KING TIDE 2016:

A GLIMPSE AT WHAT SOUTH FLORIDA'S FUTURE COULD LOOK LIKE

Briefing Book for U. S. Congressman Ted Deutch

Las Olas Isles at Mola Canal, Fort Lauderdale: "The Venice of America." Image Source: Broward County

2438 E. Las Olas Blvd, Fort Lauderdale, FL 33301

Monday, October 17, 2016 9:00 -10:00 a.m.

Coordinated by:

FAU
FLORIDA CENTER FOR ENVIRONMENTAL STUDIES
Charles E. Schmidt College of Science
Florida Atlantic University

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  - *Ricardo Alvarez, President & Director, MITIGAT.com, Inc.*
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Adaptation Pathways 1.0

A Guide for Navigating Sea-Level Rise in the Built Environment

EXECUTIVE SUMMARY

Adaptation Pathways 1.0 summarizes the 3rd Sea-Level Rise Summit organized by the Florida Center for Environmental Studies at Florida Atlantic University. The event, subtitled "Connected Futures from Alaska to Florida," was held May 3-5, 2016, at the Ft. Lauderdale Hyatt Pier 66. In recent years, many conferences and meetings have identified the problems we face, and outlined some theoretical solutions. What we lacked was guidance for implementing specific adaptations. The goal of the Summit was to produce a first-generation roadmap for adaptation, by translating our knowledge and ideas into action. Our resulting ***Adaptation Pathways*** (see Section III of this report) have emerged as the product of intense and sustained interactions with Summit participants, representing a broad cross-section of society.

There are three principal take-away messages from the Summit:

1. The environmental changes underway in the subtropics and in the Arctic are not unfolding in a vacuum. Our communities also face other challenges, such as the availability of good jobs and rising summertime temperatures. Any new efforts to enhance sea level or coastal erosion resilience should support not degrade other features of socio-ecological resilience.

2. To advance along our adaptation pathways, all four sectors of society – private sector, public sector, academia, and civil society – must interact more often. Stakeholders need to build trust and a shared awareness. The goal of these interactions should not be to achieve perfect consensus, but instead a greater ability to collaborate on potential solutions.

3. There appear to be six groups of problems linked to sea-level rise and coastal erosion in our two regions, each with an associated generalized adaptation pathway for implementing solutions (see Section III):

	PROBLEM DOMAIN		ADAPTATION PATHWAY
1	**Community Engagement**	→	**Listening & Partnering**
2	**Public Health, Science & Metrics**	→	**Novel Measuring & Monitoring**
3	**Financial Policies & Building Regulations**	→	**Aligning Incentives**
4	**Hard Infrastructure**	→	**Supporting Public-Private Partnerships (P3's)**
5	**Soft Infrastructure**	→	**Green Landscaping**
6	**Relocation**	→	**Multi-Level Coordinating**

Finally, it is important to recall that the environmental changes unfolding today – at both low and high latitudes – are dynamic. As such, the insights generated by this Summit will need to evolve to keep pace with changing conditions on the ground. Hence the suffix "1.0" in the name of this document: we expect to update and expand this information as time passes. We invite you to contribute to that conversation by telephone (954-236-1104), email (arctic-florida@fau.edu), or social media.

DOWNLOAD THE FULL REPORT AT: http://www.ces.fau.edu/arctic-florida/pathways.php

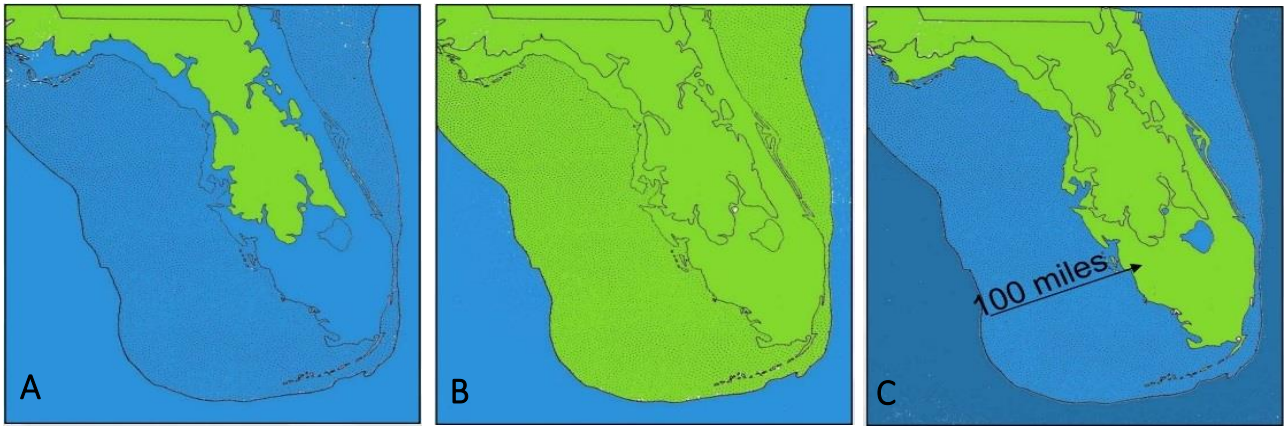
SCIENTIFIC BACKGROUND FOR CITIZENS CONCERNED ABOUT SEA-LEVEL RISE IN SOUTH FLORIDA

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.

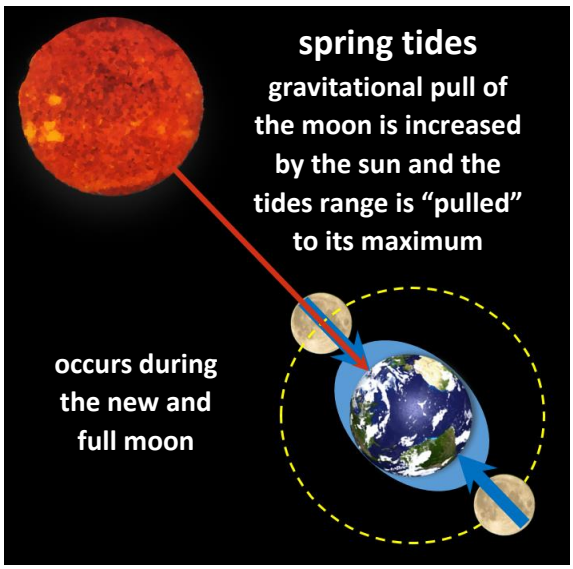


Florida During the Past Interglacial, Glacial, and Present. *Image Source: Wanless*

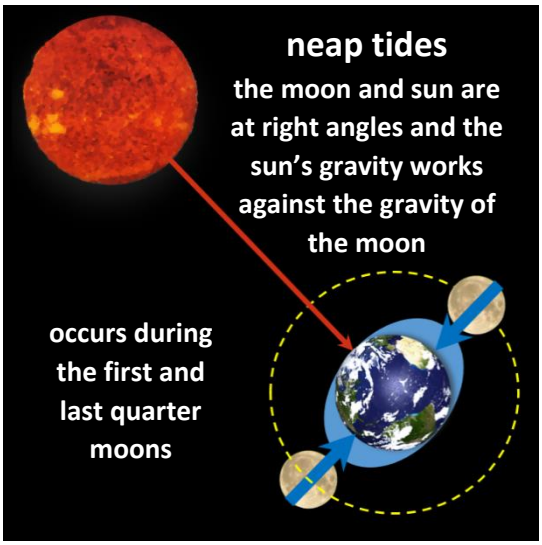
CHANGING TIDES

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, changing the height of the sea surface. 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***,



Spring Tides. Image Source: Alana Edwards



Neap Tides. Image Source: Alana Edwards

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.

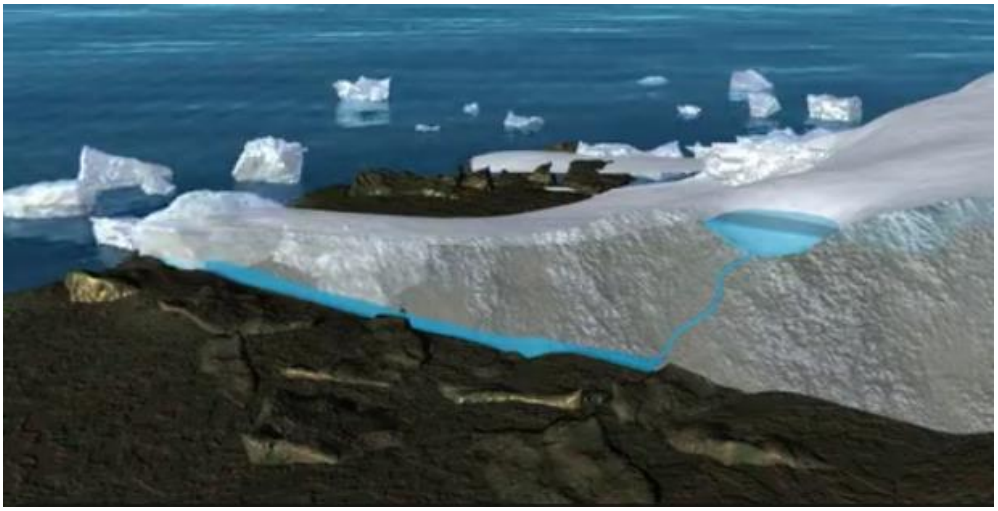
Around the first and last quarter moons, the moon and sun are at a right angle in respect to Earth. Therefore, instead of working together, the sun's gravity is working against the gravity of the moon and this leads to tides levels at their minimum. These are known as ***neap tides*** and they occur 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. 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.



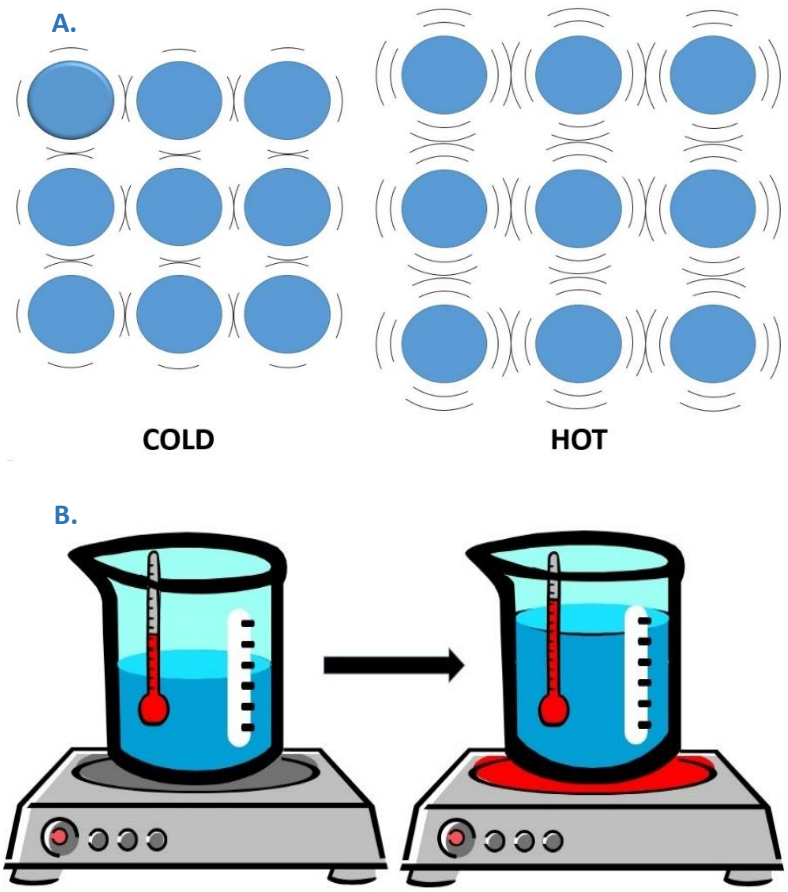
Melting Land Ice. Image Source: [NASA/Goddard Space Flight Center Conceptual Image Lab]

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 storage capacity than land due to water's higher specific heat. Specific heat is defined as the amount of heat energy required to raise or lower the temperature of a gram of a substance by 1 ° Celsius.

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 volume of ocean water expands. This 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.



Thermal Expansion. A.) As water is heated, the kinetic energy of the water molecules increases, causing the molecules to vibrate more and move apart. B.) In turn, the water expands in volume. Image source: Alana Edwards

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.

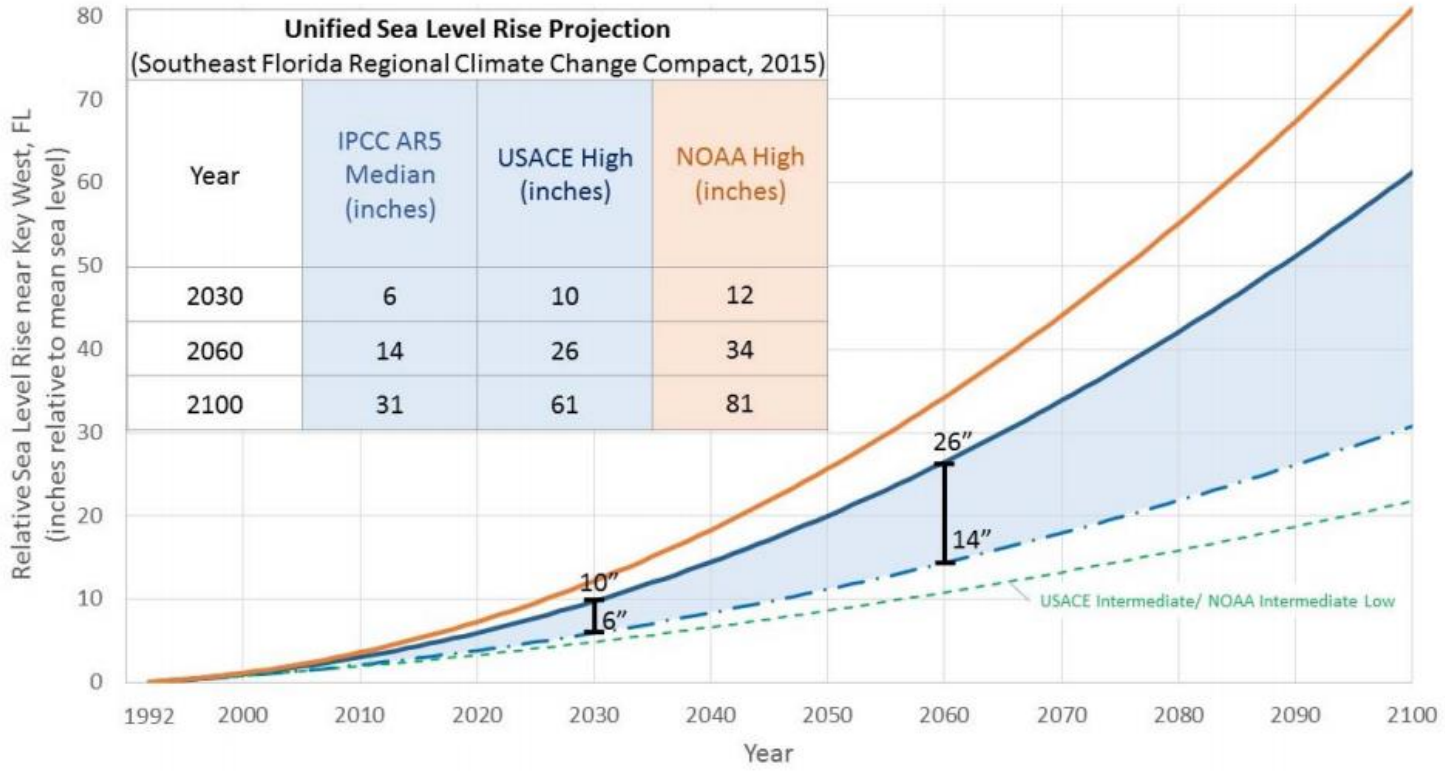
Florida At Night. Image Source: **NASA**

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

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
(Southeast Florida Regional Climate Change Compact, 2015)

Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81



Unified Sea Level Rise Projection from the Southeast Florida Regional Climate Change Compact, 2015. Image Source: **http://www.southeastfloridaclimatecompact.org**

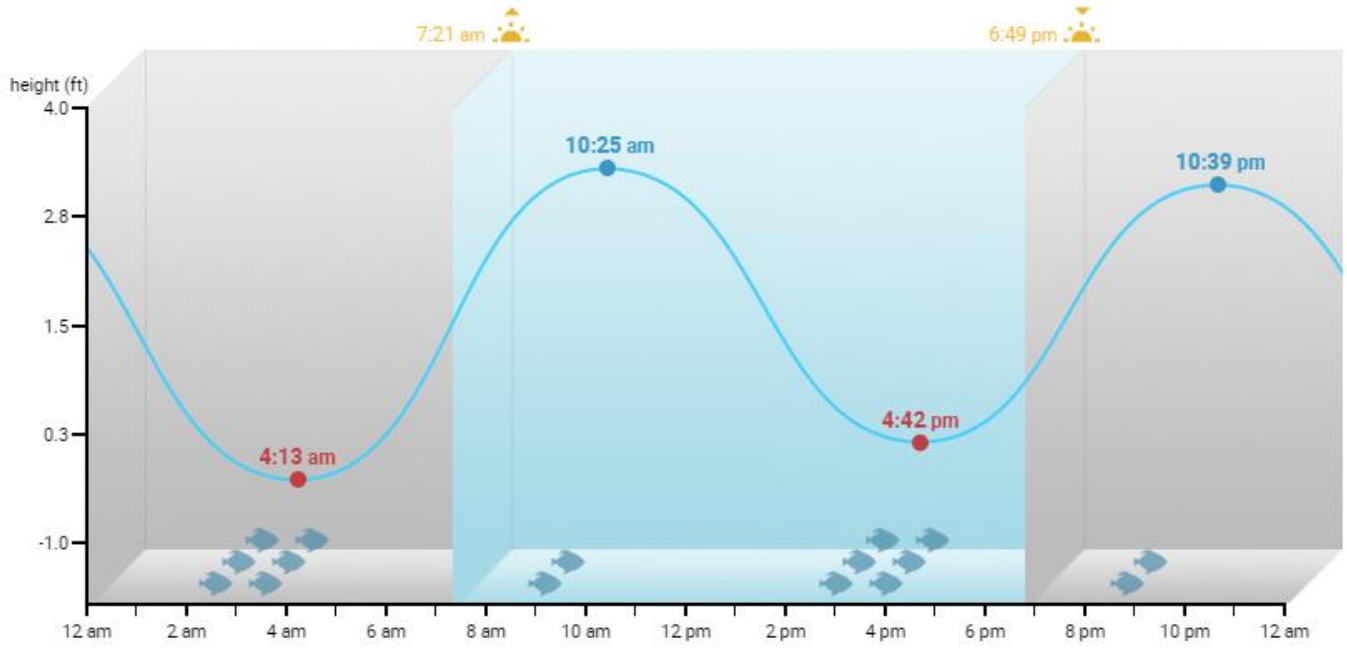
EFFECT: EXTREME HIGH TIDES & KING TIDES

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***

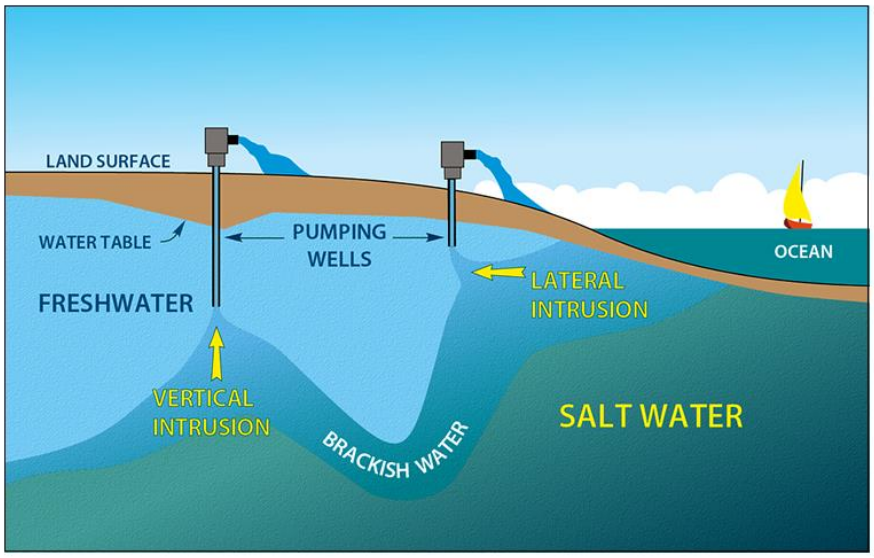
As sea levels continue to rise, these flooding events will occur more frequently. Just 1.5 feet of sea-level rise can cause approximately 573 flooding events per year. This means that approximately three quarters of the year these areas will experience extreme high tide events twice a day. For much of 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 Andrews Avenue Bridge (New River), Ft. Lauderdale on October 17, 2016. The first high tide predicted to be 3.27 feet at 10:25am. Source: Tidetable.net

EFFECT: THREATS TO OUR COASTAL WATER SUPPLY

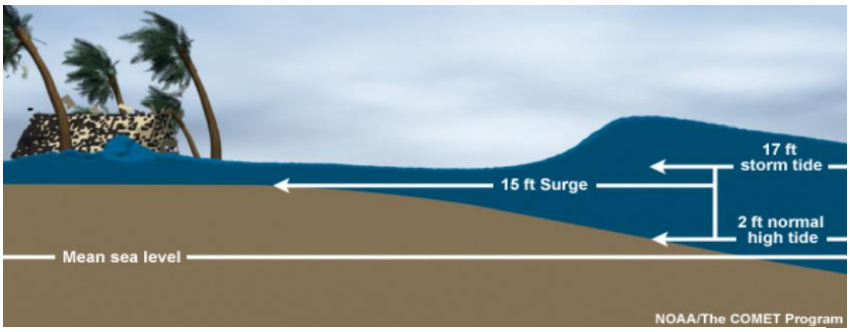
Along our coasts are dozens of wells that tap into our freshwater aquifer. During periods when there is little rain and our aquifers have not had time to "recharge," any withdrawal can lead to saltwater intrusion. This is because we are withdrawing so much freshwater that we start pulling up brackish water. As depicted in 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

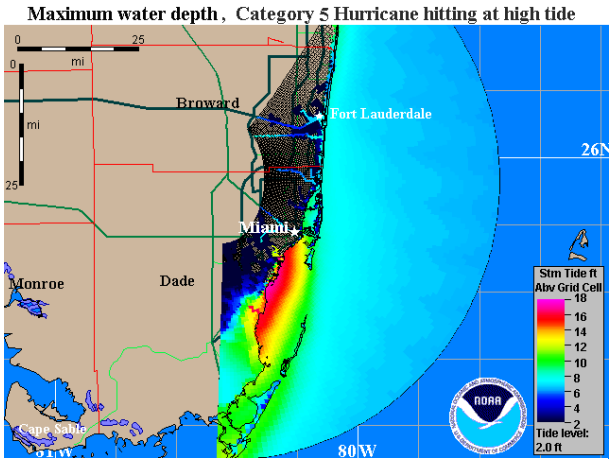
According to NOAA, storm surge is "an abnormal rise of water generated by a storm, over and above the predicted astronomical tide." In the presence of a storm, the water levels will change due to the strong winds from the storm. Therefore, we would expect that storm surge would be higher during hurricanes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



Storm Surge. Image Source: NOAA

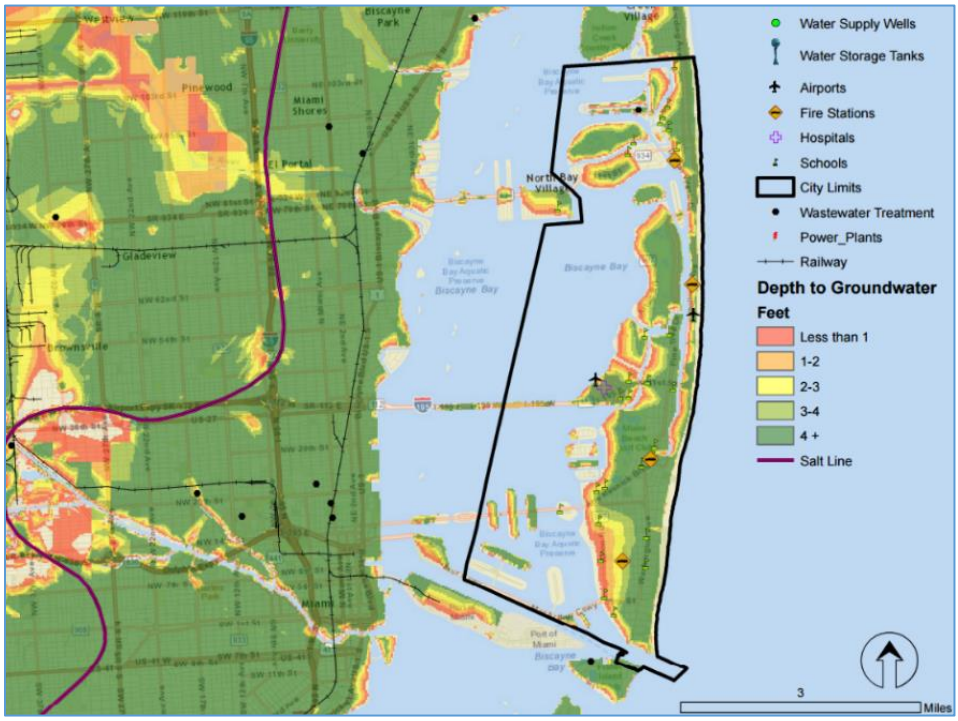
Now factor in higher sea levels and consider how that might affect storm surge. The combination of higher sea levels and storm surge has the potential of causing devastating damages to South Florida's coastal communities. The buildings near our coastline were not designed to withstand these higher surges.

Therefore, our coastal communities are likely going to need to make some changes to these vulnerable buildings. Some examples include elevating, "hardening", or even relocating some of these structures. In some cases, abandonment may be the only option available.



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, 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?

As seen in the diagram on the previous page, saltwater intrusion is affecting our coastal wells. The diagram shows saltwater coming in from under the freshwater. As sea levels continue to rise, we will see the saltwater continuing to move inland. As it does this, saltwater 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. 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 (above) that many areas inland are bright orange indicating that the water table is less than 1 foot below the surface.

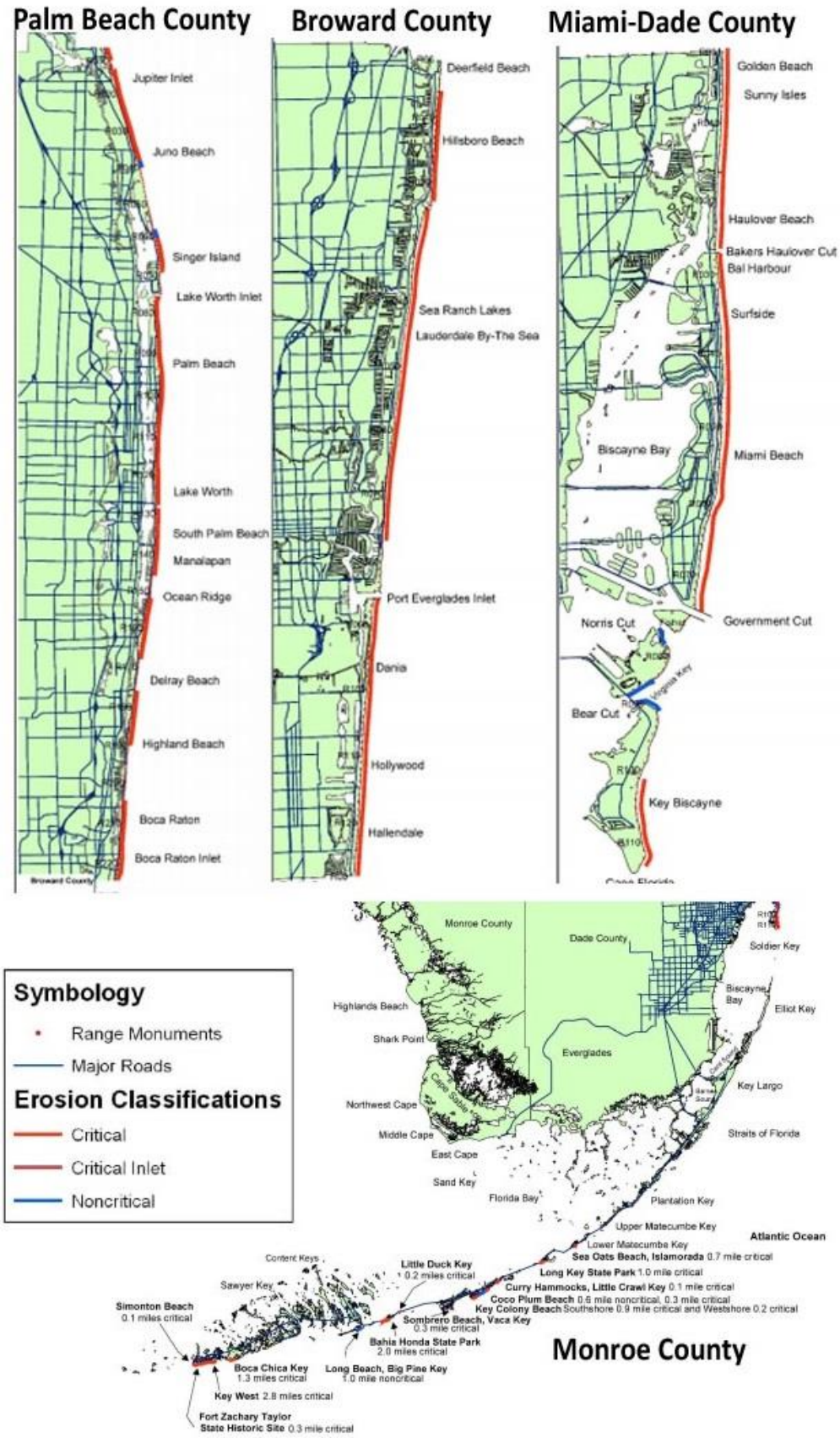
EFFECT: INCREASED BEACH EROSION AND THE COST OF NOURISHMENT

Our beaches are constantly changing due to both natural and anthropogenic forces causing 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 Florida. Therefore, maintaining our beaches for tourism has been a major priority for coastal communities. Florida's Department of Environmental Protection recently released a report that 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. 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, beach nourishment efforts that keep pace with sea-level rise, as well as replace sand washed away by wave action, may be more costly and not a viable solution in specific locations due to the physical conditions.



Critically eroded beaches in south Florida. Adapted from FDEP.