat

The financial sustainability of retreat is compared to that of protection, and it is determined that over the long term, retreat will generally cost less than protection (Coburn 2004, Titus 1991). Within the proposed recommendations and strategies limitation of public investment in coastal zone development is briefly noted. The role of insurance policies in discouraging retreat is also noted. These issues are directly related to the financial sustainability of coastal development patterns.

Protection

One of the most important cost considerations when protecting development from sea level rise is the long term public and private costs that will be incurred from increases in coastal hazards. This cost is addressed in this paper but not integrated within the strategies for protection in Section Three. These strategies were based on the assumption that protection is occurring, regardless of potential costs from coastal hazards. The focus of the protective strategies in this paper is on the financial costs of the direct costs of strategy itself, not the overall regional and statewide financial implications.

In protective strategies, the primary considerations with relation to financial sustainability were the costs of constructing and maintaining a coastal protection structure. For example, several of the strategies proposed require artificial fill, which could be prohibitively expensive in terms of the amount required to protect long distances of shoreline. Therefore, the costs of any of the protective strategies in this study would have to be compared against the value of the resource being protected.

The use of ecosystem restoration as part of shoreline protection strategies was considered to have potential financial value. This would be true if ecosystems are able to adapt to sea level rise with minimal human intervention while still providing protective services.

Accommodation

The financial sustainability of accommodation is not directly addressed, but is considered in the design guidelines proposed for ‘areas likely to be inundated’. Land use practices are recommended that are either non-permanent, or are able to accommodate inundation. These practices will minimize the costs of repairing and protecting coastal development.

Characteristics of Study Area and Typical Coastal Ecology

The study area is located in northern Palm Beach County and the jurisdictions falling within this area are the Village of North Palm Beach and Palm Beach Shores, the latter of which is located on the barrier island. The development within the region consists primarily of single family residential, condominium, and commercial development of relatively high economic value. The exception to this is John D. MacArthur State Park, a conservation area of approximately 437 acres. The primary transportation corridors within the study area are US Hwy 1 and A1A. The mainland coastline within the study area is sheltered by a barrier island system, and within the study area this is called Singer Island. The shoreline of this barrier island consists of a sandy beach and a primary dune with tropical maritime forests occurring on the backdune where it is not developed. To the west of Singer Island is the 20 mile long Lake Worth Lagoon a valuable recreational amenity that contains highly productive estuaries. The Lake Worth Lagoon is connected to the Indian River Lagoon to the north by the Atlantic Intracoastal Waterway, an inland navigation channel traversing the east coast of Florida. The Jupiter Inlet and Palm Beach inlets are to the north and south outside of the study area. To the west outside of the study area and parallel to the Lake Worth Lagoon is the Atlantic coastal ridge. This represents an ancient line of dunes, formed 100,000 years ago when the sea was 30 feet higher, and is composed of well-drained sandy soils. (TCRPC 2005) The highest elevation within the limits of the study area, which are drawn just west of the Lake Worth Lagoon and US Hwy 1, is approximately 20 feet.

Longshore sediment flow along the Atlantic Coast of Florida and within this region is north to south. Precise understanding of sedimentation and erosional processes within this area is difficult due to the substantial shoreline alterations and protections that have occurred (Thieke 2008). The Atlantic coast within the study area is considered a high energy shoreline, while the coasts within the Lake Worth Lagoon could be considered low energy shorelines.

In North Palm Beach, much of the low energy mainland shoreline bordering the Intracoastal Waterway consists of seawalls with some small areas where natural shorelines exist. With the exception of John D MacArthur State Park, there are few large contiguous lands containing natural communities and shorelines in coastal Palm Beach County. The park is within the study area and adjacent to North Palm Beach. It contains both high and low energy shorelines, and was used as a model of what would likely be the natural condition of the developed shorelines within the study area. For these reasons, this area provides a suitable basis for an understanding of the ecology of the lagoon and barrier island that compose most of the study area.

John D. MacArthur State Park is located on Singer Island, the barrier island sheltering North Palm Beach, and includes the beach and dunes, bayside estuary, and islands. The park includes almost 2 miles of sandy beaches and dunes populated by dune species including Railroad Vine and Bay Bean, which stabilize the beach after a storm so that other species such as Sea Oats can grow. Sea grapes grow behind the Sea Oats further up and on the backside of the dune.

The backdune includes an intermittent strip of tropical maritime hammock. Mature tropical maritime hammock occurs further inland within the park on the strip of land between Lake Worth Cove and A1A. Some of the species occurring within these hammocks are Gumbo Limbo, Cabbage Palm, Mastic, Strangler Fig, and Live Oak (MacArthur Plants 2008). These forests

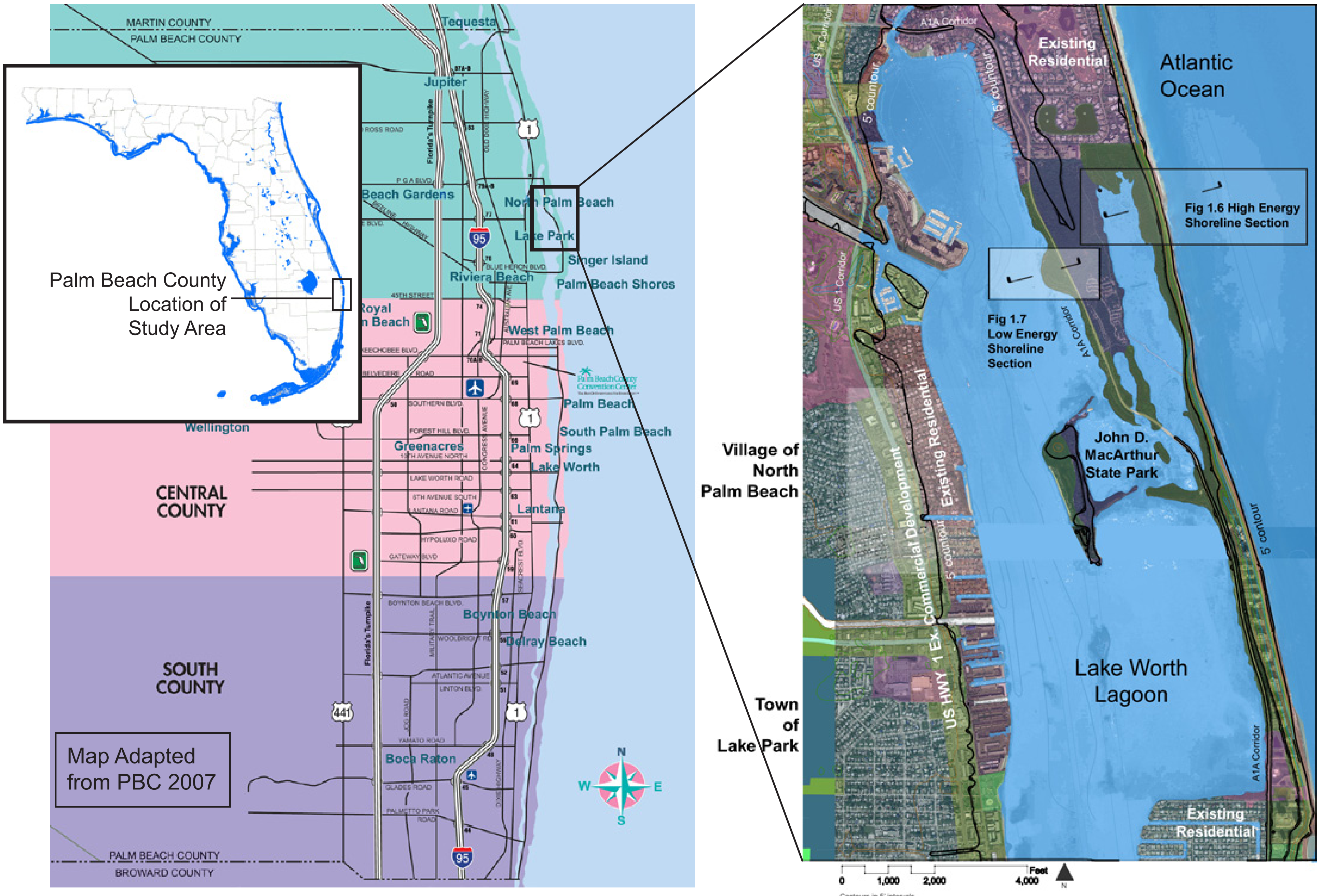


Figure 1.5: Location of Study Area
Sources: PBC 2007, gap_lcov 2000, TOPO 1997, LABINS 2008

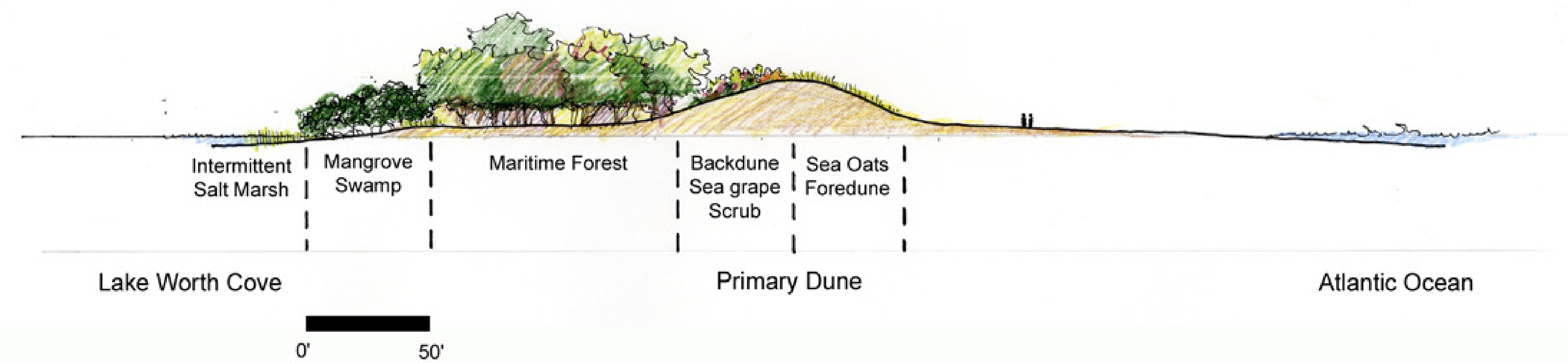


Figure 1.6: Section through Existing High Energy Shoreline Ecosystems: This is a section cut through the barrier island at MacArthur Beach State Park. ***Map Sources***: McHarg 1967, MacArthur 2008, Meyers 1990, **TOPO 1997**

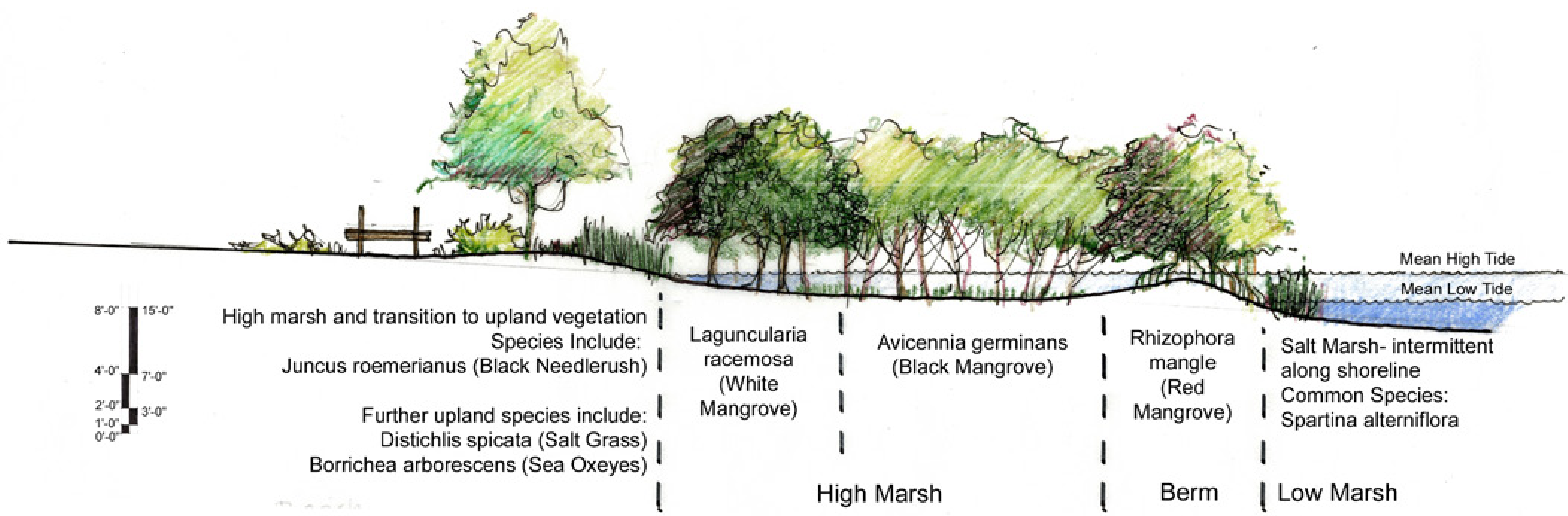


Figure 1.7: Section through Existing Low Energy Shoreline Ecosystems
Map Sources: MacArthur 2008, Myers 1990

constitute the northernmost extant remaining of tropical forest growing on a sandy substrate (Myers 1990). Mangroves and saltwater marshes border the estuaries within Lake Worth Cove and the Intracoastal Waterway. Patches of seagrass occur in many locations throughout the estuaries (gap_lcov 2000) (seagrs_2003 2003). The tide fluctuates such that mudflats are exposed in some of these estuaries at low tide.

Effects of Sea Level Rise

The following section discusses sea level rise in terms of its specific effects on the study area. It is important to recognize that sea level rise is unpredictable and could change drastically due to sudden changes in the global environment. Even moderate amounts of sea level rise will begin to have effects on coastal ecosystems and development.

The amount of sea level rise that is projected to occur in various regions throughout the world varies, and there are some locations where sea levels are actually projected to decrease. Within Florida, a rise of 36 inches by 2100 is feasible (Mulkey 2007), and a rise of 60 inches was used for the analysis in this study (TCRPC 2005). The relative sea level rise per century for the study area has been about 28 cm (Myers 1990) and has occured at about 2-3 mm per year. For comparison, mangroves are able to accrete sediment at about 1.5-2 mm per year (Clark 2008) and may be flooded if sea level rise rates increase. Depending on the shoreline gradient, a 1 foot rise in sea level can cause a shoreline retreat of 1000 feet or more (Bush et al. 2004). The study area has the greatest percent probability for the entire Atlantic and Gulf Coasts for hurricane occurance, and a 100 year storm surge projection of 7.7 feet (Bush et al. 2004). The tidal range for the study area is about three feet (Myers 1990). Storm surge, tidal range, and sea level rise should all be taken into account when defining 'areas likely to be inundated' within the study area.

In a report by the Treasure Coast Regional Planning Council (TCRPC), "Sea Level Rise in the Treasure Coast Region", the gravity of the effects of sea level rise on Florida are summarized as, "the prospect of sea level rise is of particular concern to the State of Florida because of its expansive coastline, low elevations and flat topography, economic dependence of the tourism industry on beaches and coastal resources, and significant public and private investment in coastal areas. The 2004 population estimates indicate that Florida has about 17.5 million residents and the majority of these people live and work near coastal areas. The ramifications of sea level rise in Florida could be far reaching. In areas with a gently sloping shoreline the horizontal advance of the sea can be 150 to 200 times the vertical rise. This can cause increased erosion, flooding, and raise the frequency and severity of storm surges. Additionally, rising sea levels can contaminate freshwater supplies by causing saltwater intrusion into river systems, canals, groundwater aquifers, and low lying coastal wetlands such as the Everglades ecosystem" (TCRPC 2005).

The following is an excerpt from the House of Representatives Select Committee on Energy Independence and Global Warming site on the effects of sea level rise in Florida.

"By 2100, sea levels along Florida's coast could rise as much as 20 inches; possibly even more if the Greenland or West Antarctica ice sheets break up more rapidly than predicted. It is estimated that a rise in sea level of 12 inches would flood coastal real estate 100 to 1000 feet inland, devastating coastal populations and economies".

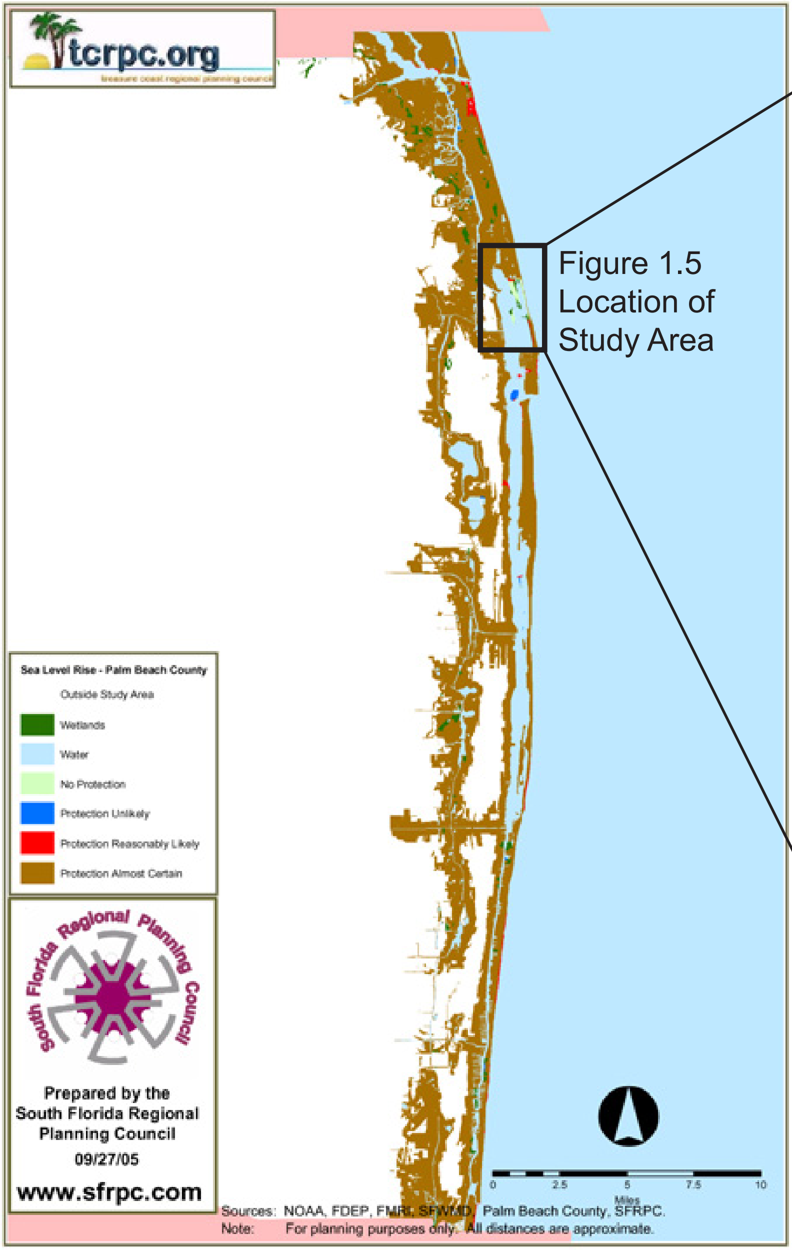
"Sea-level rise also puts a tremendous strain on Florida's ecosystems. Rising sea level threatens the beaches, wetlands, and mangrove forests that surround the state. Some of the small islands of the Florida Keys could completely disappear due to rising sea levels. Inland ecosystems will also suffer as salt water intrusion into the Everglades or up rivers impacts freshwater plants and animals. Critical habitats for fish and birds, as well as endangered species like the key deer, American alligator and Florida panther, will be severely reduced and could disappear altogether".

"America's biggest living coral reef, a popular tourist attraction, is found in the Florida Keys. Florida's coral reefs are already experiencing bleaching - a potentially irreversible process - due to environmental stresses, including warmer ocean temperatures. Additionally, carbon dioxide absorbed by the ocean from the atmosphere alters the chemical balance of sea water, threatening coral health".

"All of these changes pose devastating consequences to Florida's economy. Areas facing inundation from climate change attract 4 million tourists a year, who generate $3.4 billion a year for the state. Rising sea levels could destroy the beaches that bring in $15 billion of revenue a year. A decreasing wildlife population could threaten the $6.2 billion hunting, fishing and wildlife viewing industry that employs over 120,000 Floridians. In addition, more intense hurricanes could spell economic disaster for Florida". (House Energy Committee 2008)

The EPA has initiated a nationwide program promoting planning for and awareness of sea level rise. In 2000 the Southwest Florida Regional Planning Council received an EPA grant to coordinate the study of sea level rise throughout the state and in 2002 contracted the TCRPC to conduct a study within the Treasure Coast Region. The TCRPC produced the above referenced report, similar to those produced by other regional planning councils, which creates maps of the Treasure Coast Region distinguishing shores likely to be protected from sea level rise from those shores unlikely to be protected where natural shoreline retreat will probably occur. These designations were made based on strict criteria and with the input of local planners, but are by no means public policy. The study area for these maps is everything below the 10 foot contour or within 1000 feet of the shore. The map projecting responses in Palm Beach County is shown in Figure 1.8.

Palm Beach County does not currently have policies that specifically deal with sea level rise, but these will be considered in the next comprehensive plan update in 2009. The maps created by the TCRPC confirm determinations made in this study by designating most of the North Palm Beach study area as "Protection Almost Certain". MacArthur Beach State Park, which is located on the barrier island east of North Palm Beach, is an exception to this and is designated as receiving no protection. This is because it is projected that management of publicly owned conservation areas will allow natural responses to sea level rise. The report states that it would be possible for the barrier island to be breached at this point without interrupting travel on SR A1A, which runs on the west side of the barrier island, but that SR A1A would be protected as necessary. One method of protecting travel on SR A1A would be to elevate the road, allowing tidal movement beneath it, and increasing protection from flooding. Local planners also state that roads necessary for hurricane evacuation on the barrier islands would be repaired. The report states that the adequacy of flood control structures in the canals in the area should be evaluated. Further information on the effects of sea level rise on Palm Beach County and the Treasure Coast Region outside of the study area can be gained from this report. (TCRPC 2005)



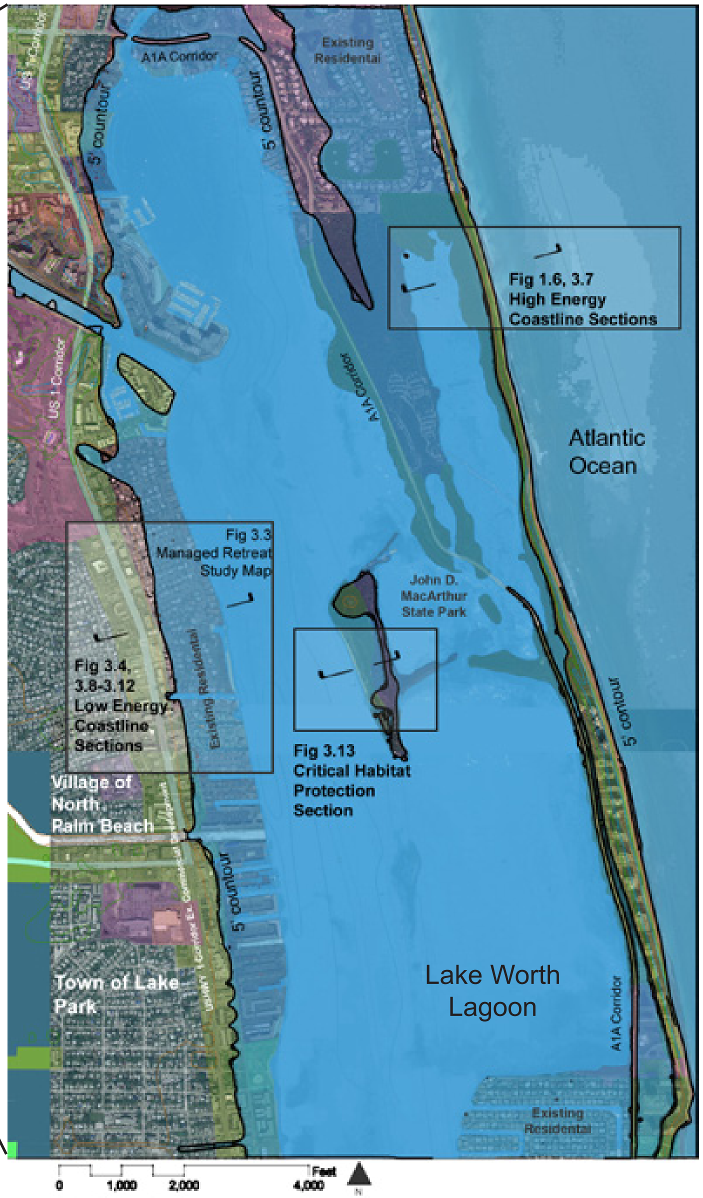


Figure 1.9: Inundation Caused by Five Feet of Inundation
Map Sources: gap_lcov 2000, TOPO 1997, LABINS 2008

Figure 1.8: Anticipated Response to Five Feet of Sea Level Rise in Palm Beach County (TCRPC 2005)

PART TWO: RESEARCH SUMMARY

The following section includes a summary and excerpts from the research sections in Part 4, Appendices and is included for ease of reference.

Florida Coastal Ecology

Ecosystem Services with Potential to Mitigate the Effects of Sea Level Rise

The purpose of this research is to describe ecosystem services that may aid in either flood attenuation, mitigation of the intrusive and erosive effects of sea level rise, or to minimize the destructive effects of storm surge. This serves several purposes. The first is to underscore the importance of coastal ecosystems to people living in Florida and that active human involvement in the preservation and adaptation of these ecosystems in the face of sea level rise must be a priority. This however is not the primary focus as the values and intricacies of ecosystem services are discussed in far greater depth in other publications. The second and more important purpose for discussion of ecosystem services is based on the idea that an understanding of the ways ecosystems respond to coastal hazards can inform human design responses to these hazards. This can be manifested in use of the ecosystem itself as part of a design response to sea level rise or through use of the underlying principles of the ecosystem service reinterpreted through design.

The conclusions of this research are that preservation of coastal ecosystems is important to maintain essential regulatory ecosystem services such as sediment collection and wave energy reduction. It is also hypothesized based on this and other research that attempts to replicate these services through designed and engineered artificial structures could be an unwise approach to coastal shoreline management. This is because engineered shoreline stabilization and protection structures frequently fail to function, are often financially unsustainable, create an incentive for development within hazard zones, and generally have negative ecological side effects.

It was also concluded that carbon sequestration services may become a particularly important part of ecosystem valuation and preservation through value added in the carbon offset market.

Adaptation of Florida Coastal Ecosystems to Sea Level Rise

This research focuses on the effects of sea level rise on ecosystems and their ability to adapt. The overall ability of ecosystems to adapt and recover is discussed, followed by description of the ability of specific ecosystems to adapt to sea level rise. This is followed by research on strategies for ecosystem adaptation. The focus of this research is on land based or near shore ecosystems.

It was concluded that though it is uncertain to what extent sea level rise will affect ecosystems, it is likely that degradation and overall loss of coastal ecosystems will occur. The ability for ecosystems to recover and persist will depend on their ability to make permanent structural or functional changes, either by relocating or by adapting. The ability for ecosystems to adapt to projected sea level rise will be hindered by two primary factors: coastal development that limits the ability for ecosystems to retreat inland, and greater than historic rates of climate change and sea level rise, which exceed abilities for ecosystems to accrete sediment, retreat, or otherwise adapt.

Strategies for ecosystem adaptation are discussed including facilitation of ecosystem retreat, alongshore easements, and construction of living shorelines. The research concluded that proactive human planning and intervention will be necessary to facilitate ecosystem adaptation. One way of assisting in ecosystem adaptation to sea level rise is through facilitation of ecosystem retreat. Ecosystem retreat could be defined as the upland or landward shift of ecosystems (in response to sea level rise). A primary component of this is prohibition of shoreline protection and hardening structures. Another component is setting aside uplands for lower elevation ecosystems to retreat to.

Alongshore easements are one method of setting aside land for ecosystem retreat, adaptation, and management. The depth of this area would vary according to location. In addition to being an area for ecosystem management, it would also function as a buffer between development and the sea, reducing the impact of coastal hazards, and could be held in public trust as parkland or reserved for water dependent uses. With the exception of strategies to aid in ecosystem adaptation, coastal hardening would be prohibited in these areas and shoreline retreat would be allowed. The land would probably be in ‘areas likely to be inundated’ by seawater, and it would probably be necessary to incorporate additional land further upland as seawaters inundate. The management of this land would incorporate the idea that it is in transition, and the guidelines in Part 3, Accomodation could be applied.

To create this easement, governments and land trusts could focus on the purchase of properties or development rights of properties where there is a significant hazard to development, but which has value as land for ecosystem retreat or restoration. Purchase of development rights on properties more than fifty percent damaged could be a way to limit rebuilding in coastal hazard zones at a lower cost. Development disincentives or sale incentives could also encourage the sale of these rights. Rolling easements and deed restrictions on shoreline hardening may also be policy components.

Living shorelines are discussed as an ecologically sustainable approach to shoreline restoration, which would occur within alongshore easements. Construction of a living shoreline is an alternative to traditional coastal stabilization methods. The Virginia Institute of Marine Science Center for Coastal Resources Management describes living shorelines in the following excerpt.

“A “Living Shoreline Treatment” is a shoreline management practice that addresses erosion by providing for long-term protection, restoration or enhancement of vegetated shoreline habitats. This is accomplished through the strategic placement of plants, stone, sand fill and other structural and organic materials. Living Shoreline Treatments do not include structures that sever natural processes & connections between riparian, intertidal and aquatic areas such as tidal exchange, sediment movement, plant community transitions & groundwater flow” (Living Shorelines 2008).

The use of this approach will help maintain regulatory ecosystem services such as erosion reduction and water and air pollution filtration, while providing animal habitat, aesthetic, and recreational value.

Coastal Management

Managed Retreat Overview and Issues

The process of managed retreat and its associated issues were researched for this study. Managed retreat is essentially the practice of moving development out of harm’s way in a planned and controlled manner and can be used as a proactive method of adapting coastal development to rising sea levels. Neal et al. define several ways in which managed retreat can occur including abandonment, relocation, setbacks and easements, land acquisition, and avoidance. Managed retreat is recommended as a basis for all coastal management responses, and the associated issues are discussed in the research contained in Part 4.

Controlled Inundation Areas and Managed Realignment

This section briefly discusses controlled inundation and managed realignment as methods for designating and planning areas that will be inundated. Controlled inundation areas (CIA) are defined as areas which are generally protected but are allowed to be inundated in times of flooding. Managed realignment is defined as discontinuing the protection of certain tracts of land as identified through comprehensive planning. Both methods could be used as part of overall protective strategies or as part of a phased managed retreat strategy.

Strategies for Responding to Coastal Hazards and Sea Level Rise

This section includes a list of traditional strategies for response to sea level rise, which was useful in organizing this paper, and is helpful in understanding the variety of shoreline response options and terminology.

Rolling Easements and Additional Policy Options

Policies that can be used to implement managed retreat were researched. Based on the research done for this paper, rolling easements seem be the most simple and logical starting point for managed retreat policy. In rolling easement policies, coastal protection is prohibited, and the definition of public lands as lands below the mean high water mark is enforced. Since shorelines are no longer protected, the mean high water line will migrate landward in response to sea level rise. With the exception of coastal protection measures, property owners are allowed to use coastal lowlands as they choose, but a legal mechanism is set up to ensure that the land is abandoned as it is inundated.
James Titus describes rolling easements in the following quote. “Although compensation may be required, this approach (implementation of rolling easements) would cost less than 1 percent as much as purchasing the land, and would be (1) economically efficient by enabling real estate markets to incorporate expectations of future sea level rise; (2) constitutional by compensating property owners; and (3) politically feasible by pleasing people who care about the long-term fate of the coastal environment without disturbing people who either are unconcerned about the distant future or do not believe sea level will rise” (Titus 1991).

There are also issues associated with rolling easements that could make their use more difficult in certain situations. One of these is the potential for ‘takings’, which could be claimed by a property owner who feels that property value or developable land has been lost due to rolling easement policies. This is discussed further in Part 4.

Conflict Analysis between Conservation Lands and Sea Level Rise

Arc GIS was used to analyze conflicts between conservation land priorities and various levels of sea level rise. The conservation lands were defined by the Critical Lands/Water Identification Project (CLIP), a project that identifies and prioritizes Florida’s essential ecosystems for the purpose of land use planning. This data was received from Dr. Tom Hoctor, University of Florida

Geoplan Center. Sea level rise data was obtained from Andrew Whittle, University of Kentucky.

Case Studies

The focus of this case study research is on design based projects demonstrating adaptation to sea level rise, although projects responding to flood risks have also been included. The primary focus is on responses on developed coastlines, though some projects in non-developed areas have been included.

A variety of sources were reviewed for information on case study projects including journals, websites, books, and magazines, but no definitive source exists discussing projects related to sea level rise. Very few projects were found that address sea level rise, though many projects address periodic inundation. Projects that were of value were the Salt Pond Restoration Project in the San Francisco Bay, a 15,100 acre tidal wetland restoration project in South San Francisco Bay. The project is specifically addressing sea level rise in its planning process. The redevelopment of the Anterp, Belgium Quays was also a valuable case study project as it is one of the few located addressing sea level rise with a design based approach. The Room for the River project, sponsored by the Dutch Ministry of Transport, Public Works, and Water Management, is also valuable, which investigates strategies for dealing with higher river discharges on the Rhine River in combination with higher sea levels. Dike strengthening is looked at as a last option, and strategies are explored for creating room for the river to expand rather than increasing shoreline protection and hazard risk.

Excerpts from Publications

Several excerpts from publications are included that could not be included within the general text of this document, but that were deemed important references. These include an excerpt from the description of the South Bay Salt Pond Restoration Project in the San Francisco Bay, an excerpt from a report titled, “Anticipatory Planning for Sea Level Rise along the Coast of Maine”, which contains an assessment of the vulnerability of the State of Maine to sea level rise and recommendations for response, and an excerpt from a 2008 article written by Jonathan Barnett and Kristina Hill and titled, “Design for Rising Sea Levels”, in the Harvard Design Magazine.

PART THREE: RESULTS AND CONCLUSIONS

INTRODUCTION

This section forms the recommendations and strategies defined through the research, which can be used to inform coastal policy and land use planning. The focus was on exploring protection, accommodation, and retreat strategies as applied to a specific site and on presenting information that can be used by planners and policy makers to respond to sea level rise.

The coastline of North Palm Beach, Florida was used as a study area, and these conclusions must not be taken as directly applicable to any community other than that of the study area. They can be used as a starting point to develop strategies for response to sea level rise.

The first section, Options and Recommendations for Coastal Management begins with a comparison of managed retreat, protection, and accomodation as potential responses to sea level rise. This comparison forms the basis of the ultimate recommendation for managed retreat over shoreline protection or accommodation responses that aren't part of an overall retreat strategy. This section is followed by a description of sample goals and objectives. The following section contains some basic steps that should be taken to begin to address sea level rise response.

The second section, Strategies for Adaptation to Sea Level Rise, examines in greater detail protective, managed retreat, and accommodation strategies at a community scale through plans, sections, and design guidelines. The feasibility of protection on high and low energy coastlines and for various shoreline conditions is examined (i.e. shorelines with an existing seawall, a beach, or shorelines encompassing a critical conservation area). The final section contains the study's conclusions, and areas identified for further research.

Comparison of Protective, Managed Retreat, and Adaptive Responses to Coastal Hazards

The goal of this section is to summarize and compare shoreline protection, managed retreat, and accommodation as methods of responding to coastal hazards and sea level rise. The conclusion of this section is to recommend managed retreat as a long term response, because it is the most ecologically and financially sustainable solution over the long term. Accommodation is recommended as a short term response to sea level rise. Shoreline protection is not recommended outside of certain unique circumstances and as a part of a longer term plan for retreat or adaptation. The following sections describe the basis for this conclusion.

Shoreline Protection

Shoreline or coastal protection is the use of, “structural, defensive measures to protect the land from the sea, so that land use can continue” (TCRPC 2005). The goal is to maintain a stable shoreline position, and a variety of methods of protection exist including ‘hard’ and ‘soft’ methods. Examples of hard methods include seawalls, groins, and breakwaters. Soft methods include beach nourishment and elevating surfaces with fill (TCRPC 2005). Beach nourishment is particularly used in locations where the beach is a valuable public or private amenity. The drawbacks of hard and soft shoreline protection methods are summarized below (Coburn 2004):

(1) Unable to perform as planned
(2) Unsustainably expensive on both local and regional scales
(3) An inequitable distribution of public funds
(4) Harmful to coastal ecosystems
(5) Damaging to the recreational value of the beach
(6) Catalysts of increased hazard-zone development

An unpublished paper from the Duke Program for the Study of Developed Coastlines summarizes the negative ecological effects of coastal protection in the following quote, “Engineered solutions (i.e. hard and soft stabilization) actively modify the beach, ultimately disturbing both natural processes and habitat. Jetties, groins, breakwaters, and seawalls destroy both the natural beach and the beach ecosystem by modifying transport mechanisms and increasing erosion rates. Nourishment introduces foreign sediment, which disturbs natural processes, kills *swashzone organisms, hinders sea bird feeding, obstructs sea turtle nesting, raises the surface temperature of the beach, and increases nearshore turbidity. Moreover, nourishment frequently results in the emplacement of sharp shells, gravel, and mud that inconvenience beachgoers and detract from the recreational experience” (Coburn 2004).

As sea levels rise, the negative ecological effects of coastal protection will become even more damaging. As sea levels rise, shorelines, barrier islands and wetlands often respond by moving in a landward direction. The use of hard structures for shoreline protection makes this landward movement possible, causing flooding and eventual collapse of of shoreline ecosystems. A moderate increase in sea level can lead to the gradual extinction of many shoreline ecosystems and species (Titus 1991). It is for this reason that discontinuation of coastal protection and provision of lands for coastal ecosystem retreat is extremely important.

One of the most important problems with continuing coastal protection or ‘holding the line’ is that sea level rise will only increase coastal hazards and the risk borne by development and habitation in coastal hazard zones. The sea is an unconquerable force whose dynamic processes will continue regardless of human

* The swashzone is the area upon the shoreline where wave uprush and retreat occur.

activity. Increased storm frequency, erosion, and higher water levels will likely cause the repair, construction, and maintenance of coastal protective devices to become more financially unsustainable as sea levels rise. Coastal development will experience increased damage, and if protection occurs, greater potential risk from overtopping or deterioration of protective devices. The allocation of public funds in hazard areas and current insurance industry policies will likely become increasingly inequitable. Coastal development protection encourages development in hazard areas, exacerbating the issues described above.

Functionally, one important issue that will need to be addressed by any strategy for protection is the allowance for upland drainage. Protective structures such as dikes that allow existing inland grades to remain the same run the risk of creating a bathtub, with sea water on the outside, and water on the inside with nowhere to go. Mechanical devices can be used to drain water from behind the dike, but these would be expensive along long expanses of shoreline and run the risk of failure.

Managed Retreat

An alternative to coastal protection is managed retreat. This method is the ultimate recommendation of this study for response to sea level rise because it is the most financially and ecologically sustainable method of response over the long term. Neal et al. define managed retreat as, "the application of coastal zone management and mitigation tools designed to move existing and planned development out of the path of eroding coastlines and coastal hazards" (Neal et al., 602). It is essentially moving development out of harm's way in a planned and controlled manner, and can be used as a proactive method of adapting human development to rising sea levels. Retreat may occur in a variety of ways including abandonment, relocation, implementation of setbacks, land acquisition, and avoidance of hazards in the first place (Neal et al. 2005).

Retreat has none of the disadvantages of coastal protection, although it has its own associated issues. It does not negatively impact the natural beach or the beach ecosystem, and in fact creates opportunities for ecosystem retreat, which is an important component of ecosystem adaptation to sea level rise. "Retreat protects a natural resource and the economy dependent upon that resource without degrading either, an objective that shoreline stabilization consistently fails to achieve. Retreat is a policy of living with the shoreline, rather than living on the shoreline" (Coburn 2004).
The goals of retreat can be summarized as (Coburn 2004):

- Protect coastal natural resources from development induced harm
- Minimize damage and loss of property
- Maximize the value of coastal property
- Distribute the costs of managed retreat policies equitably

Over the long term, retreat will also likely be the most financially sustainable response to sea level rise. This is because it removes development from the coastal hazard zone, where high costs will be incurred from storm, inundation, and shoreline erosion (Coburn 2008). These costs are currently inequitably spread to non-coastal property owners through Florida insurance policies (Jerry 2008). Retreat also eliminates the expense of coastal protection, which will only increase due to sea level rise.

Retreat policies do create a variety of issues. The most obvious of these is the loss of property by retreating owners and land uses. This creates potential conflicts caused by in-migration of populations (Brody 2007). There are political issues such as appealing to constituencies with high economic investment in coastal properties and constitutional issues with the potential for 'takings'. A 'takings' could be claimed by a property owner who feels that managed retreat policies, such as shoreline setbacks, rolling easements, or prohibition of protection, result in a loss of developable land or land value for their property.

Additional issues include a potential loss of tourism when protection or nourishment activities are discontinued in place of retreat. Key West and Miami Beach are locations that could suffer from discontinuation of these policies. There is also a concern among some communities that retreat will cause a loss of tax base and property revenue (Coburn 2008). The short term cost of retreat versus protection, as well as the incentives for coastal development created by the insurance industry and consumer demand are additional factors working against the implementation of retreat responses to sea level rise. Solutions to these issues are discussed in Part 4, Managed Retreat Overview and Issues.

One method of implementing retreat policies is through rolling easements. These are created by prohibiting structures that interfere with naturally migrating shores and by enforcing the mean high water line as the extent of publicly owned lands. This solution deals with several potential issues associated with retreat. It is "economically efficient by enabling real estate markets to incorporate expectations of future sea level rise; (2) constitutional by compensating property owners; and (3) politically feasible by pleasing people who care about the long term fate of the coastal environment without disturbing people who either are unconcerned about the distant future or do not believe sea level will rise" (Titus 1991). This and other policy approaches may be implemented as part of planning for sea level rise and as an alternative to continued coastal protection.

Reference Part 4, Rolling Easements and Other Policy Options

Accommodation

Accommodation of sea level rise is defined as the use of strategies that allow for the use of vulnerable lands to continue, but that do not attempt to prevent flooding or inundation with shoreline protection (TCRPC 2005). It is a realistic combination of protective and retreat methods. Accommodation strategies are addressed in Part 3, Accommodation, which outlines strategies and design guidelines for the use of ‘‘areas likely to be inundated’’. Some examples include elevation of buildings or discontinuing habitation of lower floors, construction of buildings that are relocation friendly, and land uses that are temporary or can be inundated without excessive damage. The allowance for natural shoreline processes to continue is a key element of adaptive strategies.

Accommodation strategies may be suitable for land uses such as public parks or certain aquaculture industries in order to maintain the use of vulnerable lands. They are not a substitute for managed retreat where most other land uses are concerned such as residential or many industrial uses. This is because continuation of these land uses will either require protection, or if not protected, will experience increased coastal hazards and will likely be financially and ecologically unsustainable.

Goals and Objectives for ‘areas likely to be inundated’

Coastal management strategies and development responses to sea level rise inundation must be based on well-founded goals and objectives with consideration of a variety of factors. Goals for management strategies must be formed with consideration of time and lifespan in relation to the rate of sea level rise and inundation. For example, the goals of a project designed to be temporary may not require them to adapt to levels of rise projected far in the future. The value of a solution must also be a consideration of its cost versus its longevity.

In the adaptation strategies explored in this study, the over arching goals were financial and ecological sustainability with a focus on maintaining the highest possible level of natural coastal system functionality. The achievement of these goals is not possible in all situations or at all time scales.

The following are sample goals and objectives for coastal responses to sea level rise that can be used as a starting point for forming goals for individual projects and management plans. These goals are based on a long term strategy of retreat, and should be referenced in tandem with Part 3, Accommodation, which outlines design guidelines for ‘areas likely to be inundated’. Goals defined by other coastal management plans should also be referenced.

Coastal Management and Development Response Goals and Objectives

Overall goals for coastal management and development response should incorporate the following considerations: Ecological sustainability, financial sustainability, and hazard mitigation.

Coastal management responses should:

- Create no negative effects on coastal ecosystems and processes and support and enhance natural ecosystem and shoreline response to sea level rise.

- Minimize immediate negative impacts on coastal properties and land owners.

- Be financially sustainable over the short and long term

- Plan for varying rates and levels of sea level rise by being either adaptable or temporary.

- Consider a variety of factors including allowance for public access, support for water dependent businesses, and minimizing impact on historic and cultural resources.

- Use creative design, planning, and policy strategies to reap benefits from the effects of sea level rise.

The following are draft goals for managed retreat defined in Coburn 2004. They have been included for reference and comparison, but are taken from a draft report and should be referenced as such.

Protect Coastal Resources
To protect barrier beaches that serve as the basis for coastal economies, policymakers and property owners must allow

•shorelines to migrate landward in response to sea level rise
•dunes and dune grasses to move landward with the beach
•storms to overwash and deposit sand behind dunes
•inlets to open, close, and switch channels

Furthermore, local or state governments must mandate the removal of all hard stabilization (including sandbags) artificially holding the shoreline in place.

Minimize Property Damage
To minimize damages to coastal properties, federal, state, and local lawmakers must

•identify hazard-prone structures
•implement policies that promote the gradual, strategic removal of threatened structures
•redirect funding allocated for 'shoreline erosion and protection projects' to retreat projects
•improve monitoring of coastal development through the enforcement of existing regulations
•plan for the retreat of successive rows of shorefront structures through land use plans that enforce stricter building codes
•encourage development in lower hazard areas (i.e. topographic highs and the mainland)
•account for continuous, rapid, and unpredictable changes in environmental conditions

Maximize Coastal Property Value
To maintain the recreational beach necessary to maximize the value of coastal properties, policymakers and property owners must

•protect barrier beach systems in their natural state
•remove or relocate structures vulnerable to erosion, thus limiting hazard-induced damages
•mandate construction of relocation-friendly buildings and infrastructure

Distribute Costs Equitably
To ensure that the beneficiaries of coastal development bear the associated costs, federal, state, and local policymakers must

•internalize costs through sales, property, and occupancy taxes on coastal development and tourism
•use property owner funded programs, such as the National Flood Insurance Program, to supplement public expenditures
•provide incentive to retreat through local zoning ordinances and state policies that distribute funds based upon community preparedness

How to Proceed Step by Step

The following steps should be taken by state and local governments as part of their sea level rise response.

• Inundation Maps: Create high resolution maps illustrating sea level rise projections for upland inundation that can be used for regional land use planning (Ankersen 2007). A consistent methodology should be adopted statewide for the creation of these maps though regions can adapt this methodology for their own uses. Maps should be based on the most likely worst case scenario projections in order to minimize risk, and the line of projected inundation should be based on mean high water levels rather than the mean sea or tide levels. If possible, erosion and storm surge estimates should be incorporated. The maps produced by the South Florida Regional Planning Council present a starting point for these purposes (See citation TCRPC 2005 and Figure 1.8).

• Shoreline Assessment: The state and counties should undertake comprehensive assessments of likely changes to shorelines, coastal processes, and ecosystems due to sea level rise. These should be scientifically based studies and should inform Comprehensive Plans and Future Land Use Maps.

• Suitability Analysis: Conduct a land use suitability analysis to inform Future Land Use Maps, local Comprehensive Plans, and state policies as the basis for defining response strategies on a regional basis. This analysis should be based on the shoreline assessment described above and other applicable research such as CLIP (Critical Lands/Water Identification Project). This analysis should do the following:

- Determine which areas are most appropriate for development protection and retreat.
- Determine which areas are most appropriate for ecosystem protection and retreat
- Determine which areas are most appropriate for seawater inundation or will be allowed to adapt naturally.

• Define goals and objectives based on the results of the suitability analysis and incorporate these goals and objectives into the comprehensive plan and future land use map.

• Define policies to implement the goals and objectives relative to region specific issues. Policies for response to sea level rise are discussed in Part 4, Appendix C. The consideration of rolling easements is recommended through this study.

• The following are some important considerations and actions that should be taken.

- Improve early warning systems and flood hazard mapping for storms.
- Reassess coastal floodplain designations based on sea level intrusion projections.
- Continue close monitoring for changes in coastal systems using GIS (Alongi 1998)
- Identify land use measures to ensure that wetlands and other ecosystems migrate as sea level rises where possible. (EPA 2008)
- Develop plans for increased afforestation of wetlands in suitable areas (Alongi 1998)
- Develop policies to help protect freshwater supplies from contamination by saltwater.

• Coastline protection may be prohibited as discussed in Titus 1998. If this is not decided, local governments should analyze the environmental consequences of shore protection and promote shore protection techniques that do not destroy all habitat. (EPA 2008). Any allowance of protection should be informed by the suitability analysis as described earlier.

• Governments should take active roles in encouraging relocation of urban, agricultural, maricultural activities (Alongi 1998)

Introduction

This section contains strategies for adaptation to sea level rise in various shoreline conditions including high and low energy coastlines, and developed and undeveloped coastlines. Strategies for retreat, protection, and accomodation are discussed. The focus is on ecologically and financially sustainable solutions to coastal management.

Coastal management strategies, in particular if protection is considered, must be unique for each site and set of shoreline characteristics including coastal ecology, wave and erosive energy, shoreline gradient, and sedimentation availability.

Figure 3.1 shows the locations of the high and low energy shorelines within the study area. Maps such as this that diagram the types of coastal conditions and ecosystems within a region must be used to form appropriate strategies for adaptation to sea level rise.

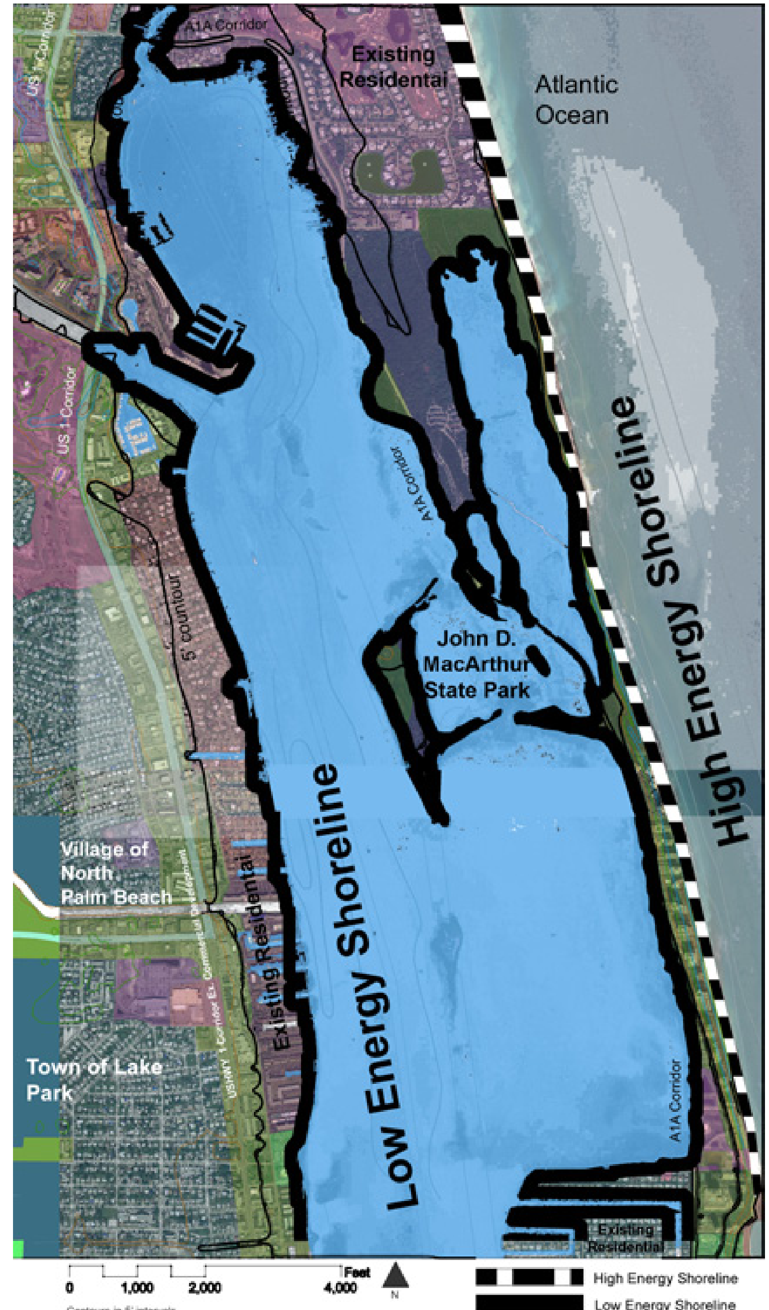


Figure 3.1: Location of High and Low Energy Shorelines
This map is based on the 2008 shoreline locations
Map Sources: gap_lcov 2000, TOPO 1997, LABINS 2008

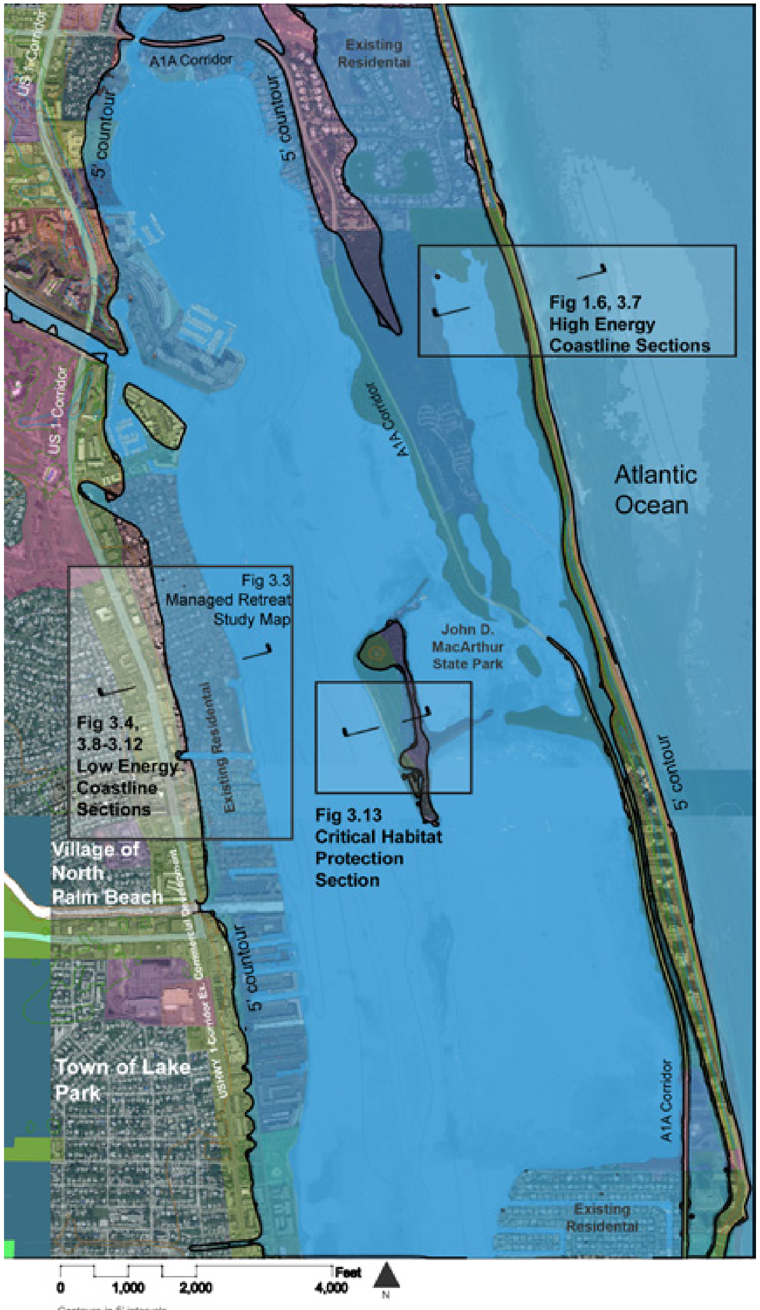


Figure 3.2: Five Foot Inundation and Location of Coastal Sections used for Strategies: This map identifies the study area and important site information. It also identifies the locations of maps and diagrams in later sections. The blue overlay is a rough representation of sea level inundation with a rise of five feet as used in the following sections. This map does not take into account tidal fluctuations or erosion estimates.

Map Sources: gap_lcov 2000, TOPO 1997, LABINS 2008

Introduction

The diagrams in this section illustrate managed retreat from a five foot sea level rise in the study area. Issues, strategies, and policies are noted and diagrammed. The diagrams assume a policy of no shoreline protection and natural shoreline retreat. This strategy was also formed with consideration of basic principles of waterfront design such as allowance for public access. Implementation of some of the recommendations in the following diagrams could occur over time or as part of a phased response, possibly triggered by certain benchmarks of rise. Others should be pursued immediately as planning responses to sea level rise projections.

Some of the primary components of these strategies are as follows. Plans for managed retreat should define areas “likely to be inundated” based on sea level rise, erosion, and storm surge projections. These areas would have unique regulations attached for development, and new construction that cannot accommodate sea level rise would not be allowed. An alongshore buffer/easement would be reserved for ecosystem adaptation and retreat.

For the purposes of this example, storm surge projections were not incorporated in defining the ‘areas likely to be inundated’. This is because projected storm surge covers the entire study area and would make it unuseable for the purposes of this example. For this reason, the line of inundation and area of potential inundation defined in the following diagrams should be considered as rolling lines, and not considered entirely accurate for the study area.

Ecosystem Management and Reestablishment as part of Managed Retreat

Within the managed retreat strategies proposed, ecological considerations are incorporated through the provision of an alongshore buffer for ecosystem management, adaptation, and retreat. The buffer allows for natural shoreline migration to occur while also decreasing hazards to coastal development, since new permanent construction would be prohibited. This buffer could be created through a variety of methods including rolling easement policies, land acquisitions, and deed restrictions. Managed retreat coupled with proactive management of ecosystems is the most ecologically sustainable method of responding to sea level rise, because it removes barriers that prevent ecosystems and shorelines from retreating. Figure 3.4 illustrates a section through this buffer and the adjacent area likely to be inundated on a low energy shoreline. The illustration of the retreating shoreline ecosystems is based on the premise that the geologic structure and the retreating ecosystems would remain similar to what exists on current shorelines at current sea levels. This could be a relatively accurate projection in this study area because of its geology and consistent shoreline gradient. With regard to beaches, the Bruun rule proposes that a beach moves up and back and retains the same profile as sea level rises, though there are researchers who disagree with this rule (Pilkey 2000). If accurate, it supports the maintenance of a similar coastal profile over the long term in response to sea level rise as is shown in Figure 3.4. In reality, the structure of shoreline ecosystems may vary quite drastically due due to species die-offs, thinning or expansion of certain ecosystems, and species succession. It is not certain what the effects of sea level rise will be on shoreline ecosystems. Research indicates that it is feasible that similar species and ecosystems will continue to exist within the study area if ecosystems are allowed to retreat, but this is not conclusive.

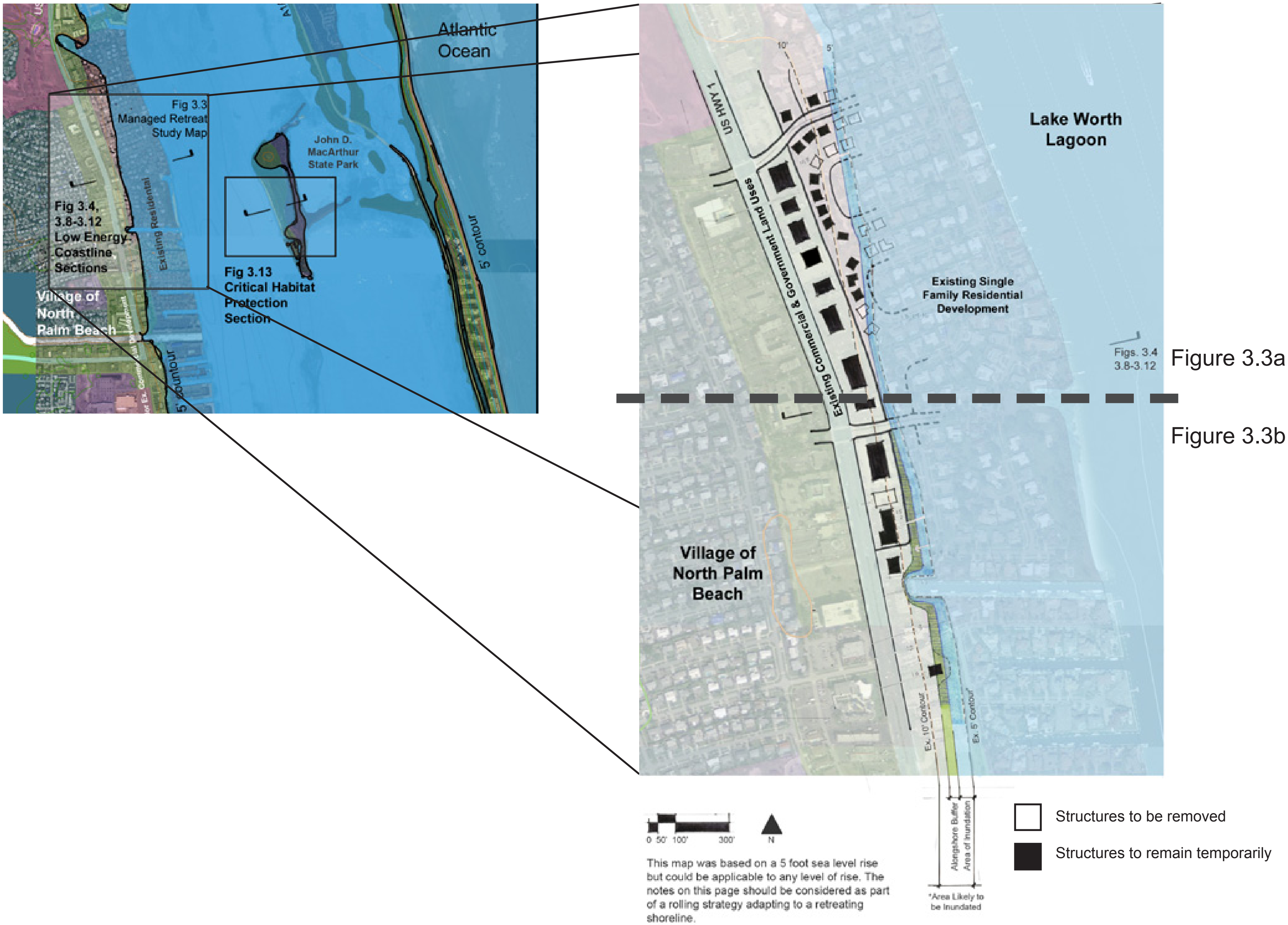
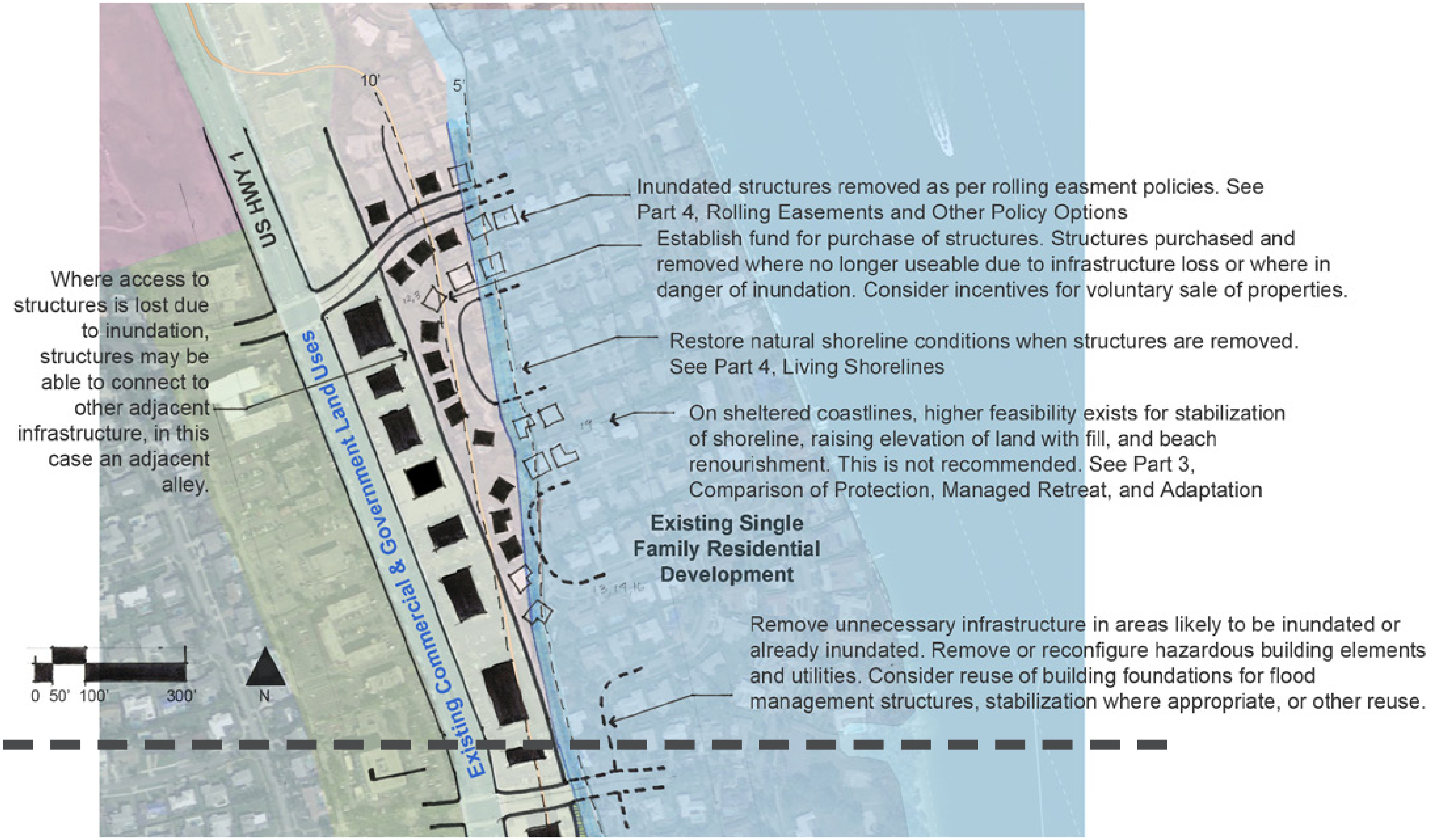


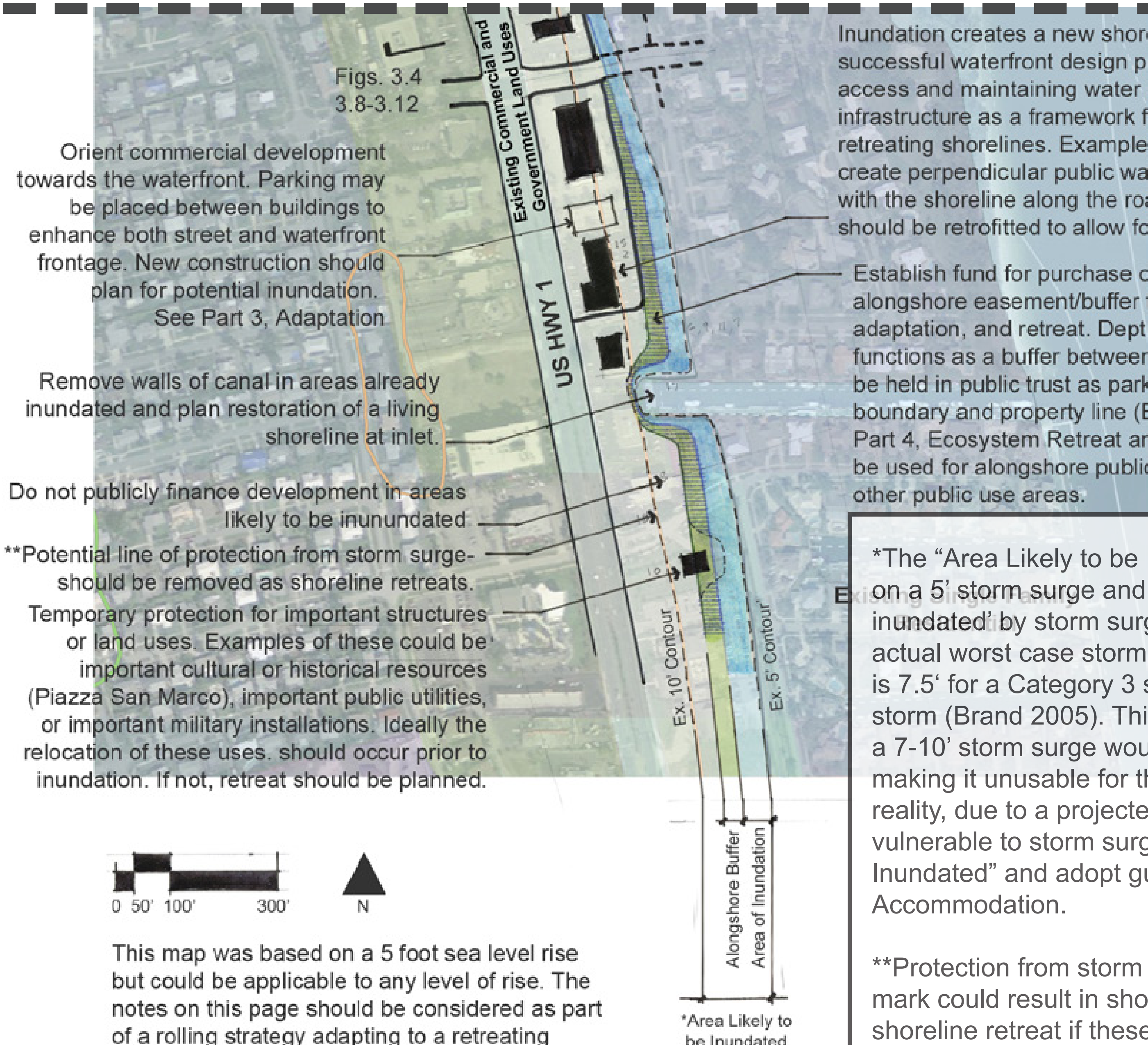
Figure 3.3: Managed Retreat: Detailed Study of Adaptive Strategies, Policies, and Issues
Map Sources: gap_lcov 2000, TOPO 1997, LABINS 2008



Structures to be removed

Structures to remain temporarily

Figure 3.3a: Detail One



*The “Area Likely to be Inundated” was defined based on a 5’ storm surge and refers to ‘areas likely to be inundated’ by storm surge or future sea level rise.The actual worst case storm surge for Palm Beach County is 7.5‘ for a Category 3 storm and 10.9’ for a Category 5 storm (Brand 2005). This number wasn’t used because a 7-10’ storm surge would inundate the entire study area making it unusable for the purposes of this exercise. In reality, due to a projected increase in storm events, areas vulnerable to storm surge should be classified “Likely to be Inundated” and adopt guidelines similar to those in Part 3, Accommodation.

**Protection from storm surge above the mean high water mark could result in shoreline hardening and inhibit natural shoreline retreat if these structures are not removed as sea level rises. Care should be taken to avoid these results

This map was based on a 5 foot sea level rise but could be applicable to any level of rise. The notes on this page should be considered as part of a rolling strategy adapting to a retreating shoreline.

Figure 3.3b: Detail Two

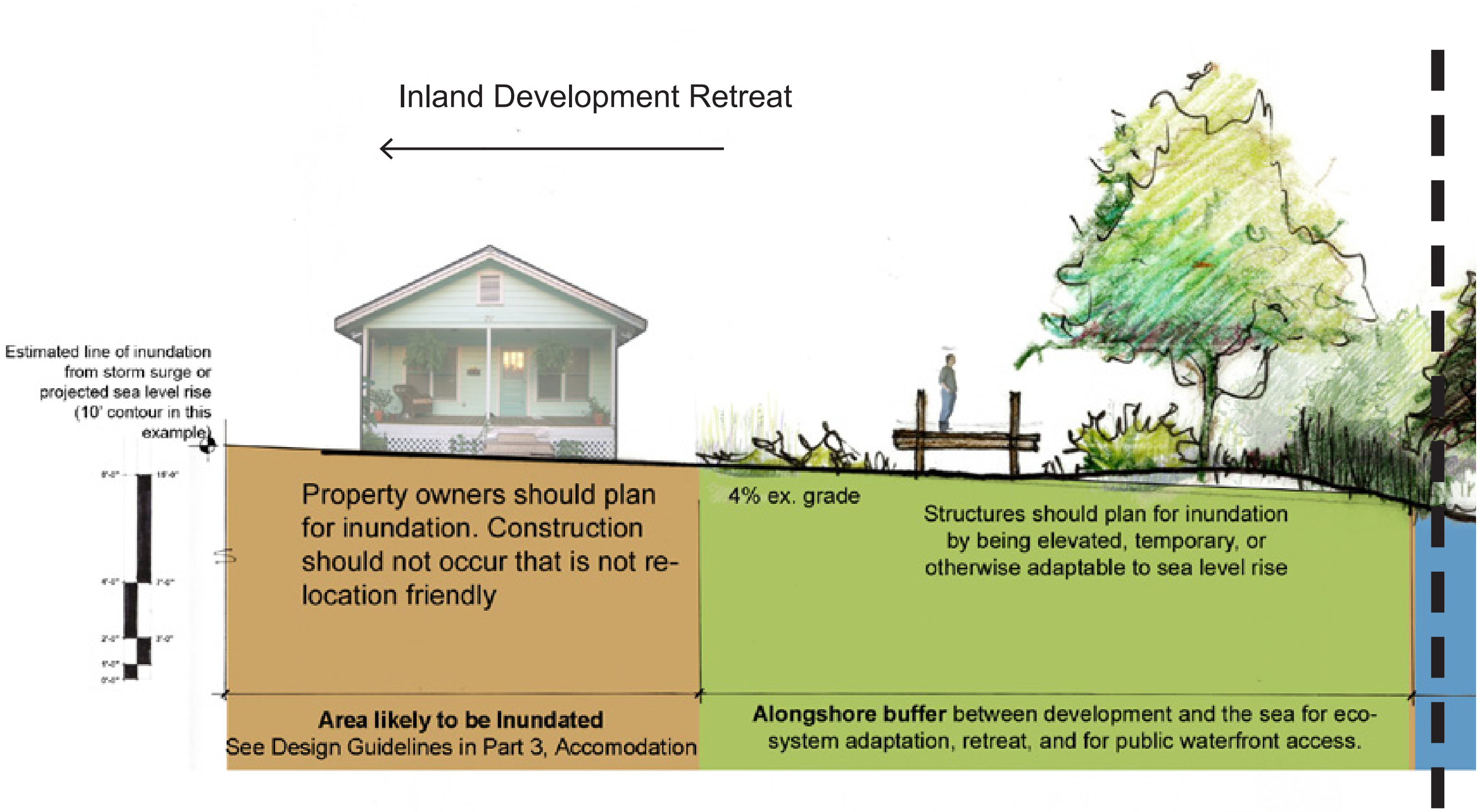
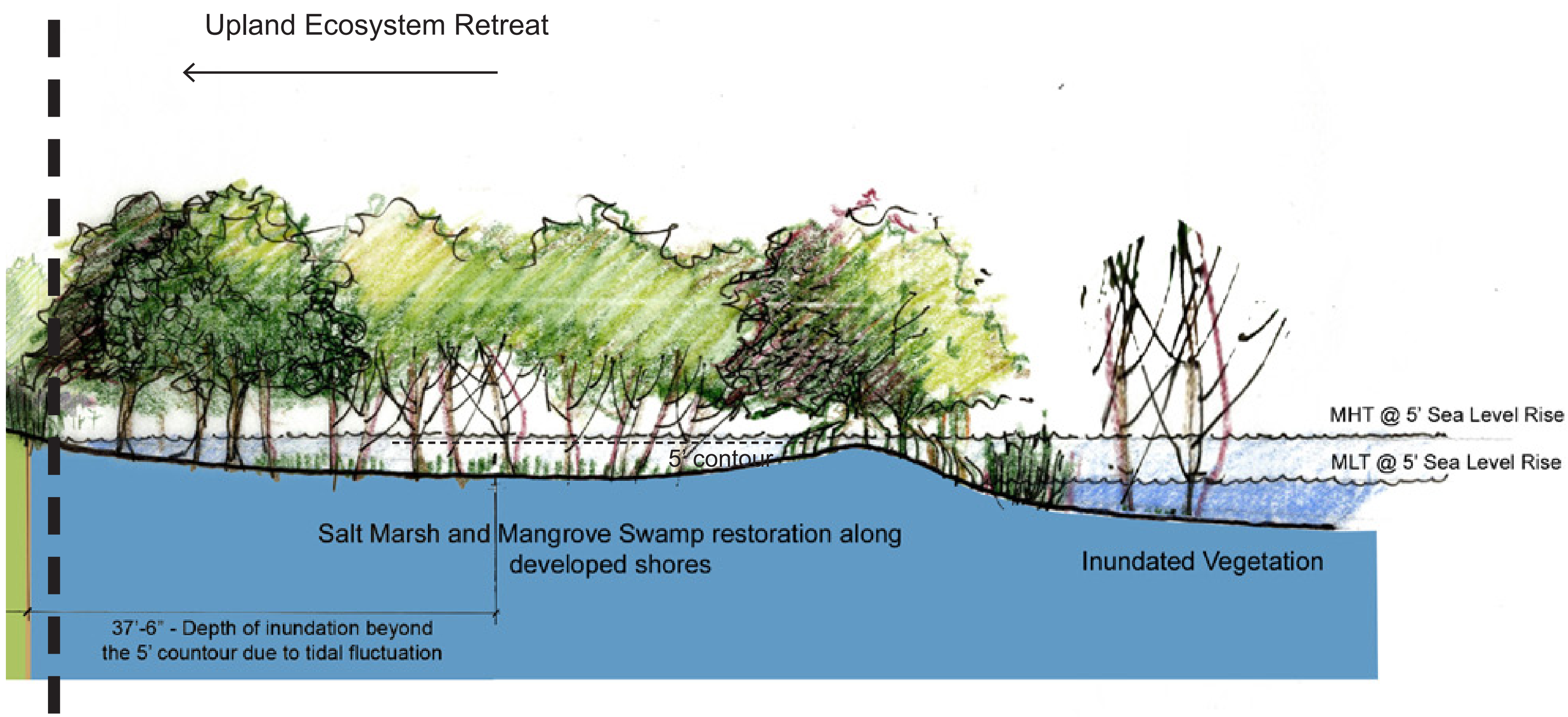


Figure 3.4, Managed Retreat: Section Through Area Likely to be Inundated: This section is cut through the low energy shoreline in North Palm Beach and shows the proposed alongshore buffer and "Area likely to be Inundated". The diagram is based on the premise that shoreline protection would be prohibited and development would retreat from the shoreline. The resulting shore would contain an alongshore buffer for ecosystem adaptation and retreat created through land purchases, deed restrictions, and the use of a rolling easement. Upland of this buffer an area would be zoned "Likely to be Inundated" based on storm surge, sea level rise, and erosion projections. Design guidelines and restrictions would be instituted for the use of this area (see Part 3, Accommodation).


Upland Ecosystem Retreat
MHT @ 5' Sea Level Rise
5' contour
MLT @ 5' Sea Level Rise
Salt Marsh and Mangrove Swamp restoration along
developed shores
Inundated Vegetation
37'-6" - Depth of inundation beyond
the 5' countour due to tidal fluctuation

Introduction

The following pages examine shoreline protection in response to sea level rise on high and low energy coastlines. Protective strategies are discussed for various coastal conditions such as beaches, developed areas, and conservation areas. These have been formulated based on a projected response of coastal protection as described in by the Treasure Coast Regional Planning Council study.

The science of coastal engineering and protection is well advanced and there are probably protective solutions for most coastal conditions. ***However, the basic problem with coastal development and shoreline protection in general is that it attempts to fix or make static an environment that is inherently dynamic and shifting These attempts result in ecologically and financially unsustainable shoreline environments.***

The general conclusion and recommendation outlined in this section is that managed retreat policies should be a starting point for all actions taken in response to hazards caused by sea level rise. However, it is recognized that there are places on the coast requiring at least temporary shoreline protection or where shoreline protection is almost certain to occur. For this reason, strategies should be explored for shoreline protection that are more financially and ecologically sustainable than traditional coastal protection strategies. This section proposes and explores the feasibility of several such strategies.

It is also important to recognize that strategies for response are site specific and time dependent. Strategies that will work in one site will not work in another seemingly identical site. The functionality of a strategy will also change over time and therefore intertemporal and phased management and planning that incorporates change is vital.

In areas of high density and high land value such as Miami Beach, property owners and policy makers should plan for retreat over the long term. If instead protection is chosen as the long-term approach, communities must attempt to stabilize the coastline against erosive processes and from a protective standpoint use strategies similar to those used in the Netherlands. Strategies like those being proposed in the Netherlands would be implemented in phases over a long period of time, possibly in response to predetermined benchmarks of sea level rise or other financial or political benchmarks (See Klijn 2001).

Policy makers who allow temporary protection measures should be careful that they don’t become permanent measures that encourage further development and disencourage retreat.

Finally, a number of researchers and professors have been consulted in the formulation of these strategies, and their viability has been loosely confirmed. The feasibility of these strategies has also been explored through other research and uncertainties have been noted where they exist. This said, they are still only concepts and require much more research to verify their suitability.

Realistic Goals for Shoreline Protection

Several researchers were asked to define realistic goals for shoreline protection and the information below summarizes this information.

The definition of goals depends on the rate and amount of rise, and the necessary response (based on existing land use requirements) over a period of time.

Feasiblity of short term protection goals- Stabilization is generally possible, but the level of financial and ecological sustainability and the lifespan of the coastal protection strategy depend on coastal dynamics and the strategy used. Nourishment for example may be relatively long lasting on certain shorelines but less so on others.

Feasibility of long term protection goals- The feasibility of protection depends on the rate and level of sea level rise and coastal dynamics. Protection will not be possible after a certain point and retreat will be the only option because of cost (example: 10 feet of rise due to ice cap melting). Protection will probably not be ecologically sustainable, particularly on high energy coastlines.

Guidelines used in the Development of Protective Design Strategies

The following goals were used for the development of the protective design strategies included in this study.

- Strategies should be financially and ecologically sustainable as defined in this paper.
- Strategies should be specific and tangible. One should be able to draw it.
- Strategies should be informed by and keyed to policies and research.
- Horizontal protective strategies should be explored that preserve connections between uplands and the waterfront.
- Focus should be on onshore anthropocentric response, though offshore systems are an important consideration. This is merely to limit the scope of research, not to imply priorities.
- In protective shore conditions, attempt to restore natural conditions in such a way as to allow the shore to adapt and retreat if and when possible.
- Strategies should address intertemporal implementation and management

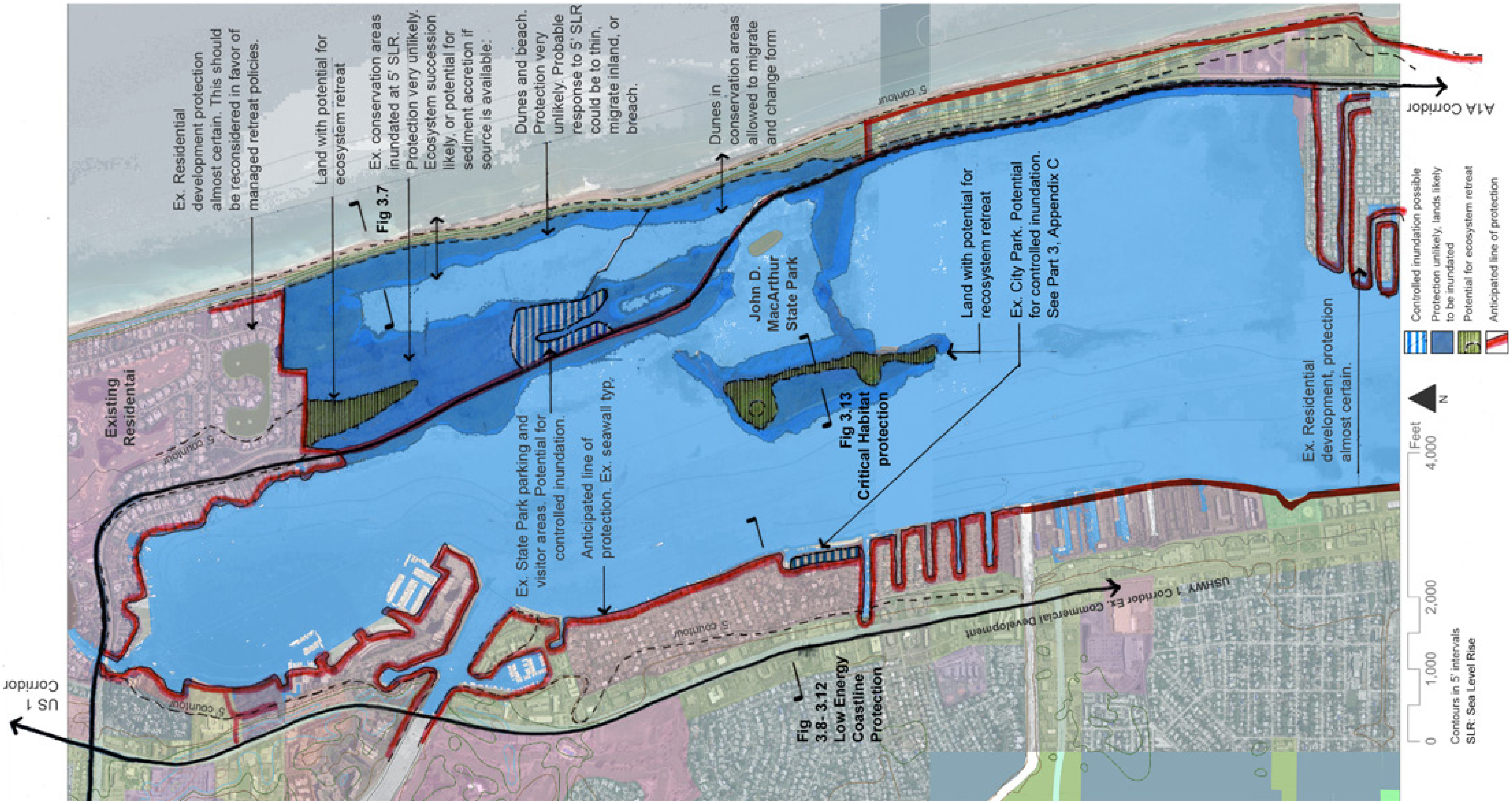


Figure 3.5: Protection: Study of Likely Shoreline Responses in North Palm Beach
This diagram illustrates shores almost certain to be protected, potential for controlled inundation areas, and shores unlikely to be protected in North Palm Beach.
Note: Controlled Inundation Areas in this map refer to areas generally protected, but where inundation could be allowed during storm events. See Part 4, Appendix C, Controlled Inundation Areas.

Map Sources: gap_lcov 2000, TOPO 1997, LABINS 2008, TCRPC 2005

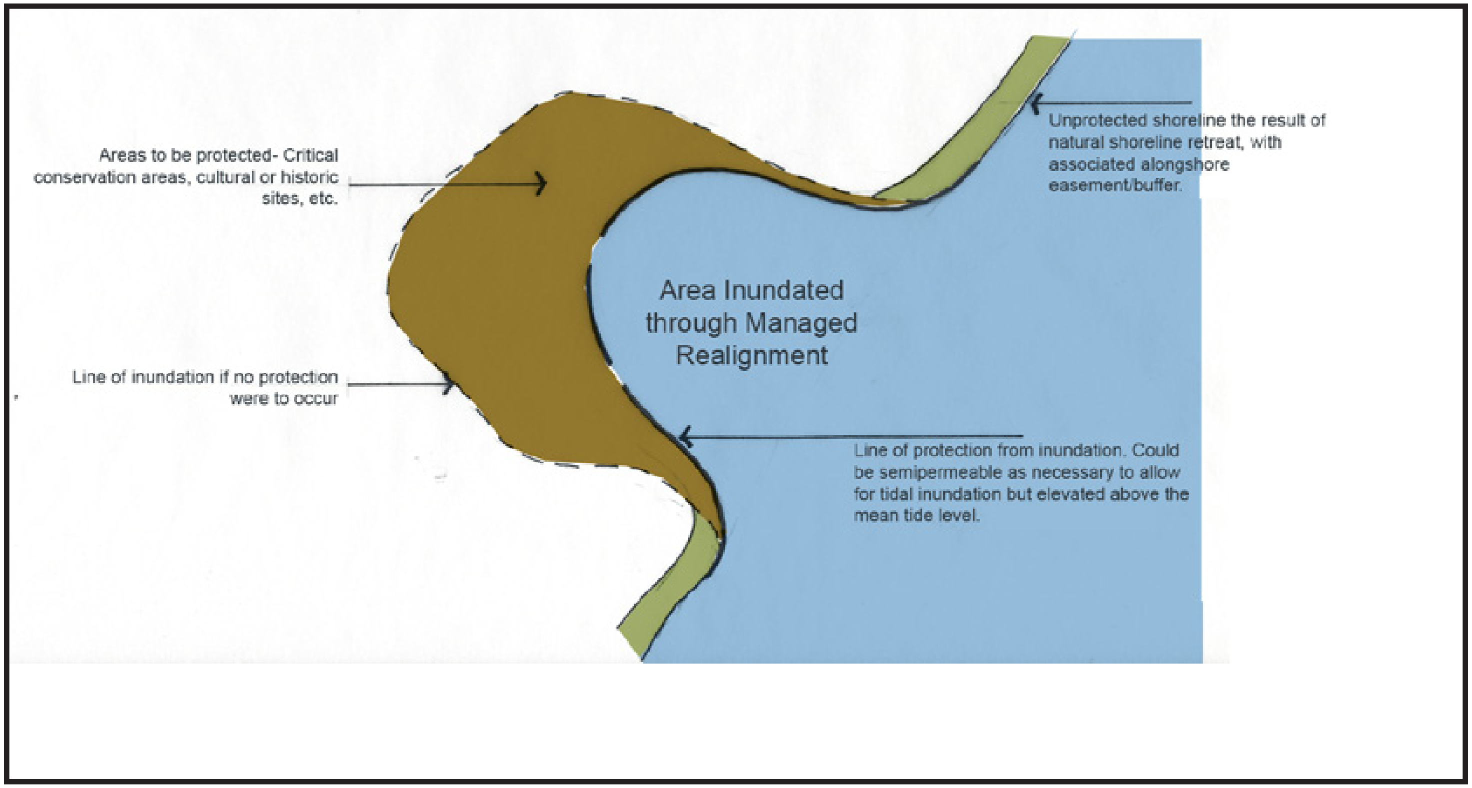


Figure 3.6: Critical Lands Protection: Not to Scale
This diagram illustrates the use of managed realignment and selective protection to preserve critical lands from inundation. Examples of critical lands could be historic St. Augustine or a conservation priority one land as defined by the Critical Lands/Waters Identification Project. No critical lands of this type were identified in the study area. In almost all situations, this approach should be seen as part of a longterm managed retreat policy. There will be situations where this may be more difficult such as in the case of St. Augustine.

High Energy Shoreline Development Protection

Areas defined by the Treasure Coast Regional Planning Council as Protection Almost Certain (Brown)

Definition of High Energy Shoreline

Shorelines within the study area that border the Atlantic Ocean are classified as high energy open coastlines. These shorelines occur both on barrier islands and on the mainland along the Treasure Coast. These coasts experience more dynamic wave action and sediment flow than sheltered low energy coasts such as within the Intracoastal Waterway. As such, sustainable protection measures for these shorelines will vary in type and feasibility from those on low energy coastlines.

Example: Town of Palm Beach and Singer Island

Feasibility of Protection

Summary

Sustainable shoreline protection in response to sea level rise is probably not feasible. Property owners on barrier islands and on mainland coasts where inundation is projected must ultimately plan for retreat. Hard stabilization methods in particular should be avoided. Protective methods if used should be limited to soft protection such as beach nourishment.

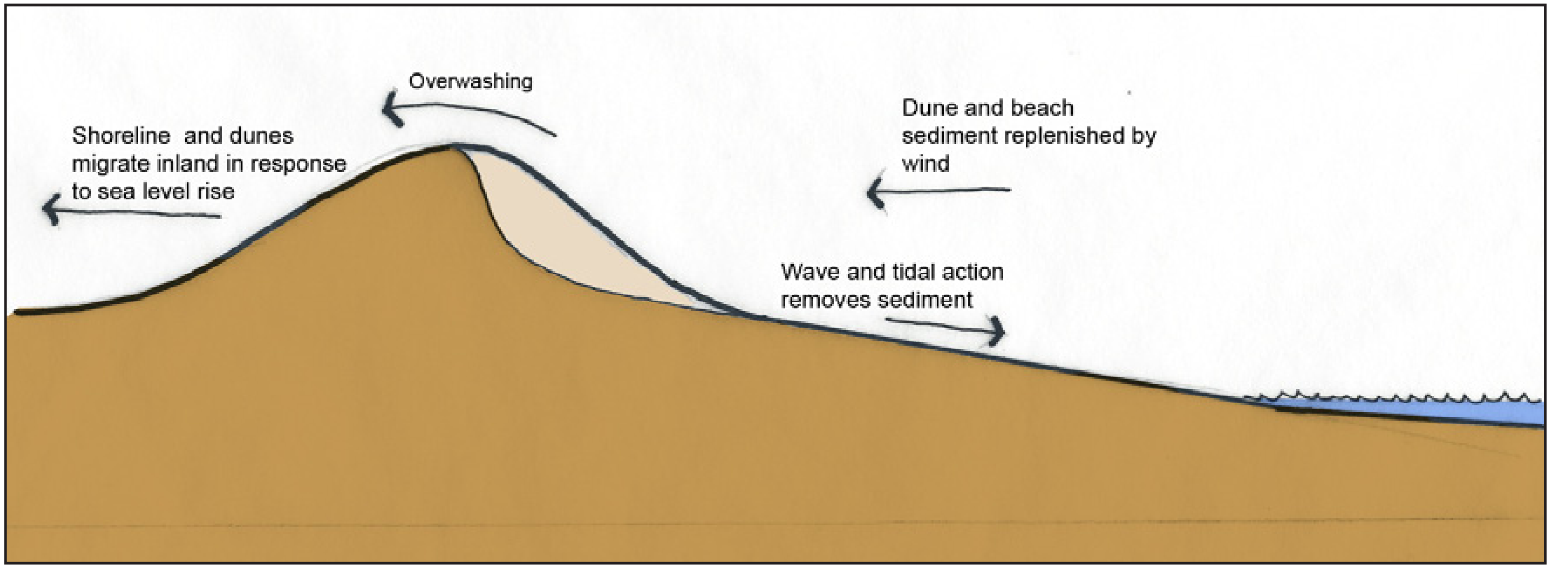
Further Description

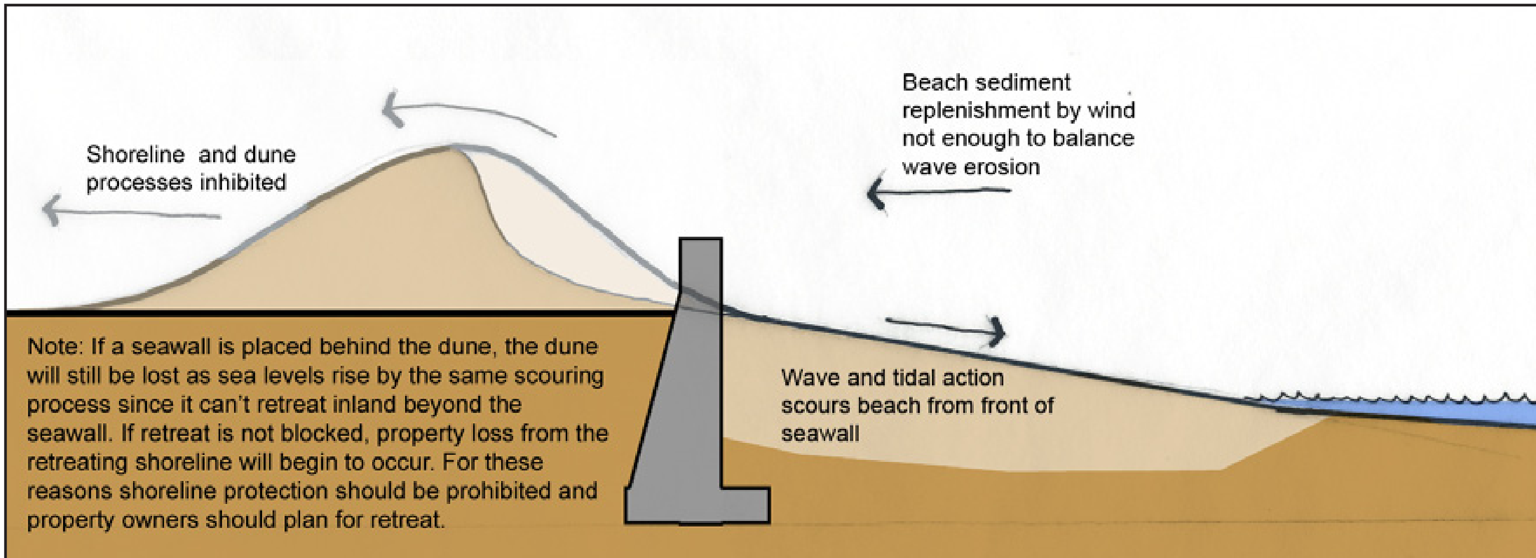
Damage to coastal structures and properties is almost certain due to projected increases in storms and higher storm surge caused by sea level rise. Protective methods will ultimately be temporary and economically and ecologically unsustainable due to coastal dynamics magnified by sea level rise. The reasons for this are briefly discussed below.

“On coasts with a low shoreline gradient, the natural response of barrier islands and beaches to sea level rise at its projected rate will be to retreat at a rate of 100-1000 feet for each foot of sea level rise. On barrier islands, the natural response is to become thinner and migrate landward. Cross island overwash (of sea water) over dunes is important in allowing islands to retreat-sediment from the front of the island is washed to the backside” (Pilkey 2000: 94). Coastal hardening due to development hinders these natural processes limiting the ability of coastlines to adapt to sea level rise. However, the processes will still occur causing increasing damage and threat to development and increasing cost for protection, particularly along high energy coastlines. This will cause coastal protection to be ultimately temporary and financially unsustainable. Maintaining 2008 shoreline positions on barrier islands will not be possible after a certain level of sea level rise, such as 10 feet resulting from ice cap melt (Thieke 2008). An interesting approach to enabling barrier island migration is given in Pilkey 2000, which involves placing fill on the mainland side of the island and allowing the seaward side of the island to migrate. This could be used in conjunction with a type of rolling property line (Clark 2008), but the implementation of this strategy has not been explored and seems to have a variety of issues.

In addition to being functionally unsustainable, coastal hardening will have ecological impacts. Hard stabilization methods in particular should be avoided (Pilkey 2000, p 98, Coburn 2004).

Soft stabilization methods were also considered including beach nourishment and vegetative stabilization. Nourishment is a viable option for certain coastlines in the short term. Its main drawback is that it can be financially unsustainable, and there may also be negative ecological effects. Vegetative stabilization is discussed as follows.





If a seawall is placed in front of the dune, the beach will be scoured away. The property will experience increased risk from storms as waves from rising sea levels overtop the seawall and since the natural buffer provided by the beach and dune no longer exists.

Figure 3.7 High Energy Shoreline Dynamics: Not to Scale

The purpose of this diagram is to illustrate the difficulty and inappropriateness of protection on high energy coastlines

Ecosystem Reestablishment and Stabilization of High Energy Protected Shorelines

Maintainence of functional ecosystems and reestablishment of ecosystems on protected high energy shorelines in the face of sea level rise is probably not feasible. The dynamic tendancy for shoreline migration in response to sea level rise is discussed in many other publications and is counter to maintenance of a static shoreline position (see Bush et al. 2004). Ecosystem reestablishment as a method of stabilizing shorelines and protecting development was investigated. It is the determination of this research that the tendancy for shorelines to migrate, coupled with the high wave and erosion energy on open shorelines, does not allow for vegetative shoreline stabilization and survival of shoreline ecosystems while maintaining a static shoreline position (Bush et al. 2004). Thus, reestablishment of ecosystems as part of high energy shoreline protection measures will likely be unsuccessful over the long term.

Vegetative stabilization of dunes is discussed in Section 8.5 of the 3rd ed of the FEMA Coastal Construction Manual. The Manual states that success of stabilization depends in large part on the condition of the beach waterward of the dune, and that projects on eroding shorelines will be shortlived (as will likely occur due to sea level rise) (FEMA Coastal Construction Manual).

Vegetative stabilization of the beach below the mean low tide level was investigated as a way of maintaining the beach, and hence the upland dune. as well. This may be possible in the short term if such vegetation occurs naturally, but not in the long term after a certain amount of sea level rise. The feasibility of vegetative stabilization below the low tide level would be a particularly good direction for research continuation, but was not confirmed in this research.

Low Energy Shoreline Development Protection

Areas defined by the Treasure Coast Regional Planning Council as Protection Almost Certain (Brown)

Definition of Low Energy Shoreline

Low energy coastlines within the study area are those that recieve less wave energy and less dynamic sediment flows than those of high energy coastlines. Within the study area these are primarily coastlines bordering the Intracoastal Waterway.

Example: Village of North Palm Beach: Development along Intracoastal Waterway

Feasibility of Protection

Summary

Property owners should ultimately plan for coastline retreat. Temporary protective measures may be possible that are relatively financially and ecologically sustainable as described in Figures 2.3 - 2.6, but the viability of these strategies needs to be further examined.

Further Description

Due to the reasons previously outlined developed areas should plan for retreat. Sea level rise is unpredictable and rates could quickly change drastically due to factors such as melting of the Greenland and Antarctic ice caps (Tol 2005). Sea level rise wil create additional hazards for coastal development including inundation, erosion, and increased storm surge. Therefore, development should adopt an approach of gradual retreat from the coastline and ***interim adaptive measures if retreat is not immediately possible*** (See Part 3, Accommodation). Sea level rise projections can help guide this retreat, possibly by triggering actions based on certain benchmarks of rise, but as stated above do not necessarily provide a reliable basis for policies due to their imprecision.

If protective measures are to be implemented along sheltered or low energy coastlines as projected by the Treasure Coast Regional Planning Council (TCRPC 2005), there may be an opportunity to design coastal protection systems that are relatively ecologically and financially sustainable. This is in part due to differences in coastal dynamics between sheltered and open coastlines such as less wave action and erosion, as well as to differences in vegetative communities and land formations.

The following sections investigate strategies for protection of the existing shoreline position in North Palm Beach with the goal of pursuing higher levels of ecological and financial sustainability. This was seen as an opportunity for shoreline restoration if suitable alternatives could be found to seawall construction and strengthening in response to sea level rise. Figure 3.8 is a diagram of the existing seawall, which is typical along much of the shoreline. Figure 3.9 diagrams heightening of the existing seawall and Figures 3.10 - 3.11 diagram alternative solutions to heightening the seawall based on the above outlined goals. Figures 3.12 and 3.13 diagram beach nourishment and conservation land protection respectively.

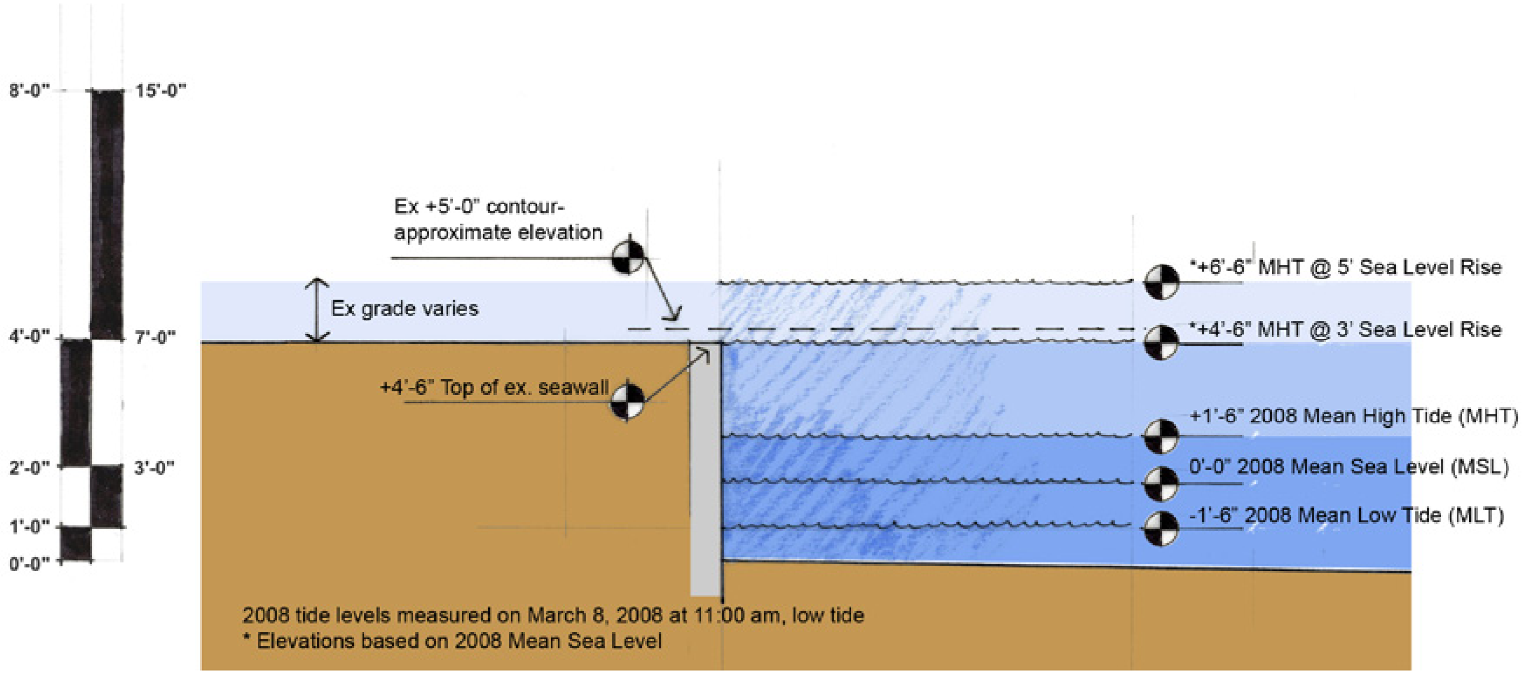


Figure 3.8: Section through Existing Seawall: This diagram shows tidal fluctuations in relationship to a seawall assumed typical for North Palm Beach. Sea level rise of three and five feet is shown based on the 2008 mean high tide. Tidal levels were measured on site at low tide on March 3, 2008 at 11:00 am, and verified by research. On-site measurements were essential in order to determine tide levels relative to the height of the existing seawall. Seawalls are a common condition along much of the developed coast of North Palm Beach, so this shoreline condition was chosen for primary focus in this section.

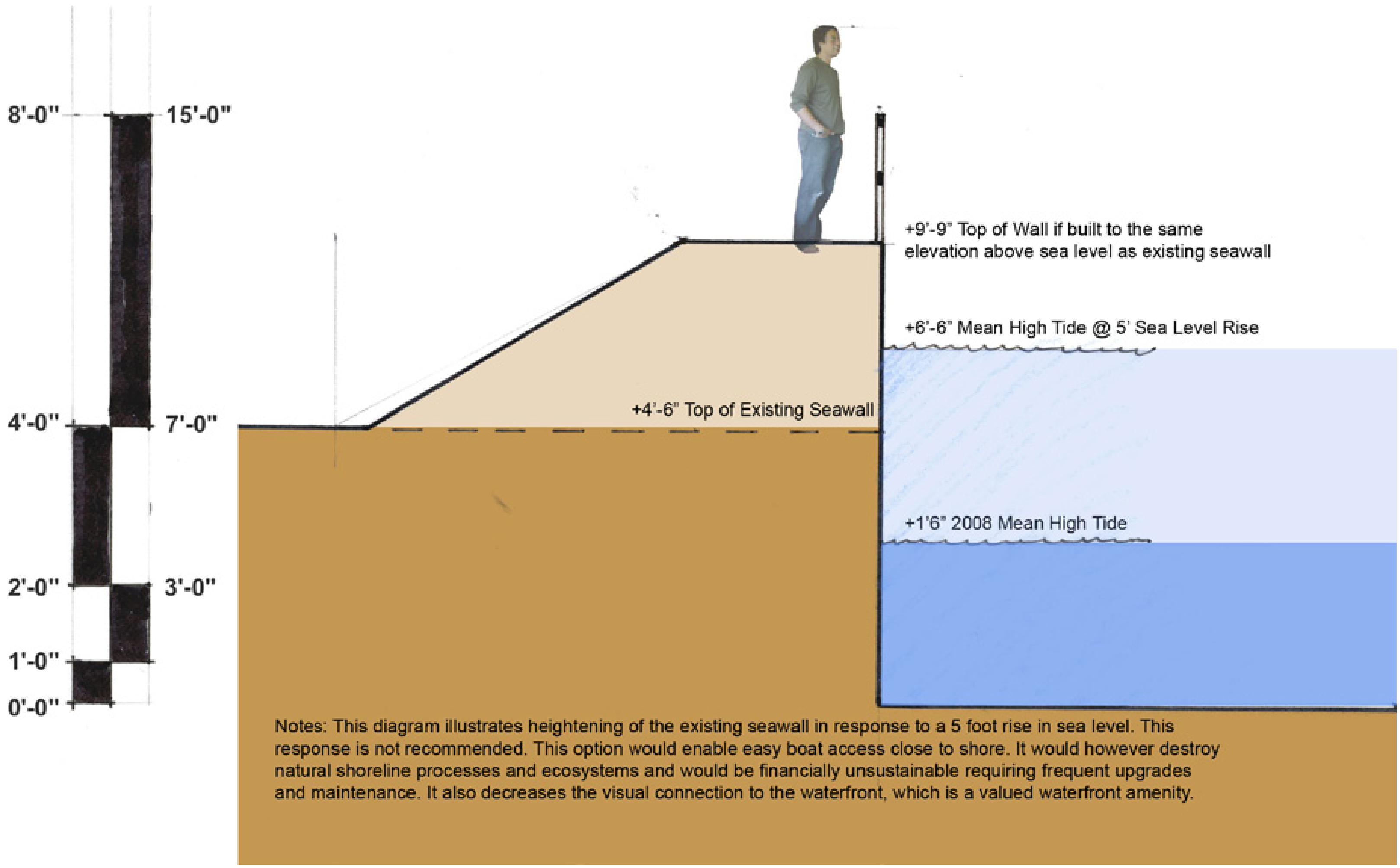


Figure 3.9: Extension of the existing seawall in response to a five foot sea level rise

Ecosystem Reestablishment on Low Energy Protected Shorelines

The following section discusses the approach adopted towards the reestablishment of vegetation and ecosystems as diagrammed in the following pages. Within the protective strategies proposed, living shoreline principles are reflected through the restoration of vegetative stabilizing species that replace the existing seawall and form foundations for a living shoreline.

On low energy shorelines it may be possible to maintain re-established ecosystems, while still maintaining existing shoreline positions in the face of sea level rise. This is because low energy shorelines recieve less wave and erosive energy than do high energy shorelines. The caveat to this is that ecosystems must still be able to retreat in response to sea level rise. This may be possible through establishment of ecosystems seaward of the existing shoreline, which can retreat up to the existing shoreline position. This option for ecosystem retreat creates several issues, the primary being the source of sediment on sediment starved shores, and the filling in of waterways, which could constitute a taking of public land.

Another option for ecosystem retreat is to allow retreat inland from existing shorelines. Shoreline protection must be discontinued for this to occur. This method creates issues because protection of the existing shoreline must be prohibited creating the potential for 'takings', the area required for retreat reduces the area of developable land on private properties, and because the retreat of ecosystems may be blocked by upland structures.

In the following diagrams, the first method of ecosystem retreat was used as a basis because it allows protection of existing shoreline positions. Based on the existing natural communities in the study area, marsh and mangrove communities are probably most suitable for ecosystem reestablishment. The ability of these communities to stabilize sediment makes them particularly appropriate for use in strategies for sea level rise adaptation. Salt marshes are often most extensive in areas with low gradient and high tidal range, and for this reason were chosen as more suitable for establishment in wide intertidal zones (Myers 1990). Marsh grasses such as Spartina are often the first species to colonize an intertidal zone, and are succeeded by mangroves that eliminate the grass by shading (Myers 1990). Mangroves were determined to be more suitable for re-vegetation where shoreline gradients are higher because they do not require a low shoreline gradient for retreat as much as provision of land to retreat to (Clark 2008), and because the typical ecology of the study area has grasses occuring in areas of lower shoreline gradient, and mangroves occuring upland of this. In the event of a barrier island breach, these species may no longer be appropriate because of their inability to withstand higher wave energy and erosion.

Introduction to Figures 3.10-3.11

Figures 3.10 and 3.11 refer to the same existing seawall diagrammed on the previous pages. They illustrate an alternative strategy to strengthening of the existing seawall as shown in Figure 3.9. The goal of the strategies proposed in the following diagrams was to explore an ecologically and financially sustainable option for protection of existing shoreline positions, primarily where seawalls currently exist. The reconstruction of an adaptable riparian corridor was examined as a method of achieving these goals, with the objective of providing the same level of protection as would be achieved through seawall construction.

The ultimate sustainability of these solutions needs to be researched further, and one of the primary issues is the source of the sediment required to implement the strategies, particularly on sediment starved coasts (Putz 2008). A choice would have to be made between bringing in sand from other sources and trapping sand, which interferes with natural sediment flows. Other important issues include the taking of sovereign submerged lands, and the allowance for upland drainage to avoid a bathtub effect. The specifics of construction, such as choice of vegetative species, needs to be carefully evaluated. The performance and impacts of this strategy below the mean low tide level also need to be researched.

Figures 3.11a and 3.11b demonstrate ecosystem retreat by establishing ecosystems seaward of the existing shoreline and seawall. They do this by creating an offshore berm upon which vegetation can be established in shallow waters and gradually placing fill behind this berm in keeping with the rate of sea level rise, creating land up which ecosystems can retreat. In places where a seawall exists, this option can be used to create a shallow gradient for ecosystem retreat, while maintaining the shoreline position defined by the seawall.

Another alternative that does not require this offshore berm is shown below in Figure 3.10. This option involves placement of fill closer to the existing shoreline and seawall, thereby reducing the amount of fill required and takings of submerged land, but creating a steeper shoreline gradient. A third option is to remove the existing seawall and restore a natural shoreline gradient and ecosystems. This would however cause a loss of land for coastal property owners and does not protect existing shoreline positions, so was not diagrammed here.

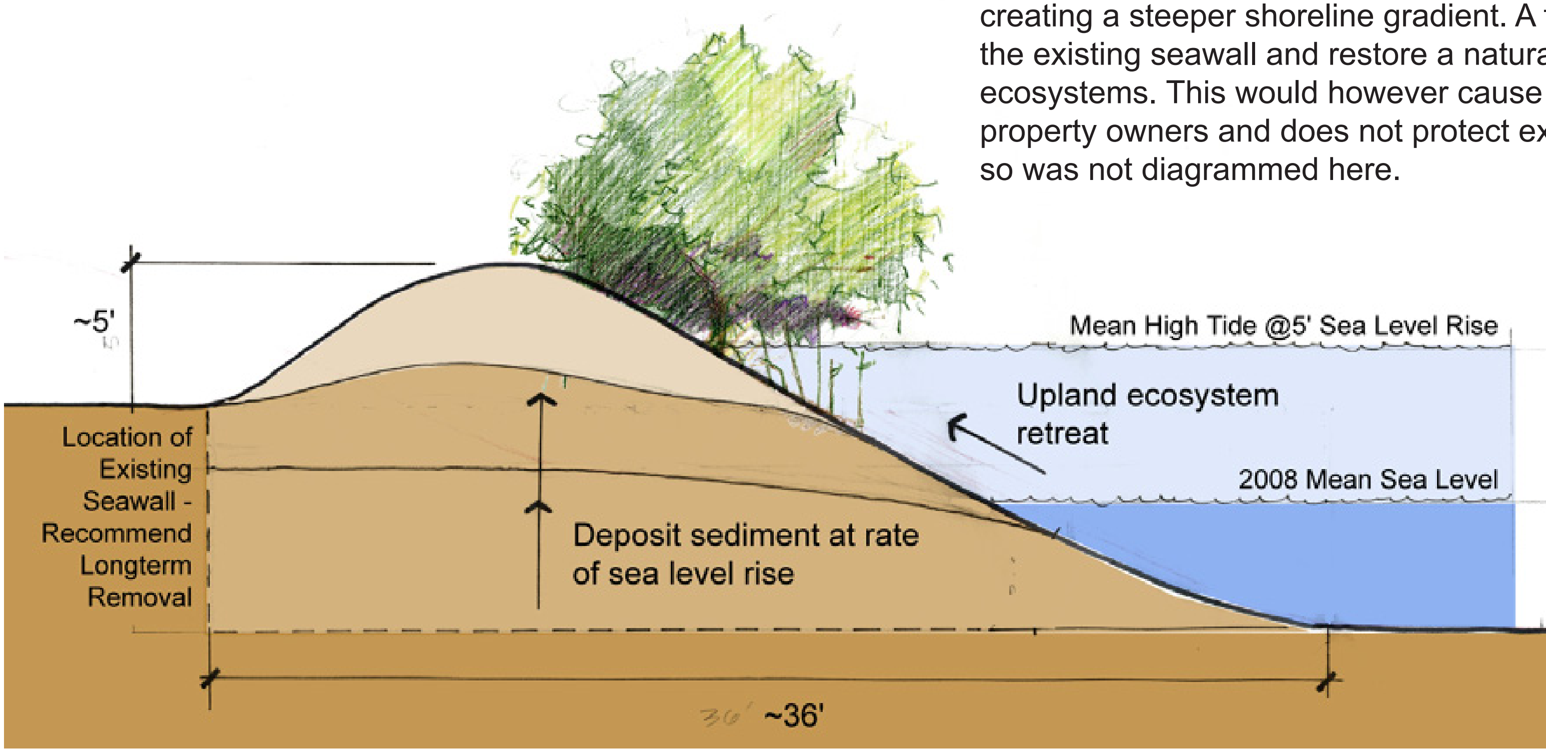


Figure 3.10: Protection of Existing Low Energy Shoreline through Ecosystem Restoration: High Shoreline Gradient

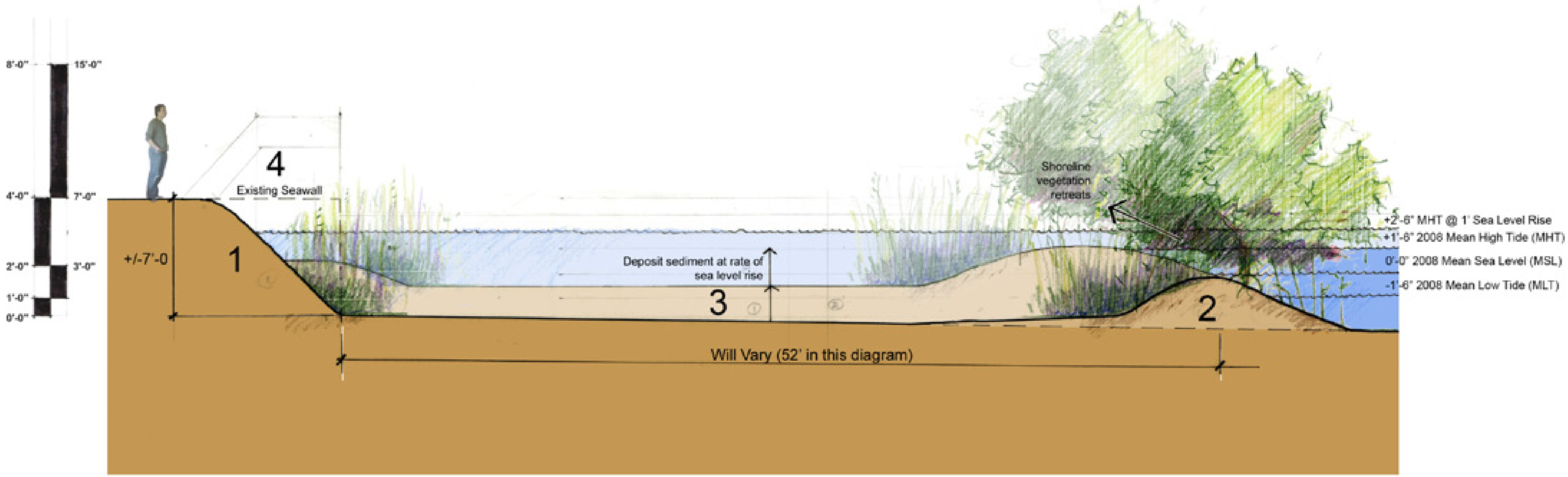


Figure 3.11a: Protection of Existing Low Energy Shoreline through Ecosystem Restoration: Low Shoreline Gradient

<u>Steps for Implementation</u>

The following are steps that could be taken to implement the shoreline protection strategy shown above. The objective of this strategy is to provide the same level of protection as would be gained by building a dike or strengthening the seawall. The financial cost would be high, but spread over a long period of time. The ecological sustainability of this strategy is debatable, as discussed previously.

1. Prohibit additional coastal hardening or construction of seawalls. Offer incentives for removal of existing shoreline protection structures as they require maintenance and restore a sloped shore profile. Establish vegetative stabilization along the shoreline.
2. Establish Mangroves or other stabilizing vegetation in shallow waters offshore on low berms as required to elevate plants within the tidal zone. Create breaks and adjust the height of berms to allow tidal flow.
3. In the space between the mainland and offshore plantings establish salt marsh grasses or other appropriate wetland species as necessary to maintain functional ecosystems. Within this area, deposit sediment at rate the required to allow wetland plantings to adapt to the rate of sea level rise (rate of sea level rise minus the accretion rate of the plantings).
4. Costs should be shared between public and private sources. Private property owners can contribute the money that would normally be spent on privately funded protective structures, with the understanding that the organization providing the remainder of the funding is providing a shoreline stabilization service.

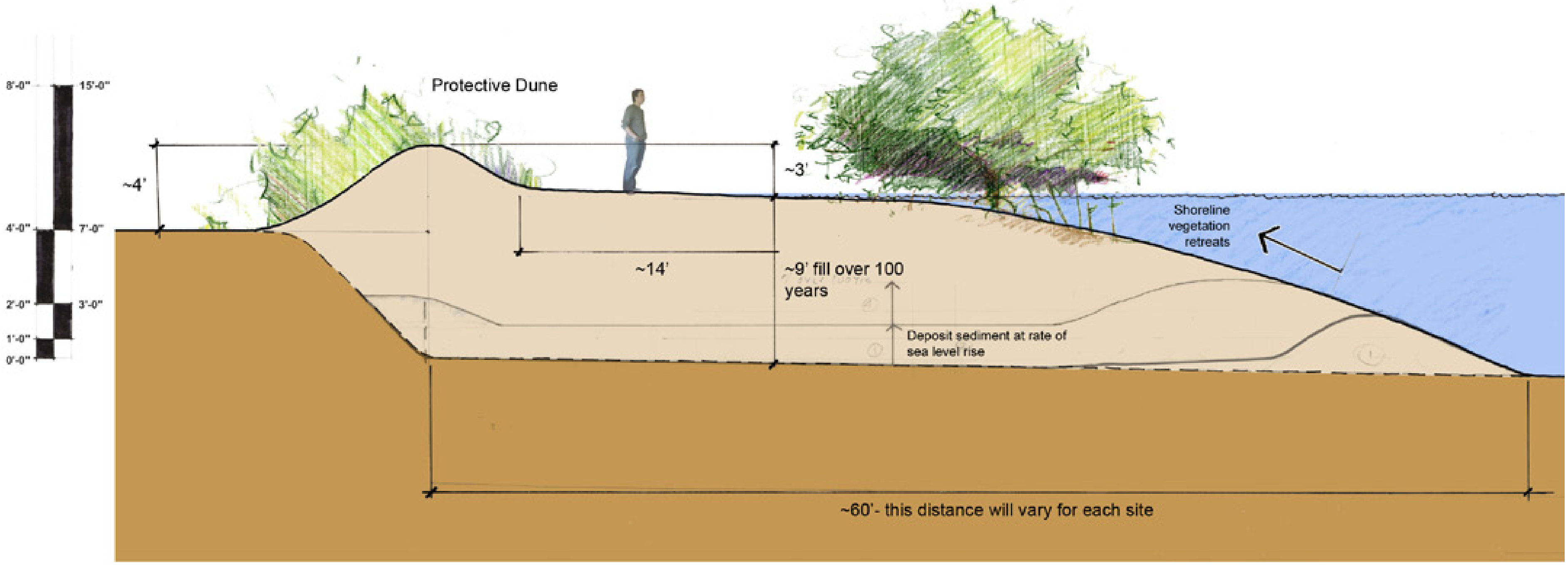


Figure 3.11b: Protection of Existing Low Energy Shoreline through Ecosystem Restoration: Low Shoreline Gradient

Additional Notes:

The viability of this solution was informally verified through consultation with several researchers, but additional study is required. In order to adapt to sea level rise, mangroves and other shoreline plants need a place within the tidal zone in which to retreat, and their ability to adapt to sea level rise is in large part a function of the rate of sea level rise being roughly equivalent to the rate of accretion. Artificially enhanced accretion through placement of fill could accomplish this goal. ***It may also be possible to place fill directly on top of mangrove plantings, killing the old but allowing new seedlings to grow. This would decrease the area and amount of fill needed to implement this strategy*** (Clark 2008)***.***

Dimensions shown in this diagram will vary based on site conditions. For example, depending on site conditions it may not be necessary to create an offshore berm, but rather to add or remove fill along the existing shoreline creating a sloped shoreline profile up which ecosystems can retreat. The height of the dune in this example was based on providing the same level of vertical protection as if the existing seawall was heightened. Construction of a dune may not be appropriate based on natural shoreline conditions or sediment availability, but if not, another suitable alternative should be found that provides the same level of protection.

Beach Protection

Areas defined by the Treasure Coast Regional Planning Council as Protection Almost Certain (Brown) or Protection Reasonably Likely (Red)

Example: Riviera Beach

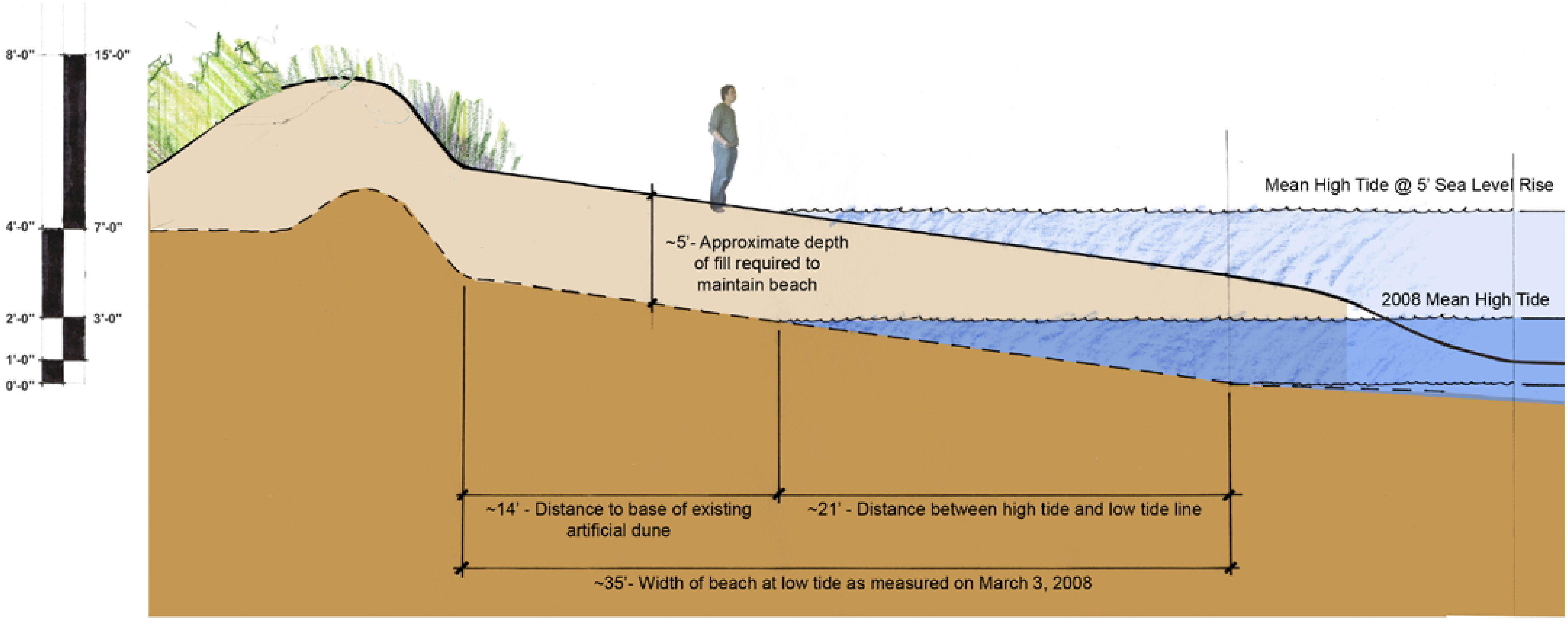
Feasibility of Protection

Summary

Beach management should incorporate plans that allow natural shoreline migration and processes. Beaches should not be protected.

Further Description

Figure 3.12 illustrates beach nourishment of an existing mainland beach in the Intracoastal Waterway in North Palm Beach. Nourishment may have negative ecological effects and can be financially unsustainable depending on the project location. Sea level rise may exacerbate these difficulties. Protection of beaches through nourishment is not recommended in lieu of natural shoreline migration, however there are beaches that directly abut valuable developement or that have high recreational value. Protection of these beaches through nourishment on low energy shorelines may be relatively long lasting and financially sustainable. Protection of high energy coastlines through nourishment will likely by short term solutions and financially unsustainable. Stabilzation of these beaches through hard methods such as sills, groins, and offshore breakwaters can negatively affect sediment flow and may not function for stabilization. Vegetative stabilization was also investigated but at this time was deemed not possible (FEMA Coastal Construction Manual).



Note: This section is drawn through an existing beach in North Palm Beach at Lakeside Park immediately south of the section cutline. It illustrates the amount of artificial fill required to maintain the beach without allowing coastline retreat. This could be feasible because the beach is on a sheltered low energy coastline. It is probably not a financially or ecologically sustainable solution.

Figure 3.12: Beach Nourishment

Conservation Land Protection on Low Energy Shorelines

Feasibility of Protection:

Summary

Artificial protection of conservation lands is not recommended; instead, natural adaptive and successional process should be allowed to take place. Protection should only occur for critical conservation lands of a very high priority level, where ecosystem loss due to sea level rise is almost certain, and where no other adaptive approach is possible such as provision of lands for ecosystem retreat. Figure 3.13 illustrates a concept for protection of ecosystems fitting this description.

Intervention may be appropriate that assists ecosystems in adapting to the rate of sea level rise. Planning should occur that allows for retreat and adaptation of ecosystems in response to sea level rise, in particular by anticipating conflicts with development.

Example: Figure 3.13 is a section cut through a portion of John D. MacArthur State Park for illustrative purposes, but the level of habitat criticality of this area has not been verified.

Further Description:

Protection of conservation lands is not recommended because it will interfere with coastal processes and natural adaptation and succession. Artificial structures that combat natural processes will require regular maintenance to remain functional. If ecosystem establishment is used to protect shorelines it may be difficult to maintain them as functional (UNEP-WCMC 2006). Interference with natural processes often has many associated and unanticipated negative ecological effects, which would have to be weighed against the value of the conservation lands being protected. For example, when shoreline ecosystems are altered in order to preseve upland ecosystems, upland species will be preserved, but the traditional shoreline animal and plant species will probably suffer (Clark 2008).

Allowing natural adaptation is financially and ecologically more sustainable than protection. Ecosystems that are allowed to respond naturally will evolve and may be stronger than those that are not allowed to respond naturally. Shorelines have always adapted to fluctuations in sea level and will continue to do so if change and succession are accepted.

This said, there may be some situations where protection is necessary- for example to preserve valuable habitat for Florida Panthers where habitat loss would result in the loss of a critical population of panthers. The Critcal Lands/Water Identification Project identifies such critical conservation lands. This situation will most likely occur due to loss of habitat from inundation or salt water intrusion, where human development hinders the ability for natural systems to retreat, or if the rate of sea level rise is too great for an ecosystem to adapt and net loss of critical ecosystems is expected. However, these situations should be rigorously evaluated for other alternatives.

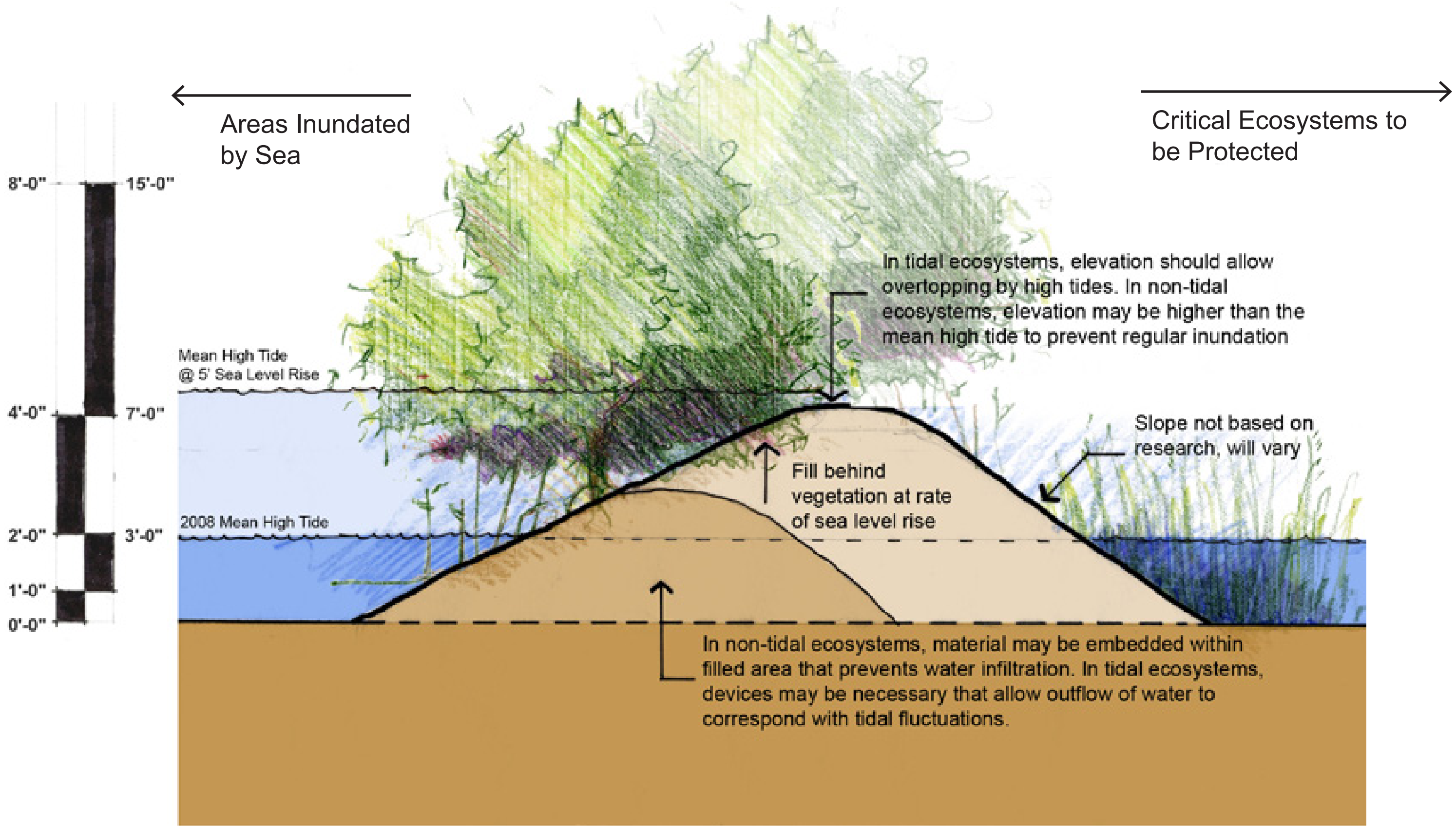


Figure 3.13: Critical Ecosystem Protection

This diagram illustrates a potential strategy for protecting critical conservation lands. This strategy could be constructed in phases. It could also be part of a longterm managed retreat strategy and function to increase the amount of time allowed for ecosystem adaptation or as a temporary protective measure while alternative conservation lands are being secured or lands for ecosystem retreat. Water flow is a primary issue with this sort of strategy. Regulated tidal exchange strategies such as overtopping, seepage or valves could be considered as part of strategies to allow water flow in and out of the protected area. Note differences between protection of tidal and non-tidal ecosystems.

Design Guidelines for 'Areas Likely to be Inundated'

In this study, accommodation of sea level rise is addressed through design guidelines for 'areas likely to be inundated'. 'areas likely to be inundated' should be defined by storm surge, erosion, and sea level rise projections, and these areas should have unique standards for use and development. New construction that cannot accomodate sea level rise through ecologically and financially sustainable methods as described in the guidelines should not occur in areas where inundation is likely. The guidelines included here are by no means comprehensive or applicable to all communities, but have been compiled based on a variety of sources and conversations as a basis for individual community design guidelines.

The goals defined by this paper for coastal management responses to sea level rise are:

Ecological sustainability
Financial sustainability
Hazard mitigation

For all coastal communities, the following points are important considerations for coastal management in areas of likely inundation. Part 3, Managed Retreat applies these points to a specific site.

• Land Use: Create an alongshore buffer and encourage short term or adaptable land uses. Encourage water dependent uses, public uses such as parks, or conservation designations for 'areas likely to be inundated'

• Public Access: Allow alongshore public access through coastal buffer areas or within rolling easements

• Coastal Management: Disallow coastal hardening. Allow natural shoreline migration.

• Construction: Disallow permanent "hard" infrastructure. Plan for construction with a shorter lifespan. For docks and piers use floating rather than pier anchored construction.

Guidelines for Site Planning, Design, and Management

Plan for and allow natural coastline responses to sea level rise. Account for continuous, rapid, and unpredictable changes in environmental conditions. (Coburn 2004)

Land Use: In lands that are likely to be inundated or eroded, support land uses that are water dependent, temporary, adaptable, or evolve as sea levels rise.

Uses: Maintain water dependent land uses adjacent to the shore. Public parks and conservation lands are recommended uses.

Easements: Maintain an alongshore easement for ecosystem management, adaptation, and retreat. Depth will vary according to location. This functions as a buffer between development and the sea and may be held in public trust as parkland. It is essentially a rolling town boundary and property line (Ellis 2008). This easement would incorporate existing public lands, lands purchased from retreating private property owners, and alongshore public access easements obtained through bulkhead permits as outlined in Titus 1998.

Coastal Hazard Mitigation: Mitigate the effects of coastal hazards to development. Note: A balance must be sought between mitigating the effects of coastal hazards and encouraging development and infrastructure.

Existing Construction Policy Approaches (Coburn 2004):

- Implement policies that promote the gradual, strategic removal of structures threatened by erosion, storm hazards, and sea level rise inundation.
- Redirect funding allocated for 'shoreline erosion and protection projects' to retreat projects
- Improve monitoring of coastal development through the enforcement of existing regulations
- Plan for the retreat of successive rows of shorefront structures through land use plans that enforce stricter building codes

New construction: New construction should be prohibited in areas where sea inundation is projected unless structures are built in such a way as to plan for and respond to sea level rise. New construction should particularly be limited on barrier islands or low elevation islands. Construction of publicly financed infrastructure in areas of likely inundation should be limited.

- Rolling Easements: The acceptance of rolling easements, which enable shoreline migration, may be mandated as a condition for new development (Titus 1998).

Lot Design: Design long lots perpendicular to the coast that allow inundation as well as development on the upland end of the lot. This lot formation is more advisable than thin lots parallel to the coast that bear the risk of complete loss of development potential due to seawater intrusion. Buildings should be sited on the upland edge of the lot.

Maintaining Ecosystem Services

- Water Retention (Sponge Surfaces): Maintain ecosystems that naturally retain water such as wetlands. These ecosystems can help minimize damage from storm surge.
- Natural Buffers: Maintain natural buffering systems such as mangrove forests and dunes.

Water Management and Conservation: Mitigate and plan for projected salt water intrusion and freshwater shortages.

Water Usage: Implement and enforce sustainable water conservation and use strategies through incentives, education, and policies.

Greywater Collection: Implement and incentivize greywater collection and reuse strategies

Stormwater Management: Use sustainable stormwater management practices including on-site filtration and allowing infiltration in upland areas.

Stormwater Collection: Use stormwater collection devices such as cisterns and rain gardens.

- Research Requirement: In areas where infiltration will result in salt water contamination, research should be conducted on the consequences of collecting all stormwater from all possible impervious surfaces including paved areas. The goal of this would be increased freshwater collection, but it could have a negative effect by reducing ground infiltration.

Shoreline Management: Maintain and support natural coastal processes such as sedimentation transport and allow natural ecosystem migration in response to sea level rise. Other guidelines should be referenced in addition to these regarding shoreline management.

Disallow construction of coastal hardening structures such as seawalls. (Titus 1998 recommends complete prohibition of coastal hardening as part of rolling easement policies)

Mandate the removal of all hard stabilization (including sandbags) artificially holding the shoreline in place. (Coburn 2004)

Minimize negative interference with coastal ecosystems that are important to sedimentation processes such as dune and beach systems or mangrove forests. Negative interference could be defined as any human intervention that inhibits natural processes. This should include the following actions Coburn 2004):

- Protect barrier beach systems in their natural state
- Allow shorelines to migrate landward in response to sea level rise
- Allow dunes and dune grasses to move landward with the beach
- Allow storms to overwash and deposit sand behind dunes
- Allow inlets to open, close, and switch channels

Exceptions where human intervention in these processes could be appropriate are:

- Where natural processes responding to sea level rise will result in the loss of a critical habitat linkage. In this situation the value of the habitat should be evaluated against the measures that would be required to sustain it.

<u>Shoreline management:</u> Where coastal hardening structures are removed, living shorelines should be constructed. Living shorelines are a method of shoreline stabilization that attempts to restore functional riparian and littoral ecosystems while maintaining natural shoreline processes.

Ecosystem Adaptation and Retreat: Proactively assist in ecosystem adaptation. This entails various measures including ecosystem stabilization, restoration, and setting aside of lands for ecosystem retreat.

Support and manage existing coastal ecosystems such as wetlands, coastal marshes, dunes, and beaches

Implement ecosystem restoration on publicly owned lands

<u>Ecosystem retreat:</u> Allocate land for upland ecosystem retreat from sea water inundation. The description of the South Bay Salt Pond Restoration Project in Appendix F provides design strategies for implementing ecosystem retreat. Some important additional steps are listed below:

- Use Critical Lands/Water Identification Project (CLIP) information and land use conflict analysis to designate priority areas for ecosystem retreat.

- Allocate lands for ecosystem retreat and restoration based on land use conflict analysis

- Maintain an alongshore easement for managed ecosystem adaptation. Depth would vary according to location.

- Limit coastal hardening and soft engineering solutions.

Guidelines for New Construction and Existing Structure Modification

The design of new construction should plan for and respond to sea level rise. Structures can learn from historic vernacular architectural responses to coastal hazards. Just as coastal armoring encourages habitation in coastal hazard areas, so do hardened structures. A mandate for hardened structures encourages unwise investment in coastal lands, which will prove to be costly for both private property owners and governments. It is possible that building codes should mandate less permanent construction methods in coastal hazard areas and focus on improving evacuation responses.

Function: Designs should be evaluated whose uses and function adapt and change over time in response to sea level rise. Zoning codes may be revised to take into account change of land use based on certain benchmarks of sea level rise.

Adaptability

Non-permanent structures and surfaces: In lands where inundation is likely, structures that are designed with a shorter life span may be appropriate

- Consider the design of surfaces and structures that can erode, decompose naturally such as crushed shell, mulch, or rammed/compacted earth.

Relocation: Structures and infrastructure should be relocation-friendly, particularly if constructed with high financial investment

- Piers or other foundation construction techniques that allow dismounting of the building from the foundation may be used.
- Floating structures are recommended for overwater construction such as docks.
- Modular structures that can be easily disassembled may be used.

Elevation: Structures may be appropriate that are elevated above sea level rise projections. Design considerations should include durability during storm events, access to the structure after sea levels rise, and ecological impact.

Plant Species

Cultivate flood and salt tolerant landscape plants and crops in ‘areas likely to be inundated’ (Ellis, 2008)

Consider the lifespan of plantings in relation to the rate of sea level rise. Plant short term or salt tolerant plants in areas that where inundation is likely to occur in the short term, and nonsalt tolerant hardwood trees in upland areas that are not soon projected to be inundated.

Cost: Cost of structures in areas where inundation is likely should be evaluated in terms of the life span of the structure. Lower cost or easily moveable structures may be appropriate in areas where inundation is likely.

Abandonment: Structures that are expected to be abandoned after a certain level of inundation should be constructed and managed to minimize environmental hazards.

Structures where abandonment is expected should be constructed of materials that do not pose an environmental hazard.

In the case of abandonment, structures should be able to be disassembled so that there are no environmentally hazardous materials remaining.

Additional Notes on Moveability and Permanence

• Easily moveable- Structures that are easily moveable or easily disassembled will adapt more easily to managed retreat policies. If a structure is for some reason placed with in an area where inundation is likely, ease of mobility will clearly help it adapt. Wood framed structures or modular structures are examples. Moveability may be a good alternative to non-permanence for property owners with few financial resources to invest.

• Non-permanent structures- Construction methods that are less permanent but allow easy reconstruction have been built worldwide throughout history, and as civilizations grow more ‘advanced’ the permanence of structures often seems to increase. Traditional Japanese construction methods are examples of this. Another way to think of these methods is as non-rigid. Eastern philosophy discusses the supremacy of water over stone because the water adapts but is persistent whereas the stone resists but eventually is eroded. The applicability of this to Florida is that hardening of shores and structures is an attempt to defy powerful natural processes. Perhaps hardening of coastal structures and coastlines to defy coastal hazards is not advisable, but rather less hardening and improved retreat and evacuation measures are more appropriate. An important caveat to this is that economic investment into non-permanent structures must be weighed in terms of their longevity. Small local governments and property owners will have to be wise with the use of their resources in areas that are likely to be inundated.

• An organization that offers an opposing point to the idea of non-permanence is the Institute for Building and Home Safety (IBHS), which has a “Fortified for Safer Living Designation” that outlines guidelines for site and building hardening against natural disasters. This idea is much more intuitive than non-permanence for Americans, who invest much into their homes and buildings and certainly do not want to see them destroyed or plan on rebuilding. IBHS is a national nonprofit insurance industry trade association.

References:

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The primary conclusions and findings from this research are as follows. These are specific for the study area, but are also applicable statewide.

• *Ecologically and financially sustainable shoreline protection is probably not possible as defined in this paper, particularly on high energy shorelines. Shoreline protection will only be feasible up to a certain amount of sea level rise, after which the financial costs will be too great to justify protection.*

On high energy shorelines, coastal protection that attempts to maintain a static shoreline position is in direct opposition to natural coastline processes such as sediment flow and ecosystem migration. Protection of these shores is ecologically unsustainable because by impeding these processes it disturbs natural shorelines and the associated ecosystems. It is financially unsustainable because it encourages inappropriate development and use of lands in hazard zones where development will be at increasingly higher levels of risk from inundation, erosion, and storm events. This will require continued maintenance and investment in shoreline protection structures.

On low energy shorelines, coastal protection is more feasible because of reduced wave erosion. For this reason, the maintenance of structures could be less expensive, but the effects from storm events will still create high costs for coastal development. Coastal protection structures will be ecologically unsustainable as well. Among other negative effects, these structures alter sediment flow patterns, break connections to upland communities, and disturb existing shoreline ecosystems. With relation to sea level rise, protection is particularly unsustainable because it prevents shoreline ecosystem retreat upland in response to sea level rise.

At some amount of sea level rise (10-15 feet), the cost of protecting either high or low energy shorelines will be too great to justify protection.

• *As an alternative to shoreline protection, managed retreat policies should be implemented and shorelines should generally be allowed to retreat naturally.*

Research defined managed retreat as the most ecologically and financially sustainable method of response to sea level rise over the long term. With regard to ecological sustainability, retreat allows natural shoreline responses to sea level ries to occur and creates room for ecosystem retreat. Retreat will be financially more sustainable than protection in the long term because it moves development out of the way of coastal hazards avoiding high costs from property damage. Retreat will also be less expensive than the long term maintenance of shoreline protection structures depending on the site conditions, the amount of sea level rise that occurs, and whether property owners factor retreat into their plans early on. There are economic, political, and constitutional issues associated with the implementation of managed retreat. The research for this paper indicates that there are methods of addressing these issues, one of which is through rolling easements. These issues are discussed in greater depth in other studies and were not the focus of this paper (See Titus 1998).

• *Proactive human action is necessary to facilitate ecosystem adaptation to sea level rise.*

It is very likely that sea level rise will result in ecosystem degradation and loss. Shoreline protection exacerbates the effects of sea level rise by inhibiting the ability of ecosystems to naturally adapt and retreat. Proactive action is necessary to preserve ecosystems in the face of sea level rise. Some of the most important actions that should be taken to facilitate ecosystem adaptation are the removal of shoreline protection structures and other development that impedes ecosystem retreat. It is also important to allocate lands for ecosystem retreat and restoration as part of land use plans.

• *Guidelines must be adopted for the use of 'areas likely to be inundated'.*

'areas likely to be inundated' are defined as those areas in danger of flooding from storm surge or sea level rise. It is important to adopt guidelines for 'areas likely to be inundated' for several reasons. First, suitable land uses within these areas will be better able to respond and adapt to coastal hazards, minimizing financial loss and hazards to coastal populations. Second, suitable land use within these areas can facilitate ecosystem adaptation and allow natural shoreline processes and migration to occur. Some of the key elements discussed as part of guidelines for 'areas likely to be inundated' are the discontinuation of permanent land uses that are not relocation friendly, the conversion to land uses that accommodate inundation, and the provision of lands for ecosystem retreat including an alongshore buffer for ecosystem retreat and management.

Areas for Further Research

There are many areas of research that this study was unable to address, as well as applications of research that would occur with the availability of additional time. These are as follows:

• The integration of conceptual design methodology in this project was less than anticipated due to time constraints and the level of research required to propose informed solutions. Solutions with a focus on conceptual process and design should be explored.

• Focus should be placed on land use conflict analysis caused by in-migration. The LUCIS model developed by University of Florida professors Paul Zwick and Peggy Carr could be a good method for approaching this analysis.

• Coastal response to sea level rise needs to be analyzed through greater analysis of watersheds and drainage basins. Analysis should also occur based on long shore perpendicular sections that factor in a variety of ecosystem and geographic relationships.

• Strategies for adaptation along river shorelines should be explored. The Room for the River Project (Klijn 2001) provides a good point of departure for defining flood management strategies along river shorelines, but may need to be adapted for applicability to permanent inundation.

• Consideration of saltwater intrusion into freshwater bodies should be integrated more fully as part of adaptive strategies.

• It would be valuable to explore the feasibility of vegetative stabilization below the mean low tide level, particularly on high energy shorelines.

• The effects of a barrier island breach on the ecology of the Lake Worth Lagoon, and necessary changes in adaptive strategies to sea level rise should be evaluated.

Adaptive measures that address specific coastal issues should be explored in greater depth. These issues include:

• Adaptation of cultural and historic resources to inundation and how management of these resources can fit into managed retreat policies should be examined.

• Adaptation of working waterfront industries and other water dependent land uses to managed retreat policies should be examined.

• The consequences of a barrier island breach, and how this should alter protective response strategies should be examined. For example, species used for shoreline revegetation will vary due to changes in wave energy and salinity caused by a breach.

As shown in this study, it is essential for Florida communities to plan for the likelihood of sea level rise. Each region should uniquely address adaptive measures, but there are common principles that planners should address such as the necessity of assisting in ecosystem adaptation. Communities should endeavor to minimize the negative effects and ultimately explore the potential for positive outcomes from sea level rise.

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Accommodation: The use of strategies that allow for the use of vulnerable lands to continue, but that do not attempt to prevent flooding or inundation with shoreline protection.

Area Likely to Be Inundated: Lands that are likely to be flooded by storm surge, sea level rise, or due to erosion based on current projections and trends.

Coastal/Shoreline Hardening: The attempt to maintain existing shoreline positions through fixed methods intended to provide for longterm stabilization and protection.

Ecological Sustainability: The level to which coastal management strategies support and maintain fully functional natural coastal processes and healthy riparian, littoral, and aquatic ecosystems.

Financial Sustainability: The ability of governments and private land owners to fund and maintain coastal management strategies without undue financial costs over the life of the project. Undue financial costs could be defined by the value of the coastal management strategy as evaluated against alternative strategies and within the framework of a broader budget.

High/Low Energy Shoreline: Defined by the amount of wave energy recieved along a shoreline.

Littoral Zone: The intertidal area between mean high tide and mean low tide marks.

Managed Retreat: Moving development out of harm's way in a planned and controlled manner using techniques such as property abandonment, structure relocation, and hazard avoidance.

Protection: Shoreline stabilizing or hardening techniques such as seawalls and beach nourishment that attempt to maintain a static shoreline position.

Riparian Zone: The biologically distinctive area that forms the transition zone between upland and aquatic ecosystems.

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This section describes some important sources of information referenced in this research. It does not cover all sources listed in the annotated bibliography. Preliminary research was conducted on waterfront design principles, coastal ecosystems and processes, traditional engineering and development responses to coastal hazards, and managed retreat as a response to coastal hazards. Further research was then undertaken to locate real world or design projects (case study projects) addressing sea level rise and policy options for response. The references for this research are included at the end of each section and in Part 4, Bibliography.

The majority of literature discussing sea level rise falls under several categories: scientific evidence of sea level rise, discussion of effects and responses by coastal ecosystems- in particular wetlands, policy and land use implications, and managed retreat policies. Literature was found to be lacking that discussed response to sea level rise from a design point of view, particularly in terms of gradual and long-term inundation. Few sources were found that showed graphic illustration of concepts for specific sites. Most importantly, almost no sources discussed solutions for coastlines where retreat is unlikely to occur and protection is almost certain. Solutions for coastal protection from an ecologically and financially sustainable point of view are not discussed. Coastal protection is frequently discussed in terms of being an unsuitable response followed by planning options that can be used in lieu of protection and policies to implement retreat. This is in my mind a critical gap in research. Literature discussing sea level rise specific to Florida does exist though it falls within the parameters outlined above.

Waterfront Design Principles: Principles of waterfront design have been discussed in a variety of publications and presentations. Some of the primary sources reviewed were local government design guidelines and ordinances, online presentations and publications such as from the City of Cleveland, ULI, and PPS, and consultations from the University of Florida Conservation Clinic. The following is a compilation of common principles identified in the projects researched.

Principles for Good Waterfront Design

- Facilitate Public Access- Create opportunities for public visual and physical access to the waterfront.
- Protect Natural Ecology- Protect, restore, and enhance natural environmental conditions.
- Facilitate Appropriate Economic Development- Use the waterfront as an attraction to encourage mixed-use development. The question of encouraging water dependent uses also is particularly important, and seemed to recieve a low level of emphasis in the examples discussed above.
- Facilitate Social and Economic Equity- Create a variety of development and housing types along the waterfront to accommodate various income levels. This is to combat waterfront that is exclusively accessible to high-income users.

Coastal Ecosystems and Processes: Research did not identify substantial detailed information on coastal ecosystem services. Several sources give a broad overview of ecosystem services and probable functions, but little detailed information. Ecosystems of Florida edited by Ronald L. Myers and John J. Ewel is an extremely important source of information on Florida ecosystems. The Millenium Ecosystem Assessment edited by Lelys Bravo De Guenni, et al is an important source of information on ecosystem processes and services. Nature's Services: Societal Dependence on Natural Ecosystems edited by Gretchen Daily is another source of information on ecosystem services. The UNEP-

WCMC publication, “In the front line: shoreline protection and other ecosystem services from mangroves and coral reefs” is an excellent source of information on ecosystem services provided by reefs and mangrove forests.

Coastal Protection: Information is plentiful on the effects of traditional coastal protection solutions such as sea walls and groins on natural shorelines. The Western Carolina University Program for the Study of Developed Shorelines was a valuable source on information on this topic. An unconventional point of interest was found in the EPA online resource for global warming discussing the idea that some situations exist where no action is necessary in response to sea level rise. The resource states that, “port facilities and many other coastal structures are rebuilt frequently enough, and the impact of sea level rise is small enough, so that new facilities need merely consider current sea level. Moreover, many structures can be erected rapidly enough so that anticipating sea level rise in unnecessary” (EPA Global Warming Publications 2004). It also makes the point that engineering activities may be able to focus on the current sea level, whereas land use and planning decisions must incorporate long-term consideration of sea level rise. (EPA Global Warming Publications 2004)

Managed Retreat and Land Use: Information on managed retreat as a response to sea level rise is plentiful. Managed retreat seems to be recommended by the majority of planners and policy makers. The Western Carolina University Program for the Study of Developed Shorelines has published a variety of papers on managed retreat that are extremely valuable sources of information on this topic. The EPA Global Warming Publications resource was quite valuable in locating key publications to be referenced. The 2007 report by Dr. Stephen Mulkey to the Century Commission was referenced heavily for Florida specific information and provided a basis for discussions of land use responses to sea level rise.

Case Studies: A variety of sources were reviewed for information on case study projects including journals, websites, books, and magazines, but no definitive source exists discussing projects related to sea level rise. Very few projects were found that address sea level rise, though many projects address periodic inundation. Sources and information on the projects reviewed are located in Part 4, Appendix E. Projects that were of value were the Salt Pond Restoration Project in the San Francisco Bay, a 15,100 acre tidal wetland restoration project in South San Francisco Bay. The project is specifically addressing sea level rise in its planning process. The redevelopment of the Anterp Quays was also a valuable case study project as it is one of the few located addressing sea level rise with a design based approach. The Room for the River project is also valuable, and it investigates strategies for dealing with higher river discharges on the Rhine River in combination with higher sea levels. Dike strengthening is looked at as a last option, and strategies are explored for creating room for the river to expand rather than increasing shoreline protection and hazard risk.

Policy Options: Several sources were reviewed that discuss policy options to respond to sea level rise. The final recommendations included in this report are primarily based on the publications by James G. Titus, EPA.

Additional valuable information was referenced from the publication on sea level rise published by the Treasure Coast Regional Planning Council. This publication discusses anticipated responses to a five foot rise in sea level along the Treasure Coast. Throughout the course of the research various researchers and professionals were also consulted, and their input proved invaluable for informing, confirming, and directing the research approach. The names of some of these are located in the bibliography.

Research on Florida Coastal Ecology is broken down into the following sections.

A Description of Ecosystem Services with Potential to Mitigate the Effects of Sea Level Rise

Adaptation of Florida Coastal Ecosystems to Sea Level Rise

- Introduction
- Ecosystem Recovery Time and Ability to Adapt to Sea Level Rise
- Effects of Sea Level Rise on Selected Ecosystems

- Overview of Strategies for Ecosystem Adaptation
- Ecosystem Retreat and Alongshore Easements
- Living Shorelines

Description of Ecosystem System Services with Potential to Mitigate the Effects of Sea Level Rise

The purpose of this section is to describe ecosystem services that may aid in either flood attenuation, mitigation of the intrusive and erosive effects of sea level rise, and to minimize the destructive effects of storm surge. This serves several purposes. The first is to underscore the importance of coastal ecosystems to people living in Florida and that active human involvement in the preservation and adaptation of these ecosystems in the face of sea level rise must be a priority. This however will not be a primary focus as the values and intricacies of ecosystem services are discussed in far greater depth in other publications. The second and more important purpose for discussion of ecosystem services is based on the idea that an understanding of the ways ecosystems respond to coastal hazards can inform human design responses to these hazards. This can be manifested in use of the ecosystem itself as part of a design response to sea level rise or through use of the underlying principles of the ecosystem service reinterpreted through design.

“Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life” (Daily 1997). Ecosystem services are broken down into classifications of provisioning, regulating, cultural, or supporting services. Examples of provisioning services are food and water. Regulating services could include climate or disease regulation. Cultural services are those nonmaterial benefits people obtain from connection to the environment. Supporting services could include nutrient cycling, which is essential for maintaining life. With regard to all ecosystem services, it is important to recognize that ecosystems are interrelated and interdependent, so that human impact on one ecosystem service will affect other ecosystem services.

The following sections are broken down into two parts. The first is a description of some of the regulating ecosystem services provided by coastal ecosystems in Florida. These are by no means comprehensive, but the main purpose of this research was to inform design solutions. The second part is a description of rough design and planning implications that were drawn from an understanding of the ecosystem service. These should by no means be considered anything more than documentation of a brainstorming process.

Sedimentation and Shoreline Stabilization

This ecosystem service could be the most pertinent for informing coastal design in response to seawater intrusion. Coastal sedimentation is the natural equivalent of beach renourishment. One of the reasons this process is important for humans is because the natural accumulation of sand balances coastal erosion. This is a dynamic condition where some regions experience more erosion and some experience more renourishment. The effects of human activities such as coastal hardening on these processes has been great and are should be decreased. The coastal ecosystems below are some of those involved in sedimentation and stabilization that may be especially applicable to coastal design in response to seawater inundation. Various other natural systems, in addition to those coastal systems discussed below, play a role in the trapping of sediments and stabilization of shorelines including tidal marshes and seagrass beds, rocky slopes and shorelines, and barrier islands.

Coral Reefs

Offshore sources of sediment are important sources of sand for beaches and islands, and these sources will play a role in the adaptation of these systems to rising sea level. "Reefs produce sand that forms and replenishes sandy beaches and islands, the sediment accumulating when corals and other calcified organisms break down after their death" (UNEP-WCMC 2006). This sediment is however light and erodes more easily than other sediment sources (Thieke 2008). It is important to maintain natural reefs for this purpose, but sea level rise may present great challenges to the survival of natural reefs.

Mangrove Habitats

Mangrove forests play an important role in the accretion of Florida coastlines by trapping and stabilizing intertidal sediments and providing shoreline protection and stabilization. (Myers 1990) Mangroves also help to stabilize coastal land by trapping river sediment and other upland runoff (UNEP-WCMC 2006). The ability of mangroves to actually build new land is doubtful (Rey 2002). Mangroves are less effective at stabilization and may not survive on open coasts where strong erosional forces exist such as along the southeast Atlantic coast of Florida.

Dune Systems

With regard to shoreline sedimentation, dunes function as sediment reserves and to stabilize coastlines. Myers states that in natural conditions, "sand stored in the foredune is moved offshore by storm waves and restored to the beach with the return of normal wave conditions. Winds move the sand back to the line of plant growth, and a new dune is built up" (Myers 1990). "Encroachment in dune areas often results in shoreline destabilization, resulting in expensive and ongoing public works projects such as the building of breakwaters or seawalls and sand renourishment" (De Guenni et al. 2005).

Tidal Marshes

Mullahey et al. describe the function of salt marshes in the following quote. "On low energy coastlines and estuaries, the Salt Marsh functions as a transition zone from terrestrial to oceanic life. Salt marshes perform an important function in the stabilization and protection of shorelines, especially during storm tides. Nutrients, sediments and detritus from upland systems are redistributed by tidal action, making the marsh one of the most productive natural ecological systems. The area serves as a habitat for the early life stages of numerous ocean species as they feed on countless invertebrate organisms. Many wildlife forms overlap normal ranges at least seasonally to become harvesters and, in many cases, part of the natural food chain". (Mullahey et al.)

Tidal marshes collect sediment from incoming tides, and if sediment availability is high enough in proportion to the rate of sea level rise, marshes can build and adapt to sea level rise without significant loss of area. These ecosystems could be an important part of coastal protection measures that are more ecologically sustainable than traditional methods such as dike and seawall construction. This idea is examined in Figure 3.10, Protection through Ecosystem Restoration. A good case study example of this process can be found in Louters 1994, which describes adaptation to sea level rise of the Wadden Sea tidal marshes on the coast of the Netherlands.

Design Implications

- Minimize disruption to natural coastal sedimentation processes in all stages of the process- source, transport, and collection
- Minimize coastal hardening
- Preserve habitats that are important to sedimentation processes
- Consider ways to artificially increase silt collection, although not at the expense of natural siltation processes.
- Built devices that trap sediments similar to mangroves- in keeping with natural rates of sedimentation, extending from coast outward
- Development of silt collecting habitats as part of coastal designs

<u>Water Retention and Transfer</u>

Some natural soils have a large capacity to retain and store water, facilitate transfer of groundwater, and prevent or reduce flooding. “The capacity to hold water is dependent on soil texture (size of soil particles and spaces between them) and soil structure (nature and origin of aggregates and pores). For instance, clay soils have a larger capacity to hold water than sandy soils due to pore size” (De Guenni et al. 2005). Floodplain wetlands can have a significant role in flood attenuation. It is important to recognize that because the source of water from sea level rise is essentially infinite and inundation will be constant, water retention will be most important for periodic flood mitigation.

A case study project that is integrating plans for wetland restoration and measures for responding to sea level rise is the South Bay Salt Pond Restoration Project in the San Francisco Bay. See Part 4, Appendix E for a description of this project.

Design Implications

- Maintain ecosystems that naturally retain water
- Sponge surfaces that attenuate the volume of storm surges

<u>Wave and Storm Buffering</u>

This ecosystem service may be less applicable to sea level rise, but is applicable to mitigation of the effects of storms caused by climate change. Barrier beaches, inland wetlands and lakes, coastal barrier islands, coastal wetlands, coastal rivers floodplains, and coastal vegetation are all important ecosystem components that reduce the impacts of floodwaters produced by coastal storm events. Preserving natural buffers such as coral reefs, mangrove forests, and sandbars can help attenuate storm effects (De Guenni et al. 2005). These ecosystems are part of an interconnected system and the functionality of each element depends on the others being present. The United Nations Environment Programme World Conservation Monitoring Center (UNEP-WCMC) states that, “Reefs and mangroves play an important role in shore protection under normal sea conditions and during hurricanes and tropical storms. At least 70-90 per cent of the energy of wind generated waves is absorbed, depending on how healthy these ecosystems are and their physical and ecological characteristics” (UNEP-WCMC 2006). Clearly these ecosystem services are valuable in the face of the projected increase in storms due to sea level rise. The following are some of the ecosystems that provide wave and storm buffering services, and it is important to integrate these ecosystems in adaptive coastal development to preserve their ecosystem services.

Mangrove Forests

“Mangroves dissipate the energy and size of waves as a result of the drag forces exerted by their multiple roots and stems. Wave energy may be reduced by 75 percent in the wave's passage through 200 metres of mangrove but, as with coral reefs, other factors also have an influence, including coastal profile, water depth and bottom configuration. One study suggested that a 1.5-km belt of mangrove may be able to reduce entirely a wave one metre high" (cited in UNEP-WCMC 2006).

Dune and Barrier Island Systems

Dunes and barrier islands protect uplands or inlands from coastal dynamics such as erosion or storm surge. They do this by absorbing and blocking wave energy. These systems are dynamic and will remain dynamic in spite of coastal hardening.

Coral Reefs

Coral reefs have the capacity to reduce wave energy from storms. "The waves normally seen on the ocean are generated by wind, and have most of their energy in the surface waters. The reef flat (the zone of a reef extending seaward across the lagoon) and the reef crest (the seaward edge of the reef flat) absorb most of a wave's force, often up to or more than 90 per cent" (as cited in UNEP-WCMC 2006). "The greater the width of reef flat between the reef edge and the shore, the more wave energy is lost" (UNEP-WCMC 2006).

"The amount of energy reduction also depends on the extent of fragmentation of the reef, as a continuous reef acts more as a breakwater than a reef that is broken by channels. The state of the tide and the depth of water over the reef – at low tide a reef affords more protection – and whether it 'plunges' on to or 'spills' over the reef top also play a role" (as cited in UNEP-WCMC 2006). "Quantifying what the reduction in wave energy may mean in terms of shore protection is more difficult. In Sri Lanka, however, it has been estimated that with current rates of erosion and assuming that 1 kilometre of reef protects 5 kilometres of shoreline, 1 km2 of coral reef can prevent 2 000 m2 of erosion a year" (as cited in UNEP-WCMC 2006).

"The role of reefs as breakwaters is also demonstrated by the many artificial structures that are being installed for shoreline protection in locations with no natural reefs. These often have a negative impact, in terms of creating unwanted longshore drift, but they nevertheless show how reef-type barriers influence wave action, even being installed to improve surfing conditions" (cited in UNEP-WCMC 2006).

Design Implications

- Maintain natural buffering systems
- Structures that don't prohibit erosion, but also stabilize shore
- Building of buffers, breaks that buffer storms but allow sedimentation process to continue
- Dam that generates energy from incoming tides but allows tidal flow
- Structures that simulate effects of coral reefs
- Structures and landscapes that emulate structure of dune without creating effects of coastal hardening
- Structures that produce drag similar to mangrove roots and stems

<u>Carbon Sequestration</u>

Carbon sequestration is an important ecosystem service that may provide added economic value to ecosystems with the formation of a carbon market. Added economic value may be an important factor in the preservation of conservation lands and ecosystems in the face of increasing populations in Florida. Land use conflicts caused by in-migration away from areas inundated by sea level rise will be an additional and important factor working against the conservation of ecosystems. This idea is discussed in depth in Stephen Mulkey's 2007 article, "Climate Change and Land Use in Florida: Interdependencies and Opportunities". The following excerpt from a description of the South Bay Salt Pond Restoration Project describes the process of carbon sequestration in salt marshes, but other lands are also important for this purpose including many agricultural lands.

"Current research shows that restoring tidal salt marshes is one of the most effective measures for sequestering carbon available to us. While people often look to planting trees as a way to take carbon out of the atmosphere, marsh restoration may be even more efficient, per unit area, at removing carbon. Tidal marshes are extremely productive habitats that capture significant amounts of carbon from the atmosphere, which are stored in marsh soils. Unlike many freshwater wetlands, saltwater tidal marshes release only negligible amounts of methane, a powerful greenhouse gas; therefore, the carbon storage benefits of tidal salt marshes are not reduced by methane production. In addition, as sea levels rise, tidal marsh plains continue to build up to match the rise in water level—if suspended sediments are adequate—continually pulling carbon dioxide out of the air in the process. While specific research is needed to quantify the carbon sequestration capacity of San Francisco Bay tidal marshes, in general, restoring tidal marshes is an effective method, recommended by the Intergovernmental Panel on Climate Change, for removing carbon dioxide from the atmosphere. Researchers Choi, et al. (2004) conclude that, "Because of higher rates of C (carbon) sequestration and lower CH_4 emissions, coastal wetlands could be more valuable C (carbon) sinks per unit area than other ecosystem in a warmer world" (South Bay 2008).

Ecosystem Adaptation to Sea Level Rise

Sections contained within this research are as follows.

- Introduction
- Ecosystem Recovery Time and Ability to Adapt to Sea Level Rise
- Effects of Sea Level Rise on Selected Ecosystems
- Overview of Strategies for Ecosystem Adaptation
- Ecosystem Retreat and Alongshore Easements
- Living Shorelines

<u>Introduction</u>

"Sometimes trying to return a system to its pre-event condition is not the wisest response, because the historical steady state may be wholly inappropriate for the new (or existing) set of environmental and socioeconomic conditions" (Easterling 2004).

Coastal ecosystems experience a variety of stresses including those caused by aquaculture, pollution, development, and climate change. The response of ecosystems to sea level rise will vary according to location, geographic and regional conditions, and the magnitude of sea level rise. The capacity for ecosystems to persist in the face of sea level rise can be considered in terms of "the resistance (ability to withstand change) and resilience (ability to recover from change)" (Hansen 2003). "Conservation efforts can enhance resistance and resilience to climate change by alleviating the overall pressures on the system, giving it more flexibility to mobilize its natural defenses" (Hansen 2003).

Sea level rise will affect intertidal and coastal ecosystems by inundating them with water and affecting the availability of light, as well as altering patterns of water movement both intertidally and subtidally (Hansen 2003). Inundation has additionalal effects of increasing salinity beyond levels to which certain ecosystems can adapt, as well as increasing coastal erosion.

The general response of coastlines to sea level rise will be to retreat. Changes in shoreline position in response to sea level rise is based on a combination of various factors including local sediment supply and coastal slope, which have historically determined whether they advance, retreat, or remain in position. Ecosystems will need to retreat with the shoreline in order to survive.

The sort of intervention necessary to preserve coastal ecosystems must be carefully considered. “There are two terms in common use: ‘restoration’, which means that all the key ecological processes and functions and all the former biodiversity are reestablished; and ‘rehabilitation’ which means that most, but not all, are reestablished” (UNEP-WCMC 2006). Restoration and rehabilitation are often less successful than natural recovery because it is difficult to attain the same level of biodiversity and functional ecological processes through artificial endeavors (UNEP-WCMC 2006). This implies that in some cases it may be better to encourage natural ecosystem retreat and adaptation than to rely on artificial reestablishment of ecosystems.

The ability for ecosystems to retreat and adapt is necessary to maintain ecosystem services, and active human intervention in helping ecosystems adapt to sea level rise is essential. In site and regional planning and design, space must be allocated for ecosystem retreat and restoration. When designating lands for ecosystem restoration, it is important to consider which ecosystems will be most impacted by sea level rise. These may be the regions or systems that require greater human intervention. Because of specific ecosystem requirements such as soil and topography type, suitable areas must be carefully defined and prioritized for ecosystem retreat. Critical conservation lands and ecosystems have already been identified in CLIP (Critical Lands/ Water Identification Project), and Part 4 includes an analysis of conflicts between these lands and inundation due to sea level rise. Lands can be allocated for critical ecosystems based on the relative importance of the ecosystem and consideration of competing land uses. GIS will be an important tool to help resolve these areas of conflict on a regional scale. (Mulkey 2007) Perhaps a percentage of land can be required on a county-by-county basis for ecosystem retreat.

Design and Policy Implications

- Proactive human intervention and management of ecosystems is necessary
- Use land use conflict analysis to designate priority areas for ecosystem retreat based on current research such as the Critical Lands/Water Identification Project (CLIP).
- Allocate lands for ecosystem retreat based on this analysis.
- Maintain an alongshore easement for managed ecosystem adaptation and public access. The depth of this easement would vary according to location.
- Limit coastal hardening and soft engineering solutions and allow natural shoreline responses to sea level rise.

<u>Ecosystem Recovery Time and Ability to Adapt</u>

Ecosystems have a built in ability adapt to and recover from environmental stresses such as hurricanes, fires, and fluctuations in sea level. These stresses are important within many species’ lifecycles and for the maintenance of stable natural systems. Shorelines are naturally dynamic and changing, and sea level fluctuations have occurred throughout history. In response to these fluctuations, coastal systems have retreated or expanded depending on variables such as the rate of rise, shoreline gradient, and sedimentation patterns.

It is still unclear to what extent anthropogenic climate change will affect coastal ecosystems (Mulkey 2007). It is important to recognize that the effects of sea level rise are not the same as one-time events such as storms or fires. The ability for ecosystems to recover and persist will depend on their ability to make permanent structural or functional changes, either by relocating or by adapting. The ability for ecosystems to adapt to projected sea level rise will be hindered by two primary factors: coastal development that limits the ability for ecosystems to retreat inland (Titus 1991), and greater than historic rates of climate change and sea level rise, which exceed abilities for ecosystems to accrete sediment, retreat, or otherwise adapt (Myers 1990; De Guenni et al. 2005).

“In most if not all cases, global climate change impacts act in negative synergy with other threats to marine organisms and can be the factor sending ecosystems over the threshold levels of stability and productivity” (De Guenni et al. 2005). An example of the negative effects of climate change on coastal ecosystems is the probable displacement of freshwater systems by saltwater habitats in low-lying floodplains due to sea inundation. Plant species not tolerant to increased salinity or inundation would be eliminated and succeeded by other species such as mangroves or salt marsh grasses. Changes in the vegetation would affect both resident and migratory animals as well (De Guenni et al. 2005). If these freshwater systems are not able to retreat to other lands, due to coastal development or are unable to otherwise adapt, they will be lost and may not recover. A specific example of this process is beginning to occur in Florida along the Gulf of Mexico. Williams et al. describe the effects of storms and drought on gulf coast forests in the context of on-going sea level rise. It was found that although storms and drought did cause coastal forest mortalities, their ability to regenerate and recover was reduced or eliminated in locations affected by sea level rise, due to the effects of increased tidal flooding and salt stress (Williams et al. 2003). Sea level rise affected forest stands first by eliminating canopy tree regeneration based on the salt tolerance of seedlings, “then by increasing the mortality rates of older trees, and eventually resulting in the replacement of forest by salt marsh” (Desantis et al. 2007).

Through these examples, it is the conclusion of this research that it is unwise to depend on the natural ability of ecosystems to recover from sea level rise related stresses, though these natural responses should still be allowed for in coastal management strategies. Human intervention to assist in ecosystem adaptation to sea level rise will be necessary (Hansen 2003).

<u>Effects of Sea Level Rise and Development on Specific Ecosystems</u>

This section describes the vulnerability of coastal ecosystems to human development and sea level rise. With regard to sea level rise vulnerability, “The IPCC has identified deltas, estuaries, and small islands as the coastal systems most vulnerable to climate change and sea level rise” (De Guenni et. al. 2005; p 522). The following is a description of the risks to certain ecosystems caused by sea level rise and other human activities. These risks should inform design guidelines and policies.

Mangrove Habitats

“Mangroves can be affected by pollution or any activity that covers the roots with water or mud for a long period. Permanent flooding, dikes, and impoundments cause many deaths. Restriction of tidal circulation with causeways or undersized culverts can also damage stands of mangroves, particularly if salinity is lowered to allow freshwater vegetation to flourish. It is projected that rising sea levels will affect mangrove ecosystems to different extents. Mangroves can probably keep pace with sea level rise if sedimentation rates are high. Since sedimentation rates are highly variable throughout Florida, some areas will probably keep pace with sea level rise and some will become inundated by the sea. In areas of sea inundation, if the shoreline gradient is low, mangroves will probably just retreat inland maintaining or increasing mangrove area. In areas with a steep shoreline gradient, or where there is no low-lying land for inland expansion, mangrove area will shrink" (Myers 1990). Mangroves need a place within the tidal zone in which to retreat, and their ability to adapt to sea level rise is in large part a function of the rate of sea level rise being roughly equivalent to the rate of accretion (Clark 2008). Sediment reduction due to coastal armoring and river damming may also limit the ability of mangrove forests to accrete sediment in keeping with sea level rise rates.

Dunes and Barrier Islands

Coastal development affects natural systems when it 'hardens' the beachfront with seawalls. These alter the circulation of sand so that some parts of the beach erode, while others accrete more sand. Myers states that in natural conditions, "sand stored in the foredune is moved offshore by storm waves and restored to the beach with the return of normal wave conditions. Winds move the sand back to the line of plant growth, and a new dune is built up. When structures built on the foredune and the beachfront are 'hardened' with seawalls, this store of sand is removed from the system and storm waves may permanently scour the beach" (Myers 1990).

The natural response of barrier islands to sea level rise is to thin and shift inland. Coastal hardening static and prevents the dynamic movement of the barrier island and dunes. Because of these natural processes, attempts to protect development on barrier islands on high-energy coastlines will be very difficult. Titus describes this process in the following excerpt from his report, "Greenhouse Effect and Coastal Wetland Policy: How Americans Could Abandon an Area the Size of Massachusetts and Minimum Cost". "Barrier islands tend to respond to sea level rise by migrating landward, as storms wash sand from the ocean to the bay side. This "overwash" process may enable undeveloped barrier islands and their adjacent wetlands to keep pace with an accelerated rise in sea level. However, sea level rise might also cause these islands to disintegrate, which has already happened in Louisiana. Although additional inlets would create new tidal deltas, the long-term impact of barrier island disintegration would be to reduce total wetland acreage, as larger waves could enter the estuary and erode them. The deepening of estuaries associated with rising sea level would also allow larger waves to strike wetland shores. Development on barrier islands could have an ambiguous impact. Structures and other human activities thwart the ability of storms to wash sand landward to nourish the bayside wetlands. On the other hand, the value of the development virtually guarantees that substantial efforts will be taken to ensure that these islands do not break up; barrier islands will continue to prevent ocean waves from striking wetlands in the back bays". (Titus 1991: 5)

Salt Marshes and Wetlands

In Florida, historically the major human impacts on salt marshes, "have been due to mosquito control measures; most recently due to salt marsh impoundments that have negative and positive effects on natural systems. These retain water above the mean high water during the mosquito breeding season" (Myers 1990).

With respect to sea level rise the 2005 Millenium Ecosystem Assessment states that, "changes in relative sea level have affected and continue to affect salt marsh productivity and functioning, especially the ability of marshes to accumulate and retain sediments" (De Guenni et. al. 2005; pg. 520). "Sea level rise may occur too quickly for salt marshes to advance inland with the sea. Change in elevation near ancient sandhills will decrease the width of the intertidal zone. Unless tidal range increases sufficiently, suitable area for salt marsh development will be decreased" (Myers 1990). Titus states that, "Sea level rise can disrupt wetlands by inundation, erosion, or saltwater intrusion. In some cases, wetlands will be converted to open water; in other cases, the type of vegetation will change, but a particular area will still be wetland (Titus 1991).

The ability of wetlands to retreat will also be inhibited by coastal development protection. In his report, "Greenhouse Effect and Coastal Wetland Policy: How Americans Could Abandon an Area the Size of Massachusetts and Minimum Cost", James Titus compares wetland loss from shoreline protection with that along unprotected shorelines. He states that, "the additional wetlands lost from protecting developed shores would be a small fraction of the total wetland loss due to sea level rise. But comparing the loss of wetland acreage understates the difference between protecting and abandoning developed areas: in the former case, many areas would lose all their wetlands while in the latter case, the band of wetlands would narrow, but persist. The ability of wetlands to provide habitat for fisheries appears to depend more on the length of wetland shorelines than on total area….sea level rise would not necessarily reduce the length of wetland shores if developed areas are abandoned". (Titus 1991: 5).

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Overview of Strategies for Ecosystem Adaptation

As is evident from the preceding discussion, Florida ecosystems will require proactive assistance to remain healthy in the face of greater than historic rates of sea level rise. Ecosystems have traditionally adapted to sea level fluctuations, but the increased rate caused by global climate change will make it difficult for many ecosystems to adapt. This difficulty is compounded by the effects of human development on ecosystems and their ability to adapt, in particular the limitations on ecosystem retreat caused by coastal hardening structures (Titus 1991). It is however important to balance human intervention with allowance for natural processes and succession. For this reason, a conflict analysis between conservation priority lands and sea level rise is useful in that it helps define which lands may require active intervention, and which lands have less conservation priority and may be allowed to adapt without intervention. See Part 4, Appendix D. This research has identified the discontinuation of coastal hardening coupled with the facilitation of ecosystem retreat as particularly important measures to assist in ecosystem adaptation.

Hansen et al. recommend a two-pronged approach for conserving ecosystems and biodiversity, which is drastically reducing greenhouse gas emissions and to act locally to increase resistance and resilience of natural systems to climate change. Essentially, land managers will need to buy time for natural systems to adapt while climate changes stabilize, as this will take time even if greenhouse gas emissions are reduced to zero.

In describing the importance of integrating climate change threats into conservation plans, Hansen et al. state that, “conservation planning is the key to protection of biodiversity and ecosystem function. The majority of planning to date has focused on issues relating to space; designing reserves to protect moderately “pristine” tracts of land or water. While we have protected only a fraction of the area needed to meet recommended spatial goals, we must also start addressing threats that originate outside reserves and protected areas. Environmental threats like climate change require that we extend conservation planning beyond the boundaries of protected areas, and into a future in which ecosystems and biomes may be quite different than they are today. We must also realize that while it is incumbent on us to take action now to design, test and adopt conservation strategies that respond to climate change, these efforts are not the long-term solution. Even the best-designed approaches to increasing resistance and resilience to climate change will work only for changes of a few degrees (in temperature) at most. In essence, we are only buying ecosystems time, but time they desperately need while efforts are made to stabilize atmospheric concentrations of greenhouse gases and limit the rate and extent of climate change” (Hansen 2003).

Hansen et al. provide a list of important actions to increase resistance and resilience of tropical marine systems to climate change, and these are summarized below (as adapted from Hansen 2003: 165).

Create Sufficient and Appropriate Space for Ecosystem Reserves

- Create reserves that contain representative system types (coral reef, mangrove, seagrass) across environmental gradients
- Create networks of reserves
- Protect areas that are more stable during periods of climate change as refuges
- Protect physical and biological heterogeneity
- Restore degraded habitats

Reduce or eliminate non-climatic stresses

- Eliminate destructive fishing practices and overfishing.
- Reduce pollution including terrestrial nutrients and pesticides
- Reduce damaging extraction activities

Protect resistant and resilient populations and communities

- Identify those populations less susceptible to the effects of climate change
- Maintain diverse genepools and natural diversity of ecosystems.

Ecosystem Retreat and Alongshore Easements

As introduced above, one way of assisting in ecosystem adaptation to sea level rise is by facilitating ecosystem retreat. Ecosystem retreat could be defined as the upland or landward shift of ecosystems (in response to sea level rise). A primary component of this is prohibition of shoreline protection and hardening structures (Titus 1991,1998). Another component is setting aside uplands for lower elevation ecosystems to retreat to. Wetlands in particular will be squeezed between development and rising seas (Titus 1991).

An important strategy for allowing ecosystem retreat is for coastal communities to maintain an alongshore easement for ecosystem management, adaptation, and retreat. This easement would migrate inland in tandem with shoreline migration. The depth of this area would vary according to location. In addition to being an area for ecosystem management, it would also function as a buffer between development and the sea, reducing the impact of coastal hazards, and could be held in public trust as parkland or reserved for water dependent uses. With the exception of strategies to aid in ecosystem adaptation, coastal hardening would be prohibited in these areas and shoreline retreat would be allowed. The land would probably be in 'areas likely to be inundated' by seawater, and it would probably be necessary to incorporate additional land further upland as seawaters inundate. The management of this land would incorporate the idea that it is in transition, and the guidelines in Part 4, Accommodation could be applied. An migrating alongshore easement, even if it is narrow, will still be a valuable tool for the preservation of wetlands. Titus states that, "the ability of wetlands to provide habitat for fisheries appears to depend more on the length of wetland shorelines than on total area….sea level rise would not necessarily reduce the length of wetland shores if developed areas are abandoned" (Titus 1991). Connections should be made between this and other conservation lands (Hansen 2003).

To create this easement, governments and land trusts could focus on the purchase properties or development rights of properties where there is a significant hazard to development, but which has value as land for ecosystem retreat or restoration. Purchase of development rights on properties more than fifty percent damaged could be a way to limit rebuilding in coastal hazard zones at a lower cost. Development disincentives or sale incentives could also encourage the sale of these rights. Rolling easements and deed restrictions on shoreline hardening are other alternatives for implementation of alongshore easements.

It is important to understand the value of ecosystems so that they receive priority in land use planning. One promising way of assessing the value of ecosystems is based on their potential for carbon sequestration. If a carbon trading market is established as in Europe, the preservation of ecosystems would come with financial incentives (Mulkey 2007). More difficult is the valuation of ecosystems based on natural/intrinsic value and ecosystem services (Reference Daily 2000). Valuation of any of these factors will serve to protect ecosystems, and value for ecosystems in the land use planning process. This will be particularly important in the face of loss of developable land and land use conflicts caused by sea inundation.

Living Shorelines, Ecosystem Reestablishment, and Sustainability

Construction of a living shoreline is an alternative to traditional hard protective structures that involves reestablishment of shoreline stabilizing vegetation, ecosystems, and processes. The Virginia Institute of Marine Science Center for Coastal Resources Management describes living shorelines in the following excerpt.

"A "Living Shoreline Treatment" is a shoreline management practice that addresses erosion by providing for long-term protection, restoration or enhancement of vegetated shoreline habitats. This is accomplished through the strategic placement of plants, stone, sand fill and other structural and organic materials. Living Shoreline Treatments do not include structures that sever natural processes & connections between riparian, intertidal and aquatic areas such as tidal exchange, sediment movement, plant community transitions & groundwater flow" (Living Shorelines 2008).

The concepts of living shorelines were explored in this project as a method of addressing the goals of financially and ecologically sustainable coastal development protection.The use of this approach can help maintain regulatory ecosystem services such as erosion reduction and water and air pollution filtration, while providing animal habitat, aesthetic, and recreational value.

Ecological sustainability was previously defined as, "*the level to which coastal management strategies support and maintain fully functional natural coastal processes and healthy riparian, littoral, and aquatic ecosystems"*. Both ecosystem reestablishment and active management of existing ecosystems on living shorelines are critical for the maintainenance natural processes and healthy ecosystems in the face of sea level rise. Riparian and littoral zones contain very productive and complex ecosystems, which play a critical role within the lifecycle of many species. Within the study area these ecosystems include mangrove swamps and salt marshes. Management of a living shoreline requires maintaining these ecosystems and advantages include the provision of animal habitat and corridors, reduced shoreline erosion, and water and air pollution filtration.

When ecological sustainability is considered in terms of the ability of an ecosystem to 'sustain' itself or remain fully functional, the level of sustainability will vary between protective, adaptive, and retreat responses. Retreat strategies that allow natural shoreline migration and that assist in ecosystem adaptation in response to sea level rise will be more likely to maintain functional ecosystems. Protective strategies will interrupt the natural shoreline processes, in spite of the use of living shorelines. For example, attempts to stabilize a high-energy shoreline through the use of living shoreline strategies will wage a constant battle against erosion and shoreline retreat. Adaptive measures, when not allowing shoreline retreat, will also encounter difficulty in maintaining functional natural shorelines. (Titus 1991, Bush 2004)

Maintenance of a living shoreline may also be important for the financial sustainability of a management strategy. Construction and maintenance of living shorelines coupled with allowance for shoreline migration may have a lower overall cost than the maintenance and construction of hard stabilization structures. Living shorelines have a built in capacity to respond to dynamic coastal processes that hard stabilization does not possess. The financial impacts of hard stabilization on adjacent shorelines and property owners compared to that of living shorelines should also be part of broader financial considerations. In addition, living shorelines also have the potential to create financial benefits stemming from tourism, recreational value, and higher property values due to aesthetic appeal.

Living shoreline principles were integrated in the protection, retreat, and accommodation strategies proposed in this study. Within the managed retreat strategies proposed, living shorelines are integrated primarily through the provision of an alongshore buffer for ecosystem management, adaptation, and retreat. This buffer will allow for natural shoreline migration to occur while also decreasing hazards to coastal development, since new permanent construction would be prohibited. Within the protective strategies proposed, living shoreline principles are reflected through the restoration of a vegetative stabilizing species that replace the existing seawall and form foundations for a living shoreline.

Managed Retreat: Overview and Issues

Overview

For the purposes of this paper, assumptions were made based on scientific evidence that global climate change is occurring and causing sea level rise. Human populations will have to respond and adapt to the intrusion of seawater inland due to sea level rise. One important method of adaptation is managed retreat. Shore hardening and protection, as used in the Netherlands, is another method of responding to seawater inundation. Adaptive methods exist somewhere between retreat and protection such as elevated or floating structures. The reality is that a combination of responsive methods will be necessary. The goal of this section is to briefly describe the process of managed retreat and the issues surrounding its implementation in Florida.

Neal et al. define managed retreat as, "the application of coastal zone management and mitigation tools designed to move existing and planned development out of the path of eroding coastlines and coastal hazards" (Neal et al., 602). It is essentially moving development out of harm's way in a planned and controlled manner, and can be used as a proactive method of adapting coastal development to rising sea levels.

Sea level rise in Florida will require particularly proactive methods of adaptation due to the topographic character of the coast, as well as the traditional character of coastal development. Many locations throughout the state are at a low elevation extending from the coast far inland, which means that the distance seas intrude inland will be great. Managed retreat policies will be especially important due to the amount of property and types of development affected by this intrusion.

Managed retreat can be implemented at all levels starting with actions of the private landowner and extending to the creation of Federal policies, and there are many ways for Florida communities to implement managed retreat at a grassroots small-scale.

The following topics will be outlined with regard to managed retreat.

- Basic Methods of Retreat from Coastal Hazards
- Implications of Managed Retreat Policies in Florida: Issues and Solutions

Basic Methods of Retreat from Coastal Hazards

The following section defines and outlines primary methods of managed retreat as adapted from an excelllent description of managed retreat by Neal et al. in The Encyclopedia of Coastal Science. The description referenced also outlines policy options and implications for each of these methods as well as advantages and disadvantages for each method.

<u>Abandonment</u>
Neal et al. describes abandonment as being either, "unplanned or part of a planned strategy of retreat. Historically, abandonment is often an unplanned, post-storm response to destruction of buildings and land loss" (Neal et al. 2005). A recent example is the abandonment of buildings in the wake of Hurricane Katrina.

"Planned abandonment can be incorporated into managed retreat in several ways. Long-term planned abandonment can follow what is sometimes called the do nothing approach. Buildings are regarded as having a fixed life span, and when their time comes to fall into the sea, bay, or lake, no attempt is made to protect them. Buildings are razed either just before or after failing. Planned abandonment can be achieved by prohibiting post storm construction, or by requiring relocation landward of the revised post storm setback control line" (Neal et al. 2005).

Relocation

Relocation can be active, passive, or long term.
"Active relocation is undertaken by either moving a building back before it is threatened, or, if threatened before it is damaged. Passive relocation is achieved by rebuilding a destroyed structure in another area, away from the shore, and out of the coastal hazard zone.
Long term relocation usually implies a broader strategy through community zoning or land use plans that identify a frontal zone of buildings likely to be impacted by known erosion rates or predicted flood levels from storm surge and coastal flooding. These buildings are then relocated over an extensive period…" (Neal et al. 2005).

Setbacks

Setbacks can be "string line" or "rolling".
"A string line setback simply requires that construction be a fixed distance from a reference line (e.g., the back of the beach, the vegetation line, or the crest of the dune line). The regulatory line is not adjusted for changes such as storm impact. A rolling setback is one in which the regulatory line shifts landward as the high tide shoreline erodes…" (Neal et al. 2005).

Land Acquisition

Land acquisition refers to lands acquired for the public trust through federal, state, and local ownership (Neal et al. 2005). Florida has many land acquisition programs, the primary state program being Florida Forever. Land acquisition will be important for many reasons discussed later including allowance for ecosystem retreat, allowance for commercial fishing and water dependent use easements, and sovereign submerged lands.

Avoidance

Avoidance is essentially the decision not to locate in a hazardous area (Neal et al. 2005). This can obviously be a private land owner decision, or a reflected in government planning policies. Although nature may ultimately be the taker, it may be important for governments not to overstep their boundaries in taking of private property rights.

Implications of Managed Retreat Policies in Florida: Issues and Solutions

The issues related to managed retreat policies have been discussed in depth in other publications. A publication discussing many of these issues by James G. Titus from the Maryland Law Review is titled, "Rising Seas, Coastal Erosion, and the Takings Clause: How to Save Wetlands and Beaches without Hurting Property Owners". The following section briefly introduces some of these primary issues and begins to outline possible solutions. Policy options for implementation of managed retreat are included in Part 4, Appendix C. Rolling easements, purchase of development rights, and deed restrictions are some of the options available. It is important to reference these as they are the vehicles for addressing issues caused by managed retreat and sea level rise.

The most obvious issue created by managed retreat is the loss of property by retreating owners and land uses. This creates potential conflicts caused by in-migration of populations (Brody 2007). There are political issues such as appealing to constituencies with high economic investment in coastal properties and constitutional issues with the potential for 'takings'. A 'takings' could be claimed by a property owner who feels that managed retreat policies, such as shoreline setbacks, rolling easements, or prohibition of protection, result in a loss of developable land or land value for their property.

Additional issues include a potential loss of tourism, sales tax revenue, and hotel occupancy when protection or nourishment activities are discontinued in place of retreat. Key West and Miami Beach are locations that could suffer from discontinuation of these policies. There is also a concern among some communities that retreat will cause a loss of tax base and property revenue (Coburn 2008). The short term cost of retreat versus protection, as well as the incentives for coastal development created by the insurance industry and consumer demand are additional factors working against the implementation of retreat responses to sea level rise.

Governmental Involvement

Proactive guidance by local, state, and national governments is essential to minimize the negative effects of sea level rise. If seawater inundation occurs gradually, the slowness with which the effects will be felt may not inspire an effective and voluntary response of retreat by individual property owners. To predict future responses to sea level rise it is useful to look at historic responses to coastal hazards such as that prior and after Hurricane Katrina. Informed property owners or those affected by water intrusion may respond by selling property, though any development by the purchaser will still be at risk. This issue can be addressed by development limitations, disincentives, or purchase by entities that commit to limited development (such as purchase for state conservation). Another probable response to sea intrusion will be shoreline and building hardening. It is possible that development will retreat only when no other alternative exists, likely in response to storm destruction or imminent intrusion of water over roads and into buildings. This of course will have economic repercussions. A laissez faire approach would let the market work itself out. However, this probably wouldn't be the smoothest approach over time. Obviously it falls to local and state government to guide property owner responses to sea level rise in order to minimize negative effects. Managed retreat and in particular rolling easements are approaches that could be used to guide policies.

It is the author's opinion that the limits of Federal regulatory power of states need to be explored. This is because broad best management practices, superseding local interests, may better address the overall welfare of the nation's coastlines than fragmented inconsistent policies. In reference to sea level rise, the value of holistic and coordinated adaptation along the nation's coasts based on past experience and scientific evidence seems inarguable. This sort of action would not be without its potential pitfalls. Currently, the primary authorization for Federal management of coastal areas is the Coastal Zone Management Act (CZMA). The goal of this act is management of the nation's coastal resources balancing economic development with environmental conservation (Ocean and Coastal Resource Management 2007). Some of the basic questions that could be explored are as follows. Can coastal areas and the ecosystem services provided be considered part of the commons, the management of which creates affects that bridge political boundaries? If so, who has the power to regulate the commons? On what basis would Federal regulatory power be based, especially outside of the Commerce Clause? Is it appropriate for large scale governmental regulation over resources whose management has serious implications for local economy, human populations, and ecosystems? It is the author's opinion that the concept of rolling easements as described in Titus 1998 has the ability to address many of these questions.

Governments will need to 'retreat' from old policies. A basic approach should be taken- disincentives for coastal development and for property owners to maintain their current habitation of the coast, and incentives for inland development and for property owners to retreat from the coast. One disincentive for coastal development would be to decrease public investment in infrastructure that supports coastal development. Another would be to enact more restrictions on coastal development. Building codes for coastal development could become more stringent. This sort of action would serve to generally disencourage coastal development, but definitely could have the potential to encourage appropriate site and building design and development.

Property tax revenues based on coastal property values will be an important factor in managed retreat policies. Obviously these revenues are important to local governments, as are the property values to property owners. Property values based on development potential will be threatened, but if property value (especially of lands threatened or inundated by seawater) can be assessed through other methods, such as potential for carbon sequestration or public recreational value, then perhaps these values can be maintained in the face of seawater inundation. Development rights could be purchased for recreational easements along the coastal edge of threatened properties. Also, with a coastline edge that ‘rolls’ inland perhaps some properties will gain in value while others decrease so that there is little net loss in local tax revenues based on property value. Properties that could increase in value might be ‘newly coastal’ properties at the edge of the projected seawater inundation or inland low coastal risk properties. It is also important to realize that a decrease in certain property values will make it easier for land trusts to purchase property for ecosystem retreat and other sea level related purposes. Coburn 2008 addresses property value concerns by pointing out that removal of shoreline structures as part of retreat policies may actually be the removal of the least valuable row because of danger from coastal hazards. He also points out that removal of waterfront structures will create scarcity, and since demand for coastal properties is unlikely to diminish, this will raise the value of remaining properties with the potential to supplement tax revenues (Coburn 2008).

A related question is what happens to properties that are completely inundated or submerged? Will the property owner maintain ownership or will the lands be redefined as sovereign submerged lands? If the lands become sovereign, would funds have to be allocated for purchase? This would be difficult based on current assessed values, but inundated lands will lose value if their value is based on development potential. Rolling easement policies deal with this question by simply enforcing the existing policy that lands below the mean high tide line are public. As shorelines migrate inland, the extents of publicly owned land will also migrate inland.

A challenge that any managed retreat policy must address is the need for public support. Policies cannot just be applied to an unwilling population, but be created with the participation of constituents and with the overall good of human and non-human populations in mind. Public education and development incentives are some ways to accomplish this.

Takings

The implementation of managed retreat policies in Florida creates potential conflicts with the perfect market structural concept of takings. The Bert J. Harris Jr., Private Property Rights Protection Act is an attempt to protect private property owners from unfair burdens or restrictions on private property rights and provides for relief or compensation to a private property owner. This is also distinct from “takings” as also protected in the constitution. Managed retreat policies will have to avoid being classified as taking of property rights however necessary these ‘takings’ might actually be. There are many policy options that can help avoid this pitfall such as purchase of development rights. An important unknown is of course where a source of funding will be located. Rolling easements address this issue by simply enforcing an existing policy, and giving the property owner time to plan for sea level inundation. The effects of rolling easements can also be construed as 'takings', but there are precedents for the use of rolling easements and several strong arguments against the interpretation of a '.takings' (Titus 1998).

Exclusivity

Managed retreat implies a loss of property whether due to coastal land use policies or sea inundation. The question is, should a property owner be compensated for this loss and how? The perfect market structural concept of exclusivity is an issue because those who develop in coastal hazard areas do not necessarily bear the full cost of their decisions when the hand of disaster strikes. If coastal property owners are responsible for their own costs it will become a natural disincentive to development in hazard zones.

Currently, inland property owners subsidize the risk taken by coastal property owners. Many coastal property owners posess state subsidized insurance, and are charged rates below the actual value of the risk they bear. This has the effect of continuing to encourage development in hazard zones, thereby increasing the level of risk and potential cost should a natural disaster occur. If coastal property owners are made to pay insurance in proportion to the risk associated with their location, it will create a disincentive for coastal development. Hazard areas will need to be redefined by inundation, erosion, and storm surge projections, and these hazard areas should recieve more rigid development standards.

Loss of Developable Land and Added Land Value

As already discussed, it seems inevitable that sea level rise will affect coastal land values. If property value is based solely on potential for development as is traditional in coastal properties, it seems likely that seawater intrusion that reduces the area of developable property will reduce property values in areas partially inundated and negate property values in areas completely inundated. If property value can be derived from other means this effect may be reduced and value may even be added. Some alternative sources of property value in light of sea level rise could be carbon sequestration, natural habitat value, and value for fisheries production.

The first of these, carbon sequestration, is presented in a 2007 report to the Century Commission by Dr Stephen Mulkey, "Climate change and land use in Florida: Interdependencies and opportunities". The report discusses the potential for climate change mitigation through land use policy changes. Florida has great opportunity for economic development through participation in carbon markets and through land management for climate mitigation. Increasing populations and land use conflicts caused by in-migration (away from areas inundated by sea level rise) will be factors working against the conservation of ecosystems. Because of their carbon sequestration potential, economic value can be added to natural or agricultural lands in the carbon offset market and will help maintain these land uses in the face of urban development. (Mulkey 2007)

After seawater intrudes into coastal properties, there may also be value added to the land based on its potential for aquaculture and fisheries industries. This land could be leased by the original landowner to marine aquaculture industries.

Ecosystem Retreat

Ecosystem value can be quantified based on carbon sequestration as discussed above, but much more difficult, could be quantified based on natural/intrinsic and human ecosystem services.

Valuation of any of these factors will serve to protect ecosystems, and will be a source of property value in the face of loss of developable land. Governmental or private land trusts could purchase development rights of coastal land where there is a significant hazard to development, but which has potential ecosystem value. Development disincentives or other public policies could encourage the sale of these rights. These lands could be restored as conservation land with their historic habitat, reserved as land for sea intrusion, or 'reserved' for retreating habitat needs such as coastal wetlands and salt marshes displaced by seawater. This is related to the idea of managed realignment, defined by Neal et al. as the management of the coast in a way sympathetic to nature by letting parts of a coastline erode in a controlled way to create habitat (Neal et al. 2005). Proactive human intervention, through allocation of land, ecosystem reconstruction, and artificial human creation of ecosystems will probably be necessary to preserve coastal ecosystems unable to adapt quickly to rising sea levels. Strategic purchase of lands to reserve for ecosystem retreat could be part of overall county future land use planning. Human created wetlands and salt marshes would have added value not only as ecosystems that should be preserved as part of the commons of the state (based on both human and natural ecosystem services) but also as carbon sequestration areas. The creation of these ecosystems will be aided in some cases by seawater intrusion. Again, this is a way of adding value to those lands with loss of development potential.

In-Migration and Land Use Conflicts

Managed retreat will inevitably cause conflicts with inland land uses (Brody 2007). As urban coastal development moves inland, i.e. in-migration, pressure will likely be placed on agricultural and natural lands to convert to urban uses. Of course long range and comprehensive planning must occur to ensure that these conflicts are resolved with proper consideration of social, environmental, and economic factors. With reference to the taking of agricultural and natural lands that contribute to carbon sequestration Dr. Mulkey states that, "Adaptation through strategic retreat of human populations from rising seas will consume some land that could otherwise be dedicated to carbon sequestration. The interdependency of these issues makes clear the need for comprehensive planning over a timescale of at least a century" (Mulkey 2007). Clearly there will be land use conflicts, and holistic comprehensive planning will be more important than ever. Some primary issues are allowance for increased density, preservation of agricultural and natural lands, and allowance for ecosystem retreat. Design strategies such as urban gardens, and increased landscape cover must also be implemented so that urban development that supercedes natural and agricultural lands will also contribute to carbon sequestration.

Impact on Cultural Heritage

A primary issue with exclusive use of managed retreat policies is how to deal with the loss of not just property but cultural heritage. Archeological sites may no longer be accessible by land, but can still be investigated underwater. In the case of historic buildings, documentation and relocation is probably more viable than protective measures such as dikes. This is due to the structure (wood frame) of many historic buildings in Florida, which allows them to be more easily moved or deconstructed than masonry buildings (the Alhambra or Vatican). Relocation of masonry buildings is also an option. An excellent example of this is the relocation of the Cape Hatteras Lighthouse by the National Park Service between 1998 and 2000 in response to encroaching seawaters. This option was chosen in lieu of more traditional shoreline hardening approaches. (Cape Hatteras Lighthouse Relocation Articles and Images 2001). It may be necessary to designate sites that must be sacrificed, sites essential to preserve, and sites that can be protected with appropriate planning (Berenfeld 2008).

Loss of Tourism

Coburn 2008 addresses the impact of retreat on coastal tourism by pointing out that demand for coastal amenities is unlikely to decrease. Increased scarcity will only result in higher demand for the remaining resources (Coburn 2008). In addition, the preservation of ecosystems by allowing for retreat and adaptation will be more important for the recreational tourist industry than the preservation of high value private properties through shoreline protection.

Fisheries, Working Waterfronts, and Other Water Dependent Uses

A final issue that must be considered is how water dependent land uses that need to be adjacent to the coast can adjust to a retreating shoreline. Several points that seem important are as follows. In the face of increased competition between land uses caused by in-migration, it will be more important than ever that land is expressly reserved and designated for water dependent uses. Alongshore easements could be reserved for water dependent uses, function as a buffer between development, and an area for ecosystem adaptation and management. The negative ecological effects of seawater intrusion and the subsequent effects on commercial fishing industries will also need to be taken into account in state and local policies.

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Controlled Inundation Areas and Managed Realignment

Both controlled inundation and managed realignment share the principle of designating and planning areas that will be inundated. Managed realignment is also sometimes referred to as controlled inundation, but for these purposes, the two terms are separated as they refer to two distinct strategies with different results. Both methods could be used as part of a regional protection strategy or as part of a phased managed retreat strategy.

Controlled inundation areas (CIA) are defined as areas which are generally protected but are allowed to be inundated in times of flooding. Some of the benefits of this strategy are flood protection while maintaining creative, non-permanent, low vulnerability uses of within the floodplain. Flood protection is achieved because a place for the floodwaters to go has been provided, rather than trapping of the floodwaters behind levies. This idea can be applied to storm surge waters resulting from hurricanes, though huge tracts of land would have to be set aside for this volume of water. These areas are created by maintaining a protected edge and a sluice with an adjoining pumping station to control the water in the designated flood zone in times of inundation. (Comcoast 2007)

Managed realignment is defined as discontinuing the protection of certain tracts of land as identified through comprehensive planning. Natural shoreline processes will be allowed to occur, likely resulting in inundation. In areas already protected from the sea by structures such as dikes, the existing dike is opened up either partly or fully to allow inundation. (Comcoast 2007)

Strategies for Responding to Coastal Hazards and Sea Level Rise

(modified after Neal et. al., 2005, property damage mitigation options)

This should not be considered a comprehensive list, and new alternatives should be creatively explored. An additional useful reference is Klijn 2001, “Room for the Rhine in the Netherlands: A Summary of Research Results”, which proposes specific measures to provide room for expansion of the Rhine River, with dike strengthening as an option only used when other strategies are impractical.

1. *Offshore Barriers*

a. Permeable- wave energy reducing barriers
   i. Offshore breakwaters

b. Non-Permeable- offshore barriers that control tide and water levels.
Case Study: MOSE project, Venice, Italy
Note: This method can be very expensive. It is most applicable to areas of high density development, or areas highly significant for economic, cultural, or other reasons.

2. *Hard Shoreline Stabilization*

Note: Hard stabilization is not recommended except in places where other alternatives do not exist. See Part 3, Options and Recommendations for Coastal Development
Case Study: Antwerp Quays, Antwerp, Belgium

a. Shore-parallel Hard Stabilization
   i. Seawalls
   ii. Bulkheads
   iii. Revetments-
   iv. Sills
   vi. Dike Construction: Related Case Study: SE Coastal Park, Barcelona
      1. Dike overtopping: Required action: replace the top of the dike and its inner slope with a revetment that will not wear away by severe overtopping (Comcoast 2007).
      2. Foreland Protection: Moving the line forward by erecting a second, effective additional defence. Required action: Constructing a low embankment on the foreland or a breaker on the foreshore itself (Comcoast 2007).

b. Shore-perpendicular Hard Stabilization
   i. Groins
   ii. Jetties

3. *Soft Shoreline Stabilization*

a. Beach Nourishment

b. Increasing sand dune volume
   i. Sand fencing
   ii. Raise frontal dune elevation
   iii. Plug dune gaps

c. Natural Shoreline Management and Living Coastline Construction
Case Study: South Bay Salt Ponds Restoration
Maintenance and restoration of natural coastal conditions can provide many ecosystem services that can help mitigate the effects of sea level rise, especially by assisting in sediment collection and erosion control. A variety of other benefits are to be gained from maintaining a natural shoreline such as stormwater purification and flood control services. See Part 4, FLorida Coastal Ecology

4. ***Modification of Development and Infrastructure*** (control through zoning, building codes, insurance eligibility requirements)
See Part 3, Accommodation
Case Study: Percival Landing, Olympia, WA.

a. Retrofit structures- Dry Floodproofing, Wet Floodproofing
b. Floating Structures
c. Elevated structures
d. Choose elevated building sites
e. Lower density development
f. Curve and elevate roads
g. Block roads terminating in dune gaps
h. Move utility and service lines into uplands or bury below erosion level

5. Managed retreat

a. Abandonment
    i. Unplanned
    ii. Planned
b. Relocation
    i. Active (relocate before damaged)
    ii. Passive (rebuild destroyed structures elsewhere)
    iii. Long-term relocation plans (zoning, land use planning)
c. Setbacks and Easements
    i. Fixed
    ii. Rolling
d. Acquisition
e. Avoidance: recognize hazard areas and avoid tidal inlets (past, present and future), swashes, permanent over wash passes, wave-velocity zones

Rolling Easements

The following is a discussion of one approach to sea level rise policy using the concept of rolling easements. It is based on an overall response of managed retreat as is the ultimate recommendation of this study. Response to sea level rise will require a combination of policy approaches depending on local conditions. Policy approaches were not the focus of this study and in depth discussion of policies occurs in other papers. Based on the research done for this paper, the following policy approach seems be the most simple and logical starting point for most situations. The following section is based primarily on publications by James G. Titus, Project Manager for Sea Level Rise in the U.S. Environmental Protection Agency's Office of Policy.

There are many issues that sea level rise policies will need to address including:

Allowing coastal ecosystem retreat and adaptation
Constitutionality and avoiding 'takings'
Economic Feasibility and Impact- public and private
Political Feasibility
Hazard Mitigation
Encouraging the use of sound waterfront design and management principles.

Titus compares the merits of various approaches to sea level rise response policies in the reports, "Greenhouse Effect And Coastal Wetland Policy: How Americans Could Abandon An Area The Size Of Massachusetts At Minimum Cost" and "Rising Seas, Coastal Erosion, and the Takings Clause: How to Save Wetlands and Beaches without Hurting Property Owners". He discusses three broad categories of policy approaches which are preventing development, deferring action, and rolling easements.

Preventing Development: Examples of development prevention policies could be coastal setbacks. Among various issues, this creates potential conflicts with the 'Takings Clause' of the Constitution and therefore would be difficult to implement.

Deferring Action: Deferring action is similar to natural selection. Coastline development will be allowed to continue, and populations will naturally retreat as hazards increas. The problem is that deferring action allows no guarantee that natural coastal systems will be protected, or that high value development will retreat.

Rolling Easements: Coastal protection is prohibited, and the definition of public lands as lands below the mean high water mark is enforced. Since shorelines are no longer protected, the mean high water line will migrate landward in response to sea level rise. With the exception of coastal protection measures, property owners are allowed to use coastal lowlands as they choose, but a legal mechanism is set up to ensure that the land is abandoned as it is inundated.

"Although compensation may be required, this approach would cost less than 1 percent as much as purchasing the land, and would be (1) economically efficient by enabling real estate markets to incorporate expectations of future sea level rise; (2) constitutional by compensating property owners; and (3) politically feasible by pleasing people who care about the long-term fate of the coastal environment without disturbing people who either are unconcerned about the distant future or do not believe sea level will rise" (Titus 1991).

The use of rolling easements also addresses ecosystem adaptation to sea level rise. In the report, "Greenhouse Effect

And Coastal Wetland Policy: How Americans Could Abandon An Area The Size Of Massachusetts At Minimum Cost", Titus discusses the three above outlined categories of approach to sea level rise policy with a focus on providing for wetland retreat. He summarizes these approaches in the following passage from the report.

"One of the impacts (of sea level rise) would be the loss of coastal wetlands. Although the inundation of adjacent dry land would enable new wetlands to form, much of this land is or will soon be developed. If developed areas are protected, wetlands will be squeezed between an advancing sea and the land being protected, which has already happened in China and the Netherlands, where people have built dikes for centuries.

Unlike those countries, the United States has enough land to accommodate the landward migration of wetlands; but governments lack the funds to purchase all the coastal lowlands that might be inundated and the legal authority to prohibit their development" (Titus 1991).

Rolling easements address these problems by prohiting the coastal protection that prevents inland wetland migration. Governments do not need to purchase the lands necessary for migration, since tidal lands are sovereign by definition. Purchase of lands for ecosystem adaptation could be focused on non-tidal lands.

Implementation of Rolling Easements

The basic ideas of rolling easement implementation are to disallow or create disincentives for coastal protection and to enforce the mean high water line as the edge of public lands. Titus describes the implementation of rolling easement policies in the following passage.

"Rolling easements can be implemented with (a) eminent domain purchases of options, easements, covenants, or defeasible estates that transfer title if a bulkhead is built or the sea rises by a certain degree, or (b) statutes that accomplish the same result.

The simplest way to implement rolling easements throughout a state would be to prohibit bulkheads or any other structures that interfere with naturally migrating shores. Another approach would be for the government to purchase a property right to take possession of privately owned land whenever the sea rises by a particular amount. Alternatively, the deed to the property could specify that the boundary between publicly owned tidelands and the privately owned dryland will migrate inland to the natural high water mark, whether or not human activities artificially prevent the water from intruding" (Titus 1998: 1313).

"A government could also obtain a rolling easement by passing a statute that simply clarified existing property law by stating that all coastal land is subject to a rolling easement" (Titus 1998: 1313). This statute would also prohibit bulkheads, seawalls, and other coastal hardening structures. Individual structures would be subject to a rolling easement as a condition for a building permit. Entire developments would be subject to rolling easements as a condition for subdivision, or for activities that require wetlands to be filled (Titus 1998).

Titus further describes the implementation of rolling easements with the following points. Bulkheads and any filling of privately owned land are prohibited except to the extent necessary to keep the property useful, e.g., to build a driveway (necessary to maintain access to the property). No one needs to abandon a house if it is safe and on private property. Houses on high marsh would probably be safe. Those in front of an ocean dune would often be unsafe or would interfere with preexisting easements. During the first decade a house is on public land, no one is forced out of the house, but the state charges rent.
(Titus 1998).

Shoreline Protection and the Potential for Takings

The disallowance of bulkheads and other shoreline protection structures creates the potential for interpretation of a 'takings' from private property owners. This position could be maintained by a property owner who feels that the inability to protect their shoreline from erosion results in loss of developable land and land value.

A counterpoint to this is described in great depth in Titus 1998. Among various methods in which common law could support rolling easements and the prohibition of coastal hardening, Titus discusses the ideas of symmetry and nuisance principles.

The basic idea of symmetry is that *shoreline ownership advances and retreats with changes in shoreline position, and that these boundaries are not altered by private property owners' activities that alter the shoreline.* The effects of erosion are naturally to decrease the property of dryland owners. Bulkheads and other protective structures shift this loss onto the tidelands owner. Property owners are not allowed to expand their holdings by bulkheading and filling seaward, thereby infringing on the tideland owner's property. Allowing the same owner to fill and bulkhead eroded land would create an asymmetry. In addition, a property owner does not *lose* the right to exclude the public when they lower dry land to become navigable water. It would create an asymmetry to allow the property owner to *gain* the right to exclude the public by elevating dry land so that it does not become navigable water. (Titus 1998: 1371-1378).

Nuisance principles are applicable in that coastal hardening structures eventually reduce the area of publicly owned tidelands. The protection of one property owner at the expense of another property violates nuisance doctrines (Titus 1998). The nuisance doctrine also may be applicable in cases where protection of an updrift property creates a nuisance for a downdrift property, such as the downdrift shore erosion and sediment starvation created by groins.

Protecting Public Alongshore Access

The desire to protect private property from shoreline erosion can conflict with the public's right to use the beach. Rolling easements may be used to address alongshore public waterfront access., and an example of this can be found in the Teaxas Open Beaches Act 61.011, which protects public beach access with a rolling public easement that migrates landward with shoreline erosion.

Titus presents a strategy where governments and land conservation groups can buy an access right that vests only when the land is eroded away below an exsiting bulkhead. The bulkhead permit is granted on condition of public access along the shore above the bulkhead once the shore below the bulkhead has eroded (Titus 1998: 1310).

Public access is an important part of a successful waterfront, and will continue to be so with shifting shorelines. If careful planning does not occur, rising seas will inundate the portions of the coastline normally reserved for public access leaving only private property along the coast.

Precedent Legislation

Several precedents do exist for the implementation of rolling easements and shoreline structure removal as discussed in Titus 1998. One of these is found in Maine's Coastal Sand Dune Rules, which state that if the shoreline recedes to such a point that the coastal wetland extends to any part of a structure, including support posts for a period of six months or more, that the structure must be removed and the site restored to natural conditions within one year (Titus 1998). Another valuable precedent is found in the Texas Open Beaches Act 61.011, which subjects property along the Gulf of Mexico to a rolling easement, enables the prevention of repairing storm damaged structures, and allows the requirement of structures to be removed under certain circumstances.
Fewer valuable precedents exist for the removal of structures on sheltered shorelines than on open coastlines. One of these is found in the Rhode Island Coastal Resource Management Program which, "specifically prohibits hard structures inland of the marsh in some areas so that wetlands can migrate inland as sea level rises. This policy, however, does not explicitly require homes to be relocated" (Titus 1998: 1374-1377).

References

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Additional Policy Options

The following list of policy options and actions was taken from the proceedings of the Second Skidway Institute of Oceanography Conference on America's Eroding Shoreline. This source is cited below and is available from the Duke Program for the Study of Developed Shorelines website.

"National Strategy for Beach Preservation". Second Skidway Institute of Oceanography Conference on America's Eroding Shoreline. Georgia. 1985.

Federal Government:

1. *End all federal expenditures, direct or indirect, in support of private coastal development. Require private coastal development to pay its full cost.*
2. *Replace economic incentives for private development in high risk areas with incentives to relocate and build in other areas.*
3. *Acquire undeveloped areas to preserve natural features or the recreational beaches important to the public.*
4. *Discontinue government backed insurance programs for new development and substantial rebuilding and require flood insurance for existing structures to be actuarially sound. Also condition the use of insurance receipts or disaster payments on rebuilding outside coastal hazard areas.*
5. *Permit the use of offshore sand supplies for beach nourishment only where the value and extent of development outweighs other values and where nourishment would not deprive other communities of natural sand supplies.*
6. *Encourage research in new technologies for managing beach areas, especially inlets and navigation channels, without disturbing natural processes.*
7. *Provide special tax incentives and disincentives to limit development in the units of the Coastal Barriers Resources System and V Zones, including the following:*
    - *Remove the limits on deductions for gifts of land to government or conservation groups if the land is in a threatened area.*
    - *Allow tax deductible gifts with the right of the owner to use improvements until damaged by erosion or storms.*
    - *Eliminate casualty loss tax deductions for properties in high risk zones purchased or built after adoption of a new policy.*
    - *Eliminate Accelerated Cost Recovery System for property in high risk zones.*
    - *Treat gains on property in high risk areas as ordinary income, rather than as capital gains.*
    - *Put businesses and homeowners on an equal footing by disallowing as business expenses the costs of draining, filling, or building protective measures on properties in the high risk zone.*
    - *Repeal the deduction for interest paid on loans for properties in the high risk zones.*
    - *Allow tax exempt financing for the financing of public acquisition of properties in the hazard areas.*
    - *Give preferential tax treatment to profits made on sales to public bodies or conservation groups.*
8. *Amend the Interstate Land Sales Act to require the disclosure of the possible consequences of buying or building in hazard zones.*
9. *Stimulate full disclosure by removing the "private offering" exemption in Section 4(2) of the Securities Act of 1933 for proposed private investment and development in units of the Coastal Barrier Resources System and in V Zones identified by the National Flood Insurance Program.*
10. *Establish a firm policy that all usable (compatible) sand material from navigation projects be placed on adjacent beaches.*

State Government:

1. End all state expenditures, direct or indirect, in support of private coastal development.
2. Require private coastal development to pay its full cost.
3. Halt tax free exempt financing of private development on ocean beaches.
4. Acquire undeveloped areas with natural features or recreational beaches important to the public.
5. End state funding for roads and other public works serving high risk areas unless most of the benefits accrue to public coastal areas.
6. Halt stabilization, including sea walls, groins, jetties and other hardened construction, especially since such structures usually set off a chain of greater and greater defenses that typically lead to appeals for public subsidy, while destroying nature's system of beach maintenance.
7. Create a property transfer tax to fund acquisition of important coastal resources, public beaches and beach access, as already done in Florida and Massachusetts.
8. Create a tax check-off system or provide for earmarking tax refunds for public purchase of property in the high risk zones.
9. Allow special favorable tax assessments for land in high risk zones whose owners donate conservation easements or adopt uses compatible with preserving the natural beaches (e.g., fishing camps, some recreational uses, parks, etc.).
10. Establish building set-backs that protect natural beaches and primary dunes and that prohibit permanent structures in threatened areas. Where seasonal changes in beaches create new beach areas, prohibit building on newly accreted land.
11. Require developers and real estate agencies marketing property to disclose in writing the risks of being in the high hazard areas, including the costs associated with such risks during the expected life of their building.
12. Require when recording each change of ownership or new financing, a current plat be filed showing the lot lines, location of buildings and the shoreline location. Deed descriptions might note specific risks of hazard zones.
13. Require a successful applicant for a permit to rebuild in a hazard area to waive their rights to petition government for public aid when future damage occurs.
14. Educate the public about the nature of open ocean beaches, public and private property interests, and the economic consequences of beach management options and about how hardened defenses of private property burdens the taxpayer and denies citizens access to and use of their public beaches.
15. Enact enabling legislation, if necessary, to allow local government to create transferable development rights programs.

Local Government:

Land use planning should guide a variety of specific measures. Local land use plans should identify areas threatened by coastal erosion and flooding. Many coastal management acts already identify these areas. Land use plans and development regulations ought to prohibit unmovable buildings whose life spans will at any time place them in the path of the retreating shoreline.

1. Adopt zoning and land use controls that encourage development in safe areas by providing property owners who have to move back from the shore with development incentives elsewhere - e.g., cluster development, transferable development rights, extra building height, or total area.
2. Assign a non-conforming status to high risk uses of land just as zoning codes consider certain uses non-conforming. Regulations could prohibit non-conforming uses from being rebuilt after a certain level of damage has been sustained.
3. Require new subdivisions to set aside lands in safe areas for those who must retreat from the shore. Where shoreline retreat is likely to threaten buildings, lots could be required to have space for at least one back step large enough to safeguard the relocated

building from rising sea level for at least the term of its projected life or require developers to set aside areas of land for future relocation.

4. Remove or require demolition of structures that become a threat to public safety, including seawalls and other structures in the surf zone and high risk buildings.

5. Remove hard stabilization structures that no longer serve their purpose and cause adverse affects to nearby shoreline.

6. Establish a fund to buy up property that should not be built upon. Such a fund would allow government to move quickly to buy storm damaged property when owners are most likely to sell at the lowest prices.

7. Establish a system of Transferable Development Rights in which presently developed or undeveloped oceanfront property is endowed with separable development rights that can be used or sold further inland if the oceanfront areas cannot be rebuilt or developed. If a government were to prohibit building or severely limit the density allowed on a given property, it could provide economic relief to the owner by assigning transferable and thus salable development rights.

8. Develop zoning provisions that have special standards for areas of unstable beaches, including a "floating zone" in which zoning designation and standards move with natural features such as mean high water, dune, or vegetation line.

9. Levy special impact assessments on risky development to provide a reserve fund for buying out damaged properties.

10. Using what is known of long term erosion rates, set time limits on the residential use of certain beach fronts, enabling the owners to plan a realistic depreciation and income projection into their financial plans.

11. Establish building set-backs that protect natural beaches and primary dunes and that prohibit permanent structures in threatened areas. Where seasonal changes in beaches create new beach areas, prohibit building on newly accreted land.

<u>All Levels of Government:</u>

1. Tailor infrastructure planning to discourage high risk development. One of the strongest motivations to development is the extension of public works--water, sewer, or roads. Federal and state funding should not be available for infrastructure in areas threatened by erosion except to service recreational use of the beaches. Local planning for infrastructure should direct it toward safe areas.

2. Adopt user fees to assess the users of public investment for the cost of goods and services, in keeping with the tradition of individual responsibility. Part of such a policy would be to adjust insurance rates to reflect the real cost of insuring oceanfront property, to price utility service to reflect the greater cost of installation and maintenance.

3. Adopt a policy for triggered removal judged by measurement of sea level rise and long-term shoreline retreat. Rather than wait for disaster to strike with all its expenses and dangers, regulations might establish a "trigger" mark after which a threatened structure would have to be removed within a specified time.

4. Coordinate protection and regulation. Where beach nourishment or other stabilization projects help a community protect property or preserve a public beach, permission or funding (or both) of the protective measures could be coupled with restrictions on further development.

5. Let buildings fall in. In many cases this will be the only feasible response to shoreline retreat and accompanying natural disasters.

<u>Private Sector:</u>

1. *Develop innovative technologies to adapt to changing public policy, with emphasis on new modes of sand by-pass, inlet maintenance, and residential construction.*
2. *Real estate organizations such as the National Association of Realtors and the National Association of Homebuilders should educate their members about the need for new policies and about development patterns that can minimize the effects of new regulations.*
3. *Professional appraisers and economists should develop standards for assessing the effects of new policies on property values.*

Appendix D: Conflict Analysis between Conservation Lands and Sea Level Rise

Arc GIS was used to analyze conflicts between conservation land priorities and various levels of sea level rise. The conservation lands were defined by the Critical Lands/Water Identification Project (CLIP), a project that identifies and prioritizes Florida's essential ecosystems for the purpose of land use planning. This data was received from Dr. Tom Hoctor, University of Florida Geoplan Center. Sea level rise data was obtained from Andrew Whittle, University of Kentucky.

Conflict analysis was done for Ecological Greenways, Strategic Habitat Conservation Areas, FNAI Species Habitats, FWC Species Biodiversity Hotspots, and FNAI Priority Natural Communities datasets as defined by CLIP. Sea level rise data for 0.2, 0.5, 1, 2, 3, and 5 meter levels of rise was combined with the CLIP datasets to calculate the number of acres of various CLIP lands that would be inundated. The analysis did not take into account either erosion or tidal fluctuations. This was because erosion estimates were not available and the sea level rise projections used do not take into account tidal fluctuations. Analysis such as this can be used to identify priority lands that may require human intervention to remain healthy in the face of sea level rise.

The following pages, Figures 4.1-4.4 illustrate the results of this study for the Ecological Greenways dataset. Lands with value as an ecological greenway are classified according to six priority levels, priority one being the most important lands. For the Ecological Greenways dataset, the area that would be inundated by various amounts of sea level rise was calculated for each of these six priority levels.

Data for the maps shown is as follows

Acres of Inundated Ecological Greenways

CLIP Priority Level	Sea Level Rise (meters) 0.5	1	2	5
1	17,958	49,417	160,208	611,375
2	115,589	285,251	528,081	1,103,220
3	6,420	13,745	81,037	158,923
4	30,218	50,905	75,131	168,715
5	2,342	4,220	8,003	23,184
6	891,909	2,217,989	2,637,113	4,558,035

Legend

Critical Ecological Greenways- defined by CLIP analysis (Oetting and Hoctor 2007)

Inundated lands outside of critical ecological greenways

Inundated lands within critical ecological greenways

Map Sources: Gap_lcov 2000, Whittle 2008, Oetting and Hoctor 2007

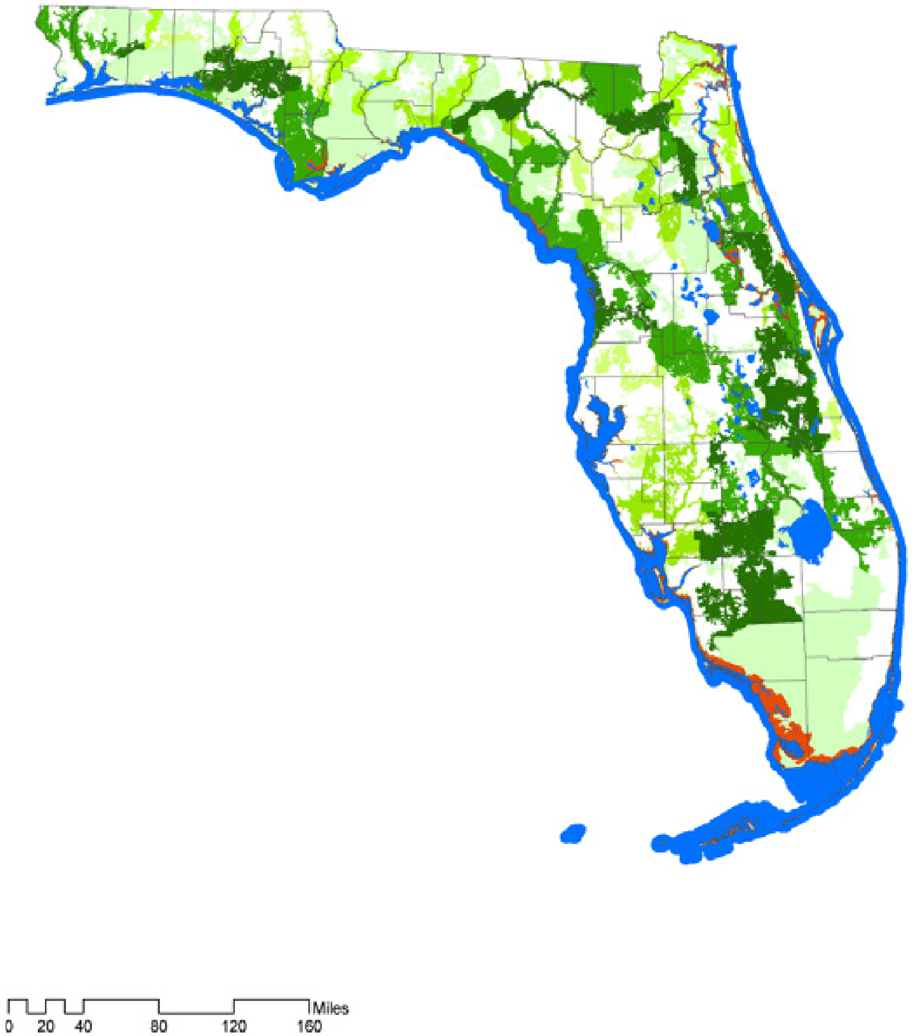

Figure 4.1: Ecological Greenways Inundated by 0.5 Meter Seal Level Rise (1.64 feet)

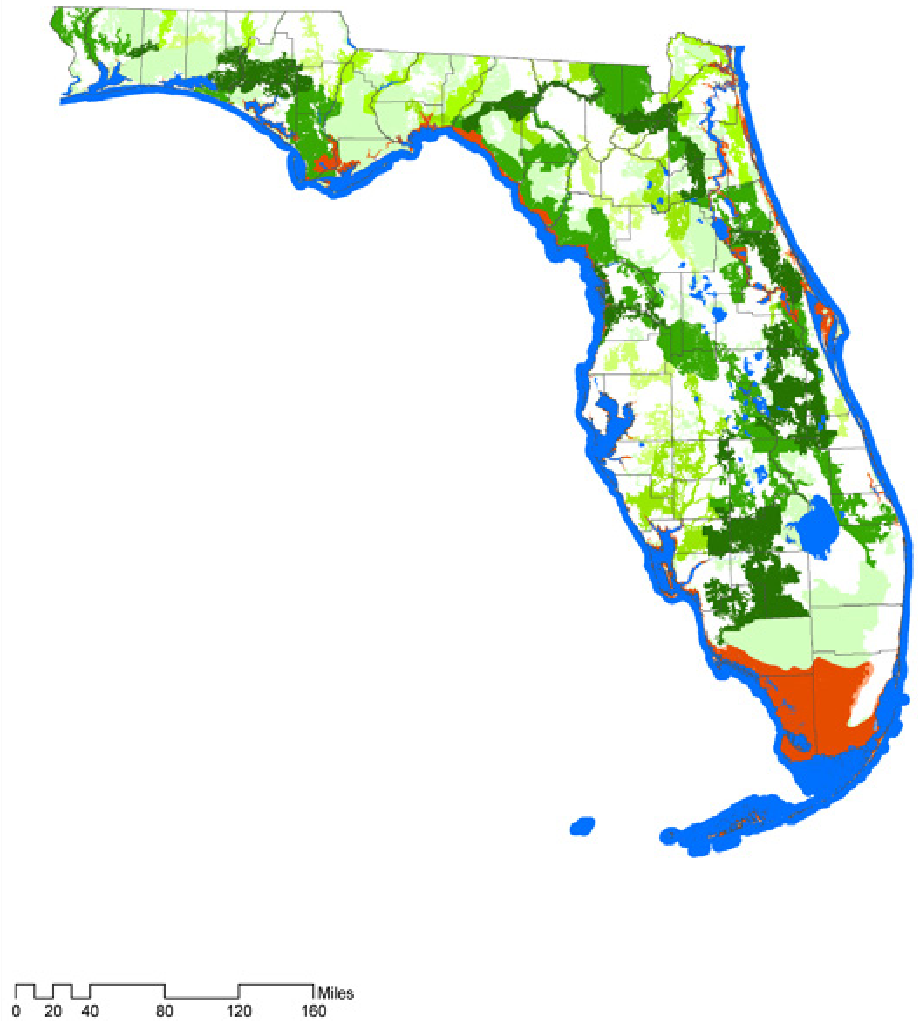

Figure 4.2: Ecological Greenways Inundated by 1 Meter Seal Level Rise (3.28 feet)

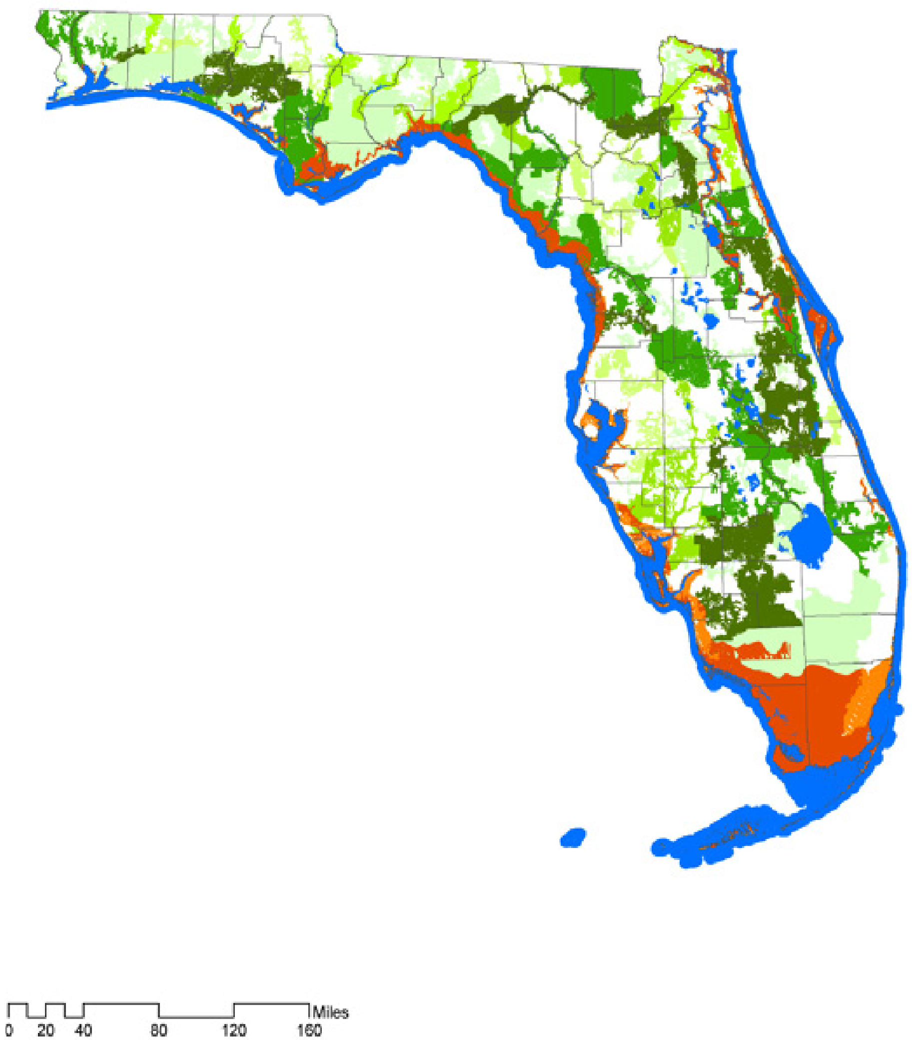

Figure 4.3: Ecological Greenways Inundated by 2 Meter Seal Level Rise (6.56 feet)

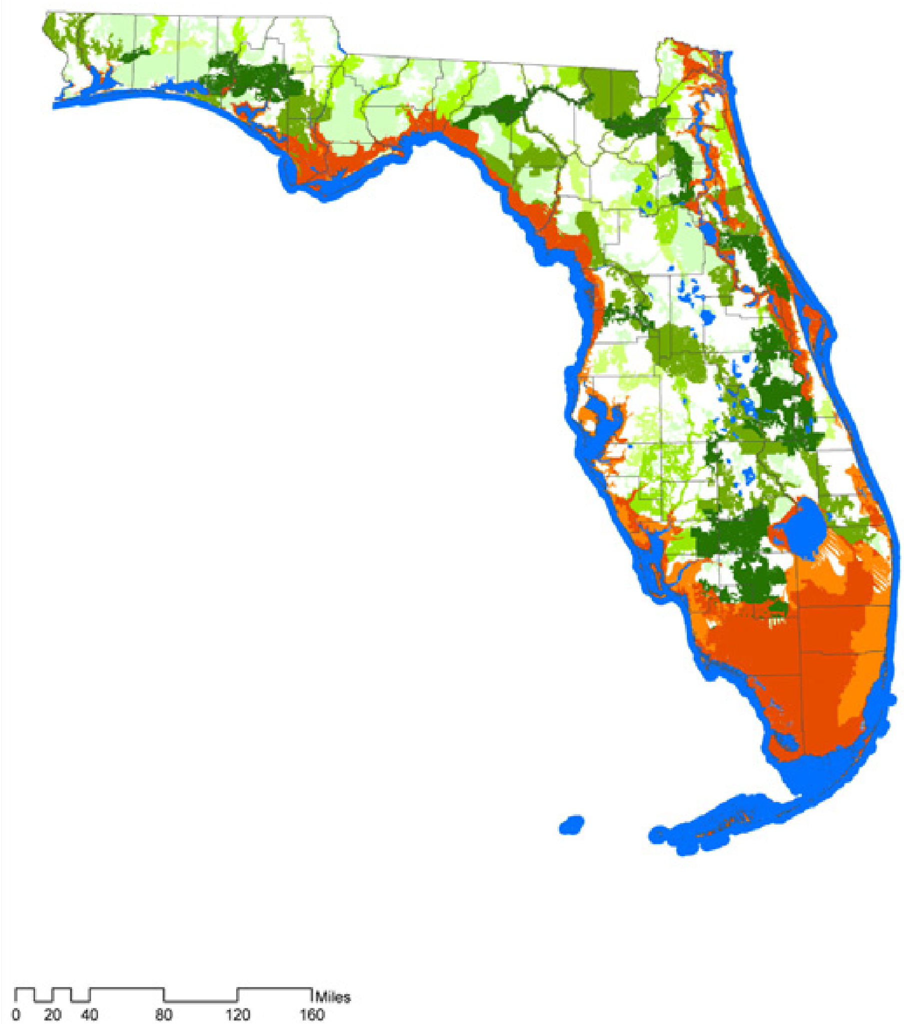

Figure 4.4: Ecological Greenways Inundated by 5 Meter Seal Level Rise (16.40 feet)

The focus of this case study research is on design based projects demonstrating adaptation to sea level rise, although projects responding to flood risks have also been included. The primary focus is on responses on developed coastlines, though some projects in non-developed areas have been included.

Some of the more pertinent projects related to sea level rise are:

5. Antwerp Quays: This project is one of the few design focused projects that addresses permanent inundation by sea level rise.

12. South Bay Salt Pond Restoration Project: The South Bay Salt Pond Restoration Project is a 15,100 acre tidal wetland restoration project in South San Francisco Bay. The project is specifically addressing sea level rise in its planning process.

14. Percival Waterfront: This is a waterfront revitalization project in the Olympia, Washington that is proposing to address sea level rise through design and planning measures.

Additional Topics Section: Room for the Rhine Project: This project proposes specific methods for creating more room for the Rhine River to flood as climate change causes increased flooding. It is less applicable the scope of this project, which focuses on permanent inundation from sea level rise, but it is an incredibly valuable project.

The following additional projects were researched.

1. SE Coastal Park, Barcelona
Foreign Office Architects

The concept of this project is based on artificial dune construction. Dunes protect flora and fauna and buffer wind naturally. These provide space for an amphitheatre and paths between and transition between the rooftop of a parking garage and the shoreline. They are planted on the landward side as natural dunes would be, and pavers form the coastal side that allow volunteer plants to grow between.

Issues: What is the impact of creating artificial static dunes on dynamic coastal processes? Perhaps this is valuable as part of a strategy for protecting developed areas from sea level rise where conservation of the natural littoral zone and processes is not an issue.

2. Louisville Waterfront Park
Hargreaves Associates
Strategies: Flexible floodplain development

Majority of park in periodic flood zone. Slope stabilization through native plantings and construction methods, fast draining soils, durable bolted site furnishings. Lower banks stabilized with geo-textiles and gabions planted with riparian species. Landforms sited in tandem with river flows to minimize damage as waters rise and fall. Lawns constructed with shredded material in topsoil layer which binds with grass roots for stabilization. Constant slope to river allows debris to retreat with flood waters. Program placed according to what can be temporarily flooded and what cannot.

3. Guadalupe River Park
Hargreaves Associates
Strategies: Flexible floodplain development

Flood water control. Pathways that can be navigated at high or low water levels. Flood resistant site furnishings, gabions planted with native riverine species that withstand periodic inundation

4. Los Angeles State Historic Park, Trinity River Corridor, Dallas
Hargreaves Associates
Strategies: Flexible floodplain development

5. Antwerp Quays
Antwerp, Belgium: Scheldt River Waterfront
Strategies: Urban shoreline barriers

The primary goals of this project are to connect the city with the water while providing protection from floods and rising sea levels. It was important that the quays were user friendly spaces, not simply barricades. Some of the interesting ideas generated about these two seemingly conflicting uses were of the quays as an underlying element where the users and their activities give the quays meaning. Flexible use of the quays is an important idea. Some of the design ideas about how to form the flood defense itself were to allow it to dissolve completely into new topography-in contrast to a linear vertical seawall. This has the potential to maintain a functional littoral space. Another idea was to use the flood defense as balcony, building, stairs, or a removable system, as an architectural and landscape architectural element. An important element of the contest winning solution was a number of different modular sections or type profiles that address the varying functions along the quay but also unify the space. (Topos 59: 93-97)

Metropolis Magazine describes the winning proposal in the following excerpt, "their (PROAP/WIT) proposal is distinguished by a conscious decision to eschew a fully formed image-driven design. "One of the things we rejected was the kind of approach where people arrive at a place that has been studied for years and years, and then propose—with incredible arrogance—to promote a very different image of that place," Nunes says. "That's what we see when a big architectural star is invited to a place." Indeed, most proposals to the competition featured illustrations of happy strollers walking through landscaped parkland safely elevated above the floodplain of the Scheldt".

"The PROAP/WIT scheme was more diagrammatic, in both its form of presentation and its design strategy. "Landscape is created by successive processes and not by one action," Nunes says. "We put together a master plan instead of a project. We decided to present a table of scenarios with approaches and consequences, trying to reduce things to a blank slate where some basic rules—a process—could be developed"

"That process will be governed by a series of ten topographical sections that read from above like the keys of a piano. Each key will address the river in a distinct fashion: one section, resting on pontoons, will rise and fall with the tides; another will slope down gradually from a protective berm; a third will cantilever out over the water. All suitably answer the demands of the Sigma Plan while retaining access—visual and physical—to the river. "Think of it as a toolbox for how the city reclaims contact with the water," WIT's Jan De Rop says. The spaces themselves will be left relatively open and unprogrammed, with minimal landscaping and few permanent structures—ideally suited to the temporary events (fairs, concerts, festivals) that typically make use of the vacant lots now. When flooding inevitably comes, there won't be much to destroy, but the city beyond will be protected" (Lamster 2007).

Reference:
Lamster, Mark. “The City and the Stream”. Metropolismag. September 19, 2007. Metropolis Magazine. January 2008. <http://www.metropolismag.com/cda/story.php?artid=2929>

6. <u>Sigma Plan</u>
This project defines strategies for flood control and protection for the River Scheldt Estuary. The original goals were:

- reinforcing and heightening of the dikes in the entire Sea-Scheldt basin (512 km);
- creation of controlled inundation areas to initially offset the threats of extremely high water levels;
- construction of a flood barrier in Oosterweel.

The project has increased focus on defining locations for controlled inundation (CIA) which also can imitate conditions for marsh and mudflat development. (Comcoast 2007)

Note: Controlled Inundation could be an important part of mitigating storm surge damage in Florida.

7. <u>Rio Piedras Restoration</u>
San Juan, Puerto Rico, 37 hectares
Strategies: Ecological restoration: flood control- increased channel width, infiltration, and shoreline stabilization

This project occurs where the Rio Piedras River runs through the University of Puerto Rico Botanical Garden. The Rio Piedras river channel will be widened and terraced to convey and hold water. The lower terrace is the primary floodway and provides conveyance for 2-10 year floods and is used for research, experimentation, and education. The second upper shelf provides conveyance for 100 year floods and is used for public recreation. Shelf widths vary according to available land and site constraints. The landscape architects, Field Operations, designed a modular perforated concrete unit (looks like Swiss cheese) allowing for different stabilization needs. In areas needing the most stabilization: low flow channels and narrow zones, under bridges, and near existing buildings, pores are filled with riprap or are designed with continuous revetement. The lowest shelf is part vegetated and part vegetated riprap. The highest shelf is reinforced with erosion control textiles and vegetation. A floodplain located elsewhere detains floodwater in collection basins reducing erosion and peak flow. (Topos 59, p 71-72)

8. <u>Oriental Bay</u>
Wellington, New Zealand, 1 km of coastline
Strategies: Coastal Hardening

The project is designed to control coastal erosion processes to help preserve a public beach using three control points. One of these is a volume of stacked concrete slabs that creates an artificial headland and places for people to access the water. (Topos 59: 22)

Issues: What is the greater effect of controlling coastal erosion? Is this justifiable for preservation of an important public amenity?

9. <u>Point Fraser Wetland</u>
Perth, Australia, 5.8 hectares
Strategies: Ecosystem construction: water purification, sediment loss reduction

The point Fraser Wetland is a constructed inner city wetland in Perth, Australia. The primary goals of the project are to improve the quality of urban stormwater before discharge into the river, to provide wildlife habitat, and a public park. (Topos 59: 14)

10. Venice
Strategies: Offshore barrier, dry and wet floodproofing

From my research, the MOSE project is the primary project in operation that is designed to cope with rising sea levels. Other methods of adaptation currently in use are:

- Decreased ground floor occupation
- Cementing ground floor windows
- Allowance for water- elevated circulation platforms, wet floodproofing

Mose Project

The MOSE project is the proposal under construction to build retractable floodgates at the mouths of the inlets linking the Venice Lagoon to the Adriatic Sea. The primary objective is to mitigate the periodic flooding of the City of Venice. Other proposals to control flooding in Venice have included narrowing the inlet channels to reduce the water flow from the sea into the lagoon, and banning tankers and large ships from entering.

Some criticism of the project is found in the following excerpt from a PBS article. "The project has long had a bevy of critics: Italian and international environmentalists, along with scientists who for three decades have disapprovingly followed the path to the MOSE solution. Those opposed believe that relentlessly rising seas will make MOSE obsolete within a few years. They also worry that officials would need to raise the gates so often that the normal ebb and flow of the cleansing tides would dramatically affect aquatic life within the lagoon and make the city unlivable for long periods, as sewage normally flushed from the lagoon remains behind. These critics want more studies conducted on the gates' potential environmental impact, and they want the international scientific and engineering community to come up with new solutions that would protect Venice for the next century rather than for just the next few decades. (Keahey 2002)

"In order to build trenches for the MOSE gates, they are going to dig up millions of cubic meters of seabed and replace it with cement, which could seriously alter the ecosystem," says Alberto Vitucci, a journalist who has been covering the project for years. "The entire mechanism will be underwater, making maintenance extremely difficult and costly. And the authorities never took any alternative projects into serious consideration." (Poggioli 2008)

References:
Poggioli, Sylvia. ''MOSE Project Aims to Part Venice Floods''. NPR. January 7, 2008. NPR. January 7, 2008. <http://www.npr.org/templates/story/story.php?storyId=17855145>

SAL.VE: Activities for the Safeguarding of Venice and its Lagoon. Ministry for Infrastructure - Venice Water Authority, Consorzio Venezia Nuova. January 2008. <http://www.salve.it/uk/ >

Keahey, John. "Weighing the Solutions: Sinking City of Venice". NOVA Science Programming On-Air and Online. October 2002. PBS. January 2008. <http://www.pbs.org/wgbh/nova/venice/solutions.html>

11. Sundarban Islands
The Sundarban Islands are a group of 54 small islands in northeast India and Bangladesch. They comprise the Sundarbans National Park, a UNESCO World Heritage Site and contain the world's largest area of mangrove forests. Mangrove restoration and reforestation is underway to combat the impacts of sea level rise on the islands. Few good sources were found on this project.

References:
(Sundarbans) “People of the Sunderban’s take action to arrest sea level rise”. Greenpeace. October 15, 2007. Greenpeace. January 2008. <http://www.greenpeace.org/india/press/releases/people-of-the-sunderban-s-take>

“Unesco World Heritage Center: Sundarbans National Park”. UNESCO. March 21, 2008. UNESCO World Heritage Centre. January 2008. <http://whc.unesco.org/en/list/452>

12. South Bay Salt Pond Restoration Project
EDAW Landscape Architects
Strategies: Ecological Restoration for Flood Management, Levies, Adaptive Management.

The South Bay Salt Pond Restoration Project is a 15,100 acre tidal wetland restoration project in South San Francisco Bay. This project provides is an excellent source of information on wetland restoration.

Some pertinent excerpts related specifically to how sea level rise is addressed in this project are included below as quoted from the project website. These are included for ease of research for those referencing this case study.

References:
(South Bay) “South Bay Salt Pond Restoration Project”. 2008. California Coastal Conservancy. January 2008. <http://www.southbayrestoration.org/index.html>

13. Comcoast Project (COMbined functions in COASTal defence zones)

This is a Northern European initiative that “developed and demonstrated innovative solutions for flood protection in coastal areas” (Comcoast 2007). It is a valuable source for understanding basic flood protection strategies and provides good graphic illustrations of these strategies.

As quoted from the project website, “ComCoast created multifunctional flood management schemes with a more gradual transition from sea to land, which benefits the wider coastal community and environment whilst offering economically sound options. The ComCoast concept focused on coastal areas comprising embankments. The European Union Community Initiative Programme Interreg IIIB North Sea Region and the project partners jointly financed the project costs of € 5,8 million” (Comcoast 2007).

Reference:
Comcoast. December 2007. Combined Functions in Coastal Defence Zones Project. January 2008. <www.Comcoast.org>

14. Percival Landing, Olympia, WA

This is an ongoing project for the redevelopment of a portion of the waterfront in Olympia, Washington. This is one of the few projects identified by research that is not primarily conceptual and that is actually considering sea level rise from a design perspective. The City Staff are recommending design parameters for a design life of 50 years and design to accommodate a sea level rise of up to two feet. The plans available show some basic strategies dealing with sea level rise being considered but do not show comprehensive design integration, and the strategies shown do not seem especially innovative or ecologically sensitive.

Reference:
"Percival Landing". February 2008. City of Olympia, Washington. January 2008. <http://www.olympiawa.gov/cityservices/par/percivallanding/ >

(Percival Landing Agenda Item) "Special Council Meeting Agenda Item One: Percival Landing Sea Level Rise and Design Life". January 15, 2008. City of Olympia, Washington. January 2008. <http://www.olympiawa.gov/documents/CouncilPackets/20080114/SC_PercivalLandingSTF.pdf >

Student projects related to sea level rise

15. Victoria University of Wellington School of Architecture, LADN 411 Design Studio

The students in this studio focused on the condition of 4 low lying coastal sites in Wellington, New Zealand: Rongatai, Waitangi Stream, Seatoun and Petone.

The potentials of adaptation were examined through the construction of protective structures (eg. reefs, dunes, dykes, sea walls) and the management of change over time through a strategy of managed retreat.

Reference:
"Victoria University of Wellington School of Architecture BDes Landscape Architecture Gallery". Victoria University of Wellington. September 2007. Victoria University of Wellington. January 2008. <http://www.victoria.ac.nz/architecture/landscape/gallery/index.aspx>

16. UMass Amherst Department of Landscape Architecture and Regional Planning: Jason Miller and Justin Alexander
Project: New Orleans Redevelopment
Strategy: Controlled Inundation

This project examines the control of floodwaters in New Orleans through a blueway and greenways network. This network allows water to flow in and out of city and is connected to Lake Pontchatrain.

Note: It is not clear to what level this project addresses sea level rise as opposed to periodic flooding. The concept is good, but if designed to respond to sea level rise would produce a quite different network pattern due to topographic variations than is represented in the drawings. This would not be the case if dikes are used, but the wisdom of reliance on dikes in New Orleans is questionable.

Reference:
"UMass Amherst, Student Gallery, Landscape Architecture and Regional Planning". UMass. 2008. UMass Amherst. January 2008. <http://www.umass.edu/larp/gallery.html >

17. University of Toronto, Toronto:
Van Thi Diep, Student Affiliate ASLA
Project: Halifax Harbor Festival Event Landscape
Strategies: Buoyant Landscapes

This project proposes buoyant platforms anchored to the quay side that can be deployed for additional festival space. This increases or maintains the area of useable space as sea waters inundate the harbor.

Issues: Behavior of the floating platforms in storms. This is particularly an issue in Florida.

Reference:
"ASLA 2007 Student Awards". ASLA. 2007. American Society of Landscape Architects. January 2008. <http://www.asla.org/awards/2007/studentawards/406.html>

Additional Case Study Topics Researched

The following are some additional topics and sources that were reviewed while searching for design focused case study projects. These topics and sources did not ultimately contain information that was used in this report, but were important to address in the case study research. The topics include locations, publications, and projects.

<u>• New Orleans</u>
I did a search for sea level rise adaptation projects associated with New Orleans and did not discover any significant sources of information. This search would be more fruitful with more time allocated and merits further research. One starting point for research is the following source:

(LaCoast). "Sample CWPPRA Projects Mitigating Sea-level Rise". LaCoast. USGS National Wetlands Research Center. 2008. <http://www.lacoast.gov/watermarks/2003-02/6projects/index.htm>

<u>• San Francisco</u>
A search for sea level rise adaptation projects was done for San Francisco. The following two sources were identified, though others may exist.

(SFBCDC) "Climate Change Planning Project". 2006. The San Francisco Bay Conservation and Development Commission. December 2007. <http://www.bcdc.ca.gov/index.php?cat=56>
"South Bay Salt Pond Restoration Project". 2008. California Coastal Conservancy. January 2008. <http://www.southbayrestoration.org/index.html>

<u>• International Panel for Climate Change 2007 Reports:</u>
Several chapters from the 2007 IPCC report were reviewed. Chapter 17.2.2, Assessment of Adaptation Practices, Options, Constraints, and Capacity was reviewed for design based adaptation information. The information in this source is less focused on design, and more focused on policy and planning, and as such was more difficult to apply to this project. It references Easterling 2004.

• Easterling, W.E. "Coping with Global Climate Change: The Role of Adaptation in the United States". Pew Center on Global Climate Change, 2004.

This is a valuable source for information on adaptation to climate change. Pages 27-28 of the report focus specifically on adaptation to sea level rise in the United States. The focus of this section is less on design and more oriented towards policy and planning with specific examples of communities or regions that are adopting sea level response policies.

• Room for the Rhine Project, Ministry of Transport, Public Works, and Water Management, Netherlands

This project proposes specific measures to provide room for expansion of the Rhine River due to sea level rise, with dike strengthening as an option only used when other strategies are impractical. The project was ultimately deemed not directly applicable to the scope of the project (focused on permanent sea level rise inundation) because the project focuses in large part on periodic flooding rather than permanent inundation. It is however extremely valuable as a discussion of river flooding and provides a very interesting portfolio of flood protection strategies.

Barnett, Jonathan and Kristina Hill. “Design for Rising Sea Levels”. Harvard Design Magazine. Issue Number 27, Fall 2007/Winter 2008

The following excerpt is from a 2008 article written by Jonathan Barnett and Kristina Hill and titled, “Design for Rising Sea Levels”, in the Harvard Design Magazine. The excerpt discusses methods of responding to sea level rise, first discussing the three basic response types of protection, retreat, and accommodation. It then moves into a very interesting discussion of horizontal rather than vertical methods of adaptation, which strongly influenced the strategies illustrated in Part 3.

Protecting Coastal Development

There are essentially three ways of dealing with the effect of rising seas on coastal development.

1. Development can be moved away from the shore, and the shoreline can be restored to a state that will accept the fluctuations of rising tides and storm surges. This may be the best alternative for individual houses in vulnerable locations, but it would be the last resort for whole cities.

2. Development can be raised above flood levels, in its current place. Individual houses raised a story or more above ground are becoming a familiar sight in coastal locations. This is not a great design strategy in denser areas, where it would make more sense to raise the streets and buildings for an entire district. FEMA regulations permit parking to be below flood levels, so both parking and utilities could remain at today’s grade level; future utilities and parking would actually cost less with that approach, since it is cheaper to build parking and utilities up from grade than to excavate. Street levels and side sewer lines were raised in the mid-19th century in entire districts of Chicago and Seattle to improve drainage. Raising the elevation of a whole urban district can work, although it is obviously expensive and requires the coordination of public and private investment.

3. Protect coastal cities with a combination of wetlands restoration, flood walls, and pumps. A version of this strategy, minus significant wetland restoration, failed in New Orleans; although the walls should have worked, their construction turned out to be faulty. After devastating storm surges from North Sea storms in 1953, the governments of Great Britain and the Netherlands invested in major engineering protection against flood surges. The Thames estuary protection includes barriers across the approximately 1,600-foot width of the Thames River to protect central London. These retractable steel barriers rest on the river bottom in sections between five-story towers and swivel upward and sideways to hold back a flood surge. They have been used many times since completion in 1983, and more often recently. At a cost of more than 500 million pounds in 1983 (which today would exceed a billion pounds and equal about $1.9 billion USD), the project was paid for primarily by public taxation and was designed to last until 2030. The centerpiece of storm surge protection in the Netherlands is a much larger estuary-mouth barrier, the Oosterscheldekering, built from 1976 to 1986 just south of Rotterdam. That behemoth is 5.6 miles long and mostly fixed in place, with movable gates along slightly less than half its length to allow tidewaters and boats to pass through in fair weather. Built at a cost of 2.5 billion euros (or about $3.4 billion USD), the dam was designed to last 200 years. These are expensive investments, but even these big numbers are much smaller than the property values protected: New York, for example, has more than $1 trillion in insured coastal property.

Landscape as coastal infrastructure

In the more complex third strategy we described above that *includes mechanical barriers and pumps as well as wetlands, the open question is how landscape can form an infrastructure for coasts.*

Most design thinking for coastal protection explores options in the vertical plane: walls, mechanical barrier arms, levees, and houses on stilts. The alternative is to think horizontally. If we could design a living coastal infrastructure that would support marine ecosystems and also absorb some wave energy and flood water and allow that new coastal infrastructure to migrate inland as sea levels rise, we would have the kind of solution that engineers sometimes call a belt-and-suspenders approach. In New Orleans, a statistic widely quoted was that every five miles of coastal wetlands restored could reduce storm surge by about a foot. When storm surges are expected to exceed twenty feet, coastal wetlands alone don't seem an immediate practical solution. Sandy barrier islands like those found at the mouth of New York harbor or Virginia's eastern shore can move by ten feet in a single year. Clearly, like mechanical barriers and pumps, landscape strategies have to be used very carefully to achieve significant long-term benefits. The designs must address the specific limiting factors that exist in ecosystems and human systems.

Two of the most significant limiting factors for the growth of shallow-water sea grass beds that nurture fish and crabs are insufficient light, since rays of sunshine are blocked by turbid water that suspends sediments and pollution in storm-water runoff. Artificial islands and reefs of various kinds can make deep water shallower, creating places where sea grasses can grow, as long as we simultaneously continue to improve the quality of water running off cities, suburbs, and farmlands. If the artificial islands and reefs are built to float in a submerged position, rather than fixed in place on the bottom of bays or beaches, we can move them inland as the sea rises to form a flexible new marine edge. These structures could be built with select materials from the industrial waste stream, and by recycling some materials from buildings that are being torn down and replaced. The questions of cost and modularity will be important, along with the ability of these floating structures to absorb wave energy or create flood storage on the freshwater side.

There are three critical reasons to consider these horizontal approaches: first, they are the best solution for supporting coastal ecosystems short of simply removing big sections of coastal cities along their waterfronts and restoring pre-development habitat; second, in most coastal building situations the value of the assets being protected will not justify billions of dollars in investment in vertical coastal barrier systems. And third, if we don't pay what it takes for new barriers to make sure they are built to open mechanically, they will contribute to more severe problems for aquatic ecosystems. The simpler strategies of decamping or raising the floor levels of buildings may be viable options in low-density development, but the more comprehensive solution to protect lower-density urbanization as well as ocean ecosystems is to unpack our vertical strategies and reconsider systems that can operate in the horizontal zone.

Barrier methods for protecting development from sea-level rise
The Thames and Eastern Scheldt barriers provide templates that can be applied to comparable situations where the value of property is so high that it could justify these investments. Structures analogous to the Thames Barrier could be placed across the Narrows, the entrance to New York Harbor, and across the passage from Long Island Sound, roughly where the Throgs Neck Bridge is located, to protect many vulnerable locations from storm surges. The outer reaches of New York's waterways could be protected by a barrier on the model of the Eastern Scheldt in the Netherlands, connecting barrier beaches from Sandy Hook

to Coney Island. If such a barrier were needed, it would be part of a system of seawalls that would protect the barrier beaches themselves. An early version of such a seawall is the one built on Galveston Island after the 1900 hurricane. Boston Harbor could be protected by a series of seawalls along the coast and something like the Eastern Scheldt barrier across its opening. An installation like the Thames Barrier across the Shanghai River might protect Shanghai's Pudong district from storm surges, and perhaps a barrier even longer than the one across the Eastern Scheldt could protect the whole Arabian Gulf.

"Anticipatory Planning for Sea Level Rise along the Coast of Maine". U.S. EPA Office of Policy, Planning, and Evaluation. September 1995.

The following is an excerpt from a publication titled, "Anticipatory Planning for Sea Level Rise along the Coast of Maine", as described on the Environmental Protection Agency's Global Warming Publications website. The report contains an assessment of the vulnerability of the State of Maine to sea level rise and recommendations for response. The conclusions and recommendations of the report provide a very good list of actions and policies that could be applicable to other regions. The following summary of the report's conclusions and recommendations is taken from the below referenced site. The report can also be downloaded from this site.

EPA Global Warming Publications. November 24, 2004. US EPA. 2008. <http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ResourceCenterPublicationsSeaLevelRiseIndex.html>

Conclusions and Recommendations

The key premises underlying the recommendation are that the state should:

- *protect and strengthen the ability of natural systems to adjust to changes in shoreline position; and*
- *prevent new development which is likely to interfere with the ability of natural systems to adjust to changes in shoreline position.*

In Chapter Seven, the report recommends three different types of actions:

1. *concrete anticipatory policies and design standards to guide public investment in buildings, roads and similar infrastructure;*
2. *specific planning and regulatory policies; and*

3. longer range strategic assessment, research and educational actions. The specific recommendations, developed in more detail throughout the report, are summarized as follows:

<u>Anticipatory Policies and Design Standards</u>
1. Review all new coastal public works projects to determine if minor, cost-effective changes can be made in design or siting to accommodate a changed shoreline position or more intense storms;

2. Discourage an irreversible commitment of public resources for new infrastructure or structures in areas likely to be affected by accelerated sea-level rise, except as necessary to support continued economic viability and efficient functioning of water-dependent uses;

3. Increase the amount of publicly-owned or controlled upland area adjacent to public waterfront access areas to allow for landward movement;

4. Expand coastal nature preserves and acquire key undeveloped coastal wetlands and adjacent conservation areas to provide sufficient upland buffer areas for wetland migration;

<u>Planning and Regulatory Policies</u>
5. Halt attempts to stabilize the shoreline within or adjacent to the soft coasts and maintain/restore the ability for coastal sand dune systems, coastal wetlands and eroding bluffs to migrate inland.

6. Along all soft coasts, establish setbacks for all structures (including walls and bulkheads) based on projected shoreline position assuming a 100 cm rise in sea level over the next century to protect the natural systems.

7. As a limited exception to #6, in those areas expected to remain stable over the next 100 years assuming a continuation of historic sea-level rise, allow construction of new, small, easily-movable structures (excluding seawalls or bulkheads) built at low densities adjacent to sand beaches or marshes on the condition that they be removed if they begin to interfere with coastal processes.

8. As a limited exception to #6, allow new structures for functionally water-dependent uses which meet certain performance standards.

9. Treat existing development within the area threatened by erosion or inundation from a sea-level rise of 100 cm over the next century as non-conforming structures, prohibit expansion or intensification of use, but allow ordinary maintenance and repair so long as not damaged by more than 50% of its value. To the extent legally feasible, require the owner to remove the structure if it is damaged by more than 50% of its value, if the structure becomes located on public land, or becomes a public nuisance.

10. On any site unlikely to be affected by a 100 cm rise but likely to affected by a 100 to 200 cm rise over the next century, allow new subdivision development only if it meets performance standards for cluster development designed to minimize the costs of protection.

11. Supplement State regulatory procedures by encouraging/requiring other agencies and municipalities to consider the probability of future increased rates of sea-level rise in making investment, development and permitting decisions.
Strategic Assessment, Research, and Educational Actions
12. Designate one State agency as the lead agency for monitoring issues associated with global climate change and sea-level rise.

13. The lead State agency and cooperating State agencies should undertake additional research to document coastal erosion and to determine how revised global or regional projects of particular impacts of global climate change may affect Maine.

14. Undertake a substantial education effort aimed at local officials, code enforcement officers, other State agencies, current and potential coastal landowners and the general public to focus on the hazards of coastal erosion and inundation, possible impacts of accelerated sea-level rise, the costs of engineered "solutions" and the benefits of conserving the soft coasts as a resilient natural system.

15. As funding permits, undertake supplemental studies on related impacts, specifically including the impacts of coastal flooding/ storm surges and salinization/saltwater intrusion with accelerated sea-level rise. In addition, continue to assess policy response options, particularly rolling easements or other market-based approaches, to supplement the use of regulatory setbacks.

The study makes the most detailed recommendations with regard to modification of regulatory strategies. However, researchers also recommend additional evaluation of policy options, including market-based approaches such as the acquisition of rolling easements, to facilitate planning for even longer time frames (beyond 100 years) or higher than projected sea-level rise (greater than 100 cm. by 2100).

There are opportunities for the State to demonstrate leadership in non-regulatory spheres in preparing for the possibility of an accelerated rate of sea-level rise. For example, it should illustrate sound economic analysis by incorporating an awareness of sea-level rise projections into its decisions about public works projects, capital investments, public waterfront access siting, and acquisition of conservation areas.

State agencies should also provide leadership through the development and transfer of technical information. Maine Geological Survey and other State agencies should continue to monitor national global climate change projections, analyze the implications of national projections for the State of Maine, and provide technical assistance to municipalities about coastal erosion, historic rates of sea-level rise, and local impacts of projected accelerated rates of change.

The State should also undertake a widespread public education effort to emphasize the non-static nature of the shoreline and the benefits to other shoreline owners, the community and the State of protecting the ability of natural systems to adjust to changes in shoreline position. It is particularly critical to convey information about anticipated shoreline change, coastal processes, and related regulatory constraints to current and potential coastal landowners so that they do not harbor any unrealistic expectations about being able to interfere with natural coastal processes. Finally, it is important for the State to continue to be an active participant in anticipatory planning for sea-level rise and global climate change. For example, the State should contribute to efforts to mitigate the global and local impacts of greenhouse gasses by participating in appropriate emission reduction efforts. Through a designated lead agency, the State should also keep abreast of scientific developments and evolving legal tools. It should plan to revisit its adaptive response strategy on a periodic basis, perhaps on a ten year schedule. This iterative approach will allow the State to incorporate evolving scientific information, evaluate emerging legal tools, and refine its approach based on the best information available at that time.

(South Bay) "South Bay Salt Pond Restoration Project". 2008. California Coastal Conservancy. January 2008. <http://www.southbayrestoration.org/index.html>

The South Bay Salt Pond Restoration Project is a 15,100 acre tidal wetland restoration project in South San Francisco Bay. This project provides is an excellent source of information on wetland restoration, and the project is specifically addressing sea level rise in its planning process. The following quotes are taken from descriptions of the South Bay Salt Pond Restoration on their website, http://www.southbayrestoration.org/index.html , and describe the extent to which sea level rise has been taken into account in the project planning and response measures being taken. Very specific measures are outlined, which was rarely located in the research. A more cohesive and comprehensive project description should be taken from the project website.

"The Project would use phased implementation, monitoring and adaptive management to plan for and accommodate a range of potential future sea level rise. Updated sea level rise estimates would be used as future phases were designed and implemented. Monitoring and adaptive management would provide updated assessments of future sea level rise, inform planning for future phases, and adjust previously- implemented phases as needed. These are described in the Adaptive Management Plan and summarized in Section 2.3 of the EIS/R. Examples of monitoring and adaptive management activities:

- *As part of the adaptive management program, the Project would monitor sea level rise in the South Bay and review the scientific literature on sea level rise on an ongoing basis (discussed in EIS/R Section 2.3 and Appendix D).*
- *Additional monitoring and modeling of sediment dynamics within the South Bay are planned as part of the Adaptive Management Plan. A longer-term modeling effort led by Principal Investigators at U.C. Berkeley and Stanford University is being initiated to develop a coupled hydrodynamic and sediment transport model of the South Bay. The model, coupled with monitoring data from previous restorations and the Phase 1 actions, would inform future phasing and implementation with respect to sea level rise, sediment supply and sediment sinks. In the long term, the model may be extended to include morphological, water quality and biological modules to improve the ability to predict ecosystem response to restoration actions.*
- *The Adaptive Management Plan and SBGA provide examples of adaptive management actions that could be used to narrow the range of uncertainties and encourage restoration success: adjusting the phasing to better match the sediment supply; maintaining levees along the bayfront edge to shelter restored tidal areas from wave energy and encourage marsh formation; removing levees along the bayfront edge to restore sustainable mudflats within the ponds; restoring natural shorelines such as shell breaches, wrack lines, and Bay-edge pans; using imported fill to raise pond beds to elevations conducive to vegetation establishment; and prioritizing restoration of less subsided ponds and/or ponds close to sediment supplies within the Project Area.*

In summary, the Project would seek to accommodate accelerated sea level rise, to the extent practicable, in order to maximize achievement of the Project Objectives" (South Bay 2008).

"Flood management is integrated with restoration planning to ensure flood protection for local communities. Where feasible, flood capacities of local creeks, flood control channels, and rivers will be increased by widening the mouths of the waterways and reestablishing connections to historical flood plains. As ponds are opened to the tide, levees between the newly created tidal marsh and local communities are built or enhanced to provide flood protection" (South Bay 2008).

"Higher than anticipated sea level rise rates that result in delayed

or arrested marsh establishment could affect the progression between the 50:50 and 90:10 alternatives presented in the EIS/R. Tidal habitat restoration may be closer to the 50:50 bookend to increase the sediment supply to those ponds that are tidally restored. Adaptive management efforts would be used to encourage marsh establishment in the tidal ponds. The restoration actions most sensitive to sea level rise would contain features to accommodate accelerated sea level rise, such as constructing a gradually sloping marsh/upland transition zone surface that provides an elevation gradient over which tidal marsh could shift upslope as sea level rises and initiating marsh vegetation plantings to maximize sediment-trapping efficiencies and enhance the accumulation of organic matter in the developing marsh sediments" (South Bay 2008).

"The future design of the flood protection levees would also take into account the best available information on sea level rise at the time of project-level planning and design. The plans would outline a strategy for low-, mid-, and high-end sea level rise predictions. For example, the plan may include building a levee to accommodate the 50-year mid-range sea level rise projection, and incorporate features or outline a process to deal with higher or lower rates of sea level rise. Lower than anticipated sea level rise is generally not anticipated to be a problem. Higher than anticipated sea level rise would require subsequent design phases to raise the levee (i.e., widening and raising the levee or building a flood wall) before sea level rises above the design level for flood protection. Other options would include overbuilding the levee initially to anticipate a higher rate of sea level rise, either by building a higher levee, or by building a levee with a wider base to more easily accommodate future increases in levee height. The future design of the flood protection levee would balance the cost and benefits of the potential approaches at the time of design. The project-level analysis and design would be presented in a future project-level EIS/R. Subsequent phases of environmental documentation may also be required to address changes to the Project based on updated sea level rise information and analysis. For example, there may be a need to import more fill than currently anticipated in this programmatic EIS/R for flood protection levee construction and maintenance of the flood protection and managed pond levees" (South Bay 2008).

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