Satellite Beach Sea Level Rise
Data and Analysis

SETTING

Satellite Beach is a residential community located in Brevard County, Florida with a population estimated at 10,848 in 2008. The community is 98% built-out, with a population density greater than 85% of Florida's municipalities (due primarily to lack of extensive industrial or commercial development).

The City encompasses 2,467 acres (3.8 square miles). However, 1 square mile of this is water, leaving 1,850 acres (2.9 square miles) of upland area spanning the barrier island separating Brevard County's Atlantic Ocean coastline from the Banana River segment of the Indian River Lagoon. The City's upland areas are bounded by 2.8 miles of ocean beach, 1.3 miles of shoreline on the Banana River, and 7.2 miles of shoreline fronting navigable canals connected to the Banana River. The largest east-west City dimension across the island is 1.5 miles. The island is separated from the mainland by the mile-plus wide Indian River, the narrow southern tip of Merritt Island (less than one quarter mile wide), and the Banana River, which varies in width between about one half and three quarters of a mile adjacent to the Satellite Beach shoreline. As a result, **a storm surge of about ten feet above mean sea level would place the highest elevations in the City (along its ocean shoreline) approximately three miles out to sea from the coastal ridge on which US 1 and the Florida East Coast Railroad are built on the mainland**.

Analysis using LIDAR data providing ground elevation values accurate to within about 4 inches shows the following distribution of land elevations in the City (*see topographic and submergence maps at Attachments 1 and 2 and hypsographic curve at Attachment 3*).

Feet Above Mean Sea Level	% of City's Land Area At or Below that Elevation
2	6
3	12
4	24
6	50
10	86

Only 14% of the City's land area is at an elevation of 10 feet or greater. This high land lies on the City's eastern edge, straddling SR A1A. The distribution of tax base, building area, and number of residential units are fairly evenly distributed across the elevation regimes comprising the City, with a modest under-representation at lower elevations and over-representation at higher elevations. These parameters, therefore, can be considered for planning purposes to be nearly proportional to land area in the City.

THREAT

The *Wind and Flood Hazard Assessment of Critical NASA Assets at Kennedy Space Center* (KSC-FF-5225) commissioned by NASA and published in June 2000 used the best available meteorological history and model information to estimate the probability of **hurricanes** impacting the area including Satellite Beach. The results are as follow:

Category Storm (weak)	Sustained Wind	Probability	Return Period
1	78-86 mph	65% in a 10 year period	10 years
2	99-102 mph	47% in a 25 year period	40 years
3	115-120 mph	39% in a 50 year period	100 years
4	133-142 mph	28% in a 100 year period	300 years
5	158-164 mph	6% in a 100 year period	1,700 years

These numbers lend credence to the popular perception that Satellite Beach is located in a portion of the North American Atlantic shoreline with a low incidence of catastrophic hurricanes. They also indicate that the City can expect weak hurricanes on a fairly regular basis, on average, more frequently than once per decade. The record-breaking hurricane season of 2004 demonstrated that **the City is not immune to major hurricane damage**, even from minimal hurricane strength winds. The City suffered damage from Charlie (tropical storm strength in Melbourne), Frances (maximum sustained local winds of 75 mph and gusts to 80 mph in Melbourne), and Jeanne (maximum sustained local winds of 80 mph and gusts to 100 mph in Satellite Beach) in 2004. Total estimated damage and recovery costs to City government and residents from Charlie were $48,000, in keeping with previous storms. Estimated damage and recovery costs for Frances and Jeanne came to over $69 million, orders of magnitude greater than any previous losses to the City, despite maximum local winds of Category 1 status. A post-storm damage assessment determined that 7% of the City's living units were rendered uninhabitable. The extensive damage from Hurricanes Frances and Jeanne were due primarily to wind. However, there were three homes on the ocean that were damaged sufficiently badly by being undermined by the surf that they were torn down (one five years after being damaged), and the concrete sloping seawall that had protected the Sandcastle Condominium since 1964 was undermined sufficiently that it had to be removed and replaced.

The NASA vulnerability study included **storm surge** among the threats to facilities on Kennedy Space Center. Modeling validated and calibrated against conditions during Hurricane Erin indicates that storm surge from a hurricane following the most likely track at the time of Mean Higher High Tide (Mean Sea Level plus 2 feet) would have the following characteristics:

Category Storm	Surge Elevation Above Sea Level	% of City Inundated
3	10 ft	86
4	12 ft	94
5	14 ft	96

To this would be added waves estimated at 15 feet or greater for such storms. The wave model input parameters used in the NASA study were conservative, since there is no historical data with which to calibrate the model, and it would be prudent to overestimate the threat given the value of the assets to be protected. However, **waves half the estimated height on top of the estimated surge for a Category 3 storm would essentially match the highest elevations in the City.**

The threat from storm surge will increase as sea level rises. As the elevation above water level of the tops of dunes and armoring protecting the ocean shoreline decreases, the probability of their being overtopped by any given storm increases, as does the amount by which they are overtopped when that does occur. This will be the case regardless of whether the frequency or intensity of tropical storms changes. While storm surge threatens the City with acute episodic flooding even today, **the gradual rise in average sea level will eventually threaten the City with chronic flooding** once sea level gets sufficiently close to the elevation of developed portions of the City.

Studies commissioned by the US Army Corps of Engineers and Brevard County have documented long-term loss of oceanfront land due to **coastal erosion**. Historical data indicate the location of the top of the dune bluff is retreating at a rate of about 0.6 foot per year. This has occurred during a period when local sea level rose approximately 1 inch per decade, indicating that locally every inch rise in sea level results in the migration landward, on average, of about 72 inches for the dune bluff. Comparison with surveys conducted in 1844 and 1859 suggests that in the century-and-a-half since that time there has been slight net accretion (perhaps 50 to 150 feet) of land between Patrick Air Force Base and the northern end of the City, little change in the shoreline in the portion of the City north of Cassia Boulevard, and loss of as much as 1,700 feet (0.3 mile) in the vicinity of Volunteer Way. **Accelerating sea level rise is expected to increase the rate of dune bluff retreat to about 1 foot per year. This presents a threat to the City's extensive oceanfront development, which has resulted already in 25% of the City's ocean shoreline being armored in some manner.**

The net transport of sand associated with coastal erosion occurs over multiple cycles of erosion and rebuilding that occur with changing seasons and storm events. Large storm events can accelerate this landward motion through an alternative mechanism, island **overwash**, in which material from the beach and dunes is washed over the island into the lagoon separating the barrier island from the mainland. In effect, the island is folded over itself in a very short period of time measured in hours, normally to form wetlands on its lagoon side. In more extreme events the island can be eroded to the point where the entire island, or a large portion of the island, disappears and becomes open water (**island breaching**). Nearby evidence for such events on the barrier island include the Thousand Islands in Cocoa Beach and the complex eastern shoreline of the Indian River north of Sebastian Inlet. The only report of such an event locally is associated with a Category 1 hurricane that flooded the barrier island in the vicinity of Cocoa Beach as it moved north along the coast about 15 miles east of Melbourne on 24 August 1885. The presence of a ridge of limestone bedrock and a discontinuous bed of coquina rock at slightly below current mean low tide under much of the island, but absent under the lagoon, provides a degree of anchoring for the island in its current location. However, the influence of that "anchor" will decrease as sea level rises. Also, the coquina is a soft, friable rock; it is easily broken into segments that the surf can move onto the beach, as is occasionally evident at Hightower Beach Park after an erosion event. As such, if exposed on a large scale, it could be scoured away, removing a component of the foundation of the island. The next anchor of competent rock forms the southern tip of Merritt Island on the western shore of the Banana River. **As with hurricanes, it appears that local conditions mitigate against overwash and island breaching in the vicinity of Satellite Beach.**

Sea level rise is particularly relevant in light of the City's highest elevation being 20 feet above sea level at one point east of A1A, and over 15 feet only along about 40% of the City's ocean shoreline in the vicinity of State Road A1A eastward. Approximately 20% of the City's oceanfront dune lies in each one-foot interval between 12 and 15 feet elevation. The elevation then drops toward the west to 3 to 5 feet above sea level along the bulkheaded canal banks forming the western boundary of the main portion of the City (the land west of South Patrick Drive and on Lansing, Samsons, and Tortoise Islands being comprised of spoil dredged from the canals used to fill what had been a normally flooded mangrove swamp). **The lowest**

ground elevations in the developed portion of the City lie in the block east of South Patrick Drive where no fill was placed prior to construction.

Variations in natural processes complicate the issue of estimating the impact of sea level rise on the City. The most obvious variable is that the level of water in the ocean and the lagoon does not remain constant, even over a period of one day. Ocean **tides** locally have an average daily range of 3.5 feet elevation, with average high tide being 1.76 feet above mean water, and the maximum annual elevation of high tide above mean water (perigean tide) being about 3.4 feet, about equal to the average daily tidal range. The Banana River daily average tidal variation is about 2.5 inches. The Banana River's mean annual highest tide (perigean) elevation is at 13 inches, about 5 times the average daily tidal variation. The ocean and lagoon tidal characteristics differ: the ratio of annual high tide versus daily high tide above mean water level in the lagoon is about twice that in the ocean, although the absolute magnitude of the variation is significantly less. Those living along the ocean shoreline expect annual highest tides about twice the average tide, measured in feet, and base decisions on this expectation. **The practical implication for those living along the Banana River and in low-lying areas interior to the City is that they need to consider the mean annual highest tide of 13 inches (which persists for several weeks in the fall of each year), even though the average tidal range in the river is less than 3 inches.**

The **water table** underlying the City is intimately tied to the surrounding surface waters. As the surface water elevation changes, so does the water table, with the rise or fall propagating inland from the shoreline over time. Based on 105 boreholes taken between A1A and South Patrick Drive in 2000, the seasonal high water table in the City lies, on average, 3 feet below the surface. However, this varies considerably, with one location 1 foot below the surface, 10% less than 2 feet below, 65% of the values below 3 feet, and one location 10 feet below. As sea level rises, the water table will also rise. As the seasonal high water table approaches the surface it will eventually influence which plants can grow, transitioning from today's norm of xeric (dry) or mesic conditions through most of the City to more hydric (wet) and mesic conditions at the expense of xeric conditions. The rate at which the water table will rise in any given location is governed by many factors. As such, it is difficult to predict under what conditions a particular location will experience a significant change in local hydrology. However, it is safe to state that a rising water table eventually will have an impact on the built environment, as well as the natural environment. **A sufficiently high water table for a sufficient period of time will compromise the integrity of paved roads and building foundations.** As the water table rises, it will saturate the base material underlying the asphalt driving surface of roads, resulting in failure of the paving if cars are driven over it under these conditions. Similarly, a rising water table will saturate the soil under foundations, reducing its load bearing capacity and increasing the probability overlying foundations will shift or fail, compromising the integrity of the structures that they support.

OPTIONS

There exist a limited suite of generic physical means to respond to sea level rise. Review of literature addressing sea level rise reveals six generic responses. In order of increasing aggressiveness they are: ignore, abandon, strategic withdrawal (also referred to as retreat), accommodate, defend, and attack.

The most common current response to sea level rise appears to be to **ignore** it. Most of the world's population are either unaware sea level is rising, or do not consider it an issue of importance to them. At the other end of the response spectrum, the Dutch have been **attack**ing the sea for centuries, reclaiming former open water by use of fill and dikes backed by elaborate drainage systems and pumps. They have made devising responses to sea level rise an export commodity.

An obvious response to sea level rise is to **defend** an asset by placing a barrier around it to prevent rising water from harming it. This response has resulted in the proliferation of armoring (protecting against erosion) and dikes (protecting against flooding) along shorelines in much of the developed world, with the extreme case being the Netherlands. Alternatively, sea level rise can be **accommodate**d by means such as elevating an asset in place above the level of danger. This response results in homes on stilts adjacent to waters prone to flooding, including in much of the lesser-developed world where communities lack organization or resources to construct dikes. Both defense and accommodation leave the asset in place. Instead of protecting an asset in place, the asset can be moved in a **strategic withdrawal**. This tactic has been used with multiple lighthouses, including the Cape Canaveral light. Instead of protecting or moving an asset, it can be **abandon**ed. It can be abandoned in place, either after being damaged beyond economical recovery, or before it is damaged. This would be an expected response for a low value asset for which protection or relocation would be uneconomical. As an alternative to abandonment in place, an asset can be removed (not moved). This is equivalent to abandonment in place, but removes the likelihood that the deteriorating asset will become a problem. Abandoning an asset can result in an associated response to sea level rise, relocation – of the function(s) the asset served without moving the asset, itself. Relocation of a function without moving the asset is a form of strategic withdrawal.

The generic options provide a framework within which exist a multitude of variations: physical, legal, or social. These include rolling easements, building codes, and insurance programs. The variations are essentially limitless.

The potential generic responses to sea level rise available to Satellite Beach are limited by local conditions. The 2.9 square miles of uplands comprising the City are surrounded on two sides by 11.3 miles of shoreline, 8.5 miles of which are on the low-lying western side of the City. Most of the ocean and canal-front shorelines are developed to within a few tens of feet of the water. In addition, the City is built on sandy soil overlying porous limestone bedrock. As such, use of dikes is impractical. Even if dikes were effective, water would seep through the soil, requiring continuous pumping at significant expense as now is the case in the Netherlands. Raising slab-on-grade masonry buildings (typical of most buildings in Satellite Beach) is difficult and expensive. Not only must the brittle masonry structure by raised and properly supported, the water and sewer lines buried in the soil beneath the slab must be restored after it is raised. This might be worthwhile for a building with high value (economically, historically, or socially), but it is not likely with homes typical of the City. In addition, this does nothing to address the issue of flooding streets, which will normally occur before the building is at risk. The difficulty in raising buildings typical of the City makes it even less likely that they would be moved to a new location, if one were available in the 98% built-out community.

The lack of ability to realistically either protect or physically move most assets in the City leaves one primary option, to relocate the functions of those assets. This can be done either in an organized manner prior to a crisis or on an *ad hoc* basis afterward. If the City chooses to remain a community as long as feasible, the relocation could take place within the existing boundaries of the City in the form of redevelopment, most likely in those portions of the City that are at higher elevations. Since the City is primarily a residential community, with only 7% of its land area devoted to commercial uses, relocation would involve primarily relocation of living units. At build-out under current planning conditions the City will have approximately 6,100 living units (4,400 existing plus 320 (including 200 mixed-use) allowed to be built outside the planned unit development comprising the former South Housing plus 1,385 units in the PUD at build-out). Apportioned among 1,850 acres, 6,100 living units result in an average residential density of 3.3 units per acre. Eventually consolidating all these units to the 14% of the City more than 10 feet above mean sea level would result in a residential density of 23.5 units per acre. This is less than the density of 8 of the City's 33 existing condominium and apartment complexes, cumulatively containing 33% of the City's condominium and apartment units.

ECONOMICS

Any response to sea level rise will be implemented only if there is available sufficient funding with which to pay for it. The source of that funding will determine how much, if anything, is available to pay for a given response. As with responses, there is a suite of potential generic sources of funds with which to implement activities in response to sea level rise. These can be private (the occupant, the owner, a group comprised of those with property at-risk, the local community) and government (local, county, state, national, or international).

The **occupant** of the property that is to be protected is closest to the issue physically. This could be a tenant or the **owner**. In the latter case the individual is motivated because they are investing in their own property. In the case of the tenant, they have less motivation, since it is not their real property that will incur damage, but only their personal property. As with tenants paying for lawn care and pool maintenance, the degree to which they invest in the activity can be expected to be less than what the property owner would invest. A local **group of property owners** can band together and cooperatively invest in a response scheme. The nature of responses to sea level rise, such as dikes or raising the ground level, is such that a group response should include all those impacted. As such, this level or economic cooperation can be hindered by holdouts who do not desire to participate. The problem of non-participation can be overcome by establishing a formal funding mechanism such as a local assessment or taxing district including all those impacted by sea level rise, in which unanimous agreement to participate is not necessary. This concept can be expanded to include the entire **local community**, including those who are not directly impacted. In this case the funding can come from local government general revenues instead of a special assessment or tax. The **local** options of special districts or use of general government funds can be expanded to the regional level, as with **county** municipal service taxing units for roads or fire service and Brevard County's current central role in placing sand on the County's eroding ocean beaches; the **state** level, as with water management districts; the **national** level, as with the Army Corps of Engineers' flood control projects and the Federal Emergency Management Agency's flood insurance program; or at the **international** level.

Realistically, it is unlikely that foreign governments are going to look favorably on funding responses to sea level rise in the United States. As a result of a lawsuit, the federal government is currently funding a portion of the local beach re-nourishment activity – for a period of 50 years, if Congress appropriates the funds each year. However, federal funding for other coastal protection initiatives can be expected to concentrate on those areas and projects that have the greatest social impact, such as major harbors and airports, with modest value residential neighborhoods such as Satellite Beach well down the list of priorities. The state is also contributing to local beach renourishment, but again, it is not clear that this commitment will last, particularly as sea level rise impacts a growing portion of Florida's 2,276 miles of tidal shoreline (where over $1 trillion in real estate value is at risk in just Monroe, Miami-Dade, Broward, and Palm Beach Counties). This leaves local and regional options, in which it is unlikely that a majority of residents of the region, or even the county, will be willing to contribute to measures that are perceived to directly benefit only those who live on or near the waterfront. As a result, **local residents are the most likely candidates to pay for measures responding to sea level rise**. However, there is a limit to how much City residents will contribute to responding to sea level rise before they move out of the City. As such, **the *per capita* cost of responsive measures is constrained by what those who will be paying for the measures are willing to invest in those measures**.

REACTION TIME

The best available published estimates of the rate of sea level rise for the rest of this century suggest that it would be prudent to plan for an 8- to 16-inch rise by 2050 and 20 to 48 inches by 2100. If anywhere near accurate, this indicates that development along the City's waterfronts need not be concerned about rising waters inundating their property in the next few decades, although the threat of storm surge will continue to be a valid concern, as it is today. However, adding 8 to 16 inches to mean water level in the lagoon will reduce significantly freeboard for development at low elevations above the mean annual highest tide rising a foot above mean water level. Because the City's building code requires the base elevation of occupied buildings to be at least 18 inches above the crown of the road, in all but a few cases roads will be impacted by high water before the interiors of homes. At some time these tides can be expected to begin to overwash low-lying road paving and/or temporarily raise the water table under paving for sufficiently long periods to soften the road base underlying the asphalt, resulting in failure of the paving if cars are driven over it under these conditions. Rebuilding roadways on a recurring basis by the City will not be affordable at an average cost of $0.5 to $1 million per lane mile.

By the end of the century, if the projected rate of sea level rise is accurate, the City can expect to see adverse impacts on the built environment in the western portion of the City. The minimum estimated 20-inch rise, plus a 1-foot annual rise, will approach or exceed the elevation of paving on several roadways, including portions of South Patrick Drive. The midpoint of the estimated range (34 inches) would place these locations below mean water level. The upper bound would place 24% of the City's land area below mean water level, with the annual 1-foot rise inundating slightly over 40% of the City's land area.

Although estimates of sea level rise tend to focus on the end of the century as the time for which to make predictions, there is no evidence that the process will stop at that time. To the contrary, evidence suggests the rate will continue to increase over the next century and more. As a result, plans appropriate for the end of this century cannot be expected to address the full impact of sea level rise.

Comparing the hypsographic curve at Attachment 3 with the timeframes now projected for the rate of sea level rise, **the City has time, decades it appears, in which to plan in an orderly manner for sea level rise before the City experiences major impacts to the built environment.** There are, however, **four caveats**. **First**, this assumes no storm causing catastrophic damage strikes in that time period. **Second**, The initial impact, if not a storm, is quite certainly not going to be rising tide waters entering the living space of occupied homes. Before that happens there are multiple possibilities. For example, rising waters may cause local flooding of streets, or at least destabilize street base material sufficiently to damage or destroy the driving surface; or reduced capacity in stormwater systems may cause increasingly frequent flooding. The initial impact need not even involve local water levels. Widespread flooding in other coastal areas could render government-subsidized flood insurance unavailable or too expensive for the average homeowner. Without insurance, lenders will not finance purchase of a home, reducing the pool of potential purchasers to those with access to sufficient cash to purchase a home without borrowing. Similarly, if news media begin reporting recurring flooding of low-lying land attributed to sea level rise, it may result in people becoming less likely to buy near tidal shorelines. Either insurance problems or news reporting can be expected to depress the value of properties at risk of flooding. **Third**, the timeline ignores the fact that much infrastructure has a design life of 50 to 100 years; structures such as public buildings; roads; potable water, sanitary sewer, and stormwater systems; and power and communications networks and nodes built, or rebuilt, today can expect to be in use at the middle, and perhaps the end, of the century. The City consciously designs its stormwater system components for at least a 50-year service life. As such, it would be prudent to locate and design infrastructure in a manner that will accommodate reasonable estimates of the status of sea level rise during their design life. Where the opportunity arises, choices should favor “low regret” and “no regret” options, where the choice will result in little or no regret should estimates of sea level rise turn out to be overstated. **Fourth**, rising water levels will have a profound affect on Samsons Island, the City's largest park. Uplands will become wetlands, and wetlands will either become open water or the mangrove fringe along the island's shorelines will increase in breadth. Eventually gopher tortoises living on the island will be unable to burrow and will either be moved or perish.

Given the uncertainty in estimates of the rate of sea level rise, orderly planning would suggest that the topic be monitored and plans, or planning horizons, be adjusted if there are significant changes in the rate of estimated rise. As such, **the City would be advised to include in its Comprehensive Plan a goal or objective to track sea level rise.** Associated policies could identify the Comprehensive Planning Advisory Board (CPAB) as the segment of government to do so, and identify tipping points at which specific actions, whether to develop planned responses or to implement planned responses, should be initiated.

RESPONSE/IMPLEMENTATION

Satellite Beach has time to address sea level rise in an orderly manner; it is not a crisis requiring immediate action. As such, the logical place to begin is to develop a plan, or plans, to address expected or potentially important impacts. Given that sea level is a developing issue with new and changing information becoming available on a relatively frequent basis, plans should be sufficiently flexible and robust to respond to those changes; the plan(s), themselves, must be well conceived if they are to be expected to be relevant decades into the future and to produce actions that are consistent with conditions not now known. Therefore, the **City should plan to plan for sea level rise**, using as a starting point the technical report developed as part of the U.S. EPA Climate Ready Estuary grant project along with then-current information on the potential for sea level rise.

Given the major uncertainties in estimates of the rate of sea level rise, it is prudent to avoid linking actions to specific dates or elevation values. Instead, **the City chooses to use adaptive management in which actions are initiated as conditions cross a threshold indicating a reasonable probability that a specific condition will be present at a specific date**. Consistent with this concept, **the City will look for low-regret and no-regret opportunities to address sea level rise as it conducts normal operations**.

In the meantime **the City will endeavor to inform its residents about the issue and elicit from the broad community a sense of what types of response are considered most desirable. These community-generated concepts then can be developed into an action plan, which itself can be refined and expanded as knowledge of the threat becomes better defined.**

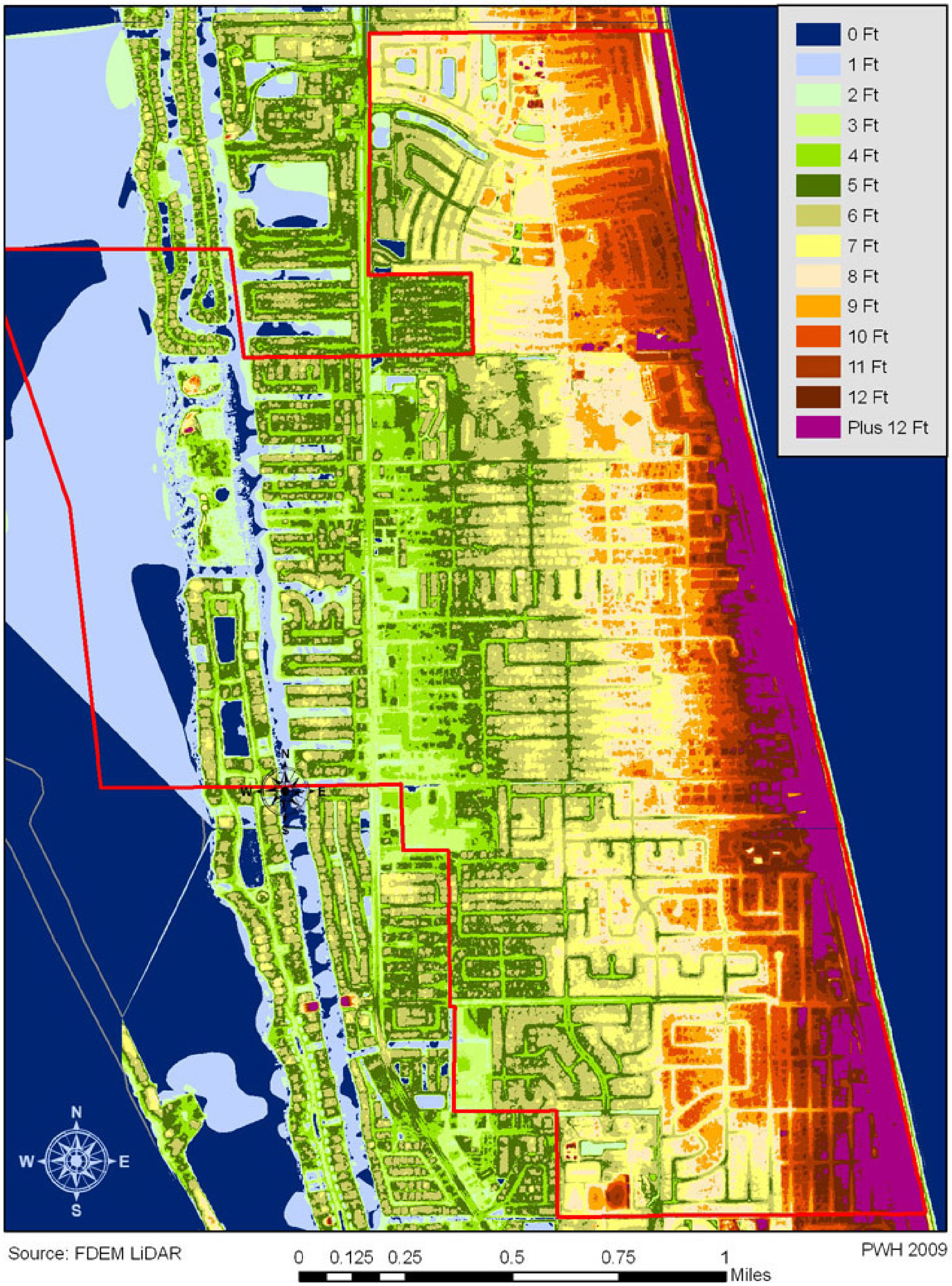
Three Attachments

1. Satellite Beach Topography
2. Submergence Map
3. Hypsographic Curve

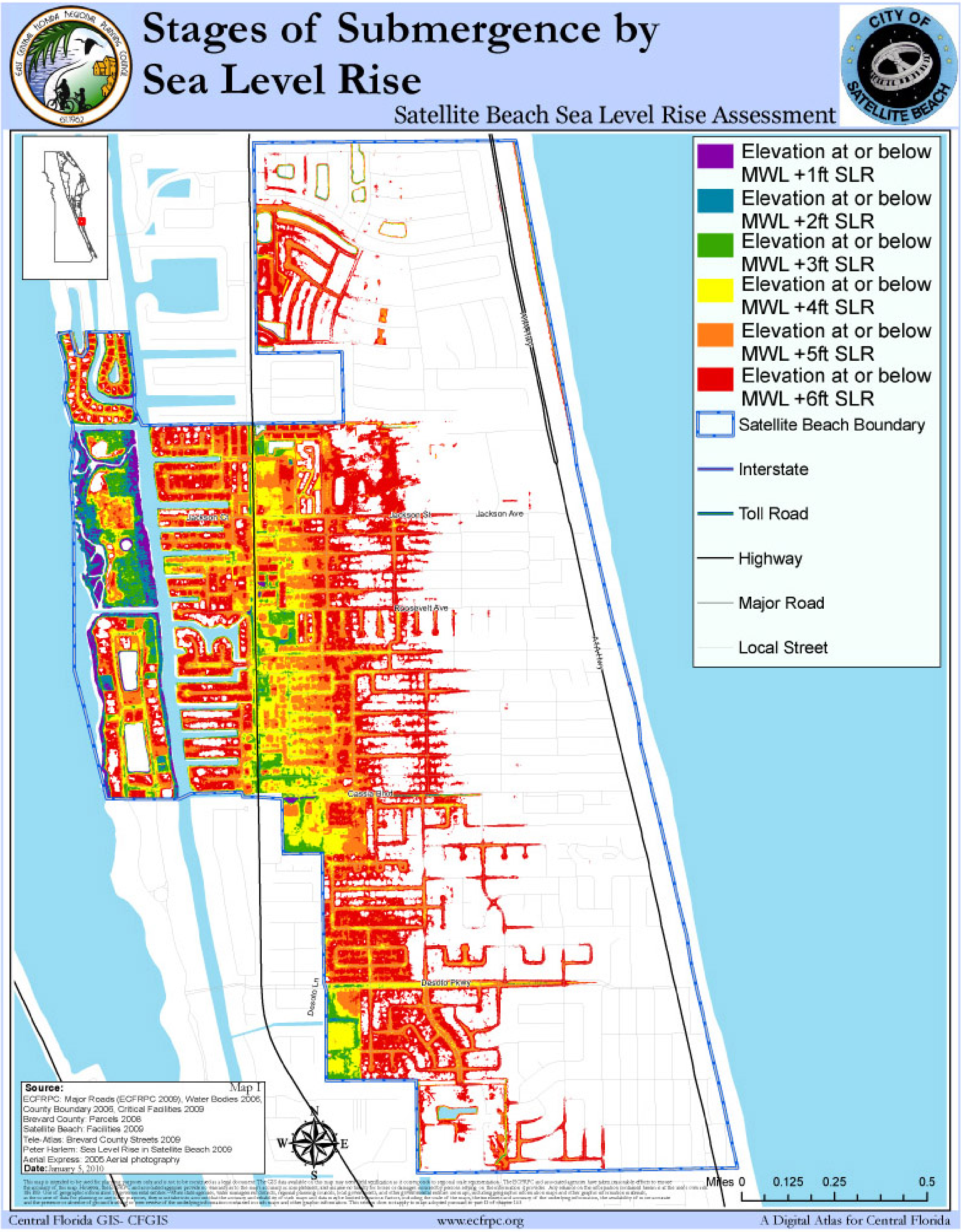
Appendix

Municipal Adaptation technical report

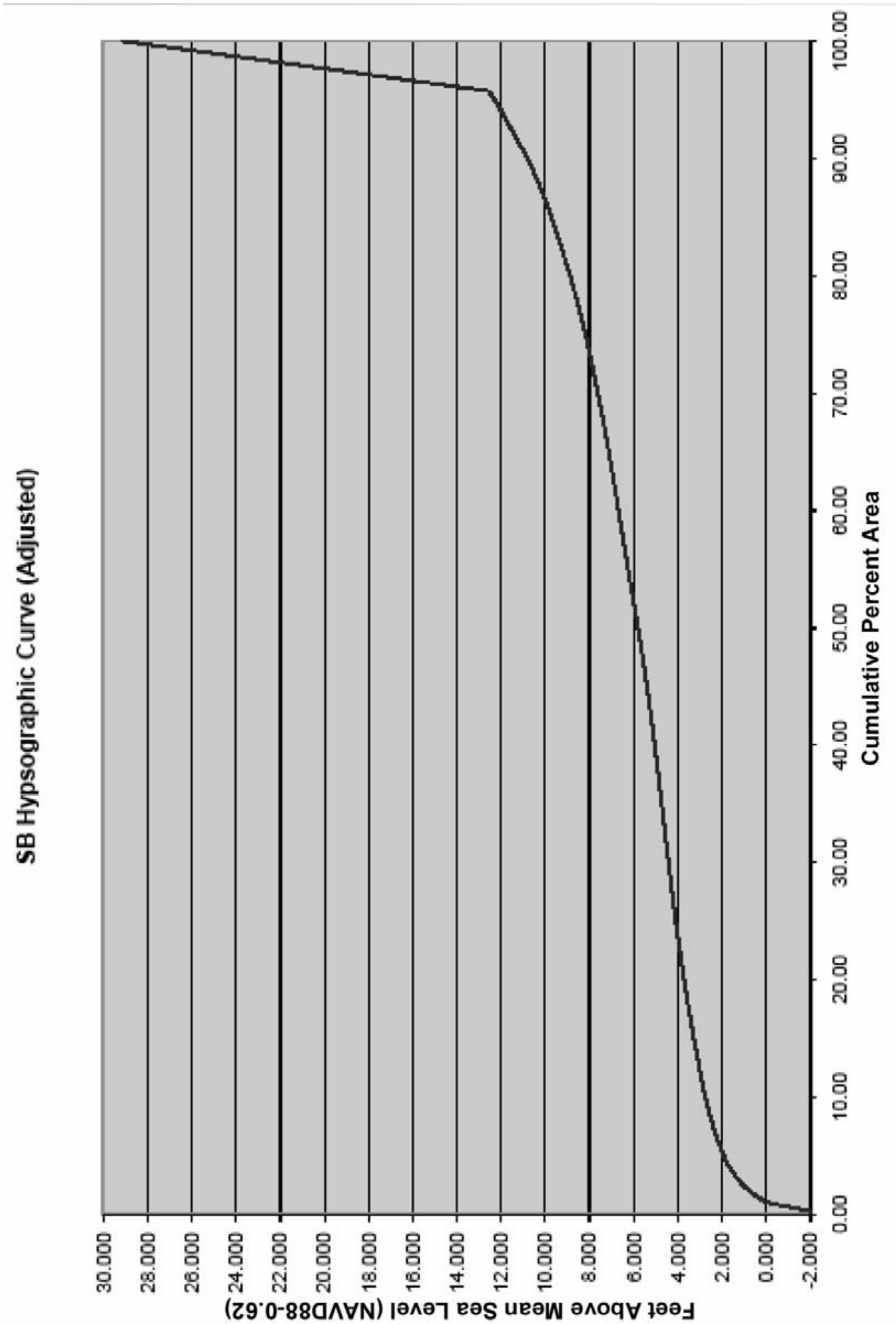
Satellite Beach Topography



Attachment 1



Attachment 2



Attachment 3