# SOUTHEAST FLORIDA'S RESILIENT WATER RESOURCES

» INCLUDING A CASE STUDY FOR THE CITY OF POMPANO BEACH

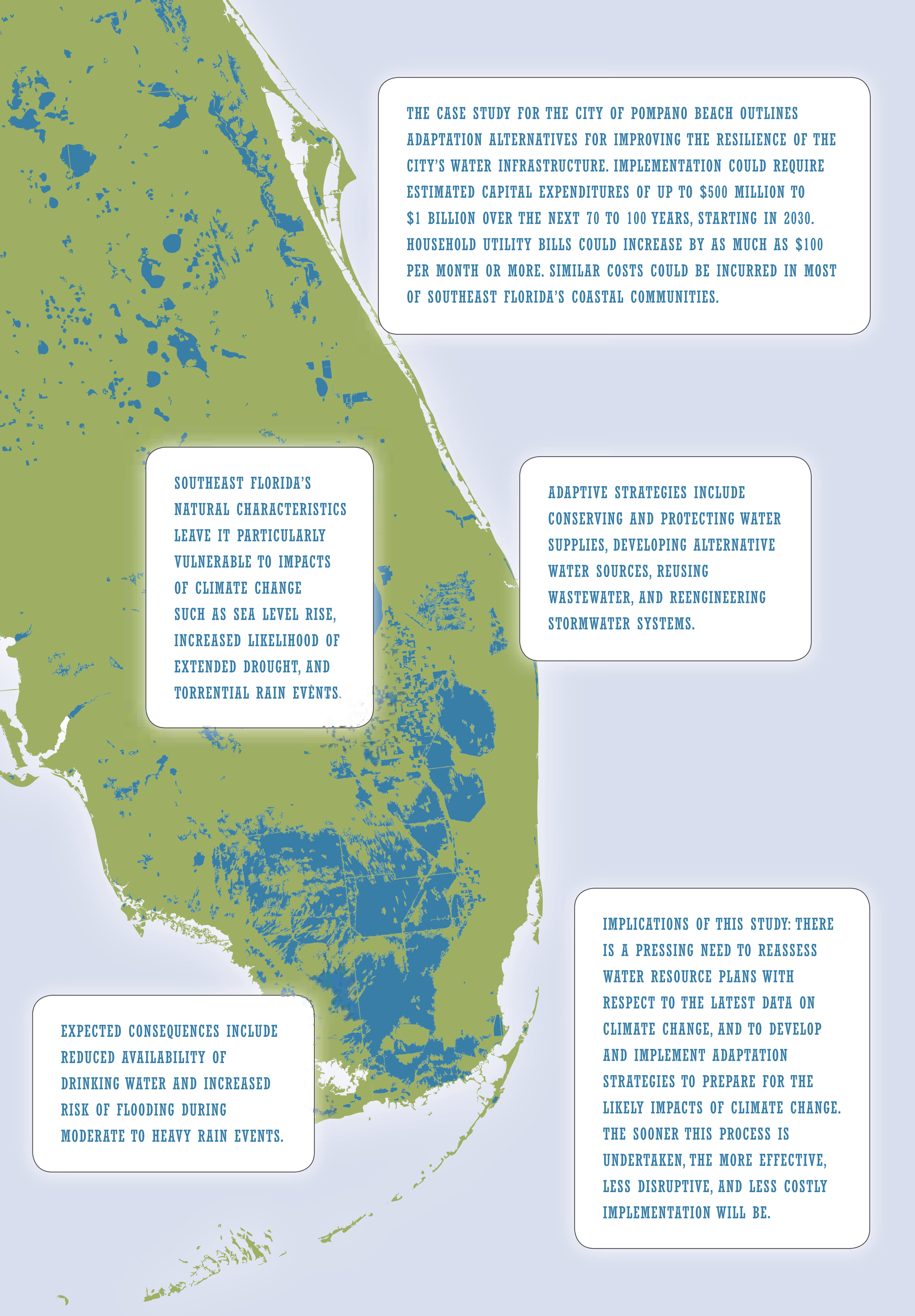
Florida Atlantic University

# SOUTHEAST FLORIDA'S WATER INFRASTRUCTURE IS VULNERABLE TO CLIMATE CHANGE

THE WATER INFRASTRUCTURE IN FLORIDA IS COMPLEX AND CAPITAL INTENSIVE. MUCH OF IT WAS DESIGNED AND INSTALLED MORE THAN 50 YEARS AGO, LONG BEFORE CLIMATE CHANGE WAS CONSIDERED A THREAT. SEA LEVEL RISE SINCE THEN IS ALREADY STRESSING THE SYSTEM TODAY. SEA LEVEL IS PROJECTED TO RISE 3 TO 6 INCHES ABOVE 2010 LEVELS BY 2030 AND 12 TO 21 INCHES BY 2060.

CHANGES TO INFRASTRUCTURE ARE REQUIRED TO PROTECT FRESHWATER SUPPLIES, DRAINAGE SYSTEMS, AND VALUABLE ECOSYSTEMS, AND TO PREVENT FLOODING AND SEVERE ECONOMIC LOSSES.

UP TO 70% OF THE DRAINAGE CAPACITY OF THE 28 COASTAL FLOOD/SALINITY CONTROL STRUCTURES PROTECTING SOUTHEAST FLORIDA FROM FLOODING AND SALTWATER INTRUSION COULD BE LOST WITH SEA LEVEL RISE OF ONLY 3 TO 9 INCHES, ANTICIPATED BY ABOUT 2030 TO 2050. ADAPTATION MAY REQUIRE THE ADDITION OF HIGH-CAPACITY PUMPING STATIONS COSTING APPROXIMATELY $70 MILLION EACH (PLUS NECESSARY LAND ACQUISITIONS). THREE PUMPING STATIONS COSTING A TOTAL OF OVER $200 MILLION (PLUS LAND) COULD BE NEEDED IN NORTH MIAMI-DADE COUNTY IN THE NEAR FUTURE.



THE CASE STUDY FOR THE CITY OF POMPANO BEACH OUTLINES ADAPTATION ALTERNATIVES FOR IMPROVING THE RESILIENCE OF THE CITY'S WATER INFRASTRUCTURE. IMPLEMENTATION COULD REQUIRE ESTIMATED CAPITAL EXPENDITURES OF UP TO $500 MILLION TO $1 BILLION OVER THE NEXT 70 TO 100 YEARS, STARTING IN 2030. HOUSEHOLD UTILITY BILLS COULD INCREASE BY AS MUCH AS $100 PER MONTH OR MORE. SIMILAR COSTS COULD BE INCURRED IN MOST OF SOUTHEAST FLORIDA'S COASTAL COMMUNITIES.

SOUTHEAST FLORIDA'S NATURAL CHARACTERISTICS LEAVE IT PARTICULARLY VULNERABLE TO IMPACTS OF CLIMATE CHANGE SUCH AS SEA LEVEL RISE, INCREASED LIKELIHOOD OF EXTENDED DROUGHT, AND TORRENTIAL RAIN EVENTS.

ADAPTIVE STRATEGIES INCLUDE CONSERVING AND PROTECTING WATER SUPPLIES, DEVELOPING ALTERNATIVE WATER SOURCES, REUSING WASTEWATER, AND REENGINEERING STORMWATER SYSTEMS.

EXPECTED CONSEQUENCES INCLUDE REDUCED AVAILABILITY OF DRINKING WATER AND INCREASED RISK OF FLOODING DURING MODERATE TO HEAVY RAIN EVENTS.

IMPLICATIONS OF THIS STUDY: THERE IS A PRESSING NEED TO REASSESS WATER RESOURCE PLANS WITH RESPECT TO THE LATEST DATA ON CLIMATE CHANGE, AND TO DEVELOP AND IMPLEMENT ADAPTATION STRATEGIES TO PREPARE FOR THE LIKELY IMPACTS OF CLIMATE CHANGE. THE SOONER THIS PROCESS IS UNDERTAKEN, THE MORE EFFECTIVE, LESS DISRUPTIVE, AND LESS COSTLY IMPLEMENTATION WILL BE.

**SOUTHEAST FLORIDA IS RANKED AS ONE OF THE TEN MOST VULNERABLE COASTAL METROPOLITAN AREAS IN THE WORLD.**

# SOUTHEAST FLORIDA'S UNIQUE VULNERABILITY TO CLIMATE CHANGE



**SOUTHEAST FLORIDA, WITH A POPULATION OF 5.5 MILLION, IS RANKED AS ONE OF THE TEN MOST VULNERABLE** coastal metropolitan areas in the world. Expected local impacts of global climate change include sea level rise (Table 1), extremes in precipitation patterns, and more intense storms. Southeast Florida is particularly susceptible to these impacts because of the characteristics listed below.

### CHARACTERISTICS OF SOUTHEAST FLORIDA INCLUDE:

- **a wide variation in seasonal rainfall,** with dry winters and springs, and wet summers and autumns;
- **high volumes of rainfall,** of about 60 inches per year, equivalent to a total of 1 billion gallons per square mile per year, with 70% during the rainy summer and autumn seasons;
- **periods of drought,** especially during the dry winter and spring seasons;
- **torrential rainfall,** from thunderstorms, tropical storms, and hurricanes, especially during the wet season;
- **low elevations,** less than 5 feet above mean sea level in many areas (Figure 1);
- **open water system,** consisting of porous soil and an open coastal aquifer (the Biscayne Aquifer, Figure 2); and
- **a vulnerable location,** surrounded by the subtropical mid-Atlantic Ocean and the Gulf of Mexico.

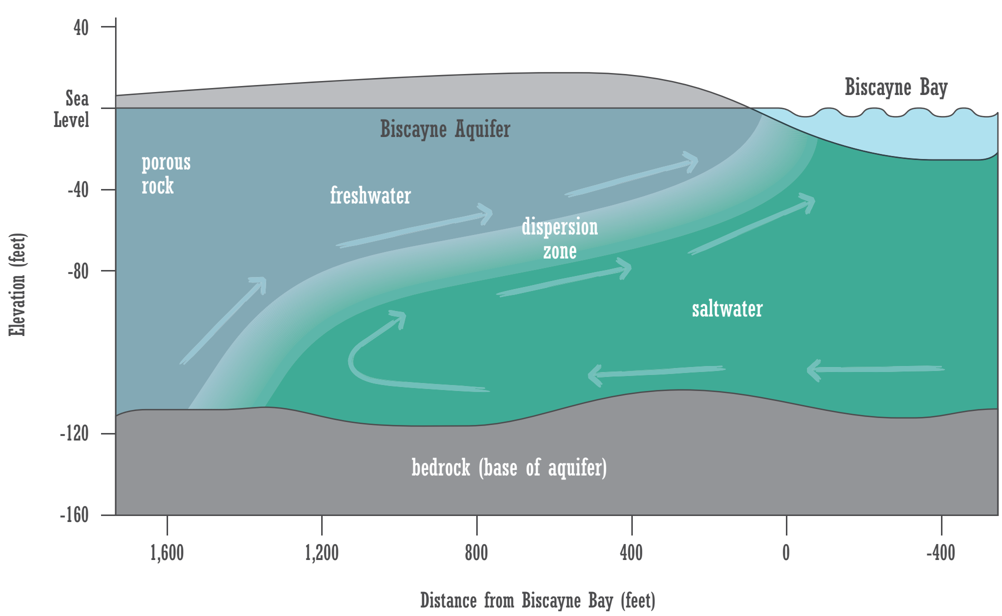
## Table 1. Range in Projected Sea Level Rise by 2100

| Year | Projected Sea Level Rise above 2010 Levels (feet) |
|---|---|
| 2030 | 0.25 – 0.5 |
| 2060 | 1.0 – 1.75 |
| 2100 | 2.5 – 5.0 |

## Figure 1. Low Elevations

The red areas of this map indicate parts of Southeast Florida that are below 3.28 ft (1 m) elevation above mean high tide, or about 5 ft above mean sea level. These regions could be at risk of serious flooding late in this century as sea level rises. [Credit: Weiss & Overpeck, Univ. Arizona]

## Figure 2. Open Water System




The Biscayne Aquifer is the primary source of freshwater in Southeast Florida. This aquifer is unconfined and open to the Atlantic Ocean. Freshwater flows through the aquifer to the ocean, where it pushes against and mixes with saltwater in the dispersion zone.

**WATER MANAGERS IN SOUTHEAST FLORIDA ARE ALREADY FACING AGING INFRASTRUCTURE DESIGN AND SALTWATER INTRUSION OF DRINKING WATER SUPPLIES.**

## WATER INFRASTRUCTURE IN SOUTHEAST FLORIDA

The landscape of Southeast Florida has been changed dramatically by the construction of elaborate systems of canals, dikes, levees, flow control structures, pumps, and other water control facilities (Figure 3). These water control systems have converted the region from extensive marshlands into one of the largest metropolitan areas in the United States.

**Figure 3. Water Control System**


A levee separates the Everglades, on the left, from an urban area on the right. An interstate highway runs up the center of the image.

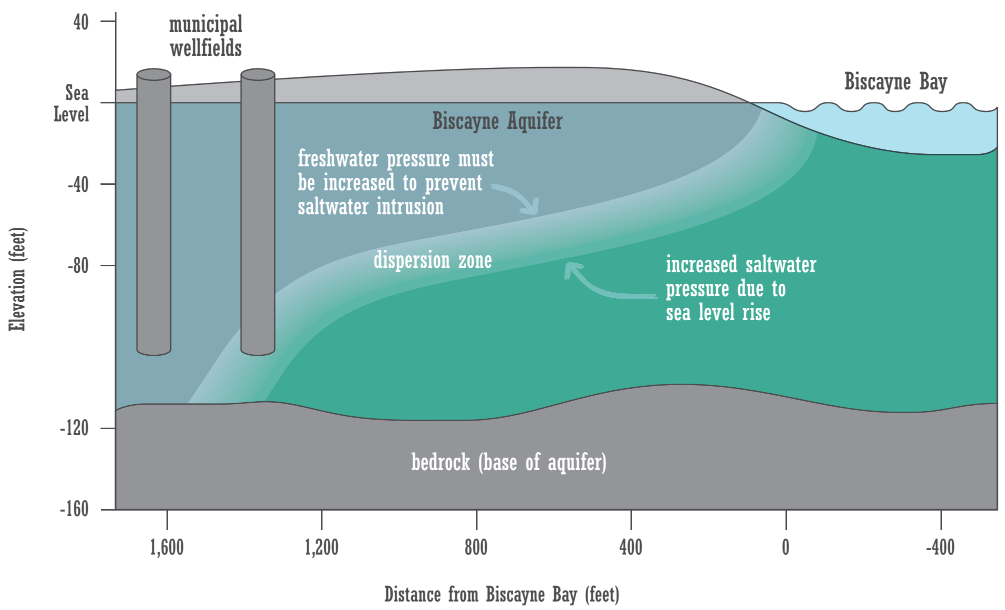
Water managers in Southeast Florida are already facing two major challenges:

**1. AGING INFRASTRUCTURE:** Most of the stormwater drainage infrastructure in Southeast Florida was designed and installed over 50 years ago. This infrastructure was based on sea level at that time, and did not anticipate sea level rise. The 4-5 inch rise in sea level since then has already decreased the flow capacity of coastal flood control structures. In areas with low elevation, some floodgates can no longer be opened at high tide to discharge excess stormwater.

**2. SALTWATER INTRUSION OF DRINKING WATER SUPPLIES:** Because the Biscayne Aquifer is open to the Atlantic Ocean, there is a dispersion zone between saltwater and freshwater. In order to avoid saltwater contamination of municipal water supplies, this dispersion zone must be prevented from intruding on water wellfields (Figure 4). To do so, the water table is maintained at the highest elevations possible. This keeps adequate freshwater pressure on the dispersion zone. However, many easterly wellfields are already threatened by saltwater intrusion due to increased withdrawals and rising sea level.



**Figure 4. Salt Water Intrusion**

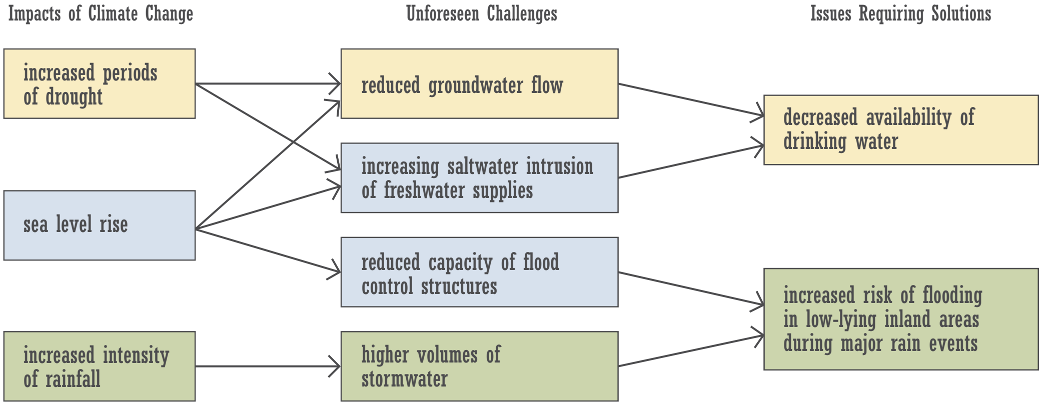



As sea level rises, the pressure of saltwater on the dispersion zone increases, pushing saltwater further into the aquifer.

## UNFORESEEN NEAR-TERM CHALLENGES DUE TO CLIMATE CHANGE

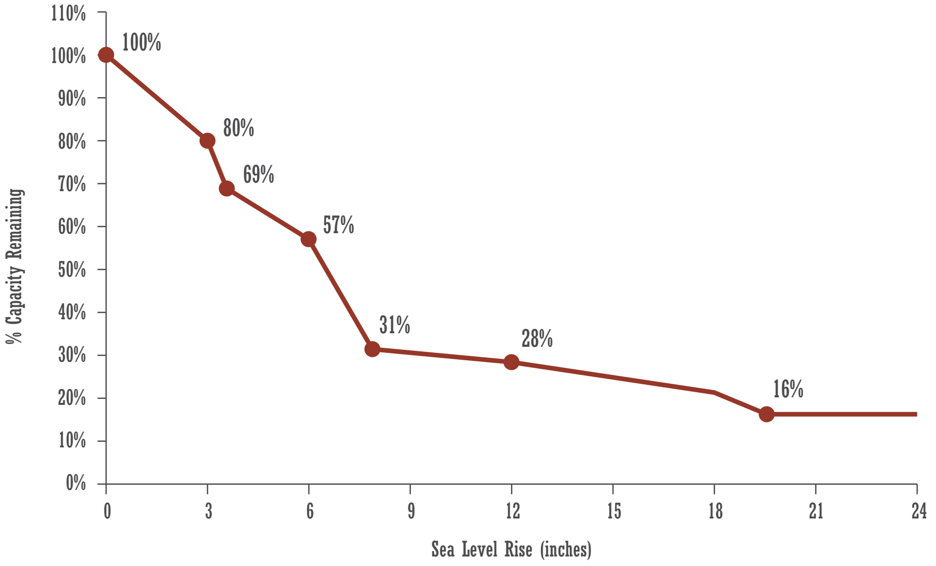
Significant challenges to the water systems in Southeast Florida are expected to begin within the next two decades due to climate change. As shown in the flow chart below, water managers will have to deal with reduced groundwater flow, increasing saltwater intrusion, higher volumes of stormwater, and reduced capacity of flood control structures (Figure 5).

**Figure 5. Challenges to Water System**




Resulting issues include decreased availability of drinking water and increased risk of flooding. These issues are expected to worsen as the impacts of climate change intensify over time.

**Figure 6. Coastal Control Structures – % Capacity Remaining vs. Sea Level Rise**




Sea level rise will reduce the capacity of flood control structures in Southeast Florida's stormwater drainage canals.

ADAPTATION MEASURES WILL BE **EXPENSIVE** AND **ENERGY-INTENSIVE**. HOWEVER, THEY WOULD **PREVENT EVEN HIGHER COSTS** DUE TO LOSSES.

## WHY CHANGES TO WATER INFRASTRUCTURE ARE REQUIRED

### 1. TO PROTECT SUPPLIES OF FRESHWATER.

Sea level rise of only 3-6 inches higher than the 2010 level, expected by about 2030, will increase saltwater intrusion of freshwater supplies, and decrease the flow of groundwater. These impacts will be worsened during more intense periods of drought in the dry winter/spring seasons. In addition, sea level rise increases the risk of salt water contamination due to hurricane storm surge. As a result, increased risk of water shortages is expected.

### 2. TO PREVENT FLOODING.

Increased risks of flooding are expected due to a variety of interrelated causes, including: decreased capacity of flood control structures; greater volumes of stormwater during torrential rainstorms (Figure 7); inundation of low-lying barrier islands and coastal areas due to sea level rise and higher hurricane storm surges, which can also penetrate further inland.

### 3. TO MAINTAIN DRAINAGE SYSTEMS.

Rising sea levels will severely compromise the stormwater drainage system. As shown in Figure 6 on the previous page, a sea-level increase of 9 inches above the 2010 level, which could occur as early as 2040, would reduce the overall capacity of flood control structures in Southeast Florida by up to 70%. Without major re-engineering of drainage systems, an increase of 3 to 4 feet could leave large areas of Southeast Florida under water.

### 4. TO PROTECT VALUABLE ECOSYSTEMS.

As the sea level rises over the next century, the southern Everglades will likely become a saltwater marsh. The ecology of the region will change, affecting the habitats of endangered species (Figure 8). As brackish water migrates northward in the Everglades, the Biscayne Aquifer that supplies drinking water to urban areas may also be threatened with saltwater contamination.

### 5. TO PREVENT SEVERE ECONOMIC LOSSES.

Adaptation measures will be expensive and energy-intensive. However, they would prevent even higher costs due to losses in the following areas: increased damage from flooding and hurricanes; water shortages due to drought; contamination of drinking water supplies; and, eventually, the possible relocation of human populations from vulnerable locations.

**Figure 7. Torrential Rain**

Heavy rainfall events are already common in Southeast Florida. Increased intensity of storms and rising sea level will increase the risk of flooding.

**Figure 8. Endangered Species**

The Everglades is home to endangered species including the Florida panther, the Everglades Snail Kite, and the Cape Sable Seaside Sparrow.

FIND A **BALANCE** BETWEEN **RETAINING** AS MUCH FRESHWATER IN THE WATER SYSTEM AS POSSIBLE, AND **ALLOWING** FOR INCREASED QUANTITIES OF STORMWATER.

# RECOMMENDATIONS

## AND CONCLUSIONS

**FRESHWATER RESOURCES IN SOUTHEAST FLORIDA MUST BE MAINTAINED IN ORDER TO OFFSET THE CONSEQUENCES** of saltwater intrusion and drought. However, to prevent flooding, sufficient volume must be left in water systems for sudden downpours. As a result, water managers need to find a balance between retaining as much freshwater in the water system as possible, and allowing for increased quantities of stormwater. Table 2 lists five categories for water managers to consider.

**Table 2. Water Resource Adaptation Alternatives**

| Adaptation Strategy | Examples |
|---|---|
| Water conservation | • encourage reduced water use (e.g., subsidize water-saving devices and enforce landscape watering restrictions) |
| Protection of existing water sources | • protect existing municipal wellfields and water control structures<br>• relocate wellfields as necessary |
| Development of alternative water sources | • desalinate brackish waters<br>• capture and store stormwater<br>• store excess water underground using aquifer storage and recovery (ASR) |
| Wastewater reclamation and reuse | • use treated wastewater (e.g., for irrigation, industrial use, and to recharge aquifers) |
| Stormwater management | • re-engineer canal systems, flood control structures, and pumps |

## RECOMMENDATIONS FROM THIS STUDY

1. Re-evaluate current policies and incorporate climate change into all water resource planning.
2. Bring scientists, engineers, water managers, and decision-makers together to work on the incorporation of climate change into water resource management plans.
3. Quantitatively evaluate the vulnerability of flood control structures and stormwater drainage systems. Develop plans for enhancement.
4. Assess and evaluate the impacts of climate change on groundwater supplies. Develop plans to protect freshwater supplies and to develop alternative water sources.
5. Develop and implement increased freshwater storage and conservation to protect against water shortages due to drought or other causes.
6. Determine the increases in electric power supplies that will be needed in order to implement adaptation plans.

## CONCLUSIONS

Until now, water management planning in Southeast Florida has been based on the assumption that environmental conditions will remain within historic ranges. This assumption is no longer valid. Unprecedented sea level rise and other climate change impacts are likely to result in serious threats to the water supply, increased risks of flooding, hurricane damage, huge infrastructure investments, and other consequences both known and unknown at this time.

Although the focus of this study is on Southeast Florida, many of the concerns and conclusions can be applied to other coastal metropolitan areas throughout the nation. The adaptation measures described in this study will be necessary to prepare for the unavoidable impacts of climate change.



## LIMITATIONS OF THIS STUDY

1. **Limitations in climate change projections:** The main uncertainty when predicting the effects of climate change is the possible range of human choices regarding energy policy and land use in the future. For this reason, projected impacts are based on a range of scenarios.
2. **Limitations in projections of sea level rise and other climate change impacts:** When predicting sea level rise and other potential impacts of climate change, a key uncertainty is the potential for positive climate feedbacks due to reduced ice cover, melting permafrost, increased humidity, etc., and the possibility that irreversible thresholds may be crossed. These could dramatically increase the rate and extent of glacial melting and sea level rise.
3. **Limitations in projections on impacts on Southeast Florida's water systems:** Extensive research and integrated hydrological modeling is required to predict the effects of climate change impacts on Southeast Florida's water systems more accurately, and to test alternative solutions.

SEA LEVEL RISE IS THE MOST SIGNIFICANT CLIMATE CHANGE ISSUE FACED BY THE CITY OF POMPANO BEACH

# CASE STUDY

## ADAPTATION STRATEGIES FOR THE CITY OF POMPANO BEACH WATER UTILITY

**THE CITY OF POMPANO BEACH IS LOCATED IN NORTHEAST BROWARD COUNTY, FLORIDA.** Positioned along the coast of the Atlantic Ocean, the City includes three miles of beachfront (Figure 9). Water bodies within the City include the Intracoastal Waterway (Figure 10), and primary and secondary canals for drainage.

Figure 9. The City of Pompano Beach

Figure 10. The Atlantic Intracoastal Waterway runs from Key West, Florida, to Norfolk, Virginia



A Case Study of the City of Pompano Beach Water Utility was conducted in cooperation with the utility's management and staff by Frederick Bloetscher, Ph.D., and Daniel Meeroff, Ph.D., both faculty members of the Department of Civil, Environmental, and Geomatics Engineering at Florida Atlantic University (FAU); and by Barry Heimlich, a Research Affiliate for the Climate Change Research Initiative at the Florida Center for Environmental Studies at FAU.

The City of Pompano Beach was chosen for the case study because it is confronting many of the issues faced by utilities in Southeast Florida. Saltwater intrusion, flooding, and storm events are common to all coastal areas of Southeast Florida. However, sea level rise is the most significant climate change issue faced by the City.

The City has two municipal wellfields: the Eastern and Western Wellfields. The Eastern Wellfield is threatened by saltwater intrusion, and has been monitored since 1996. The permitted daily volume of water drawn from this wellfield has been reduced to prevent further saltwater intrusion. The City of Pompano Beach Water Utility is considering a pilot test to use hydrodynamic barriers in order to help protect the Eastern Wellfield. The utility is also expanding its wastewater reclamation and reuse program.

Figure 11. Water treatment plant in the City of Pompano Beach

## POTENTIAL VULNERABILITIES TO THE IMPACTS OF CLIMATE CHANGE

Like the rest of Southeast Florida, the City of Pompano Beach is particularly vulnerable to three specific impacts of climate change: changes in precipitation patterns; increased storm intensities; and sea level rise.

### VULNERABILITY TO DROUGHT AND HEAVY RAINFALL EVENTS

The City is already susceptible to water shortages, and this vulnerability will continue. The City has implemented irrigation restrictions and reduced withdrawals from the Eastern Wellfield. The City is developing alternative water sources, including wastewater reuse for irrigation and a recycled wastewater distribution system.

The City is also vulnerable to expected increases in heavy rainfall events, which increase the risk of flooding, contamination of the water supply, and disruption of transportation and other services.

### VULNERABILITY TO INCREASED INTENSITY OF STORMS

The City's utilities are vulnerable to hurricanes, tropical storms, and strong thunderstorms in the following areas:

1. Water pipes may be uprooted by fallen trees during storms (Figure 12).
2. Loss of grid power at facilities may occur during intense storm events.
3. Flooding during rainstorms can overwhelm storm drainage systems.
4. Storm surge during hurricanes can cause severe coastal flooding, widespread destruction, and saltwater contamination of groundwater.
5. There is a slight chance that equipment could fail catastrophically during severe storms.

**Figure 12. Fallen trees can damage the water distribution system.**

As storm intensities increase due to climate change, these vulnerabilities are likely to become more severe.

### VULNERABILITY TO SEA LEVEL RISE

Sea level rise is an even more significant, long-term problem for the City of Pompano Beach. Except for areas of the City on barrier islands and directly on the waterfront, the City's elevation at 10-15 feet is higher than much of Southeast Florida. However, the City is vulnerable in the following areas:

1. Low-lying coastal areas may be inundated.
2. Groundwater and wellfields are likely to be increasingly contaminated with saltwater.
3. A higher water table will reduce the soil's capacity to store rainfall.
4. Septic tanks (about 15% of households) and drainage systems may no longer work effectively.

### CHALLENGES FACING THE CITY OF POMPANO BEACH

As sea level rises, the City may:

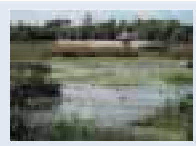
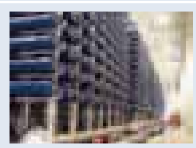
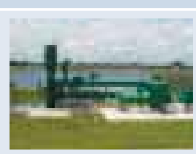
- be less able to rely on the Eastern Wellfield as it becomes contaminated with saltwater;
- need to relocate its wellfields;
- need to convert septic tanks to central sewers;
- need to upgrade the sewer system to prevent groundwater inflow;
- need to set up long-term storage areas for reclaimed water; and
- need to add pump stations to enhance stormwater drainage.

### ASSESSMENT OF ENGINEERED SOLUTIONS AND COSTS

This study evaluated the effects of climate change on the City of Pompano Beach, and suggested a series of adaptive steps. Adapting to climate change will require a wide variety of strategies, including desalination, wastewater reclamation, and new structures such as pumping stations, wells, and locks.

Table 3, on the next page, lists suggested strategies for the City of Pompano Beach. Each strategy would require detailed engineering analysis to confirm the costs and to enable decisions between alternatives. However, Table 3 provides a general guide to the range of costs expected in order to address major concerns.

## Table 3: Recommended Strategies and Estimated Costs

| Sea level rise | Recommended strategy | Estimated cost |
|---|---|---|
| **Near-term (by 2030)** | | |
| 0-0.5 ft | 1. Eliminate trees in rights-of-way to avoid storm damage. | $ millions (requires assessment) |
| | 2. Upgrade water plant equipment to prevent failure from storm damage. | depends on results of engineering studies |
| | 3. Install pump stations in low-lying areas to reduce stormwater flooding  Pump station | start at $1.5 to 5 million per station |
| | 4. Encourage water conservation. | $40 million over first 10 years + $1 million/yr thereafter |
| | 5. Repair and upgrade the sewage system. | start at $12.5 million, plus annual cost |
| **(2030 to 2060)** | | |
| 0.5-1 ft | 6. Reuse wastewater for irrigation to reduce consumption of groundwater. | over $25 million |
| | 7. Use reclaimed wastewater to recharge aquifers, offsetting saltwater intrusion.  Treated wastewater can recharge the aquifer in human-made wetlands | up to $200 million |
| **(2040 to 2070)** | | |
| 1-2 ft | 8. Treat saltwater and brackish water to produce drinking water.  Reverse Osmosis Water Treatment Facility | $45-50 million |
| | 9. Install additional pump stations to control flooding in inland flood plains. | start at $1.5-5 million each (would need at least 12) |
| | 10. Install a sewage system to replace inoperative septic systems. | assessed against property owners at $10,000 each; total cost under $20 million |
| | 11. Close private irrigation wells to conserve water. Encourage use of recovered wastewater. | depends on results of engineering studies |
| | 12. Relocate wellfields. | $20 million |
| | 13. Install salinity control structures to significantly reduce saltwater intrusion. | up to $10 million, may require additional pumping stations at $2-5 million each |
| **(2070 to 2100)** | | |
| before 3 ft | 14. Inject reclaimed wastewater into brackish aquifers.  A typical aquifer storage and recovery (ASR) wellhead | $30 million for wells and piping, unknown for water treatment |
| **(2080 to >2100)** | | |
| 3-4 ft | 15. Implement major renovation of flood control systems. Consider treating and discharging excess water into the Everglades. | $ billions |
| **(2100)** | | |
| greater than 4 ft | 16. Prepare for low-lying areas of the city to be abandoned (worst-case scenario). | $ billions |
| | 17. Implement a large-scale system of dikes (worst-case scenario). | $ billions |

Primary References:

Barry Heimlich, Frederick Bloetscher, Daniel Meeroff & Jim Murley, *Southeast Florida's Resilient Water Resources: Adaptation to the Effects of Sea Level Rise and Other Impacts of Climate Change*, Florida Atlantic University, November 2009. http://www.ces.fau.edu/files/projects/climate_change/SE_Florida_Resilient_Water_Resources.pdf

Frederick Bloetscher, Daniel Meeroff & Barry Heimlich, *Improving the Resilience of a Municipal Water Utility Against the Likely Impacts of Climate Change – A Case Study: City of Pompano Beach Water Utility*, Florida Atlantic University, November 2009, http://ces.fau.edu/files/projects/climate_change/PompanoBeachWater_CaseStudy.pdf

Heimlich and Murley are with the Climate Change Research Initiative at the Florida Center for Environmental Studies at Florida Atlantic University (FAU). Bloetscher and Meeroff are assistant professors in FAU's Department of Civil, Environmental, and Geomatics Engineering.

This project was funded by a grant from the Bipartisan Policy Center.

The Bipartisan Policy Center has engaged MOSAIC, a carbon neutral EPA Green Power Partner, for the production of this brochure, using 100% wind power. The savings below are achieved when PC recycled fiber is used in place of virgin fiber. Your project uses 145 lbs of paper which has a postconsumer recycled percentage of 10%

0 trees preserved for the future

0 lbs water-borne waste not created

59 gal wastewater flow saved

7 lbs solid waste not generated

13 lbs net greenhouse gases prevented

98,600 BTUs energy not consumed

Design by www.katetallentdesign.com

Florida Atlantic University
5353 Parkside Drive, Building SR
Jupiter, FL 33458
T 561-799-8554
www.ces.fau.edu

BIPARTISAN POLICY CENTER
1225 I Street, NW, Suite 1000
Washington, DC 20005
T 202-637-0400

www.bipartisanpolicy.org