

Case Study

Resources

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South Florida Rising Tides: Should We Stay or Should We Go?



*Rock Reef Pass sign in Everglades National Park.
Image Source: [NPS](#)*

"I don't think people realize how vulnerable Florida is," said Dr. Harold R. Wanless, the chairman of the geological sciences department at the University of Miami. "We're going to get four or five or six feet of water, or more, by the end of the century. You have to wake up to the reality of what's coming."¹

The reality of sea level rise is not just a future problem. Even with no rain and sunny skies, South Florida's coastal cities are facing a future of flooding from high tide events combined with sea level rise. Extreme high tides occur in the fall each year, when the gravitational attraction of both the sun and moon on Earth is greatest. In the fall, these extremely high tides are sometimes referred to as King Tides.

Just a few miles into Everglades National Park a sign reads *Rock Reef Pass: Elevation 3 feet*. South Florida is flat, and its low elevation makes it a high risk area for flooding during major rain events such as tropical storm and hurricanes. We usually think about the wind and rain damage from hurricanes but the storm surge can pose even more damage, several feet of water washing over the land.



*King Tide event in Delray Beach, Florida on October 8, 2014.
Image Source: Alana Edwards*



*Dr. Harold Wanless from the University of Miami.
Source: [Marketplace](#)*

During these events, the tides can be so high in low-lying areas of South Florida that many streets become flooded. Salt water, not fresh water, percolates up through storm drains. Many areas become impassible causing negative impacts for both residents and businesses. Standing water can potentially pose human health threats. As sea levels continue to rise, South Florida will experience more frequent tidal flooding events.

"This is what global warming looks like," Wanless said. "If you live in South Florida and you're not building a boat, you're not facing reality."²

Meanwhile, Porsche Design Studio is currently constructing a 60-story skyscraper in Sunny Isles Beach, just north of Miami Beach, where the new residents will be able to park their Porsche(s) right outside their door, made possible by a glass car elevator that travels 600-ft per minute! The cost to purchase one of these condos range from \$4-15 million.



Figure 1 – Porsche Design Tower in Sunny Isles Beach near Miami. Source: [Porsche Design](#)

Wanless is concerned about such development. “We are building like there is no tomorrow. And unfortunately, at some point, there is no tomorrow for down here. We will have to move on. We have a real catastrophe on hands and we need to plan for it.”³

While Dr. Wanless’ message may seem extreme to some, South Florida’s environment is changing and its citizens must decide whether to try to adapt and redesign our cities for resilience, or relocate.

“People tell me that I should try to end my talks with a message of hope. So here is my message of hope: I really hope that people are listening.”⁴

Quotes in this case obtained from:

- 1 – [South Florida Faces Ominous Prospects From Rising Waters](#)
- 2 – Climate Progress - [Scientist: ‘Miami, As We Know It Today, Is Doomed. It’s Not A Question Of If. It’s A Question Of When.’](#)
- 3 – The Ed Show - [GOP lawmakers ignore climate science Rising Tides: The Climate Crisis](#)
- 4 – Presentation at the [CLEO South Florida Climate Action Rally & Panel](#)

SHOULD WE STAY OR SHOULD WE GO?

COLLABORATIVE RESEARCH AND CITY PLANNING MEETING FOR CITIZENS CONCERNED ABOUT SEA LEVEL RISE IN SOUTH FLORIDA

DIRECTIONS: You will assume the role of a concerned citizen scientist living in one of four south Florida counties: Palm Beach, Broward, Miami-Dade or Monroe County. You have been assigned to represent county/city and one of three stakeholder perspectives—water managers, residents, or business leaders. You will alternate between meeting in your county/city group and your community stakeholder group. Your final project will be a PowerPoint presentation of your county and example city’s social and environmental impacts from sea level rise. The presentation should include recommendations for a city planning committee to help guide them with preparing an adaptation action plan.

COLLABORATIVE RESEARCH

Part 1 – First County Community Stakeholders Meeting

Community Representatives use [NOAA’s Digital Coast Sea Level Rise Viewer](#)

- Gather with the other members of your county and:
 - review the *Scientific Background for Citizens*, and
 - look at flooding frequency for their area using NOAA’s Digital Coast Sea Level Rise Viewer – Use the worksheet provided and work in pairs to use the tool and answer the questions on the worksheet.

Part 2 – Stakeholder Group Meetings

Identify social and environmental impacts

- Now you will meet with your community stakeholder group. You will be given a worksheet and, as a group, you will:
 - Review several resources that are provided to you and search for information that relates to your stakeholder group.
 - Answer the questions on your worksheet.

Part 3 – Second County Community Stakeholders Meeting

Identify social and environmental vulnerabilities

- You will return to your county group and you will:
 - Use NOAA’s Digital Coast SLR Viewer again to analyze the socio-environmental vulnerabilities. You may work in pairs to fill in your worksheet.
 - Work as a team to answer questions based on all of your findings (city sea level rise, stakeholder findings for your county/city, & city vulnerabilities. Discuss your results.



- Prepare a presentation of your county's socio-environmental impacts from sea level rise with recommendations for a city planning committee. The goal of this presentation is to help guide them with preparing an adaptation action plan. Your presentation should include:
 - ✓ Evidence of what is happening that they are observing in their counties.
 - ✓ Explanation of why this is specifically happening as a result of sea level rise.
 - ✓ Recommendations with supporting arguments for adapting to and mitigating climate change over the long term in their communities.
 - ✓ Important questions that you would like your elected official to research and address.

MOCK CITY PLANNING MEETING

Your teacher will serve as the moderator for the individual town hall meetings. Our goal for each county meeting is to broadly discuss the question: *Should We Stay? Or Should We Go?* While you are presenting for your county, your classmates will take on the role of the city council and listen to your EVIDENCE, EXPLANATIONS, and RECOMMENDATIONS to help guide them with preparing an adaptation action plan.

- You will have a total of 15 minutes to make your case to the city council.
- All team members must participate in some part of the presentation, expressing their views regarding the recommendations and data or other evidence to support your views.
- Proper etiquette is expected, and only one person in the group should speak at a time. The first time you speak, make sure you acknowledge the specific stakeholder role that you are representing.

While your team is presenting, your classmates will be filling out the scoring guide that will determine how well you make your case. Your classmates will then discuss and evaluate your recommendations.



SCIENTIFIC BACKGROUND FOR CITIZENS CONCERNED ABOUT SEA LEVEL RISE IN SOUTH FLORIDA

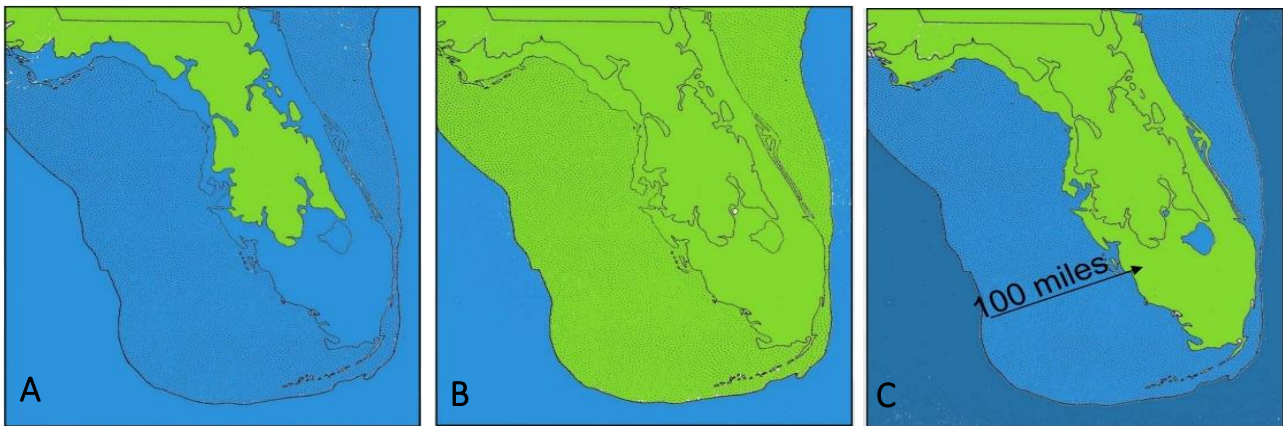
SOUTH FLORIDA'S UNIQUE GEOLOGY



Limestone. Image Source: SFMWD

The geology of southern Florida is very unique. Just underneath our surface is a porous substrate made of calcium carbonate known as limestone.

Throughout Florida's geologic history there have been changes in sea level. During interglacial periods, when glaciers melted, sea levels in Florida would have been higher. During these periods of higher water, limestone, built up from the shells and skeletons of organisms that once lived in the oceans, formed on the shallow sea bottom. This sedimentary rock consists of layers of mineral and rock particles. Then, during glacial periods, the water would recede as glaciers formed, revealing much of the Floridan platform upon which Florida sits.

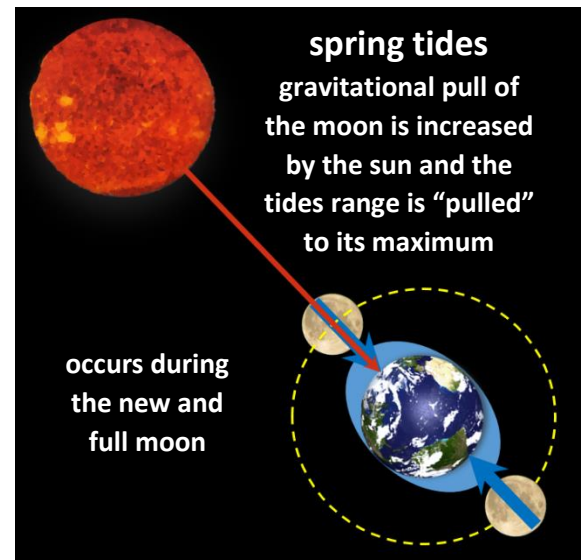


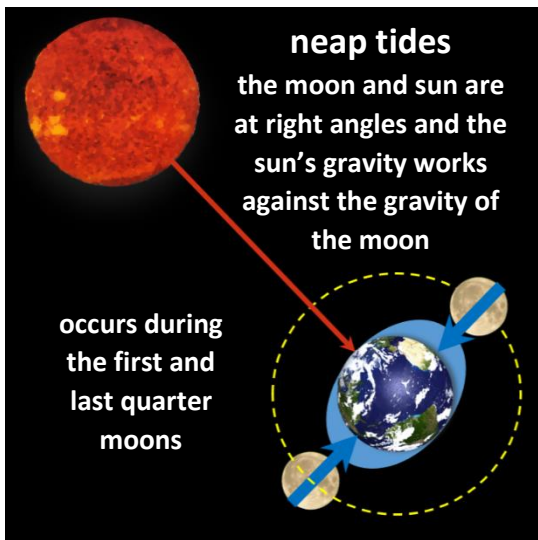
Florida During the Past Interglacial, Glacial, and Present. Image Source: Wanless

CHANGING TIDES

These long-term changes in sea level occurred over thousands of years, and they determined our geology in Florida. However, we also see variations in the ocean's level every day as a result of our changing tides. We notice these changes close to our shoreline, but they affect the entire ocean. What causes these changes in the tide? While the moon plays the largest role in the gravitational pull that dictates the tides, the sun also plays a role. This gravitational pull from the moon and sun create two bulges on opposite sides of Earth. These bulges, for the most part, follow the position of the moon.

During the new and full moon, the sun, Earth and moon form a line in space. In this arrangement, the gravitational pull of the moon is increased by that of the sun, "pulling" the tide's range to its maximum. These tides are known as **spring tides**, not because of the time of the year but because they "spring" upward. These spring tides are the highest and lowest tides of the month.





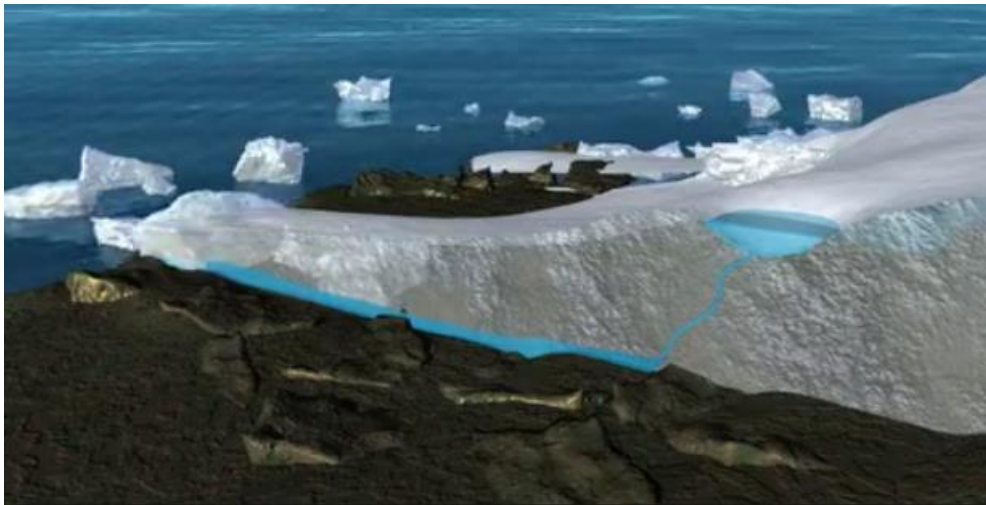
Around the first and last quarter moons, the moon and sun are at a right angle in respect to Earth. Therefore, instead of working together, the sun's gravity is working against the gravity of the moon and this leads to tides levels at their minimum. These are known as **neap tides** and they occur twice a month. The cycle between spring and neap tides occurs approximately every 7 days.

THE EFFECTS OF SEA LEVEL RISE ON FLORIDA'S COASTAL RESOURCES

DRIVER: SEA LEVEL RISE

THE CAUSES OF RISING SEA LEVELS

The topic of sea level rise has gained national media attention in the last several years. As you just learned, Earth has cooled and warmed, and as a result, the area and volume of the ice on Earth's surface has increased and decreased. In a period of a colder climate, there is more ice covering the planet; hence sea level is lower. During interglacial periods, ice melts and sea level rises. However, the origin of the melting ice makes a difference.



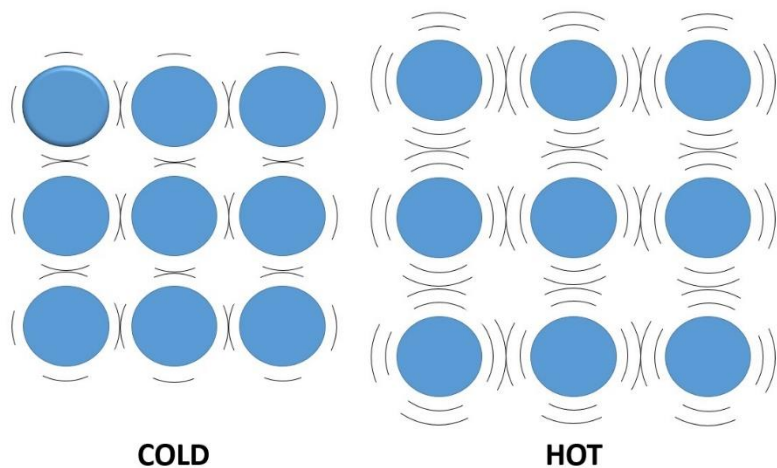
Melting Land Ice. Image Source: [NASA/Goddard Space Flight Center Conceptual Image Lab](#)

When ice over land melts, it adds to the volume of water in the oceans, causing the level of the water to rise. The melting of sea ice does NOT contribute directly to a rise in water level, because the ice is already floating and displacing water. Archimedes' Principle explains why. Water in the solid form (ice) is less dense than water, which causes it to float. Only about 10% of the ice floats above the surface, and when ice

melts, the volume of the water that was displaced by the ice equals the melted ice or water. In other words, the change in volume exactly counterbalances the extra volume of the ice that was up above the water's surface.

Another cause of sea level rise is thermal expansion of the oceans. The oceans have a greater heat capacity than land due to the high specific heat (the amount of heat energy required to raise or lower the temperature of a gram of a substance by 1 ° Celsius) and the mass of water being heated.

The ocean's high heat capacity allows it to absorb and store a large amount of heat energy with a small increase in temperature. This unique property of water has allowed the oceans to absorb as much as 90% of the additional energy added to the climate system since the mid-1900s. But as the ocean absorbs and stores more heat energy, the



Thermal Expansion. As water is heated, the kinetic energy of the water molecules increases, causing the molecules to vibrate more and move apart.

volume of ocean water expands. This is referred to as thermal expansion. Hence, thermal expansion causes an increase in sea level.

While vulnerable coastal cities will not become inundated overnight, scientific data from numerous organizations show that sea levels globally are increasing. The causes of sea level rise are well known.

The unknowns are how quickly sea level will rise and the risks and costs to people around the world.

RATE OF RISE SINCE THE INDUSTRIAL REVOLUTION

According to the Intergovernmental Panel on Climate Change (IPCC), thermal expansion and glacier melt have been the main contributors to 20th century global mean sea level rise. After 2,000 years of little change, sea level rose about 0.2 meters (8 inches) during the past century. About 75% of the observed rise (high confidence) since 1971 is from thermal expansion and glaciers in Greenland. Thermal expansion has occurred as the top 30 meters (1,000 feet) has warmed by 0.3°C (0.5°F) over the past 50 years. Since the early 1990s, the contribution of ice sheets in Greenland and Antarctica to sea level rise has increased, partly due to the warming of the adjacent ocean. The Greenland Ice Sheet is experiencing record surface melting with a record rate of loss in the past decade. If Greenland melts, there could be as much as a 7.2 meters (24 feet) rise in sea level. If the West Antarctica Ice Sheet melted, ocean levels could rise by approximately 5–6 meters (16–20 feet). If all of the ice on Antarctica melted, global sea level would rise 61 meters (200 feet).

SOUTH FLORIDA'S VULNERABLE COASTLINE

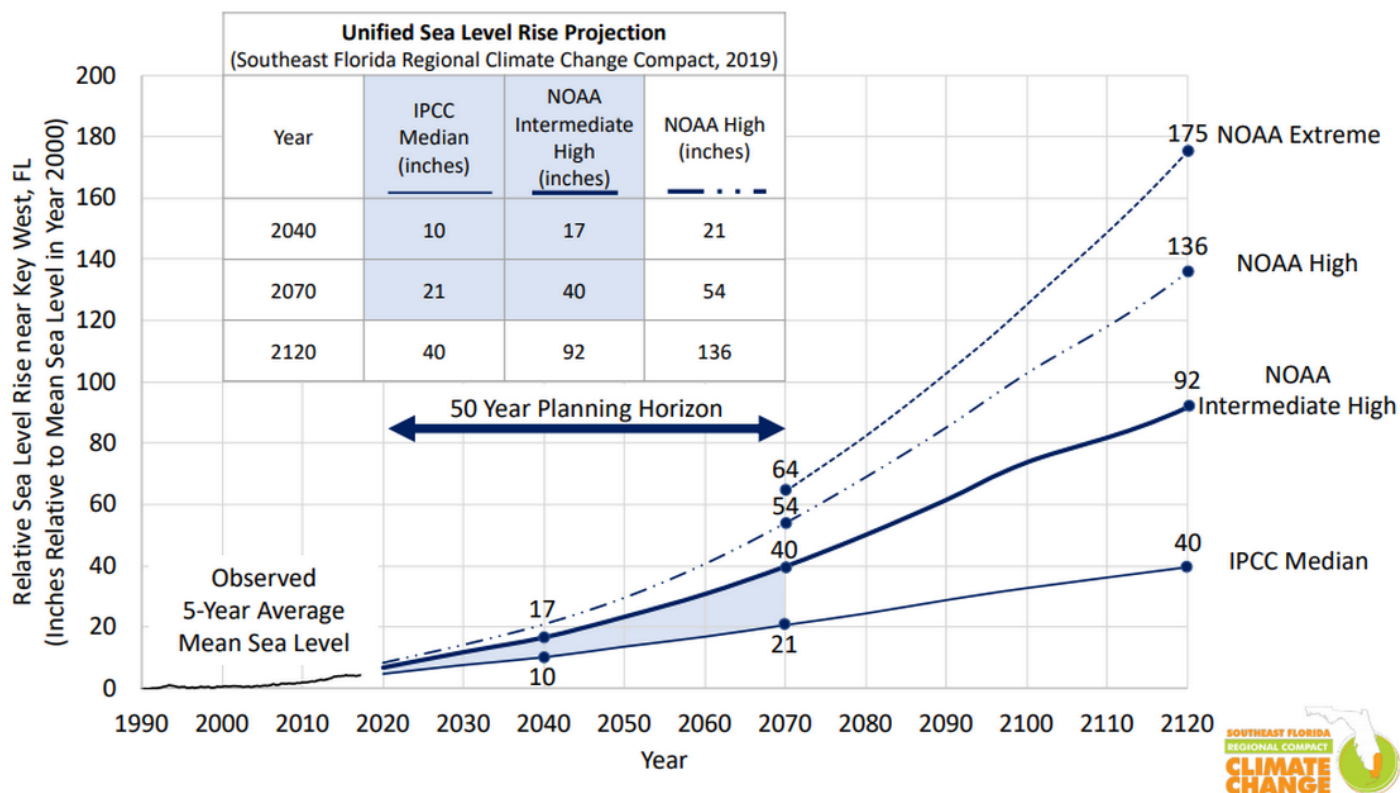
In October of 2014, astronauts aboard the International Space Station took this photograph of Florida. This photograph clearly shows why Florida's coastal regions are especially vulnerable to sea level rise.



South Florida is ground zero for sea level rise. Sea level rise is a problem we must consider in the future, but it is also one that is impacting the residents of South Florida right now!

Florida At Night. Image Source: [NASA](#)

The Southeast Florida Regional Climate Compact recently released their new projections for South Florida sea level rise and these projections show even greater sea level rise for the next few decades. Notice the difference between the "most optimistic scenario" and the "high risk projects" projection. What will these changes in sea level mean for the residents of South Florida?



Unified Sea Level Rise Projection from the Southeast Florida Regional Climate Change Compact. Image Source: [Southeast Florida Climate Compact](#)

EFFECT: EXTREME HIGH TIDES & KING TIDES

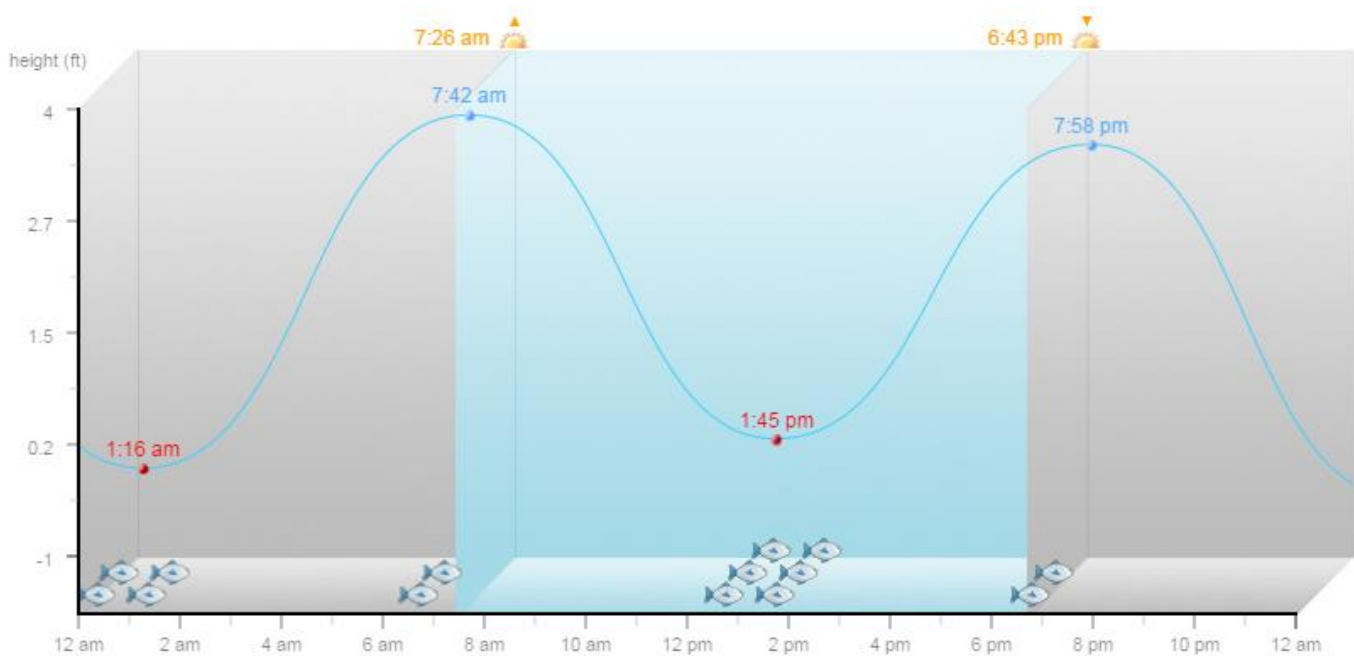
As you just learned, spring tides (Perigean-spring tides) occur twice a month throughout the year. However, in the fall each year, these tides are more extreme due to the shorter distance between the moon and Earth. These extremely high tides are sometimes referred to as **King Tides**, and they will become more prevalent in the future.

We are now seeing tides so high in some areas of South Florida that many streets become flooded. During the King Tide of October 2015, many tide stations along the east coast were well over 3 feet at high tide for the majority of the month.



King Tide in Delray Beach, Florida on October 8, 2014. Image Source: Alana Edwards

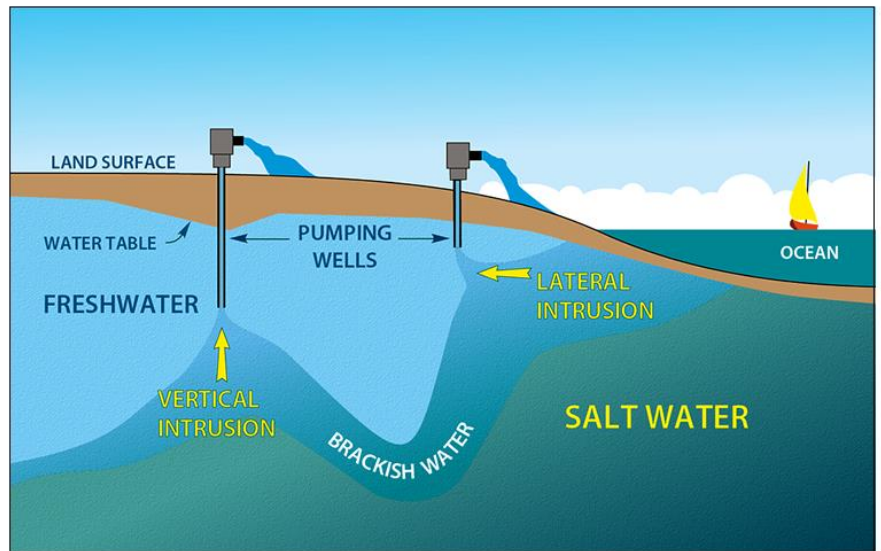
As sea levels continue to rise, these flooding events will occur more frequently. Just 1.5 feet of sea level rise can cause approximately 573 flooding events per year. This means that approximately three quarters of the year these areas will experience extreme high tide events twice a day. For much of that time, the water will be so high that it will not retreat for several days causing constant flooding over this period. Consider how this will affect your life. What will you have to do differently?



Tide gauge reading for Port Everglades on October 26, 2015. Source: Tidetable.net

EFFECT: THREATS TO OUR COASTAL WATER SUPPLY

Along our coasts are dozens of wells that tap into our freshwater aquifer. During periods when there is little rain and our aquifers have not had time to “recharge”, any withdrawal can lead to saltwater intrusion. This is because we are withdrawing so much freshwater that we start pulling up brackish water. On the image on the right, this type of saltwater intrusion is referred to as vertical intrusion. This can occur in the absence of sea level rise. However, with rising sea levels and the increased withdrawals of water as our South Florida population grows, saltwater intrusion will become more problematic. Wells that are closest to the coastline will experience the greatest impacts resulting from “lateral intrusion.” Many cities, such as Hallandale and Deerfield Beach, are closing wells because they are no longer usable. Other cities are rebuilding wells away from the coast to lessen the chances of saltwater intrusion.



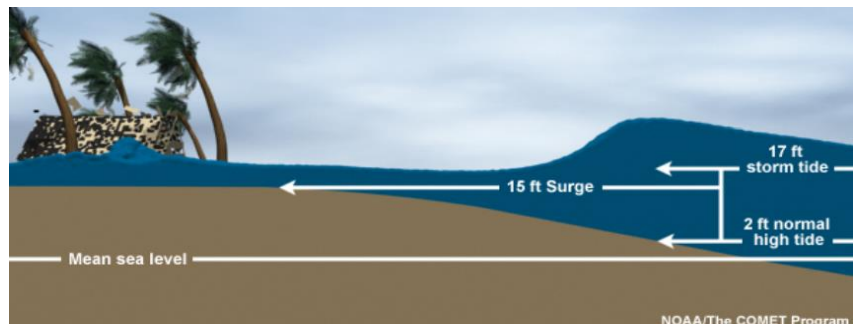
Saltwater Intrusion. Image Source: [SJRWMD](#)

EFFECT: HIGHER STORM SURGE AND IMPACTS ON OUR COASTAL INFRASTRUCTURE

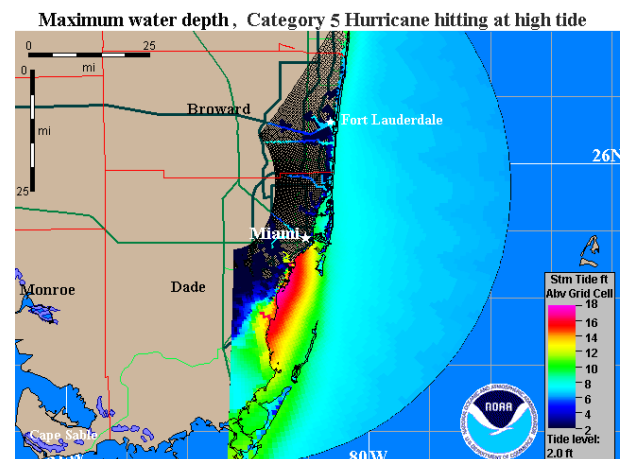
According to NOAA, storm surge is “an abnormal rise of water generated by a storm, over and above the predicted astronomical tide.” In the presence of a storm, the water levels will change due to the strong winds from the storm. Therefore, we would expect that storm surge would be higher during hurricanes and the higher the storm category, the stronger the storm surge.

Now factor in higher sea levels and consider how that might affect storm surge. The combination of higher seas levels and storm surge has the potential of causing devastating damages to South Florida’s coastal communities. The buildings near our coastline were not designed to withstand these higher surges.

Therefore, our coastal communities are likely going to need to make some changes to these vulnerable buildings. Some examples would be to elevate, “harden”, or even relocate some of these structures. In some cases, abandonment may be the only option available.

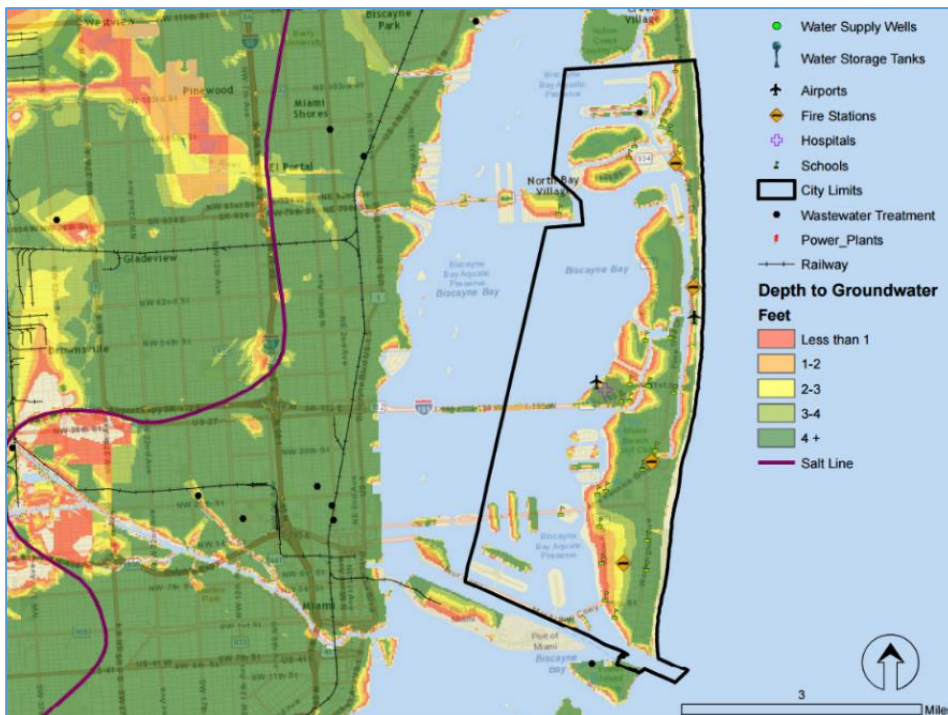


Storm Surge. Image Source: [NOAA](#)



Storm Surge Map for South Florida. Image Source: [Weather Underground](#)

EFFECT: INCREASED RISK OF FLOODING



Depth to Groundwater for Miami Beach. Map Created by Adam Chapman

As sea levels continue to rise, of course the areas at lower elevation will be at risk of flooding. What about inland areas that are higher in elevation? Would these areas be safe from sea level rise flooding?

You learned earlier about how saltwater intrusion is affecting our coastal wells. The diagram showed the saltwater coming in from under the freshwater. As sea levels continue to rise, we will see the saltwater continuing to move inland, and, as it does this it will push the freshwater further away from the coast and upward toward the surface.

What this means is that our water table, which is just below our surface, will be pushed upward by the intruding saltwater wedge.

Therefore, even if your home is 15 feet above sea level, if the depth to the water table is just a few feet, then the addition of a few feet of sea level rise will increase the chances of flooding in your area. With this higher water table, one bad storm could cause flooding for days. Notice on the map of Miami Beach (on the left) that many areas inland are bright pink indicating that the water table is less than 1 foot below the surface.

EFFECT: INCREASED BEACH EROSION AND THE COST OF NOURISHMENT

Our beaches are constantly changing due to both natural and anthropogenic forces that cause erosion. Erosion occurs naturally as wave action pounds our shorelines causing the sand to be washed away. After a tropical storm or hurricane, these effects would be even more pronounced. However, the creation of inlets and other man-made structures along our coast have added to this erosion process. On one side of the structure sand will build up but on the opposite side there is more erosion.

As our beaches are a major tourist destination, they have a high economic value to our state. Therefore, maintaining our beaches for tourism has been a major priority for coastal communities. Florida's Department of Environmental Protection recently released a report in which it identified over 500 miles of our beaches as critically eroded (see map on next page). They define a critically eroded area as "a segment of the shoreline where natural processes or human activity have caused or contributed to erosion and recession of the beach or dune system to such a degree that upland development, recreational interests, wildlife habitat, or important cultural resources are threatened or lost." The majority of the southeast Florida coastline is considered to be critically eroded.

The way in which our beaches are restored is through a process called beach nourishment. This process is accomplished by collecting sand with a dredge from an offshore location and then piping it onto the beach. As it is piped onto the beach, it is a mixture of water and sand but once the water drains away, the sand is left behind, which is then moved by bulldozers. By adding sand to sand to our beaches through nourishment, it reduces the need for building coastal structures such as sea walls.

What effect will sea level rise have on beach erosion? Sea level rise may exacerbate beach erosion by allowing stronger currents to get closer to the shoreline. Also, consider that with higher sea levels, the beaches will now be underwater so the issue becomes inundation rather than erosion. Therefore, a beach nourishment effort to keep pace with sea level rise as well as replace sand washed away by wave action probably would be unaffordable and may not be a viable solution in specific locations due to the physical conditions.

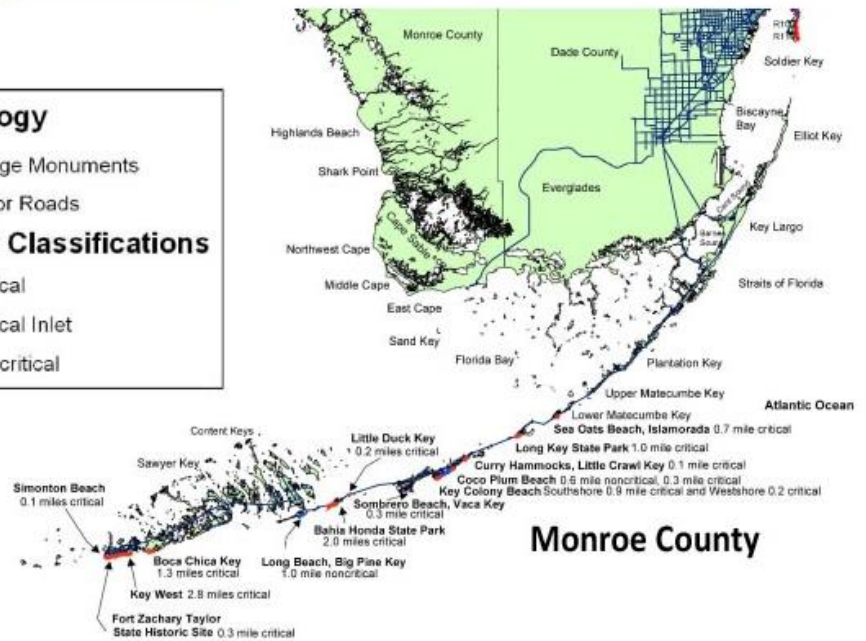


Symbology

- Range Monuments
- Major Roads

Erosion Classifications

- Critical
- Critical Inlet
- Noncritical

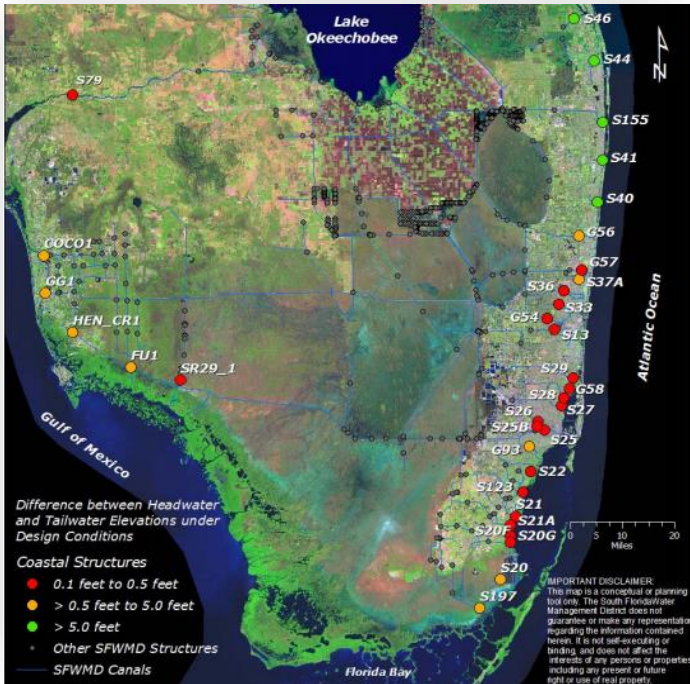


Critically eroded beaches in southern Florida. Adapted from [FDEP](#).

SCIENTIFIC BACKGROUND FOR WATER MANAGERS IN SOUTH FLORIDA

The South Florida Water Management District (SFWMD) is responsible for managing the water throughout southern Florida. Their staff oversee approximately 2,100 miles of canals and 2,000 miles of levees/berms, 71 pump stations and more than 600 water control structures and 625 project culverts.

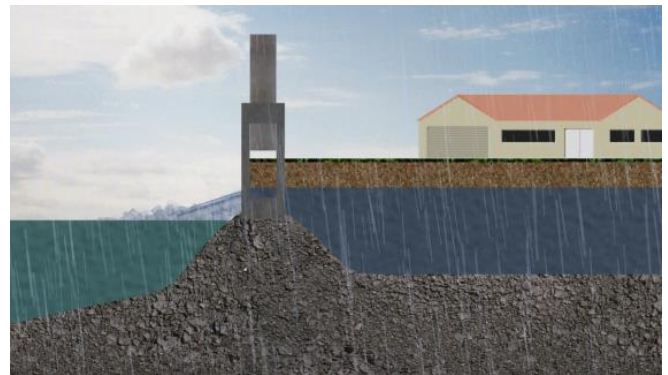
FLOOD CONTROL STRUCTURES



Map showing SFWMD's vulnerable flood control structures. Image Source: [SFWMD](#)

However, in the last century, sea levels have risen more than 8 inches in the last century and approximately 5 inches of that rise has occurred in the five to six decades since those structures were built. As a result, many of our coastal flood control structures are compromised. Along the east coast there are 28 of these gravity structures. The most vulnerable of these structures are located in Miami Dade and Broward counties (in red on map above).

Of the 600 water control structures throughout the SFWMD, there are several dozen located along the east and west coasts. These structures are dependent on sea level for gravity discharge. In other words, since the water is higher on the inland side than the ocean side, when the gates are opened, the water flows out because of gravity (see image below).



Coastal Flood Control Structures without and with higher sea levels. Image Source: [SFWMD](#)



Forward Pump at S-26 Structure. Image Source: [SFMWD](#)

Higher sea levels make these structures (also known as “spillways”) not as effective at dumping excess stormwater out to sea. During extreme high tides, when sea levels are even higher, water managers are forced to keep these flood gates closed, thus increasing the risk of flooding in coastal communities (see image above) and affecting the entire flood control network in south Florida. To fix this problem, the SFWMD plans to build “forward pumps” that push stormwater out to sea while also keeping the flood gates closed. These forward pumps are expensive to install at a cost of approximately \$1 million per pump.

SALTWATER INTRUSION

Our coastal communities in South Florida obtain the majority of our water supply from wellfields that tap into our underground freshwater aquifers. You’ve learned that our demand as well as the current sea level has already caused saltwater intrusion to threaten our water supply. In the mid-1990’s, scientists from several agencies determined the saltwater interface (as seen on the map as the red line along the coast). This line shows how far inland the saltwater is intruding. You can see that the areas from Palm Beach south to Miami-Dade are especially vulnerable.

Studies are underway all along the coast to determine just how much this saltwater interface has changed in the last 20 years. Preliminary results show that it is moving inland, and this trend will continue as sea levels continue to rise.



Saltwater interface. Image Source: [SFMWD](#)

References:

- [Climate Change and Water Management in South Florida](#)
- [Climate Change and Sea-Level Rise in Florida an Update of the Effects of Climate Change on Florida’s Ocean & Coastal Resources – December 2010](#)

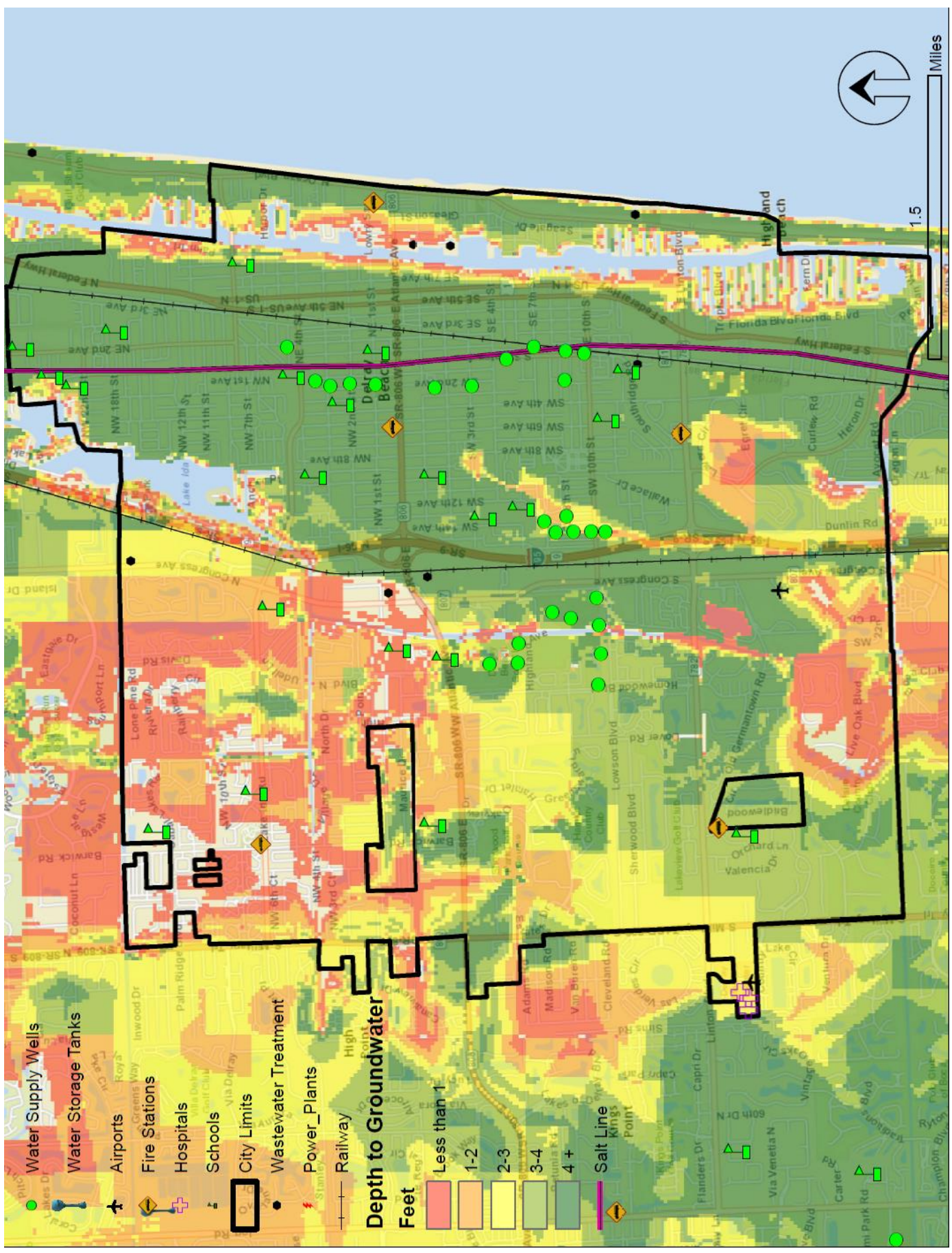
DELRAY BEACH, PALM BEACH COUNTY

COUNTY FACTS

Population:	1.372 million (2013)
Property Values, 2015	
• Total number of parcels:	632,448
• Just Value (per FL Dept of Revenue):	\$206,384,411,653.00
• Current Property Tax Value (County Budget's FY 2015):	\$953.9 Million dollars

CITY FACTS

Population:	Est. 65,055 (2014)
Average Elevation:	19 feet
Low-lying neighborhood elevation:	Elevation 2.24 feet
Percent of population 65 and older:	23.6% (2010)
No. of Schools:	24
No. of Hospitals:	3
No. of Fire Stations:	8
No. of Airports:	3
No. of Water Supply Wells:	73
No. of Waste Water Treatment:	12
No. of Water Storage Tanks:	1
No. of Water Treatment Plants:	3

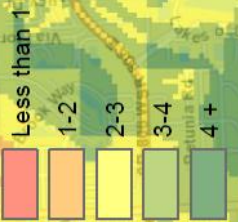


Water Supply Wells
Water Storage Tanks

Airports
Fire Stations
Hospitals
Schools

City Limits
Wastewater Treatment
Power Plants
Railway

Depth to Groundwater
Feet



Salt Line



DELRAY BEACH IN PALM BEACH COUNTY

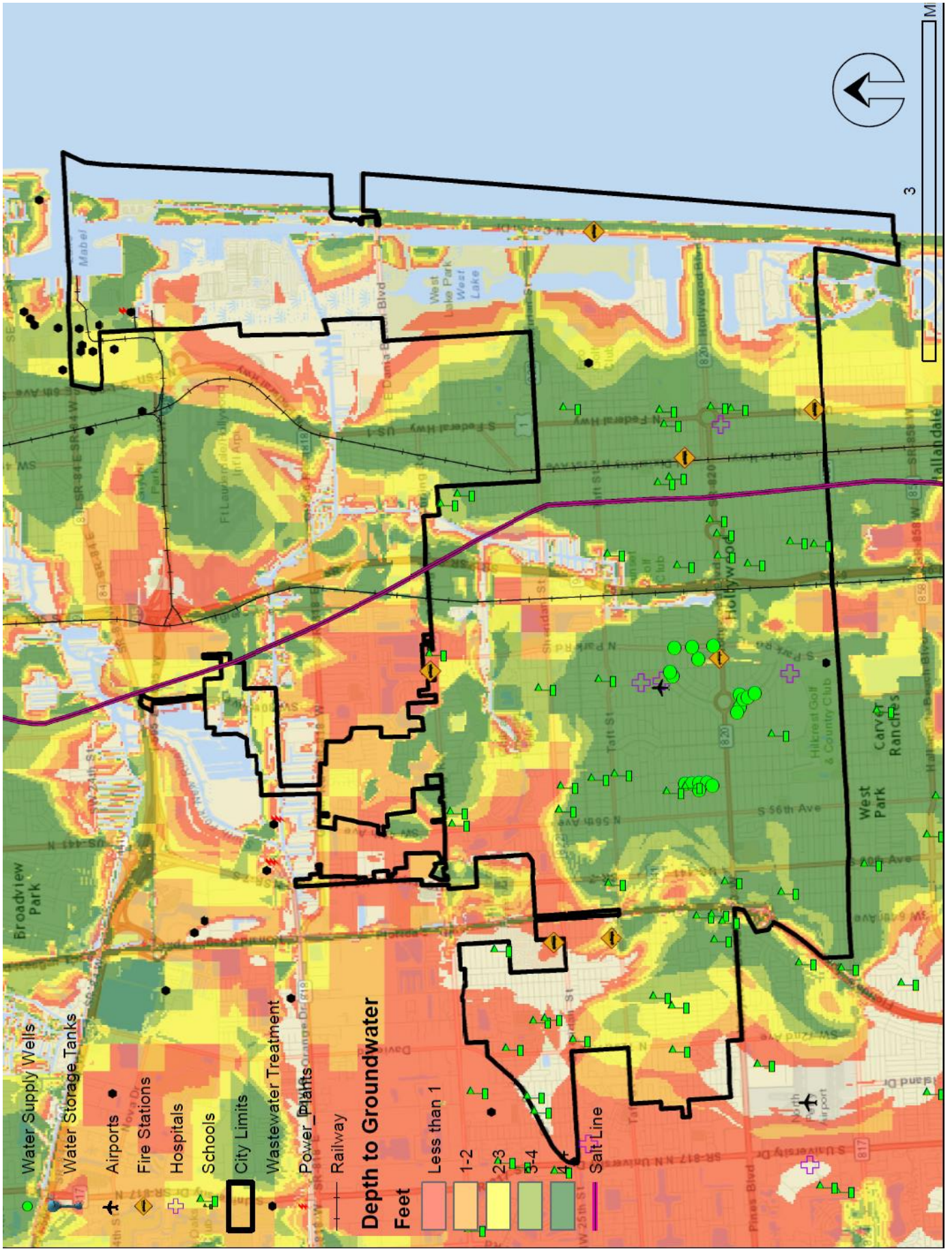
HOLLYWOOD, BROWARD COUNTY

COUNTY FACTS

Population:	1.839 Million (2013)
Property Values, 2015	
• Total number of parcels:	742,665
• Just Value (per FL Dept of Revenue):	\$215,978,129,130.00
• Current Property Tax Value (County Budget's FY 2015):	\$806.9 Million dollars

CITY FACTS

Population:	146,526 (2013) / Est. 148047 (2014)
Average Elevation:	9 feet
Low-lying neighborhood elevation:	Elevation 1.31 feet
Percent of population 65 and older:	15.1% (2010)
No. of Schools:	118
No. of Hospitals:	7
No. of Fire Stations:	8
No. of Airports:	3
No. of Water Supply Wells:	18
No. of Waste Water Treatment:	20
No. of Water Storage Tanks:	0
No. of Water Treatment Plants:	4



HOLLYWOOD IN BROWARD COUNTY

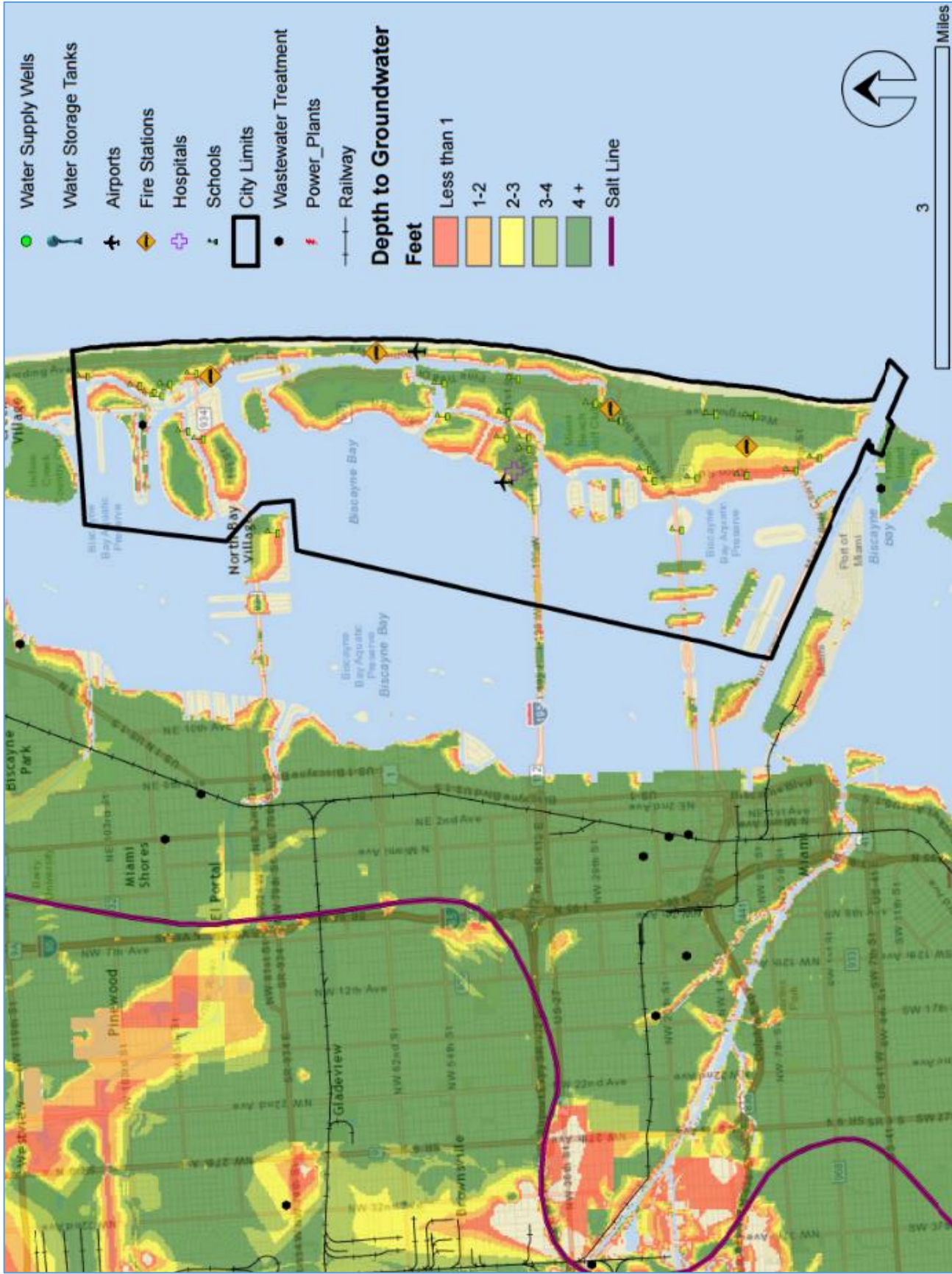
MIAMI BEACH, MIAMI-DADE COUNTY

COUNTY FACTS

Population:	2.617 million (2013)
Property Values, 2015	
Total number of parcels:	904,123
Just Value (per FL Dept of Revenue):	\$326,749,953,001.00
Current Property Tax Value (County Budget's FY 2015):	\$1,493,370,000

CITY FACTS

Population:	87,779 (2010) / Est. 91,732 (2014)
Average Elevation:	5 feet
Low-lying neighborhood elevation:	Elevation 2.39 feet
Percent of population 65 and older:	16.2% (2010)
No. of Schools:	30
No. of Hospitals:	1
No. of Fire Stations:	5
No. of Airports:	2
No. of Water Supply Wells:	19
No. of Waste Water Treatment:	1
No. of Water Storage Tanks:	0
No. of Water Treatment Plants:	2



MIAMI BEACH IN MIAMI-DADE COUNTY

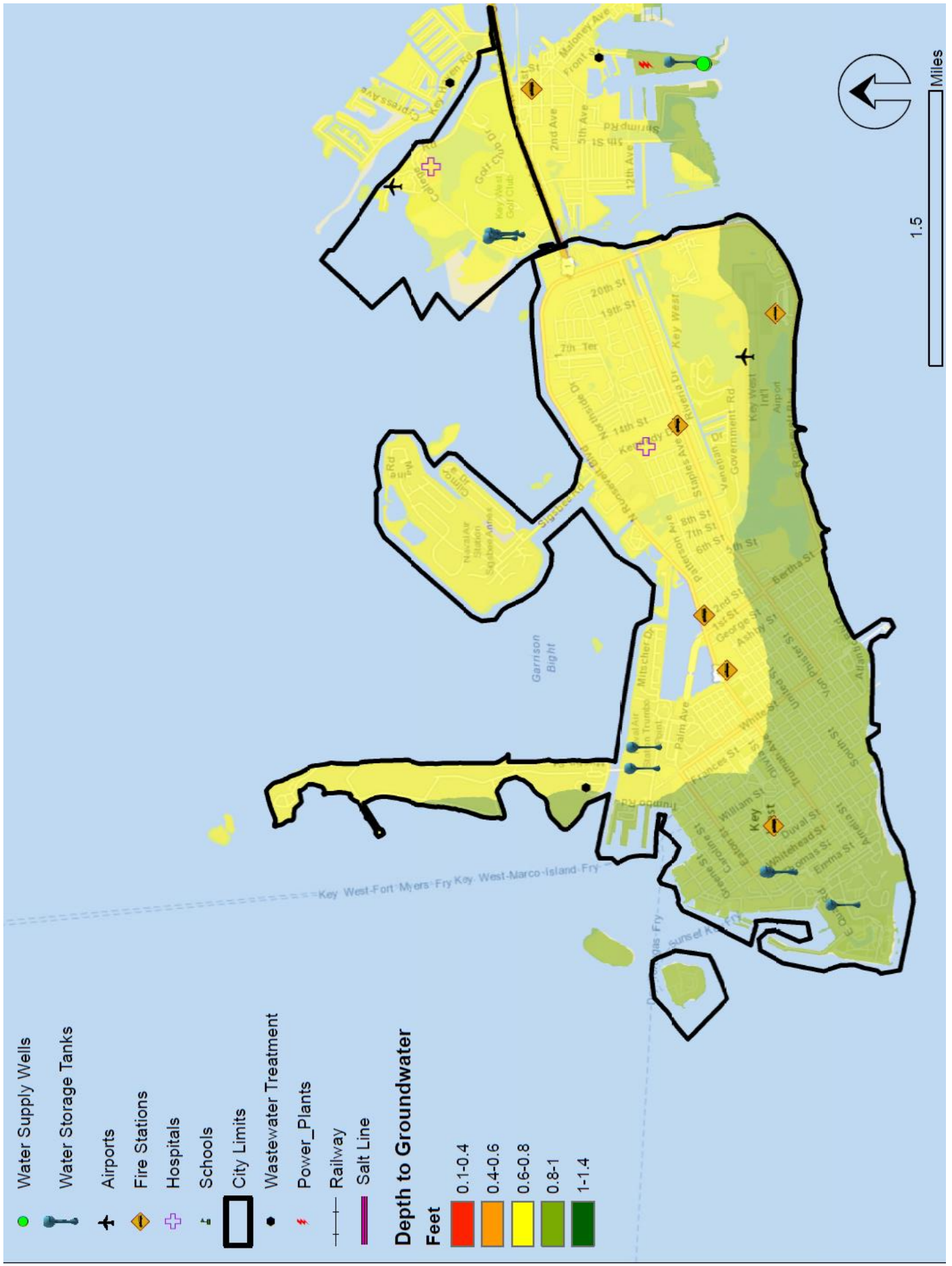
KEY WEST, MONROE COUNTY

COUNTY FACTS

Population:	76,351 (2013)
Property Values, 2015	
Total number of parcels:	90,095
Just Value (per FL Dept of Revenue):	\$30,654,612,093.00
Current Property Tax Value (County Budget's FY 2015):	\$79,413,674.00

CITY FACTS

Population:	24,649 (2010) / Est. 25,704 (2014)
Average Elevation:	3 feet
Low-lying neighborhood elevation:	Elevation 1.38 feet
Percent of population 65 and older:	12.8% (2010)
No. of Schools:	14
No. of Hospitals:	2
No. of Fire Stations:	6
No. of Airports:	3
No. of Water Supply Wells:	1
No. of Waste Water Treatment:	7
No. of Water Storage Tanks:	6
No. of Water Treatment Plants:	2



Adaptation Approaches to Sea-Level Rise in Florida¹

Ondine Wells, Whitney Gray, and Paul Monaghan²

Sea-Level Rise in Florida

There is consensus among the scientific community that climate change is occurring and will have far-reaching effects on our global ecosystems and human systems. Atmospheric and ocean temperatures have risen, the Greenland and Antarctic ice sheets have lost mass, sea levels have risen, and ocean acidification has increased. It is predicted that sea levels will continue to rise as a result of continued warming and ice-sheet melting (IPCC 2013). Florida's ecosystems and human systems are particularly vulnerable to sea-level rise because more than half of the population (Crossett et al. 2004) live near the state's more than 1,200 miles of coastline (FDEP 2013). Some areas of Florida, including coastal ecosystems, transitional habitats, the Everglades, and island ecosystems such as the Florida Keys, likely will experience extreme changes as a result of sea-level rise (Geselbracht et al. 2011). Endemic, rare, threatened, and endangered species that rely upon these ecosystems are particularly at risk of decline and, at worst, extinction (Aiello-Lammens et al. 2011; Fei, Cox, and Whittle 2011). In some cases, the effects of sea-level rise are already being seen as vulnerable populations decline or migrate (Maschinski et al. 2011).

Natural and Human Adaptation

In Florida, adaptation to climate change is occurring in both natural and human systems. Natural systems can adapt to changes on their own, given proper conditions, but people can also do things to help ecosystems change

and survive. These measures typically fall into one of four categories: resistance, resilience, response, or realignment. *Resistance* is the process of maintaining current conditions despite climate change. This might include actions like creating berms around vulnerable areas to keep sea-level rise from affecting an ecosystem. *Resilience* focuses on helping an ecosystem survive a disturbance and return to desired conditions. Activities that improve resilience, such as coastal ecosystem restoration, put the ecosystem into the best possible condition. *Response* strategies—like designing habitat corridors to promote species migration—seek to assist the transition of an ecosystem to a new, future condition. *Realignment* is typically used in a heavily disturbed ecosystem and concentrates on its future condition (Millar, Stephenson, and Stephens 2007).

Human adaptation focuses on making communities resilient so that they can withstand future changes. These adaptation approaches may include protection, accommodation, or managed relocation. *Protection* strategies typically include defensive barriers such as shoreline armoring or beach nourishment. *Accommodation* strategies use design measures to allow structures to stay in place when future changes occur. For example, elevating a building allows it to survive flooding. *Managed relocation* is moving assets at high risk to new, safer locations. This can be achieved through rolling easements or Transfers of Development Rights (Deyle, Bailey, and Matheny, 2007).

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Table 1.

Adaptation Approach	How it works
Physical Approaches	
No-rebuild zones/rolling easements	Establish areas where structures will not be rebuilt following severe storm damage, or provide opportunities for inland migration of wetlands and shorelines
Shoreline setbacks	Move the developable area farther from the shoreline
Structural approaches	Design buildings that will withstand future changes in sea level or storm surges, or that allow habitats to adapt to changing conditions
Ecological resiliency	Strengthen the resiliency of existing ecological communities by reducing non-climate-related threats such as invasive species or habitat fragmentation
Habitat corridors	Connect natural areas and enable species dispersal and migration
Habitat acquisition	Acquire and preserve lands that may become future habitats for displaced species
Water-control structures (flood-control and stormwater-management systems)	Design to allow the migration of species inland as sea levels rise
Living shorelines	Support species diversity as well as protection from storm surges
Seed banks	Collect and store seeds from species at risk of extinction or extreme loss
Oyster reef restoration	Restore oyster reefs as a mechanism for reducing erosion and damage from storm surges
Assisted migration	Relocate species that are in danger of losing their habitat
Captive breeding/assisted propagation	Assist species in danger of extinction or extreme loss
Green infrastructure and Low-Impact Development (LID)	Use green features to prevent storm surges and control stormwater runoff
Policy Approaches	
Comprehensive plans	Identify Adaptation Action Areas (as defined in the Florida Statutes) in areas at an increased risk of flooding due to sea-level rise, including AAAs that protect natural resources; use natural adaptation approaches in these areas
Land-Development Regulations	Incorporate physical approaches into local regulations
Process Approaches	
Leverage intellectual and material capital via collaborations among stakeholders	Work beyond jurisdictional boundaries to develop collaborations between government and natural-resource-management agencies; engage staff from multiple departments (natural-resource-management, sustainability, extension, planning, and growth-management) as well as experts from other organizations such as the water-management districts, national parks and forests, environmental groups, US Geological Services, Florida Fish and Wildlife Conservation Commission, and US Fish and Wildlife Service
Reach consensus on scientific data	Establish agreement upon projections and data sets through “science cafes,” media, and Extension outreach
Develop localized strategies within regional approaches	Provide flexibility for individual partners to adapt locally while working regionally
Form interdisciplinary teams	Increase flexibility and on-going collaboration between planners, citizens, and scientists
Frame the issues	Recognize different values and interests while working toward common goals
Build community buy-in	Engage local residents and organizations in designing and implementing strategies

Human adaptation often can conflict with the process of adaptation in natural systems. For example, shoreline hardening may prevent sea turtles from nesting further up shore as sea-level rises (Rizkala and Savage 2011), and inhibit inland migration of seagrass and mangrove habitats that are critical fish nurseries. Consequences may include a decline in fisheries or a shoreline’s increased susceptibility to hurricanes. As humans move inland due to the pressures of sea-level rise and increased storm intensity, they will begin occupying now undeveloped lands. This could result in increased habitat fragmentation as well as competition

with organisms that are also migrating inland or are already present (Noss 2011).

There are, however, human adaptation strategies that can successfully address the needs of both natural and human communities, and these fall into three categories: physical, policy, and process. *Physical* approaches include changes to the natural or man-made environment. *Policy* approaches are typically implemented through comprehensive plans and land development regulations. *Process* approaches are mechanisms by which both physical and policy strategies

can be implemented more effectively. Not all strategies may be suitable for every location or for every species. Determining which adaptation strategies are most appropriate may require an ecosystem- or landscape-scale approach that crosses political boundaries and demands a more collaborative, coordinated effort among multiple governments, agencies, and public and private entities.

As coastal communities prepare for sea-level rise, they can use these and other strategies to integrate natural adaptation processes into their planning processes. Because natural systems rarely follow political boundaries, a more coordinated planning effort between multiple governments and agencies may be necessary. Planners may also consider using an adaptive management approach that would allow the community greater flexibility when responding to unanticipated impacts of climate change. By taking a proactive approach to adaptation rather than a reactive one, communities will be able to better protect the resources upon which they depend.

Helpful Resources

Florida Department of Economic Opportunity (FDEO). *Adaptation planning*. <http://www.floridajobs.org/community-planning-and-development/programs/technical-assistance/community-resiliency/adaptation-planning>

Florida Sea Grant, Coastal Planning Policy Tools <https://www.flseagrant.org/climatechange/coastalplanning/resources/policy-tools/>

Climate Adaptation Knowledge Exchange <http://www.cakex.org/>

Georgetown Climate Center, Adaptation Clearinghouse <http://www.georgetownclimate.org/adaptation/clearinghouse>

Sea Level Changes in the Southeastern United States: Past, Present and Future http://floridaclimateinstitute.org/images/reports/201108mitchum_sealevel.pdf

Florida Water Management and Adaptation in the Face of Climate Change http://floridaclimateinstitute.org/images/reports/water_management.pdf

National Park Service, Climate Change Response Strategy http://www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf

National Fish, Wildlife & Plants Climate Adaptation Strategy <http://www.wildlifeadaptationstrategy.gov/pdf/NFWPCAS-Final.pdf>

EPA Climate Ready Estuaries <http://www2.epa.gov/cre>

Marshes on the Move http://www.csc.noaa.gov/digitalcoast/_/pdf/Marshes_on_the_move.pdf

Climate Ready Water Utilities <http://water.epa.gov/infrastructure/watersecurity/climate/>

Rolling Easements <http://water.epa.gov/type/oceb/cre/upload/rollingeasementsprimer.pdf>

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