Attachment 4

REPORT ON FLOODING AND SALT WATER INTRUSION

September 2016

Final Report for Resolution R-48-15 in support of the Sea Level Rise Task Force final recommendations

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Note on all figures:
If you have any questions or trouble reading any of the figures, please contact the Office of Resilience at green@miamidade.gov to request additional information or a higher resolution version.

Introduction – Supporting Resolution & Context

On January 21, 2015 the Miami-Dade County Board of County Commissioners passed Resolution R-48-15. This resolution directed the Mayor or the Mayor's designee to,

> "work in conjunction with the Office of Intergovernmental Affairs and jointly with the South Florida Water Management District, the United States Geological Survey, and the other member counties of the Southeast Florida Regional Climate Change Compact partners, to conduct a comprehensive study and develop adaptation strategies to address potential flood damage reduction and saltwater intrusion associated with sea level rise and to put forth a time frame for implementation and potential funding mechanisms."

This is the final report in support of the aforementioned resolution. This report provides a summary of the major efforts, complete or underway, to understand the implications of sea level rise on increased risks for flooding and saltwater intrusion. This report was developed over the past year in partnership with multiple agencies including the U.S. Geological Survey, The South Florida Water Management District, and The Army Corps of Engineers. The County has worked with these entities and many others to conduct a comprehensive review of all the studies and adaptation work that is going on to address flooding and saltwater intrusion.

Because of the large volume of work happening, it is not possible to describe each project and its findings in full detail. Instead, the report provides a summary and a roadmap of these initiatives. More detailed information on any of the initiatives included in the report can be provided by the Office of Resilience or the leading institution.

It is important to note that this report presents only a partial snapshot of the current efforts to understand these issues. Tens of millions of dollars have and are being directed to answering and addressing these questions. Multiple entities are engaged in directing this research including local and state universities, multiple federal, state, regional and local agencies, the private sector, non-profits and corporations, and the Southeast Florida Regional Climate Compact ("The Compact"). The level of research and planning in Miami-Dade County focused on adaptation to sea level rise and salt water intrusion is exceptional. Miami-Dade County is fortunate to have the support of many world class entities dedicated to understanding the issues and researching adaptation measures. Most importantly, Miami-Dade County continues to benefit tremendously from the close collaboration facilitated by The Compact and the Florida Climate Institute. Investments in research and adaptation measures have increased steadily and will likely continue for the foreseeable future. It is worth underscoring that the County has benefited significantly from outside funding from philanthropies, federal agencies, and universities.

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This report also provides a roadmap to where updated information can be found. Many institutions including the National Aeronautics and Space Administration, The National Climate Assessment, the South Florida Water Management District, National Oceanographic and Atmospheric Administration and many non-profit groups have helped synthesize the existing information and made it into publicly accessible, user friendly webpages.

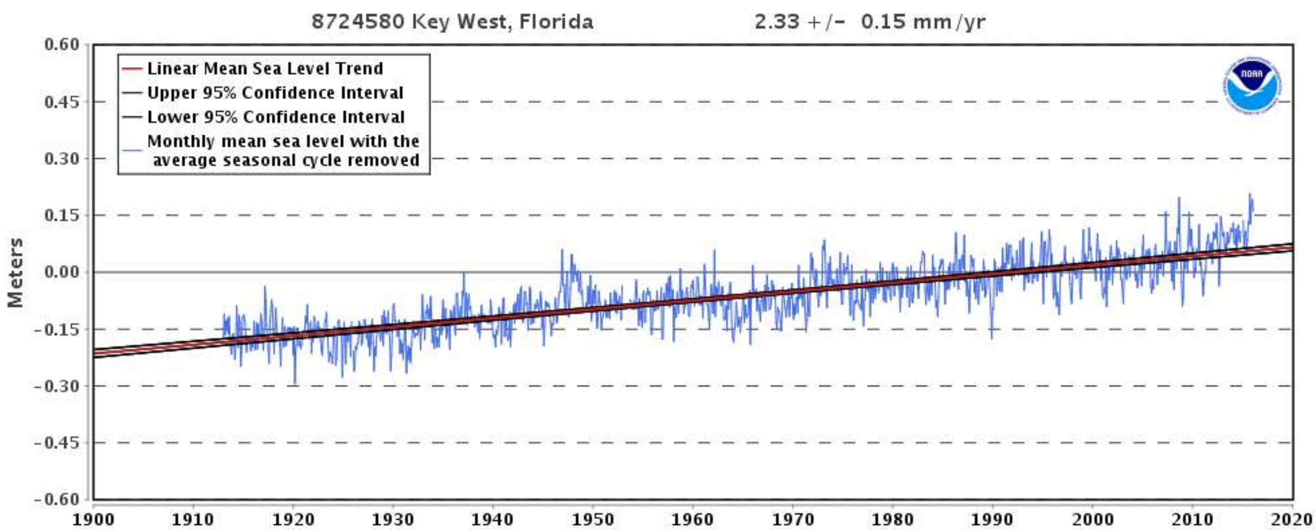
This report also includes a review of on-going efforts to mitigate the risks of flooding and saltwater intrusion. While these risks are being amplified by sea level rise, many entities including the Miami-Dade County Water and Sewer Department, the Miami-Dade Department of Regulatory and Economic Resources' Water Management Division, and the South Florida Water Management District have been monitoring these risks for years. The impact of sea level rise on these risks is an active area of study; however, the available information including the Compact's sea level rise projection, is being incorporated into on-going programs. Sea level rise has amplified the need to evaluate the effectiveness of specific infrastructure and general strategies. Re-evaluating these complex water management systems and evaluating the appropriate adaptation measures for different components of the system is underway, but will take years to fully complete. The process could be expedited with additional funding or it could be accelerated by prioritizing investments in known mitigation needs. For example, there are more than 1,000 projects that are part of the Local Mitigation Strategy that could reduce the Community's vulnerability to known hazards in the short term and the vulnerabilities to longer-term changes.

This report also includes potential funding mechanisms for adaptation measures, details research gaps and next steps. Overall the report provides a snapshot of the extensive work taking place to better understand the impact of sea level rise on flooding and saltwater intrusion. Given the breadth of this work it is only possible to provide a summary, however, more information can easily be provided by the Office of Resilience or the leading institution.

Sea Level Rise- What can be Expected

Since reliable record keeping began over 100 years ago at the tide gauge in Key West, the average sea level has risen approximately 228 millimeters (9 inches) (Figure 1). This means that sea levels have been increasing by approximately 2.33 (+/- 0.15) millimeters per year in the past century. This is slightly higher than the global average rise of 0.17-0.21 meters (or 6.69-8.27 inches) over the same period. The rise in average global average sea levels has been primarily due to thermal expansion (as warmer water occupies more volume) and to melting land-based ice from glaciers and ice sheets. Over the next century the rate of sea level rise is very likely to accelerate due to increased melting from land-based ice sheets, in particular Greenland, and continued thermal expansion.[1]

Figure 1: Sea level rise records from tide gauge data in Key West, Florida



Source: National Oceanographic and Atmospheric Administration

Recognizing the need for clear, consistent, and local information about future sea level rise projections, The Compact developed the, "Unified Sea Level Rise Projection for Southeast Florida".[2] The original projection was updated in 2015 by a panel of local scientists using the most recent and best available data.

The projection (Figure 2) describes the sea level rise expected compared to 1992 levels. From that starting point, the region can expect to see average sea levels 6 to 10 inches higher by 2030, 14 to 34 inches higher by 2060, and 31 to 81 inches higher by 2100. There is a more certain estimate for near-term changes and a greater uncertainty surrounding water levels at the end of this century. According to the Work Group that developed the projection, there is a wider

[1] For a more detailed review of the causes and contributions to changing sea levels see the IPCC's Fifth Assessment Report Chapter 12 "Sea Level Change" available at http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf

[2] Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact) October 2015. *Unified Sea Level Rise Projection For Southeast Florida*. A document prepared for the Southeast Florida Regional Climate Change Compact Steering Committee

range of future projections due to the uncertainty around "future greenhouse gas emissions and their geophysical effects, the incomplete quantitative understanding of all geophysical processes affecting the rate of sea level rise in climate models and current limitations of climate models to predict the future."[3]

Figure 2: Unified sea level rise projection for Southeast Florida

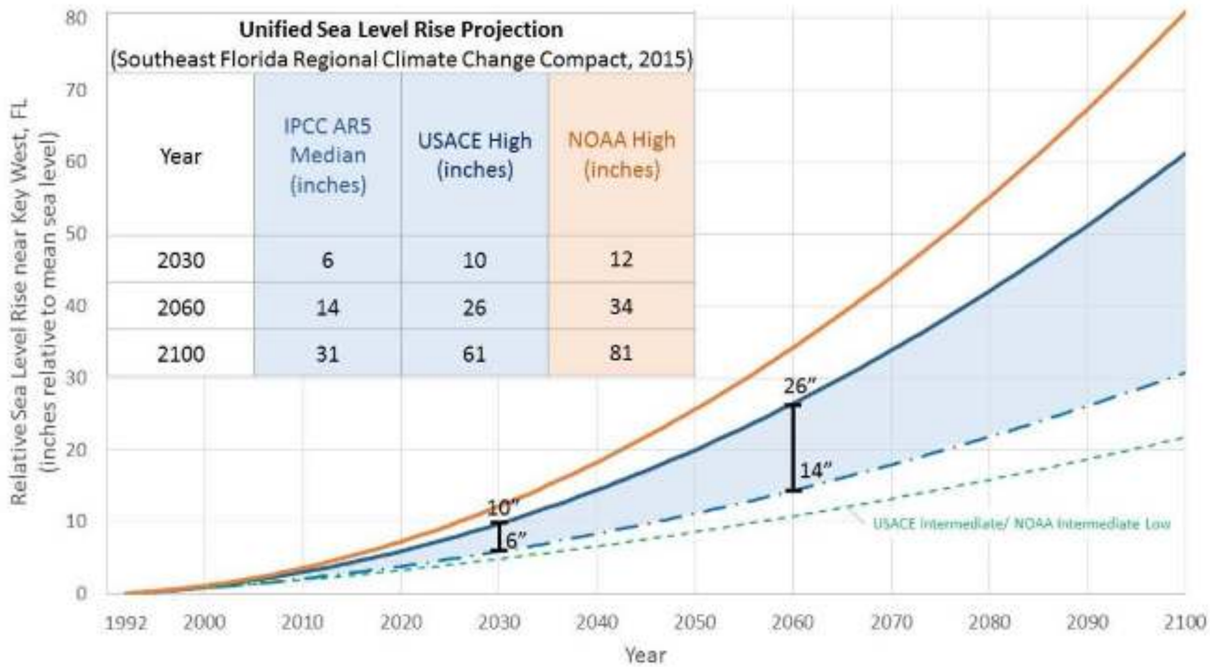


Figure 1: Unified Sea Level Rise Projection. These projections are referenced to mean sea level at the Key West tide gauge. The projection includes three global curves adapted for regional application: the median of the IPCC AR5 RCP8.5 scenario as the lowest boundary (blue dashed curve), the USACE High curve as the upper boundary for the short term for use until 2060 (solid blue line), and the NOAA High curve as the uppermost boundary for medium and long term use (orange solid curve). The incorporated table lists the projection values at years 2030, 2060 and 2100. The USACE Intermediate or NOAA Intermediate Low curve is displayed on the figure for reference (green dashed curve). This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.

Source: Southeast Florida Regional Climate Change Compact

Due to the range of potential changes, the Work Group recommended including multiple sea level rise "curves". This was intended to give decision-makers flexibility to tailor information to suit different purposes. The lower curve could be used when designing projects that are low-risk, have a short design life, or low replacement costs. For example, this estimate may be appropriate when designing a surface parking lot or park gazebo that is intended to last for 20-30 years. The highest curve, or most conservative estimate, would be a more appropriate estimate to use for projects such as a new substation, a major evacuation route, or a hospital. The scientific members of the workgroup recommended using the shaded blue zone for most projects with a short planning horizon. This shaded area "reflects what the Work Group projects will be the most likely range of sea level rise for the remainder of the 21st Century."

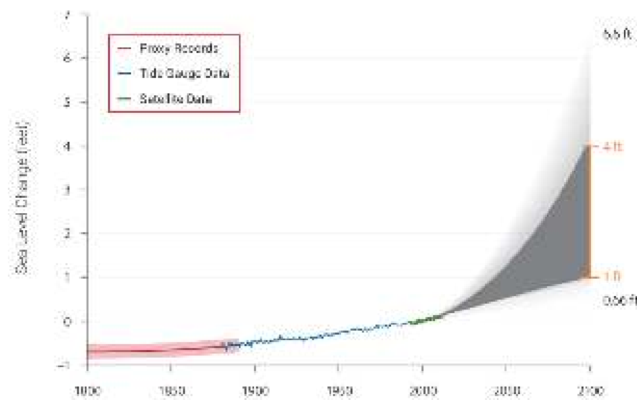
The projections developed by the Compact are most appropriate for use in local planning efforts because they incorporate local variables such as land subsidence, changing ocean

[3] Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact) October 2015. *Unified Sea Level Rise Projection For Southeast Florida*. A document prepared for the Southeast Florida Regional Climate Change Compact Steering Committee. p. 1

currents, and gravitational changes due to mass redistribution. However, for individuals interested in staying current on how global sea levels are changing there are a number of useful sources for general information:

- **The National Climate Assessment** report summarizes the impacts of climate change on the United States, now and in the future.[4] A team of more than 300 experts created the report. An entire chapter is dedicated to sea level rise (Figure 3).

Figure 3: National Climate Assessment's information on sea level rise

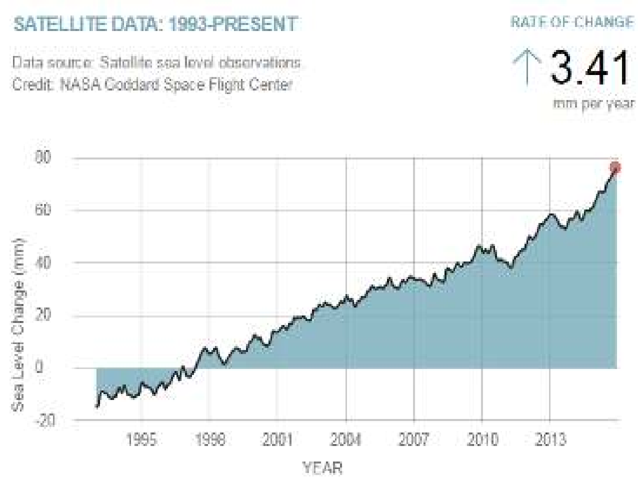


Source: National Climate Assessment

- **National Aeronautics and Space Administration's Global Climate Change** project maintains very up-to-date estimates of the rate of sea level rise based on satellite observations and tide gauge records (Figure 4).[5]

- **The Intergovernmental Panel on Climate Change** provides an up-to-date view of the current state of scientific knowledge relevant to climate change.[6] The most recent report, the Fifth Assessment Report, includes several chapters focused on sea level rise. This report includes very detailed information about the contributing sources to sea level change including warming oceans, melting ice sheets, melting glaciers, and others.

Figure 4: NASA's observations of sea level rise from satellite observations, 1993-present



Source: NASA Goddard Space Flight Center

- **The National Oceanographic and Atmospheric Administration's Tides and Currents** provides near real time observation of local water levels across the country.[7] There are many stations in the region that provide high-quality data including a station on Virginia Key. This can provide valuable information about actual water levels to assist the County in monitoring king tides when the observed levels are higher than what has been predicted as they were this past October (Figure 5). This site also provides updated sea level rise trends based on observation from tide gauges across the country. This information can help verify

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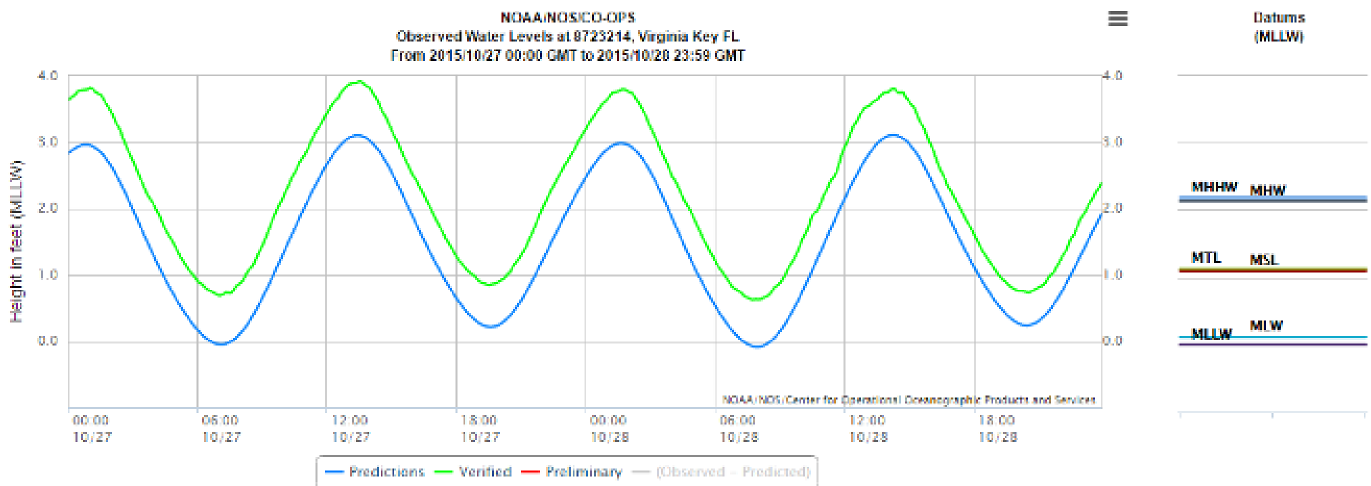
[4] The report is available at http://nca2014.globalchange.gov/
[5] This information is available at http://climate.nasa.gov/vital-signs/sea-level/
[6] Information is available at http://www.ipcc.ch/
[7] Information is available at https://tidesandcurrents.noaa.gov/

sea level rise projections and reveal the level of inter-annual variability that decision makers could plan for.

Figure 5: Observations of water levels at Virginia Key, FL in October 2015



Source: National Oceanographic and Atmospheric Administration/NOS Center for Operational Oceanographic Products and Services

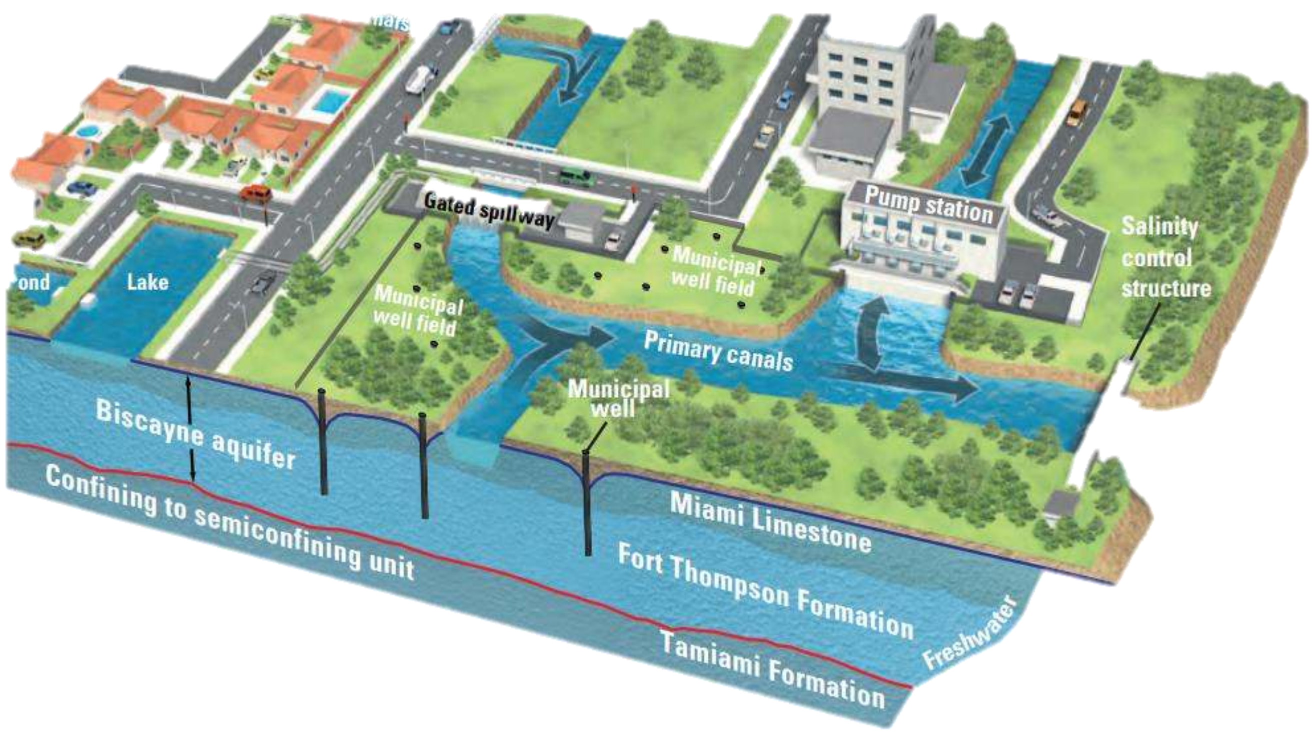
Flooding

Overview of the Risks

As sea levels rise the risks of flooding increases; however, just as there are multiple causes of flooding there are similarly many different impacts from rising sea levels. Higher average water levels can contribute directly to higher high tides and storm surges. This type of flooding can be observed most easily when water "overtops" existing sea walls and floods the urban areas of the County during seasonally higher tides.

Perhaps more importantly, higher sea levels also contribute indirectly to flooding by impacting groundwater levels and the drainage network. As groundwater levels rise, lands that were drained as a result of the canal project may be more difficult to protect from flooding. In certain areas it could become challenging to draw down the groundwater levels without active management and/or pumping. As the groundwater rises it is also possible to lose the storage capacity in the soil that typically helps alleviate flooding after rain events. With some loss of the capacity to infiltrate, water levels may remain higher for longer periods of time, particularly during the rainy season. Higher groundwater and sea levels may also incrementally reduce the effectiveness of the drainage infrastructure meaning that the extent or duration of flooding may

Figure 6: Conceptual diagram showing the components of the surface-water management in Miami-Dade County



Source: Image modified from South Florida Water Management District, 2010 last longer than it has in the past. For example, if French drains or other exfiltration systems become saturated this may compromise their effectiveness.

Sea level rise will likely amplify flooding risk across the region; however, the specific impacts will be highly local. These local difference can be attributed to local differences in topography or soil type, but more importantly due to the extensive manipulation of the local hydrology through management efforts. Across the region water is carefully managed by the South Florida Water Management District through the regional canal network, by the County and the secondary canal network and drainage infrastructure, and by the municipalities and even individual property owners through additional water and stormwater management efforts. These entities carefully monitor and manage water levels to reduce the risk of flooding to the greatest extent permeable. While Southeast Florida is inherently vulnerable to flooding due to its low topography, porous substrate and exposure to tropical storms, there are multiple efforts underway to reduce those risks. Several projects at the regional and local level are underway to ensure that the on-going planning and management efforts are fully incorporating the implications of changing sea levels. There is substantial regional expertise in water management and this will help the region adapt its infrastructure and operations to changing conditions.

The following section will provide additional details on how sea level rise is being studied and incorporated into on-going efforts.

Major On-Going and Planned Studies

The next section details the status of several of the most important studies that are focused on flooding risks in Miami-Dade County. These are a subset of the most important studies.

The South Florida Water Management District Level of Service Studies

One of the core responsibilities of the South Florida Water Management District is to operate and maintain an extensive water management network of canals, levees, water storage areas, pump stations and other water control structures (Figure 6). This system, called the "Central and Southern Florida Project", is one of the largest flood control systems in the world. The South Florida Water Management District is also the lead state agency responsible for restoring America's Everglades, currently the largest environmental project in North America.

Historical data shows that sea levels have risen about four inches in the last 50 years. The Compact's "Unified Sea Level Rise Projection" predicts sea level in South Florida's coastal areas will rise by 6 to 10 inches by 2030, relative to the 1992 mean sea level (Figure 2). Historic sea level rise is already causing challenges to some District operations. In Miami-Dade County some water control gates cannot be opened twice a day at high tide, when the level of the ocean is higher than the level of water in the canals.

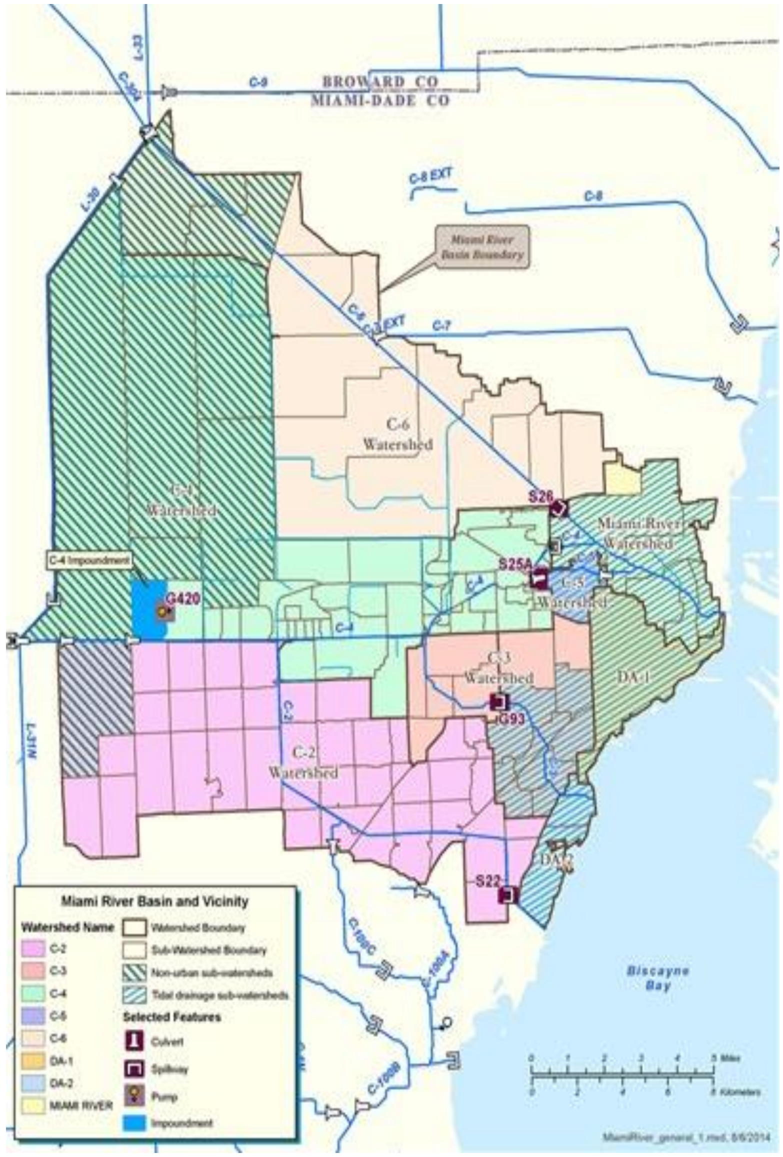
The existing Central and Southern Florida system was built by the federal government in the 1950s with minimal, if any, consideration given to potential future sea level rise. The South Florida Water Management District has worked extensively to coordinate at all levels of government to assist adaption to the impacts of current and projected sea level rise. The South Florida Water Management District has been examining the issue since 2008 to determine the best short-term and long-term strategies. As part of planning efforts, the District has written three white papers and two are currently available on the District's website.[8] Currently, the 2009 white paper on climate and sea level rise is being updated with the most recent information. The South Florida Water Management District has already installed two forward pumps in some of the most vulnerable areas near the Miami International Airport, in coordination with the Federal Emergency Management Agency. The project allows the District to continue draining floodwaters in the near future even as the sea rises. The South Florida Water Management District has also invested in the creation of a reservoir, or impoundment, in the western area of the county (C-4 basin) to reduce flooding in the more urbanized southern and eastern regions, and to facilitate groundwater recharge which can help reduce salt water intrusion.

The South Florida Water Management District has a new program to evaluate the current and future Level of Service for flood protection throughout the 16-county region as a means of

[8] These reports are available at: http://www.sfwmd.gov/portal/pls/portal/portal_apps.repository_lib_pkg.repository_browse?p_keywords=climatechange&p_thumbnails=no

identifying and prioritizing long-term infrastructure needs. Level of Service projects provide a process to establish flood protection thresholds for each basin. These thresholds inform and initiate retrofitting and adaptation efforts that will be implemented in conjunction with the annual structure maintenance program. Results of these studies will be used to identify sea levels at which existing infrastructure can no longer provide flood protection, facilities at risk of being impacted by flooding, and the potential need for improvements to operations, canal conveyance, or primary and secondary drainage facilities.

Figure 7: Miami River basin and vicinity



Source: South Florida Water Management District

The level of service study is a key component of an "adaptive resilience" approach to reducing potential flood risks and damages. Once levels of existing and potential future risks have been defined, the first step is to initiate non-structural and operational changes to reduce the extent and duration of flooding. Next, the District will need to monitor conditions over time and establish thresholds for hydrologic changes that trigger the need for infrastructure replacement. Finally, the District will initiate infrastructure replacement and upgrade strategies based on construction time once conditions are realized and thresholds met.

Despite being inadequate for present conditions, the original water management infrastructure has seen significant improvements to increase stormwater storage, improve drainage of excess surface water into groundwater, reduce groundwater inflow from the Everglades, provide pumping capacity to remove water from developed areas, and increase discharges from coastal structures. Because of all these changes and improvements, current capacity to protect developed areas from flooding and remove excess water has greatly increased; however, the level of flood protection that exists within the system today remains uncertain in the face of increased pressure in the future. As coastal water levels increase in the future, this will result in corresponding increases of upstream water levels within each watershed.

The effects of these changes in water levels on the level of service (or level of flood protection) were first evaluated in a recent pilot study of the C-4 canal watershed in Miami-Dade County. This study assessed the level of flood protection within the watershed to identify risk to existing resources and needs for improvements to primary drainage system operations and infrastructure. The methodology used in this investigation will subsequently be applied to the remaining watersheds in the Miami River system (Figure 7) and to other watersheds throughout the District. This initial study of methods and criteria were based on a simplified hydrologic and hydraulic model and a set of performance measures that were developed for the study. The C-4 canal watershed was selected for this investigation because it has a mixture of residential, commercial, and industrial development, environmentally-sensitive wetlands, a major wellfield used for public water supply, and a long history of water management concerns. This area has seen extensive population growth and changes in land use since the design and construction of the original federal flood control project in the 1950s. Much of the western portion of the watershed has been dredged to create large lakes and rock pits and the rock has been used to provide fill for development. During the same period, sea level has increased approximately six inches, thereby reducing the discharge capacity of the coastal structures.

The South Florida Water Management District Pre-Disaster Mitigation Project

In April 2015, The South Florida Water Management District was awarded a Pre-Disaster Mitigation Competitive Grant from the Federal Emergency Management Agency through the Florida Division of Emergency Management.[9] The study, focused on the C-7, C-8, and C-9 basins in northern Miami-Dade County, seeks to reduce the potential for loss of life and property by developing and implementing a Local Mitigation Strategy to identify hazards and possible mitigation activities. The project includes two elements:

1) a technical assessment of the flood protection level of service for the existing infrastructure under current and future sea level rise scenarios; and
2) a strategic assessment of alternative mitigation strategies which can be incorporated into the Miami-Dade Local Mitigation Strategy.

Major work products expected from this study include:

- Updated Basin Atlases: The South Florida Water Management District will expand the recently completed Miami River Operations Atlas to include Basins 7, 8, and 9. The basin atlas will provide comprehensive descriptions of infrastructure and water management operations and identify emerging issues within each watershed.

[9] Federal Emergency Management Agency Grant Application Number PDMC-PL-04-FL-2014-004

- Assessment of existing level of flood protection: This contract will produce an assessment of the flood protection level of service that exists in Basins 7, 8, and 9 provided by the existing District infrastructure. Current sea level conditions are assumed for this assessment.
- Assessment of 2065 level of flood protection assuming no infrastructure changes: This contract will produce an assessment of the flood protection level of service for three sea level scenarios assuming no changes to the existing water management infrastructure.
- Identification of alternative flood mitigation strategies: Development of up to four alternative flood mitigation strategies will be identified by RAND Corporation working in collaboration with Miami-Dade County.
- Assessment of 2065 level of flood protection for flood mitigation strategies: The modeling tools under this contract will be utilized to evaluate the level of service provided by alternative flood mitigation strategies for three future sea level scenarios.

Collaboration between the South Florida Water Management District and the Netherlands

In April 2014, the South Florida Water Management District established a Memorandum of Agreement with the Ministry of Infrastructure and the Environment of the Netherlands and the Delfland Water Board to work cooperatively and share information, expertise, and strategies on flood control, water supply, spatial development, environmental ecosystem restoration, crisis management, modelling, service level practices, sea level rise, climate adaptation strategies, and salt water intrusion impacts. The Delfland Water Board is the water management authority for part of the Netherlands with expertise in many disciplines. Through this project the District is able to collaborate on various water management topics of mutual interest including saltwater intrusion, sea level rise, climate change, and emergency management. Because there are many similarities in the water management systems of South Florida and the Netherlands, these organizations agreed to work towards an annually updated comprehensive thematic work program on information and best practices exchange. The additional expertise of Dutch partners will contribute to the regional efforts of the District, the U.S. Geological Survey, Miami-Dade County and the Compact to better understand potential flood damage and saltwater intrusion and begin to develop adaptation strategies.

Additionally, the District participated in a project led by Deltares, a world-renowned research institute based in the Netherlands, to conduct a research effort addressing flood and drought risk management in Miami-Dade County. The ensuing project: "Flood and Drought Risk Management Under Climate Change: Methods for Strategy Evaluation and Cost Optimization," was funded by the National Oceanographic and Atmospheric Administration. This effort, nearing its completion, will use level of service modeling to determine hydrologic and economic flood damages in the C-4 basin within the County under future sea level and storm scenarios. The study aims to accomplish the following objectives:

- Further analyze the impacts of climate change on the occurrence of floods and droughts in the District;

- Gain more insight into the intended and unintended effects of flood and drought risk reduction measures;
- Develop and apply a method to evaluate the capability of the water management system to effectively address extreme events (floods and droughts), and use the outcomes to assess comprehensive adaptation strategies aimed at flood and drought risk reduction under climate change;
- Apply an economic optimization method for determining the optimal investment in flood risk reduction with the intention to have the project document the process of adapting the method from the Netherlands to Florida, and identifying what is required to apply the optimization method to other regions;
- Assess and communicate the usefulness of applying this optimization method for decision making in water resource management; and
- Publish the general outcomes on the methods and the specific outcomes for the case study area, through two stakeholder and expert workshops and scientific (journal) publications.

The report will be presented to the stakeholders in the region during the summer of 2016.

U.S. Geological Survey- Surface Groundwater Interface Model

To evaluate the effects of pumping groundwater on canal leakage and regional groundwater flow, the U.S. Geological Survey developed and calibrated a coupled surface-water/groundwater model of the urban areas of Miami-Dade County.[10] The development of this model is an important component to understanding the effects of sea level rise on both the risks of flooding and saltwater intrusion. The model is designed to simulate surface-water stage (water levels) and discharge (water releases) in the managed canal system and dynamic canal leakage to the Biscayne Aquifer, in addition to seepage to the canal from the aquifer. The model was developed using the U.S. Geological Survey's MODFLOW–NWT.[11]

The model represents the complexities of the interconnected surface-water and groundwater systems that affect how the systems respond to pumping groundwater, sea-level rise, and other hydrologic stresses. The model also quantifies the relative effects of pumping groundwater and sea-level rise on the surface-water and groundwater systems. Supporting data and other information is available at the U.S. Geological Survey's publication library. [12]

The study found that analytical and simulated water budgets for the period from 1996 through 2010 indicated that most of the water discharging through the salinity control structures is

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[10] Hughes, Joseph D., and White, Jeremy T., 2014, Hydrologic conditions in urban Miami-Dade County, Florida, and the effect of groundwater pumpage and increased sea level on canal leakage and regional groundwater flow: Scientific Investigations Report.

[11] MODFLOW-NWT is a standalone program that is intended for solving problems involving drying and rewetting nonlinearities of the unconfined groundwater-flow equation.

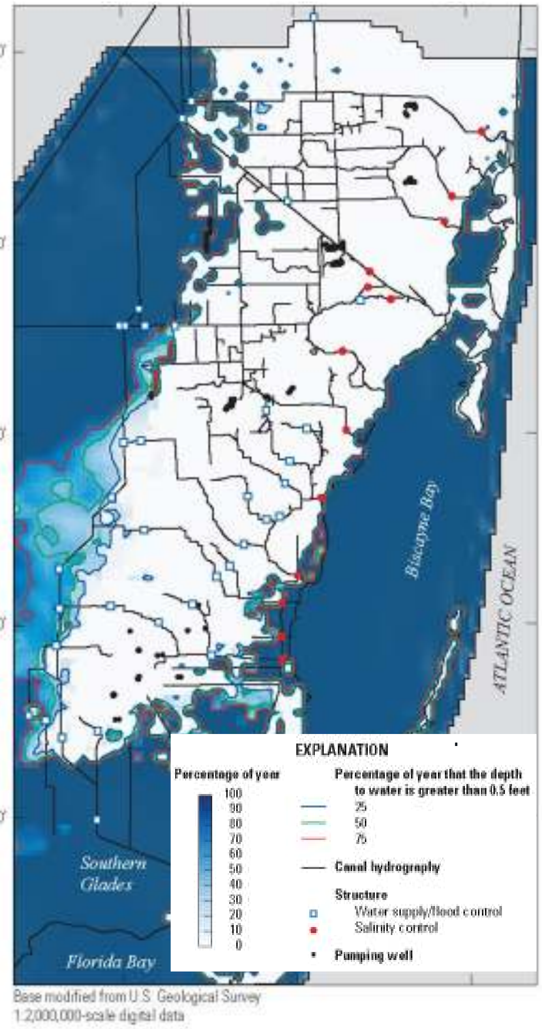
[12] Hughes, Joseph D., and White, Jeremy T., 2014, Hydrologic conditions in urban Miami-Dade County, Florida, and the effect of groundwater pumpage and increased sea level on canal leakage and regional groundwater flow: Scientific Investigations Report. http://pubs.usgs.gov/sir/2014/5162

derived from within the urban parts of the study area than from upstream releases, and that, on average, the canals drain more water from the Biscayne Aquifer than they supply to the aquifer by downward leakage.

Increased sea level caused higher water-table elevations in urban areas and decreased hydraulic gradients across the system. The largest increases in water-table elevations occurred seaward of the salinity control structures. Higher sea levels increased the extent of flood-prone areas and the percentage of time water-table elevations were less than 0.5 foot below land surface (Figure 8). The water table was less than 0.5 feet below land surface in a total of 5,672 onshore model cells (or approximately 547 square miles) in the increased sea-level scenario during the 30th year of the scenario simulation period (Figure 8). The 30th year of the simulation would represent the possible conditions in 2040. Increased sea level resulted in a 10.32 square mile increase in flood-prone areas and a 4-percent increase in the percentage of the time flood-prone areas have a water-table depth less than 0.5 feet below land surface during the 30 year simulation.

Increased sea level also resulted in landward migration of the freshwater-seawater interface. These findings are described later in the report.

Figure 8: Percentage of time water-table elevations are less than 0.5 ft. below land surface in the 30th year of the scenario simulation period for increased sea-level and groundwater pumpage conditions



Source: U.S. Geological Survey

U.S. Geological Survey Mapping of Water Levels and Trends in Miami-Dade County

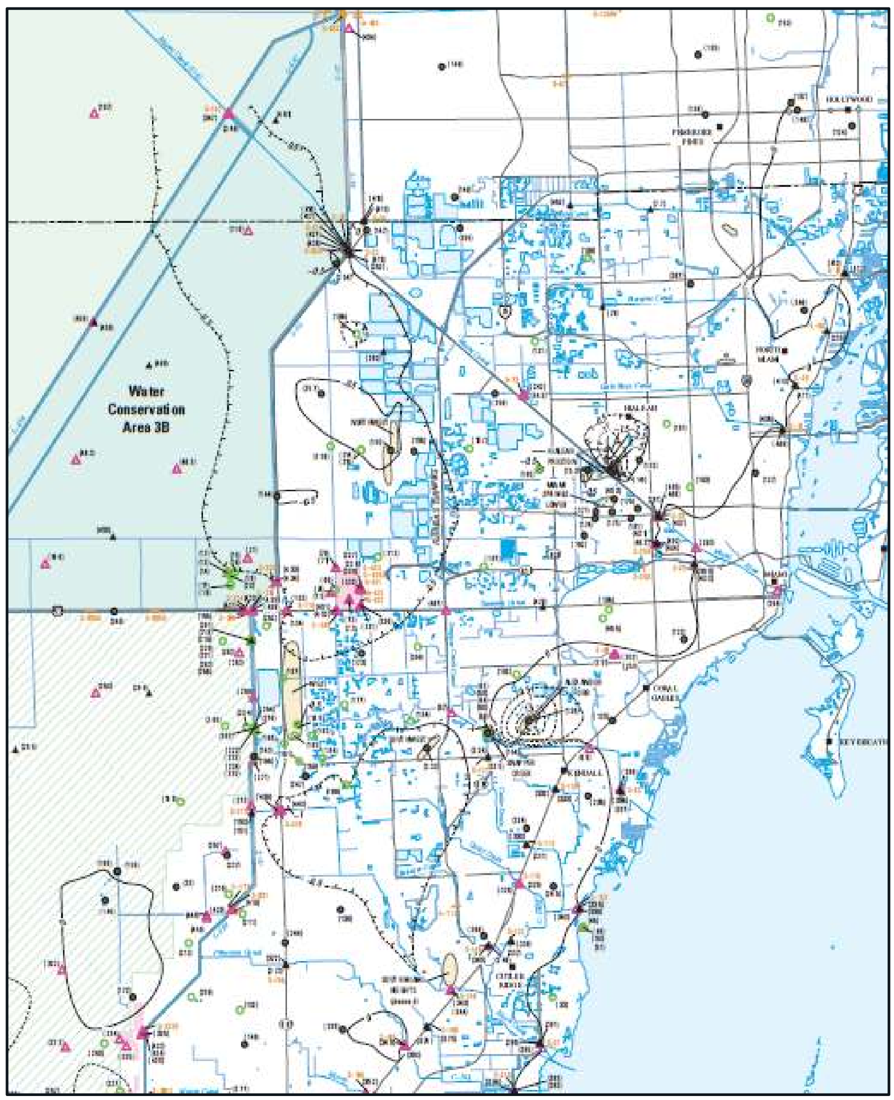
Statistical analyses and maps representing mean, high, and low water-level conditions in the surface water and groundwater of Miami-Dade County were made by the U.S. Geological Survey in cooperation with the Miami-Dade County Department of Regulatory and Economic Resources to help inform decisions necessary for urban planning and development.[13] Sixteen maps were created to show contours of:

[13] Prinos, S.T., and Dixon, J.F., 2016, Data, Statistics, and Geographic Information System Files, Pertaining to Mapping of Water Levels in the Biscayne Aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000-2009 - Scientific data associated with USGS SIR 2015-5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

(1) the mean of daily water levels at each site during October and May for the 2000-2009 water years;
(2) the 25th, 50th, and 75th percentiles of the daily water levels at each site during October, May, and all months during the period of 2000-2009; and
(3) the differences between mean October and May water levels, as well as the differences in the percentiles of water levels for all months, for the periods of 1990-1999 and 2000-2009.

These maps and statistics provide a generalized understanding of the variations of water levels in the aquifer, rather than a survey of concurrent water levels. Water-level measurements from 473 sites in Miami-Dade County and surrounding counties were analyzed to generate statistical analyses. The study monitored surface-water levels in canals and wetland areas and groundwater levels in the Biscayne Aquifer. Maps were created by importing site coordinates, summary water-level statistics, and completeness of record statistics into a geographic information system and interpolating between water levels at monitoring sites in the canals and water levels along the coastline (Figure 9).

Figure 9: Snapshot of groundwater level change



Source: U.S. Geological Survey, 2016

Although the ability of the maps to depict differences in water levels between 1990-1999 and 2000-2009 was limited by missing data, results indicate that near the coast, water levels were generally higher in May during the 2000-2009 study period than during 1990-1999 period and that inland water levels were generally lower during the 2000-2009 period than the 1990-1999 period. Generally, the 25th, 50th, and 75th percentiles of water levels from all months were also higher near the coast and lower inland during later period as compared to the earlier period. Mean October water levels during 2000-2009 were generally higher than levels during 1990-1999 in much of western Miami-Dade County but were lower in a large part of eastern Miami-Dade County. The report notes that, "these increases could be related, at least in part, to the effects of sea-level rise."

This study will inform the review of the County Flood Criteria. Where conditions have changed substantially from when the criteria were last updated in 1990, the criteria may need to be updated to reflect current conditions. The changes in conditions have been most pronounced in coastal areas. The data and maps generated by this study are available at the U.S. Geological Survey's publication library.[14] The study also provides information on how the monitoring network could be improved.

RAND Corporation Study

The RAND Corporation is working with Miami-Dade County and the Southeast Florida Regional Climate Change Compact on a MacArthur Foundation funded project titled "Adaptation Planning for Sea Level Rise and Climate Change in Southeast Florida: Understanding the Interactions of New Infrastructure, Land Use Changes, and Water Management." The project will complement the very strong leadership and technical base that already has been established in the Southeastern Florida region and will focus on Miami-Dade and Broward Counties. The project's over-arching goal is to help improve the region's capacity to adapt to changing climate and development conditions with minimal economic and social disruption. Current planning methods are challenged by the difficulty of incorporating into the decision-making process the direct and indirect changes associated with new infrastructure. Similarly, it is difficult to incorporate these considerations during permitting and development decisions for individual projects. The project will develop an integrated system of simulation models for the region that will provide a transparent, interactive tool, and a level analytical playing field to assess potential interactions among water management, transportation, and land use decisions under a range of scenarios.

The project goal is to help decision makers and stakeholders in the region gain a better understanding of the costs and benefits of both action and inaction across a wide range of scenarios. In collaboration with technical experts and partners within the region, RAND's engagement will help support: rigorous evaluation of vulnerabilities of land-based assets, application of models to support economic loss and benefit-cost evaluations, assessment of alternative funding and financing strategies, and identification of preferred and phased risk-reduction strategies. The project will also seek to test several hypotheses including the following three suppositions:

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[14] Prinos, S.T., and Dixon, J.F., 2016, Data, Statistics, and Geographic Information System Files, Pertaining to Mapping of Water Levels in the Biscayne Aquifer, Water Conservation Areas, and Everglades National Park, Miami-Dade County, Florida, 2000-2009 - Scientific data associated with USGS SIR 2015-5005: U.S. Geological Survey Data Release, http://dx.doi.org/10.5066/F7M61H9W.

(1) more compact development will reduce the costs of providing selected public services,

(2) current land use plans will raise the costs and increase the challenge of water management in the region relative to more coordinated efforts,

(3) uncoordinated local land use and water management plans (e.g. individual county or city permitting of projects without consideration of externalities imposed on neighboring jurisdictions) will have negative economic consequences at the regional scale. After initial discussions with the District, Miami-Dade and Broward counties, the RAND corporation staff has decided to use existing models developed by the District and the counties to investigate both flooding and water supply performance under future SLR and climate scenarios.

Federal Emergency Management Agency's Revision of Miami-Dade's Flood Insurance Rate Maps

The Federal Emergency Management Agency's National Flood Insurance Program, which provides the majority of flood insurance coverage for Miami-Dade County, relies upon Flood Insurance Rate Maps to set the price of insurance premiums and purchase requirements. The Flood Insurance Rate Maps are the official maps of a community which delineate the special hazard areas, based on the best available technical data.

The last Miami-Dade County Flood Insurance Rate Map was updated in 2009 and included a 100-year catastrophic rain event and storm surge under current conditions.

The Federal Emergency Management Agency is currently revising the Flood Insurance Rate Maps for other parts of the county. The County was awarded a $1.25 million grant in 2015 to continue working with The Federal Emergency Management Agency as a 'technical partner' in the development of the next update of the County's Flood Insurance Rate maps. These maps are anticipated to become effective in the next three to five years. The County's Stormwater Master Plan mapping and modeling data is used by The Federal Emergency Management Agency in their map updates. The maps are officially adopted by local communities and are legally part of the building code requirements to protect new construction and substantial improvements of private and public facilities. Insurance coverage and claims also rely on the official Flood Insurance Rate maps.

In addition to the datum change, The Federal Emergency Management Agency is also revising the Flood Insurance Rate maps to reflect updated hydrologic conditions and historical sea level rise resulting from increasing average tide data and historic surge events. This mapping does not incorporate future sea level rise projections. This is being performed in two separate map revision cycles as described below.

- Riverine Modeling Update: Draft maps will be released for public comment in 2019. The new maps will take effect (contingent upon public review process) one year later.
- Coastal Modeling Update: These maps are expected to consider historical tide gauge and surge data with possible flood elevation increases. Final changes in the base flood elevation

will be determined at the time of map release. In 2019 draft maps will be released for public comment. New maps are expected to take effect (contingent upon public review process) one year later.

Miami-Dade Interagency Coastal Flood Risk Reduction Study with the U.S. Army Corps of Engineers

To address the impacts of sea level rise, this study will utilize modeling tools to analyze the effectiveness of natural barriers and non-structural flood protection measures along the coastline, develop operating rules for the pre-storm operation of the regional water management system, and develop and implement a Decision Support System assisting in pre-storm operation decisions to reduce flood risk in communities along the coastline. The study is being conducted in partnership with Miami-Dade County, The U.S. Army Corps of Engineers, The U.S. Department of the Interior, The U.S. Geological Survey, the South Florida Water Management District, The Nature Conservancy, and Florida Atlantic University. This diverse group is studying and developing adaptive strategies to address flood damage reduction and saltwater intrusion associated with sea level rise.

This study will use existing numerical modeling tools, including the hydrodynamic model ADCIRC, to compute the surge generated by historic and synthetic storm scenarios along Miami-Dade's coastline. Outputs will be used to determine the effectiveness of non-structural flood control measures, such as dune restoration and/or enhancement, wetland or urban forest vegetation management, and/or land use changes, to protect existing infrastructure and structures from damaging storm surges and reduce coastal flooding. This study will also develop a Decision Support System tool to help officials prepare the region for pre-storm operations by providing probabilistic projections of storm surge scenarios and hydrologic responses of levels in canals). If implemented appropriately, those nonstructural measures that prove effective in this modeling exercise can result in decreased damages and reduce potential loss of life when hazardous weather conditions occur (Figure 10).

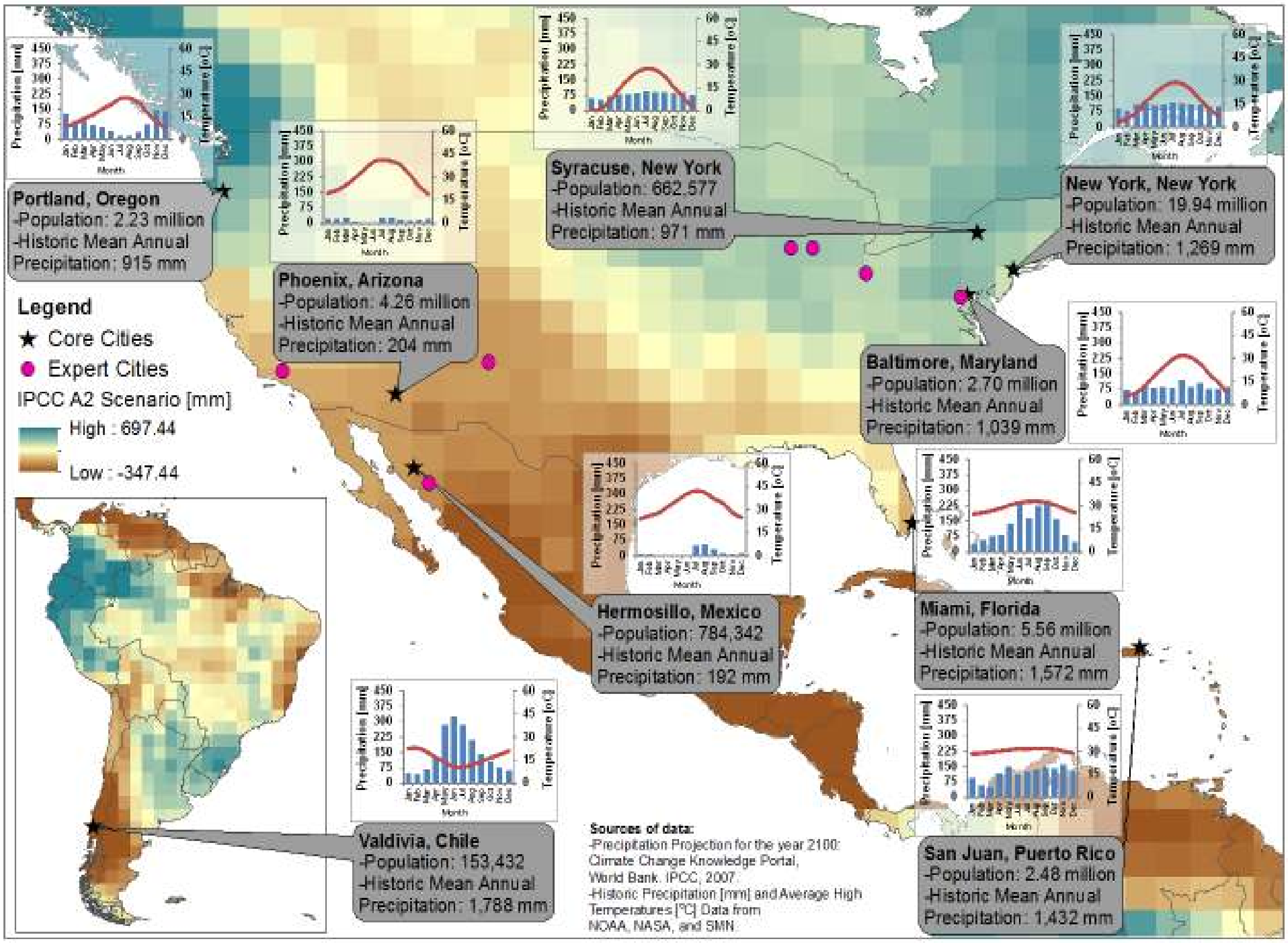
Figure 10: Dunes provide flood protection

Source: Miami-Dade County

Sustainability Research Network- Urban Resilience to Extreme

The Urban Resilience to Extremes Sustainability Research Network focuses on integrating social, ecological, and technical systems to devise, analyze, and support urban infrastructure decisions in the face of climatic uncertainty. Climate change is widely considered to be one of the biggest challenges to global sustainability. According to the Intergovernmental Panel on Climate Change, extreme events are likely to increase in frequency. Weather-related extreme

Figure 11: Urban Resilience Sustainability Research Network Cities



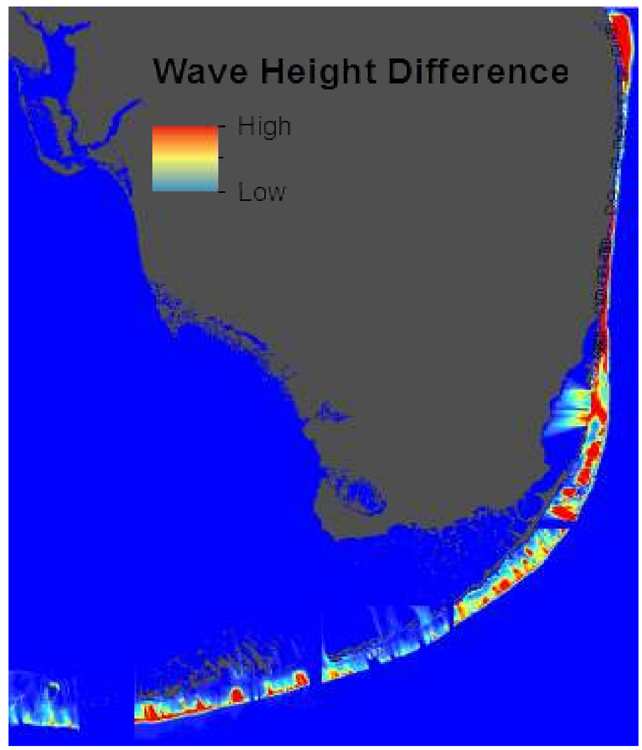
Source: The Urban Resilience to Extremes Sustainability Research Network

events are the most immediate way that people experience climate change. Urban areas are particularly vulnerable to such events, given their location, concentration of people, and increasingly complex and interdependent infrastructures.

The current infrastructure of urban areas is aging and proving inadequate for protecting city populations. Infrastructure must be resilient, provide ecosystem services, improve social wellbeing, and exploit new technologies in ways that benefit all segments of urban populations and are appropriate to each particular urban context. To meet these challenges, the Urban Resilience to Extremes project envisions a new framework aimed at integrating social-ecological-technical/infrastructural system dimensions to conceptualize and analyze infrastructure decisions in a more holistic way and to work directly with cities and practitioners to envision and implement transitions to more resilient and sustainable infrastructure. In addition to their collaboration with researchers in Miami at Florida International University, and practitioner group comprised of city of Miami Beach staff and other local stakeholders, as part of the Miami team, other project cities include Baltimore, Maryland, Hermosillo, Mexico, New York, Phoenix, Arizona, Portland, Oregon, San Juan, Puerto Rico, Syracuse, New York, and Valdivia, Chile (Figure 11).

Southeast Florida Regional Climate Change Compact's Shoreline Resilience Working Group- Assessment of The Potential for Nature-Based Coastal Defenses in Southeast Florida

Figure 12: Analysis of the benefits of coral reefs in reducing wave heights during a strong storm



Source: The Nature Conservancy

This assessment of the potential for nature-based coastal defenses in Southeast Florida is aimed at quantifying the effectiveness of natural systems at protecting shorelines and coastal regions against the impacts of coastal hazards. Results from this effort will provide valuable information about the efficacy of different nature-based coastal defenses strategies in the region to protect against erosion and/or flooding. The anticipated results will also help better prioritize the location and craft the design components of nature-based solutions to protect against the impacts of coastal hazards.[15] This research project, which began in 2014 and is set to conclude in 2016, has created a clearinghouse for best practices and technical information about the effectiveness of nature-based coastal defense structures, compiled a list of completed projects, and identified the suitability of shorelines for various project types that will help protect the region. To date the project has catalogued opportunities to protect or restore coral reefs and nearshore hard bottom ecosystems, to close gaps in existing sand dunes, to protect or restore coastal wetlands, and to create living shorelines that combine natural and constructed element in most of Southeast Florida.

The project's scientists completed their initial suitability analysis and have identified suitable sites for nature-based coastal defense based on ecological and physical conditions. For example,

[15] More information about the Shoreline Resilience Working Group is available at www.nature.org/southeastfloridareport and more information about the potential for nature-based coastal defenses is available at http://coastalresilience.org/

the analysis has revealed areas where coral reefs have the potential to significantly reduce wave heights during a storm (red areas in Figure 12). The analysis also identified 89 potential project sites for dune restoration in Miami-Dade County. Finally, the project's team completed a living shoreline suitability analysis for most of the inland waters and portions of the exposed shorelines of Palm Beach, Broward and Miami-Dade Counties.

The South Florida Water, Sustainability, and Climate Project

Every day in South Florida about 7.7 million people, companies, and farms use more than 3 billion gallons of water. Different water use optimization strategies are needed when considering expected population growth and impacts of climate change. In order to investigate various strategies, a 5-year $5 million dollar project focused on South Florida was initiated in 2013. Project researchers are seeking to develop hydrological and economic criteria for evaluating current and future water use and provide new insights into the value of water resources. With this knowledge, the trade-offs decision-makers face under various climate change, economic, population, and sea level rise scenarios can be evaluated.

The South Florida Water, Sustainability, and Climate Project is supported by the National Science Foundation's Water, Sustainability, and Climate Program, with joint support from the United States Department of Agriculture's National Institute of Food and Agriculture. The full research proposal title is "WSC-Category 2 Collaborative: Robust Decision-making for South Florida Water Resources by Ecosystem Service Valuation, Hydro-economic Optimization, and Conflict Resolution Modeling." The project's objectives are to:

(1) Develop a hydro-economic model for South Florida that optimizes water allocations based on the economic value of water;
(2) Develop new information on the economic value of ecosystem services to be incorporated into model formulations;
(3) Test management schemes designed to increase the resilience of water resources to climate variability, climate change, and SLR;
(4) Engage stakeholders to improve understanding of the cognitive and perceptual biases in risk management and decision-making; and
(5) Develop recommendations for adaptive water management that optimize economic and ecological productivity and foster sustained public support.

Social and behavioral scientists will also investigate how individuals' perceptions of risks to the water supply differ, and how these differences influence decisions made under uncertain conditions, such as those faced by South Floridians due to sea level rise. Finally, with agency and stakeholder involvement, the project will develop recommendations for adaptive water management policies. The project team is an interdisciplinary group of hydrologists, ecologists, economists, and social scientists from six Florida universities (Florida International University, Florida State University, University of Miami, University of Florida, South Florida and Central Florida University), Pennsylvania State University, the Universities of Pennsylvania and Hawaii, Michigan Technological University, Geodesign Technologies, the South Florida Water Management District, and the United States Geological Survey.

Storm Surge Modeling Efforts

Storm surge is the abnormal rise of water created by a strong storm.[16] In South Florida a significant storm surge is typically associated with a tropical storm. The storm surge results in temporarily higher water levels that recede after the storm has passed. Changing average water levels will have a non-linear impact on how storm surge affects Miami-Dade County. In very general terms, however, higher average water levels are likely to contribute to higher storm surges and potential wider area of land inundated by such a surge. As illustrated in the following studies, however, the precise changes will be much more complex.

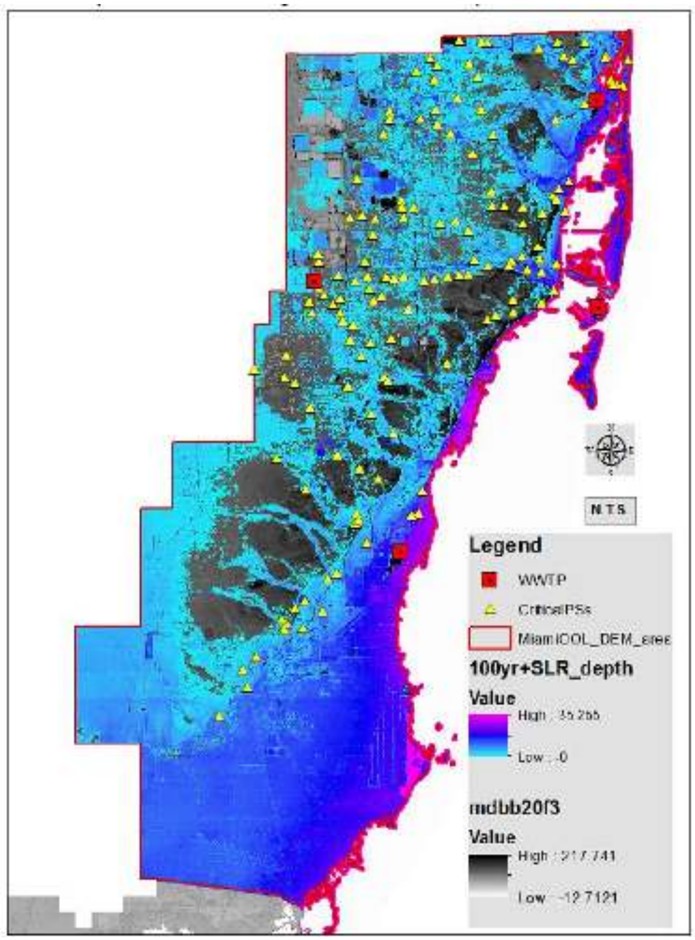
A number of different studies have been completed or are in process to understand and map the potential impacts of storm surges when accounting for higher future sea levels in Miami-Dade County. Though this report only summarizes them briefly, these studies offer key inputs to other efforts such as the County's vulnerability assessments, emergency management planning, and transportation studies, among others.

Miami-Dade Water and Sewer Department Facility Hardening Plan

This study applied the projections of changes in sea level rise and precipitation to estimate the resulting surge elevations and inland flood maps for specified climate events, which was used by other components of the Water and Sewer Department program to develop wastewater facility hardening plans (Figure 13). The purpose of the surge modeling is to provide surge boundary conditions to drive the flood model to assess flood propagation inland. The surge model, which couples waves, tides, and meteorologically induced surges, covers the entire North Atlantic, stretching from Newfoundland to South America. The mesh resolution is refined progressively landward to resolve bathymetric details in the project vicinity.

Based on a review of hurricane climatology of the Southeast coast of Florida, where the project site was located, Hurricane Andrew generated the largest surge event along

Figure 13: Storm surge estimates incorporating sea level



Source: CH2MHill

[16] For more information on storm surges see National Oceanographic and Atmospheric Administration's National Hurricane Center's webpage on the topic, available at http://www.nhc.noaa.gov/surge/

the project coastline and was selected as the base hurricane set. A strategy of parallel shifts in the historical track in the north-south direction was adopted to derive the largest surge elevation at each of Water and Sewer Department's three wastewater treatment plants. The peak surge elevations extracted from the Federal Emergency Management Agency's transects were combined by selecting the maximum of the three track-based results. The composite modeled peak surge elevations were pegged to The Federal Emergency Management Agency's stillwater elevations to derive the 100 year surge elevations under specified sea level rise scenarios using linear scaling.

Two sea level rise projections of 1.23 meters and 0.93 meters in the year 2075 were adopted based on guidance from the Compact's Sea Level Rise Workgroup. The results of the 1.23 meter scenario were applied as surge boundary conditions in flood modeling while the results of the 0.93 meter scenario were used to support the use of linear scaling of the 1.23 meter scenario results for other SLR projections as a first order estimate.

Assessing the Vulnerability of South Florida to Increased Storm Surge from Sea Level Rise

Another important study of the implications on sea level rise on storm surge has been completed by Professor Brian J. Soden from the Rosenstiel School for Marine and Atmospheric Science at the University of Miami.

Typically, in instances where sea level rise is of concern, the commonly used approach for determining inundation relies on computing mean high-water shorelines relative to contours of topography, given a constant increase in eustatic (uniform, global, high-pass filtered) sea level rise, overlaid on a large-scale geographical background map. These analyses neither take into account the impact from storm surge, nor variations in water levels due to complex hydrodynamic effects. Coastal ocean models can more accurately simulate realistic water levels because their sophisticated numerical algorithms account for nonlinear interactions between wind/tidal forcing, bathymetric depth, land cover, and intricacies in coastline geometry. These modeling systems can more precisely identify threats from SLR, quantify their uncertainty, and provide vital information for planning and building the sustainable, hazard-resilient coastal communities of the future.

In this study, Professor Soden used the National Weather Service's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model to simulate the impact of projected changes in sea level on inundation in South Florida. Forty-six historical tropical cyclones between the years 1900-2010 that made landfall in South Florida and 26 other storms that skirted the Florida coast were selected for simulating the maximum surface water elevation. The input wind parameters for SLOSH were extracted from the National Hurricane Center best track data for each storm. For the sea level rise simulations, initial pre-storm water levels were set to values of 0, 0.5, 1, 2, and 3 feet to simulate current and future climate scenarios projected out to the year 2100 for South Florida by the U.S. Army Corps of Engineers.[17]

The SLOSH modeling system provides 37 localized grid basins (12 operational) for the state of Florida. The grid basin for each storm was chosen to maximize horizontal resolution and areal coverage at the landfall point and the storm tracks were adjusted in time to guarantee at least 48 hours of offshore, pre-landfall and 24 hours of inland, post-landfall wind forcing. This study presents results from 3 grid basins in South Florida, centered in Miami, the Florida Keys, and Palm Beach.

Comparison of Three Methods for Estimating the Sea Level Rise Effect on Storm Surge Flooding

Another very important report was published by Florida International University Professor, Keqi Zhang, and colleagues.[18] This study analyzed the impact of sea level rise on storm surge using several methods, including the Coastal Estuarine Storm Tide (CEST) model. Two linear methods, including the simple linear addition and linear addition by expansion, and numerical simulations, were employed to estimate storm surges and associated flooding caused by Hurricane Andrew for scenarios of sea level rise from 0.15 m to 1.05, with an interval of 0.15 m. The interaction between storm surge and sea level rise is almost linear at the open Atlantic Ocean outside Biscayne Bay, with slight reduction in peak storm surge heights as sea level rises. The nonlinear interaction between storm surges and sea level rise is weak in Biscayne Bay, leading to small differences in peak storm surge heights estimated by three methods. Therefore, it is appropriate to estimate elevated storm surges caused by sea level rise in these areas by adding the sea level rise magnitude to storm surge heights. However, the magnitude and extent of inundation at the mainland area by Biscayne Bay, estimated by numerical simulations are, respectively, 22–24 % and 16–30 % larger on average than those generated by the linear addition by expansion and the simple linear addition methods. This indicates a strong nonlinear interaction between storm surge and sea level rise. The population and property affected by the storm surge inundation estimated by numerical simulations differ up to 50–140 % from that estimated by two linear addition methods. Therefore, it is inappropriate to estimate the exacerbated magnitude and extent of storm surge flooding and affected population and property caused by sea level rise by using the linear addition methods. The strong nonlinear interaction between surge flooding and sea level rise at a specific location occurs at the initial stage of sea level rise when the water depth under an elevated sea level is less than 0.7 m, while the interaction becomes linear as the depth exceeds 0.7 m.

Estimates of Storm Surge Using the ADCIRC Model

Two research efforts described earlier are using ADCIRC to evaluate the risk of storm surge in Miami-Dade County. The first project is the remapping of the Flood Insurance Rate Maps of coastal Miami-Dade County used in the National Flood Insurance Program. The other project is

[17] U.S. Army Corps of Engineers, "Sea Level Change Curve Calculator (2014.88) User Manual" (2014) Available at http://www.corpsclimate.us/docs/SLC_Calculator_Manual_2014_88.pdf

[18] Zhang, K., Li, Y., Liu, H., *et al.,* "Comparison of three methods for estimating the sea level rise effect on storm surge flooding" Climate Change (2012) 115, No. 3-4

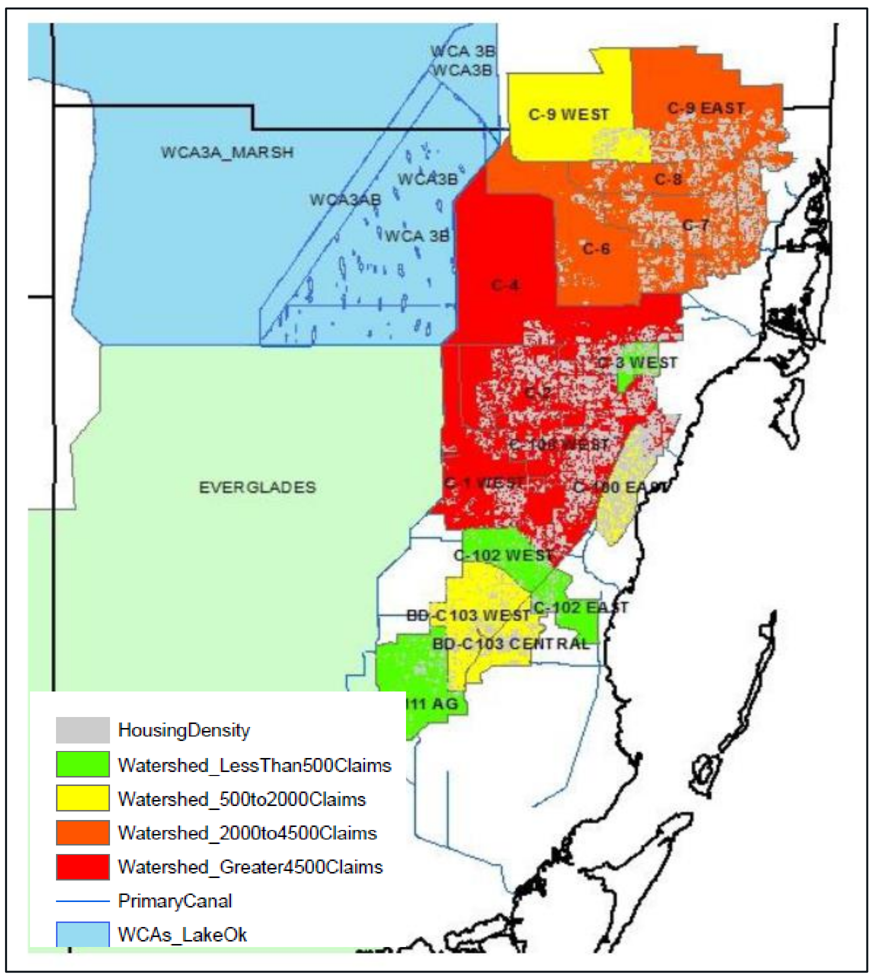
the Army Corps funded research project focused on the efficacy of non-structural flood reduction measures. ADCIRC is a system of computer programs for solving time dependent, free surface circulation and transport of fluids problems in two and three dimensions.

Studies Describing Miami-Dade County's Exposure to Flooding

The Florida Public Hurricane Loss Model

The International Hurricane Research Center at Florida International University is leading a multi-university effort with funding from the Florida Office of Insurance Regulation to develop an innovative, public hurricane loss model. In 2013 the State funded this initiative to enhance the model by adding both a storm surge and fresh water flooding component. The new components will assess storm surge and hurricane-related rain flood risk, and estimate both the insured and uninsured losses they may create. When it is completed, it will provide a state of the art innovative, transparent, combined model that can separate wind losses from flood losses and help resolve the issue of the ultimate cause of damages. It will also provide a more refined and actuarially sound method of estimating insured losses and determining fair pricing for all sources of hurricane risk. The model will also allow planners to conduct simulations and scenario analysis that can help state and local governments with disaster planning and land use planning. Additionally, results from the effort could be used to help the County and other relevant parties assess the costs and benefits of alternative mitigation strategies. This enhancement will take approximately three to four years to complete and is projected to be ready around 2017. More than two dozen professors and experts have been involved in developing the model.

Figure 14: High flood claim watersheds in Miami-Dade County



Source: Czajkowski, J., Engle, V., Martinez, C.

Economic Impacts of Urban Flooding in South Florida Due to Higher Groundwater Levels

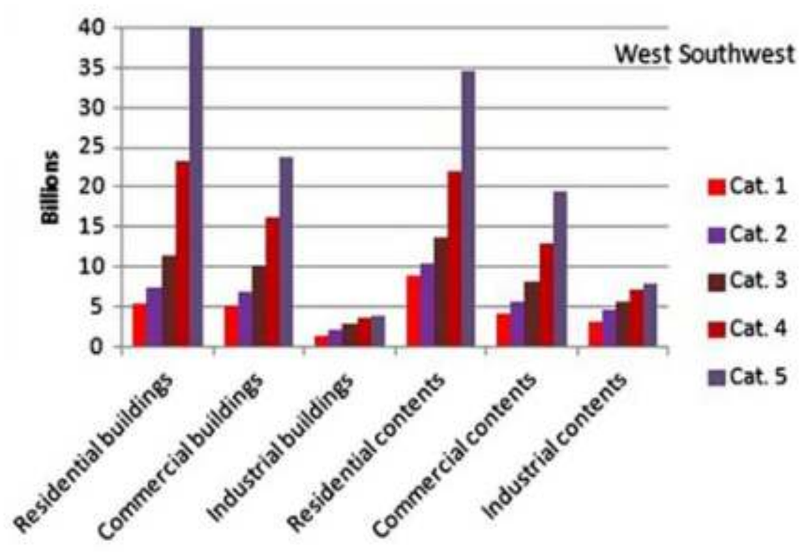
The study "Economic Impacts of Urban Flooding in South Florida: Potential Consequences of Managing Groundwater to Prevent Salt Water Intrusion," reviewed the possible economic trade-offs associated with the competing demands to manage regional water resources to both prevent salt water intrusion and reduce flooding risk.[19] This study provides an excellent review of the complexity of managing water resources given the region's vulnerability to salt water intrusion caused by the low topography, existing high water table, the permeable karst substrate, and sea level rise.

With higher average sea levels, canal water levels may have to be increased to prevent increased salt water intrusion. However, higher canal water levels also lead to an increased risk of inland flooding and associated economic losses, especially during the annual wet seasons. Monthly flood claims in 16 Miami-Dade watersheds (Figure 14) were collected for the timeframe of 1996 to 2010, and statistically related to corresponding watershed groundwater levels, controlling for other relevant flooding factors. This study therefore created new models that reveal the historical relationships between flood insurance claims and groundwater levels in Miami-Dade County. Utilization of the model results suggest that in a heavily developed urbanized watershed, monthly flooding losses could be as high as $8 million under current high groundwater level conditions. This is the first estimate of this kind in south Florida, thus, this study is highly relevant to future decision making related to evaluating economic trade-offs associated with different water management regimes.

Assessment of Storm Surge Damage to Coastal Settlements in Southeast Florida

The "Assessment of Storm Surge Damage to Coastal Settlements in Southeast Florida" investigated flooding risks associated with different potential hurricanes.[20] The results of this study showed that, in the absence of protections, losses from large storm surges will be very high, reaching up to tens of billions of U.S. dollars (Figure 15). This study found that, of the scenarios tested, the minimum damage to the study region would be 32 billion dollars (from a Category 1 storm from the east) and found the maximum damage would be 185 billion dollars (resulting from a Category 5 storm from the West/Southwest). The study also demonstrated how economic impacts could change if protections are built up prior to the weather event. This analysis helps illuminate the potential for different levels of protection to reduce damages. This allows for evaluation of the benefits from structural protection measures. These

Figure 15: Potential impacts from a hurricane from the west southwest



Source: Elisabeth Genovese and Colin Green, 2015

[19] Czajkowski, J., Engel, V., Martinez, C., et al. "Economic impacts of urban flooding in south Florida: Potential consequences of managing groundwater to prevent salt water intrusion" (2015) Available at: http://opim.wharton.upenn.edu/risk/library/WP201510_GWLevelsFloodClaims_Czajkowski-etal.pdf

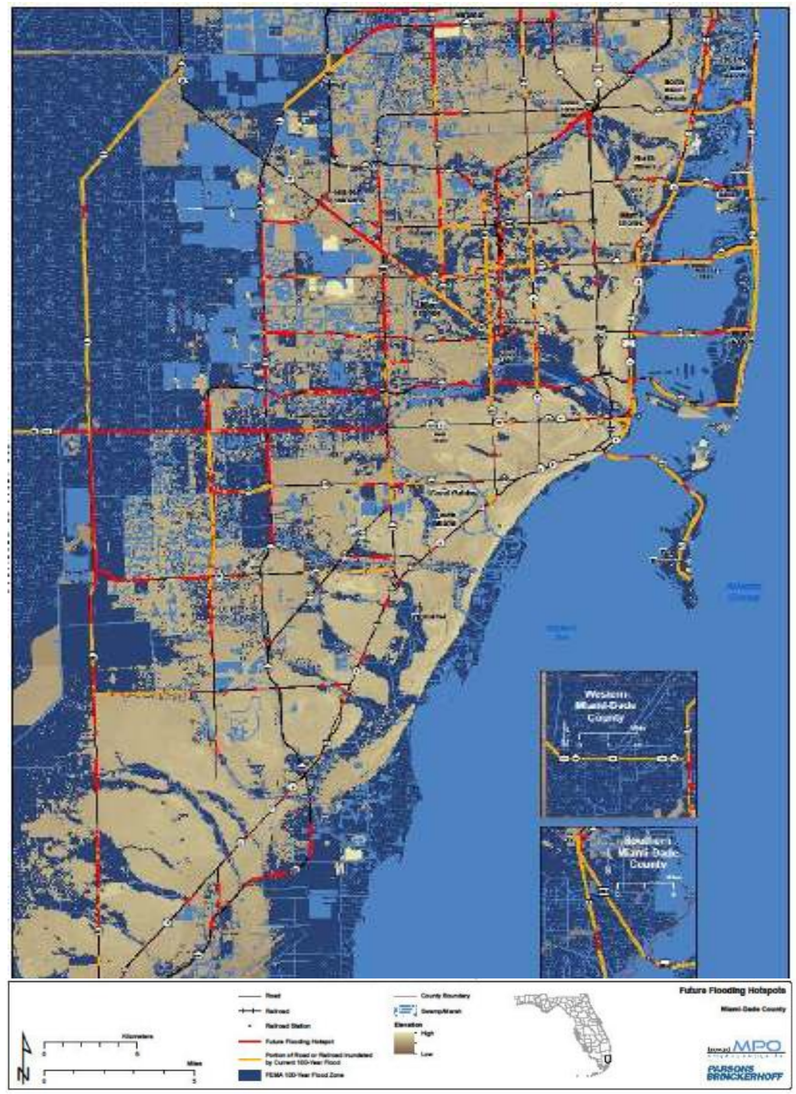
[20] Elisabeth Genovese and Colin Green "Assessment of storm surge damage to coastal settlements in Southeast Florida" Journal of Risk Research (2015) Vol. 18, No. 4, 407-427

results could be used as inputs into a robust decision-making process to determine the future of coastal protection in South Florida.

South Florida Climate Change Vulnerability Assessment and Adaptation Pilot Project

This study explored the vulnerability of certain transportation assets within Miami-Dade County (Figure 16).[21] In 2013, the Federal Highway Administration sponsored climate resilience pilot studies in selected states and metropolitan areas. These pilot studies examined approaches to conduct climate change and extreme weather vulnerability assessments of transportation infrastructure and analyzed measures to improve resiliency. The Southeast Florida four-county region was one of the chosen pilot project areas.

Figure 16: Future flooding hotspots along the regional transportation network, Miami-Dade County



Source: Federal Highway Administration, 2013 South Florida Climate Change Vulnerability Assessment and Adaptation Pilot Project – submitted to the Broward Metropolitan Planning Organization by Parsons Brinckerhoff, Inc. April 2015

The study examined three climate change-related stresses: sea level rise inundation, storm surge flooding, and heavy precipitation induced flooding. Only roadway and passenger rail facilities on the designated regional transportation network were considered as part of the analysis. The overall approach to the vulnerability assessment was based on the Federal Highway Administration's Climate Change and Extreme Weather Vulnerability Assessment Framework.

The level of vulnerability for any particular asset was defined as a product of three factors, following the guidance in the agency's Vulnerability Framework: exposure, sensitivity, and adaptive capacity.

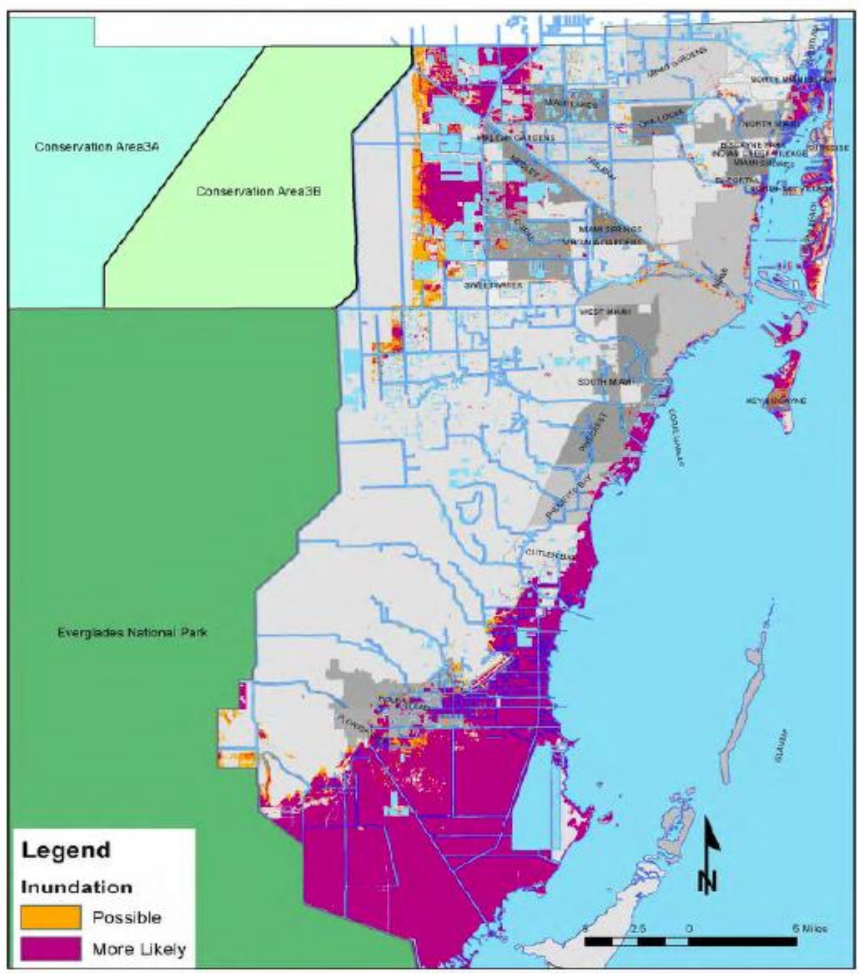
[21] South Florida Climate Change Vulnerability Assessment and Adaptation Pilot Project – submitted to the Broward Metropolitan Planning Organization by Parsons Brinckerhoff, Inc. April 2015

The initial pilot project concluded that the regional transportation network exhibited significant potential vulnerability to sea level rise and other climate change and extreme weather impacts. A follow up study is now underway to supplement the aforementioned Climate Resilience Pilot Project for Southeast Florida by contributing to a more robust understanding of potential sea level rise and storm surge impacts on mobility in the region (including general economic impacts). In doing so, a potential expanded application of the recently-adopted regional travel demand model also will be tested and help foster greater understanding of the role of critical evacuation. It will also help increase understanding of other routes in the broader network as an illustrative aid to emergency management and other planners in the region.

Analysis of the Vulnerability of South Florida to Sea Level Rise

The Southeast Florida Regional Climate Change Compact completed a regional vulnerability analysis based on projections of one, two, and three feet of sea level rise (Figure 17). This analysis was based on land and sea elevations only and did not consider flooding related to existing drainage issues associated with rain events or those caused by storm surge. It provides an overview highlighting locations that are low lying in comparison to various sea level rise scenarios. Additional analysis and more sophisticated models would be required to determine hydrologic connections and actual surface water response to rising sea levels.

Figure 17: Vulnerability analysis of Miami-Dade County to 3 feet of sea level rise



Source: Southeast Florida Regional Climate Change Compact

The analyses mapped areas that might be inundated by increased tidal elevations above current mean higher high water elevations. The study did not take into account existing ground water levels, tidal anomalies, future water management and operations, or flood mitigation practices.

This initial scoping study found that the upper estimate of taxable property value vulnerable in Monroe, Broward, and Palm Beach Counties is greater than $4 billion.[22] In the scenario that evaluated three feet of sea level rise, these values rose to over $31 billion. At the one foot scenario, property with a current taxable value of $403-828 million was vulnerable. At three feet of sea level rise, properties valued an aggregate of $6,901-12,109 million were impacted. Under a one foot scenario, 1.3% of the County is impacted, though it was primarily conservation lands which were inundated. At the two foot scenario, 3% of the land is impacted with Electrical Generation Facilities among the top land uses impacted. At the three foot scenario, 7% of the total land mass of the County is impacted including 28% of the agricultural lands and 10% of the transit-oriented development areas. In terms of acres inundated, wetland hardwood forest and vegetated non-forested wetlands are among the major habitats impacted.

[22] Miami-Dade County did not assign a dollar value to the infrastructure at risk and was therefore not included in the estimate of value.

On-going Adaptation Efforts

Miami-Dade County Stormwater Master Plan

In 1992, Miami-Dade County began the development of a countywide stormwater management program. The Water Management Division in the Regulatory and Economic Resources Department administers the program, which is an essential component to identify and solve current and future stormwater drainage, flooding, and water quality problems in the service territory. Miami-Dade County is highly advanced in stormwater adaptation planning and implementing actionable mitigation projects. This record is demonstrated by the County's position within in The Federal Emergency Management Agency Community Rating System Program. This program recognizes communities that go above and beyond the minimum requirements for managing floodplains. The County currently has an excellent rating of five placing the County in the top 8% of all participating communities nationwide. This rating is due to the County's efforts to plan, improve, maintain, and operate the local stormwater and flood control system.

Fees collected by the stormwater utility are used to provide drainage services to the residents of the unincorporated Miami-Dade County service area. In some areas, the County's Secondary Canal System also provides drainage benefits to incorporated municipal residents. The County's Water Management Division supports numerous programs, including the County's Comprehensive Development Master Plan process, emergency preparedness and management, stormwater infrastructure maintenance, engineering evaluations and improvements to the County's' Flood Protection and Water Quality Levels of Service, as well as the County's local and regional efforts on climate change, sea level rise, and adaptation planning. The stormwater master planning process is extensive and recommends investments for flood prevention, and infrastructure improvements, as well as operations and maintenance targets. Because the stormwater master plan is integral to the Comprehensive Development Master Plan, the progress and effectiveness of the Stormwater Master Plan is monitored during the periodic "Evaluation Assessment Review" conducted by the State.

The Stormwater Master Plan already includes existing, as well as recognized, forecasts for critical engineering data such as ground water levels, critical surface water stages, storm surge, tidal elevations and anomalies, and water management operations. The County also uses the latest Federal Emergency Management Agency's risk assessment tools and risk management methodology for floodplain mapping; The Compact's most recent sea level rise projections; the latest The Federal Emergency Management Agency's Flood Insurance Rate Maps; and the latest Florida Building Code requirements for new construction and substantial improvements to existing infrastructure, both public and private.

Implementation of the Miami-Dade County Stormwater Master Plan ensures that the County continually:

- Evaluates existing and future forecasted water quantity and water quality conditions

- Develops, prioritizes, and budgets for stormwater management and engineering solutions
- Continually models, value engineers, and analyzes future impacts and mitigation scenarios to effectively address long-term strategic infrastructure planning and stormwater management decisions (including SLR adaptation)
- Develops best management practices for flood protection, reduction, and water quality improvements

Stormwater infrastructure projects, per industry engineering standards, are designed to perform for the next 30 to 50 years with the forecasted sea level rise, or best available tidal elevations forecasted for each area. The Division is continually analyzing and updating its models and regulatory framework to incorporate future changes, if any, in the hydrology, precipitation levels, ground and surface water stages, tidal elevations, and regional water management practices. This commitment to "modeling forward" is what allows the Division to study "what if" scenarios and implement future capital infrastructure and code changes to continue to provide cost effective flood control levels of service.

Miami-Dade County Local Mitigation Strategy

Miami-Dade County's Local Mitigation Strategy is a whole community initiative designed to reduce or eliminate long-term risk to human life and property from hazards, including flooding. The Local Mitigation Strategy plan is a multi-volume plan that documents the planning process and addresses mitigation measures in relation to the hazard risk and vulnerability assessment of Miami-Dade County. This is a living document that is updated semi-annually to integrate and reflect current and projected issues and track mitigation measures. The strategy includes actions that have occurred, are occurring, and are planned for or desired. This plan is a compendium of efforts of the whole community, integrating governmental and non-governmental agencies such as the non-profit and private sector, educational and faith-based organizations, as well as individual communities, families and individuals.

The plan was created by the Local Mitigation Strategy Working Group, led by the Miami-Dade County Office of Emergency Management. The Local Mitigation Strategy Working Group is made up of representatives from Miami-Dade municipalities, County departments, state and federal agencies, schools, colleges and universities, hospitals, private for-profit, and not-for-profit organizations. Because the plan is approved by The Federal Emergency Management Agency, it enables members of the working group to access available funding for mitigation such as, but not limited to, the Hazard Mitigation Grant Program, Pre-Disaster Mitigation, and Flood Mitigation Assistance. Funding from the Federal Emergency Management Agency prioritizes addressing Severe Repetitive Loss and Repetitive Flood claims.

One of the most important components of the Local Mitigation Strategy is its second section, which contains a list of mitigation projects. This list includes projects that have been completed, are being pursued, or have been identified as a need to address a known risk. Many of these projects focus on reducing the risk of flooding and will support the County's adaptation to rising sea levels. This past year alone, more than 12 major projects from the Local Mitigation Strategy were completed (Table 1), representing more than $37 million in mitigation investments. In addition, 23 more projects are under construction representing a further investment of more than $35 million (Table 2). A study conducted by the Multi-hazard Mitigation Council shows that there is a saving of four dollar for every dollar invested into mitigation measures.

Table 1: A sample of local mitigation projects completed in 2015

Local Mitigation Strategy Project Status Reported 01/2015-12/31/2015			
Completed Projects			
Region	**Location**	**Investment**	**Funding Source**
Aventura	NE 29 Place Phase 1 drainage work	$425,000	FDEP
Cutler Bay	Caribbean Boulevard JPA project reduce flooding and increase traffic flow	$11,173,054	CITT funds
Cutler Bay	SW 212 Street Drainage Improvements from SW 87 Ave to SW 85 Ave	$850,000	TAP & FL Leg. Approp. Grant
Florida City	Generator for Underground Drainage for Friedland Manor	$904,739	State Small City CDBG and City Funds
Homestead	Land acquisition for storm water drainage	$3,000,000	Capital Improvement
Key Biscayne	Erosion Control Implementation	$10,000	Public Works General fund
Key Biscayne	Stormwater outfall rehabilitation on Harbor Drive	$150,000	Stormwater Utility and grant
Mount Sinai	Relocation of generators for energy facility into hurricane rated enclosure	$8,994,838	State DEM
Seaport	Construction of New Seawall - Area 2	$9,600,000	FDOT
Seaport	Storm Bollards	$70,115	Seaport Funds
Seaport	Concrete Panels	$619,858	Seaport Funds
Sweetwater	Stormwater Improvements Phase IIB North Project	$1,600,000	U.S, EPA, Miami Dade GOB
	Total	$37,397,604	

Table 2: Local mitigation projects under construction as of January 2016

Mitigation Projects Under Construction			
Region	**Location**	**Investment**	**Funding Source**
Cutler Bay	Reduction of Floating Debris	$60,000	Funding Secured
Cutler Bay	Flood Zone Data GIS System	$140,000	Stormwater Utility Fees
El Portal	Village of El Portal Stormwater Improvements	$10,000,000	Capital Improvement

Hialeah	Roadway/Stormwater Improvements (SE 4 ST to	$151,469	City Capital Improvement
Hialeah Gardens	Central District Drainage Improvements	$2,500,000	Capital Improvement
Homestead	Wastewater Infiltration/Inflow	$2,400,000	Capital Improvement
Homestead	Sidewalks/ Roadway Improvements	$200,000	Capital Improvement Plan
Homestead	New Sewer Mains	$2,000,000	Capital Improvement
Homestead	Sewer lines in the Northwest Neighborhood and the West Industrial	$3,300,000	Capital Improvement
Miami Beach	Venetian Islands Drainage Improvements	$9,100,000	Grant Applied For
Miami Beach	Drainage Hot Spots	**	Grant
Miami Beach	Venetian Islands – Neighborhood	**	Grant
Miami Beach	Sunset Islands 3 & 4 – Neighborhood Improvements	**	Grant
Miami Beach	Lower North Bay Road – Neighborhood Improvements	**	Grant
Miami Beach	Citywide Dune Restoration & Enhancement Project	$400,000	Grant
Miami Gardens	Create GIS Layer for Storm Sewer	$100,000	*
North Miami	Flood Prevention and Mitigation: Drainage Basin13	$500,000	Capital Improvement
North Miami	Sanitary Sewer Backup	$700,000	Capital Improvement
North Miami	Surge Resistance and Flood Mitigation at Keystone Point and Sans Souci	$500,000	Capital Improvement
North Miami	NE 172nd Drainage Improvement	$17,916	Capital Improvement
North Miami Beach	Install Additional Storm Water Basins or Increase Existing Basins	$60,000	Capital Improvement
North Miami Beach	Construct Storm Water System- may include Injection Wells in Areas Prone to Flooding	$120,000	Capital Improvement
North Miami Beach	Clean and Improve Drainage Systems	$428,400	Capital Improvement
North Miami Beach	Eastern Shores Drainage Repair/Replacement	$450,000	Capital Improvement
Palmetto Bay	Flood Zone Data Maintenance: GIS System	$100,000	Capital Improvement
Palmetto Bay	Localized Drainage Improvements	$900,000	Capital Improvement
Sweetwater	South Florida Water Management District Flood Protection Berm	$1,000,000	South Florida Water Management District
Total		$35,127,785	

Continuing to fund mitigation projects already identified in the Local Mitigation Strategy will also help reduce the County's own exposure in addition to the exposure of the community more broadly.[23] As of December 2015, the Local Mitigation Strategy contained more than 1,020 projects identified as having the potential to reduce the County's exposure to known hazards; many of these are focused specifically on addressing flooding risks.[24] Increasing funding for these projects would significantly expedite adaptation.

Miami-Dade County Beach Nourishment Program

As sea levels rise they affect the beach profiles and erosion rates. Beach nourishment can help slow these changes to the County's beaches and dunes and provide important storm protection benefits. For these reasons, Miami-Dade County Environmental Resources Management and other local, Federal and State agencies work together to enhance and protect our beaches from the effects of sea and wind erosion. In an effort to improve the performance and cost-effectiveness of the Beach Erosion Control and Hurricane Surge Protection project from 1966, a number of project-wide, and site-specific, studies have been conducted to better identify these problem areas, assess the causal factors for the high erosion rates, and develop recommendations for remediating these areas. The recommendations for managing these hotspot areas of high erosion, range from no action to structural solutions such as the installation of breakwaters and groins. Tens of millions of dollars have been and will continue to be invested in these programs in order to protect our shoreline and coastal infrastructure from the effects of sea level rise.[25]

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[23] More information about the Local Mitigation Strategy is available at http://www.miamidade.gov/fire/mitigation.asp

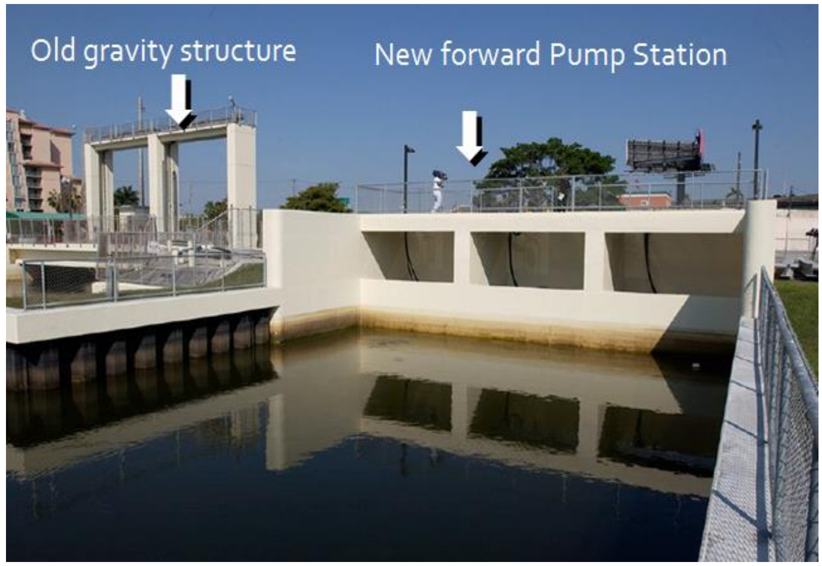
[24] The most recently published list of Local Mitigation Strategy projects is available at http://www.miamidade.gov/fire/library/OEM/local-mitigation-strategy-part-2-projects.pdf

[25] More information about the County's beach renourishment program is available at http://www.miamidade.gov/environment/beach-renourishment.asp

South Florida Water Management District Adaptation Efforts

The South Florida Water Management District continues to investigate the impacts of sea level rise on the District's mission of flood control, which could impact operations in the future. The South Florida Water Management District is working to address flooding caused by land use changes and sea level rise in Miami-Dade County. Two examples of infrastructure modifications to address flooding caused by land use changes and sea level rise in Miami-Dade County are described below.

Figure 18: Adaptation of the District's gravity-based water management infrastructure

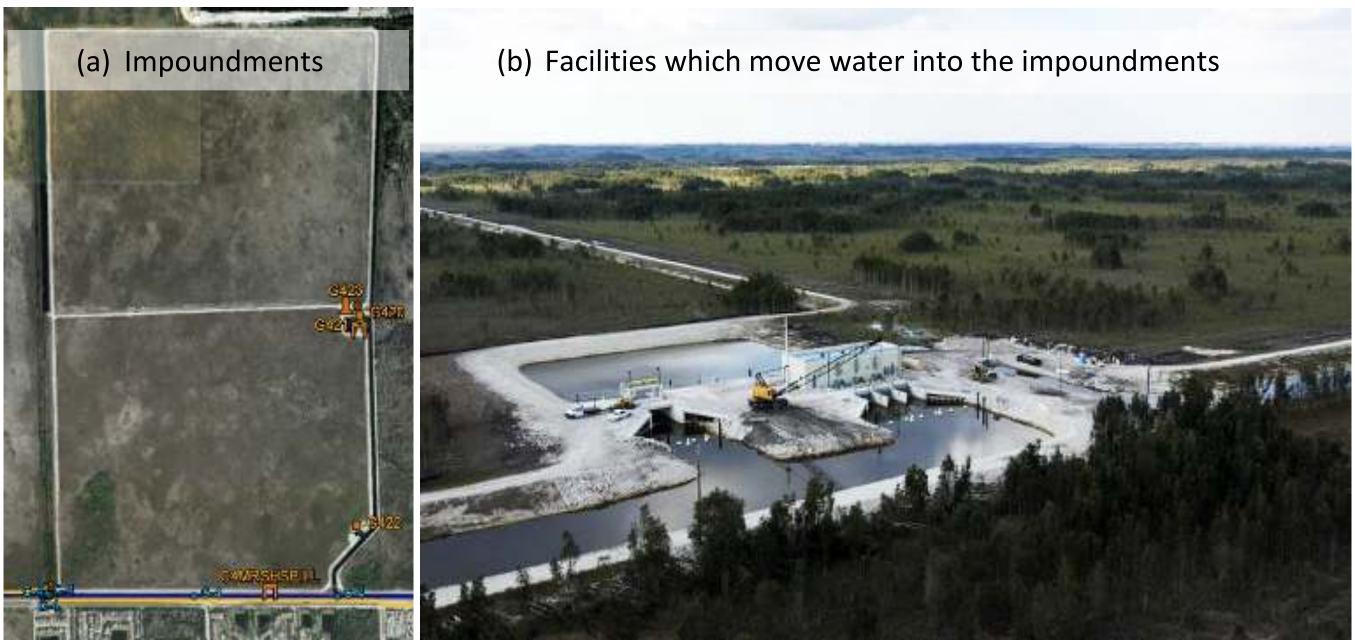


Source: South Florida Water Management District

The first example (Figure 18) shows two pumps at two coastal water control structures in Miami Dade County. The water control structures (also salinity control barriers) which discharge flood waters in the urbanized areas of Miami-Dade County were designed and built by U.S. Army Corps of Engineers during the 1950's when emphasis on sea level rise was minimal. With today's current water levels, some of the structures face higher than normal water levels during high tide, preventing the older gravity-based structures from discharging flood waters at the capacity they were designed for. In order to retrofit this condition and provide the necessary flood protection in areas around the Miami International Airport, two pumps (also called forward pumps) have been installed. These two projects were partially funded by The Federal Emergency Management Agency.

The second example of infrastructure modification in Miami-Dade County focuses on heavily urbanized areas along Tamiami Trail (south of Miami International Airport) that are subject to significant flooding during major storm events, such as tropical storms and hurricanes. Traditionally, flood waters are discharge from urban areas to the ocean. However, as explained above, the efficiency of moving water through a highly constrained canal system and water control structures is inadequate. The South Florida Water Management District has implemented a solution to this problem by moving flood waters west, for temporary storage in a newly constructed impoundment. Figure 19 shows the Western C-4 Impoundment, which was constructed to store excess flood waters. This facility improves flood protection and facilitates groundwater recharge.

Figure 19: Stormwater impoundments built in western Miami-Dade County

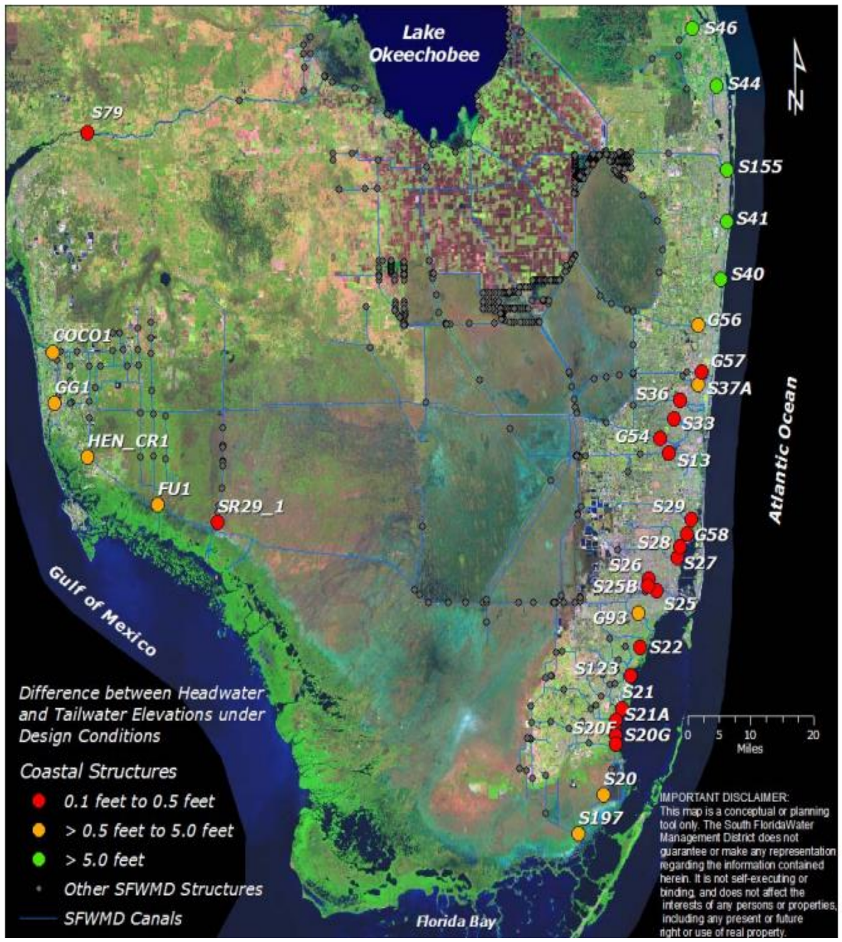


Source: South Florida Water Management District

The South Florida Water Management District also constantly monitors sea level rise data and the best available science to determine which information can be used for planning. There is a current emphasis on investment decision making under uncertainty. The South Florida Water Management District also continues to support The Southeast Florida Regional Climate Change Compact by providing technical assistance through several means: projections of SLR scenarios, providing technical data, participating in various climate change indicator subgroups, participating in the steering committee and local workshops, and supporting local government efforts to address sea level rise.

As described in the previous section, the South Florida Water Management District has a number of projects focused on adaptation to sea level rise including a pilot project to investigate the "Level of Service" for flood protection in Miami-Dade County. Because the original planning life of the Central and Southern Florida Project, created in 1948, is over, the South Florida Water Management District is beginning a long-term effort to understand the implications of current and future land use changes, sea level rise, and changes in rainfall extremes on the Districts' ability to manage the current system for flood control. The initial focus is on Miami-Dade County, as it is the area under their management that is most vulnerable to sea level rise. This is a part of long term strategy to ensure that the system is ready for the future.

Figure 20: Vulnerability assessment of the District's coastal structures to sea level rise. High, medium and low vulnerability areas are in red, orange and green, respectively.



Source: South Florida Water Management District

A second project is being conducted in partnership with Dutch counterparts, to investigate whether Dutch technology can be used in South Florida to manage floods. Jointly with a Dutch non-profit organization, DELTARES, the South Florida Water Management District has received funding from the National Oceanographic and Atmospheric Administration to conduct a study on flood and drought risks in Miami Dade County.

In a third project, the South Florida Water Management District is receiving funding from The Federal Emergency Management Agency to conduct flood studies in the C-7, C-8, and C-9 basins located in Miami-Dade County. This project will be a collaborative effort between the South Florida Water Management District and Miami-Dade County's Office of Emergency Management and the Office of Resilience. These studies are a part of the District's assistance to Miami-Dade County, which will help meet the requirements outlined in this resolution. Simultaneously, the agency is also providing technical assistance for studies in both Broward and Palm Beach counties. As with Miami-Dade County, assistance is provided in the form of data sharing, technical input, and project review.

The South Florida Water Management District is also planning to update their 2009 white paper on climate and sea level rise. This will likely be completed by the spring of 2016. The previous document, *Climate Change and Water Management in South Florida*, provided a foundation for discussions on the effects of global climate change on water management planning and operations in the southeast Florida region.[26] The document focused on how climate change may affect South Florida's resources and outlined the mission responsibilities of the South Florida Water Management District. The paper included an initial vulnerability analysis of the potential threats of climate change and sea level rise to water supply, flood control, coastal ecosystems, and regional water management infrastructure (Figure 20). In addition to the previous efforts, the District has been working with the State of Florida Department of Environmental Protection and other Water Management Districts to develop a white paper on state-wide efforts to address the implications of sea level rise.

Miami Dade County also maintains a continuous channel of technical and institutional communication and cooperation with Dr. Jayantha Obeysekera, Chief Modeler at the South Florida Water Management District and a member of the National Climate Assessment Development & Advisory Committee, which produced the 2014 National Climate Assessment.[27] Dr. Obeysekera works very closely with Miami-Dade County staff on issues related to sea level rise and has initiated efforts to continue to communicate these adaptation efforts to the District's Governing Board.

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[26] Available at www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/climate_change_and_water_management_in_sflorida_12nov2009.pdf

[27] More information on the National Climate Assessment can be found at http://nca2014.globalchange.gov/

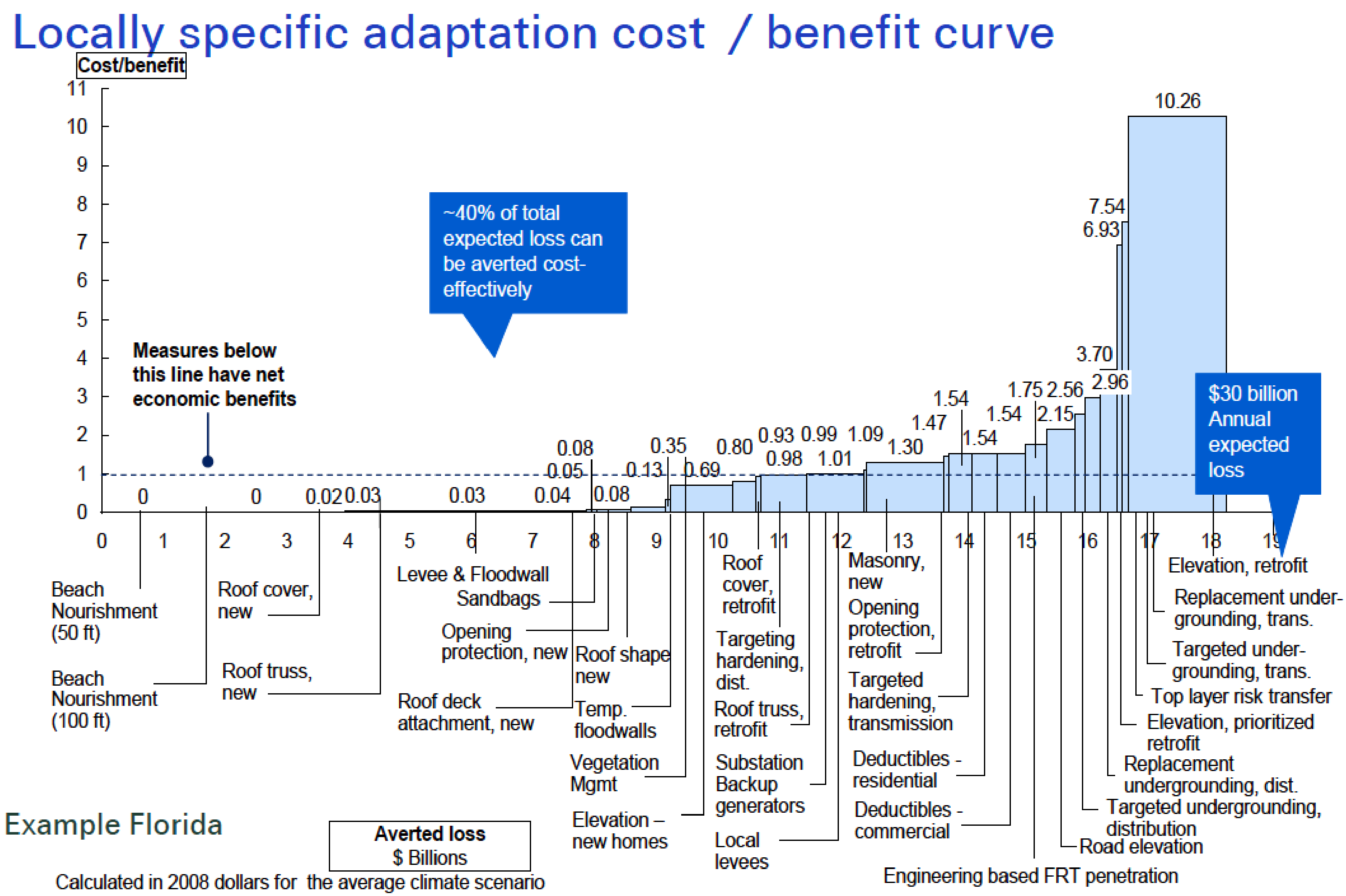
Potential Adaptation Measures

Urban expansion, sea level rise, and potential increases of extreme rainfall will stress the infrastructure in the region. Maintaining the level of service for flood protection will require a focused analysis of each major drainage basin in Miami-Dade County. Since there is a broad diversity in impacts and characteristics among basins, there is not one single solution (or even a suite of solutions) that can be applied to the entire County. For instance, two forward pumps and a western reservoir were found to be the part of a longer term solution in the C-4 basin, but such adaptation measures may not be feasible in other areas due to constraints such as land availability. Therefore, adaptation measures must be chosen on the basis of careful local analysis.

Adaptation measures should also be chosen in a way to maximize their co-benefits and cost effectiveness. As demonstrated in Figure 21 on the next page, different adaptation measure will have very different costs and benefits that are very specific to their context and design. For example, when designing a new home it may be very cost-effective to invest upfront in the marginal cost to increase the design elevation by two feet and benefit from the reduction in flood damages and insurance premiums over the lifetime of that building. In contrast, it may not be cost effective to elevate an existing building by that same amount even though it may confer the same benefits. These tradeoffs will all depend on the type of construction, value of the building, potential losses, environmental issues, and a host of other considerations. As demonstrated by the analysis conducted by SwissRe, many of the most cost effective adaptation measures include preserving and enhancing natural coastal defenses such as beaches, dunes, and mangrove forests. Similarly, it is often more cost-effective to integrate resiliency considerations into the design phase of a project as opposed to retrofitting an existing building or infrastructure.

The following tables provide a very high-level overview of some of the potential adaptation measures that may be useful in addressing some of the flooding risks in the County (Table 3). The following measures are organized by scale and the systems they primarily address; however, these distinctions are not absolute. Many measures will provide benefits at multiple scales and will provide benefits to multiple systems. It should be a priority criteria for all County projects or policies to ensure that they do confer multiple benefits across scales and systems. To reiterate, all adaptation measures must be chosen on a site-specific basis following a detailed analysis of their potential implications. What may be effective in one location may exacerbate the problem in a different context.

Figure 21: Locally-specific cost/benefit curves for a suite of adaptation measures



Source: Swiss Re

Table 3: Potential adaptation measures at different scales

Site Scale	
Buildings	• Elevate buildings • Flood-proof buildings o Wet flood-proofing o Dry flood-proofing o Passive flood barriers o Improvised flood protection (sand bags or moving equipment to higher elevations) o Deployable flood panels • Elevate the height of the interior finished floor elevation • Elevate mechanical systems • Avoid below grade parking or basements • Augment low-lying agricultural areas affected by rising groundwater levels with additional fill
Infrastructure networks	• Construct flood barriers to protect specific infrastructure
Natural systems	• Enhance swales, rain gardens, or pervious surfaces
Drainage	• Increase the storage and infiltration of rainwater on-site with swales, rain gardens, rain barrels, increasing pervious surfaces, or other measures
Neighborhood or Block Scale	
Buildings	• Redevelop and elevate flood-prone areas
Infrastructure networks	• Abandon septic tanks and connect to the sanitary sewer networks • Elevate roadways or increase drainage to avoid saturated roadways bases which could contribute to future pavement failure and additional maintenance requirements • Elevate bulkheads • Harden critical infrastructure assets against flooding (“flood-proofing)
Natural systems	• Increase the height and width of beach and dune areas • Improve dune restoration and vegetation management • Protect or restore fringing mangrove forests • Protect or restore sea grass beds which can trap sediment and reduce erosion rates • Restore wetlands in flood-prone areas
Drainage	• Increase the area of pervious surfaces where they can effectively increase infiltration • Increase pump capacities • Increase the use of stormwater gravity or injection wells • Enhance the stormwater system by creating a collection system • Install backflow preventers to restrict the flow of seawater into the stormwater system • Increase impoundment areas to temporarily store water during times of heavy rains • Reengineer outlets of canals to prevent flooding at high tide • Retrofit drainage in areas where exfiltration systems cease to work as they become submerged • Elevate flood-prone areas on fill • Increase maintenance on sewer infrastructure to remove obstructions to maintain system capacity • Improve swale areas where they have been compacted or compromised • Increase the use of porous pavements in areas where infiltration is possible • Increase the use of green roofs and facades to reduce urban run-off

Regional Scale	
Buildings	• Strengthen building codes to require greater freeboard (or elevation above the base flood elevation) • Create incentives for buildings that exceed the minimum building requirements and provide extra flood protection • Extend certain requirements for floodplain development to areas outside of the FEMA designated Special Flood Hazard Area • Require additional flood-proofing for certain critical facilities • Limit redevelopment in high hazard areas to resilient buildings • Designate areas of targeted development that are on the least flood-prone land • Amend the Post Disaster Redevelopment Plan to encourage redevelopment in the safest areas in the County and provide a mechanism to explore other options for residents who no longer wish to live in flood-prone areas • Incentivize or require real estate disclosure of a property's vulnerability
Infrastructure networks	• Cite critical facilities such as fire stations or emergency shelters outside of the special flood hazard areas when possible • Reroute traffic or evacuation routes to reduce dependence on flood-prone roadways • Increase the required height of seawalls and bulkheads • Raise the height of the District's levees and other levees along the canals
Natural systems	• Reduce development and preserve open space or pervious areas in the floodplain • Increase beach nourishment to slow erosion and increase the width of shoreline buffer areas • Increase the protection of natural barriers, such as coral reefs and the barrier islands, which reduce flooding damage • Increase setback requirements from shorelines, particularly in areas that are expected to erode • Acquire conservation lands that will reduce the risk of "coastal squeeze" and allow protective ecosystems (such as mangrove forests) to migrate with time • Prioritize the acquisition of natural areas in the floodplain that will help reduce potential flood damage or support protective ecosystems
Drainage	• Retrofit bridges or culverts that are significantly limiting, or are expected to limit, conveyance in the future • Install additional stormwater pumps • Alter the operations or infrastructure within the canal networks • Elevate flood-prone areas on fill • Install seepage barriers to reduce the flow of groundwater • Restrict impervious lot coverage and strengthen requirements to retain stormwater on site • Remove obstructions or constrictions from the floodplain

Where Updated Information can be found

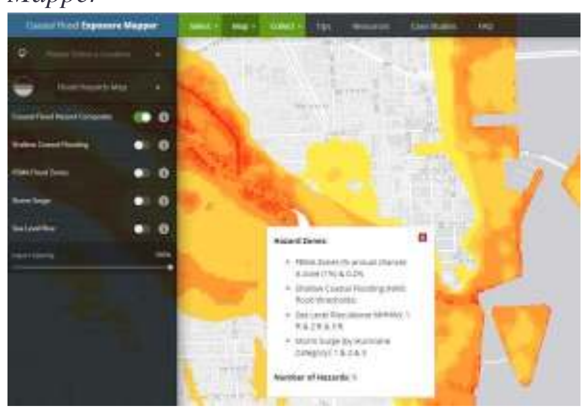
Online Viewers

A number of on-going efforts are making information about sea level rise and adaptation options publicly accessible. The following section summarizes a few of the most comprehensive "viewers" that are currently available to the public. All of the tools offer insights into the areas of the County that are low-lying and which are often, but not always, the same areas that are vulnerable to flooding. These tools are appropriate for a first examination (or "scoping analysis") to identify "hot spots" that are likely to be problematic in the future. All of the described tools use a "bathtub" inundation model, which can be helpful during preliminary studies, but cannot be used for detailed planning studies as they do not account for existing drainage infrastructure, groundwater elevation variation, erosion and other non-linear factors that influence flooding vulnerability. Despite the valuable information they can provide for a general audience, the tools are not as detailed or as accurate as the methods currently used by the County's Water Management Division and the South Florida Water Management District.

The National Oceanographic and Atmospheric Administration's Flood Exposure Mapper

The National Oceanographic and Atmospheric Association has published two user-friendly and freely accessible online viewers, allowing users to adjust the "slider" to view how different sea level rise scenarios will affect a given area.[28] The Agency has also published an online viewer that reviews coastal flooding exposure which illuminates areas of societal exposure like socially vulnerable populations, infrastructure exposure, and ecosystem exposure (Figure 22).[29] This tool includes sea level rise as one of the types of flooding it displays.

Figure 22: NOAA's Coastal Flood Exposure Mapper



Source: National Oceanographic and Atmospheric Administration

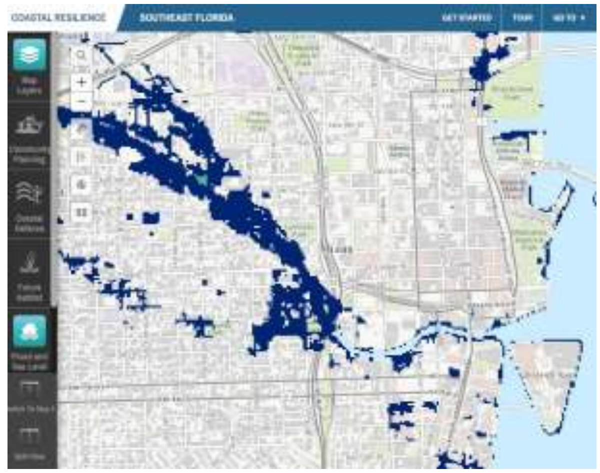
The Nature Conservancy's Coastal Resilience Tool

The Nature Conservancy has published a freely accessible, user-friendly platform to help assess the risk and vulnerability of coastal communities to the impacts of coastal hazards; identify the effectiveness of different nature-based coastal protection measures; design these nature-based solutions; and measure their effectiveness. The different tools, or applications, in this platform allow users to explore their area of interest through several filters and at different levels of detail, from a regional to a city-block level scale. For example, this platform has tools to visualize the potential impacts of sea level rise (Figure 23)[30] and to locate critical areas such as areas of erosion, areas with concentrations of repetitive loss properties, areas of on-going and

[28] Available at http://coast.noaa.gov/digitalcoast/tools/slr
[29] Available at http://coast.noaa.gov/digitalcoast/tools/flood-exposure.
[30] Available at coastalresilience.org

completed shoreline projects, and existing land use and flood zones. There are also applications to evaluate the relative effectiveness of coral reef restoration or mangrove conservation at protecting coastlines, or to identify which type of living shoreline project would be most appropriate along specific portions of the coastline. The platform is easily modified and The Nature Conservancy is prepared to add data and tools of interest to Miami-Dade County and other interested parties.

Figure 23: Nature Conservancy's Coastal Resilience Tool

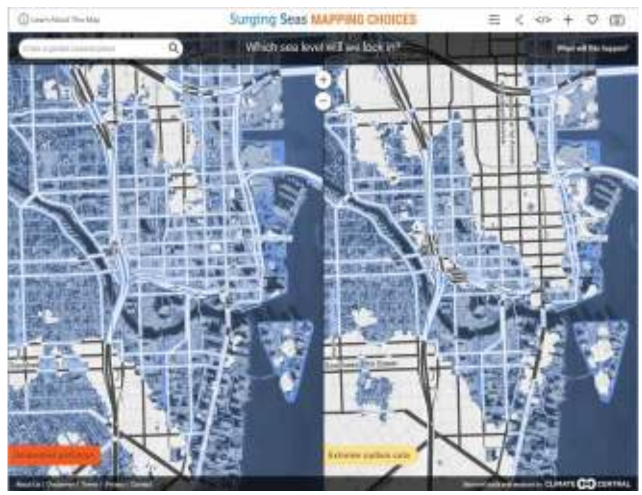


Source: The Nature Conservancy

Climate Central's Surging Seas

Climate Central has also published a similar mapping tool called the "Risk Zone Map".[31] In addition to offering a viewer showing impacts at different sea levels, the tool also offers an analysis page giving users insight into the impacted population, broken down by demographic information on race and level of social vulnerability. Their map also provides similar data about the buildings (broken down by type), infrastructure, land, and potentially contaminated sites (i.e. landfills or hazardous waste sites) that are likely to be inundated. Climate Central has also developed another mapping tool titled "Mapping Choices" which allows users to review expected amounts of sea level rise caused by different greenhouse gas scenarios (Figure 24).[32] For example, it is possible to explore the implications of continuing greenhouse gas emissions at current rates as compared to implementing extreme carbon cuts.

Figure 24: Surging Seas Mapping Choices tool by Climate Central



Source: Climate Central

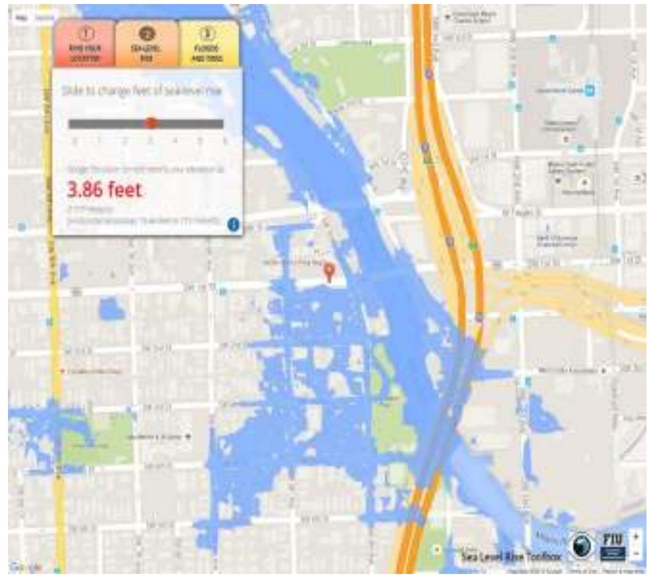
Florida International University's Eyes on the Rise

The Sea Level Rise Toolbox is part of "Eyes on the Rise", a project of Florida International University's School of Journalism and Mass Communication, led by Professors Susan Jacobson, Robert "Ted" Gutsche, Kate MacMillin, Juliet Pinto, and their students. Their map, which helps user visualize the impact of sea level rise in their neighborhood, is based upon

[31] Available at http://sealevel.climatecentral.org/ssrf/florida
[32] Available at http://choices.climatecentral.org/#12/40.7116/-74.0010?compare=temperatures&carbon-end-yr=2100&scenario-a=warming-4&scenario-b=warming-2

the State of Florida Division of Emergency Management's LiDAR (Light Detection and Ranging) Project LAS Dataset, hosted by Florida International University's International Hurricane Research Center. It is intended to project results of "static" sea level rise, not taking tidal effects in consideration. The web visualization of the "static" sea level rise map is developed by Florida International University's Geographic Information Systems Center (Figure 25). The application's main feature is an interactive sea level rise viewer where users can enter an address to visualize how a 6 foot or less increase in sea level may affect their neighborhoods in the Tri-County area of South Florida. As development on the Sea Level Rise Toolbox continues, it will also include a database of flood reports from both government and citizen sources in South Florida. Miami-Dade County recently launched an open data portal that includes flood reports, which will be included in the flood database. The flood report database will help residents identify the incidence of what the National Oceanic and Atmospheric Administration calls 'nuisance flooding,' a phenomenon that is increasingly common as coastal sea levels rise.

Figure 25: Florida International University's Eyes on the Rise mapping tool

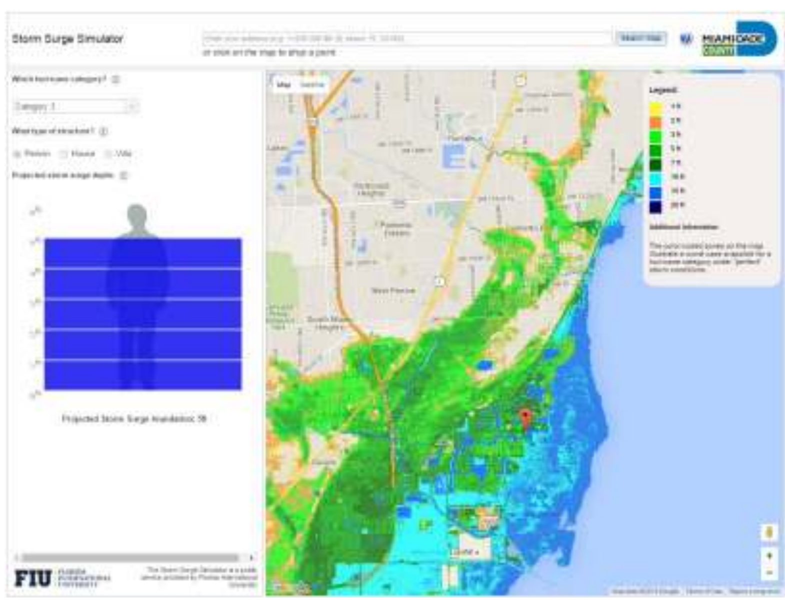


Source: Florida International University

Florida International University's Storm Surge Simulator

While it does not account for future sea level rise, another helpful online tool is Florida International University's Storm Surge Simulator, based on work of faculty experts and students at the International Hurricane Research Center and College of Engineering and Computing. This tool allows users to type in their address and see what the potential storm surge could be at their location in the event of a Category 1, 2, 3, 4, or 5 hurricane. The tool also compares the water depth to a person, house or villa in order to give users a clearer picture of what potential water depths could look like (Figure 26). While it cannot give predictive estimates of storm surge

Figure 26: Florida International University's Storm Surge Simulator Tool



Source: Florida International University based on an approaching storm, it is very useful tool to give users a general sense of the vulnerability of different areas to this hazard.

Miami-Dade County Open Data Portal

The County currently provides a wealth of environmental, hydrologic, planning, and public safety data through the GIS open data portal.[33] This portal allows the public to view information about existing flood zones and storm surge planning zones (Figure 27). More detailed information about emergency management, infrastructure upgrades, and other relevant is also available.[34] The County provides this website as a public service to its residents and visitors and is continually editing and updating GIS data to improve positional accuracy and information.

Figure 27: Miami-Dade County's open data portal

Source: Miami-Dade County Open Data Portal

[33] The data is available at http://gis.mdc.opendata.arcgis.com/
[34] The data is available at http://www.miamidade.gov/technology/gis-maps-and-apps.asp

Salt Water Intrusion

Overview of the Risks

Miami-Dade County's drinking water is drawn from The Biscayne Aquifer, a shallow, surficial aquifer. Because of the County's underlying geology is highly porous and transmissive (or permeable), the freshwater aquifer is not completely isolated from the brackish water at the coastal margins. There is a transitional area between fresh and brackish water that is often referred to as the "salt front", the "extent of saltwater intrusion", the "freshwater saltwater interface" or the "transition zone". The term saltwater intrusion is often used to describe the movement of saline, or brackish, water into freshwater aquifers.[35]

The interface between fresh and salty water is dynamic and can move both seasonally and over longer periods of time. As conditions change, the interface can move landward or seaward. For example, during times of extreme drought when there is less recharge of the aquifer, the salt front may move inland in places. In contrast, during the rainy season or during particularly wet years, the salt front may migrate closer to the coast in certain locations. The use (or withdrawal) of freshwater can also affect the movement of the salt front. For example, if there was significant withdrawal from coastal wellfields, this has the potential to accelerate saltwater intrusion. If there were significant aquifer recharge at that same location, it could have an opposite effect and could push the interface further toward the coast. Changes in land use may also have an effect, when they alter freshwater recharge.

The South Florida Water Management District has identified sea level rise as potentially increasing the vulnerability of the region's drinking water to salt water intrusion. The drinking water standard for chloride concentrations is below 250 mg/l. When concentrations exceed this level, drinking water must either be treated or alternative water sources must be used.

Major On-Going and Planned Studies

U.S. Geological Survey- Surface Groundwater Interface Model

To evaluate the effects of pumping groundwater on canal leakage and regional groundwater flow, the U.S. Geological Survey developed and calibrated a coupled surface-water/groundwater model of the urban areas of Miami-Dade County.[36] The development of this model is an important component to understanding the effects of sea level rise on both the risks of flooding and saltwater intrusion. The model is designed to simulate surface-water stage (water levels) and discharge (water releases) in the managed canal system and dynamic canal

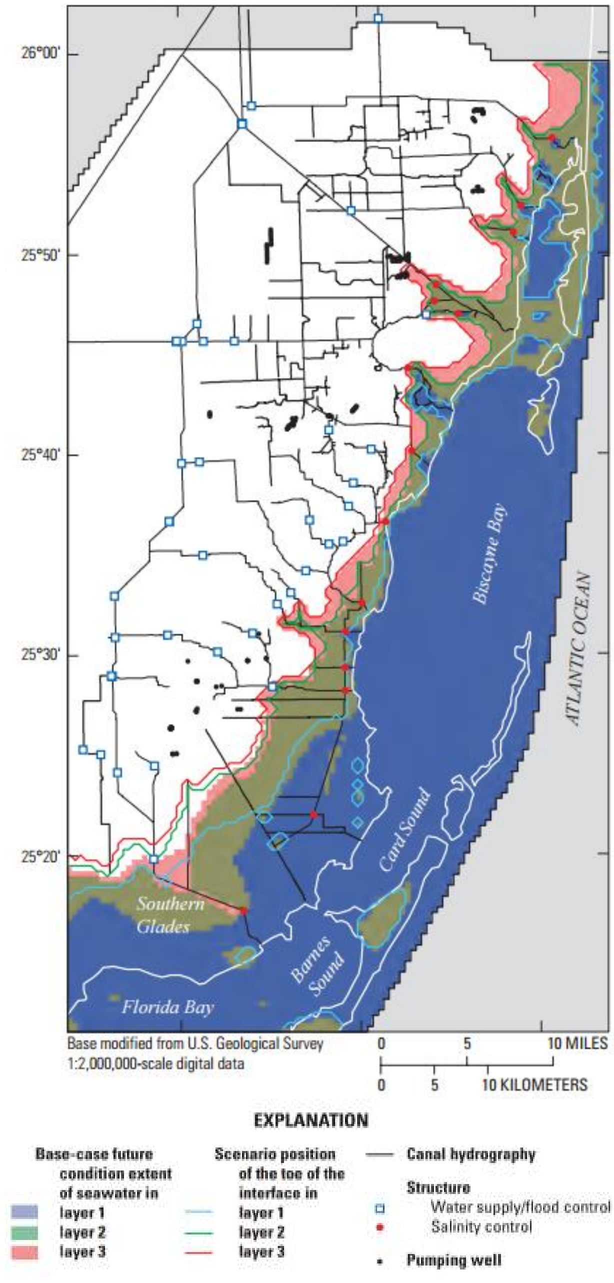
[35] Additional information on saltwater intrusion is available from the USGS at http://water.usgs.gov/ogw/gwrp/saltwater/salt.html

[36] Hughes, Joseph D., and White, Jeremy T., 2014, Hydrologic conditions in urban Miami-Dade County, Florida, and the effect of groundwater pumpage and increased sea level on canal leakage and regional groundwater flow: Scientific Investigations Report.

leakage to the Biscayne Aquifer, in addition to seepage to the canal from the aquifer. The model was developed using the U.S. Geological Survey's MODFLOW–NWT.[37]

The model represents the complexities of the interconnected surface-water and groundwater systems that affect how the systems respond to pumping groundwater, sea-level rise, and other hydrologic stresses. The model also quantifies the relative effects of pumping groundwater and sea level rise on the surface-water and groundwater systems. Supporting data and other information is available at the U.S. Geological Survey's publication library.[38]

Figure 28: Increased sea-level and groundwater pumpage conditions



Source: U.S. Geological Survey, 2011

The study found that analytical and simulated water budgets for the study period (1996- 2010) indicated that, on average, more of the water discharging through the salinity control structures is derived from draining of the Biscayne Aquifer within the urban parts of the study area that from controlled releases upstream . The position of the freshwater-seawater interface at the base of the Biscayne Aquifer did not change notably during the simulation period (1996–2010). This is consistent with the similar positions of the interface in 1984, 1995, and 2011, under similar hydrologic and groundwater pumping conditions. Landward movement of the freshwater-seawater interface above the base of the Aquifer is more prone to occur during relatively dry years.

The model was used to evaluate the effect of increased groundwater pumpage and (or) increased sea level on canal leakage, regional groundwater flow, and the position of the freshwater-seawater interface (Figure 28). Permitted groundwater pumping rates were used for Miami-Dade County Water and Sewer Department groundwater pumping wells in the

[37] MODFLOW-NWT is a standalone program that is intended for solving problems involving drying and rewetting nonlinearities of the unconfined groundwater-flow equation.

[38] Hughes, Joseph D., and White, Jeremy T., 2014, Hydrologic conditions in urban Miami-Dade County, Florida, and the effect of groundwater pumpage and increased sea level on canal leakage and regional groundwater flow: Scientific Investigations Report. http://pubs.usgs.gov/sir/2014/5162

base-case future scenario. These rates generally exceeded historical groundwater pumping rates. The results suggest seawater (saltwater) intrusion may occur at the Miami-Springs well field if the Miami Springs, Hialeah, and Preston well fields are operated using current permitted groundwater pumping rates in the base-case and increased pumping scenarios. Simulations also show that, in general, the canal system limits the adverse effects of proposed increased groundwater pumping on water-level changes and saltwater intrusion. In other words, when groundwater pumping rates increase, the canal system as simulated provides more recharge to the Aquifer, limiting groundwater-level declines and saltwater intrusion that might otherwise occur without additional recharge. Proposed increases in groundwater pumping do not have a notable effect on movement of the freshwater-seawater interface. Increased groundwater pumpage augmented lateral groundwater inflow into basins subject to additional groundwater pumpage; however, most of the additional groundwater extracted from pumping wells was supplied by changes in canal seepage and leakage in urban areas of the model.

Increased sea level resulted in landward migration of the freshwater-seawater interface. The largest changes in the position of the interface (or "salt front") occurred seaward of the salinity control structures with exception of parts of the model area that were inundated by increased sea level. These areas were primarily in the southeastern parts of the County in the C103, C111 basins, and in the Model Land and Southern Glades areas (Figure 28). Decreased water-table gradients reduced groundwater inflow, groundwater outflow, canal exchanges, surface-water inflow, and surface-water outflow through salinity control structures. Put another way, an increase in sea level reduces the hydraulic gradient, or the slope between surface-water and groundwater elevations onshore and coastal waters to the east. A reduction in the hydraulic gradient reduces canal flows through the salinity control structures and seaward flow of groundwater. This reduction in hydraulic gradient also reduces the rate at which water from the canal system can recharge the groundwater system.

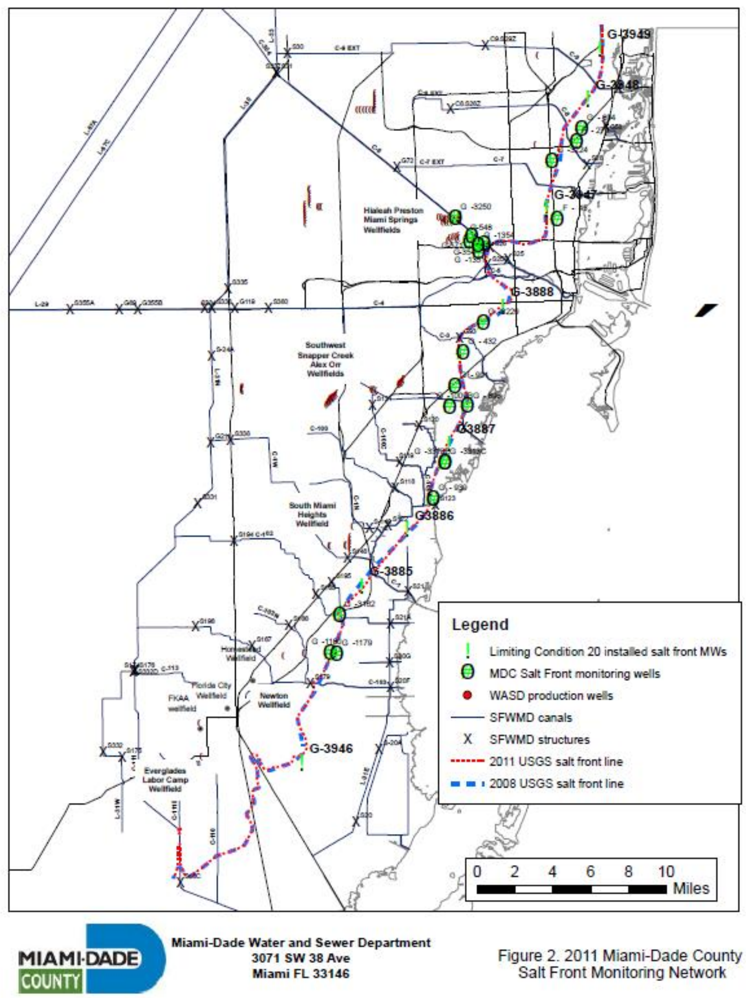
Results for the scenario that evaluated the combination of increased groundwater pumping and increased sea level did not differ substantially from the scenario that evaluated increased sea level alone. Groundwater inflow, groundwater outflow, and canal exchanges were reduced in urban areas of the study area as a result of decreased water-table gradients across the system, however, reductions were less than those in the increased sea-level scenario. The decline in groundwater levels caused by increased groundwater pumpage was lower under the increased sea-level scenario than under the increased groundwater-pumpage scenario. The largest reductions in surface-water outflow from the salinity control structures occurred with increased sea level and increased groundwater pumpage. This means that the canals are not able to drain as quickly and that there is less capacity for managing the hydrologic system. The system would be harder to drain during a rain event. There will be less ability to recharge the aquifer from the canal system, and thus less control over saltwater intrusion.

Miami-Dade County Water and Sewer Department Monitoring Network

The Miami-Dade County Water and Sewer Department is required to submit an annual Salt Front Monitoring Program summary report to the South Florida Water Management District every April 15th. The annual report summarizes hydrologic and water quality conditions ascertained from the monitoring data collected as part of the approved salt front monitoring program. This annual report includes review and analysis of the data collected and includes recommendations regarding the salt front monitoring network. The most recent report is included in Appendix 3.

Groundwater levels and chloride levels (the saltiness of the water) throughout Miami-Dade County are monitored through the joint efforts of the Miami-Dade Water and Sewer Department, the Miami-Dade Department of Regulatory and Economic Resources, and the U.S. Geological Survey. A network of small diameter wells have been drilled to the base of the Aquifer to serve as monitor wells to identify the location of the saltwater intrusion front (Figure 29).

Figure 29: Salt front monitoring network



Source: Miami-Dade County Water and Sewer Department

The salt front is identified as the location at the base of the aquifer, of the 1,000 milligrams/per liter (mg/L) isochlor. An isochlor is the line of equal chloride concentration of 1,000 mg/L. Sampling of the monitor wells is done by the U.S. Geological Survey, under a co-operative contract with the County.

Additional wells are sampled on a quarterly or yearly basis, depending on well location. Every year, the sampling schedule includes a county-wide sampling event conducted at the height of the dry season to coincide with the time when inland movement of the saltwater front would be at its peak. The data derived from that sampling is used by the U.S. Geological Survey to identify any significant movement of the salt front, and to map the location of the salt front if a significant movement is evident.

The network of monitor wells has been modified over the years, depending on the changing needs of the County and on changing hydrologic conditions. More wells have been drilled to monitor areas where the salt front is moving and sampling has been discontinued at wells by-passed by the salt front. Other monitoring wells have been drilled around the operating wellfields to provide additional protection. The monitoring and testing program now includes annual induction logging of several wells. Through time, these electric logs may show changes in the bulk conductivity, which indicates a change in "saltiness" of the water, at specific depths. The effects of formational stratigraphy and hydraulic conductivity on the intrusion patterns can be determined from that information.

Since 2007, the Miami-Dade Water and Sewer Department has contracted with the U.S. Geological Survey to update the salt front delineation and monitoring network. The main objective of this study has been to augment an existing saltwater-intrusion monitoring network through application of surface and borehole geophysical methods and the addition of new sentinel monitoring wells. Salinity data from the new wells was integrated with existing monitoring wells and used to provide an up-to-date map showing the landward limit of the saltwater in Miami-Dade County. The U.S. Geological Survey work includes three main tasks. First, evaluate existing salt front hydrologic and geologic data and provide a draft of an updated salt line. This task was completed in October, 2008. Second, to acquire surface and/or aerial resistivity data to aid placement of new monitoring wells and construction of new monitoring wells. The installation of eight monitoring wells was completed in 2010 and their sampling was conducted in 2011. Thirdly and finally, guided by the application of surface geophysics and induction logging in existing wells, the new data was integrated with existing monitoring well data to complete a final revised position of the saltwater-freshwater interface. This task was completed in March 2011.

In 2011, the salt front line was updated again, based on additional data and sample locations. The updates were released on March 31, 2011. In general, there was no significant change between the 2008 and 2011 salt front line in the north and central areas of the County. However, the line moved further inland in the south, specifically in the C-111E canal area. WASD is currently in the process of negotiating a new joint funding agreement with USGS to update the 2011 salt front line.

The most recent report, contained in full in Appendix 3, includes review and analysis of the data collected and includes recommendations regarding the salt front monitoring network. As mentioned, groundwater levels and chloride levels throughout Miami-Dade County are monitored through the 5-year Water Resource Joint Funding Agreement (JFA) with the U.S. Geological Survey. These wells either have manual water levels taken, or have been equipped with satellite telemetry to record groundwater levels in real time.[39] Four new salt front monitoring wells were installed in 2015. Wells are monitored based on a sampling protocol developed by the U.S. Geological Survey, but every year the sampling schedule includes a county-wide sampling event conducted at the height of the dry season, to coincide with the time when inland movement of the saltwater front would be at its peak.

Results of the 2015 salt front monitoring are summarized below in Table 4. An increase in the average chloride concentration was observed for some of the wells and a slight decrease for

[39] Water level data are available from the USGS at http://www.sflorida.er.usgs.gov/ddn_data/index.html

others. However, in general, there was no significant difference between 2007 and 2015 average concentration chloride levels, with the exception of the wells located in the southeastern portion of the County, where a rapid increase in salinity has been observed in the past several years. These wells are located just east of the Newton Wellfield.

Table 4: Historic chloride data from monitoring wells from 2008-2015

Station Name	2015 Min (mg/L)	2015 Max (mg/L)	Average Chloride (mg/L) 2015	Average Chloride (mg/L) 2014	Average Chloride (mg/L) 2013	Average Chloride* (mg/L) 2012	Average Chloride (mg/L) 2011	Average Chloride (mg/L) 2010	Average Chloride (mg/L) 2009	Average Chloride (mg/L) 2008
G-3313E*	4300	5900	5100	5200	4800	4600	5600	713	1500	5400
G-3313C	4800	5400	5167	4875	4533	4350.83	4716.67	4400	4250	4200
G-3250	100	210	139	134.25	36.5	200	180.83	176	139	131
G-3229	2200	2600	2442	2250	2108.3	1883	1605.83	1217	900	807
G-3224	34	37	35	34.5	35.25	41	42.25	41	41	39
G-3162	1400	1600	1475	1541.67	1425	1267	1280	1303	1284	1208
G-1354	150	350	195	176.67	135	58	48.83	48	516	53
G-1351	390	430	406.67	399.17	436	474	491.67	503	520	530
G-1180	10	28	19	20.22	37	17	24.58	27	17	30
G-1009B	65	160	80	71.83	74	75	60.42	62	59	59
G-939	3400	4300	3767	3883.33	4108	3808	3900	3750	3333	3050
G-901	4000	5200	4650	3527.27	3058	2667	2550	2438	2550	2375
G-3611	160	160	160	165	168	165	168.75	170	172	173
G-896	260	480	347	245.83	251	258	245.33	248	235	247
G-894	14	17	15	15	17	21	22.67	22	22	21
G-571	26	28	27	26.58	28	34	35.42	34	30	32
G-548	31	34	32.58	28.58	30	31	31.5	34	36	40
G-432	5900	6800	6383	5816.67	5683	5467	5141.67	4775	4500	4150
G-354	36	44	40	40.5	42	45	46.08	49	50	53
F-279	3900	4300	4067	4116.67	3892	3675	3583.33	3475	3383	3300
F-45	120	160	143	129.5	127	118	112.92	97	97	87
G-3885	27	31	30	29.92	31	36	36.33	NA	NA	NA
G-3886	46	48	47	45.77	47	49	50.83	NA	NA	NA
G-3887	2600	2800	2692	2508.33	2442	2292	2237.50	NA	NA	NA
G-3888	5700	6300	6075	5591.67	5458	5225	5029.17	NA	NA	NA
G-3946	5100	5600	5375	5066.67	4629	4158	3716.67	NA	NA	NA
G-3947	20	23	21.27	20.67	21	25	27.92	NA	NA	NA
G-3948	4200	4500	4318.18	4275	4308	4195	3991.67	NA	NA	NA
G-3949	120	130	122	117.5	116	121	114.55	NA	NA	NA

NA=not available

*Measured only once a year

Source: Miami –Dade County Water and Sewer Department

The Water and Sewer Department, in collaboration with the U.S. Geological Survey, continued sampling 68 wells to monitor for chloride concentration and specific conductance and they are conducting a time-series electromagnetic induction log from 33 wells. Following the recommendations of the 2014 Annual report, six new wells were installed on the fresh side of the

Figure 30: Additional salt front monitoring wells installed in 2015

Source: Miami-Dade County Water and Sewer Department

2011 salt front line and were immediately incorporated into the monitoring network (Figure 30). Rapid salinity increase has been observed in the southeast area of the County, east of the Newton Wellfield, in Homestead. Monitoring well G-3966 was installed in 2014 between the Newton Wellfield and the Homestead Speedway. It quickly became salty, and is now on the saltwater side of the 2011 salt front line. In response, G-3976 was installed on the fresh side of the line in that area and is being monitored monthly to follow the advancement of the salt front in the area as closely as possible.

Additional salt front monitoring wells will be scheduled for installation in 2016, to be included in the network of wells, which provide the required data to update the saltwater encroachment along the base of the Biscayne Aquifer, as necessary. The Water and Sewer Department WASD is currently negotiating a new joint funding agreement with the U.S. Geological Survey to update the 2011 salt front line with the most current data. Additional salinity monitoring stations will be added in 2016 in south Dade in the vicinity of the advancing salt front. The Water and Sewer Department recommends that the U.S. Geological Survey update the published 2011 salt front line because monitoring has indicated that the salt front has already moved further west in part of the County since the 2011 line was published.

The issue of sea level rise may have a critical impact on Miami Dade Water and Sewer Department's operations and future water supply planning. The factors affecting salt water intrusion include wellfield withdrawal rates, climate change, rates of sea level rise, and changes to the regional water management system, including Everglades Restoration. The extent to which changing average sea levels will impact the wellfields and the Biscayne Aquifer in the coming decades is uncertain at this time due to the uncertainty surrounding these variables; however, the extensive and sophisticated monitoring network allows the County to quickly adjust operations based on changing conditions and limit the risk of saltwater intrusion.

As described in the report, *Hydrologic Conditions in Urban Miami-Dade County, Florida, and the Effect of Groundwater Pumpage and Increased Sea Level on Canal Leakage and Regional Groundwater Flow,* sea level is predicted to rise in the foreseeable future.[40] The study concludes that both increased pumping and higher sea levels may promote salt water intrusion at the

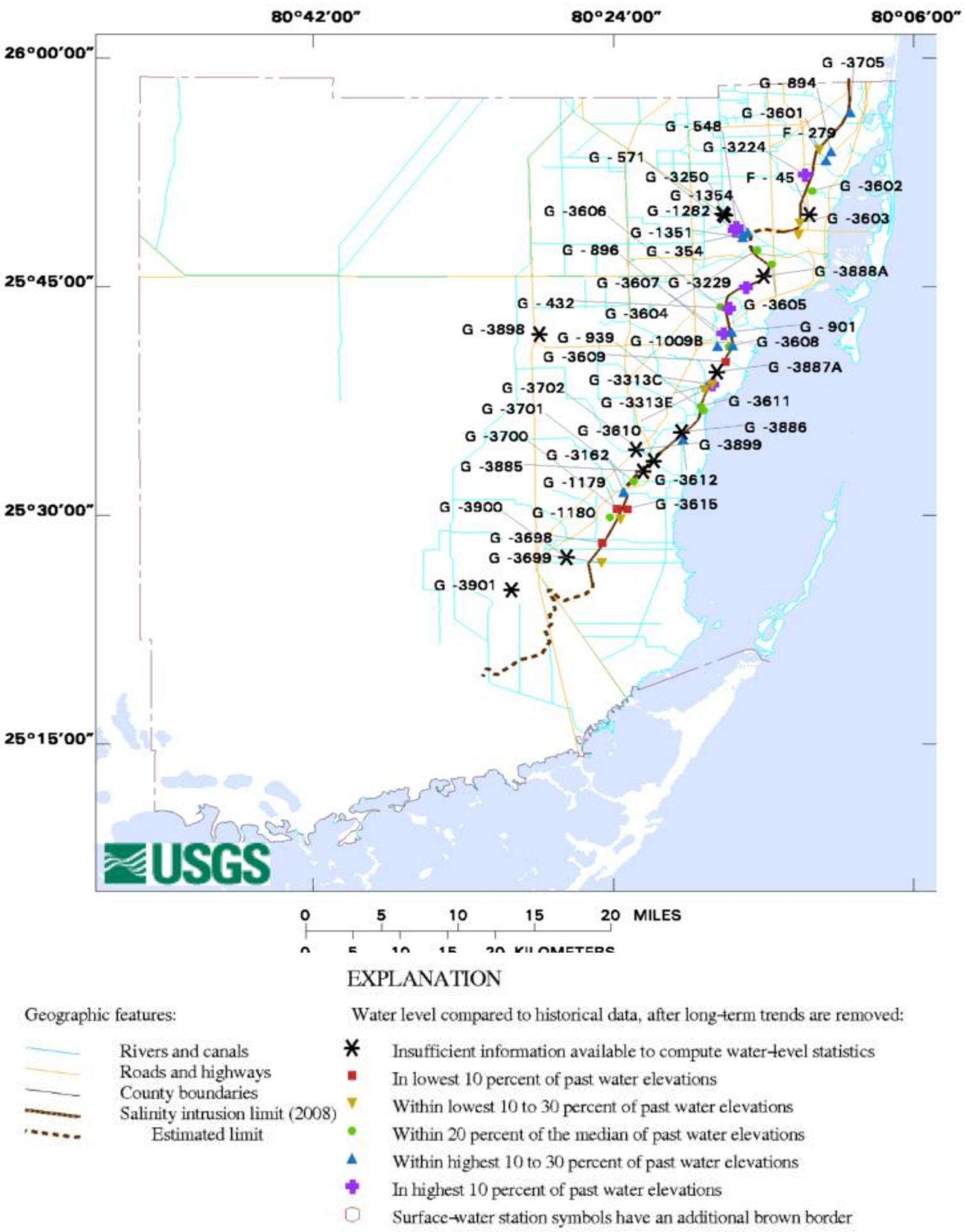
[40] "Hydrologic conditions in urban Miami-Dade County, Florida, and the effect of groundwater pumpage and increased sea level on canal leakage and regional groundwater flow "USGS 2014. Available at https://pubs.er.usgs.gov/publication/sir20145162

Miami-Spring, Hialeah, and Preston wellfields over a 30 year horizon. Miami-Dade completed an evaluation and risk assessment of Hialeah and Preston water supply which includes Miami-Springs and the evaluation recommended developing a water quality treatment plan to address this impact and Water and Sewer Department is currently working on that plan.

U.S. Geological Survey Mapping of Water Levels in Miami-Dade County

This study, described previously, is a critical component to understanding how sea level rise and groundwater pumpage will impact salt water intrusion. One figure from this comprehensive study describes how increased sea level and groundwater pumpage may affect the freshwater-seawater interface at the end of May in the 30th year of the scenario simulation period (Figure 31).

Figure 31: Water levels at selected sites, 2012

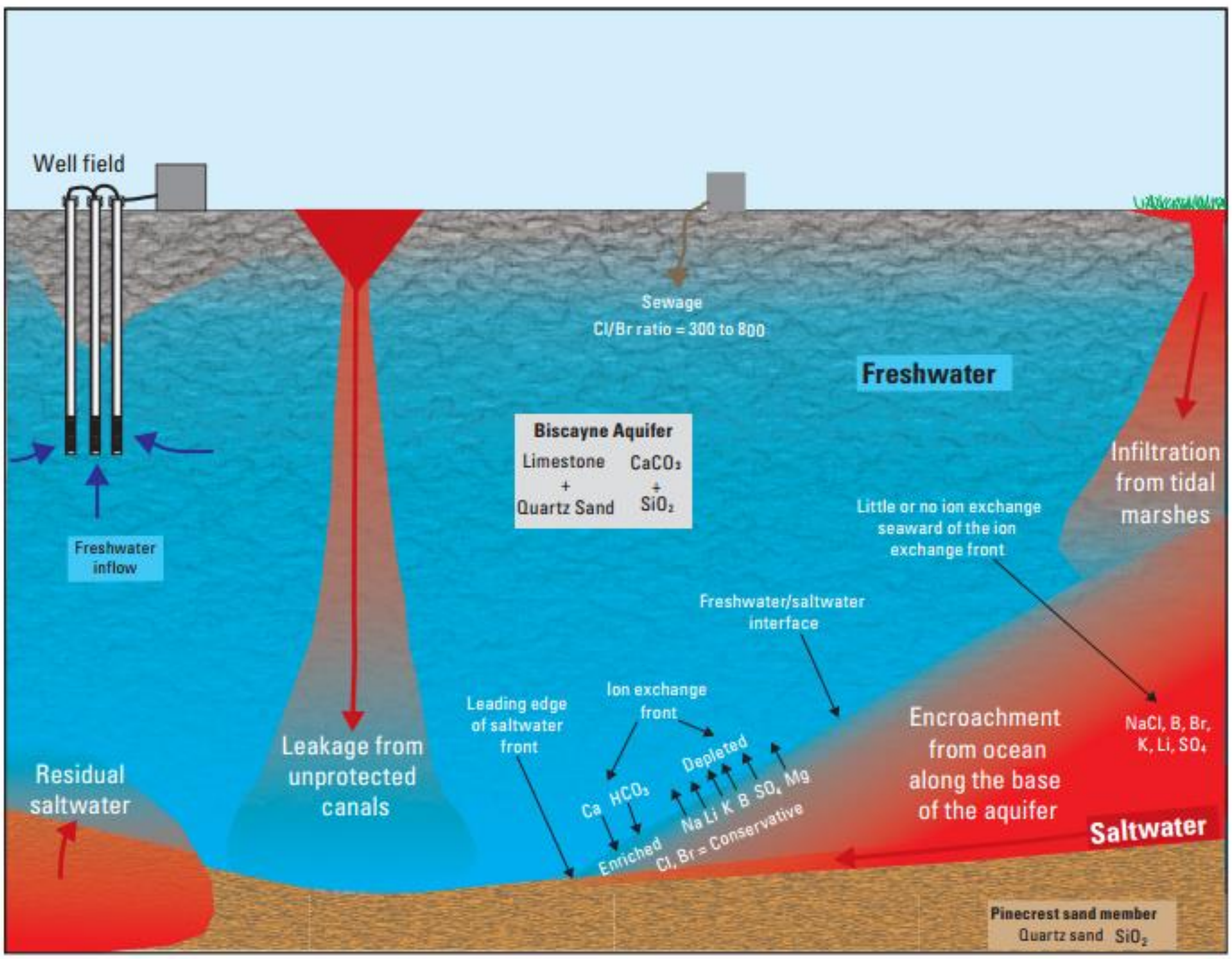


Source: U.S. Geologic Survey

U.S. Geological Survey Study on the Origins and Delineation of Saltwater Intrusion in the Biscayne Aquifer and Changes in the Distribution of Saltwater in Miami-Dade County, Florida

Saltwater intrusion of the Biscayne Aquifer began when The Everglades were drained to provide dry land for urban development and agriculture. The reduction in water levels caused by this drainage, combined with periodic droughts, allowed saltwater to flow inland along the base of the aquifer and to seep directly into the aquifer from the canals. A conceptual image of the sources and mechanisms of saltwater intrusion is shown in Figure 32.

Figure 32: Conceptual diagram of sources and mechanisms of saltwater that has intruded parts of aquifers in SE Florida



Source: U.S. Geological Survey

An examination of the inland extent of saltwater and the sources of saltwater in the aquifer was completed during 2008–2011 by using (1) all available salinity information, (2) time-series electromagnetic induction log datasets from 35 wells, (3) time-domain electromagnetic soundings collected at 79 locations, (4) a helicopter electromagnetic survey done during 2001 that was processed, calibrated, and published during the study, (5) cores and geophysical logs collected from eight sites for stratigraphic analysis, (6) eight new water-quality monitoring wells, and (7) analyses of 69 geochemical samples.

The results of the study indicate that as of 2011, approximately 1,200 square kilometers of the mainland part of the Biscayne Aquifer were intruded by saltwater. The saltwater front was mapped farther inland than it was in 1995 in eight areas, totaling about 24.1 square kilometers. In many of these areas, analyses indicated that saltwater had encroached along the base of the Aquifer. The saltwater front was mapped closer to the coast than it was in 1995 in four areas, totaling approximately 6.2 square kilometers. The changes in the extent of saltwater resulted from improved spatial information, actual movement of the saltwater front, or a combination of both.

Salinity monitoring in some of the canals between 1988 and 2010 indicated influxes of saltwater, with maximum salinities ranging from 1.4 to 32 practical salinity units upstream of the salinity control structures. Time-series electromagnetic induction log data from monitoring wells located adjacent to the Biscayne, Snapper Creek, and Black Creek Canals, and upstream of the salinity control structures, indicated shallow influxes of conductive water in the aquifer that likely resulted from leakage of brackish water or saltwater from these canals. Historical and recent salinity information from the Card Sound Road Canal indicated that saltwater may occasionally leak from this canal as far inland as 15 km. This leakage may be prevented or reduced by a salinity control structure that was installed in May 2010. Saltwater also may have leaked from the Princeton Canal.

Results of geochemical sampling and analysis indicate a close correspondence between droughts and saltwater intrusion. Comparison of average daily air temperatures in Miami, Florida, with estimates of recharge temperatures indicated that saltwater likely entered the aquifer in April or early May when water levels are typically at their lowest during the year.

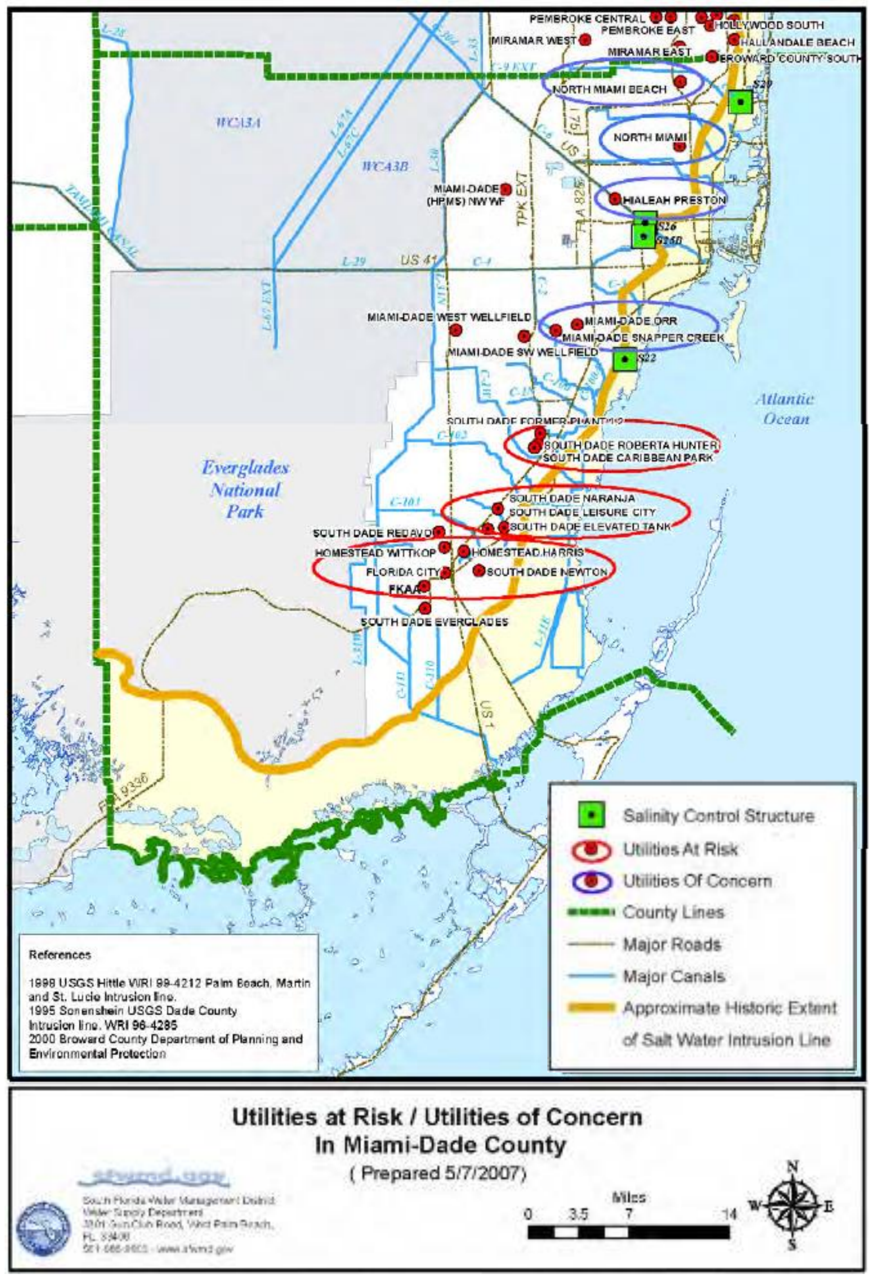
On-Going Adaptation Efforts

The South Florida Water Management District

In addition to flood control, the other three South Florida Water Management District mission elements need to be considered to develop an overall watershed management strategy: water supply, water quality, and environmental resources. Future studies will evaluate the level of service provided for these mission elements. In addition to higher risk for flooding, projected sea level rise could also cause problems with managing the water supply and natural areas of South Florida in the future as salt water intrudes into municipal wellfields and natural areas like the Everglades, likely altering habitat. To address the issue of rising sea levels causing saltwater intrusion into water supplies, the District is mapping the underground saltwater front every five years; the latest mapping was completed in 2014. The South Florida Water Management District is working with local governments that own the wellfields to incorporate the latest saltwater mapping into their water supply plans, move their wellfields, seek alternative water supplies, and emphasize water conservation

As part of the Lower East Coast Water Supply Plan Update, the District is reviewing the extent of saltwater intrusion and its potential impact on freshwater supplies throughout the region.[41] The regional canal network is operated in such a way as to minimize the risk of saltwater intrusion. The South Florida Water Management District also regulates the withdrawals from the aquifer to minimize this risk.[42] As part of that work The South Florida Water Management District has identified potential "utilities at risk" and those "of concern." Utilities were classified as "at risk" if they either did not have a western wellfield, an alternative source of water, or the ability to meet their needs through interconnection with other utilities. Additionally, other utilities were designated as "of concern" if they operated wellfields near the saltwater interface, but also had a western wellfield, or had developed an alternative source that was not threatened by saltwater intrusion.

Figure 33: Map of water utilities of concern in Miami-Dade County in 2007 relative to saltwater intrusion extent.



Source: The South Florida Water Management District

As shown in Figure 33, Miami-Dade has many facilities in the western portion of the County that have not been identified as "of concern" or "at risk." As of 2007, several facilities in the southern portion of the county were identified as "utilities at risk" and these are being closely monitored. Figure 33 also shows the approximate landward extent of the saltwater intrusion line at the time of this report.

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[41] More information is available at http://www.sfwmd.gov/portal/page/portal/xweb%20-%20release%203%20water%20supply/lower%20east%20coast%20plan

[42] More information is available at http://www.sfwmd.gov/portal/page/portal/xrepository/sfwmd_repository_pdf/2013_lec_plan.pdf

Miami-Dade County Water and Sewer Department

Miami-Dade County benefits from the extensive monitoring network, which allows the Water and Sewer Department to quickly shift water sources between wellfields as conditions require. For example, if movement of the salt front is detected in the monitoring network, withdrawals can be shifted to western wellfields to reduce pressure on eastern wellfields and reduce the risk of saltwater intrusion. Similarly, the County's ability to monitor and model long-term changes with changing sea levels and precipitation patterns gives the County the capacity to anticipate changes and adjust infrastructure and water sources as needed over the longer-term.

The County can also work with others to support regional efforts that will further reduce the risk of saltwater intrusion over the long term. For example, implementing Everglades Restoration will increase the recharge of the aquifer and will help delay saltwater intrusion. Other efforts to increase recharge such as reducing impervious surfaces, increasing detention areas, or adjusting canal stages can similarly help protect the quality of the aquifer.

The County can also continue to promote successful water conservation programs to reduce demand and increase water efficiency. These programs have already successfully delayed the need for additional infrastructure to expand capacity despite recent population growth. Continuation of these efforts will help provide future flexibility for the system.

The County is also exploring the potential to increase treatment at existing facilities should saltwater intrusion occur. While there are no immediate plans to pursue this path given its increased costs and energy demand, this remains a very technologically feasible option that could be used if conditions change in the future. Currently, however, the Water and Sewer Department is focused on enhancing the existing monitoring and modeling efforts to understand how to optimize the operation of the existing system. Current modeling suggests the major water and sewer wellfields of Northwest, West, Southwest, Snapper Creek, Alexander Orr, The South Dade Utilities, and the future South Miami Heights are not expected to be impacted by saltwater intrusion through 2040. WASD is currently working on modeling scenarios through 2075 to look at longer planning horizons.

Where Updated Information can be found

Information about the landward extent of saltwater encroachment at the base of the Biscayne Aquifer is available through the U.S. Geological Survey website.[43] This page provides information about how the map was created and provides the metadata (available in FGCD and HTML formats) as well as printable Postscript and Adobe PDF versions of the map. In addition to the map, users can access more detailed information about each of the selected monitoring sites. As of January 2016, the data available is frequently updated and provides the most recent understanding of the location of the salt front. The South Florida Water Management District also collects information about the location of the salt front annually.

More information about regional efforts to address saltwater intrusion is available from the South Florida Water Management District's Lower East Coast Water Supply Plan,[44] The Southeast Florida Regional Climate Change Compact's guidance document, "Integrating Climate Change & Water Supply Management",[45] or the U.S. Geological Survey's report, "Hydrologic Conditions in Urban Miami-Dade County, Florida, and the Effect of Groundwater Pumpage and Increased Sea Level on Canal Leakage and Regional Groundwater Flow".[46]

[43] The most recent water-level reports from groundwater wells and stream gages in southern Florida can be found on the USGS website at http://www.sflorida.er.usgs.gov/edl_data/text/mad_qw.html
[44] Available at http://www.sfwmd.gov/portal/page/portal/xweb%20-%20release%203%20water%20supply/lower%20east%20coast%20plan
[45] Available at http://www.southeastfloridaclimatecompact.org//wp-content/uploads/2014/09/rcap-igd-water-supply-final-9-9.pdf
[46] Available at http://pubs.usgs.gov/sir/2014/5162/

Potential Funding Sources

Investing in climate adaptation has the potential to yield significant savings and returns; however, implementing these measures may require new financing mechanisms. One of the primary mechanisms for supporting adaptation measures will likely be grants and special assistance programs from federal, state, regional and private entities. The following pages include a preliminary list of grants that may be suitable for certain project types.

The need to update aging infrastructure is gaining attention and political momentum at a national level. The bipartisan acknowledgement of the need for timely investment in the nation's infrastructure presents the opportunity to incorporate additional resiliency measures when updating infrastructure. Initiatives like the Transportation Infrastructure Finance Innovation Act and the Railroad Rehabilitation and Improvement Financing Program are examples of potential funding options for infrastructure-based adaptation investments. At the federal level, agencies are developing climate change adaptation plans that could include funding for components of a County-wide resiliency plan. For example, the "Climate Change Adaptation Road Map" from the Department of Defense could recognize the need to protect strategic ports or other facilities. Other federal funding could be available through Environmental Protection Agency programs which support investments in water infrastructure. A closer analysis of federal opportunities could identify other funding sources from non-traditional sources.

In addition to grants and government-based funding, resiliency measures may require innovative sources of financing. Though funding opportunities explicitly for climate adaptation are relatively new, there are resources and best practices that can help guide communities as they explore new sources. One potential approach that has already been pioneered in Miami-Dade County involves the use of Public Private Partnerships (PPPs). A recent report on innovative funding to expand national infrastructure by the Treasury Department recognized Florida as an example of permissive legislation for such partnerships.[47] There are several private sector organizations dedicated to researching and exploring opportunities for the private sector involvement in adaptation strategies. Insurance and investment companies are examples of these efforts.[48] In the case of insurance, for example, it may be of mutual interest to minimize damages and mitigate risk exposure. These natural synergies can lead to opportunities to engage with the private sector. In addition to technical cooperation through data sharing and evaluation, collaboration with the insurance sector could take the form of premium adjustments to incentivize investments in mitigation.[49]

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[47] The full report "Expanding Our Nation's Infrastructure through Innovative Financing" is available at www.treasury.gov/press-center/press-releases/Documents/Expanding%20our%20Nation%27s%20Infrastructure%20through%20Innovative%20Financing.pdf

[48] The Principles for Sustainable Insurance Initiative (www.unepfi.org/psi/) and Principles for Responsible Investment (http://www.unpri.org)a wealth of information on best practices and funding mechanisms.

[49] Municipal Climate Change Adaptation and the Insurance Industry, Harvard Law School, April 2012

Table 5 represents a subset of grants and other assistance programs drawn from a longer list created by the Office of Emergency Management in the Local Mitigation Strategy.[50] The table summarizes funding sources available to the County and other stakeholders, such as homeowners.[51]

Table 5: Grants and other state and federal assistance programs

Funding Source	Description
Florida Department of Community Affairs	• **Emergency Management Preparedness and Assistance Trust Fund** provides grants to implement projects that will further state and local emergency management objectives. • **Residential Construction Mitigation Program** provides technical and financial resources to homeowners for hurricane retrofitting. • **Florida Warning and Information Network** is a state-sponsored program to strengthen existing facilities against disasters events.
Florida Department of Environmental Protection	• **Revolving Fund Loan Program for Wastewater Treatment** provides funding to assist publicly-owned wastewater and stormwater treatment collection, transmission, disposal, and reclamation, re-use facilities as well as infiltration/inflow correction. • **Pollution Control Bond Program** provides loans to local governments for construction of stormwater, water, and wastewater facilities. Special districts are eligible as well as municipalities and county governments.
Florida Fish & Game Conservation Commission	• **Environment Education Projects** support actions to educate adult Floridians about population growth, habitat loss, coastal, and fresh water ecosystems.
Florida Inland Navigation District	• **Waterway Assistance Program & Cooperative Assistance Program** supports projects such as navigation channel dredging, channel markers, navigation signs or buoys, boat ramps, docking facilities, fishing and viewing piers, waterfront boardwalks, inlet management, environmental education, law enforcement equipment, boating safety programs, beach re-nourishment, dredge material management, environmental mitigation, and shoreline stabilization.
Federal Emergency Management Agency	• **Flood Mitigation Assistance Program** is a federal program administered in Florida by the Department of Community Affairs. Its goal is to fund cost-effective measures that reduce or eliminate the long-term risk of flood damage to property insurable under the National Flood Insurance Program. Both planning grants and project grants are project components. Planning grants assist state agencies and local governments in developing or updating flood mitigation plans that assess risk and propose possible mitigation actions. Project grants assist state agencies and local governments in implementing flood mitigation projects that will reduce risk of flood damage to repetitive loss properties identified in a flood mitigation plan. • **Hazard Mitigation Grant Program** provides funds to states, municipalities and certain private non-profit organizations to implement long-term hazard mitigation measures following a major disaster declaration. It provides 75% of the cost of elevation projects, land acquisition, relocation

[50] The full list of funding sources in available at http://www.miamidade.gov/fire/library/OEM/LMS-master-2012-12-Part-3-funding.pdf

[51] See The Local Mitigation Strategy (LMS) Part 3: The Funding available at: http://www.miamidade.gov/fire/library/OEM/LMS-master-2012-12-Part-3-funding.pdf

	of structures, or retrofitting of facilities. Funding is generated as a percent of the total cost to the federal government of a declared disaster event. • **Pre-Disaster Mitigation Program** provides funding on a nationally competitive basis to put mitigation initiatives in place prior to a disaster. Each project may receive 75% of project cost as the federal share not to exceed $3,000,000 for the federal share. • **Repetitive Flood Claims Program** is designed to reduce losses from severe flooding. Priority is given to acquisition of repetitive loss properties. No funding match required. • **The Mitigation Assistance Program** provides financial and technical assistance to states and territories, and their local governments, to create and maintain comprehensive state hazard mitigation capability. States and territories at risk to storm surge and hurricane force winds from tropical storms are eligible. • **Fannie Mae Pilot Loan Program** makes consumer installment loans available to Florida homeowners to make specific disaster prevention home improvements such as the installation of storm shutters or the construction of a safe room. All single-family homeowners in Florida are eligible for these loans.
Federal Highway Administration	• **Surface Transportation Program** can be used for enhancements in transportation infrastructure. Projects are generally selected competitively on a statewide basis.
Federal Transit Administration	• **Section 5309 capital funds** are available for fixed guideways (new starts, extensions, and rehabilitation), bus procurements, and acquisition or rehabilitation of major facilities. • **Section 5307 Urban Formula Grants** are designated for transit capital and operating assistance in urbanized areas.
U.S. Army Corps of Engineers (USACE)	• **Beach Erosion Control Projects** supports projects along public beaches to address shore erosion. • **Aquatic Ecosystem Restoration** provides a 65% federal match for construction of projects designed to carry out aquatic restoration that will improve the quality of the environment, are in the public interest, and are cost-effective. The program focuses on designing and implementing engineering solutions that restore degraded ecosystems to a more natural condition. Projects include restoration of canals, wetlands, and floodplains, including wildlife habitat. • **Flood Plain Management Services** provides USACE's services in planning and technical services without charge to state, tribal, and local governments for studies, including hurricane evacuation studies, comprehensive flood plain management studies, flood damage reduction studies, urbanization impact studies, stormwater management studies, and inventories of flood-prone structures. • **Planning Assistance to States** allows the USACE to assist local governments in the preparation of comprehensive plans for the development, utilization, and conservation of water and related land resources with up to 50% federal match. • **Technical and planning assistance** may include wetlands evaluation studies, flood damage reduction studies, flood plain management studies, and water quality/quantity studies. • **Project Modifications for Improvement of the Environment** provides funding for ecosystem restoration by modifying the structures and/or operations of water resources projects constructed by the USACE, or by

	restoring areas where a USACE project contributed to the degradation of the area. • **Emergency Bank Protection Program** provides bank protection of highways, highway bridges, essential public works, churches, hospitals, schools, and other nonprofit public services endangered by flood-caused erosion.
U.S. Department of Agriculture	• **Emergency Watershed Protection Program** provides technical and financial assistance to local sponsors for the relief of imminent hazard and reduction of the threat to life and property in watersheds damaged by severe natural events that are either local or national in nature. Disaster area declaration is not required. The act also authorizes the purchase of rural and agricultural floodplain easements designed to retire land from frequent flooding to preclude federal disaster payments, retire land to allow levee setbacks, or limit the use of the land. • **Watershed Surveys and Planning** studies are used for appraising water and related land resources and formulating alternative plans for conservation use and development. Studies are designed to provide specific information needed for planning purposes related to non-traditional flood recovery and flood plain management strategies, including land treatment measures, nonstructural measures, and structural measures. • **Rural Utilities Service Water and Waste Disposal Program** provides grants and loans to rural communities for wastewater, drinking water, solid waste, and storm drainage projects.
U.S. Department of Commerce	• **Coastal Zone Management Program Section 306 Grants** are used for coastal hazard mitigation strategies, including the development of local hazard mitigation plans, outreach and education activities, monitoring programs, and projects to enhance program management. • **Section 308 Grants** provide emergency grants to address a wide range of unforeseen or disaster-related circumstances. • **Section 309 Grants** are competitive funds designed to enhance state programs, including planning and land regulation activities, enhancing natural features, and preventative measures. • **Economic Development Administration Business Recovery Loans** program is designed to promote long-term economic development in areas experiencing substantial economic distress. Examples of projects include port development and expansions, and construction of infrastructure necessary for economic development (water/sewer).
U.S. Environmental Protection Agency	• **Clean Water Act Section 319 Grants** are awarded to implement certain non-point source programs including wetland restoration. • **Brownfields Economic Redevelopment Grants** are intended to prevent, assess, safely clean up, and sustainable reuse of Brownfields. • **Urban Waters Program** designed to help local residents and their organizations, particularly those in underserved communities, restore their urban waters in ways that also benefit community and economic revitalization.
U.S. Department of Homeland Security	• **The Citizens Corps** mission is to bring community and government leaders together to coordinate community involvement in emergency preparedness, planning, mitigation, response, and recovery. Note: The Department has recently expressed its intention to increase interactions with local governments to "combat and adapt to climate change" as well as promote "resilient infrastructure through partnerships

	with the public and private sectors". The Department is currently supporting pilot projects focused on sea level rise in other jurisdictions.
U.S. Department of Housing and Urban Development	• **Community Development Block Grant Small Cities Program** and the **Entitlement Communities Program** provide funding to cities to improve local housing, streets, utilities, and public facilities. Disaster Recovery Initiative funds are provided for disaster relief, long-term recovery, and mitigation activities in areas affected by a presidential disaster declaration.
U.S. Department of the Interior	• **Federal Land-to-Parks Transfer Program** provides funds to identify, assess, and transfer available surplus federal real property to state and local entities for use as parks, recreation areas, and open space. • **Land Acquisition program** identifies and acquires high quality lands and waters for inclusion into the National Wildlife Refuge System. • **North American Wetland Conservation Fund** provides funds to stimulate public- private partnerships to protect, restore, and manage a diversity of wetland habitats for migratory birds and other wildlife. • **Partners for Fish and Wildlife** provides financial and technical assistance to private landowners, businesses, and local governments interested in restoring wetlands and riparian habitats on their land. • **Rivers, Trails, and Conservation Assistance Program** provides staff consultants and technical assistance for river and trail corridor planning and for open space preservation efforts.

Grant funding will likely be useful to support many individual projects, however, more sustainable mechanisms will be required for larger-scale projects. Potential funding sources for such adaptation measures have been thoroughly outlined in a recent publication *Sea-Level Rise Adaptation Financing at the Local Level in Florida.*[52] This detailed white paper outlines a myriad of potential sources, their legal basis, potential legal issues or challenges, their relative strengths and weaknesses. Most importantly, the paper reviews each funding mechanism in terms of their appropriateness for supporting adaptation investments. Because the publication is focused specifically on sea level rise adaptation and Florida, it was used as the basis for the summary table below (Table 6). Many other resources exist which summarize funding options for adaptation more generally.[53] In addition to the potential mechanisms listed in this table, there may be additional sources within the twenty-five chapters on Taxation and Finance under title XIV.

[52] Houston Endowment, Thomas Ruppert & Alex Stewart, Sea-Level Rise Adaptation Financing at the Local Level in Florida, (Sept. 2015) Available at https://www.flseagrant.org/wp-content/uploads/Local-Gov-Financing_FINAL_10.8.15.pdf

[53] For example see the U.S. Resilience Toolkit available at https://toolkit.climate.gov/content/funding-opportunities or more targeted resources such as the U.S. EPA's resource on funding for green infrastructure available at: http://www.epa.gov/sites/production/files/2015-02/documents/gi_financing_options_12-2014_4.pdf or the Johnson Foundations resource on funding water infrastructure http://www.johnsonfdn.org/sites/default/files/reports_publications/WaterInfrastructure.pdf

Table 6: Potential funding mechanisms for adaptation measures drawn from "Sea-Level Rise Adaptation Financing at the Local Level in Florida"

Funding Mechanism	Strengths	Weaknesses	Considerations
Ad Valorem Taxes and Municipal Service Taxing Units (MSTUs)	• Offers flexibility: may be used for many purposes • No requirement of specific benefit proportional to or even related to taxed properties for *ad valorem* assessments • May not require a referendum to extend beyond millage limit in certain exceptions	• May offer limited funding due to millage limitations • Could require referendum to surpass millage limits in certain cases • MSTUs may result in increased responsibility of the local government to provide the services for which property is charged	• Offers flexibility to use levied taxes on functions that offer a 'real and substantial benefit to citizenry, including adaptation measures • May be increased without referendum for certain legally provided exceptions such as need for "government responsibility to properly manage beaches" • A direct connection between taxation and services is required for MSTUs
Special Assessments and Municipal Service Benefit Units (MSBU)	• May offer flexibility in terms of how the funds can be spent so long as it provides a direct special benefit proportional to each assessed property • Can support capital improvements and services for SLR adaptation • Not subject to millage limitations • Established and recognized methods of ensuring special assessment is proportional to benefits can be adapted to SLR scenarios	• Must meet requirements of special assessments • Cannot be levied on school boards or public colleges without consent • Must carefully ensure that the assessment for each property is not greater than proportional benefits to that same property • Cannot be used for general services that do not provide special benefit to the real property assessed	• A direct, special benefit is required. Assessed properties must be "fairly and reasonably apportioned" in relation to the special benefits received • Issues may arise if SLR adaptation disbursements are (1) not directly providing special benefits to real property, (2) considered a general government service, or (3) if the assessment is in excess of proportional benefits as compared to assessments on other properties
Local Option Tourist	• May facilitate a quicker pay off	• May require a referendum	• The funding stream could require a referendum

Development Tax	of bond debts accrued through beach nourishment or other projects addressing erosion • Well suited to address issues of beach nourishment, beach erosion control, park facilities, etc. • May offer flexibility within the specific uses detailed in statutory language	• Potential scope for the use of the funding for SLR may be more narrowly defined (beach nourishment, maintenance, preservation, restoration, erosion control) • May face competition from other statutorily allowed demands for funds (advertisement, capital expenditures) • The income stream is limited (between 2-6% on short-term rental transactions) with the tax available for beach maintenance, erosion, and related beach activities limited to a 2-3% tax, depending on the county	• Once available it will allow spending for SLR adaptation that aligns with the definition in the statue and follows its strict parameters, which may be limited to beach nourishment maintenance and erosion control, and other specific actions directly linked to areas of tourism • Low risk of legal issues if clearly defined statutes are followed
Stormwater & Drainage Fees	• Well understood mechanism • Can be raised to support future capital projects for future outlays specific to stormwater management and drainage systems • Relatively flexible in terms of 'how' and 'what' fees can be raised, as statute allows for collection of "enough to meet the system's capital requirements, as well as to defray operating expenses." • May address an important aspect of SLR adaptation needs and allow fund collection for future	• Scope of uses for the funds raised will be quite limited to stormwater and drainage systems • Fees must be tied to the capital and operating requirements of stormwater and drainage systems • Some agencies of the state may assert sovereign immunity if the agency does not have a contract with the utility • Developing schedule of fees might present a challenge	• May offer appropriate source of funds with relative flexibility for investments in management of stormwater and drainage systems • Flexibility exists in regard to funding mechanisms with options to adopt stormwater utilities and stormwater fees, establish set asides to invest in stormwater management system, or create stormwater management system benefit areas • When setting up a system benefit area, local governments must comply with the process as defined in section 403.0893 (3) and special assessments in section III • Stormwater utilities that charge fees, should set a differential fee that relates use of the service to the property

	stormwater and drainage needs		
Bonds	• Fairly broad range of potential funding and use restrictions • Allow for significant funds • Liberal definition of statues allowing for capital directed at serving a public purpose	• Require an ordinance or resolution as part of issuance • Ad Valorem bonds and General Obligation Bonds require a referendum • Might be limited by credit rating of each municipality • May be subject to financing costs (interest) • Subject to challenge by property owner or interested party if issuance is not clearly established by prior use and precedent or if procedures are not followed adequately. Challenges can occur even if a court has validated the decision • Requires strong argument that home rule powers allow bonds	• Bonds provide ample and potentially adequate levels of funding for SLR adaptation because constraints are general and limited to the requirement that the investment serve a public purpose • Potential limits include importance of strict adherence to correct processes and potential for bonds to be challenged by property owners or interested parties • Other limits include a required referendum for bonds that pledge faith and credit of local governments (ad valorem and general obligation bonds)
Special Districts	• Intended to assist property owners for a specific purpose, which could include adaptation to SLR • The nature of special districts, whereby they are instituted in furtherance of a specific function are complementary to specific needs related to SLR adaptation	• Creation of special districts, whether dependent or independent, requires compliance with formation requirements as laid out by state statutes • Both dependent and independent districts are bound by millage limitations, requiring referendum prior to any increase o Dependent special districts are restricted by statutorily defined millage limitations o Millage levied by independent special districts may not exceed amount authorized by law or approved by electorate with exception of units focused on water management	• The characteristic of special districts that bind their formation to a specific public purpose that is closely related to SLR adaptation makes them a useful funding mechanism for local governments • Possible limitations include millage limitations and referendum requirements • Each type of special district (dependent and independent) or unit of local government created for a special purpose has various requirements and processes • Independent special districts must be created by legislature while dependent districts can be created by municipalities
Local Government Infrastructure Surtax	• Allows a county to levy a 0.5 or 1.0 percent tax pursuant to an ordinance of a Board of County	• Requires a referendum • Have limits of use specific to those that "finance, plan and construct infrastructure" and "acquire land for…	• Offers a substantial resource to local governments with a project proposal • A ballot must include a general description of the proposed project

	Commissioner only when there is a majority vote of the electors in a referendum • Permits fund allocation to investments relevant to adaptation	protection of natural resources."	• Even though it requires a referendum because the proposed projects will need to be described, there is an opportunity to communicate the project's benefit to the public
Charter County and Regional Transportation System Surtax	• The amount levied may be up to 1.0 percent in the form of a sales surtax, and may be used for various uses related to road and bridge infrastructure (construction and maintenance)	• Applicable to counties that meet requirements detailed in Fla. Stat. §212.055 (1)(a) and subject to approval by majority vote of the electorate in a referendum	• If a county meets the requirements, the county may levy a discretionary sales surtax that is subject to approval by majority vote of the electorate in a referendum
Other	• Electric Franchise Fee: may be collected from revenue of government owned utility or fees already charged to local electric service provider • Communications Service Tax: returns from the state mandated communications tax can be an additional source of income		

Conclusion and Next Steps

Research Gaps and Needs

The studies and initiatives highlighted throughout this report reflect the significant progress made and ongoing to understand the risks, challenges and opportunities to adapt to expected sea level rise. This understanding has been built over several years and only through extensive collaboration between agencies, universities, and many other stakeholders. In addition to leveraging local capabilities, Miami-Dade County has partnered with international experts from the Netherlands, with national scientific experts within the U.S. Geological Survey, The Army Corps of Engineers, and the Federal Emergency Management Agency, and with regional entities, including local universities recognized for their exceptional research. Close collaboration with peer governments, which has been facilitated through the Southeast Florida Regional Climate Change Compact, has helped to strengthen this network, helped articulate research needs, and has helped to attract research dollars to the region.

Because sea level rise will impact the risks of flooding and saltwater intrusion in complex and indirect ways, it is necessary to draw upon scientists from many disciplines and integrate multiple methodologies and models to understand the implications of changing sea levels. In the case of flooding risk it is essential to understand the direct impacts in the form of increased duration, depth, and extent of tidal flooding. It is arguably more important, however, to understand the secondary impacts caused by storm surge amplified by higher water levels or the effects of decreased capacity of gravity-based drainage infrastructure to drain the land after a rain event. At an even more granular level, it is important to understand the capacity of each major pump or flood control structure to function under changing conditions and to test the potential effectiveness of alternative infrastructure. Therefore, understanding the effects of changing average sea levels requires understanding how the different components of the system will respond and how they will in turn affect each other.

Many efforts are underway to integrate various efforts and synthesize their results. One of the most important of these efforts is the South Florida Water Management District's Level of Service Assessment and Miami-Dade County Water Management Division's efforts to understand the implications for Miami-Dade County's stormwater basins. While these efforts are underway, they will require additional resources to complete and will require subsequent coordination to implement their findings and integrate them into relevant policies.

This progress could be expedited by providing additional support to the Water Management Division. As was stated earlier in this report, the Water Management Division first incorporated sea level rise modeling scenarios into evaluation of future flood protection thresholds (Level of Service) in 2011. Since then, analysis has been continually adapted to incorporate new projections. To date, the Water Management Division has updated the Biscayne Bay Canal in 2014 and Arch Creek in 2015 (C-8 basin) and is working on the Snake Creek (C-9) and Oleta River basins. If current resource levels are maintained, the update cycle for the 20 basins in the system is expected to take 10 years; however, needed revisions could be completed for all basins in five years with additional resources dedicated to staff, surveying, mapping and modeling. Increased funding would expedite cycle updates and would help maintain flood protection, forecasting and evaluation of regional water quality, implementation of engineering solutions, and evaluation of long-term strategic infrastructure investments.

As described previously, there are also multiple studies recently completed or underway that have attempted to relate the risks of flooding with different measures of exposure or vulnerability. For example, these research efforts have focused on attempting to quantify the economic impacts of urban flooding or potential damage from storm surge. Other efforts, such as the project with the Army Corps of Engineers, are focused on quantifying how certain protective assets such as dunes and mangroves can reduce that damage. While the economic consequences of sea level rise are components of the several on-going projects, including the RAND study and other collaborative efforts with insurance brokers and reinsurance companies, this is an area that will require significant further study and effort. In particular, it will be necessary to improve existing approaches to assessing the costs, benefits, and trade-offs associated with different adaptation pathways.

Despite the recent advances, there remains a need for research to increase our understanding, incorporate new information, and develop innovative, cost-effective solutions. Assumptions and modeling efforts will need to be continually revisited and updated based on new scientific information, and recalibrated in the wake of a major storm. Continuing to improve the level of cooperation with partners including our local universities, the South Florida Water Management District, The Army Corps of Engineers and the U.S. Geological Survey is a key to advancing these goals. Working through The Compact has been a critical component to connecting the County with these partners, strengthening collaboration, and bringing in new resources and experts to the region. These partnerships have proven beneficial to the County. For example, the County's partnership with the U.S. Geological Survey has greatly advanced the current saltwater intrusion monitoring work that helps protect the County's drinking water source.

In addition to research needs, the County can accelerate the implementation of adaptation efforts by supporting successful on-going initiatives such as the Local Mitigation Strategy, the beach nourishment program, and stormwater management improvements. The Local Mitigation Strategy is one example of the County's collaboration with the community to reduce long-term risk to citizens and property. As detailed in this report, the Local Mitigation Strategy is updated semi-annually and consists of a multi-volume plan to address known hazards, including flooding. The Strategy has informed investments in 23 projects currently under construction and supported the completion of 12 projects in 2015. In addition to stimulating local construction and engineering work, studies have demonstrated that four dollars are saved for every dollar invested in mitigation. Increasing the strategic investment in mitigation would not only directly reduce the community's immediate vulnerability to storms, it could also simultaneously reduce long-term vulnerabilities to sea level rise. There are currently more than 1,000 listed mitigation projects that are without an identified funding source.

Next Steps

There is increasing attention by Miami-Dade County, local research institutions, and communities to invest in knowledge of the challenges and opportunities ahead. Miami-Dade County has collaborated with several partners including the South Florida Water Management District, U.S. Geological Survey, member counties in the Southeast Florida Climate Change compact, and the Army Corps of Engineers to harness existing information to improve the County's resilience to the effects of climate change. This effort has resulted in numerous collaborative efforts, which have only been briefly summarized.

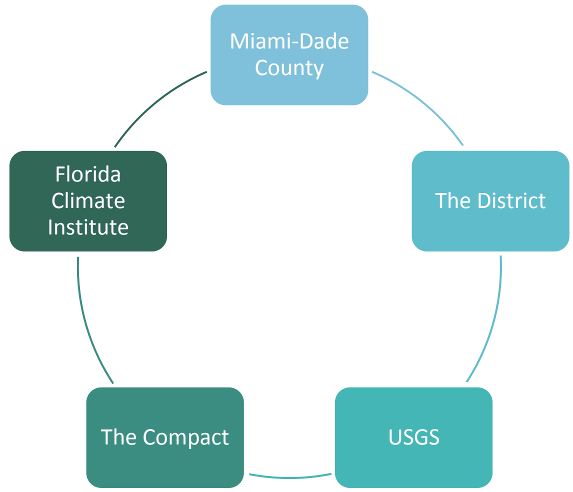
This report was developed over the last year with assistance from the aforementioned partners and other collaborators who provided a general overview of the studies and efforts to address the implications of sea level rise on flooding and saltwater intrusion; however, given the extensive scope of activity, it is not possible to provide full details on all of these efforts. Collectively, this research and multiple initiatives represent millions of dollars in investments directed to better understand these issues. It is important to note that Miami-Dade County has also been fortunate to benefit from substantial outside investment from the philanthropic community and federal agencies.

While this report provides a snapshot, many of these initiatives are on-going. For example, to improve their ability to reduce the risks of flooding, the South Florida Water Management District is working to evaluate the current and future levels of flood protection to identify and prioritize long-term infrastructure needs. The agency is conducting studies to identify hazards and possible mitigation activities, and is collaborating with Dutch experts to share expertise, strategies and information (see pages 13, 14, and 39). Miami-Dade County is also partnering with the U.S. Geological Survey to analyze groundwater flows and map changes in groundwater levels (see pages 14-17 and 49-51). A partnership with the RAND Corporation is allowing the County and Compact partners to study the interactions of new infrastructure and land use changes on future water management needs and potential flooding damages (pages 17-18). The County is also assisting the Federal Emergency Management Agency in revising and updating the County's Flood Insurance Rate Maps to more accurately reflect current conditions and the most accurate mapping techniques (see pages 18-19). Some projects are bringing together several partners like the U.S. Army Corps of Engineers, the U.S. Geological Survey, and the Nature Conservancy, to study risk mitigation alternatives and assess the potential for nature-based coastal defenses (see pages 19 and 21). In addition to County-led collaborations, Miami-Dade is also working with local and national universities through research initiatives like the Sustainability Research Network-Urban Resilience to Extremes (see page 20-21). It is worth underscoring the significant contribution the Southeast Florida Regional Climate Change Compact has made to facilitating a coordinated regional approach and attracting additional resources.

Research Steering Committee

As evidenced by the breadth and depth of the various research projects, there is a constant need for coordination and synthesis to translate these findings into smarter decision-making. Currently, Miami-Dade County staff drawn from the Office of Resilience, the Water and Sewer Department, Emergency Management and the Stormwater Masterplan program have been coordinating these internal and external efforts. This group coordinates very closely with the South Florida Water Management District, the U.S. Geological Survey, the Florida Climate Institute, and the Compact. This group helps coordinate these efforts by working with project managers to adjust the scope of work for new projects to align with the needs of practitioners in the region, sharing findings and data between projects, and assisting in the publication and dissemination of research findings to the public. To date, this coordination has been ad-hoc; however, through the development of this report the coordination has increased. Moving forward, this group will formalize its activities by meeting quarterly and providing an update on research efforts through the Florida Climate Institute, the Compact, and the Office of Resilience (Figure 34).

Figure 34: Sea Level Rise Research Steering Committee



Conclusion

This report is submitted in support of Resolution R-48-15, which directs the Mayor or his designee to work in conjunction with experts and stakeholders at various levels to "conduct a comprehensive study and develop adaptation strategies to address potential flood damage reduction and saltwater intrusion associated with sea level rise and to put forth a time frame for implementation and potential funding mechanisms." It is apparent from this report that there is extensive on-going critical research that is intended to lead to a better understanding of the impact of sea level rise on flooding and salt water intrusion in Miami-Dade and the Southeast Florida region. Because of the breadth and complexity, this report is designed to provide a snapshot and summary of the extensive and interconnected work taking place. This report is also designed to provide a roadmap to resources where updated information can be found, including synthesized, user-friendly and publicly accessible tools and web pages. The Office of Resilience can provide additional information on any of the covered studies or projects and will keep abreast of new studies and updated data.

Though rising sea levels present several challenges, there is wide recognition of this and a deep network of professionals working to increase understanding of the issues in order to develop effective responses and adaptation strategies. Enhancing these efforts and collaboration with local, national and international experts continues to be of strategic importance to the County and will continue be an integral component of identifying effective adaptation strategies as the County develops its Resilience Strategy in the coming year and moves forward with implementation.

Appendix 1: Relevant Research from Local Universities

The following summary table is followed by a synopsis of research provided to the Miami-Dade County Office of Resilience from colleagues at the Florida Climate Institute and affiliated academic research centers. The research below underscores the depth of local expertise and knowledge, but represents only a small sample of the remarkable research that is happening. Many other relevant research is on-going at other institutions both within the region and at universities across the country. Furthermore, these research summaries present only a snapshot of the status of research as of the fall of 2015 and many of the initiatives highlighted below will continue to evolve quickly over the coming years.

Summary of Relevant Research from Florida Universities			
General Topic	**Title**	**Project Timeframe**	**External affiliations**
Florida Atlantic University			
Sea-level rise-adaptation	NSF Grant for Coastal SEES Collaborative Research: A cross-site comparison of salt marsh persistence in response to sea-level rise and feedbacks from social adaptations	January 1, 2015- ~December 31, 2018	National Science Foundation (NSF) Funding
Water supply, sea level rise	Development of an adaptation toolbox to protect southeast Florida water supplies from climate change	October 2011	N/A
Resilience to extreme events (infrastructure)	Civil Infrastructure Systems CRISP Type 2/Collaborative Research: Probabilistic Resilience Assessment of Interdependent Systems (PRAISys)	September 1, 2015- ~August 31, 2018	NSF Funding
Sustainable redevelopment	Subtropical Sustainable: A context sensitive design approach to redevelopment in Broward County	2008	N/A
Florida International University			
Saltwater intrusion, sea level rise	Biscayne Aquifer Hydraulic Conductivity	2008	N/A
Socioeconomic impacts of sea level rise	Sea Level Rise Impacts on South Florida	2011	Hurricane Research Center
Sea level rise-infrastructure & saltwater intrusion	Making Robust Infrastructure Adaptation Decisions under Uncertainty	Ongoing	N/A

Summary of Relevant Research from Florida Universities (continued)			
General Topic	**Title**	**Project Timeframe**	**External affiliations**
Ecosystem adaptation to sea level rise	Understanding mechanisms that maintain wetland elevation in south Florida coastal ecosystems	2011-ongoing	SFWMD,[54] Everglades Found. & ENP[55]
Urban resilience to extreme events	Urban Resilience to Extremes Sustainability Research Network	Ongoing	N/A
	List of 9 ongoing dissertations		
Florida State University			
Hydroclimate models	Understanding and projecting precipitation variability over Florida using high resolution climate models	Ongoing	COLA[56]
University of Central Florida			
Flood-hazard maps and analysis	Analyses for Adaptation of Drainage Infrastructure in a Coastal Urban Watershed via a Worst-Case Scenario of Storm Surge and Precipitation Variability under Climate Change and Sea-Level Rise Impacts	N/A	FL Sea Grant Program, Pinellas County
University of Florida			
Sea level rise, saltwater intrusion and human response	Sea-level rise and coastal water resources	Ongoing	NSF[57] Funding
Multi-disciplinary sea level rise adaptation plan	Science-Collaborative Resiliency Planning on Florida Atlantic and Gulf Coasts	2011-2015	FL Sea Grant & NERRS[58] Funding
Adaptation to sea level rise, land use	ReCharting Longboat Key: Toward Community, Economy and Resiliency	April 2015	N/A

54 South Florida Water Management District
55 Everglades National Park
56 Center for Ocean-Land-Atmosphere Studies
57 National Science Foundation
58 National Estuarine Research Reserve System Science Collaborative

Summary of Relevant Research from Florida Universities (continued)			
General Topic	**Title**	**Project Timeframe**	**External affiliations**
Saltwater intrusion	Seawater Intrusion Impacts on Drinking Water Production	2014	N/A
Coastal inundation forecasting & impact	Assessing Climate Change Impacts on Hurricanes, Sea Level Rise and Coastal Inundation, and Coastal Ecosystems and Infrastructures	Ongoing	Working group
Water conservation-aquifers	Effectiveness of residential water conservation and demand management programs	Ongoing	N/A
Adaptation Strategies, reallocation	A Parameterized Climate Change Projection Model for Hurricane Flooding, Wave Action, Economic Damages and Population Dynamics – R/GOM-RP-2	2011-2012	FL Sea Grant, of Panama, FL
Facility adaptation planning	Development of Sea Level Rise Adaptation Planning Procedures and Tools Using NOAA Sea Level Rise Impacts Viewer	~2012	Mississippi-Alabama Sea Grant Consortium Funding
Evaluation of adaptive strategies	A Spatial-Temporal Econometric Model to Estimate Costs and Benefits of Sea-Level-Rise Adaptation Strategies – R/C-S-51	Ongoing	Florida Sea Grant, TBRPC[59]

Florida Atlantic University Submissions

NSF Grant for Coastal SEES Collaborative Research: A cross-site comparison of salt marsh persistence in response to sea-level rise and feedbacks from social adaptations

Researcher: Colin Polsky with Principal Investigator Karen McGlathery kjm4k@virginia.edu (Principal Investigator) and Patricia Wiberg (Co-Principal Investigator)
Institution: Florida Atlantic University
E-mail: cpolsky@fau.edu

Relevance to adaptation: Nearly half of the world's population lives within 100 kilometers of the coast, the area ranked as the most vulnerable to climate-driven sea-level rise (SLR). Projected rates of accelerated sea level rise are expected to cause massive changes that would transform both the ecological and social dynamics of low-lying coastal areas. It is thus essential to improve understanding of the sustainability of coupled coastal human-environment systems in the face

[59] Tampa Bay Regional Planning Council

of SLR. Salt marshes are intertidal habitats that provide a buffer for coastal communities to SLR and are also valued for many other ecosystem services, including wildlife habitat, nutrient cycling, carbon sequestration, aesthetics, and tourism. They are highly dynamic systems that have kept pace with changes in sea level over millennia. However, projected rates of SLR and increased human modification of coastal watersheds and shorelines may push marshes past a tipping point beyond which they are lost. Developing realistic scenarios of marsh vulnerability demands an integrated approach to understanding the feedbacks between the biophysical and social factors that influence the persistence of marshes and their supporting functions. This project will examine the comparative vulnerability of salt marshes to SLR in three U.S. Atlantic coastal sites that vary with respect to sediment supply, tidal range and human impacts. The research team will also address how feedbacks from potential adaptations influence marsh vulnerability, associated economic benefits and costs, and practical management decisions. Additional broader impacts include incorporating research results into curriculum used at local schools, an on-line cross-disciplinary graduate course, and on-going teacher-training programs, as well as training one postdoctoral researcher, four graduate students, and eight undergraduate researchers. This project is supported as part of the National Science Foundation's Coastal Science, Engineering, and Education for Sustainability program - Coastal SEES.

This project leverages the long-term data, experiments and modeling tools at three Atlantic Coast Long-Term Ecological Research sites (in MA, VA, GA), and addresses the broad interdisciplinary question "How will feedbacks between marsh response to SLR and human adaptation responses to potential marsh loss affect the overall sustainability of the combined socio-ecological systems?" The goals of the project are to understand: 1) how marsh vulnerability to current and projected SLR, with and without adaptation actions, compares across biogeographic provinces and a range of biophysical and social drivers; and 2) which marsh protection actions local stakeholder groups favor, and the broader sustainability and economic value implications of feasible adaptation options. The biophysical research uses historical trends, "point" and spatial models to determine threshold and long-term responses of marshes to SLR. Social responses to marsh vulnerability are integrated with biophysical models through future scenario planning with stakeholders, economic valuation of marsh adaptation options, and focus groups that place the combined project results within a concrete policy planning context to assess how marshes fit into the larger view of coastal socio-ecological sustainability. This integrated approach at multiple sites along gradients of both environmental and human drivers will allow for general conclusions to be made about human-natural system interactions and sustainability that can be broadly applicable to other coastal systems.

Start date: January 1, 2015. Estimated end date: December 31, 2018
NSF Grant: http://www.nsf.gov/awardsearch/showAward?AWD_ID=1427282

Development of an Adaptation Toolbox to Protect Southeast Florida Water Supplies from Climate Change

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Relevance to adaptation: Sea level rise and changes in precipitation patterns due to climate change present a challenge to water resources engineers and planners in southeast Florida with regard to sustainable water supplies and Everglades restoration. Because over half of the urban areas of Miami–Dade and Broward counties, as well as portions of Palm Beach County (home to 5 million people), are at an elevation below 5 feet national geodetic vertical datum (NGVD), protection against sea level rise and coastal migration presents a challenge. Current approaches to water supply will not protect the resilience and prolong the sustainability of the region's water resources. In this paper, the authors outline the potential effects of sea level rise scenarios for coastal southeast Florida and develop a toolbox of options for adaptation for water, wastewater, and stormwater utilities to apply. Any given option may not be appropriate for all utilities, and any given utility may deem there to be benefits to pursuing multiple strategies on a timeline in keeping with the latest estimates of sea level rise. The authors also developed milestones to trigger infrastructure investments, as climate changes may occur more rapidly or more slowly than currently projected.

Bloetscher et al. 405

Table 2. Summary of water supply benefits and climate change benefits from various tools in toolbox (after Heimlich et al. 2009).

Tool	Benefit to water supply	Climate change benefit
Install local pumping stations	None – reduces aquifer levels	Reduce flooding in low lying areas
Water conservation	Lowers per capita use, stretched current supplies	Reduces stress on vulnerable water supplies
Armoring the sewer system	Protects water quality and supply	Protect reclaimed water option but protecting water quality
Wastewater reclamation	Replaces use of fresh water for irrigation and industrial use	Replaces vulnerable water supplies
Aquifer recharge	Reduces raw water requirements	Recycles existing water to increase available fresh water
Protection of existing water sources	Protects water quality and supply	Reduces stress on vulnerable water supplies
Strategic well relocation	Reduce impact of coastal supplies	Increased fresh water available for countering impacts
Horizontal wells	Skims fresh water	Increased fresh water available for countering impacts
Re-engineering canal systems	Controlling water tables and protecting against contamination	Flood control
Hydrodynamic barriers	Controlling water tables and protecting against contamination	Reduce saltwater intrusion
Capture and surface storage of excess runoff	Storage mechanism for existing	Increased fresh water available for countering impacts
Septic tank closure	Protect groundwater quality	Increased fresh water availability
Close private wells	Protect groundwater quality	Increased fresh water availability
Desalination	New water source	Replaces vulnerable water supplies
Aquifer storage and recovery	Storage mechanism for existing	Increased fresh water available for countering impacts
Regionalization of alternative water supplies	Shared risks of water supply options	Economies of scale for wastewater and stormwater recovery and reuse

Full article available at:

http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/449/Bloetscher%20et%20al.%202012.%20SE%20Florida%20Adaptation%20Toolbox.pdf

NSF Funding Awarded for Civil Infrastructure Systems CRISP Type 2/Collaborative Research: Probabilistic Resilience Assessment of Interdependent Systems

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Relevance to adaptation: After a disruptive extreme event, such as an earthquake or severe storm, the socio-economic recovery of the affected region depends on the recovery of its infrastructure systems. Lifelines, such as power and water distribution systems, transportation networks, communication systems, and critical buildings have a primary role in disaster response, management, and long-term recovery. The failure to rapidly restore the services required for personal, social, and commercial activities leads to continued socio-economic losses and progressive depopulation. This collaborative project brings together scholars in Civil Engineering, Systems Engineering, Computer Science, Economics, Urban Planning, and Policy Making. Its purpose is to establish and demonstrate a comprehensive framework that combines models of individual infrastructure systems with models of their interdependencies for the assessment of interdependent infrastructure system resilience for extreme events under uncertainty. The "PRAISys" platform (Probabilistic Resilience Assessment of Interdependent Systems) will emphasize a probabilistic approach that permeates all aspects of the models, including the interdependencies. Some types of uncertainties that were not considered before (e.g., the possibility of using contingency plans that provide services without functioning infrastructure) will be classified; while mathematical and computational tools will be devised to capture their characteristics. PRAISys will enable better management and design of next generation infrastructure, more resilient to extreme events and to component failures under normal conditions. This will reduce the likelihood of extreme events becoming catastrophic in terms of casualties and injuries, long-lasting socio-economic losses, and environmental impact. The results of the research will be disseminated to the public in various forms: through series of seminars for professionals and administrators; by participating in Lehigh University's STAR academy program for disadvantaged middle and high school students; through scientific publications and presentation; and by curriculum development.

The development, calibration, and validation of PRAISys will enable research on stochastic interdependencies among infrastructure systems in the wake of an extreme event. This requires advancements in several disciplines. For instance, a new hybrid reliability model, which combines graph theory for network analysis and classic system reliability to model the probabilistic dependencies among infrastructures will be studied. The new concept of "uncertain dependencies," which are rigorously modeled and include "contingency plans" will be introduced. Advancements in stochastic network optimization will be sought, to predict the optimal strategies and to inform the disaster management. Social network data will be used as an additional source of information on the recovery of a region, in real time, mining public posts. A comprehensive decision framework will combine the results of the simulation platform with expert opinions and surveys to identify the importance of various aspects of recovery. Finally, new techniques for the collection of large sets of data from utility companies, local government and other authorities will be studied.

September 1, 2015- ~August 31 2018

Subtropical Sustainable

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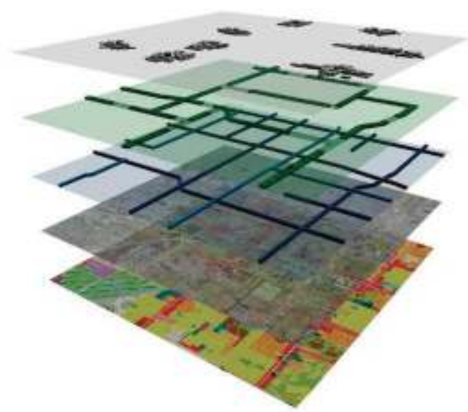
Relevance to adaptation: Broward County’s Transit | Housing Oriented Redevelopment (THOR) Pilot Study project brought various government, transportation, planning, and transit agencies together with the community and the FAU College of Architecture, Urban and Public Affairs to develop strategies for linking land use to transportation and to establish a process for context sensitive design. The initial Pilot Study involved communities situated along segments of Broward Boulevard and State Road 7 in central Broward County, Florida. Both areas were originally developed in the middle of the 20th century. The initial overriding theme of context sensitive solutions hence carried a subtheme that resonated across professions, specializations, and interests: subtropical sustainability.

The core redevelopment strategy of the Community Design Guidebook is the idea of the Quilt-Net: a network of transit and multimodal transportation corridors, greenways, and blueways, connecting new walkable urban centers that are superimposed on the existing patterns of development throughout the county. This superimposition creates a new organizing scheme for redevelopment that is more sustainable and sensitive to the environmental context. It maintains the integrity of existing single family land uses, while it transforms commercial and light industrial sites and regional activity centers into transit-oriented, mixed-use, sub-tropical, urban places accessible without the need for an automobile, from any other part of the county.



The general concept of the Quilt-Net provides a reference for examining possibilities for situating higher density development along existing county corridors that are newly designated for transit. Previous elements of the county transportation plan addressed only the efficiencies and effectiveness of moving traffic. The THOR Pilot Study introduces the possibility of new elements that address the qualitative aspects of subtropical context and design for a new transportation infrastructure suggesting new forms for sustainable redevelopment. To achieve this, the key challenge is to develop a community design process that is inclusive, multidisciplinary, and multi-jurisdictional.

Full report available at:

https://www.broward.org/PlanningAndRedevelopment/Redevelopment/Documents/subtropical_sustainable.pdf

Florida International University Submissions

Biscayne Aquifer Hydraulic Conductivity

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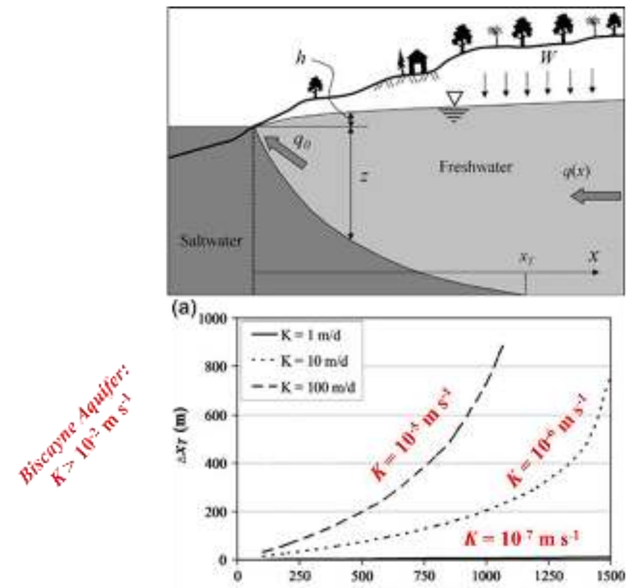

Figure 1. Landward movement of the saltwater intrusion toe as a function of the amount of sea level rise and aquifer hydraulic conductivity (Werner and Simmons, 2009). The Biscayne Aquifer is known to have a conductivity at least 3 orders of magnitude higher than the highest values considered in the analysis and its response to sea level rise could be substantially greater.

Relevance to adaptation: There is a critical need to better quantify the hydraulic conductivity in the Biscayne Aquifer because the hydraulic conductivity has been shown to strongly affect the extent of seawater intrusion in response to sea level rise (Figure 1, Werner and Simmons, 2009) and because the very high hydraulic conductivity of the Biscayne Aquifer has not been adequately determined. All existing modeling efforts rely on inconclusive hydraulic conductivity data.

Work by Werner and Simmons (2009) has shown that the extent of seawater intrusion depends strongly on the hydraulic conductivity for head-controlled aquifers such as the Biscayne Aquifer. Figure 1 shows for example that 1 meter of sea level rise should result in about 200 meters of inland movement of the saltwater intrusion toe when the hydraulic conductivity is 10^{-6} m s^{-1}. If the hydraulic conductivity is one order of magnitude higher at 10^{-5} m s^{-1} however, the inland movement of the saltwater intrusion toe is 800 meters. The Biscayne Aquifer has thick and laterally extensive zones of touching-vug porosity with vugs commonly about 2 centimeters in diameter and porosity of 50% or more. These connected vugs can impart an exceptionally high hydraulic conductivity (*K*), commonly exceeding 10^{-2} m s^{-1}, to the aquifer. Thus the inland movement of the seawater intrusion toe in response to sea level rise is likely to be much greater than it is for lower *K*.

Despite the likelihood that this is the best-studied aquifer of such high *K*, reliable values of its *K* have been challenging to establish due to the inapplicability or inconclusiveness of various test methods for extreme *K*.

Multiple methods over a broad range of scales have been used to estimate *K* values for the Biscayne Aquifer, including:

- detailed Lattice Boltzmann modeling at pore scale;
- Lattice Boltzmann modeling and laboratory measurements at core scale;
- high-resolution borehole scale geostatistical and flow modeling based on borehole images;
- borehole scale slug testing; and
- aquifer test meta-analysis.

Results indicate that maximum *K* values from these methods vary over 5 orders of magnitude from 10^{-4} to 10^{1} m s^{-1}. Some variations in *K* are due to disparities in the physical samples and aquifer reconstructions tested, but most are intrinsic to the methods. For example, limitations of standard laboratory *K* measurements of core samples truncate the distribution of Biscayne Aquifer core *K* values at about 10^{-4} m s^{-1}. Slug tests in appropriately-constructed wells in the Biscayne Aquifer are generally underdamped and appear to underestimate *K* (returning maximum values of 10^{-2} m s^{-1} comparable to a sand aquifer), possibly due to the Darcian flow assumption that underlies analysis methods for such tests. Aquifer tests are difficult to conduct in the Biscayne Aquifer and are commonly inconclusive for a variety of reasons.

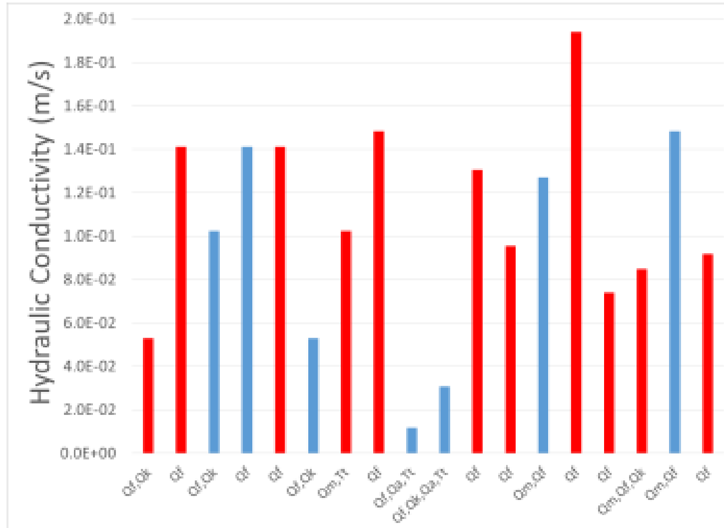

Figure2. Aquifer test database of Fish and Stewart (1991). Red bars show inconclusive results reported as 'greater than' the values shown and represent 11 out of 18 results.

LBM applied at numerous scales yields *K* values that tend to converge and agree with pipe flow expectations and specialized lab measurements on a 0.1 m diameter core model. The *K* values from LBM at core scale are consistent with LBM *K* values from 2.72 m^3-volume scale explicit pore/solid aquifer models based on novel geostatistical extrapolation of borehole optical images.

Sea Level Rise Impacts on South Florida

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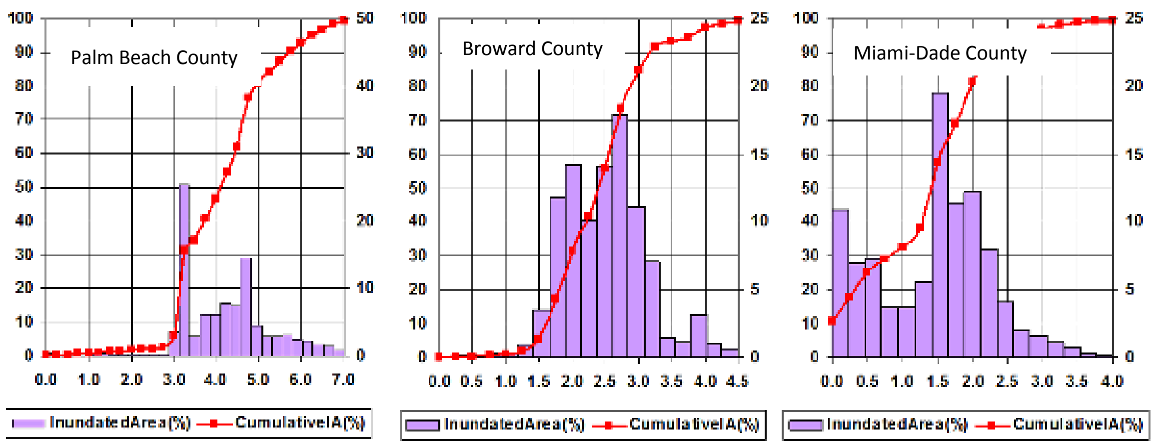
Relevance to adaptation: Combining land surface elevation data with socio-economic data allows estimation of the submerged land area, the number of people affected, and the value of submerged property with different sea level rise amounts. Consideration of different scenarios of sea level rise with time permits the estimation of submerged land area, affected population, and value of submerged property as a function of time.

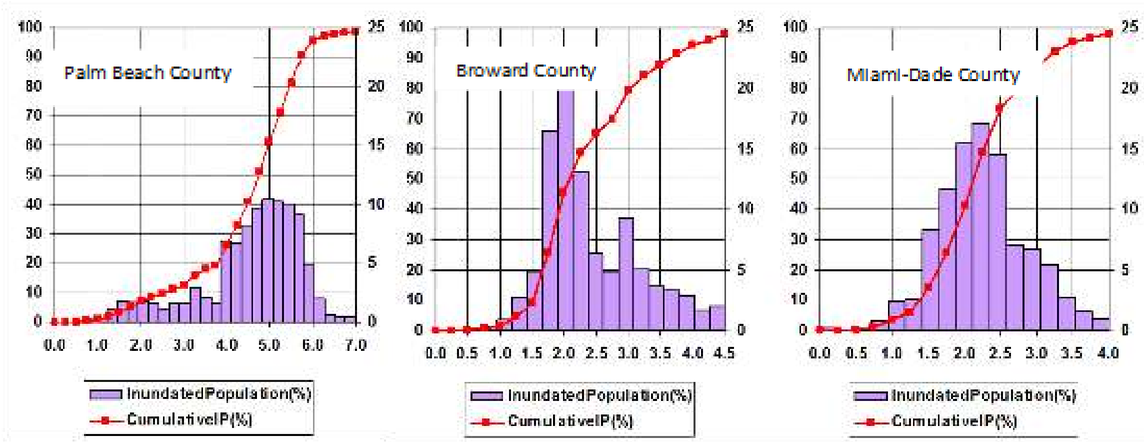
High-resolution land surface elevation data can be evaluated to assess the fractional submergence of South Florida land area for a given amount of sea level rise based on simple 'bathtub' models that assume submergence when the sea level exceeds the land surface elevation. More refined models can be used in this analysis as they become available. Calculations have been made for Palm Beach, Broward, and Miami-Dade counties. Figure 1 shows the percentage of the area inundated for increments of sea level rise in meters on the x axis. The purple bars give the percentage inundated for each increment of sea level rise as read on the right-hand side axis. For example, 1.5 meters of sea level rise inundates an additional 20% of the land area of Miami-Dade County beyond the area inundated by the next smallest increment at roughly 1.25 meters. The red curves show the cumulative inundation through 100% of each county's land area and are read on the left-hand axis. Four meters of sea level rise is enough to submerge all of Miami-Dade County's land, while 7 meters are needed to submerge all of Palm Beach County. These curves are useful because they show that even if the rate of sea level rise is steady (linear) the amount of land submerged is not expected to be a linear function; little effect may be observed until the sea reaches a critical level and large areas may be inundated soon after the critical level is reached. For exqample, Palm Beach County is expected to retain more than 95% of its land area until 3 meters of sea level rise occur; just beyond 3 meters, only 70% of the land area will remain.

Figure 9: Cumulative (left axis) and incremental (right axis) percentages of inundated land areas of Palm Beach, Broward, and Miami-Dade counties as a function of sea level rise in meters (x-axis). Based on 'bathtub' model.



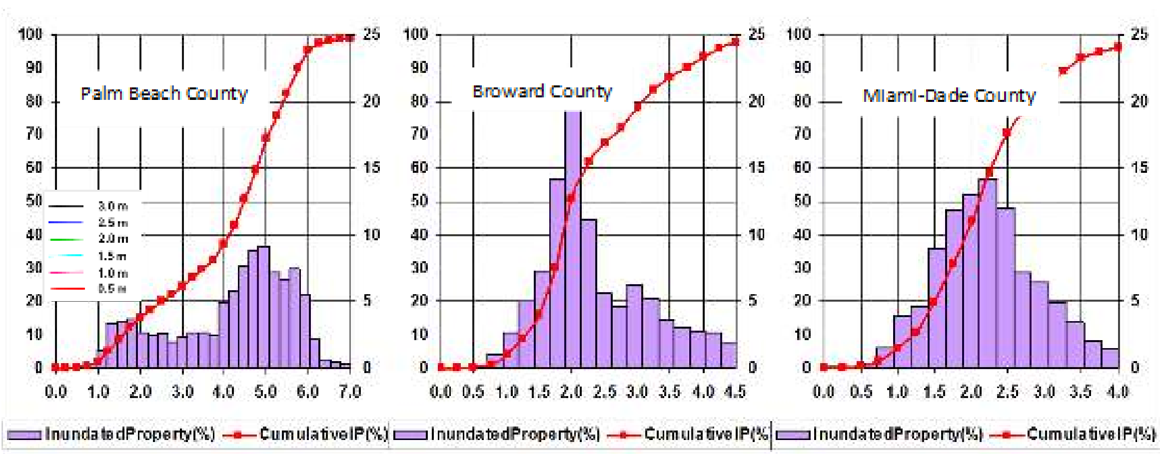
Combining the land elevation-based submergence with available socio-economic data permits other views of the information. For example, Figure 2 show the percentatges of the population affected by various increases in sea level in each of the counties.

Figure 210. Cumulative (left axis) and incremental (right axis) percentages of population affected by inundation of Palm Beach, Broward, and Miami-Dade counties as a function of sea level rise in meters (x-axis). Based on 'bathtub' model.



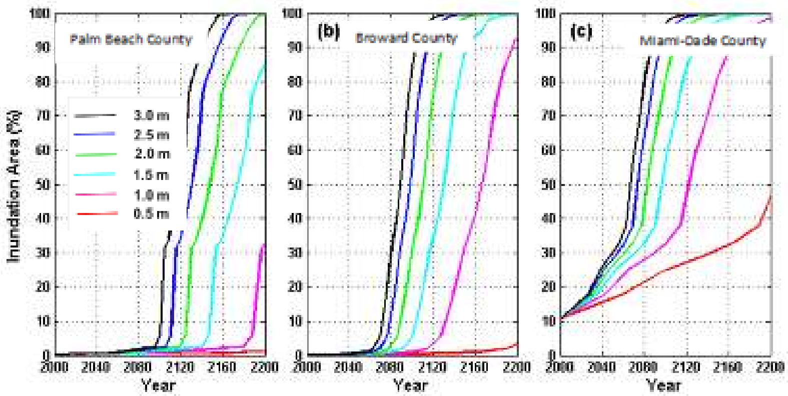
Similarly, the value of inundated property can be considered as a function of sea level rise. Figure 3 shows the cumulative and incremental percentages of property value affected by inundation for Palm Beach, Broward, and Miami-Dade counties as a function of sea level rise in meters (x-axis) based on a 'bathtub' model approach.

Figure 3:11 Cumulative (left axis) and incremental (right axis) percentages of property value affected by inundation of Palm Beach, Broward, and Miami-Dade counties as a function of sea level rise in meters (x-axis). Based on 'bathtub' model.



Finally, various sea level rise scenarios can be combined with the results above to estimate the amounts of land area loss or other factors as a function of time.

Figure 4: Cumulative inundation areas as a function of time for sea level rise amounts from 0.5 to 3 meters by 2100 as shown by legend for Palm Beach, Broward, and Miami-Dade counties.



Making Robust Infrastructure Adaptation Decisions under Uncertainty

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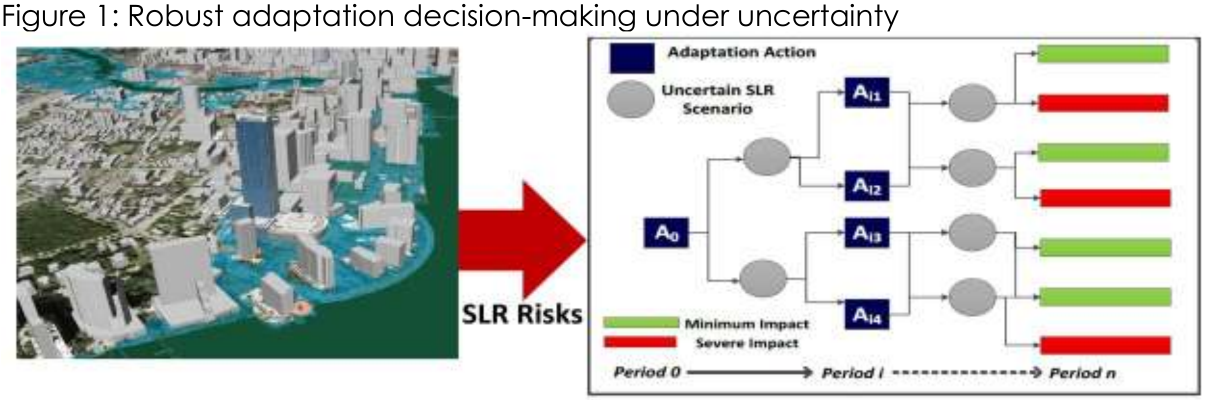
Relevance to adaptation: The objective of this ongoing research study is to identify robust strategies for adaptation of infrastructure systems under sea-level rise. Evaluation of the effectiveness of adaptation actions is critical to avoid maladaptation. Maladaptation is failure to change behaviors and undertake timely actions such that the infrastructure systems on which a society is depended becomes unable to provide the required level of service. Maladaptation may occur due to failure to take timely actions and anticipate uncertainty. Anticipation of uncertainty is particularly important to identify flexible adaptation pathways (Fig. 1) that enable re-evaluation of plans when new information becomes available.

Figure 1: Robust adaptation decision-making under uncertainty



The problem of SLR adaptation is characterized by "deep uncertainty" that makes it almost impossible and economically impractical to design "fail-safe" systems under future uncertain scenarios. In this project, advanced simulation models are created and tested to investigate the long-term impacts of sea-level rise on infrastructure systems in order to evaluate the effectiveness of various adaptation strategies based on a cost-benefit analysis. To this end, the long-term performance of infrastructure systems under various scenarios of sea-level rise and adaptation strategies is modeled using stochastic mathematical simulation. Then, the impacts of sea-level rise are determined in terms of the life cycle costs of infrastructure networks. These estimated costs are used for evaluation of the feasibility of various adaptation strategies under future uncertain scenarios. Currently, data related to water, wastewater, and roadway infrastructure from Miami-Dade and Broward Counties are being collected in order to model the long-term impacts of sea-level rise scenarios and conduct cost-benefit analysis for evaluation of adaptation strategies. At the same time, a preliminary numerical case study has been conducted to test the proof of concept for the simulation methodology. Using the data related to a sub-set of a road network, a model was created to evaluate the effectiveness of adaptation strategies in mitigating the impact of flooding induced by sea-level rise. Adaptation strategies considered include base protection through the use of well-point systems and storm-water drainage as well as raising roads elevations. Then, the projected sea-level rise data was used in order to determine the likelihood and depth of floods within a 40-year analysis horizon (Figure 2). The impact of flooding on roadways was determined based on the damages to the structural number and pavement condition. Accordingly, the annual life cycle cost of the network was determined in two scenarios: (1) no adaptation; and (2) adaptation to cope with 2ft inundation under slow sea-level rise (Fig. 3) and fast sea-level rise scenarios (Fig. 4). The difference between the annual life-cycle costs was used to determine the incremental annual value of adaptation (Figure 5), and using economic analysis, the present value of adaptation solution was determined.

Figure 12:-Sea-level rise scenarios and likelihood of flood risk

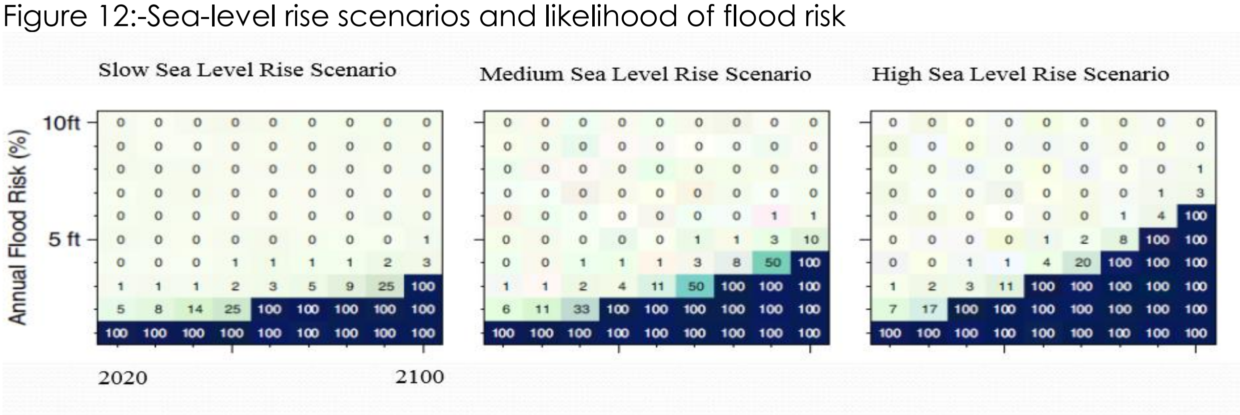


Figure 3- Annual life cycle cost of the network under slow sea-level rise

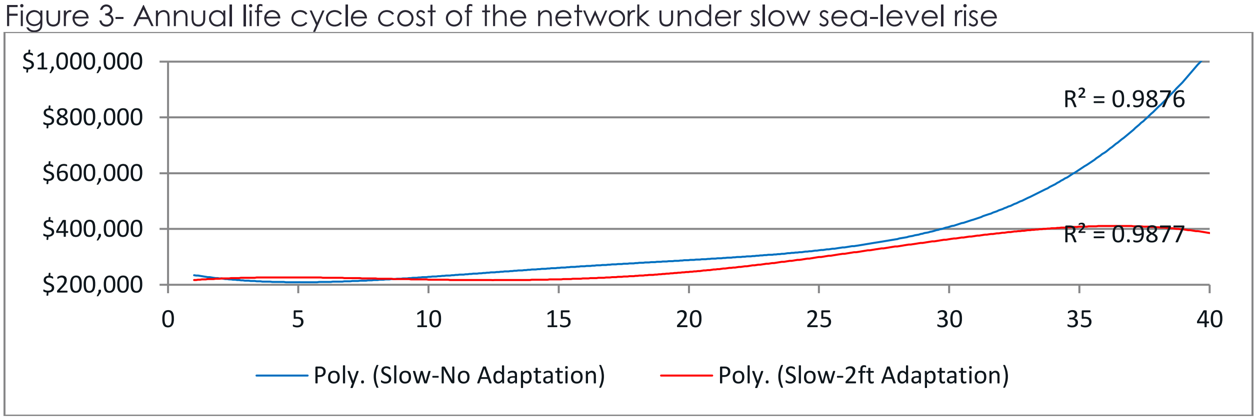


Figure 4- Annual life cycle cost of the network under fast sea-level rise

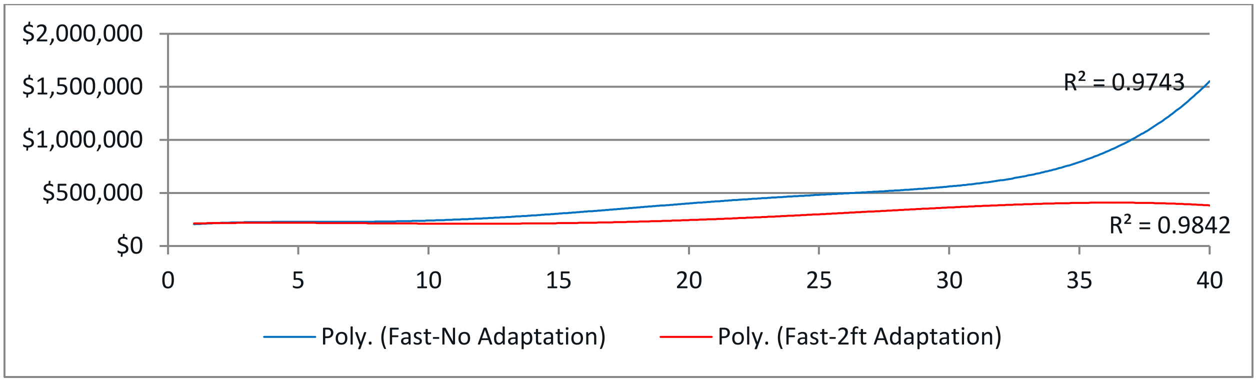
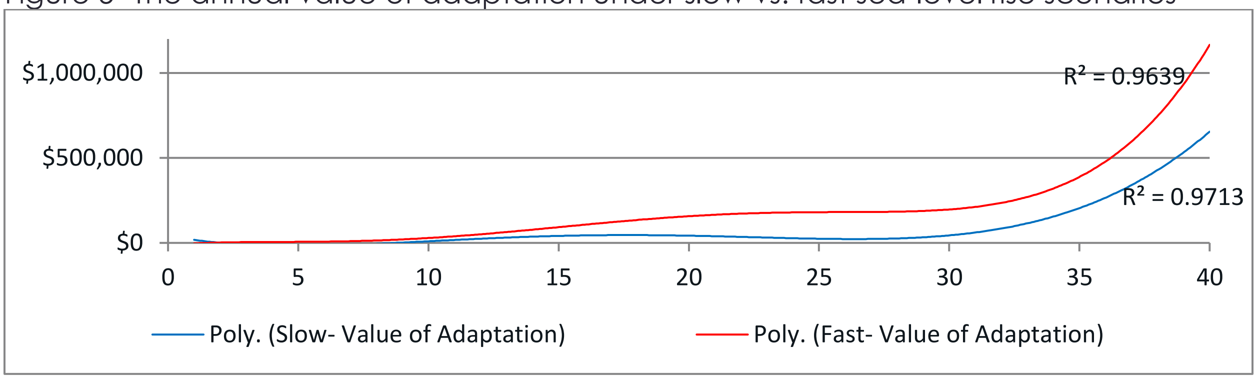


Figure 5- The annual value of adaptation under slow vs. fast sea-level rise scenarios



In an ongoing study, the adaptation of water infrastructure is being evaluated in order to identify robust strategies to cope with saltwater intrusion. Possible adaptation action alternatives for coping with salt water intrusion include exploitation of aquifers in non-affected areas, building desalination capacity in treatment plants, and building additional reclaimed water production facilities. The effectiveness of these adaptation actions are being evaluated through the use of dynamic models to simulate the impacts of sea-level rise on water infrastructure under uncertain future scenarios.

Understanding Mechanisms that Maintain Wetland Elevation in South Florida Coastal Ecosystems

Researcher: Tiffany Troxler, Evelyn Gaiser, John Kominoski (in collaboration with scientists from South Florida Water Management District, Everglades Foundation and Everglades National Park
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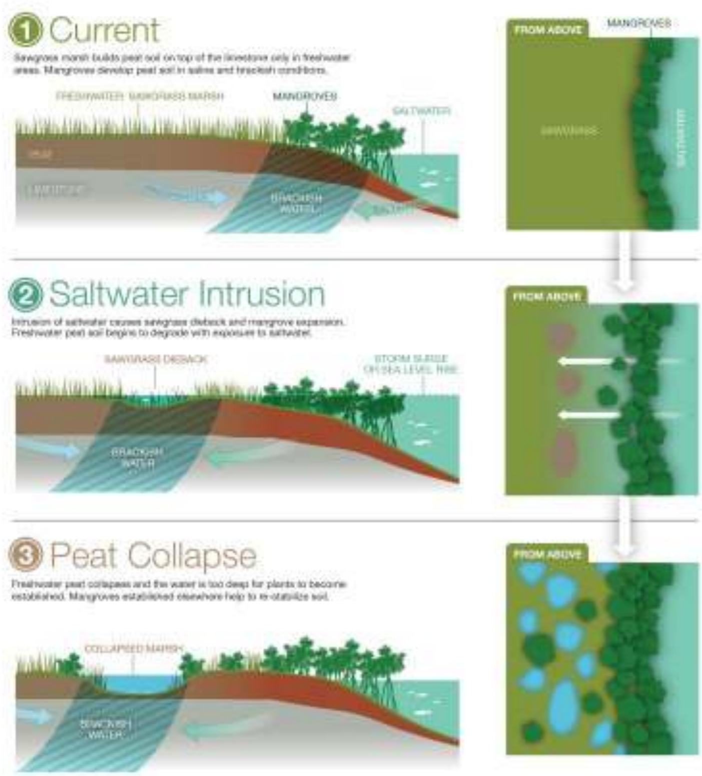
Relevance to adaptation: Sea levels in south Florida are conservatively predicted to rise 0.6 m by 2060 (Zhang et al. 2011) and this estimate now defines the upper range for the sea-level rise (SLR) planning horizon for south Florida (SFRCCC 2011, Obeysekera et al. 2015). South Florida is particularly vulnerable to SLR given the low topographic incline, shallow and highly permeable karst aquifer and large-scale hydrologic diversions that have amplified coastal transgression (Ross et al. 2000). Extensive areas of low lying land inland and along the coast increase risk of salinity intrusion. For example, about 60% of Everglades National Park (ENP) is at or under 0.9 m in elevation relative to mean sea level (Pearlstine et al. 2010). This rate of sea-level change (~1 cm yr^{-1}) and low elevation of much of ENP and other low lying areas put significant areas at greater risk of increased saltwater inundation. Subsequently, this puts south Florida's coastline at risk and consequently the ecosystem services that coastal wetlands provide. Inland transgression of mangroves has been suggested as a means by which sub-tropical and tropical coastal landscapes will "adapt" to increasing sea-level rise – mangroves will replace inland marshes as sea-level rises (citation), stabilizing soils as they transgress. Historically, rates of soil accretion of mangroves and salt marsh wetlands have kept pace with rates of SLR by accreting vertically (e.g. McKee et al., 2011). However, as inland freshwater wetlands are and will continue to be exposed to increased duration and spatial extent of inundation and salinity from seawater, the risk to soil carbon (C) balance that maintains coastal elevation increases. This is attributed to impacts that can affect soil C balance through soil oxidation-reduction potential, soil respiration, and the intensity of osmotic stress to vegetation. The term "peat collapse" has been used to describe a relatively dramatic shift in soil C balance, leading to a rapid loss of soil elevation, and culminating in a conversion of vegetated freshwater marsh to open water (Fig. 1). In this project, we are using coupled field and experimental outdoor mesocosm experiments to quantify biological, chemical and physical responses to increased salinity due to saltwater intrusion and inundation in south Florida wetland ecosystems.

Figure 1. Conceptual diagram illustrating conversion of inland wetlands to open water as a function of saltwater intrusion (H2H graphics and Davis)

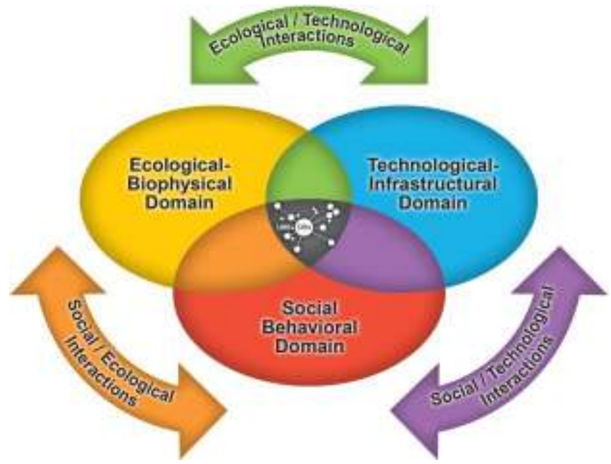


Urban Resilience to Extremes Sustainability Research Network

Researcher: Evelyn Gaiser, Tiffany Troxler, John Kominoski (in collaboration with scientists from multiple institutions, with lead institution Arizona State University)
Institution: Southeast Environmental Research Center, Florida International University

E-mail: gaisere@fiu.edu; troxlert@fiu.edu

Relevance to adaptation: Climate change is widely considered to be one of the greatest challenges to global sustainability, with extreme events being the most immediate way that people experience this phenomenon. Urban areas are particularly vulnerable to these events given their location, high concentration of people, and increasingly complex and interdependent infrastructure. Impacts of Hurricane Katrina, Superstorm Sandy, and other disasters demonstrate not just failures in built infrastructure, they highlight the inadequacy of institutions, resources, and information systems to prepare for and respond to events of this magnitude.



The highly interdisciplinary and geographically dispersed Urban Resilience to Extremes Sustainability Research Network team will develop a diverse suite of new methods and tools to assess how infrastructure can be more resilient, provide ecosystem services, improve social well-being, and exploit new technologies in ways that benefit all segments of urban populations. The Urban Resilience to Extremes Sustainability Research Network focuses on integrating social, ecological, and technical systems to devise, analyze, and support urban infrastructure decisions in the face of climate uncertainty (Figure 1). The central question of the project is:
How do Social Ecological Technological Systems (SETS) domains interact to generate vulnerability or resilience to climate-related extreme events, and how can urban SETS dynamics be guided along more resilient, equitable, and sustainable trajectories? We will use a (1) network of diverse cities, (2) a network of experts in Working Groups, (3) a holistic conceptual framework, (4) an inclusive, participatory approach, and (5) a workflow, education program, and evaluation plan that produces results and continually learns to address this question. A primary activity within the project will be to assemble and collate ecological, social, infrastructure, hydrology, and other data to address the question, working with ecologists, social scientists, engineers, planners, designers, climatologists, physical scientists to develop downscaled climate extreme projections, developing a geodatabase, and conducting computation and visualizations to conduct transitions work to achieve and implement strategies. Infrastructure that is flexible, adaptable, safe-to-fail, socially equitable, and ecologically based will enhance urban resilience in the face of a higher incidence of extreme events, more culturally diverse communities, and continued urbanization pressures. Ultimately, the Urban Resilience to Extremes Sustainability Research Network will help accelerate knowledge generation and application to encourage innovative strategies towards urban sustainability. More information on the Urban Resilience to Extremes Sustainability Research Network research initiative is available at the following link: https://sustainability.asu.edu/urbanresilience/

Dissertation and Theses at Florida International University

Chatterjee, Chiradip
Four essays of environmental risk-mitigation

Cui, Zheng
A generalized adaptive mathematical morphological filter for LIDAR data

Eisenhauer, Emily
Socio-ecological vulnerability to climate change in South Florida

Mozumder, Pallab
Coping with a natural disaster: Understanding household and social responses

Nodine, Emily
Evidence of climate variability and tropical cyclone activity from diatom assemblage dynamics in coastal southwest Florida

Stalker, Jeremy
Hydrological dynamics between a coastal aquifer and the adjacent estuarine system, Biscayne Bay, South Florida

Twigg, David
The winds of change? Exploring political effects of Hurricane Andrew

Zhang, Keqi
Twentieth century storm activity and sea level rise along the United States coast and their impact on shoreline position

Zhu, Zhenduo
Mechanisms governing the eyewall replacement cycle in numerical simulations of tropical cyclones

Florida State University Submission

Understanding and Projecting Precipitation Variability over Florida Using High Resolution Climate Models

Researcher: Vasu Misra
Institution: Center for Ocean-Land-Atmosphere Studies/Florida State University
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Relevance to adaptation: Florida is one of the regions in the continental U.S. that receives a significant amount of annual rainfall. It has distinct seasonality and is a primary source of fresh water both for groundwater recharge and consumptive use. And yet understanding its variability and projected change is a challenge for a variety of reasons including Florida's unique geography. Peninsular Florida, with close proximity to strong mesoscale surface ocean currents among other factors, warrants the use of relatively high resolution climate models to simulate its hydroclimate. In the absence of such high resolution climate models, we highlight the uncertainty in the simulation of the warm western boundary current (the Gulf Stream) in two relatively coarse spatial resolution CMIP5 (global) models used in IPCC AR5.

But before we highlight the uncertainty in the global models, we will demonstrate (Fig. 1) that differences in terrestrial rainfall over Florida during the wet season can be influenced by changes in the Gulf Stream by simple changes to ocean bathymetry in a high resolution regional coupled ocean-atmosphere model (RCM). It is very clearly seen that the rainfall over peninsular Florida is strongly influenced by the strength of the Gulf Stream in the model (not shown), with stronger Gulf Stream producing more rainfall over Florida. The RCM experiments with different bathymetry clearly suggest that large changes in western Atlantic coastal Sea Surface Temperature (SST) can be affected. This affects the gradient between local SST and surface temperature over peninsular Florida. This modulation of surface temperature gradient has a consequence on the moisture flux convergence and surface evaporation that are primary sources of moisture for rainfall over peninsular Florida (not shown).

A well-known fact is that the grid size resolution of global models in the global models are rather inadequate to resolve the rich mesoscale oceanic features in the region, and even in some instances, inadequate to properly represent the coastlines of peninsular Florida. Besides this issue of model grid resolution, we also find that there are significant differences in the prescribed bathymetry of these global models (Figs. 2a and b). The depths of the channels (e.g. Florida Straits, Yucatan Channel), the extent of the continental shelf (e.g., along the eastern coast of Florida) is significantly different in the two models (Fig. 2). The mean ocean heat transports through these channels are also significantly different. However, one needs to be careful in not attributing all of these differences in the ocean heat transport to differences in the bathymetry, as other differences in the models (e.g. systematic errors, local and remote air-sea feedback) also can potentially play a role. We, however, observe that colder SST's along the eastern coast of Florida are associated with weaker surface currents between the two CMIP5 models (Figs. 2c and d), suggesting the potential subtle role of ocean bathymetry. For example, the coastal SST along the western Atlantic in The Geophysical Fluid Dynamics Laboratory model (GFDL) (Fig. 2c) is lower than that in the Community Climate System Model 4.0 (CCSM4) (Fig. 2d) simulation. This also corresponds with weaker surface currents (Fig. 2a) and ocean heat transport (Fig. 2c) in the GFDL relative to the corresponding CCSM4 simulation in Figs. 2b and d respectively. Further along this line of argument, we find that the mean June-July-August (JJA) rainfall over peninsular Florida is much lower in the GFDL (Fig. 2e) than in the CCSM4 (Fig. 2f) simulation. The two global models are, however, significantly different in their structure, design, parameterizations, dynamical core, with very different systematic errors, ENSO characteristics and other natural variations that could all influence the SST simulation along the western coastal Atlantic. But qualitatively, the difference in surface meteorology over peninsular Florida and the difference of SST over the Gulf Stream alongside the differences in ocean heat transport between the two global models as shown in Fig. 2 is similar to the regional climate model (RCM) experiments, which is compelling.

For a region like Florida, the sustained influence of the coastal SST on the terrestrial hydroclimate needs to be taken advantage of in simulating the terrestrial regional hydroclimate when extreme weather events, like land-falling tropical cyclones that also contribute to the hydroclimate, are inherently difficult to simulate in climate models.

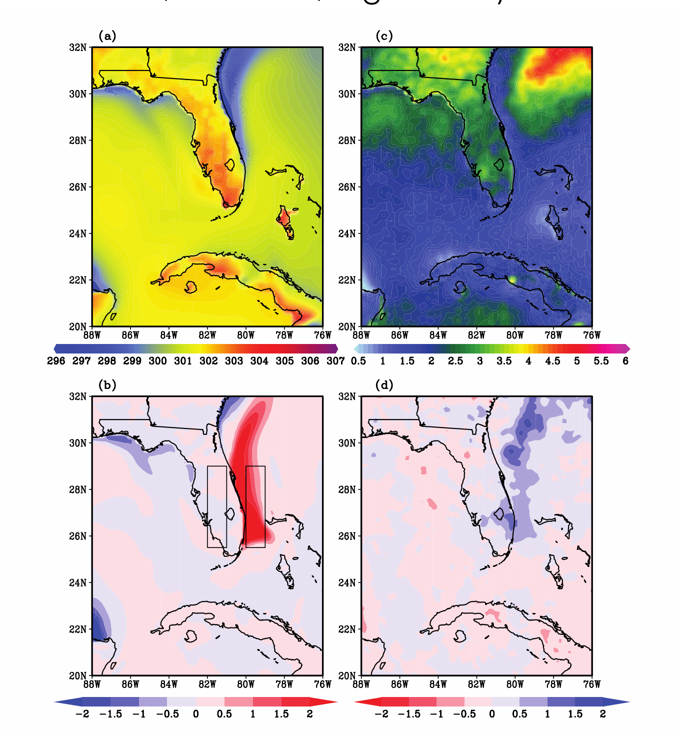

Figure 1: a) The climatological seasonal mean JJA SST and land surface temperature from a) RCM1 integration (K; fine bathymetry) and b) the corresponding differences from RCM2 (coarse bathymetry) integration (RCM1-RCM2; °C). Similarly, the climatological seasonal mean JJA

precipitation (mm day-1) from c) RCM1 integration and b) the corresponding differences from RCM2 integration (RCM1-RCM2).

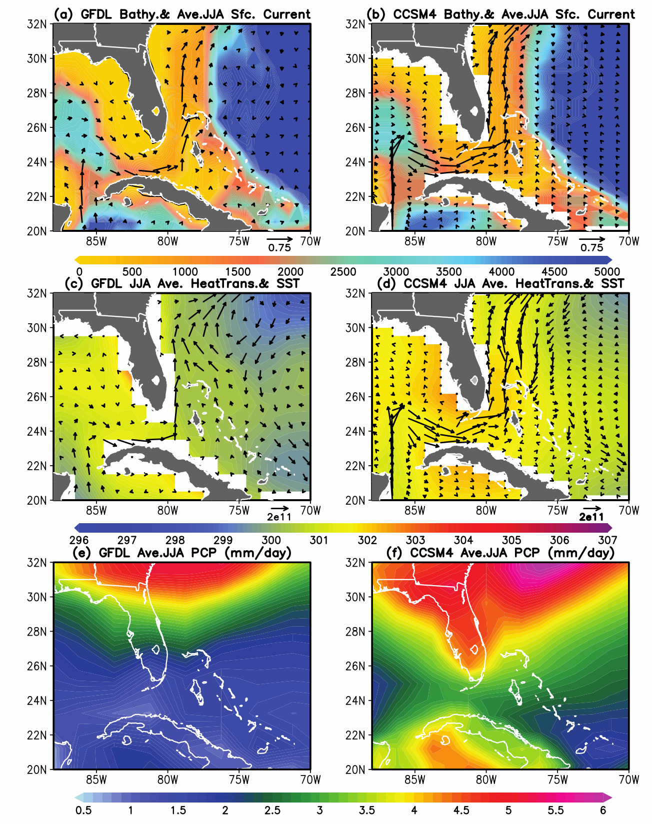

Figure 2: The bathymetry (meters) around Florida coast overlaid with the climatological JJA surface ocean currents (ms^{-1}) in a) CCSM4, and b) GFDL-ESM2G used in the 20th century simulations for CMIP5. Similarly, the climatological mean JJA SST (°C) and ocean heat transport vectors (Wm^{-1}) in c) CCSM4, and d) GFDL-ESM2G. Likewise, the climatological mean JJA precipitation (mm day^{-1}) from e) CCSM4, and f) GFDL-ESM2G.

University of Central Florida Submission

Analyses for Adaptation of Drainage Infrastructure in a Coastal Urban Watershed via a Worst-Case Scenario of Storm Surge and Precipitation Variability under Climate Change and Sea-Level Rise Impacts

Researcher: Ni-Bin Chang, Justin Joice, Rahim Harji, and Thomas Ruppert
Institution: University of Central Florida, Pinellas County Government, Florida Sea Grant Program
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Relevance to adaptation: This study analyzes the impact of storm tide and long term precipitation variability on coastal inundation in the Tampa Bay Region under a worst case scenario of climate variability and sea-level rise. The study generates flood hazard maps of the impact of storm tide and precipitation to test the response of the Cross Bayou watershed to the worst case storm conditions combined with scenarios of precipitation variability, hurricane landfall, and sea-level rise using 2030 as a period of concern. In particular two considerations were evaluated: (1) response of watershed drainage to storm tide, precipitation, and sea-level rise with current infrastructure in place and (2) response of watershed to storm tide, precipitation, and sea-level rise with changes in infrastructure such as the expansion of the Cross Bayou Canal and the promotion of low impact development.

An innovative feature of this study is that it integrates several existing models and elements to create a more holistic view of the potential interaction of various factors on existing stormwater infrastructure, thus allowing for an integrated understanding of risk that permits better design of long-lasting, costly infrastructure critical to protecting people and property in the future.

The study includes a coupled hydrodynamic circulation (ADCIRC) and wave driven model ("SWaN" or Simulated Waves Nearshore model) to simulate the propagation of wind-driven waves, tides, and storm surge from deep water to nearshore. In addition, a comprehensive hydrodynamic stormwater and hydrologic model ("ICPR 4" or Interconnected Pond Routing Model 4) is utilized to route output from the coupled hydrodynamic and wave driven model such as storm tide heights over the Tampa Bay region, in particular the Cross Bayou Watershed. The hydrodynamic stormwater and hydrologic model also takes into account hydrologic processes such as precipitation and runoff which can contribute to significant flooding in the region. Thus, the impacts of different scenarios of sea levels on drainage efficiency as well as different possible scenarios of future rainfall can be considered together for future mitigation actions.

Finally, due to the number of scenario-dependent variables in this work, including storm size, strength, direction, and speed, precipitation, and sea level, the study will utilize new, innovative statistical analysis techniques that can provide an overall measure of risk in light of so many variables.

University of Florida Submissions

Sea-Level Rise and Coastal Water Resources

Researcher: Andrea Dutton
(in collaboration with Jon Martin, Arnoldo Valle-Levinson, Andy Ogram, Zhong-Ren Peng—all at UF)
Institution: University of Florida
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Relevance to adaptation: Though many people think of sea-level rise solely as a problem of flooding and coastal inundation, the accompanying transformation to freshwater resources as well as coastal brackish to saltwater resources may well approach irreversible tipping points in terms of sustainability of human populations along the coastlines long before flooding does. In the face of rising sea-levels, there is an acute need to understand the thresholds and interplay between salt-water intrusion to groundwater aquifers, microbial response, nutrient supply and alterations to water chemistry, and the physical dynamics of fresh and salt water mixing and migration of water bodies.

Our interdisciplinary team links these diverse aspects associated with sea-level rise across a range of spatial and temporal scales (Fig. 1). In particular, we seek to compare and contrast systems with fundamentally different physical bedrock and water permeability properties (karstic carbonate bedrock with open conduits vs. siliciclastic sediment with pore spaces). This range of physical properties can presently be found along the Florida coastline, and we are using sites along the coast of Florida for some of our field studies (e.g., Indian River Lagoon and the Florida Keys).

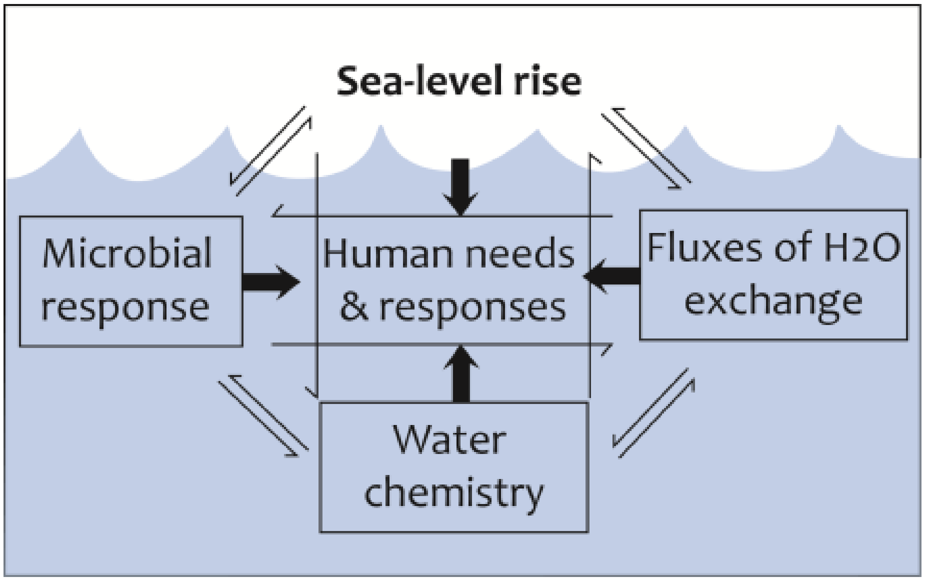

Figure 1. Conceptual diagram demonstrating links between all of the variables in the outer circle that ultimately impact the sustainability of coastal human populations. Our team of 5 PIs is constructed such that each variable in this diagram is associated with the expertise of one of the PIs.

To adequately adapt to the changes that will occur in this complex system, it is critical to define the relevant thresholds (tipping points) that cause a system to shift into an unsustainable territory. Part of our group has been working under the umbrella of an NSF-funded project on this topic and the entire team is presently applying for a larger grant from the same NSF program to expand this research.

Relevant results that will factor into adaptation strategies include the observation of changes in the rate of sea-level rise that directly impact the rate of salt-water intrusion and associated changes in water chemistry and microbial balance. Key to our assessment is the determination of whether these thresholds are the gatekeeper to reversible processes or whether they represent uni-directional changes that result in a more permanent change of state. This aspect is relevant, for example, to the dynamics of storm surges that may induce ephemeral extremes in the system. Once the storm surge has passed, the pressing question is how long will the effects persist? By studying these processes over a range of timescales, we aim to define the timescales of response for each element in the system.

In conjunction with studying the scientific aspects of the natural system, we are also incorporating an analysis of the response of coastal human communities to the threat of rising sea level. This is being accomplished by developing GIS applications to evaluate populations that may be impacted by coastal flooding and corresponding economic damages based on probabilistic different sea-level rise scenarios and time periods. A dynamic economic model will be developed based on surveys of local communities and human activity theories. Results of our salt water intrusion work include a parameterized physical response model that will be coupled with models of projected long-term sea level change and linked to our assessments of potential rates of sea-level change. Economic impacts of sea-level rise on coastal human communities will also be expressed through changes in tourist attitudes. Tourist attitudes will be evaluated through traditional surveys and data mining via social media to develop a regional tourism variation model. This model will be used to predict potential economic impacts of various sea level rise scenarios and the impacts of sea-level rise on water resources. The results will be useful to local community managers setting policy regarding human community responses to loss of coastal resources.

Research Topic: Science-Collaborative Resiliency Planning on Florida Atlantic and Gulf Coasts

Lead Researcher: Kathryn Frank
Associate Researchers: Thomas Hoctor, Michael Volk, Paul Zwick, Greg Kiker, Thomas Ruppert, Joseli Macedo, Jeff Wade
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Email: kifrank@ufl.edu

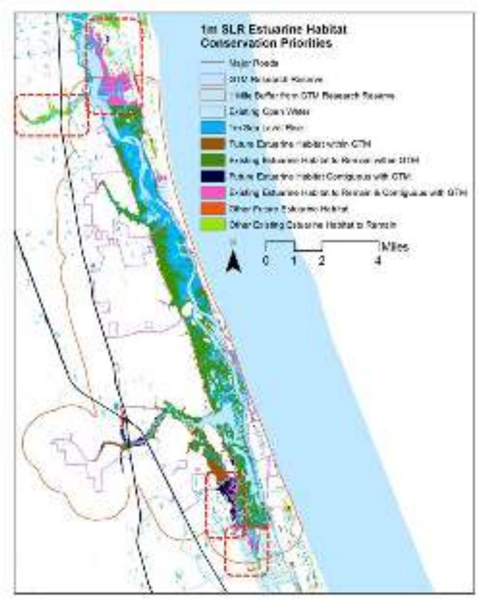
Relevance to adaptation: Coastal communities, land managers, and local governments have critical roles to play in sea level rise adaptation planning and implementation. Local adaptation planning should be both scientifically sound and collaborative in order to be successful. Additionally, to support resiliency and sustainability principles, adaptation planning should integrate concerns for the built and natural environments, as well as social and economic aspects.

This research has piloted community and regional scale adaptation planning techniques for scientific analyses, stakeholder collaboration and public engagement, policy and governance analyses, and strategy design. The three applied planning projects were conducted from 2011 to 2015 in St. Johns and Flagler counties on the northeast Florida Atlantic coast (with local partner the Guana Tolomato Matanzas National Estuarine Research Reserve and including St. Augustine and Palm Coast), and in Levy County on the Florida Gulf coast (working with the County, and cities of Cedar Key, Yankeetown, and Inglis). Funding for the projects was provided by Florida Sea Grant and the National Estuarine Research Reserve System Science Collaborative.

In each location, the research generated comprehensive, community-based and spatially explicit sea level rise vulnerability and adaptive capacity information, and recommended a wide variety of integrated adaptation strategies. Additionally, the relationships formed during the studies have led to new UF-local stakeholder initiatives being proposed. Information about the projects is available at http://planningmatanzas.org and http://changinglevycoast.org. Example recommended strategies are below:

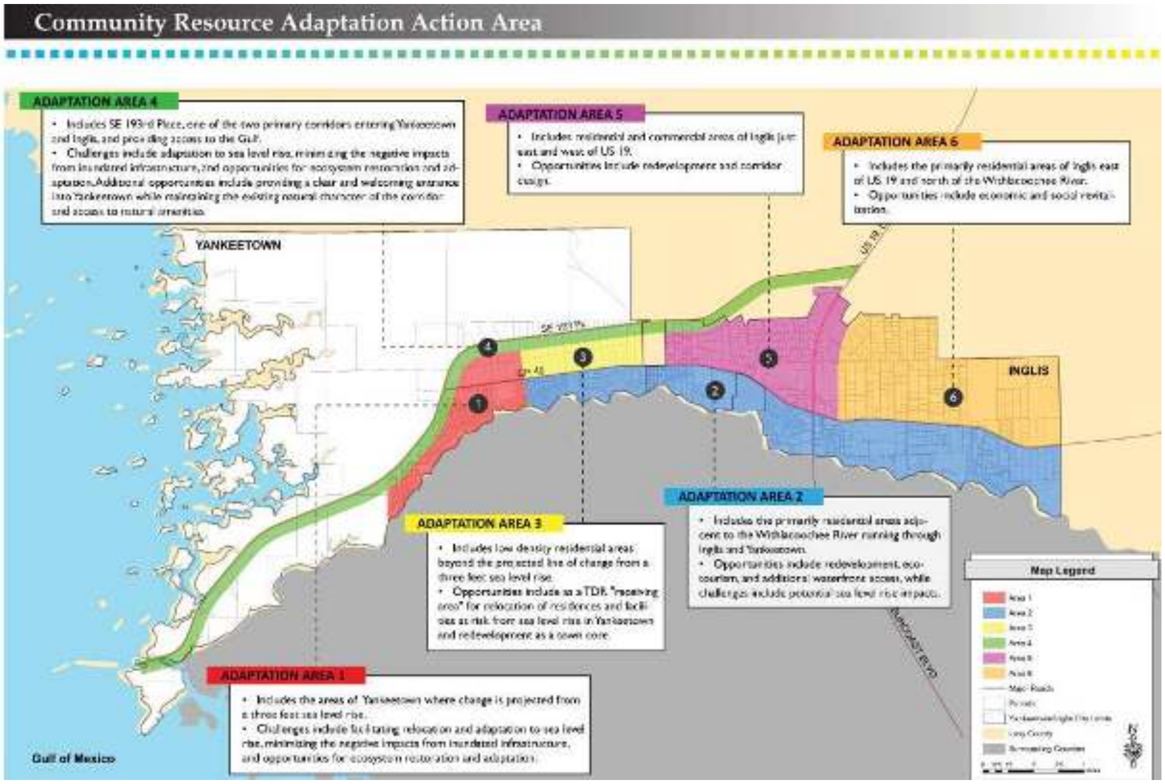
Matanzas Basin

The Matanzas Basin project modeled land cover changes for sea level rise up to 2.5 meters by 2100, future development scenarios to year 2060, and impacts to ecological resources; and it identified future conservation priorities and resilient designs of the built environment. The figures below show (1) resulting estuarine habitat conservation priorities adjacent to the GTM Research Reserve for a 1 meter sea level rise scenario, and (2) a future development scenario including adaptation of vulnerable development and avoidance of aggregated conservation priorities.



<u>Yankeetown-Inglis</u>

In the small towns of Yankeetown and Inglis in the Florida Big Bend region, the project addressed the significant flooding vulnerabilities, and recognized the capacities for adaptation. The project proposed six adaptation areas within which different sets of strategies would apply. The adaptation areas were designed to coordinate "sending and receiving areas" for adaptation, and align with social and economic goals.



Predicting and Mitigating the Effects of Sea-Level Rise and Land Use Changes on Imperiled Species and Natural Communities in Florida

Principal Investigator: Tom Hoctor, University of Florida Center for Landscape Conservation Planning; Project Manager: Michael Volk, University of Florida Center for Landscape Conservation Planning; Partners: Reed Noss, University of Central Florida; Jon Oetting, Florida Natural Areas Inventory; Paul Zwick, University of Florida; Joshua Reece, University of Central Florida
Project Period: 1/1/2011-2/15/2014

Relevance to adaptation: The goal of this project was to create a detailed assessment of the combined impacts of sea-level rise and land-use shifts on imperiled species and habitat throughout the State. This assessment was used to develop spatially explicit, science-based adaptive strategy recommendations to assist policy decisions. This work is a starting point for future assessments of the impacts of sea-level rise and adaptation options, and will form an essential foundation for future research and funding that builds on the results and methodology of this project. Of particular importance is the integration of strategies for adaptation of human communities with those that focus on adaptation of natural communities and species, so that they are harmonious and complementary rather than conflicting.

<u>Project Goal:</u> The overall goal of this project was to conduct an assessment of the potential impacts of sea-level rise and land-use change in Florida on high priority natural communities and species identified in Florida's Comprehensive Wildlife Conservation Strategy. Such an assessment is necessary for developing conservation strategies, including identification and

protection of functional connectivity, that will avoid, minimize, and mitigate anticipated impacts. This work formed the foundation for revising conservation land acquisition priorities, land-use planning and management strategies, and adaptation measures for at-risk species and natural communities to promote resistance and resilience to climate change. The specific objectives included:

Objective 1 Data Collection and Development: Collect and develop critical foundational data for assessing the combined impacts of sea-level rise and land-use changes on imperiled species in coastal areas. This objective includes development of a range of sea-level rise projection models, collection of future land-use projections, development of updated habitat models for imperiled species, and a literature review on the habitat characteristics, autecology, and risk factors for particular species.

Objective 2 Impacts Assessment: Based on the updated habitat models and literature review, assess the potential impacts of sea-level and land-use projections on imperiled taxa, natural communities, and habitat corridors as a basis for defining specific adaptive strategies.

Objective 3 Strategy Recommendations: Based on projected impacts to imperiled species and communities, identify specific strategies for mitigating the effects of climate change and facilitating species and habitat adaptation, which will provide a spatially explicit, scientific basis for future conservation policy decisions.

The full project report is at this link: http://conservation.dcp.ufl.edu/Project-Downloads.html and is titled
"Adaptation to Sea-level Rise in Florida: Biological Conservation Priorities". Outcomes from this project that are relevant to the Miami-Dade area include any of the findings related to future development patterns in the area, impacts from development and sea level rise on important species and ecosystems in the southeast Florida, as well as the potential adaptation strategies that we have outlined for specific species.

ReCharting Longboat Key: Toward Community, Economy and Resiliency

Lead Researchers: Martin Gold, Martha Kohen, Jerry Murphy
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Relevance to adaptation: Army Corps of Engineers and National Oceanic and Atmospheric Administration data suggest that sea levels at Longboat Key, an incorporated barrier island on the west coast of Florida in Sarasota and Manatee Counties, may rise as much as five (5) to six (6) feet by the year 2100. Utilizing an Urban Design Studio (UDS) comprised of UF College of Design, Construction and Planning (DCP) faculty, graduate architecture students—in conjunction with PhD candidates in architecture and planning—the research examined the natural conditions, the infrastructural concerns, the activities, and the developed land potential. The Sea Level Rise (SLR) issues for the Barrier Island condition became an underlying consideration in the wake of future impact into existing investments and lifestyles present within the island community.

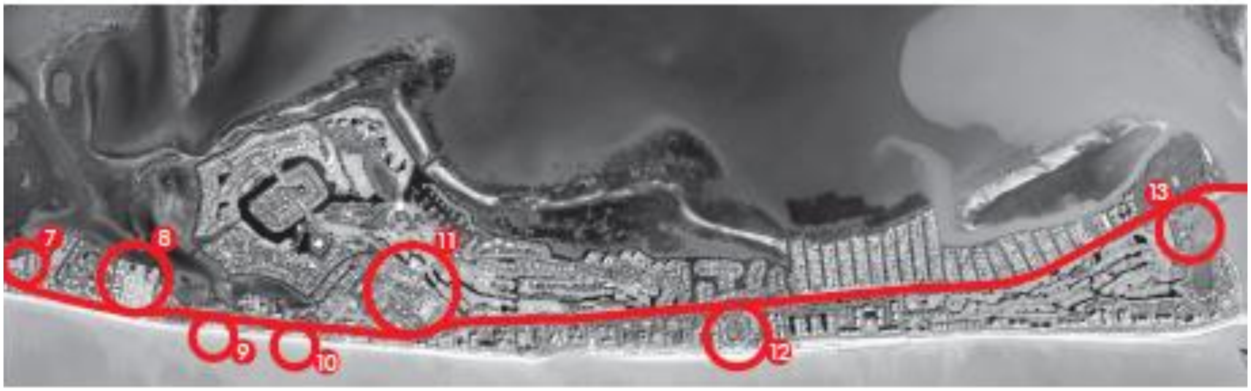
Possible futures: Four teams were formed, involving multiple DCP faculty and students. The teams were tasked with examining the barrier island condition in the context of the Gulf of Mexico and Sarasota Bay and the adjoining mainland influence on the Key. The team's diagnoses were unique in their considerations and emphases but, as a coordinated group, they were able to identify the main aspects and underlying conditions. Their individual visions, and the discussion and presentation of their ideas, contributed to raising and completing the group consciousness of the breadth of the necessary considerations, bringing depth to certain aspects selected by the teams as determining factors. Their diagnostic findings identifying strengths, threats, vulnerabilities, and weaknesses—as well as opportunities—were briefly described in text next to their team proposal graphics. The larger group provided insight, as well as technical support, for this analytical stage—in particular regarding SLR predictions at the individual parcel level.

In light of their selected aspects diagnostics, and incorporating the other teams' analyses, the four teams developed, at territorial scale, their master plan proposals that were presented to the groups and the public. The master plans include identification of design exploration sites that are representative of more generalized strategies that exemplify and support changes in natural assets, density, economic development, infrastructure, land use, mobility, public space, and residential typologies. The identified exploration sites support projects that could serve as testing grounds for proposed land use planning and land development code modifications. The projects also included the development of innovative programmatic opportunities, later exemplified by individual student redevelopment intervention project proposals.
Finally, the group's proposals were combined in a composite master plan strategy—developed after extensive group discussion and examination, inclusive of the individual plans, but selective towards the main proposals that the group prioritized. The combined master plan displays the identified universe of possibilities that introduce phasing aspects of the 21st Century priorities and feasibilities.

Recommendations:
The resulting Report outlines and details Objectives, Strategies, and Suggested Regulations that could be empowered through three (3) means of implementation:
1. Establishing incentives for private development;
2. Revising/replacing the land development regulations to remove barriers to proactive redevelopment; and
3. Direct action by the Town of Longboat Key.

Recommendations include positive steps forward to address the immediate redevelopment concerns in concert with ecological enhancement and medium to long-term challenges and threats to the Longboat Key community. The takeaway section, *Longboat Key 2101*, introduces the concept of making near-term decisions that are influenced by, and also begin to address, futures that are both fairly clear and carry forward into the next century.

4 Locations of Opportunity



Seawater Intrusion Impacts on Drinking Water Production

Researcher: Treavor Boyer
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Relevance to adaptation: As the seawater or salt content of groundwater and surface water increases, the treatment processes required to produce potable water change, and in many cases become less effective. For example, fresh groundwater typically requires minimal treatment such as chlorine addition for disinfection, and fresh surface water is typically treated by coagulation/flocculation to remove particulate and organic material followed by chlorine disinfection. The efficacy of chlorine disinfection, which is the most widely used disinfectant in drinking water treatment, is greatly altered by the presence of increasing seawater content in freshwater. Although seawater is dominated by sodium and chloride ions (i.e., common table salt), it also contains bromide ions. During chlorine disinfection the bromide ions are transformed to halogenated organic disinfection byproducts (DBPs), such as trihalomethanes (THMs) and haloacetic acids (HAAs), which are considered possible human carcinogens and regulated by the U.S. Environmental Protection Agency as primary drinking water contaminants.

Ged and Boyer (2014) and Boyer (unpublished) simulated seawater intrusion into fresh groundwater by mixing Gulf of Mexico seawater with Floridan Aquifer groundwater and Atlantic Ocean seawater with Biscayne Aquifer groundwater (see Figure 1). The most striking result is the increased formation of disinfection byproducts with increasing seawater content at a typical chlorine dose. For a very low fraction of seawater intrusion, e.g., 0.2 to 0.4% seawater by volume, the total formation of disinfection byproducts measured as trihalomethanes exceeded its maximum contaminant level of 80 µg/L. This is a critical result for water supply planning and treatment because the maximum contaminant level for trihalomethane formation is exceeded, which is based on adverse human health effects, whereas the bulk seawater content is low and does not require desalination.

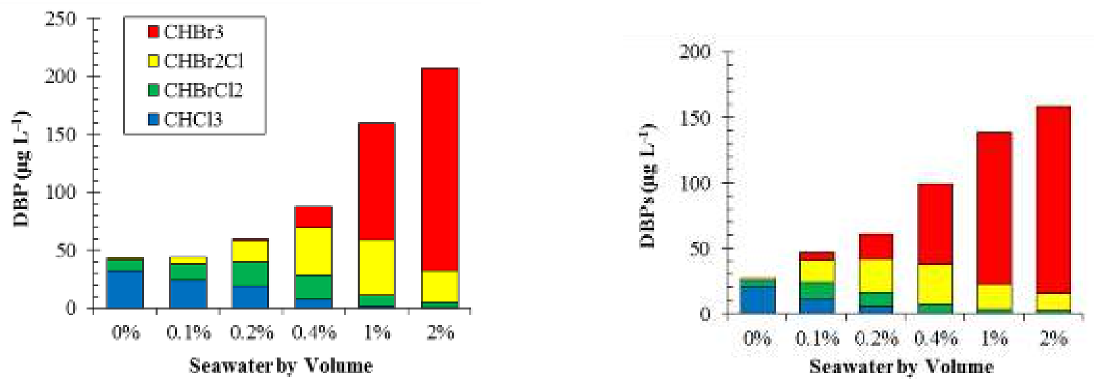

Figure 1. Formation of trihalomethanes during chlorine addition to groundwater–seawater mixtures. Gulf of Mexico (left) and Atlantic Ocean (right) seawater.

Assessing Climate Change Impacts on Hurricanes, Sea Level Rise and Coastal Inundation, and Coastal Ecosystems and Infrastructures

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Advanced Coastal Environment Systems (ACES) Group, Coastal & Oceanographic Engineering Program
David Kaplan, Lou Motz, Yafeng Yin, Christine Angelini
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Relevance to adaptation: Climate adaptation requires knowing accurate information of coastal inundation during current and future climates and their impacts on coastal ecosystems and infrastructures. Recent researches have shown that climate change can not only cause slowly varying sea level rise (SLR), but also may increase the intensity and even frequency of tropical cyclones in the future. Therefore, climate adaptation must consider the coastal inundation in future climate due to tropical cyclones and sea level rise. The Advanced Coastal Environment Systems (ACES) group at the University of Florida has used dynamic climate and coastal models to produce probabilistic coastal inundation maps in current and future climates due to the combined effects of sea level rise and increased future cyclone activities. Using the probabilistic coastal inundation maps, the ACES Group, along with the interdisciplinary faculty at ESSIE, has been and continues to be engaged in the following activities: (1) real-time forecasting the water level, currents, and salinity around the Florida Coasts; (2) predicting coastal inundation impact on population and property; (3) predicting coastal inundation impact on coastal wetlands and estuaries; (4) predicting coastal inundation impact on transportation and water systems; (5) assessing the role of coastal wetlands (marshes and mangroves) in reducing future coastal inundation risk; (6) assessing the impact of coastal inundation on inland flooding through coastal canals; and (7) assessing the impact of future coastal inundation on groundwater system and the role of groundwater in affecting future coastal inundation.

Most of the above mentioned activities are focused on the Southeast Florida region, including Miami-Dade, Broward, and Palm Beach Counties. Currently, ACES is funded by the National Oceanographic and Atmospheric Administration Climate Program Office, Florida Sea Grant, and South Eastern Coastal Ocean Observing Regional Association to conduct some of the activities mentioned above. ACES has been engaged with the Miami-Dade, Broward, and Palm Beach Counties as well as the South Eastern Florida Regional Climate Change Compact on some of the above topics, both as research partners and participants at numerous outreach activities including the Climate Change Summits and the Resilience Redesigns.

ACES develops and applies integrative multidisciplinary approaches to address the various research topics listed above. For example, some are studying the impact of various sea level rise scenarios on coastal inundation using the "bathtub" approach, which applies a single sea level rise value throughout a coastal area, e.g., Miami-Dade County. Using dynamic models, we have found that the "bathtub" approach generally over-estimates the extent and elevation of coastal inundation due to sea level rise, because the "bathtub" approach ignores the effect of land dissipation on coastal inundation. Other "bathtub" studies have combined the effect of sea level rise and future storms by adding a SLR value with a peak storm surge value calculated by statistical analysis of water level data, then applying the added inundation value throughout the coastal area. This approach, again, over-estimates the coastal inundation because it ignores the land dissipation and the interaction between the slowly varying SLR and the storm induced coastal inundation. Moreover, such maps are not true risk maps because they do not have any probabilistic information.

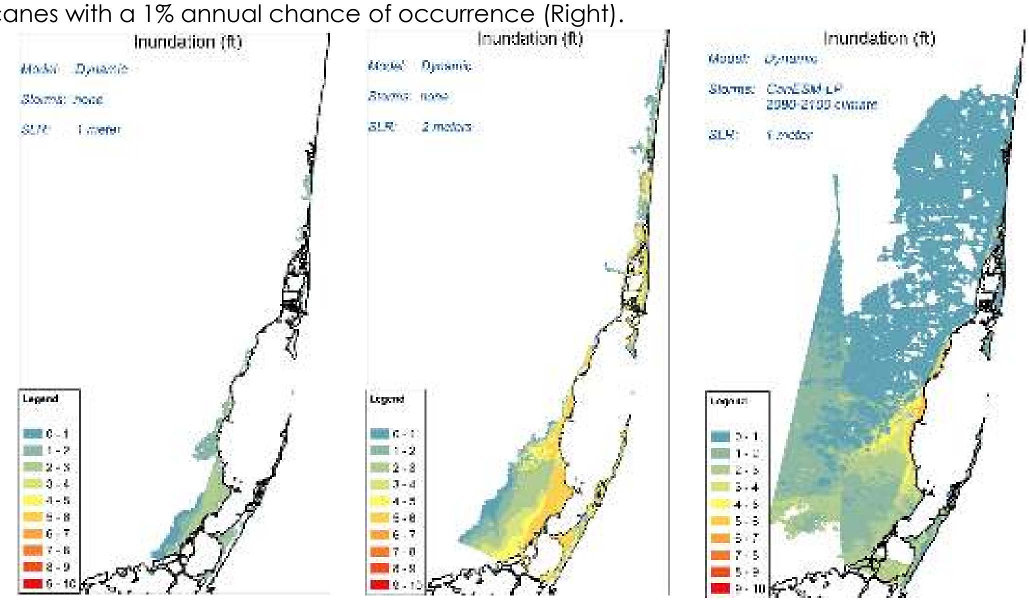
We have used dynamic global and regional climate models to predict the future storms expected in the Miami-Dade and Broward Counties, then using an integrated coastal storm surge and inundation modeling system (CH3D-SSMS, Sheng et al. 2010a and b, Sheng and Liu 2011) to produce future coastal inundation maps in the region (Sheng et al. 2012b, 2015; Sheng and Paramygin 2014). As an example, in Figure 1, we show two coastal inundation maps in the Miami-Dade County due to 1 m and 2 m SLR, as well as a 1% annual chance coastal inundation map in 2010 which includes 1m SLR and future storms. As shown in Figure 1, significant inundation levels of 4-9 ft are found in the south Miami-Dade. With higher SLR, the 1% coastal inundation level will increase further, thereby affecting more population and properties. Using the method described in Condon and Sheng (2012), we can estimate the affected population and property in the Miami-Dade in 2100. We can also assess the relative impact of SLR and future storms on future coastal inundation.

To make these future inundation projections more useful to Miami-Dade, we plan to add a groundwater model SEAWAT (Langevin and Zygnerski 2013; Sukop 2015) to the coastal inundation modeling system to allow interaction between surface water and groundwater, and to enable more accurate prediction of climate change impact on the coastal area. Motz (2014) has simulated the sea level rise impact on groundwater salinity in Broward County. If needed, surface storm water model can be added to the coupled surface water and groundwater modeling system.

Moreover, we plan to add coastal canals to our coastal model domain so we can assess the impact of future coastal inundation on inland canal systems which are maintained by the South Florida Water Management District.

Sheng et al. (2012a) developed a robust three-dimensional wetland-resolving surge-wave modeling system to simulate the effect of marshes and mangroves in reducing coastal surge and inundation. Lapetina and Sheng (2014, 2015) showed that the modeling system allows accurate simulation of surge and flood reduction by wetlands without resorting to ad-hoc tuning of bottom friction coefficients.

Figure 1. Coastal Inundation in Miami-Dade County due to 1 m Sea Level Rise (Left), 2 m SLR (Middle), and 1 m SLR plus future hurricanes with a 1% annual chance of occurrence (Right).



Effectiveness of Residential Water Conservation and Demand Management Programs

Researcher: Tatiana Borisova
Institution: Food and Resource Economics (FRED), University of Florida (UF)
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Relevance to adaptation: Water conservation and reduction in per capita water demand in urban areas is one strategy to address reductions in aquifer levels and salt water intrusion issues. FRED faculty have been examining effectiveness of various water conservation programs implemented by water utilities, local government, and Extension service. Specifically, we examined residential water conservation extension workshops (in Osceola county), residential irrigation inspections (in Alachua county), and changes in water price structure (high water use properties in Orange county). The analysis was conducted using property-level water use data provided by water utilities. The results show that all three programs are effective in changing property owners' water use; however, the effectiveness varies among programs. Local governments need to select the conservation program or a combination of program to achieve specific water conservation goals.

A Parameterized Climate Change Projection Model for Hurricane Flooding, Wave Action, Economic Damages and Population Dynamics – R/GOM-RP-2

Researcher: Zhong-Ren Peng
Institution: Department of Urban and Regional Planning, University of Florida
Email: zpeng@dcp.ufl.edu

Relevance to adaptation: Historical tidal gauges data and satellite observation have demonstrated sea level has been rising over the last 100 years and will continue to rise or even accelerate into the future (IPCC, 2014a; National Research Council, 2012; and Hsu, 2014). The key question is how coastal communities would respond if their primary residences are permanently inundated due to sea level rise (SLR). There are several adaptation strategies, including building sea walls and relocation. Building sea walls are obviously expensive (Yang, 2014); additionally, structural protection is not a feasible option for some coastal areas. Therefore, relocation may be a viable alternative. While previous studies focus on evaluating the impacts of SLR and the pros and cons of different adaptation strategies, few studies quantitatively model and assess land use changes and population relocation. This research contributes to the body of planning literature by filling this void. From the public point of view, people are not highly aware of sea level rise; according to our survey study, only half of the respondents agree that sea level is rising. Accordingly, this research establishes a channel to offer the public with scientific findings and raise the public awareness towards changing sea level, intensified flooding, and inundation.

Response: First, we identified coastal residents' perceptions regarding sea level rise and responses and attitudes towards inundation due to changing sea level and intensified storm surge. We fulfill this goal by conducting a field survey study in the City of Panama, Florida, with the collaboration from the city's Planning Department. Second, we are building a residential-relocation on the basis of sea level rise and flooding results from our project partners of Texas A&M University. Specifically, we are fulfilling the following goals:

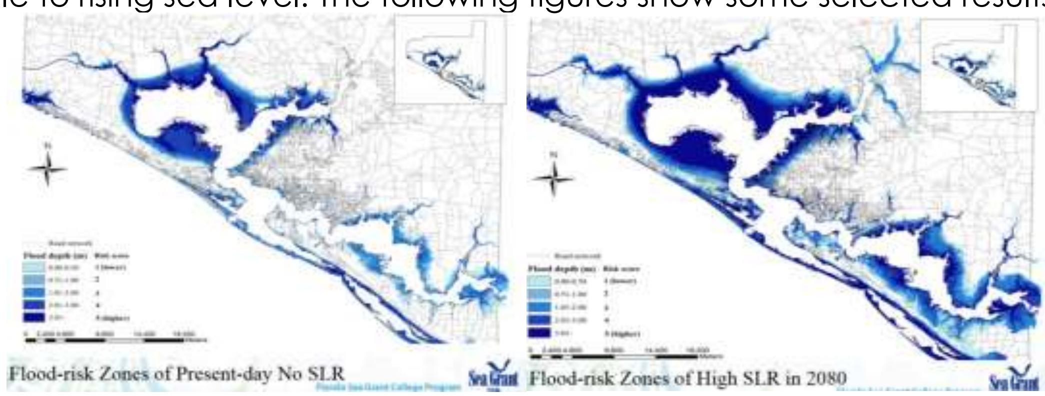
- Using Bay County, Florida as a case study, determined affected population whose primary residences would be permanently inundated due to sea level rise.
- Using Bay County, Florida as a case study, to simulate population dynamics in response to sea level rise in 2030 and 2080.

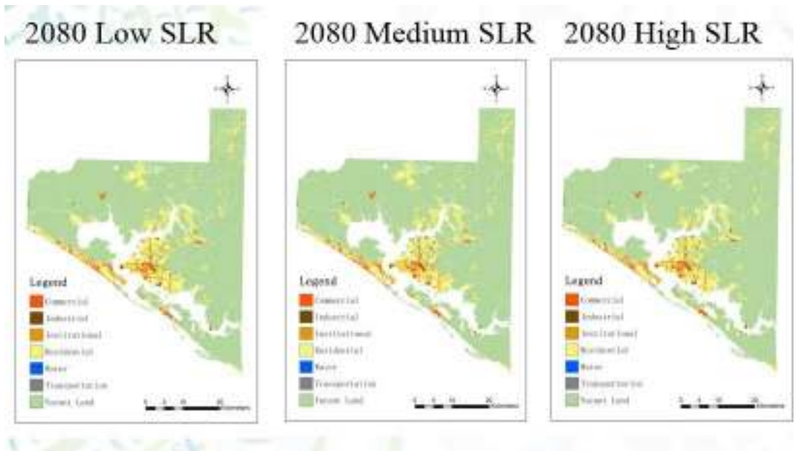
- To develop a generalized model framework that could be applied into other coastal regions which are susceptible to rising sea level.
- To provide local governments and planning agencies with guidelines and recommendations regarding population-retreat strategies and long-range land use planning that takes into account the impacts of sea level rise.

Results: One of the achievements of this project is to understand the public perception and attitudes towards sea level rise and hurricanes. Public support or opposition to sea level rise adaptation policies will be greatly influenced by public perceptions of the risks and dangers of sea-level rise. This study has conducted a survey to collect information on coastal residents' attitude toward future adaptation strategies, including preference to residential relocation. The results show that 74% of respondents would move if their primary residences are permanently inundated, and most of them prefer to move to other part of the same county.

Second, the proposed project contributes to the literature by integrating modeling, urban and regional planning, and climate change literature and to the public policy by providing a decision support tool for local governments to make scientifically sound public policies.

Another achievement of this project is to identify future available lands for residents whose primary residences would be permanently inundated due to sea level rise. Therefore, the proposed model could help local planning agencies better develop long-range land use planning under different SLR scenarios. Most importantly, the generalized model framework could be applied into other coastal regions that are susceptible to rising sea level. The following figures show some selected results.





Prediction: Results of Future Residential (SLR Adaptation)

Development of Sea Level Rise Adaptation Planning Procedures and Tools Using NOAA Sea Level Rise Impacts Viewer, funded by Mississippi-Alabama Sea Grant Consortium

Researcher: Zhong-Ren Peng
Institution: Department of Urban and Regional Planning, University of Florida
Email: zpeng@dcp.ufl.edu

Relevance to adaptation: In this study, we have conducted surveys to better understand what professionals need in the adaptation planning and how they prioritize the different facilities. The vulnerability analysis based on the survey results can therefore significantly facilitate understanding of vulnerability and adaptation planning. It directly shows where the most vulnerable area is and how the vulnerability index changes under different sea level rise scenarios. This visualization tool will be provided to planners, city managers, council members, and planning and engineering professionals within Tampa Bay Region through Tampa Bay Region Planning Council. By using this visualization tool, the scientific community, researchers and planners can better understand how sea level rise will affect Tampa Bay Region, what will be the most influential aspects of the integrated vulnerability at the census block group level, and how to prepare for sea level rise to best reduce the inundation vulnerability. It provides useful information for the local adaptation planning council to make adaptation planning more efficient and intuitive.

Response: The visualization tool will be mainly provided to different agencies, including 7 municipal planning agencies, four county agencies, state and regional environmental protection agency and department of transportation, private planning and engineering companies, and water supply authority. And we will also invite coastal community representatives to use this visualization tool in order to understand the effect of this tool on non-professional people.

Results: This tool provides a good visualization of inundated infrastructures and regional vulnerability for local agencies to improve adaptation planning efficiency through: showing vulnerable facilities and vulnerable areas under different situations and scenarios (inundated infrastructures and low-lying infrastructures under 1ft, 2ft and 5ft sea levels) providing infrastructure vulnerability index and integrated vulnerability (including economic vulnerability score, social vulnerability score, and infrastructure vulnerability score) for users to check how vulnerable a specific area is under different sea level rise scenarios from multiple aspects using users preferred interface design (Google map): http://plaza.ufl.edu/dengyujun11/SLR7.0.html

Recap: The vulnerability analysis and the tool developed provides a guidance for local planners to identify the most vulnerable infrastructures and area from different perspectives, to understand the primary causes of overall vulnerability in a region, and therefore help them to prioritize their adaptation planning focus area and sections (e.g. economic, infrastructure, socially constructed adaptive capacity).

A Spatial-Temporal Econometric Model to Estimate Costs and Benefits of Sea-Level-Rise Adaptation Strategies – R/C-S-51

Researcher: Zhong-Ren Peng
Institution: Department of Urban and Regional Planning, University of Florida; Funded by Florida Sea Grant
Email: zpeng@dcp.ufl.edu

Relevance to adaptation: Sea level is expected to rise steadily though slowly in the foreseeable future. A direct consequence of sea level rise is the inundation and flooding, inflicting considerable economic and ecological damages. A challenge for all coastal area governments and state and national politicians is to decide on an appropriate adaptation strategy to mitigate the damages and when to implement it, and more importantly on how to rally public support for the new adaptation strategy. A growing body of current research has been devoted to sea level rise impact analysis and adaptation planning. However, despite these research efforts and various existing sea level rise adaptive planning tools, decision makers and residents at coastal areas are not making significant progress to prepare for future sea level rise. One of the major reasons for this slow reaction is that people are unaware of the costs of doing nothing or postponed actions, and the benefits of taking adaptation actions. To meet this challenge, this research project has an interdisciplinary team from economics, climate change, and urban and regional planning areas who have worked together to formulate an interdisciplinary opinion so that policy makers can make scientifically sound policy decisions. Therefore, this research provides a better understanding of the economic impacts of different adaptation strategies in response to sea-level rise in the adaptation decision-making process

Response: In cooperation with Tampa Bay Regional Planning Council (TBRPC), this research project develops a temporal-spatial econometric model to evaluate the costs and benefits of various adaptive strategies. This project also provides a decision support tool that local planners and decision makers can generate and visualize such information on their own. Furthermore, this project integrates both direct and indirect economic impacts of sea level rise into the cost-benefit analysis framework, which is applied to evaluate the most commonly adopted adaptation strategies.
The economic loss has been estimated on land values, business revenue, coastal wetland ecosystem services, building damages and value of travel time delay at different time points. These economic losses are considered as benefits of adaptation strategies. Additionally, the cost of adopting these strategies are quantified at different time points which are consistent with benefit analysis. Finally, all the benefits and costs are put together to analyze the cost efficiency and best time to take actions. It also proposes an adaptation plan that assigns each strategy to its appropriate locations as a guide for local communities. An uncertainty analysis is also conducted to evaluate the cost efficiency of adaptation strategies as well as the proposed adaptation plan under different uncertainty levels.

Results and contributions: The results reveal that different strategies have very different cost efficiency. Generally speaking, the strategies that target to protect built environment have higher cost efficiency than the ones that focus more on preserving ecosystems. Furthermore, cost benefit analysis at different action time points help to decide the best action time for each strategy as well as the adaptation plan. Although current sea level rise projection is associated with high uncertainty, the uncertainty analysis shows that even under the highest uncertainty level, most adaptation strategies and the adaptation plans are more cost efficient than doing nothing.

The key benefits of this project is that it provides a tool for adaptation planning. Policy makers may have several adaptation strategies to choose from. Using this research's results, they are able to choose the one that yields the highest benefits. The project also provides a model to quantify and forecast the economic costs and benefits for each adaptation strategy.

Appendix 2: Quarterly Reports

First Quarter Update (January 31, 2015 – April 30, 2015)

On January 21, 2015, the Board of County Commissioners (Board) passed seven (7) resolutions, each supporting the implementation of one of the seven recommendations included in the "Miami-Dade Sea Level Rise Task Force Report and Recommendations." Resolution R-48-15, which requires a quarterly status report and a final report within 364 days, directs the Mayor or Mayor's designee to work in conjunction with the Office of Intergovernmental Affairs (OIA), the South Florida Water Management District, the United States Geological Survey, and other member Counties of the Southeast Florida Regional Climate Change Compact (Compact) to conduct a comprehensive study and develop adaptation strategies to address potential flood damage reduction and salt water intrusion associated with sea level rise. Pursuant to R-48-15, this status report is submitted for your review.

Background

In July 2013, the Board created the Miami-Dade Sea Level Rise Task Force (Task Force) for the purpose of reviewing current and relevant data, science and reports, and to assess the likely and potential impacts of sea level rise and storm surge on Miami-Dade County over time. On July 1, 2014, the Task Force presented a report to the Board entitled, "Miami-Dade Sea Level Rise Task Force Report and Recommendations," providing the requested assessment along with recommendations of how Miami-Dade County may can begin planning and preparing for projected sea level rise impacts. In addition, Resolution R-451-14 and Ordinance 14-79 were adopted in 2014, requiring that planning, design and construction of County infrastructure consider potential sea level rise impacts.

In February 2008, Miami-Dade County entered into Joint Funding Agreement 08E0FL20817 with the U.S. Geological Survey to develop an integrated surface/groundwater numerical flow model, with one of the objectives of the project being to evaluate if sea level rise will cause salt water intrusion into coastal wellfields. Technical staff from the Miami-Dade Water and Sewer Department has worked with the U.S. Geological Survey on this project since then, and the numerical model was formally published by the U.S. Geological Survey in September 2014. The model is designed to evaluate if the current surface-water structure control operational criteria effectively control saltwater intrusion and flooding with projected population increase and sea level rise, among other uses.

This enhanced modelling capability is extremely important to all forthcoming adaptation planning for sea level rise in Miami-Dade County and the Southeast Florida region because it is a significant improvement upon former models used to generate "bathtub" sea level rise inundation maps. It will provide critical information about the effects of sea level rise and precipitation events on the groundwater table, and how this may affect water resource management, including water supply, wastewater disposal, and canal operations. This will facilitate a more accurate understanding of areas and infrastructure more vulnerable to flooding in Miami-Dade County. The Water and Sewer Department and the U.S. Geological Survey used the modified guidance developed by the U.S. Army Corps of Engineers (USACE, 2011) and a planning scenario of 9 to 24 inches additional rise by 2060, consistent with projections presented in the 2014 National Climate Assessment, and formally adopted by the partner counties in the Compact for the modelling effort. Future efforts include updating the model to include the revised sea level rise projection, which is expected to be published in August 2015, by the Compact's Sea Level Rise Consensus Workgroup.

The South Florida Water Management District is the primary water management agency for Southeast Florida. As a result, their primary infrastructure and water management strategies are critical to good water supply, water quality, and flood control in the region, and consequently determines Miami-Dade's water management strategies and operation of secondary structures. The South Florida Water Management District and Miami-Dade County have a long history of close collaboration on water management and supply, as well as Everglades restoration, and this continued collaboration will be critical in effectively facing the additional challenges of climate change and sea level rise.

In 2009, the South Florida Water Management District's Interdepartmental Climate Change Group published a report entitled, "Climate Change and Water Management in South Florida." This report provided a good overview of the potential impacts of climate change to South Florida with regards to sea level rise, temperature, and evapotranspiration, rainfall, floods, drought, and tropical storms and hurricanes. In this report, the South Florida Water Management District stated that flood protection in Southeast Florida may be impacted by sea level rise and they identified several existing South Florida Water Management District coastal structures in Miami-Dade County that could be potentially impacted. Retrofitting of more structures with forward pumps will be considered as a feature of adaptation plans being developed to address sea level rise and rainfall changes in Miami-Dade County. The South Florida Water Management District has initiated a new pilot project to determine the current level of flood protection in the C-4 basin, to consider future changes that may impact flood protection, and to develop adaptation strategies to address such impacts. The South Florida Water Management District will also initiate similar efforts in the C-7, C-8, and C-9 Canal basins in Miami-Dade County with funding from the Federal Emergency Management Agency.

In addition to working with state and regional partners, the South Florida Water Management District is also engaging international expertise in addressing these issues. In April of 2014, the South Florida Water Management District signed a three year Memorandum of Agreement (MOA) with the Ministry of Infrastructure and the Environment of the Netherlands, and the Delfland Water Board, to work cooperatively and share information, expertise and strategies in flood control, water supply, spatial development, environmental ecosystem restoration, crisis management, modelling, service level practices, sea level rise, climate adaptation strategies and salt water intrusion impacts. Because there are many similarities in the water management systems of South Florida and the Netherlands, these two (2) organizations agreed to work towards a comprehensive thematic annual work program on information and best practices exchange, and to evaluate and update the work program annually. Therefore, the additional expertise of these Dutch partners will contribute to the regional efforts of the South Florida Water Management District, the U.S. Geological Survey, Miami-Dade County and the Compact to better understand potential flood damage and saltwater intrusion and begin to develop adaptation strategies.

Quarter 1 Progress (January 31, 2015 – April 30, 2015)

- The South Florida Water Management District has recently initiated a two year grant project that is funded by the National Oceanographic and Atmospheric Administration's Sectoral Applications Research Program. It was awarded to the South Florida Water Management District and their partner, Deltares, for their project entitled, "Flood and Drought Risk Management Under Climate Change: Methods for Strategy Evaluation and Cost Optimization." Deltares is an independent research institute which focuses on applied research in the field of water, subsurface, and infrastructure. Deltares is based in Delft and Utrecht in the Netherlands, with a USA branch (Deltares USA) based in Silver Springs, Maryland.

- This project is anticipated to contribute significantly to the directives required by R-48-15 because the project team has chosen Miami-Dade County as a pilot area to implement concepts of flood and drought risk management to: (1) determine the current level of flood protection in the C-4 basin, (2) consider future changes that may impact flood protection, and (3) develop adaptation strategies to address such impacts. Furthermore, the South Florida Water Management District will also initiate similar efforts in the C-7, C-8, and C-9 Canal basins in Miami-Dade County with funding from The Federal Emergency Management Agency. This project aims to accomplish several relevant objectives:

    - Further analyze the impacts of climate change on the occurrence of floods and droughts in the South Florida Water Management District;
    - Gain more insight into the intended and unintended effects of flood and drought risk reduction measures;
    - Develop and apply a method to evaluate the capability of the water management system to effectively address extreme events (floods and droughts), and use the outcomes for the assessment of comprehensive adaptation strategies aimed at flood and drought risk reduction under climate change;
    - Apply an economic optimization method for determining the optimal investment in flood risk reduction. With this application, the project will

document the process of moving the method from the Netherlands to Florida, and identify what is required to apply the optimization method to other regions;
  - Assess and communicate the usefulness of applying this optimization method for decision making in water resource management; and
  - Publish the general outcomes on the methods and the specific outcomes for the case study area, through two stakeholder and expert workshops and scientific (journal) publications.

- The South Florida Water Management District and its Deltares partners held a project kick-off meeting and site tour on March 23-25, 2015, where local and regional partners and contributors were formally introduced to the project and encouraged to provide suggestions for data gathering and project implementation. The Miami-Dade Office of Sustainability and the Water and Sewer Department hosted the meetings on the first two (2) days, and appropriate County technical staff participated to provide input and suggestions. Staff from the Water and Sewer Department and Public Works and Waste Management's Stormwater Master Planning Program will be integral contributors to the project.

- Staff of the Miami-Dade Regulatory and Economic Department (RER) and the Water and Sewer Department are working to establish an internal working group comprised of technical staff from key departments to begin evaluating the engineering and other expertise needed to conduct a thorough analysis and develop cost estimates to acquire the expertise and begin formulating a capital plan. One of the first tasks for the technical workgroup is to develop criteria and parameters for use in the groundwater/surface water integrated model, which will then be utilized to help determine areas and infrastructure more at risk for flooding and inundation.

- The Compact's Sea Level Rise Consensus Workgroup is currently finalizing a revised Sea Level Rise Projection for Southeast Florida. This projection, which is expected to differ to some degree from the original sea level rise projection developed in 2011, will be utilized by the partners of the Compact, including Miami-Dade County, for planning purposes. This revised projection and accompanying document are expected to be finalized and released in August 2015.

- The South Florida Water Management District hosted a meeting on April 30, 2015, with their Netherlands MOA partners, the Ministry of Infrastructure and the Environment of the Netherlands, and the Delfland Water Board, to discuss a variety of climate change and sea level rise related topics, including saltwater intrusion and "science based adaptation strategies" for water and climate. County staff participated to see how the work associated with this MOA can contribute to accomplishing the tasks required in Resolution R-48-15.

In accordance with Ordinance 14-65, this memorandum and report will be placed on the next available Board of County Commissioners meeting agenda.

If you have questions concerning the above, please contact Mark R. Woerner, AICP, Assistant Director for Planning, Department of Regulatory and Economic Resources, at (305) 375-2835 or mwoerner@miamidade.gov.

Second Quarter Update (May 1, 2015- July 30, 2015)

The following steps have been taken during the Second Quarter to address the comprehensive study referenced in this resolution:

- The Water and Sewer Department is currently evaluating the potential impact of salt water intrusion by monitoring a series of groundwater wells which indicate the fluctuating location of the salt water front line. Several projects such as earthen plugs and salinity control structures are helping to mitigate the potential impact of salt water intrusion on Miami Dade County's water supply. The resources needed to continue to protect freshwater resources are currently being re-evaluated and a final report will be available by the conclusion of 2015, indicating where additional resources are needed. This report will also assess the potential to slow or limit salt water intrusion in the future.

- On July 27, 2015, a full-day workshop was held at the South Florida Water Management District headquarters with representatives from the Miami Dade County Department of Regulatory and Economic Resources, Public Works and Waste Management, and Water and Sewer Department, and the South Florida Water Management District, U.S. Geological Survey, the Army Corps of Engineers, Deltares, Florida Climate Institute and the Compact. This workshop brought together practitioners and researchers to review all of the on-going and planned research efforts which are examining flooding risk, salt water intrusion, and adaptation approaches in the region. Participants discussed where informational and analytical gaps exist, as well as other studies or methodologies used in other regions and countries that could be drawn upon to address those gaps. The group also reviewed potential funding for adaptation measures. The on-going monitoring, modelling, and adaptation measures being taken by Public Works and Waste Management, Water and Sewer Department and the South Florida Water Management District were the focus of the afternoon workshop. RER staff is currently reviewing and revising the proposed timeline and draft outline developed from this workshop, which will be used for the final report to be presented to the Board at in January 2016. The group that participated in the July 27th workshop will continue to contribute to the development of that report and will continue to provide expertise on how this analysis can be completed with existing resources, and where additional expertise and resources will be needed.

- RER staff also contacted the Army Corps of Engineers staff members who recently completed the North Atlantic Coast Comprehensive Study. This two-year study was requested by the Obama Administration in the wake of Hurricane Sandy to systematically review and evaluate the coastal flooding risks for the Sandy affected area. The Comprehensive Study detailed coastal storm and flood risks to vulnerable populations, property, ecosystems, and infrastructure in the region. The study was intended to help local communities better prepare for future flood risks and make the latest scientific information available to local planners. While the geographic scope of the study was much larger than what is needed for Miami-Dade County, there are potential lessons that could be learned and methods for modelling coastal storm surge that could be replicated for a local assessment.

- On June 24, 2015, Florida International University hosted the kick-off event for the Compact's regional project with the RAND Corporation, known as "Water Management and Adaptation Planning to Address Sea Level Rise and Climate Change in Southeast Florida". At this meeting, members of the Compact, the U.S. Geological Survey, South Florida Water Management District, the Water and Sewer Department, the South Florida Regional Planning Council (SFRPC), The Nature Conservancy (TNC), and other academic partners developed the scope of work, schedule, and action plan for the study. Participants reviewed the region's most pressing water management decisions, completed a gap analysis identifying which key decisions currently lack sufficient analytical support, and worked through a prioritization exercise to address those gaps. RAND has previous experience helping policy makers work though complex problems and decision-making processes and has provided research and facilitation support to stakeholders in the Mississippi Delta region. RAND will be able to provide support to the Compact by helping to analyze and connect several existing models. The exact scope of the project is still being determined. It is anticipated that within the next 12-16 months this project will provide a decision support tool to help the region evaluate the economic implications of various water management regimes and infrastructure investments, as well as different land use patterns. A focus of this research will be integrating economic models to identify ways that the economic exposure of regional assets to storms and flooding risks can be minimized.

- One of the most significant factors in determining our regional flooding risk will be future precipitation patterns. Early model runs with the newly developed U.S. Geological Survey model used current precipitation patterns, but these patterns may shift in the future. A change in either direction toward drier or wetter conditions would have significant implications of regional water management strategies. On June 22 and 23, 2015, the U.S. Geological Survey and the Florida Center for Environmental Studies hosted a two day event at Florida Atlantic University to review the latest science on future precipitation patterns. The event provided a good opportunity for climate modelers and climatologists to interface directly with decision-makers and Compact members. The scientific review of the latest dynamical and statistical climate downscaling techniques revealed the importance of continuing to advance this line of research, particularly given the current uncertainty surrounding future wet and dry season conditions and their potentially significant implications for drinking water resources, agriculture, and ecosystems.

- The South Florida Water Management District continued to work on its two year National Oceanic Atmospheric Administration funded grant project "Flood and Drought Risk Management under Climate Change: Methods for Strategy Evaluation and Cost Optimization." As mentioned in the First Quarter update report, this work is being conducted jointly with Deltares, an independent research institute which focuses on applied research in the field of water, subsurface, and infrastructure. Deltares is based in Delft and Utrecht in the Netherlands, with a USA branch (Deltares USA) based in Silver Springs, Maryland.

- During this quarter, PWWM continued to advance their flood risk analysis within the C-8 and C-9 basins. The preliminary model runs for the C-8 and C-9 basins have been completed, using the previous Compact sea level rise projections (2012), current land use (2013) and future land use (2030). Inundation limits, and a new floodplain map have been prepared using the 2012 projections and an estimate for the end of wet season groundwater table. Staff are now in the process of preparing the model runs for the updated Compact sea level rise projections (2015), and a new floodplain map will be prepared using the new projections, considering future groundwater table and future land use.

Third Quarter Update (July 31, 2015- October 31, 2015)

- The following steps have been taken during the third quarter to address the comprehensive study referenced in this resolution:

- The Water and Sewer Department continues to monitor changing environmental conditions and evaluate the potential impact of saltwater intrusion. The resources needed to continue to protect freshwater resources are currently being re-evaluated and a final report will be available by January 2016, indicating where additional resources may be needed. This report will also assess the potential to slow or limit saltwater intrusion.

- The Stormwater Utility Planning Division continues to advance their flooding studies within the C-8 and C-9 basins. The division had previously developed inundation limits and new floodplain maps and an estimate for the end-of-wet season groundwater table. The division is in the process of converting the C-9 model to the appropriate vertical datum (NAVD88), in order to create a new floodplain map which will use the Compact's new unified sea level projections (2015), considering future groundwater table and future land use. The completion schedule for this first modeling work is approximately six (6) weeks after receipt of the future groundwater table from WASD, based on the new U.S. Geological Survey groundwater/surface water interface model. After this modelling phase is complete and the floodplain maps are produced, the Planning Division of RER will analyze potential land use impacts.

- In addition, the model runs for Arch Creek basin have been completed using the current Compact sea level rise projections (2015). Maps of inundation depths and new floodplain maps are being prepared using the 2015 Compact projections. Since this is a coastal basin, only the tide projections are necessary for the first round of modeling. The Planning Division of RER, will review the results for potential land use impacts.

- The model runs for Oleta River basin are being prepared, using the current Compact sea level rise projections (2015). Inundation depths maps and new floodplain maps are being prepared using the 2015 Compact projections. Since this is a coastal basin, only the tide projections are necessary for the first round of modeling. The Planning Division of RER, will review the results for potential land use impacts.

- The Florida Climate Institute (FCI) is a consortium of Florida universities with programs focused on climate change and sea level rise related research, and currently includes the University of Miami, Florida International University, Florida Atlantic University, and University of Florida, amongst other Florida universities. RER staff are working with several of the South

Florida FCI universities to assemble and summarize the best available science relevant to Miami-Dade County's vulnerability to sea level rise and saltwater intrusion, as well as research on potential adaptation options. A first draft of the submissions from the Florida Climate Institute has been drafted and will be incorporated into the final report which will be submitted to the board in January 2016. The scientific research spans the breadth of disciplines from studying social adaptation to sea level rise, to changing precipitation patterns, to modeling of the interdependencies of various infrastructural systems, to modeling the resilience of wetland ecosystems to changing sea levels.

- Work also continues on the RAND Corporation study "Adaptation Planning for Sea Level Rise and Climate Change in Southeast Florida: Understanding the Interactions of New Infrastructure, Land Use Changes, and Water Management". The technical experts working on this project are world-renowned experts in complex decision-making and are bringing a wealth of expertise to our regional adaptation challenges. While the final scope is not finalized and may still change, the intended outcome is to develop an integrated system of simulation models for the region that will provide a transparent, interactive tool, and a level analytical playing field to assess potential interactions among water management, transportation, and land use decisions under a range of scenarios. The project's ultimate goal is to provide tools to help decision-makers and stakeholders in the region gain a better understanding of the costs of both action, and inaction, across a wide range of scenarios. In collaboration with RER staff and with technical experts and partners within the region, RAND's engagement will help to support: rigorous evaluation of vulnerabilities of land-based assets, application of models to support economic loss and benefit-cost evaluations, assessment of alternative funding and financing strategies, and identification of preferred and phased risk-reduction strategies. RAND will also seek to test several hypotheses including one which proposes that more compact development will reduce the costs of providing selected public services.

- Work is also beginning on a Pre-disaster Mitigation project in the C-7, C-8, and C-9 basins. This project, funded by the Federal Emergency Management Agency and awarded to the South Florida Water Management District and State of Florida's Office of Emergency Management, will identify the most vulnerable coastal flood control structures within the pilot basins. The project will use storm surge modeling to analyze surge predictions at the downstream locations of the flood control structures, which will then be used to drive watershed simulation models for the selected basins. The project will also collect higher-resolution elevation data, canal cross sections, and land use, to develop realistic flood simulation models for two watersheds. These simulations will also incorporate a range of sea level rise projections to identify changes in the level of service over the next 25 to 50 years. This project will also include the development of various communication tools which will help local, regional, state, and federal agencies visualize the potential impacts of flooding events. This project is expected to be completed before September, 2017.

- On August 11 and 12, 2015, RER and the Stormwater Utility Planning Division staff members participated in a two day GIS-based training provided by the National Oceanographic and Atmospheric Administration. This training taught staff several techniques including: (1) how to map coastal inundation, including how to map water levels using GIS techniques; (2) how to determine the differences among various inundation products; and (3) how to access and manipulate water level, topography, bathymetry and base layer data. This includes mapping storm surge, inland flooding, shallow coastal flooding, and sea level rise. This training was integral to broadening the technical expertise and the number of full-time staff with the technical capability to support future vulnerability analyses for the County. Additionally this training is now available to all staff interested in taking advantage of it.

- On August 17, 2015, RER staff met with the director and several staff members of the University of Miami's School of Architecture's Center for Urban and Community Design. This Center, directed by Professor Sonia Chao, has extensive experience with sustainable and environmental design, and with assisting local governments to develop innovative solutions to community design challenges. This meeting focused on the precedent projects that could be useful models for Miami-Dade County to consider when framing potential adaptation options for Miami Dade County. Professor Chao also reviewed how design guidelines could be useful tools for the County as it moves forward and encourages more resilient forms of development. The discussion also focused on how to effectively integrate community participation into future adaptation planning.

- On August 20, 2015, Planning staff and Environmental Resources Management staff of RER met with The Nature Conservancy to discuss how future adaptation options can enhance ecological restoration and further The Nature Conservancy's goals to increase equity and access to safe, attractive, and healthy public spaces.

- On September 1, 2015, RER staff held a conference call with New York City Department of City Planning staff who developed NYC's "Urban Waterfront Adaptive Strategies". This guidance document identifies resilience strategies and a framework for analysis specific to different urban coastal communities. The guide also outlines the type and approximate costs and benefits associated with each different adaptation approach. It also outlines a clear framework wherein each coastal community can evaluate the appropriateness of different adaptation approaches to their particular coastal geomorphology and urban condition. This reference serves as an excellent model which could be readily replicated in Miami-Dade County to provide a similar framework for approaching adaptation.

Appendix 3: Salt Front Monitoring Program 2016 Annual Submittal

Miami-Dade
Water and Sewer Department

Miami-Dade Consolidated PWS
Water Use Permit No. 13-00017-W

Salt Front Monitoring Program
Annual Submittal
Special Permit Condition #37

Submittal date:

April 15, 2016

Miami-Dade

Water and Sewer Department

P.O. Box 33-0316, Miami, FL 33233-0316

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1. Introduction

The South Florida Water Management District (SFWMD) issued Water Use Permit # 13-0007-W (WUP) to Miami-Dade Water & Sewer Department (WASD) November 15, 2007. At the request of WASD, this permit was first modified and re-issued by the SFWMD on November 1st, 2010 and subsequently on July 16, 2012 and on February 9th, 2015. Per Special Permit Condition (SPC) #37 the Permittee is required to submit an annual Salt Front Monitoring Program summary report. The annual report summarizes hydrologic and water quality conditions ascertained from the monitoring data collected as part of the approved salt front monitoring program described in Exhibit 28 of the 2015 modified WUP. This annual report includes review and analysis of the data collected and includes recommendations regarding the salt front monitoring network. The annual submittal is due to the SFWMD on April 15, 2016. Therefore, this report is intended to comply with the SPC #37 annual report requirement. Please refer to **Appendix A** for copy of the SPC #37 of the WUP, re-issued on February 9th, 2015. This report summarizes the data collected during 2015 and previously submitted to the SFWMD in quarterly reports in April 2015, July 2015, October 2015 and January 2016, and includes the progress made on the salt front update project.

1.1 Special Permit Condition #37

As per SPC #37, WASD is required to continue submitting monitoring data in accordance with the approved comprehensive water quality/water level monitor network to assess the salt front in Miami-Dade County. This monitoring network was designed to meet the criteria SFWMD Basis of Review (BOR) for Water Use Permit Applications in the South Florida Water Management District amended April 23, 2007, Section 4.0 Monitoring Requirements; Section 4.2 Saline Water Monitoring. WASD public wellfields locations are found in **Figure 1, Appendix B**. As part of this submittal all monitoring network site names and IDs, locations (latitude and longitude), program, and well construction details are summarized in **Table C-1, Appendix C.** Groundwater levels and chloride levels throughout Miami-Dade County are monitored through the 5-year Water Resource Joint Funding Agreement (JFA) with the USGS (currently JFA 14GGESMC0000109). A copy of this JFA is included in **Appendix D**. These wells either have manual water levels taken, or have been equipped with satellite telemetry to record groundwater levels in realtime. Water level data are available from the

USGS website http://www.sflorida.er.usgs.gov/ddn_data/index.html. Wells are sampled according to the schedule for chlorides by USGS personnel following USGS sampling protocols.

1.2 Background

Saltwater intrusion in Miami-Dade County is monitored through a joint effort of the Miami-Dade Water and Sewer Department (WASD), the Division of Environmental Resources Management (DERM) of Miami-Dade Department of Regulatory and Economic Resources (RER), and the U.S. Geological Survey (USGS). A network of small diameter wells have been drilled to the base of the aquifer to serve as monitor wells to identify the location of the saltwater intrusion front. The salt front is identified as the location, at the base of the aquifer, of the 1,000 milligrams/per liter (mg/L) isochlor, or line of equal chloride concentration of 1,000 mg/L). Sampling of the monitor wells is done by the USGS, under a cooperative contract with Miami-Dade County for wells currently included in the salt front monitoring program on the schedule indicated on **Table C-1 Appendix C**. Additional wells are sampled quarterly or yearly basis depending on well location, but every year the sampling schedule includes a county-wide sampling event conducted at the height of the dry season to coincide with the time when inland movement of the saltwater front would be at its peak. The data derived from that sampling is used by the USGS to identify any significant movement of the salt front, and to map the location of the salt front if a significant movement is evident. WASD reports the data to the South Florida Water Management District (SFWMD) quarterly, as part of the WUP #13-00017-W requirements.

The USGS published an update of the salt front line was in 1995 (Sonenshein, 1997; please refer to **Figure 2, Appendix B**) and in 2011 (Scott Prinos et al). The network of monitor wells has been modified over the years, depending on the changing needs of the county and on changing hydrologic conditions. More wells have been drilled to monitor areas where the salt front is moving, and sampling of those wells already by-passed by the salt front has been discontinued. Four new salt front monitoring wells were installed in 2015 (**Figure 3, Appendix B**). Other wells have been drilled around the operating wellfields to provide additional protection. The monitoring and testing program now includes annual induction logging of several wells. These electric logs show the variations in the bulk conductivity of the well water with changes in well depth, and from that information the effects of formational stratigraphy and hydraulic conductivity on the intrusion patterns can be determined. The existing salt water front monitoring network is included as **Table C-1, Appendix C**, which includes well IDs, construction details, type of monitoring, sampling frequency, and the 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014 and 2015 chloride data currently used in the salt front delineation program.

2. Chloride Data – 2015

Results of the 2015 salt front monitoring are plotted and included as **Appendix E**, and summarized below in Table 1. An increase in the average chloride concentration was observed for some of the wells and a slight decrease for others, but in general, there was no significant difference between 2007 and 2015 average concentrations chloride levels, excepting the wells located in the southeastern portion of the County, where a rapid increase in salinity has been observed in the several past years. These wells are located just east of the Newton Wellfield (refer to **Figure 1, Appendix B** for wellfield location). Please refer to **Appendix E** for graphs summarizing the 2003 – 2015 chloride data, and the past 25 year's historical data.

Station Name	*2015 Min (mg/L)*	*2015 Max (mg/L)*	*Average Chloride (mg/L) 2015*	*Average Chloride (mg/L) 2014*	*Average Chloride (mg/L) 2013*	*Average Chloride* (mg/L) 2012*	*Average Chloride (mg/L) 2011*	*Average Chloride (mg/L) 2010*	*Average Chloride (mg/L) 2009*	*Average Chloride (mg/L) 2008*
*G-3313E**	*4300*	*5900*	*5100*	*5200*	*4800*	*4600*	*5600*	*713*	*1500*	*5400*
G-3313C	*4800*	*5400*	*5167*	*4875*	*4533*	*4350.83*	*4716.67*	*4400*	*4250*	*4200*
G-3250	*100*	*210*	*139*	*134.25*	*36.5*	*200*	*180.83*	*176*	*139*	*131*
G-3229	*2200*	*2600*	*2442*	*2250*	*2108.3*	*1883*	*1605.83*	*1217*	*900*	*807*
G-3224	*34*	*37*	*35*	*34.5*	*35.25*	*41*	*42.25*	*41*	*41*	*39*
G-3162	*1400*	*1600*	*1475*	*1541.67*	*1425*	*1267*	*1280*	*1303*	*1284*	*1208*
G-1354	*150*	*350*	*195*	*176.67*	*135*	*58*	*48.83*	*48*	*516*	*53*
G-1351	*390*	*430*	*406.67*	*399.17*	*436*	*474*	*491.67*	*503*	*520*	*530*
G-1180	*10*	*28*	*19*	*20.22*	*37*	*17*	*24.58*	*27*	*17*	*30*
G-1009B	*65*	*160*	*80*	*71.83*	*74*	*75*	*60.42*	*62*	*59*	*59*
G-939	*3400*	*4300*	*3767*	*3883.33*	*4108*	*3808*	*3900*	*3750*	*3333*	*3050*
G-901	*4000*	*5200*	*4650*	*3527.27*	*3058*	*2667*	*2550*	*2438*	*2550*	*2375*
G-3611	*160*	*160*	*160*	*165*	*168*	*165*	*168.75*	*170*	*172*	*173*
G-896	*260*	*480*	*347*	*245.83*	*251*	*258*	*245.33*	*248*	*235*	*247*
G-894	*14*	*17*	*15*	*15*	*17*	*21*	*22.67*	*22*	*22*	*21*
G-571	*26*	*28*	*27*	*26.58*	*28*	*34*	*35.42*	*34*	*30*	*32*
G-548	*31*	*34*	*32.58*	*28.58*	*30*	*31*	*31.5*	*34*	*36*	*40*
G-432	*5900*	*6800*	*6383*	*5816.67*	*5683*	*5467*	*5141.67*	*4775*	*4500*	*4150*
G-354	*36*	*44*	*40*	*40.5*	*42*	*45*	*46.08*	*49*	*50*	*53*
F-279	*3900*	*4300*	*4067*	*4116.67*	*3892*	*3675*	*3583.33*	*3475*	*3383*	*3300*
F-45	*120*	*160*	*143*	*129.5*	*127*	*118*	*112.92*	*97*	*97*	*87*
G-3885	*27*	*31*	*30*	*29.92*	*31*	*36*	*36.33*	*NA*	*NA*	*NA*
G-3886	*46*	*48*	*47*	*45.77*	*47*	*49*	*50.83*	*NA*	*NA*	*NA*

Station Name	*2015 Min (mg/L)*	*2015 Max (mg/L)*	*Average Chloride (mg/L) 2015*	*Average Chloride (mg/L) 2014*	*Average Chloride (mg/L) 2013*	*Average Chloride* (mg/L) 2012*	*Average Chloride (mg/L) 2011*	*Average Chloride (mg/L) 2010*	*Average Chloride (mg/L) 2009*	*Average Chloride (mg/L) 2008*
G-3887	*2600*	*2800*	*2692*	*2508.33*	*2442*	*2292*	*2237.50*	*NA*	*NA*	*NA*
G-3888	*5700*	*6300*	*6075*	*5591.67*	*5458*	*5225*	*5029.17*	*NA*	*NA*	*NA*
G-3946	*5100*	*5600*	*5375*	*5066.67*	*4629*	*4158*	*3716.67*	*NA*	*NA*	*NA*
G-3947	*20*	*23*	*21.27*	*20.67*	*21*	*25*	*27.92*	*NA*	*NA*	*NA*
G-3948	*4200*	*4500*	*4318.18*	*4275*	*4308*	*4195*	*3991.67*	*NA*	*NA*	*NA*
G-3949	*120*	*130*	*122*	*117.5*	*116*	*121*	*114.55*	*NA*	*NA*	*NA*

NA=not available

*Measured only once a year

3. Salt Front Update

In 2007 WASD contracted the USGS to update the salt front delineation and monitoring network. The main objective of this study was to augment an existing saltwater-intrusion monitoring network through application of surface and borehole geophysical methods and the addition of new sentinel monitoring wells. Salinity data from the new wells was integrated with existing monitoring wells, and used to provide an up-to-date map showing the landward limit of the saltwater in Miami-Dade County. The USGS work includes three main tasks. The first was to evaluate existing salt front hydrologic and geologic data, and to provide a draft of an updated salt line. This task was completed in October, 2008. The second was to acquire surface and/or aerial resistivity data to aid placement of new monitoring wells, and construction of the new monitoring wells. The installation of eight monitoring wells was completed in 2010 and their sampling was conducted in 2011. Finally, guided by the application of surface geophysics and induction logging in existing wells, the new data was integrated with existing monitoring well data to complete a final revised position of the saltwater-freshwater interface. This task was completed in March 2011.

3.1 Salt Front Update Line – 2008 and 2011

The USGS was contracted as part of JFA 08EOFL208004 to prepare a draft update of the 1995 salt front line with existing chloride data. This task was completed on October 30, 2008, as scheduled. In addition to analyzing chloride data, the USGS collected and interpreted 30 Time Domain Electromagnetic (TEM) measurements in 2008. These measurements combined with additional USGS data and data collected by other organizations were used to help evaluate the landward extent of encroachment at the base of the Biscayne aquifer. The information collected was used to create a preliminary GIS layer estimating the landward extent of seawater encroachment at the base of the Biscayne aquifer. The primary avenue for public distribution of this GIS layer is the IMS website which was also created as part of this project. This website was completed and submitted to the District in October 2009 (http://www.sflorida.er.usgs.gov/edl_data/text/mad_qw.html). The 2008 line was estimated (dotted line) in several areas. The largest area was in south Miami-Dade County where the Helicopter Electromagnetic (HEM) survey was flown but where little data existed to ground truth it. Please refer to **Figure 2, Appendix B**, for a map of the 2008 salt front line. The 1995 line is also included on **Figure 2a** for comparison. There was a minimal change in the 2008 line in north and central Miami-Dade County, however, based on the TEM/HEM measurements the 2008 line in south Miami-Dade County appears to have moved inland from the 1995 line.

USGS personnel completed in March 2009 the collection of additional 36 TEM measurements to aid in interpretation of the line particularly in south Miami-Dade County. In addition to these soundings several electromagnetic induction logs were collected from wells, and water conductivity profiles were collected in 2009. The results of the TEM investigations are published by the USGS in "Results of Time-Domain Electromagnetic Soundings in Miami-Dade and Southern Broward Counties, Florida", Fitterman, D.V., and Prinos, S.T., 2011 (accessed at http://pubs.usgs.gov/of/2011/1299/).

Based on the mapping work conducted, 8 sites were selected where additional long term monitoring was determined to be needed to continually evaluate the landward extent of saltwater encroachment. The wells have been installed, and all geophysical logging and drilling results were included in the final USGS publication. In 2011, the salt front line was again updated based on additional data and sample locations, and was released on March 31, 2011 (Origins and Delineation of Saltwater Intrusion in the Biscayne Aquifer and Changes in the Distribution of Saltwater in Miami-Dade County, Florida, Prinos et Al, 2014 (found at http://pubs.usgs.gov/sir/2014/5025/). In general, there was no significant change between the 2008 and 2011 salt front line in the north and central areas of the County. , However, the line moved further inland in the south, specifically in the C-111E canal area. Please refer to **Figure 2a, Appendix B** for a location map of the 2011 salt front line.

3.2 IMS Website

The website was completed and submitted to the District in October 2009 (http://www.sflorida.er.usgs.gov/edl_data/text/mad_qw.html). On February 9, 2011 the USGS formally released to the public the website, "Saline Intrusion Monitoring, Miami Dade County, Florida", (http://www.envirobase.usgs.gov/FLIMS/SaltFront/). This website provides easy access to salinity monitoring data to the public.

3.3 Salt Front monitoring in 2015

To comply with the WUP requirement, WASD in collaboration with the USGS continued sampling 68 wells to monitor for chloride concentration and specific conductance and conducting time-series electromagnetic induction log (TSEMIL) from 33 wells. Following the recommendations of the 2014 Annual report, six new wells were installed on the fresh side of the 2011 salt front line and were immediately incorporated into the monitoring network. These wells are following and their locations are shown in **Figure 3, Appendix B**:

- G-3601 intermediate (1" casing with screen at 105-115ft) and shallow (2" casing with screen at 70-75 ft), both located on the east bank of the Biscayne canal on Memorial Highway and NE 135th St.
- G-3976, in the City of Homestead, a 2" casing with screen at 82.2-87.2 ft.
- G-3977-S and G-3877-D (Shallow and Deep), located in the City of Miami; G-3977-D: 2" casing with screen at 118.5-123.5, G-3977-S: 1" casing with screen at 46.5-51.5 ft.
- G-3978, located in North Miami Beach, 2" casing with screen interval at 125-135 ft.

Rapid salinity increased has been observed in the southeast area of the County, east of the Newton Wellfield, in Homestead (refer to Wellfield Location Map, **Figure 1, Appendix B**). Monitoring well G-3966 was installed in 2014 between the Newton Wellfield and the Homestead Speedway, quickly became salty, and is now on the saltwater side of the 2011 salt front line. In response, G-3976 was installed in the fresh side of the line in that area and is being monitored monthly to follow the advancement of the salt front in the area as closely as possible (**Figure 3, Appendix B**).

4. Recommendations

As required by the WUP #13-0007-W, the USGS in cooperation with WASD and RER continues to monitor the saltwater intrusion in the Biscayne Aquifer in Miami Dade County. The USGS monitors a total of 68 chloride stations (four more chloride stations are being built and one rebuilt) and 33 time-series electromagnetic induction log stations (and 2 more stations will be added when the new wells are completed) as part of the cooperation with Miami Dade County. Additional salt front monitoring wells will be scheduled to be installed in 2016, to be included in the network of wells, which provide the required data to update the saltwater encroachment along the base of the Biscayne Aquifer as necessary.

WASD recommends continuing the salt front monitoring program as approved in WUP #13-0007-W. Additional salinity monitoring stations should be added in 2016 in south Dade in the vicinity of the advancing salt front. WASD recommends that the USGS update the published 2011 salt front line as monitoring has indicated the salt front has already moved further west in part of the County since the 2011 line was published.

References

Prinos, S. T., 2014, Using state-of-the-art technology to evaluate saltwater intrusion in the Biscayne aquifer of Miami-Dade County, Florida USGS Fact Sheet: 2014-3050.

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Prinos, S.T., Wacker M.A., Cunningham, K.J., and Fitterman, 2014, Origins and Delineation of Saltwater Intrusion in the Biscayne Aquifer and Changes in the Distribution of Saltwater in Miami Dade County, Florida. US Geological Service Scientific Investigation Report 2014-5025.

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U.S. Geological Survey, http://www.sflorida.er.usgs.gov/ddn_data/index.html

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U.S. Geological Survey, http://pubs.er.usgs.gov/publication/ofr20121176

U.S. Geological Survey, http://pubs.usgs.gov/of/2012/1176/downloads/

APPENDIX A

SFWMD WUP #13-00017-W Special Permit Conditions
And Exhibit 28

Table C-1. Reporting Miami-Dade County Salt Front Monitoring Wells

USGS ID	STATION NAME	LATITUDE	LONGITUDE	SITE USE	HOLE DEPTH (ft)[B]	WELL DEPTH (ft)[B]	CASING DEPTH (ft)[B]	Current GWL measurement Freq.	Current Cl Sampling Freq	Induction Log Done	2007 Chloride (mg/l)	2008 Chloride (mg/l)	2009 Chloride (mg/l)	2010 Chloride (mg/l)	2011 Chloride (mg/l)	2012 Chloride (mg/l)	2013 Chloride (mg/l)	2014 Chloride (mg/l)
253831080180204	G -3313E	25 38 34.4	-080 18 04.7	observation/monitoring	114	114	32	quarterly	quarterly	No	5100	5400	1500	713	5600	4600	4800	5200
253831080180204	G -3313C	25 38 35.1	-080 18 04.8	observation/monitoring	110	110	open hole	quarterly	quarterly	No	4000	4200	4250	4400	4717	4351	4533	4872
254946080172601	G -3250	25 49 46	-080 17 26	observation/monitoring	116	116	106	Monthly	Monthly	Yes	68	131	139	176	181	200	37	134
254457080160301	G -3229	25 44 57	-080 16 03	observation/monitoring	85	85	A	Monthly	Monthly	No	700	807	900	1217	1606	1883	2108	2250
255222080123001	G -3224	25 52 22	-080 12 30	observation/monitoring	95.5	95.5	94	Monthly	Monthly	No	44	39	41	41	42	41	35	34
253202080232601	G -3162	25 31 32	-080 23 25	observation/monitoring	92	92	82	quarterly	quarterly	No	1140	1208	1284	1303	1280	1267	1425	1542
254833080155801	G -1354	25 48 33	-080 15 58	observation/monitoring	104	104	91	Monthly	quarterly	No	56	53	516	48	49	58	135	177
254813080161501	G -1351	25 48 13	-080 16 15	observation/monitoring	103	103	100	Monthly	Monthly	No	540	530	520	503	492	474	436	399
252947080235301	G -1180	25 29 47	-080 23 53	observation/monitoring	67	67	open hole	Monthly	Monthly	No	32	30	17	27	25	17	37	20
252944080233401	G-1179	25 29 44.9	-80 23 33	observation/monitoring	80	80	open hole	twice a year	twice a year	Yes	3175	2950	2450	2350	2898	2800	Burried under construction debris	
254106080174601	G -1009B	25 41 06	-080 17 46	observation/monitoring	100	100	NA	Monthly	Monthly	No	50	59	59	62	60	75	74	72
253652080183701	G-939	25 36 53.8	-080 18 35.4	observation/monitoring	61	61	NA	twice a year	twice a year	No	3100	3050	3333	3750	3900	3808	4108	3883
254201080173001	G-901	25 42 03.0	-080 16 54.4	observation/monitoring	96	96	95	twice a year	twice a year	No	2325	2375	2550	2438	2550	2667	3058	3527
253710080184701	G -3611	25 37 10.4	-080 18 45.4	observation/monitoring	100	100	95	quarterly	quarterly	Yes	200	173	172	170	169	165	168	129
254107080165201	G - 896	25 41 07	-080 16 52	observation/monitoring	74	74	60	Monthly	Monthly	No	245	247	235	248	245	258	251	238
255350080105801	G - 894	25 53 51.7	-080 10 57.2	observation/monitoring	76	76	75	Monthly	Monthly	No	24	21	21	22	23	21	17	15
254841080164401	G - 571	25 48 41	-080 16 44	observation/monitoring	94.5	94.5	95	Monthly	Monthly	No	32	32	30	34	35	34	28	27
254855080163701	G-548	25 48 55.9	-080 16 36.4	observation/monitoring	97	97	91	Monthly	twice a year	No	41	40	36	34	32	31	30	29
254335080170501	G-432	25 43 35.9	-080 17 03.3	observation/monitoring	100	100	98	Monthly	twice a year	No	4000	4150	4500	4775	5142	5467	5683	5800
254828080161501	G - 354	25 48 28	-080 16 15	observation/monitoring	90	90.2	89	quarterly	quarterly	No	54	53	50	49	46	45	42	41
255315080111501	F-279	25 53 17.8	-080 11 14.6	observation/monitoring	117	117	NA	Monthly	quarterly	No	3150	3300	3383	3475	3583	3675	3892	4117
254943080121501	F - 45	25 49 43	-080 12 15	observation/monitoring	84.9	84.9	84	Monthly	Monthly	No	104	87	97	97	113	118	127	130
253253080221201	G-3885	25 32 53.1	-080 22 12.7	observation/monitoring	91	86	86	Monthly	Monthly	No	NA	NA	NA	NA	36	36	31	30
2535270801195400	G-3886	25 35 27.9	-080 19 54.2	observation/monitoring	109	101	101	Monthly	Monthly	No	NA	NA	NA	NA	51	49	47	46
253924080174601	G-3887	25 39 24.7	-080 17 46.8	observation/monitoring	134	130	130	Monthly	Monthly	No	NA	NA	NA	NA	2238	2292	2442	2508
254542080145901	G-3888	25 39 2407	-080 14 5908	observation/monitoring	149	144	144	Monthly	Monthly	No	NA	NA	NA	NA	5029	5225	5458	5592
252431080261001	G-3946	25 24 30.7	-080 26 09.7	observation/monitoring	99	98	87	Monthly	Monthly	No	NA	NA	NA	Under co	3717	4158	4629	5067
255011080124501	G-3947	25 50 11.3	-080 12 45.4	observation/monitoring	229	227	200	Monthly	Monthly	No	NA	NA	NA	Under co	28	25	21	21
255515080103601	G-3948	25 55 14.9	-080 10 36.2	observation/monitoring	279	277	273	Monthly	Monthly	No	NA	NA	NA	Under co	3992		4308	4282
255733080195601	G-3949	25 57 33.6	-080 09 56.5	observation/monitoring	349	349	325	Monthly	Monthly	No	NA	NA	NA	Under co	115	121	116	117

A. Per USGS, depth of the casing is not precisely known.
B. Feet Below Land Surface (bls)
GWL: groundwater level
Cl: chloride

WATER USE INDIVIDUAL PERMIT

APPLICATION NO: 140627-12 **PERMIT NUMBER:** 13-00017-W

DATE ISSUED: February 9, 2015 **EXPIRATION DATE:** February 9, 2035

PERMITTEE: MIAMI-DADE WATER AND SEWER DEPARTMENT
P O BOX 330316
MIAMI, FL 33233-0316

PROJECT NAME: MIAMI-DADE CONSOLIDATED PWS

PROJECT LOCATION: Miami-Dade County, SEE ATTACHED FOR SECTIONS, TOWNSHIPS AND RANGES

PROJECT DESCRIPTION/AUTHORIZING:

The continued use of groundwater from the Upper Floridan aquifer and Biscayne aquifer for Public water supply for the MDWASD Service Area serving 2,642,929 persons in the year 2033 with an average finished water per capita use rate of 137.2 gallons per day per person and a maximum monthly to average monthly pumping ration of 1.05:1 with an annual allocation of 140,915.50 million gallons.

This is to notify you of South Florida Water Management District's (District) agency action concerning Permit Application Number 140627-12, received June 27, 2014. This action is taken pursuant to Chapter 373, Part II, Florida Statutes (F.S.), Rule 40E-1.603 and Chapter 40E-2, Florida Administrative Code (F.A.C). Based on the information provided, District rules have been adhered to and a Water Use Individual Permit is in effect for this project subject to:

1. Not receiving a filed request for an administrative hearing pursuant to Section 120.57 and Section 120.569 (F.S.), or request a judicial review pursuant Section 120.68, F.S.; and
2. The attached 57 permit conditions.
3. The attached 37 exhibits.

By acceptance and utilization of the water authorized under this permit, the Permittee agrees to hold and save the District and its successors harmless from any and all damages, claims or liabilities that may arise by reason of the construction, maintenance or use of activities authorized by this permit. Should you object to the permit, please refer to the attached "Notice of Rights" that addresses the procedures to be followed if you desire a public hearing or other review of the proposed agency action. Should you wish to object to the proposed agency action or file a petition or request, please provide written objections, petitions, requests and/or waivers to the District, attention of Office of the District Clerk, South Florida Water Management District, Post Office Box 24680, West Palm Beach, FL 33416-4680.

CERTIFICATION OF SERVICE

I HEREBY CERTIFY THAT this written notice has been mailed or electronically transmitted to the Permittee (and the persons listed in the attached distribution list) this 10th day of February, 2015, in accordance with Section 120.60(3), F.S. Notice was also electronically posted on this date through a link on the home page of the District's website (my.sfwmd.gov/ePermitting).

BY: JUANITA BOZEMAN
DEPUTY CLERK, SOUTH FLORIDA WATER MANAGEMENT DISTRICT

SPECIAL PERMIT CONDITIONS

1. This permit is issued to:
   MIAMI-DADE WATER AND SEWER DEPARTMENT
   P O BOX 330316
   MIAMI, FL 33233-0316

2. This permit shall expire on February 9, 2035.

3. Use classification is:

   Public Water Supply
   Aquifer Storage And Recovery

4. Source classification is:

   Groundwater from:
   Biscayne Aquifer
   Upper Floridan Aquifer

5. Allocation:

   Total annual allocation is 140,915.50 million gallons (MG). (386.07 MGD)

   Total maximum monthly allocation is 12,330.11 million gallons (MG).

   Allocation from a specific source (aquifer, waterbody, facility, or facility group):

   Maximum annual allocation from Upper Floridan Aquifer shall not exceed 13,348.05 million gallons (MG). (36.60 MGD).

   Maximum annual allocation from Biscayne Aquifer shall not exceed 127,567.50 million gallons (MG). (349.50 MGD).

   Maximum monthly allocation from Upper Floridan Aquifer shall not exceed 1,167.95 million gallons (MG).

   Maximum monthly allocation from Biscayne Aquifer shall not exceed 11,162.16 million gallons (MG).

   These allocations represent the amount of water required to meet the water demands as a result of a rainfall deficit during a drought with the probability of recurring one year in ten. The Permittee shall not exceed these allocations in hydrologic conditions less than a 1-in-10 year drought event. Compliance with the annual allocation is based on the quantity withdrawn over a 12-month time period. Compliance with the maximum monthly allocation is based on the greatest quantity withdrawn in any single month. The annual allocation expressed in GPD or MGD is for informational purposes only.

If the rainfall deficit is more severe than that expected to recur once every ten years, the withdrawals shall not exceed that amount necessary to continue to meet the reasonable-beneficial demands under such conditions, provided no harm to the water resources occur and:

1. All other conditions of the permit are met; and

2. The withdrawal is otherwise consistent with applicable declared Water Shortage Orders in effect pursuant to Chapter 40E-21, F.A.C.

6. Withdrawal facilities:

Groundwater - Proposed:

1 - 24" X 50' X 2800 GPM Well Cased To 45 Feet
7 - 24" X 1200' X 2430 GPM Wells Cased To 1100 Feet
1 - 24" X 50' X 1400 GPM Well Cased To 45 Feet
3 - 24" X 72' X 1400 GPM Wells Cased To 45 Feet
8 - 17" X 1490' X 1400 GPM Wells Cased To 1080 Feet

Groundwater - Existing:

2 - 24" X 100' X 7500 GPM Wells Cased To 50 Feet
3 - 48" X 88' X 7500 GPM Wells Cased To 33 Feet
5 - 17" X 1490' X 1400 GPM Wells Cased To 1080 Feet
1 - 4" X 74' X 0 GPM Well Cased To 63.5 Feet
1 - 18" X 65' X 1500 GPM Well Cased To 50 Feet
20 - 14" X 115' X 2500 GPM Wells Cased To 80 Feet
4 - 24" X 100' X 4900 GPM Wells Cased To 35 Feet
10 - 48" X 80' X 10420 GPM Wells Cased To 46 Feet
1 - 12" X 40' X 800 GPM Well Cased To 35 Feet
1 - 42" X 68' X 10000 GPM Well Cased To 54 Feet
1 - 6" X 30' X 400 GPM Well Cased To 25 Feet
1 - 16" X 50' X 1600 GPM Well Cased To 40 Feet
1 - 30" X 115' X 4170 GPM Well Cased To 80 Feet
1 - 18" X 66' X 1500 GPM Well Cased To 53 Feet
1 - 14" X 115' X 3800 GPM Well Cased To 80 Feet
1 - 30" X 1250' X 3500 GPM Well Cased To 845 Feet
6 - 42" X 107' X 7000 GPM Wells Cased To 66 Feet
1 - 24" X 70' X 3470 GPM Well Cased To 35 Feet
7 - 16" X 100' X 4170 GPM Wells Cased To 40 Feet
2 - 24" X 70' X 6945 GPM Wells Cased To 35 Feet
1 - 42" X 68' X 8500 GPM Well Cased To 60 Feet
1 - 17" X 1490' X 1400 GPM Well Cased To 1150 Feet

4 - 40" X 100' X 10420 GPM Wells Cased To 57 Feet
1 - 30" X 1210' X 3500 GPM Well Cased To 835 Feet
1 - 42" X 68' X 8500 GPM Well Cased To 54 Feet
1 - 18" X 55' X 1500 GPM Well Cased To 45 Feet
1 - 42" X 107' X 7000 GPM Well Cased To 69 Feet
4 - 24" X 108' X 8300 GPM Wells Cased To 50 Feet
2 - 12" X 40' X 1600 GPM Wells Cased To 35 Feet
4 - 24" X 104' X 6940 GPM Wells Cased To 54 Feet
1 - 12" X 35' X 1200 GPM Well Cased To 30 Feet
1 - 48" X 80' X 10416.67 GPM Well Cased To 46 Feet
1 - 12" X 35' X 800 GPM Well Cased To 30 Feet
1 - 30" X 115' X 2500 GPM Well Cased To 80 Feet
1 - 42" X 68' X 10000 GPM Well Cased To 60 Feet
1 - 18" X 55' X 1500 GPM Well Cased To 42 Feet
6 - 20" X 100' X 4900 GPM Wells Cased To 40 Feet
1 - 16" X 100' X 7500 GPM Well Cased To 40 Feet
1 - 18" X 50' X 500 GPM Well Cased To 40 Feet
1 - 30" X 1200' X 3500 GPM Well Cased To 765 Feet
1 - " X 60' X 0 GPM Well Cased To 55 Feet
1 - 30" X 1300' X 3500 GPM Well Cased To 850 Feet
1 - 30" X 1200' X 3500 GPM Well Cased To 760 Feet

7. The Permittee shall submit all data as required by the implementation schedule for each of the permit conditions to: SFWMD at www.sfwmd.gov/ePermitting, or Regulatory Support, MSC 9611, P.O. Box 24680, West Palm Beach, FL 33416-4680.

8. The Permittee must submit the appropriate application form incorporated by reference in Rule 40E-2.101, F.A.C., to the District prior to the permit expiration date in order to continue the use of water.

9. The Permittee shall secure a well construction permit prior to construction, repair, or abandonment of all wells, as described in Chapter 40E-3, F.A.C.

10. Permittees, who are dependent on other sources of water supply such as reclaimed water or water sale agreements to meet a portion of their demands, shall include the monthly volumes from all other sources in the report to the District, unless the use of those sources is reported to another state agency, in which case the District will obtain the water use information from said agency. The water accounting method and means of calibration shall be stated on each report.

11. Prior to any withdrawals at the project, the Permittee shall provide the results of the calibration testing of the identified water accounting method(s) and equip all existing and proposed withdrawal facilities with approved water use accounting method(s) pursuant to Subsection 4.1.1 of the Applicant's Handbook for Water Use Permit Applications.

12. Every five years from the date of last calibration, the Permittee shall submit re-calibration data for each withdrawal facility.

13. Monthly withdrawals for each withdrawal facility shall be reported to the District semi-annually. The water accounting method and means of calibration shall be stated on each report.

14. The Permittee shall notify the District within 30 days of any change in service area boundary that results in a change in demand that affects its permitted allocation. The allocation shall be modified to effectuate such change.

15. If at any time there is an indication that the well casing, valves, or controls leak or have become inoperative, repairs or replacement shall be made to restore the system to an operating condition. Failure to make such repairs shall be cause for filling and abandoning the well, in accordance with procedures outlined in Chapter 40E-3, F.A.C.

16. The Permittee shall maintain an accurate flow meter at the intake of the water treatment plant for the purpose of measuring daily inflow of water.

    Permittee shall maintain a calibrated flow meter(s) at the intake (raw water) and discharge (treated water) points within the Hialeah/Preston, Alexander Orr, and proposed Hialeah RO and South Miami Heights water treatment plants for the purpose of measuring treatment losses and shall submit monthly data semi-annually as required pursuant to Special Condition 13.

17. The Standard Water Conservation Plan described in Subsection 2.3.2.F.1.a of the Applicant's Handbook for Water Use Permit Applications within the South Florida Water Management District and the Staff Report, must be implemented in accordance with the approved implementation schedule described in the following exhibit:

    The Water Conservation Plan is contained in Exhibit 18. The permittee shall submit an annual report covering water conservation activities during the prior calendar year by April 15 of each year describing water conservation activities for the year including expenditures, projects undertaken and estimated water savings.

18. The Permittee shall notify the District within 30 days of entering into an inter-local agreement, contract, or other similar instrument to deliver or receive water outside of its service area or to serve a demand not identified to determine the allocation described in this permit. A copy of such agreement shall be provided to the District. The monthly volume of water delivered and/or received via each inter-local agreement, contract, or other similar instrument shall be submitted to the District at the same reporting frequency as the withdrawals for each withdrawal facility required in this permit.

19. The Permittee shall implement the wellfield operating plan submitted in support of the permit application, as described in the District staff report.

See Exhibit 10

20. The Permittee shall determine unaccounted-for distribution system losses. Losses shall be determined for the entire distribution system on a monthly basis. Permittee shall define the manner in which unaccounted-for losses are calculated. Reports shall be submitted to the District on a yearly basis and are due by April 30th of each year.

    In the event that the annual unaccounted-for distribution system losses, as defined by Section 2.3.2.F.2.c, of the Applicants Handbook for Water Use Permit Applications [AH], exceeds 10 percent, the permittee shall include in the annual report a description of additional actions which will be implemented the following year(s) to reduce the losses to less than ten percent.

21. Public water utilities that control, either directly or indirectly, a wastewater treatment plant, and which have determined pursuant to Section 403.064, F.S., that use of reclaimed water is feasible, must provide the District with annual updates of the following information: 1) the status of distribution system construction, including location and capacity of lines; 2) a summary of uncommitted supplies for the next year; 3) copies of any new or amended local mandatory reclaimed water reuse zone ordinances; and 4) a list of end-users who have contracted to receive reclaimed water and the agreed upon quantity of water to be delivered.

22. The Permittee shall maintain an accurate flow meter at the point of discharge from the treatment plant for the purpose of measuring the daily flow of water.

    Permittee shall maintain a calibrated flow meter(s) at the intake (raw water) and discharge (treated water) points within the Hialeah/Preston, Alexander Orr, and proposed Hialeah RO and South Miami Heights water treatment plants for the purpose of measuring treatment losses and shall submit monthly data semi-annually as required pursuant to Special Condition 13.

23. Pursuant to Section 373.236(4), F.S., every ten years from the date of permit issuance, the Permittee shall submit a water use compliance report for review and approval by District Staff to SFWMD at www.sfwmd.gov/ePermitting, or Regulatory Support, MSC 9611, P.O. Box 24680, West Palm Beach, FL 33416-4680.
    (A) The results of a water conservation audit that documents the efficiency of water use on the project site using data produced from an onsite evaluation conducted. In the event that the audit indicates additional water conservation is appropriate or the per capita use rate authorized in the permit is exceeded, the permittee shall propose and implement specific actions to reduce the water use to acceptable levels within timeframes proposed by the permittee and approved by the District.

    (B) A comparison of the permitted allocation and the allocation that would apply to the project based on current District allocation rules and updated population and per capita use rates. In the event the permit allocation is greater than the allocation provided for under District rule, the permittee shall apply for a letter modification to reduce the allocation consistent with District rules and the updated population and per capita use rates to the extent they are considered by the

District to be indicative of long term trends in the population and per capita use rates over the permit duration. In the event that the permit allocation is less than allowable under District rule, the permittee shall apply for a modification of the permit to increase the allocation if the permittee intends to utilize an additional allocation, or modify its operation to comply with the existing conditions of the permit.

3. Summary of the current and previous nine years progress reports for implementation of the Alternative Water Supply Plan and any modifications necessary to continue to meet the Plan requirements and conditions for issuance.

4. Information demonstrating that the conditions for issuance of the permit are being complied with, pursuant to Special Condition 45 and Section 373.236, F.S.

5. Updates or amendments to the County's reuse plan.

24. The Permittee shall provide annual status reports to the District that summarizes the Aquifer Storage and Recovery cycle testing activities. Reports shall be submitted to the District on a yearly basis and are due by April 30th of each year.

25. The Permittee shall submit to the District an updated "Summary of Groundwater (Well) Facilities" table ("Section IV - Sources of Water", Water Use Permit Application Form 1379) within 90 days of completion of the proposed wells identifying the actual total and cased depths, pump manufacturer and model numbers, pump types, intake depths and type of meters.

26. The permittee shall operate surface water control structure known as the Mid-canal structure and bridge in accordance with the approved operational plan included in Exhibit 22. In addition, whenever this structure is opened for the purpose of raising water in the Wellfield Protection Canal down stream of the structure, the upstream structure that delivers water from the L-30 canal shall be opened in a manner to deliver equal volumes to those passed through the Mid-canal structure and bridge. The permittee shall submit operation and flow data logs regarding both structures to the District semi-annually.

27. The Permittee is authorized to exercise the emergency wells at the Medley Wellfield for a total of two hours per month as needed for bacterial clearance and pump maintenance. Operation of the emergency wells at the Medley Wellfield for more than this amount shall require prior approval from SFWMD. Pumpage data shall be collected and report in accordance with Special Condition 13.

28. No more than 15 MGD shall be withdrawn from the West Biscayne aquifer Wellfield on any given day.

29. No more than 25,550 MGY shall be withdrawn during any 12 month consecutive period from the combined Hialeah, Preston, Medley and Miami Springs Biscayne aquifer wellfields.

30. No more than 7,993 MGY shall be withdrawn during any 12 month consecutive period from the Snapper Creek Wellfield.

31. No more than 39,931 MGY shall be withdrawn during any 12 month consecutive period from the Southwest Biscayne aquifer Wellfield.

32. No more than 67,999 MGY shall be withdrawn during any 12 month consecutive period from the combined West, Southwest Snapper Creek and Alexander Orr Biscayne aquifer wellfields.

33. No more than 1,095 MGY shall be withdrawn during any 12 month consecutive period from the South Miami Heights Wellfield.

34. No more than 1,752 MGY shall be withdrawn during any 12 month consecutive period from the combined Everglades Labor Camp and Newton wellfields.

35. No more than 1,571 MGY shall be withdrawn during any 12 month consecutive period from the combined Elevated Tank, Leisure City and Naranja wellfields.

36. The Permittee shall continue to submit monitoring data in accordance with the approved water level monitoring program for this project. The existing monitoring program is described in Exhibits 30 and 32B.

37. The Permittee shall continue to submit monitoring data in accordance with the approved saline water intrusion monitoring program for this project.
See exhibits 28A and 32B for a list of monitor wells and required sampling schedule.

    The permittee shall submit annual Monitoring Program summary reports. The annual report will summarize the status of the project to update the salt front and install new monitor wells.

38. Within six months of permit issuance, an executed large user water agreement with the City of Hialeah shall be submitted to the District. In the event that the final agreement is for volumes less than those used in the formulation of the allocations in this permit, the allocations shall be reduced through a letter modification.

39. The permittee shall update the District on the status of reuse projects in Exhibit 14 on an annual basis.

40. The permittee will develop alternative water supplies in accordance with the schedules described in Exhibit 13.

    The permittee will provide annual updates of the status of all alternative water supply projects (per the timeframes contained in Special Condition 44). The status report shall include work completed to date, expenditures and any anticipated changes in the timelines.

41. In the event that a milestone specified in the alternative water supply schedule and plan contained in Exhibit 13 is going to be missed, the permittee shall notify the Executive Director of the District in writing explaining the nature of the delay, actions taken to bring the project back on schedule and an assessment of the impact the delay would have on the rates of withdrawals from the Everglades water bodies and associated canals as defined in SFWMD consumptive use permitting rules. The District will evaluate the situation and take actions as appropriate which could include: a.) granting an extension of time to complete the project (if the delay is minor and doesn't affect the Everglades Waterbodies or otherwise violates permit conditions), b.) take enforcement actions including consent orders and penalties, c.) modify allocations contained in this permit from the Biscayne aquifer including capping withdrawal rates until the alternative water supply project(s) are completed (in cases where the delay would result in violations of permit conditions) or d.) working with the Department of Community Affairs to limit increase demands for water until the alternative water supply project is completed.

42. For rehydration of Biscayne Coastal Wetlands, in consultation with the District, the FDEP and Biscayne Bay National Park, upon completion of the pilot testing program, the parties shall agree on the water quality treatment required and the feasibility, as defined in Section 2.2.4 of the Applicants Handbook for Water Use Permit Applications, of this project on or before April 15, 2015. Extension of this deadline may be issued in writing by the District upon demonstration of good cause such as events beyond the control of the permittee or after consideration of the results/data collected, the District determines that additional testing is necessary. In determining the water quality needed, the parties will consider State and Federal water quality discharge standards, the volume and timing of water to be delivered to Biscayne Bay and the location of delivery. In the event the parties do not reach agreement on the feasibility by April 15, 2015, the Permittee shall begin development of an alternate reuse project from the South District wastewater facility and shall provide the District with a proposal for an alternate project including a conceptual design and schedule for implementation on or before March 15, 2016.

43. The permittee may request temporary authorization from the District to capture and store stormwater via withdrawals from the permitted Biscayne aquifer production wells, for storage within the Floridan aquifer system consistent with their FDEP issued Underground Injection Control permits.The District will consider the availability of stormwater that is not otherwise needed for environmental protection or enhancement and is in no way bound to authorize such requests. All such requests shall be made in writing to the Director of Water Use Regulation.

44. All annual reports required in these Special Conditions shall address activities that occurred during a calendar year and shall be submitted to Water Use Compliance on or before April 15th of the following year.

45. If it is determined that the conditions for permit issuance are no longer met for the 20 year permit duration, the permittee shall obtain a modification of the Permit from the District as necessary to

come into compliance with the conditions for permit issuance. Such conditions for permit issuance include minimum flows and levels, water reservations, and other conditions ensuring the use does not cause water resource harm and is consistent with the objectives of the District, including implementation of the Comprehensive Everglades Restoration Plan.

46. The permittee shall operate the West Wellfield in accordance with the Memorandum of Understanding between the U.S. Department of the Interior, the Governor of the State of Florida, Miami Dade County and the District incorporated in Exhibit 35.

STANDARD PERMIT CONDITIONS

1. All water uses authorized by this permit shall be implemented as conditioned by this permit, including any documents incorporated by reference in a permit condition. The District may revoke this permit, in whole or in part, or take enforcement action, pursuant to Section 373.136 or 373.243, F.S., unless a permit modification has been obtained to address the noncompliance.

   The Permittee shall immediately notify the District in writing of any previously submitted material information that is later discovered to be inaccurate.

2. The Permittee is advised that this permit does not relieve any person from the requirement to obtain all necessary federal, state, local and special district authorizations.

3. The Permittee shall notify the District in writing within 30 days of any sale, transfer, or conveyance of ownership or any other loss of permitted legal control of the Project and/or related facilities from which the permitted consumptive use is made. Where Permittee's control of the land subject to the permit was demonstrated through a lease, the Permittee must either submit a new or modified lease showing that it continues to have legal control or documentation showing a transfer in control of the permitted system/project to the new landowner or new lessee. All transfers of ownership are subject to the requirements of Rule 40E-1.6107, F.A.C. Alternatively, the Permittee may surrender the consumptive use permit to the District, thereby relinquishing the right to conduct any activities under the permit.

4. Nothing in this permit should be construed to limit the authority of the District to declare a water shortage and issue orders pursuant to Chapter 373, F.S. In the event of a declared water shortage, the Permittee must adhere to the water shortage restrictions, as specified by the District. The Permittee is advised that during a water shortage, reports shall be submitted as required by District rule or order. The Permittee is advised that during a water shortage, pumpage, water levels, and water quality data shall be collected and submitted as required by District orders issued pursuant to Chapter 40E-21, F.A.C.

5. This permit does not convey to the Permittee any property rights or privileges other than those specified herein, nor relieve the permittee from complying with any applicable local government, state, or federal law, rule, or ordinance.

6. With advance notice to the Permittee, District staff with proper identification shall have permission to enter, inspect, observe, collect samples, and take measurements of permitted facilities to determine compliance with the permit conditions and permitted plans and specifications. The Permittee shall either accompany District staff onto the property or make provision for access onto the property.

7. A. The Permittee may seek modification of any term of an unexpired permit. The Permittee is advised that Section 373.239, F.S., and Rule 40E-2.331, F.A.C., are applicable to permit modifications.

   B. The Permittee shall notify the District in writing 30 days prior to any changes to the project that could potentially alter the reasonable demand reflected in the permitted allocation. Such changes include, but are not limited to, change in irrigated acreage, crop type, irrigation system, large users agreements, or water treatment method. Permittee will be required to apply for a modification of the permit for any changes in permitted allocation.

8. If any condition of the permit is violated, the permit shall be subject to review and modification, enforcement action, or revocation pursuant to Chapter 373, F.S.

9. The Permittee shall mitigate interference with existing legal uses that was caused in whole or in part by the Permittee's withdrawals, consistent with the approved mitigation plan. As necessary to offset the interference, mitigation will include pumpage reduction, replacement of the impacted individual's equipment, relocation of wells, change in withdrawal source, or other means.

   Interference to an existing legal use is defined as an impact that occurs under hydrologic conditions equal to or less severe than a 1-in-10 year drought event that results in the:

   A. Inability to withdraw water consistent with provisions of the permit, such as when remedial structural or operational actions not materially authorized by existing permits must be taken to address the interference; or

   B. Change in the quality of water pursuant to primary State Drinking Water Standards to the extent that the water can no longer be used for its authorized purpose, or such change is imminent.

10. The Permittee shall mitigate harm to the natural resources caused by the Permittee's withdrawals, as determined through reference to the conditions for permit issuance. When harm occurs, or is imminent, the District will require the Permittee to modify withdrawal rates or mitigate the harm. Harm, as determined through reference to the conditions for permit issuance includes:

    A. Reduction in ground or surface water levels that results in harmful lateral movement of the fresh water/salt water interface,

    B. Reduction in water levels that harm the hydroperiod of wetlands,

    C. Significant reduction in water levels or hydroperiod in a naturally occurring water body such as a lake or pond,

    D. Harmful movement of contaminants in violation of state water quality standards, or

    E. Harm to the natural system including damage to habitat for rare or endangered species.

11. The Permittee shall mitigate harm to existing off-site land uses caused by the Permittee's withdrawals, as determined through reference to the conditions for permit issuance. When harm occurs, or is imminent, the District will require the Permittee to modify withdrawal rates or mitigate the harm. Harm as determined through reference to the conditions for permit issuance, includes:

A. Significant reduction in water levels on the property to the extent that the designed function of the water body and related surface water management improvements are damaged, not including aesthetic values. The designed function of a water body is identified in the original permit or other governmental authorization issued for the construction of the water body. In cases where a permit was not required, the designed function shall be determined based on the purpose for the original construction of the water body (e.g. fill for construction, mining, drainage canal, etc.)

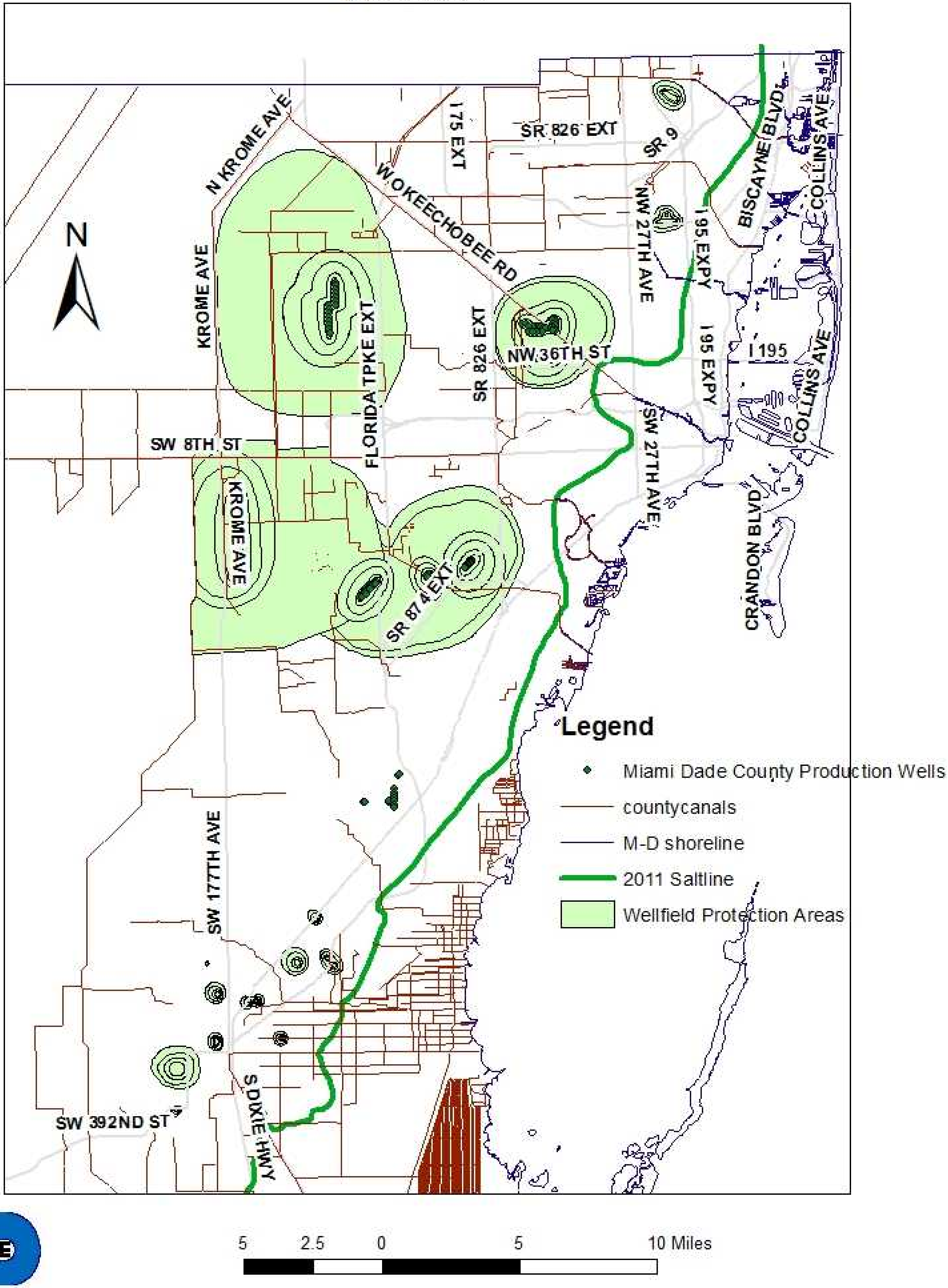
B. Damage to agriculture, including damage resulting from reduction in soil moisture resulting from consumptive use; or,

C. Land collapse or subsidence caused by reduction in water levels associated with consumptive use.

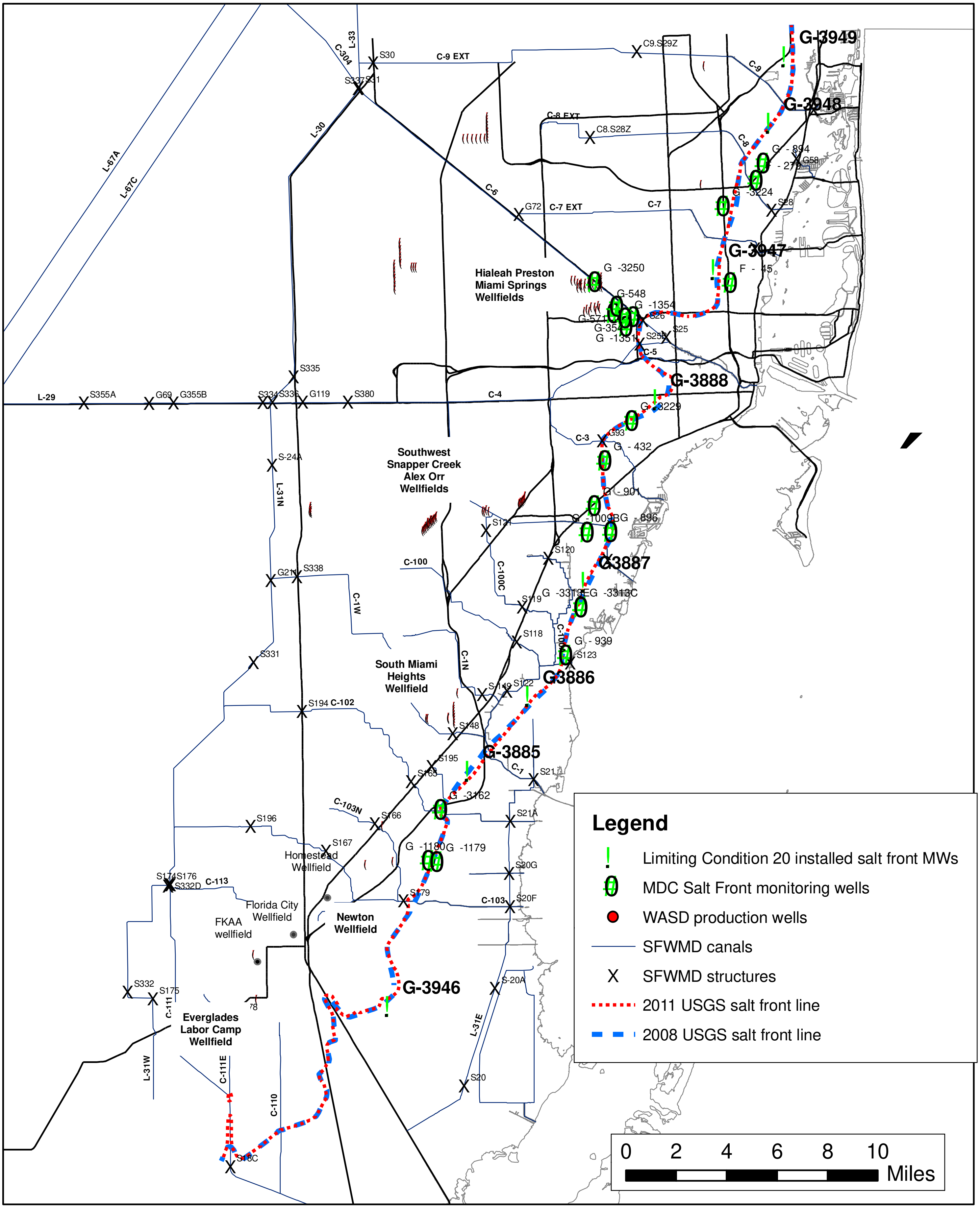
APPENDIX B

FIGURES

ADDITIONAL SALTFRONT MONITORING WELL LOCATION MAP
FIGURE 1



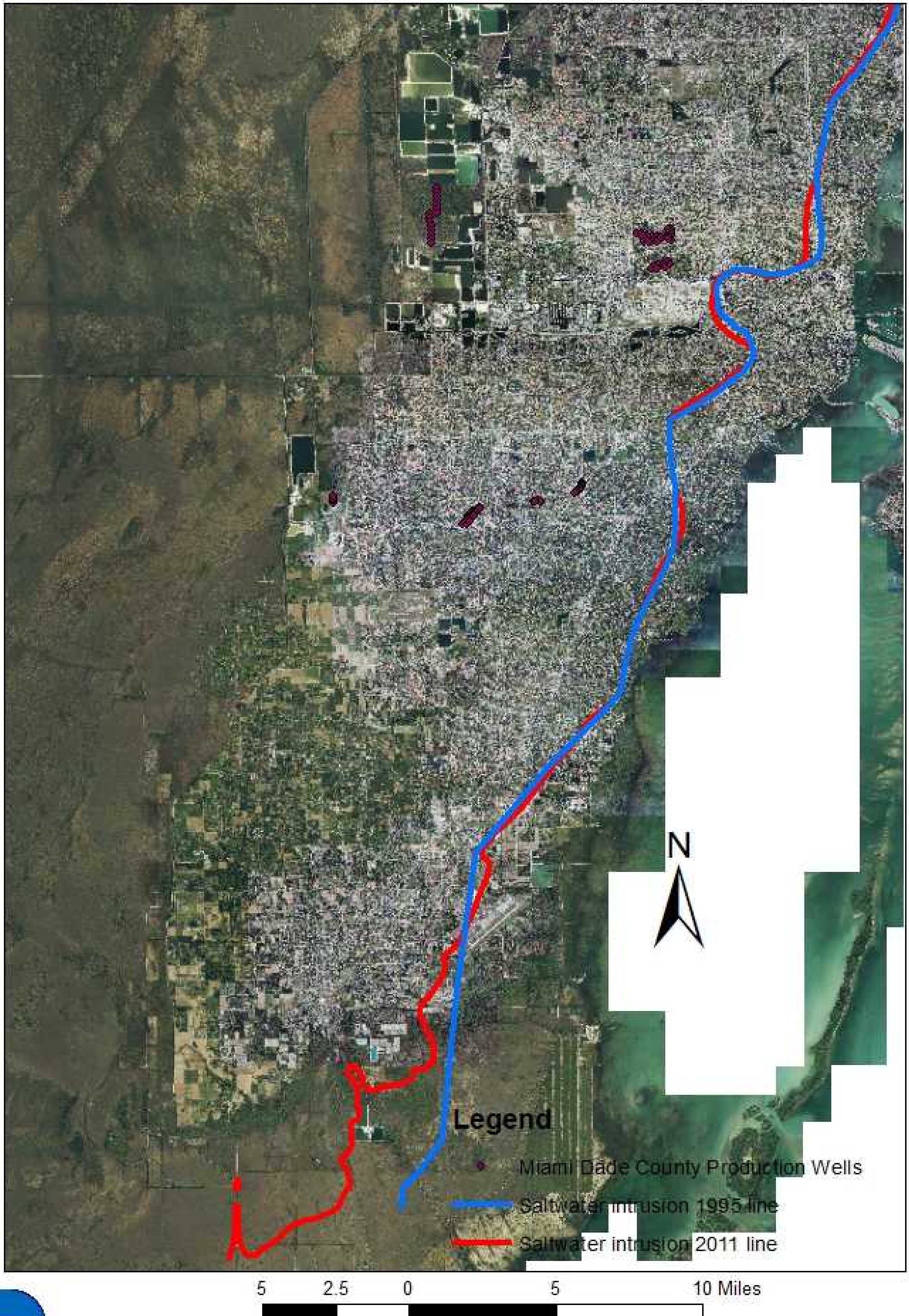
MIAMI-DADE COUNTY



Miami-Dade Water and Sewer Department
3071 SW 38 Ave
Miami FL 33146

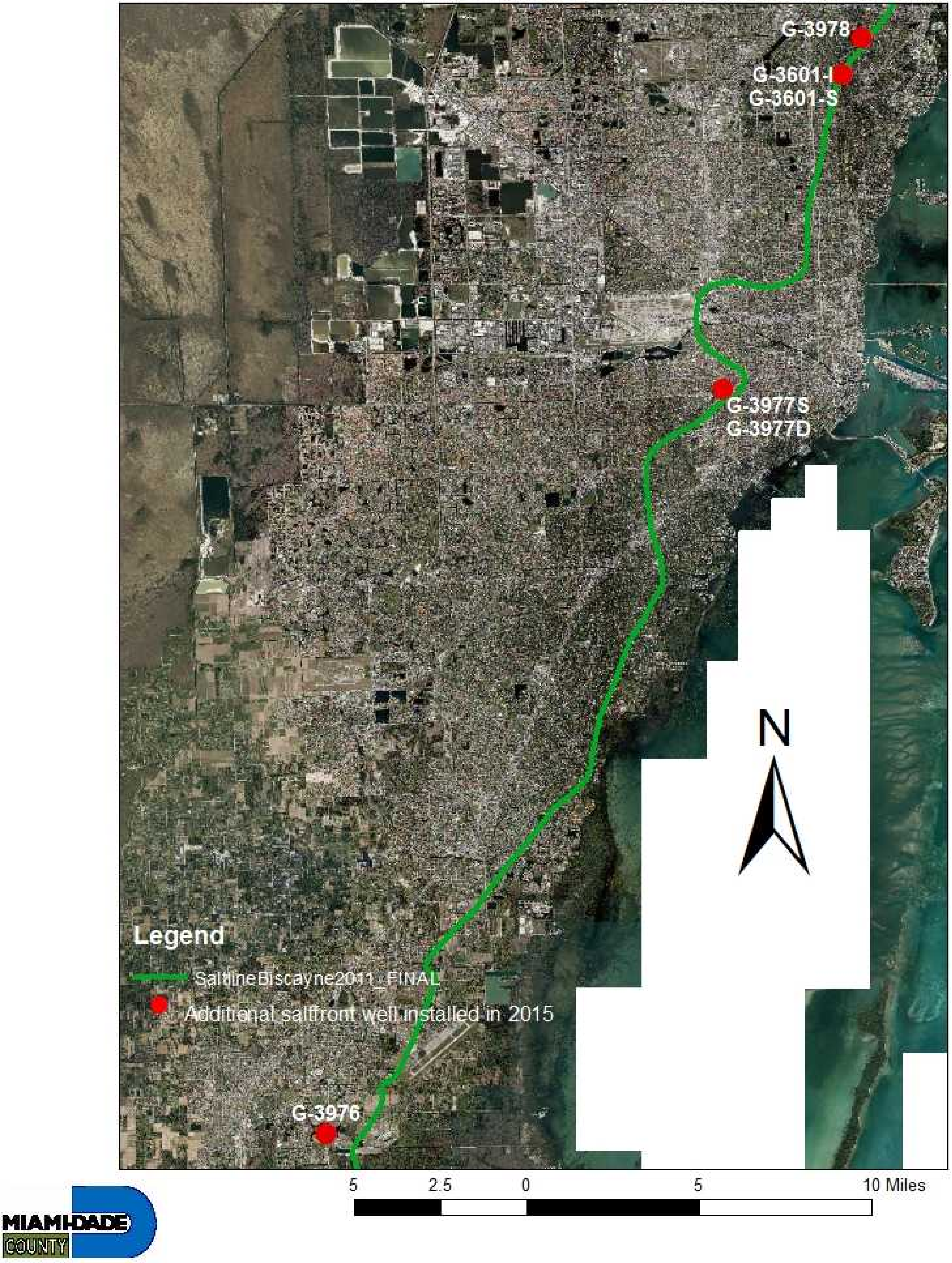
Figure 2. 2011 Miami-Dade County Salt Front Monitoring Network

1995 AND 2011 SALTFRONT LINES
LOCATION MAP
FIGURE 2a



MIAMI-DADE COUNTY

ADDITIONAL SALTFRONT MONITORING WELL
LOCATION MAP
FIGURE 3



APPENDIX C

TABLES

Table C-1. Existing Miami-Dade County Salt Front Monitoring Wells

USGS ID	STATION NAME	LATITUDE	LONGITUDE	SITE USE	HOLE DEPTH (ft)[B]	WELL DEPTH (ft)[B]	CASING DEPTH (ft)[B]	Current GWL measurement Freq.	Current Cl Sampling Freq	Induction Log Done	2007 Chloride (mg/l)	2008 Chloride (mg/l)	2009 Chloride (mg/l)	2010 Chloride (mg/l)	2011 Chloride (mg/l)	2012 Chloride (mg/l)	2013 Chloride (mg/l)	2014 Chloride (mg/l)	2015 Chloride (mg/l)
253831080180204	G -3313E	25 38 34.4	-080 18 04.7	observation/monitoring	114	114	32	quarterly	quarterly	No	5100	5400	1500	713	5600	4600	4800	5200	5100
253831080180204	G -3313C	25 38 35.1	-080 18 04.8	observation/monitoring	110	110	open hole	quarterly	quarterly	No	4000	4200	4250	4400	4717	4351	4533	4875	5167
254946080172601	G -3250	25 49 46	-080 17 26	observation/monitoring	116	116	106	Monthly	Monthly	Yes	68	131	139	176	181	200	37	134	139
254457080160301	G -3229	25 44 57	-080 16 03	observation/monitoring	85	85	A	Monthly	Monthly	No	700	807	900	1217	1606	1883	2108	2250	2442
255222080123001	G -3224	25 52 22	-080 12 30	observation/monitoring	95.5	95.5	94	Monthly	Monthly	No	44	39	41	41	42	41	35	35	35
253202080232601	G -3162	25 31 32	-080 23 25	observation/monitoring	92	92	82	quarterly	quarterly	No	1140	1208	1284	1303	1280	1267	1425	1542	1475
254833080155801	G -1354	25 48 33	-080 15 58	observation/monitoring	104	104	91	Monthly	quarterly	No	56	53	516	48	49	58	135	177	195
254813080161501	G -1351	25 48 13	-080 16 15	observation/monitoring	103	103	100	Monthly	Monthly	No	540	530	520	503	492	474	436	399	407
252947080235301	G -1180	25 29 47	-080 23 53	observation/monitoring	67	67	open hole	Monthly	Monthly	No	32	30	17	27	25	17	37	20	19
252944080233401	G-1179	25 29 44.9	-80 23 33	observation/monitoring	80	80	open hole	twice a year	twice a year	Yes	3175	2950	2450	2350	2898	2800	Destroid	Destroid	
254106080174601	G -1009B	25 41 06	-080 17 46	observation/monitoring	100	100	NA	Monthly	Monthly	No	50	59	59	62	60	75	74	72	80
253652080183701	G-939	25 36 53.8	-080 18 35.4	observation/monitoring	61	61	NA	twice a year	twice a year	No	3100	3050	3333	3750	3900	3808	4108	3883	3767
254201080173001	G-901	25 42 03.0	-080 16 54.4	observation/monitoring	96	96	95	twice a year	twice a year	No	2325	2375	2550	2438	2550	2667	3058	3527	4650
253710080184701	G -3611	25 37 10.4	-080 18 45.4	observation/monitoring	100	100	95	quarterly	quarterly	Yes	200	173	172	170	169	165	168	165	160
254107080165201	G - 896	25 41 07	-080 16 52	observation/monitoring	74	74	60	Monthly	Monthly	No	245	247	235	248	245	258	251	246	347
255350080105801	G - 894	25 53 51.7	-080 10 57.2	observation/monitoring	76	76	75	Monthly	Monthly	No	24	21	21	22	23	21	17	15	15
254841080164401	G - 571	25 48 41	-080 16 44	observation/monitoring	94.5	94.5	95	Monthly	Monthly	No	32	32	30	34	35	34	28	27	27
254855080163701	G-548	25 48 55.9	-080 16 36.4	observation/monitoring	97	97	91	Monthly	twice a year	No	41	40	36	34	32	31	30	29	33
254335080170501	G-432	25 43 35.9	-080 17 03.3	observation/monitoring	100	100	98	Monthly	twice a year	No	4000	4150	4500	4775	5142	5467	5683	5817	6383
254828080161501	G - 354	25 48 28	-080 16 15	observation/monitoring	90	90.2	89	quarterly	quarterly	No	54	53	50	49	46	45	42	41	40
255315080111501	F-279	25 53 17.8	-080 11 14.6	observation/monitoring	117	117	NA	Monthly	quarterly	No	3150	3300	3383	3475	3583	3675	3892	4117	4067
254943080121501	F - 45	25 49 43	-080 12 15	observation/monitoring	84.9	84.9	84	Monthly	Monthly	No	104	87	97	97	113	118	127	130	143
253253080221201	G-3885	25 32 53.1	-080 22 12.7	observation/monitoring	91	86	86	Monthly	Monthly	No	NA	NA	NA	NA	36	36	31	30	30
2535270801195400	G-3886	25 35 27.9	-080 19 54.2	observation/monitoring	109	101	101	Monthly	Monthly	No	NA	NA	NA	NA	51	49	47	46	47
253924080174601	G-3887	25 39 24.7	-080 17 46.8	observation/monitoring	134	130	130	Monthly	Monthly	No	NA	NA	NA	NA	2238	2292	2442	2508	2692
254542080145901	G-3888	25 39 2407	-080 14 5908	observation/monitoring	149	144	144	Monthly	Monthly	No	NA	NA	NA	NA	5029	5225	5458	5592	6075
252431080261001	G-3946	25 24 30.7	-080 26 09.7	observation/monitoring	99	98	87	Monthly	Monthly	No	NA	NA	NA	Under cor	3717	4158	4629	5067	5375
255011080124501	G-3947	25 50 11.3	-080 12 45.4	observation/monitoring	229	227	200	Monthly	Monthly	No	NA	NA	NA	Under cor	28	25	21	21	21
255515080103601	G-3948	25 55 14.9	-080 10 36.2	observation/monitoring	279	277	273	Monthly	Monthly	No	NA	NA	NA	Under cor	3992		4308	4275	4318
255733080195601	G-3949	25 57 33.6	-080 09 56.5	observation/monitoring	349	349	325	Monthly	Monthly	No	NA	NA	NA	Under cor	115	121	116	118	122

A. Per USGS, depth of the casing is not precisely known.
B. Feet Below Land Surface (bls)
GWL: groundwater level
Cl: chloride

APPENDIX D

US GEOLOGICAL SURVEY PROJECT WATER RESOURCES JOINT FUNDING AGREEMENT

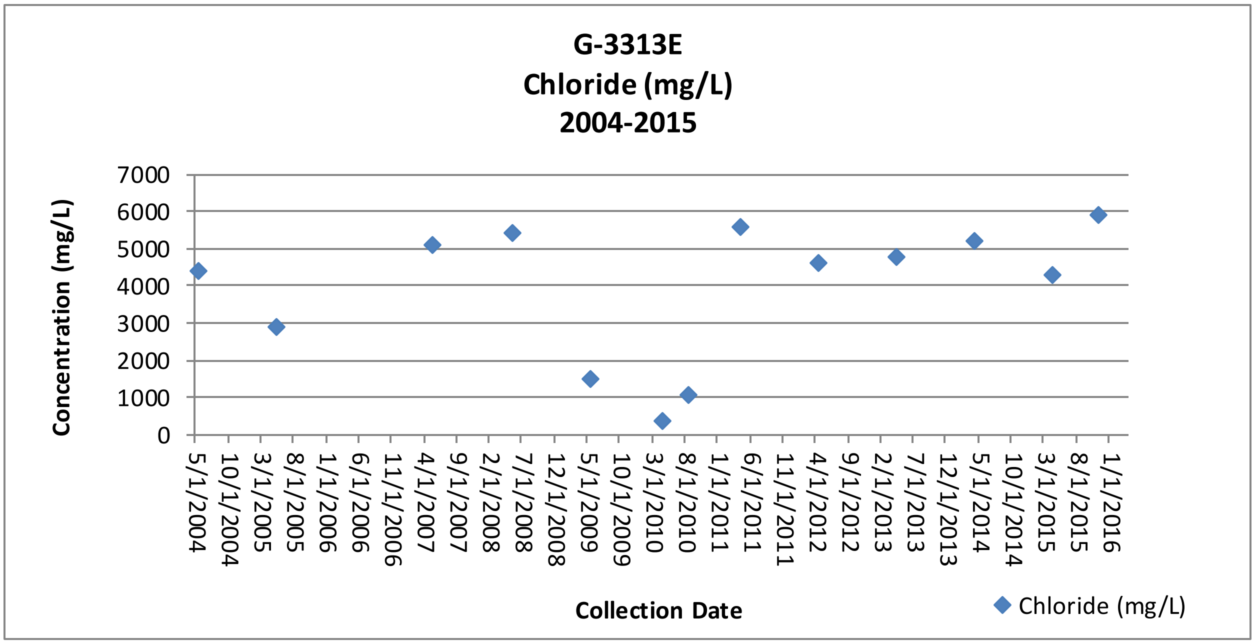
Table C-1. Existing Miami-Dade County Salt Front Monitoring Wells

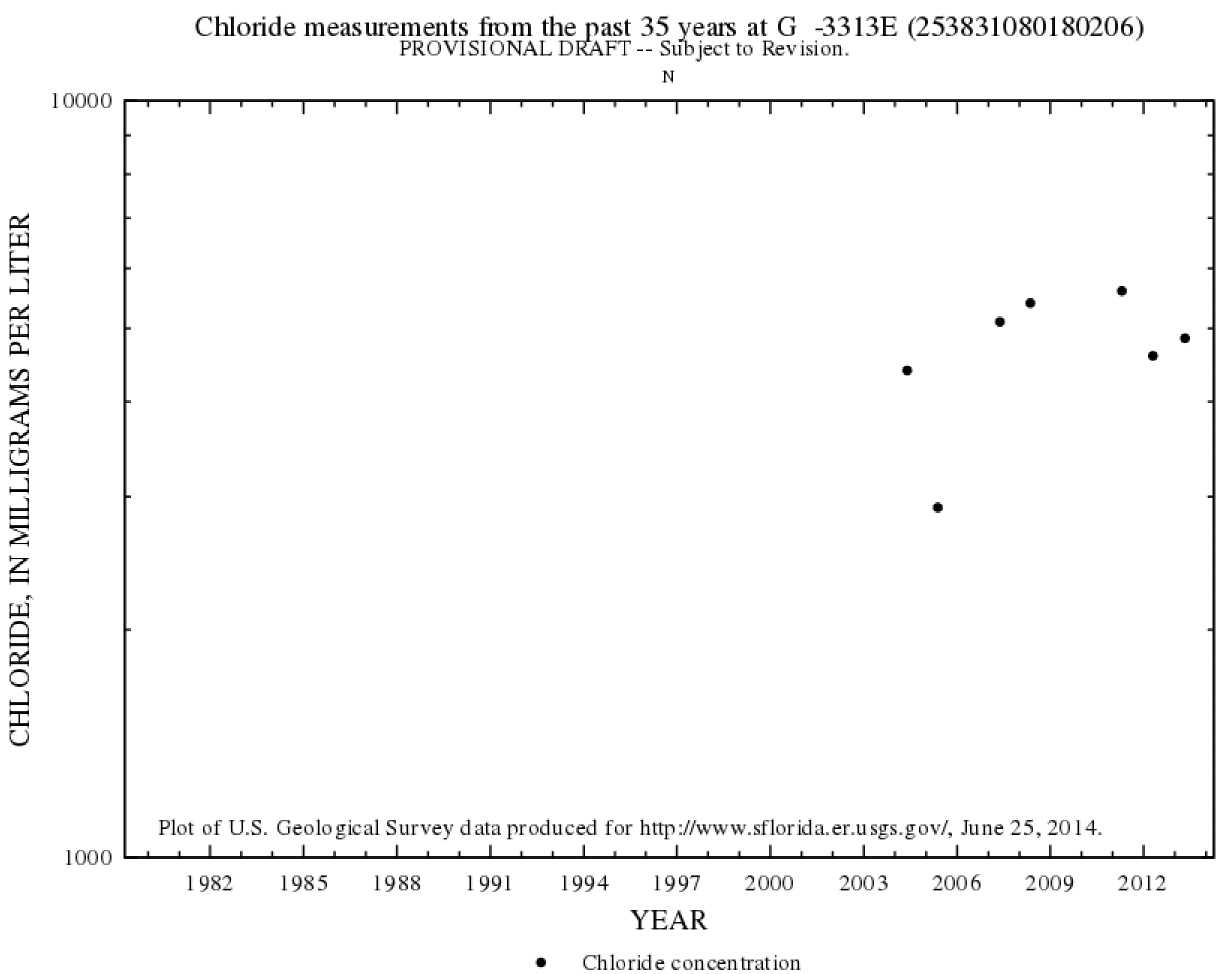
USGS ID	STATION NAME	LATITUDE	LONGITUDE	SITE USE	HOLE DEPTH (ft)[B]	WELL DEPTH (ft)[B]	CASING DEPTH (ft)[B]	Current GWL measurement Freq.	Current Cl Sampling Freq	Induction Log Done	2007 Chloride (mg/l)	2008 Chloride (mg/l)	2009 Chloride (mg/l)	2010 Chloride (mg/l)	2011 Chloride (mg/l)	2012 Chloride (mg/l)	2013 Chloride (mg/l)	2014 Chloride (mg/l)	2015 Chloride (mg/l)
253831080180204	G -3313E	25 38 34.4	-080 18 04.7	observation/monitoring	114	114	32	quarterly	quarterly	No	5100	5400	1500	713	5600	4600	4800	5200	5100
253831080180204	G -3313C	25 38 35.1	-080 18 04.8	observation/monitoring	110	110	open hole	quarterly	quarterly	No	4000	4200	4250	4400	4717	4351	4533	4875	5167
254946080172601	G -3250	25 49 46	-080 17 26	observation/monitoring	116	116	106	Monthly	Monthly	Yes	68	131	139	176	181	200	37	134	139
254457080160301	G -3229	25 44 57	-080 16 03	observation/monitoring	85	85	A	Monthly	Monthly	No	700	807	900	1217	1606	1883	2108	2250	2442
255222080123001	G -3224	25 52 22	-080 12 30	observation/monitoring	95.5	95.5	94	Monthly	Monthly	No	44	39	41	41	42	41	35	35	35
253202080232601	G -3162	25 31 32	-080 23 25	observation/monitoring	92	92	82	quarterly	quarterly	No	1140	1208	1284	1303	1280	1267	1425	1542	1475
254833080155801	G -1354	25 48 33	-080 15 58	observation/monitoring	104	104	91	Monthly	quarterly	No	56	53	516	48	49	58	135	177	195
254813080161501	G -1351	25 48 13	-080 16 15	observation/monitoring	103	103	100	Monthly	Monthly	No	540	530	520	503	492	474	436	399	407
252947080235301	G -1180	25 29 47	-080 23 53	observation/monitoring	67	67	open hole	Monthly	Monthly	No	32	30	17	27	25	17	37	20	19
252944080233401	G-1179	25 29 44.9	-80 23 33	observation/monitoring	80	80	open hole	twice a year	twice a year	Yes	3175	2950	2450	2350	2898	2800	Destroid	Destroid	
254106080174601	G -1009B	25 41 06	-080 17 46	observation/monitoring	100	100	NA	Monthly	Monthly	No	50	59	59	62	60	75	74	72	80
253652080183701	G-939	25 36 53.8	-080 18 35.4	observation/monitoring	61	61	NA	twice a year	twice a year	No	3100	3050	3333	3750	3900	3808	4108	3883	3767
254201080173001	G-901	25 42 03.0	-080 16 54.4	observation/monitoring	96	96	95	twice a year	twice a year	No	2325	2375	2550	2438	2550	2667	3058	3527	4650
253710080184701	G -3611	25 37 10.4	-080 18 45.4	observation/monitoring	100	100	95	quarterly	quarterly	Yes	200	173	172	170	169	165	168	165	160
254107080165201	G - 896	25 41 07	-080 16 52	observation/monitoring	74	74	60	Monthly	Monthly	No	245	247	235	248	245	258	251	246	347
255350080105801	G - 894	25 53 51.7	-080 10 57.2	observation/monitoring	76	76	75	Monthly	Monthly	No	24	21	21	22	23	21	17	15	15
254841080164401	G - 571	25 48 41	-080 16 44	observation/monitoring	94.5	94.5	95	Monthly	Monthly	No	32	32	30	34	35	34	28	27	27
254855080163701	G-548	25 48 55.9	-080 16 36.4	observation/monitoring	97	97	91	Monthly	twice a year	No	41	40	36	34	32	31	30	29	33
254335080170501	G-432	25 43 35.9	-080 17 03.3	observation/monitoring	100	100	98	Monthly	twice a year	No	4000	4150	4500	4775	5142	5467	5683	5817	6383
254828080161501	G - 354	25 48 28	-080 16 15	observation/monitoring	90	90.2	89	quarterly	quarterly	No	54	53	50	49	46	45	42	41	40
255315080111501	F-279	25 53 17.8	-080 11 14.6	observation/monitoring	117	117	NA	Monthly	quarterly	No	3150	3300	3383	3475	3583	3675	3892	4117	4067
254943080121501	F - 45	25 49 43	-080 12 15	observation/monitoring	84.9	84.9	84	Monthly	Monthly	No	104	87	97	97	113	118	127	130	143
253253080221201	G-3885	25 32 53.1	-080 22 12.7	observation/monitoring	91	86	86	Monthly	Monthly	No	NA	NA	NA	NA	36	36	31	30	30
2535270801195400	G-3886	25 35 27.9	-080 19 54.2	observation/monitoring	109	101	101	Monthly	Monthly	No	NA	NA	NA	NA	51	49	47	46	47
253924080174601	G-3887	25 39 24.7	-080 17 46.8	observation/monitoring	134	130	130	Monthly	Monthly	No	NA	NA	NA	NA	2238	2292	2442	2508	2692
254542080145901	G-3888	25 39 2407	-080 14 5908	observation/monitoring	149	144	144	Monthly	Monthly	No	NA	NA	NA	NA	5029	5225	5458	5592	6075
252431080261001	G-3946	25 24 30.7	-080 26 09.7	observation/monitoring	99	98	87	Monthly	Monthly	No	NA	NA	NA	Under cor	3717	4158	4629	5067	5375
255011080124501	G-3947	25 50 11.3	-080 12 45.4	observation/monitoring	229	227	200	Monthly	Monthly	No	NA	NA	NA	Under cor	28	25	21	21	21
255515080103601	G-3948	25 55 14.9	-080 10 36.2	observation/monitoring	279	277	273	Monthly	Monthly	No	NA	NA	NA	Under cor	3992		4308	4275	4318
255733080195601	G-3949	25 57 33.6	-080 09 56.5	observation/monitoring	349	349	325	Monthly	Monthly	No	NA	NA	NA	Under cor	115	121	116	118	122

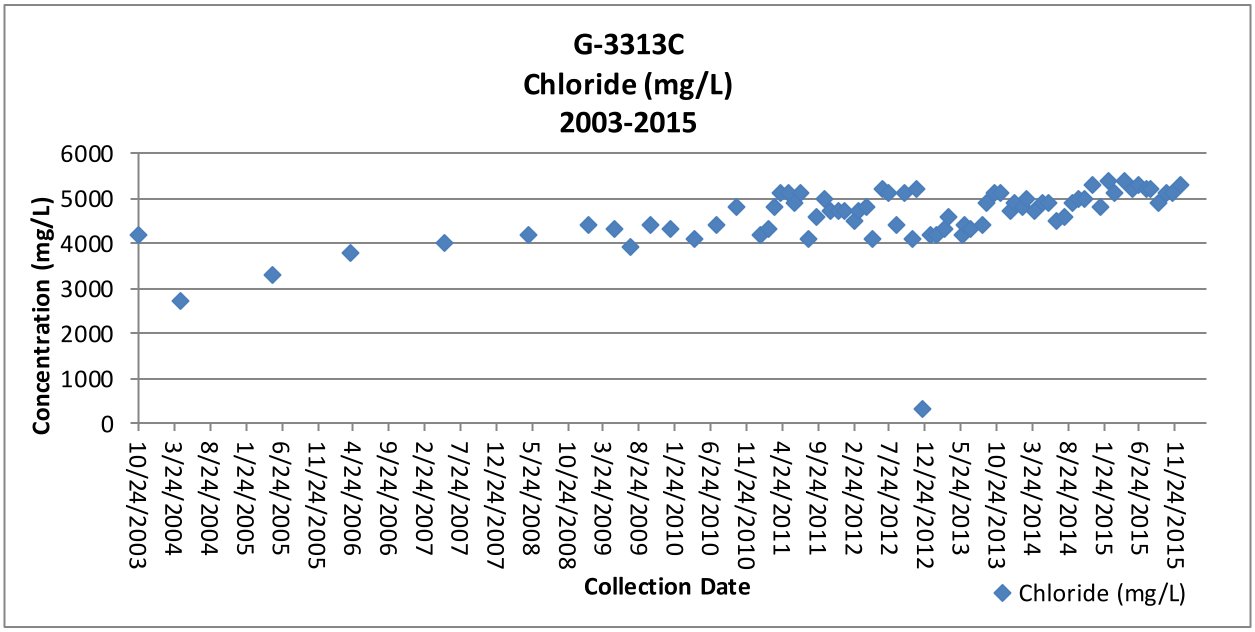
A. Per USGS, depth of the casing is not precisely known.
B. Feet Below Land Surface (bls)
GWL: groundwater level
Cl: chloride

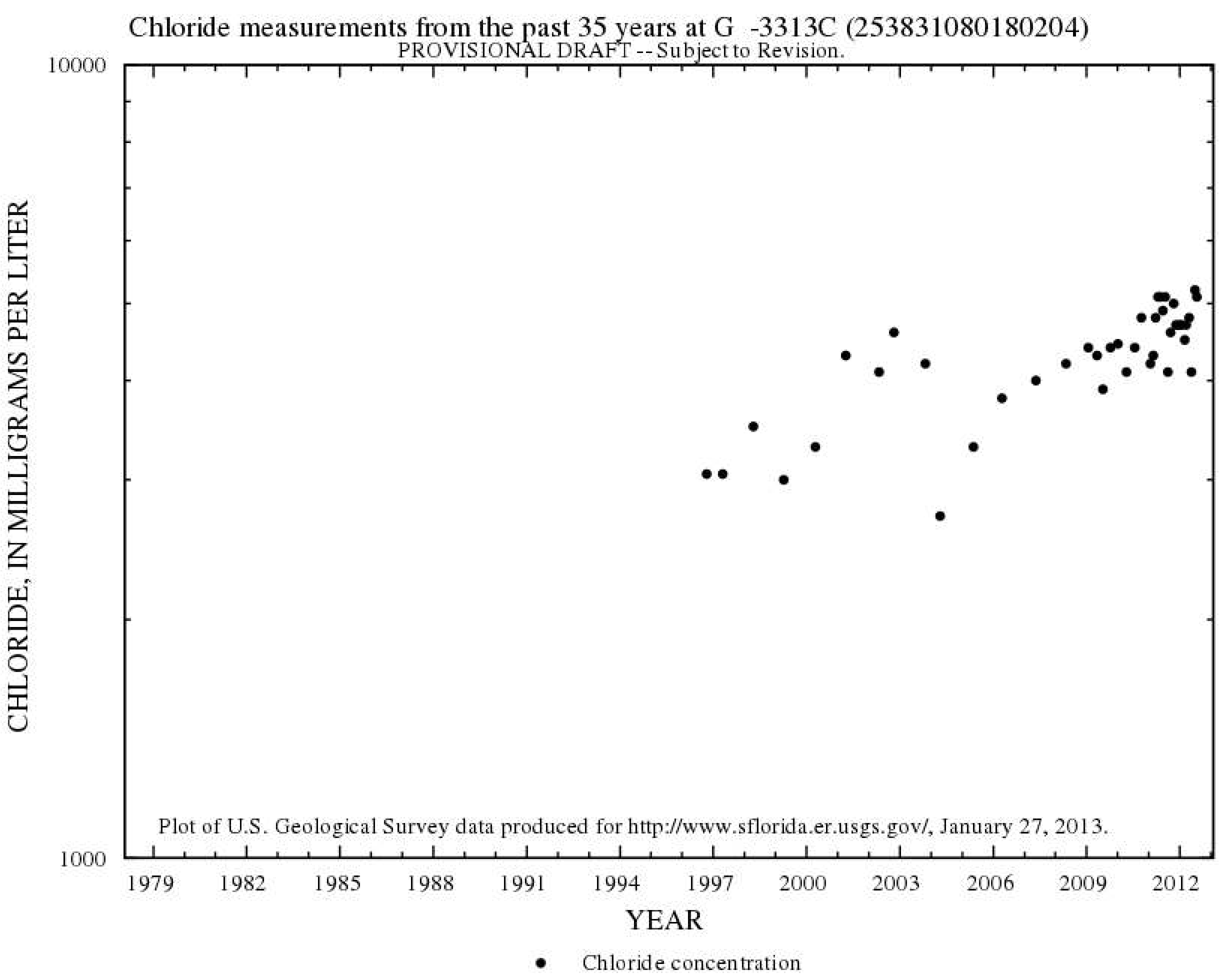
APPENDIX E

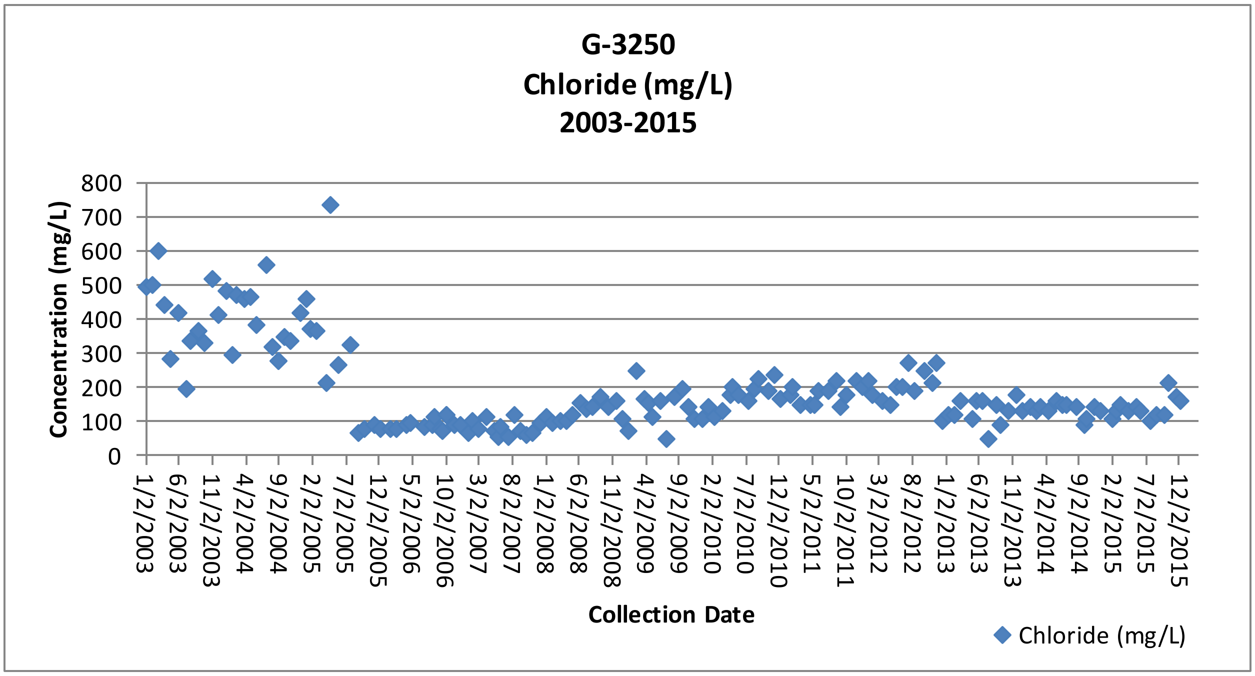
CHLORIDE HISTORICAL GRAPHS

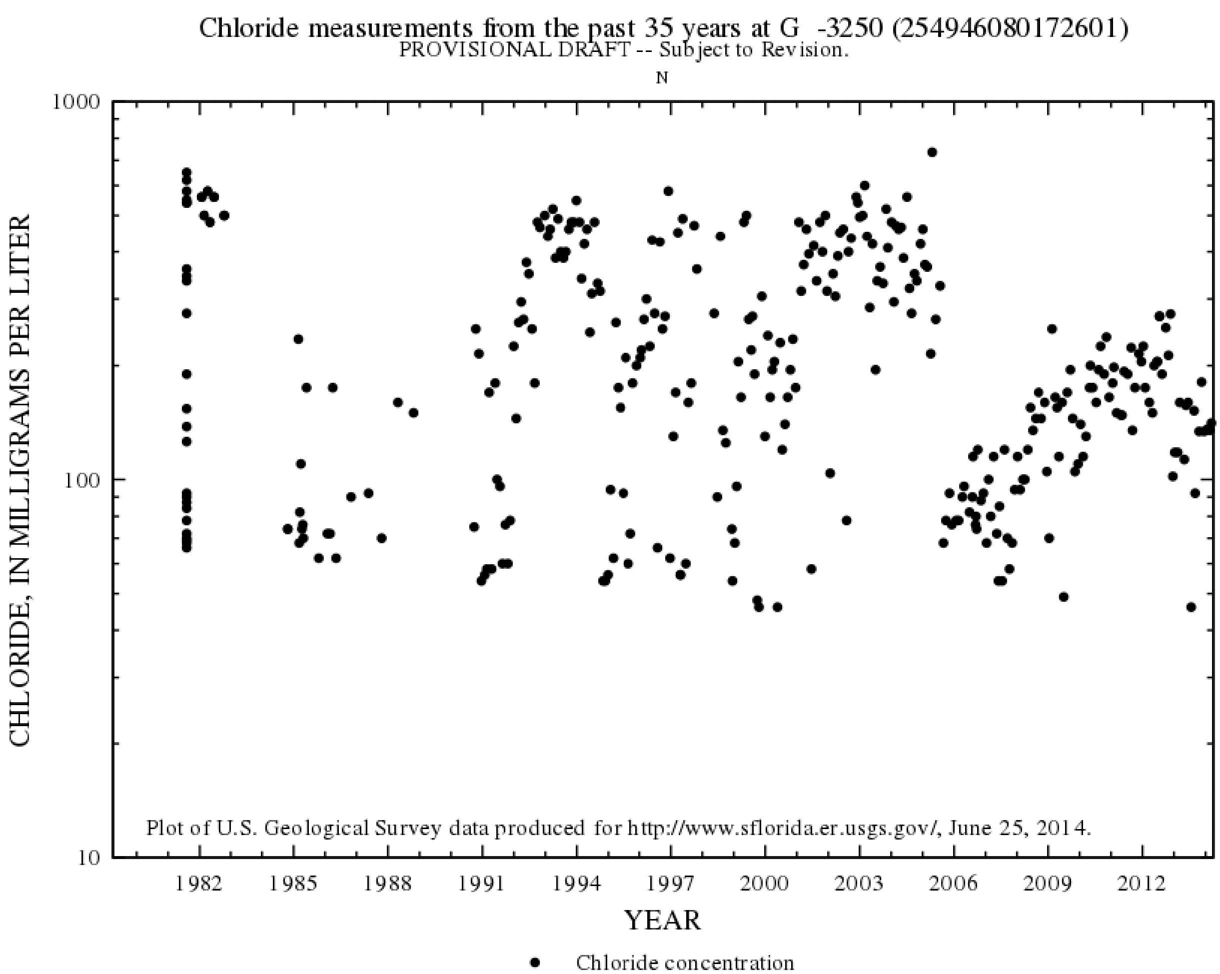

G-3313E
Chloride (mg/L)
2004-2015
Concentration (mg/L)
7000
6000
5000
4000
3000
2000
1000
0
5/1/2004
10/1/2004
3/1/2005
8/1/2005
1/1/2006
6/1/2006
11/1/2006
4/1/2007
9/1/2007
2/1/2008
7/1/2008
12/1/2008
5/1/2009
10/1/2009
3/1/2010
8/1/2010
1/1/2011
6/1/2011
11/1/2011
4/1/2012
9/1/2012
2/1/2013
7/1/2013
12/1/2013
5/1/2014
10/1/2014
3/1/2015
8/1/2015
1/1/2016
Collection Date
Chloride (mg/L)

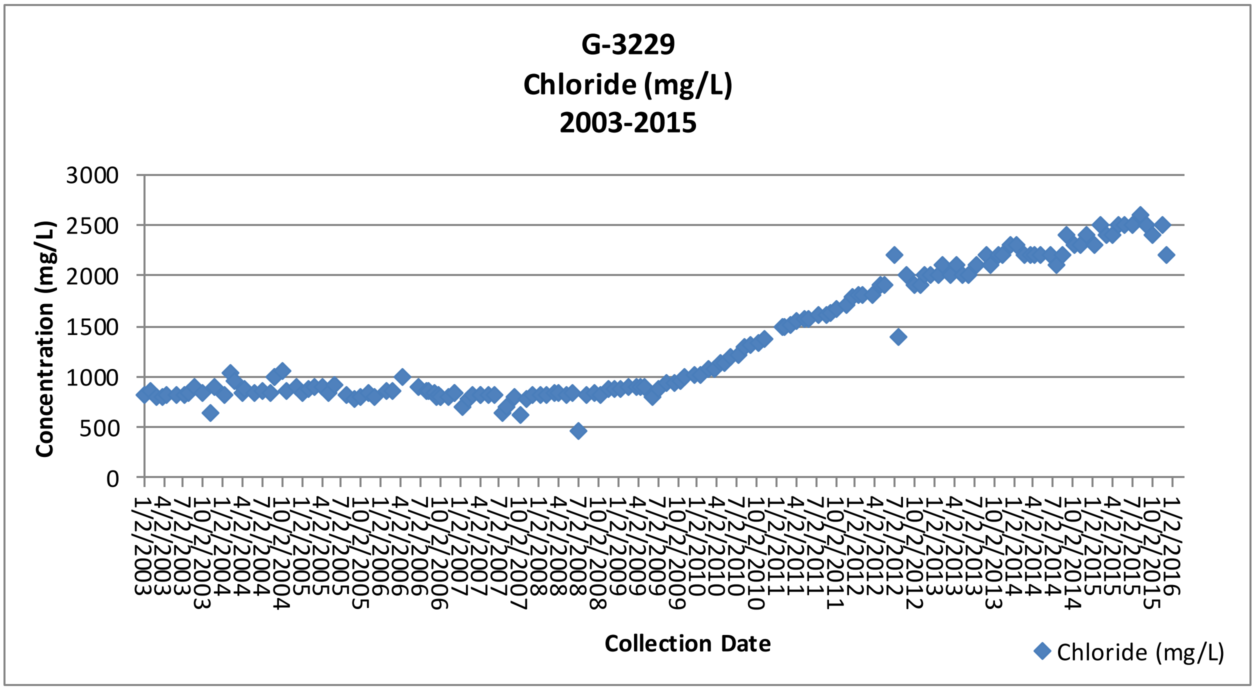

Chloride measurements from the past 35 years at G -3313E (253831080180206)
PROVISIONAL DRAFT -- Subject to Revision.
N
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration


G-3313C
Chloride (mg/L)
2003-2015
Concentration (mg/L)
6000
5000
4000
3000
2000
1000
0
10/24/2003
3/24/2004
8/24/2004
1/24/2005
6/24/2005
11/24/2005
4/24/2006
9/24/2006
2/24/2007
7/24/2007
12/24/2007
5/24/2008
10/24/2008
3/24/2009
8/24/2009
1/24/2010
6/24/2010
11/24/2010
4/24/2011
9/24/2011
2/24/2012
7/24/2012
12/24/2012
5/24/2013
10/24/2013
3/24/2014
8/24/2014
1/24/2015
6/24/2015
11/24/2015
Collection Date
Chloride (mg/L)


Chloride measurements from the past 35 years at G -3313C (253831080180204)
PROVISIONAL DRAFT -- Subject to Revision.
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, January 27, 2013.
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

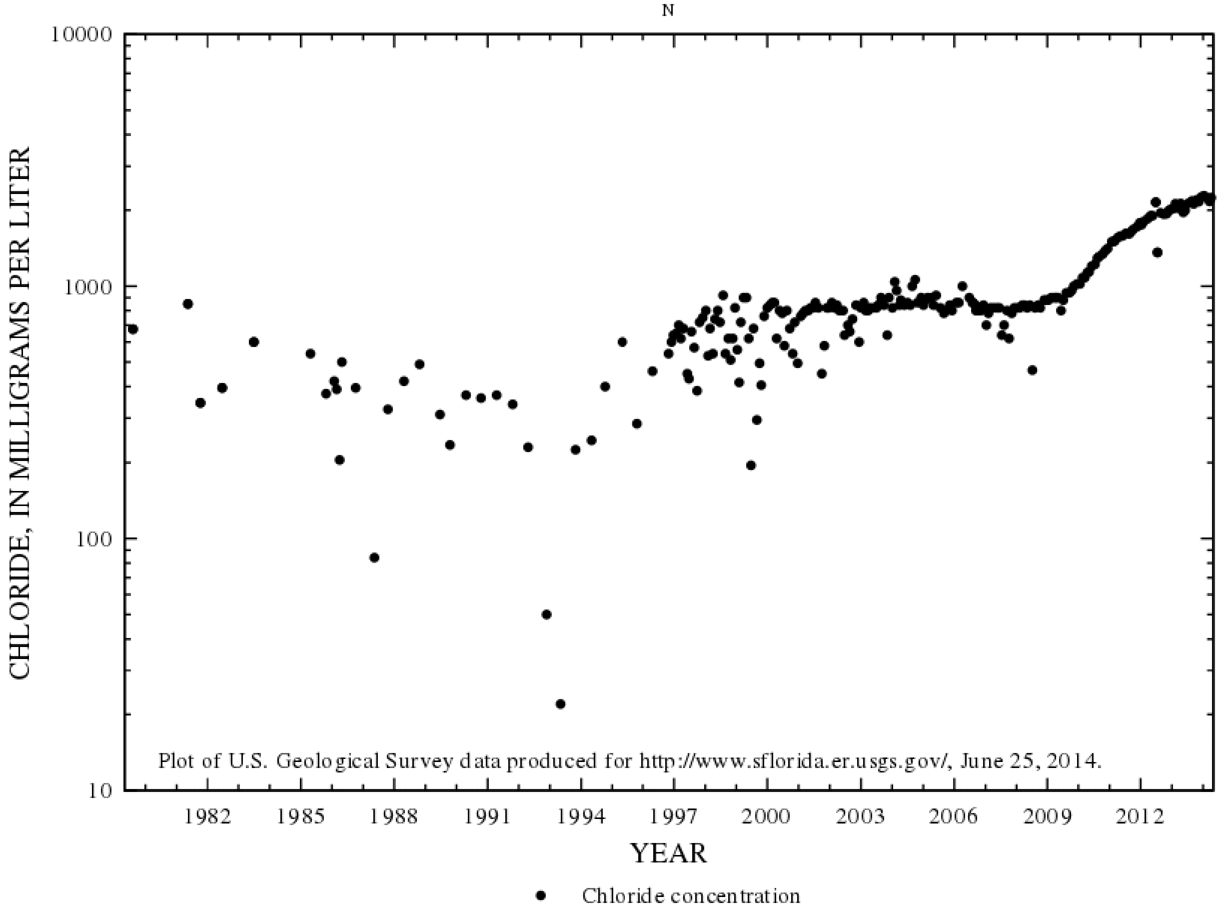

G-3250
Chloride (mg/L)
2003-2015
Concentration (mg/L)
800
700
600
500
400
300
200
100
0
1/2/2003
6/2/2003
11/2/2003
4/2/2004
9/2/2004
2/2/2005
7/2/2005
12/2/2005
5/2/2006
10/2/2006
3/2/2007
8/2/2007
1/2/2008
6/2/2008
11/2/2008
4/2/2009
9/2/2009
2/2/2010
7/2/2010
12/2/2010
5/2/2011
10/2/2011
3/2/2012
8/2/2012
1/2/2013
6/2/2013
11/2/2013
4/2/2014
9/2/2014
2/2/2015
7/2/2015
12/2/2015
Collection Date
Chloride (mg/L)

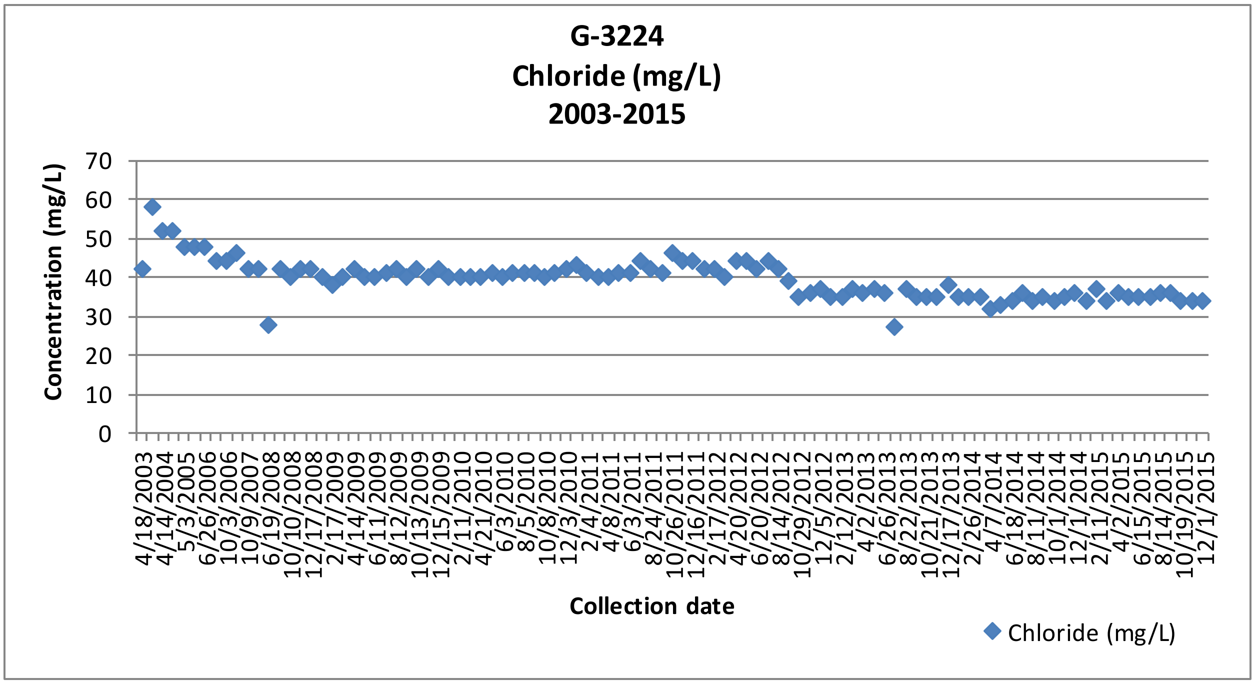

Chloride measurements from the past 35 years at G -3250 (254946080172601)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
1000
100
10
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

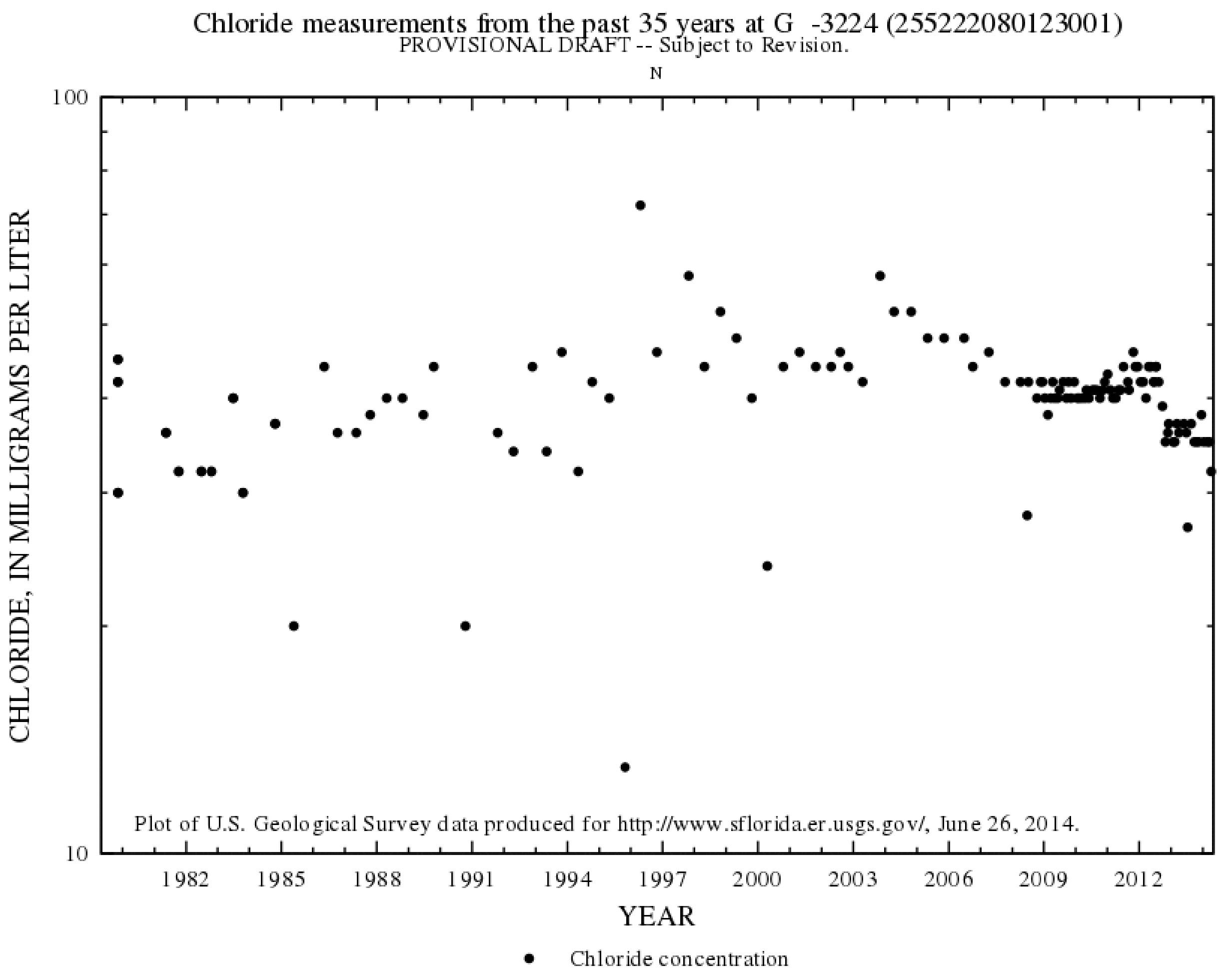


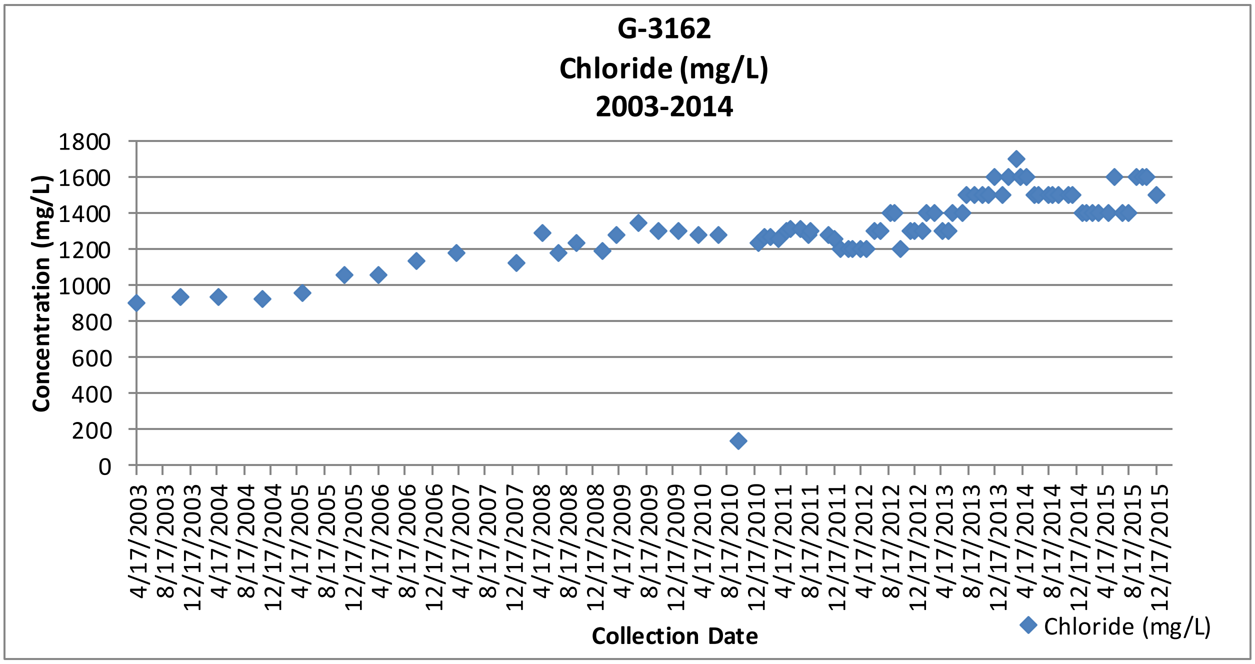
Chloride measurements from the past 35 years at G -3229 (254457080160301)

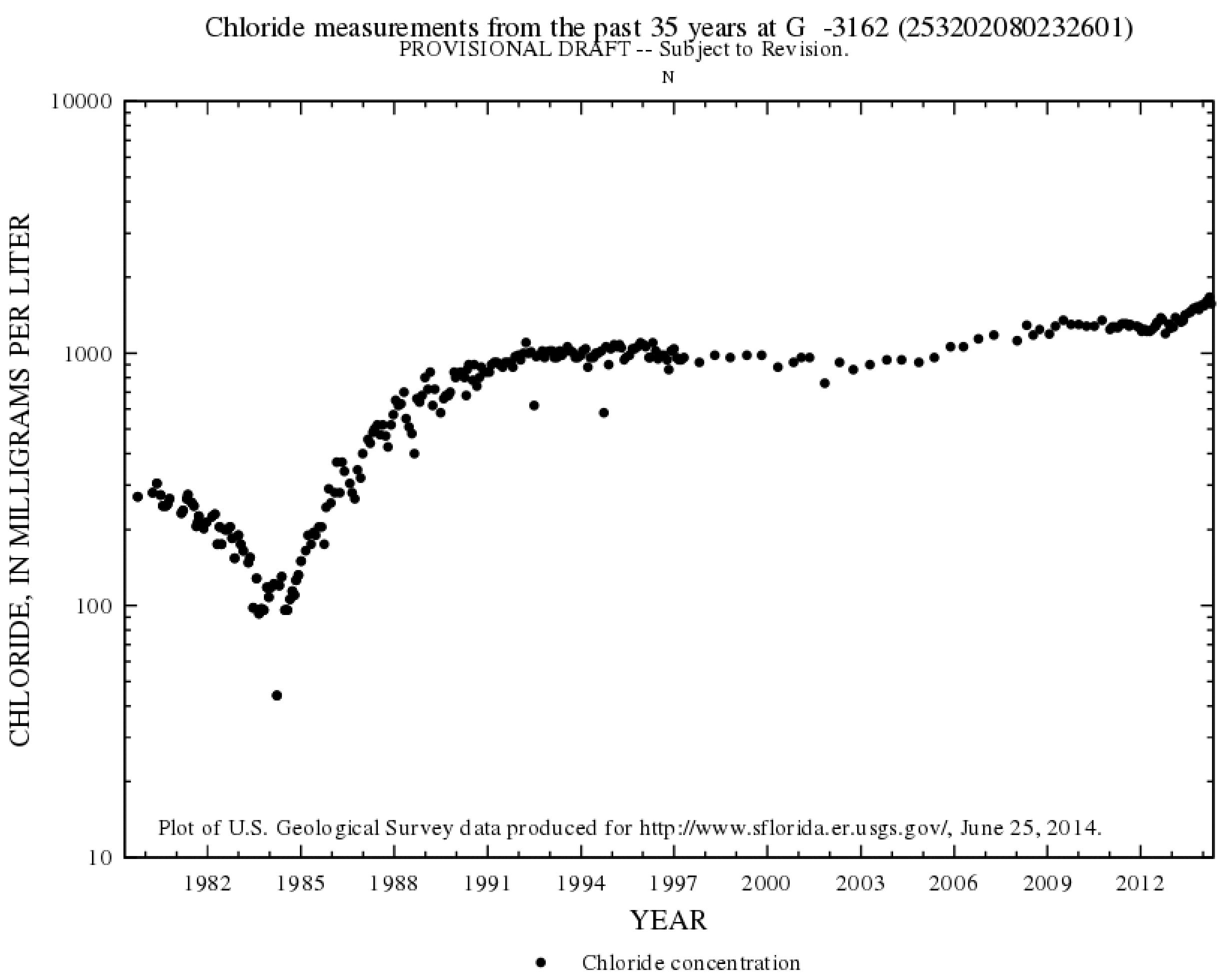
PROVISIONAL DRAFT -- Subject to Revision.

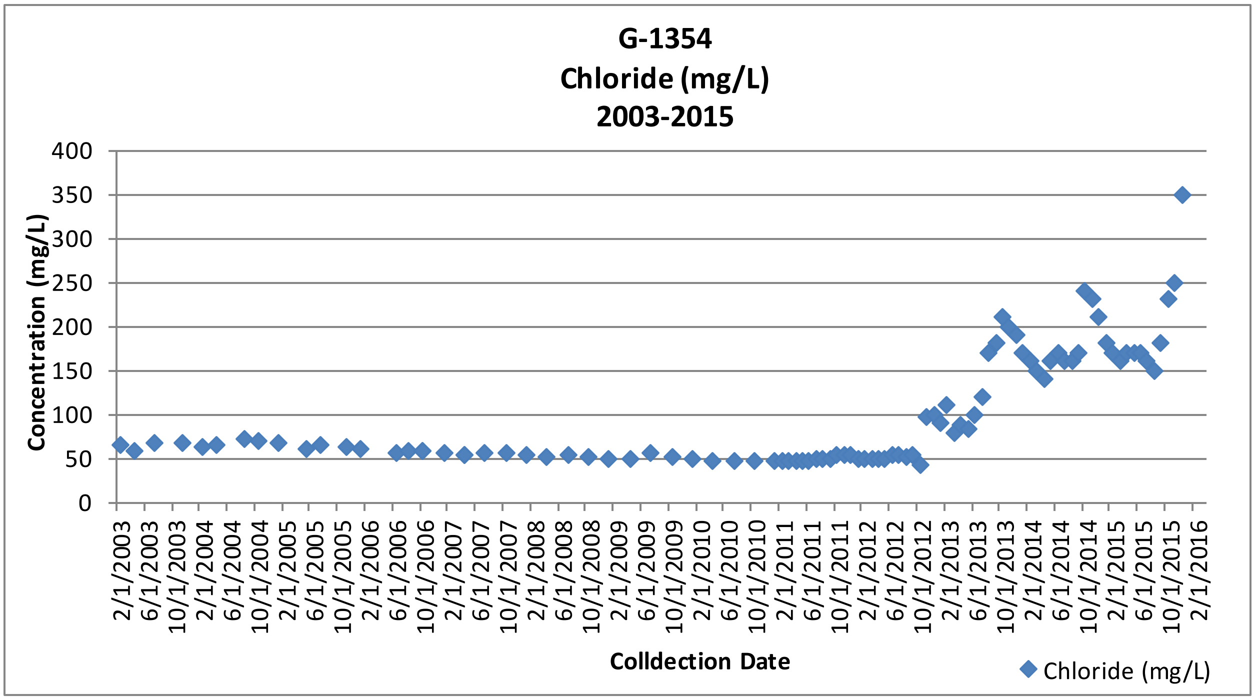



G-3224
Chloride (mg/L)
2003-2015
Concentration (mg/L)
Collection date
Chloride (mg/L)


Chloride measurements from the past 35 years at G -3224 (255222080123001)
PROVISIONAL DRAFT -- Subject to Revision.
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 26, 2014.
YEAR
Chloride concentration

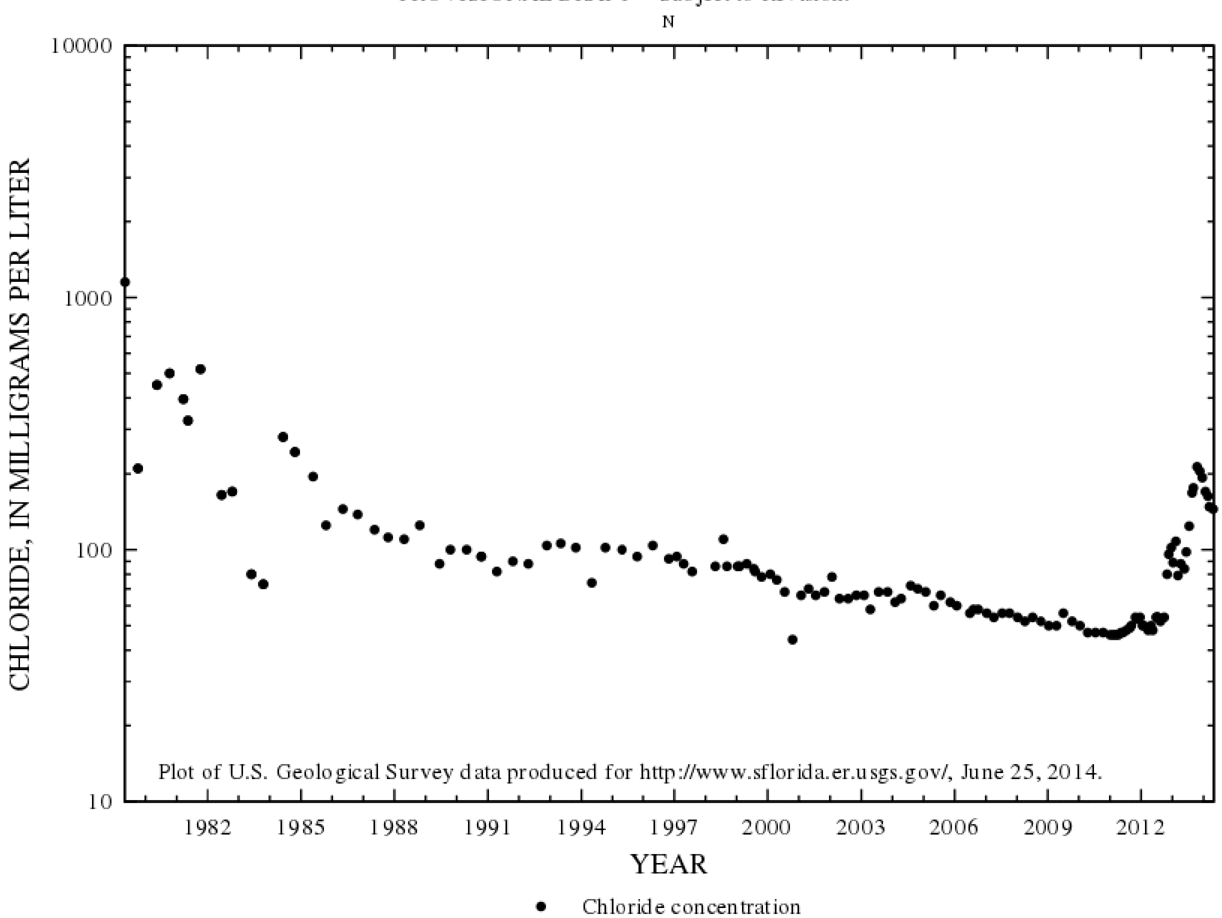

G-3162
Chloride (mg/L)
2003-2014
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
4/17/2003
8/17/2003
12/17/2003
4/17/2004
8/17/2004
12/17/2004
4/17/2005
8/17/2005
12/17/2005
4/17/2006
8/17/2006
12/17/2006
4/17/2007
8/17/2007
12/17/2007
4/17/2008
8/17/2008
12/17/2008
4/17/2009
8/17/2009
12/17/2009
4/17/2010
8/17/2010
12/17/2010
4/17/2011
8/17/2011
12/17/2011
4/17/2012
8/17/2012
12/17/2012
4/17/2013
8/17/2013
12/17/2013
4/17/2014
8/17/2014
12/17/2014
4/17/2015
8/17/2015
12/17/2015
Collection Date
Chloride (mg/L)

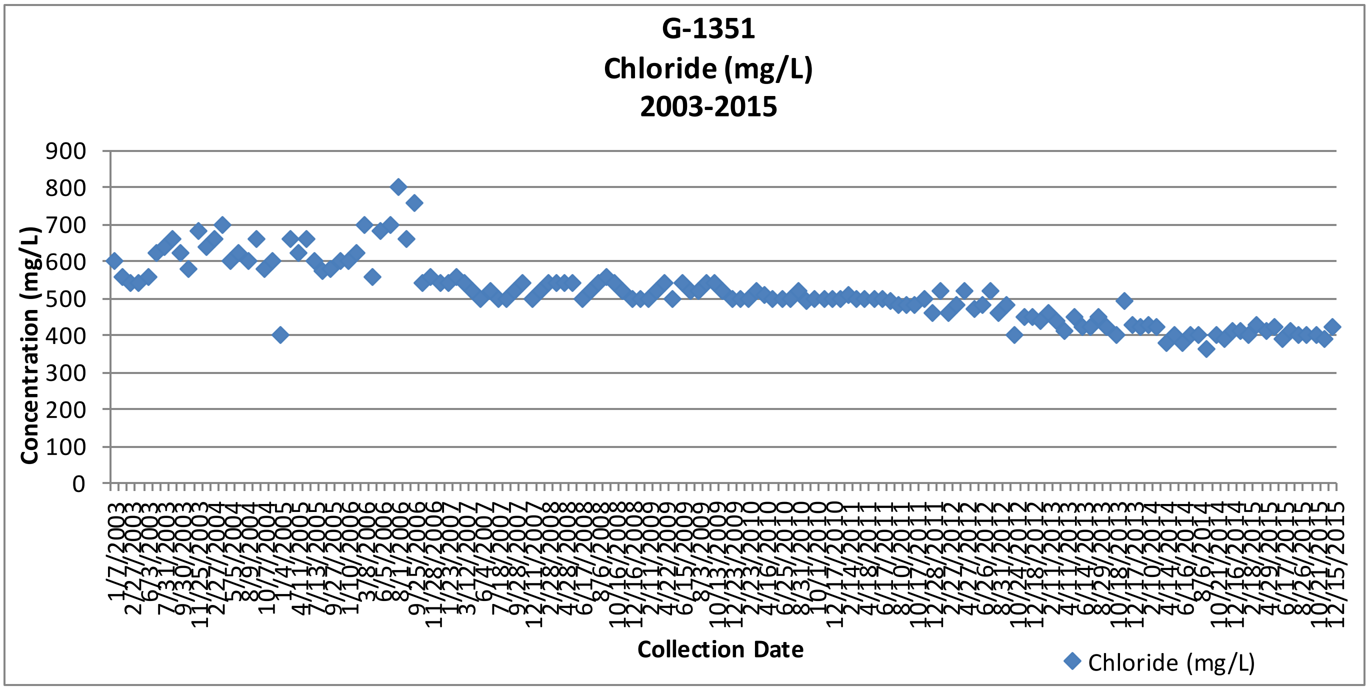

Chloride measurements from the past 35 years at G -3162 (253202080232601)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
10000
1000
100
10
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration



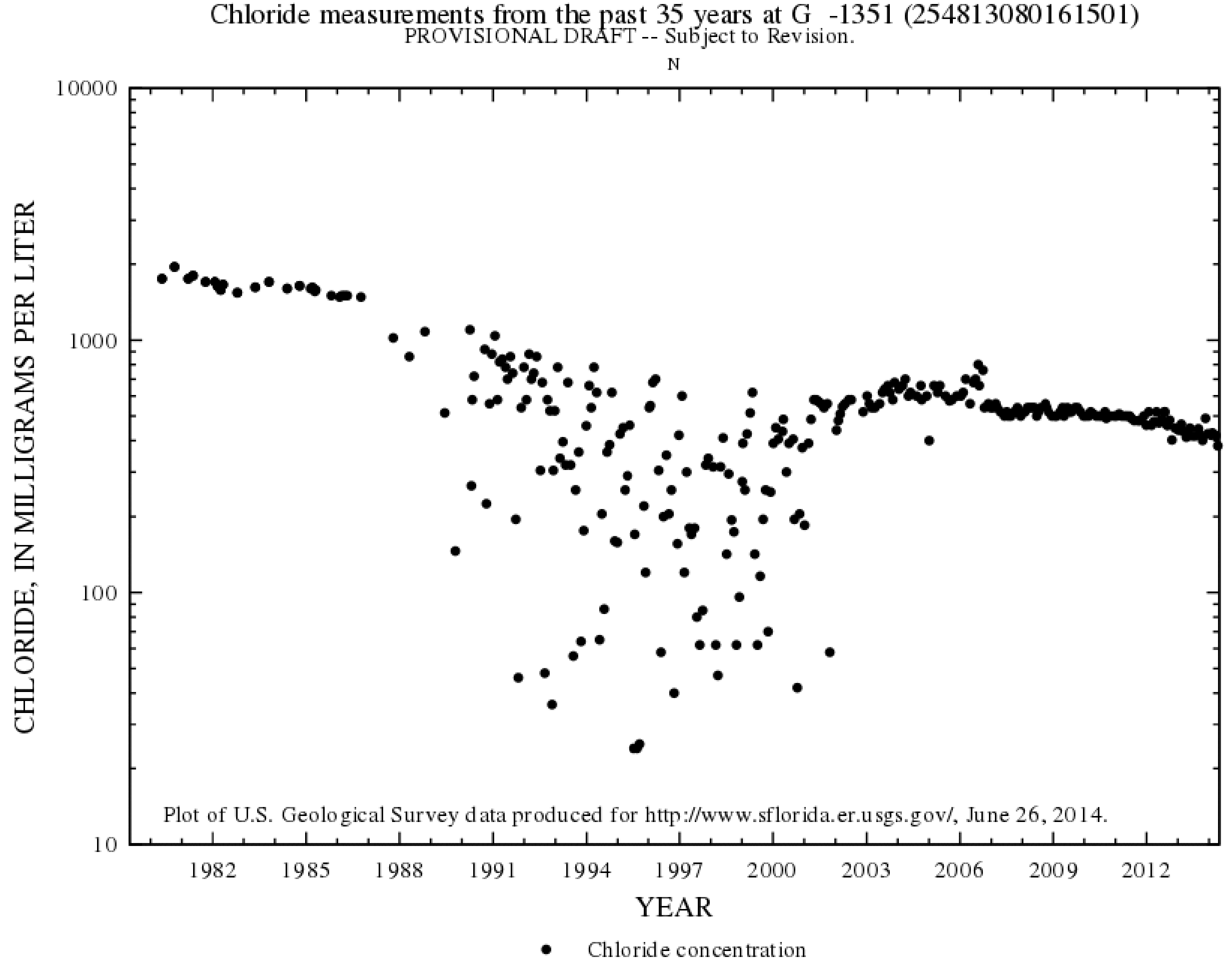
Chloride measurements from the past 35 years at G -1354 (254833080155801)

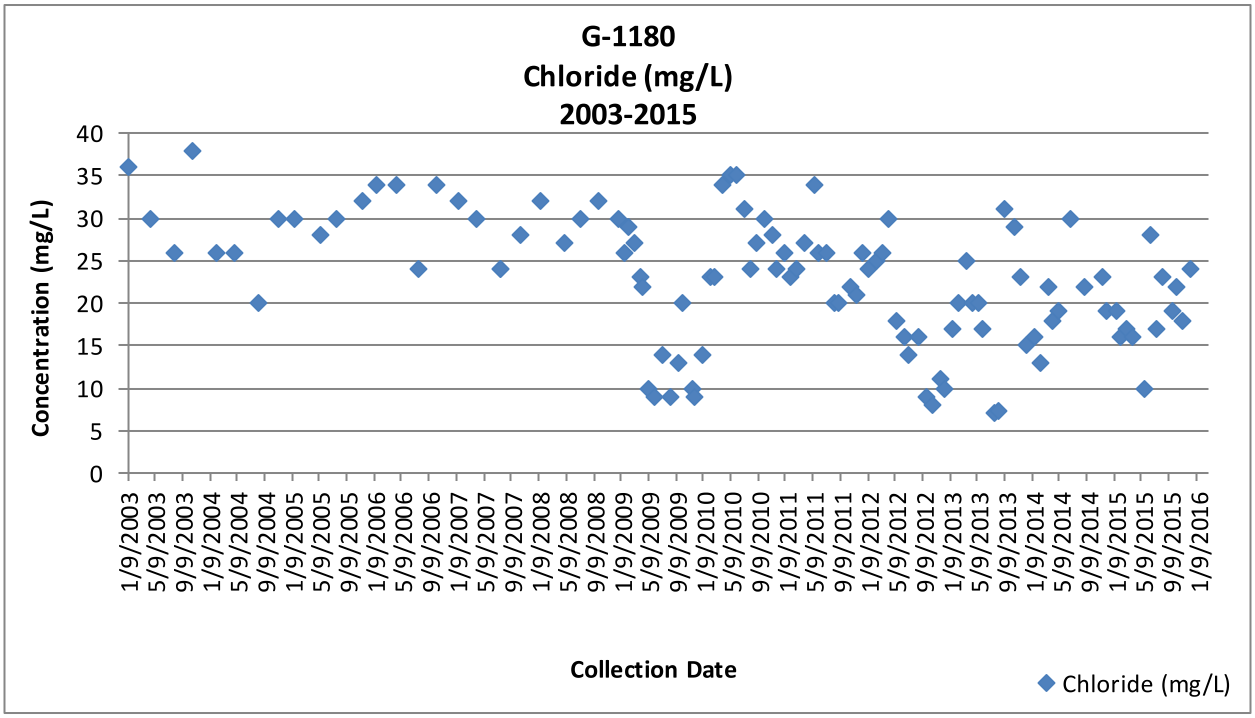
PROVISIONAL DRAFT -- Subject to Revision.





Chloride measurements from the past 35 years at G -1351 (254813080161501)




G-1180
Chloride (mg/L)
2003-2015
Concentration (mg/L)
Collection Date
Chloride (mg/L)
40
35
30
25
20
15
10
5
0
1/9/2003
5/9/2003
9/9/2003
1/9/2004
5/9/2004
9/9/2004
1/9/2005
5/9/2005
9/9/2005
1/9/2006
5/9/2006
9/9/2006
1/9/2007
5/9/2007
9/9/2007
1/9/2008
5/9/2008
9/9/2008
1/9/2009
5/9/2009
9/9/2009
1/9/2010
5/9/2010
9/9/2010
1/9/2011
5/9/2011
9/9/2011
1/9/2012
5/9/2012
9/9/2012
1/9/2013
5/9/2013
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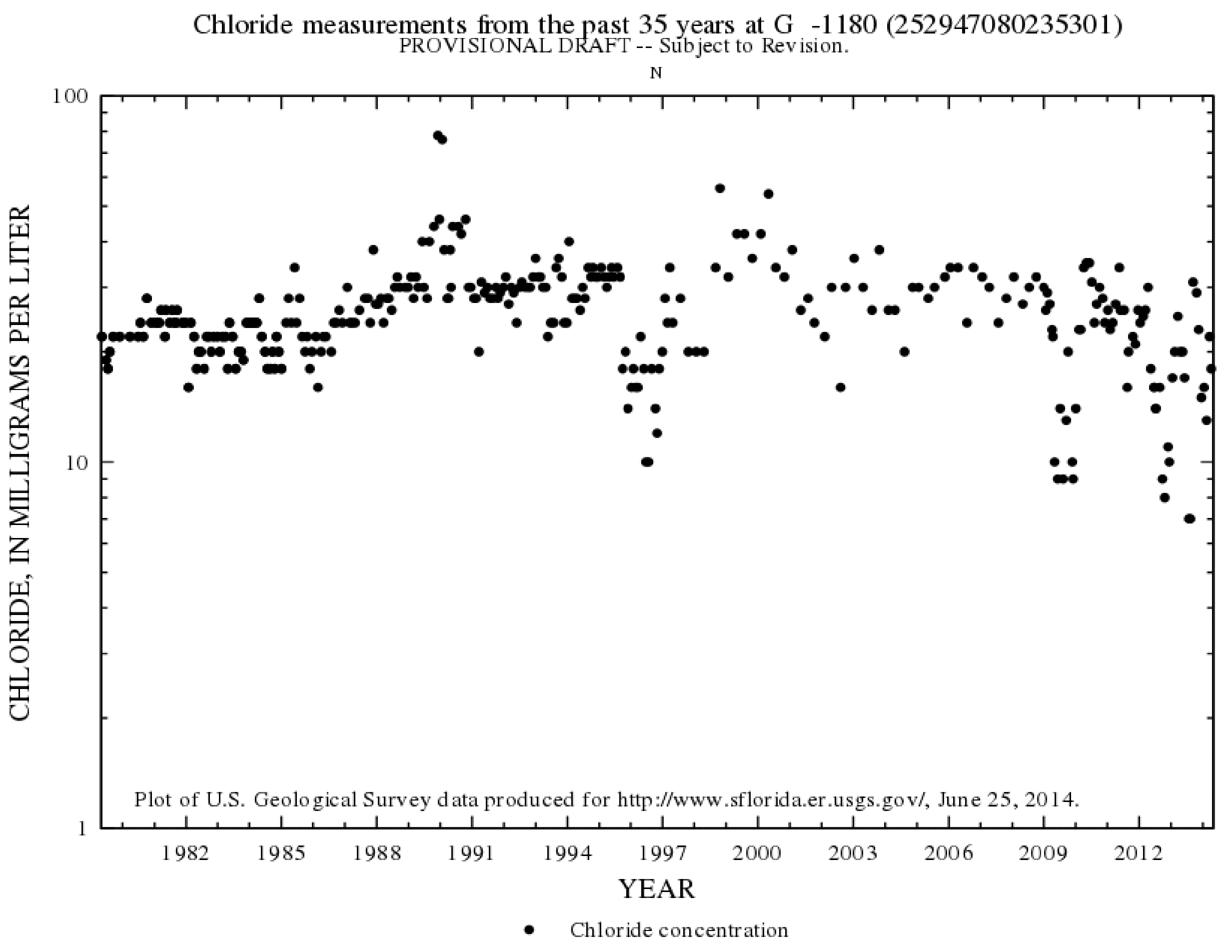
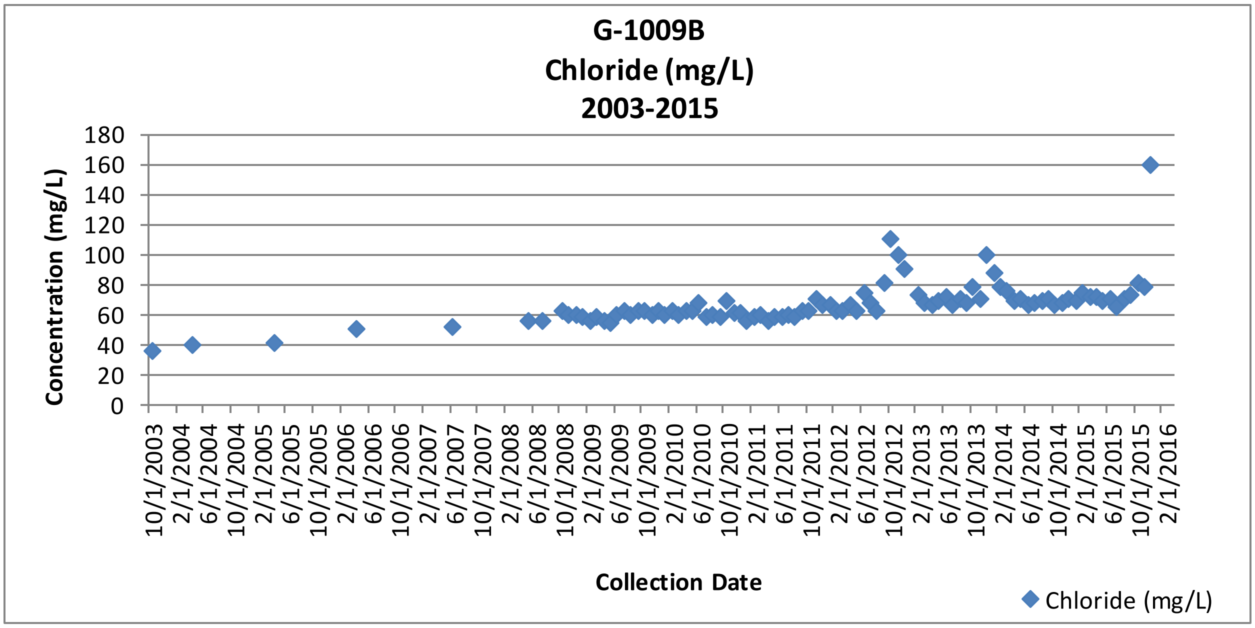
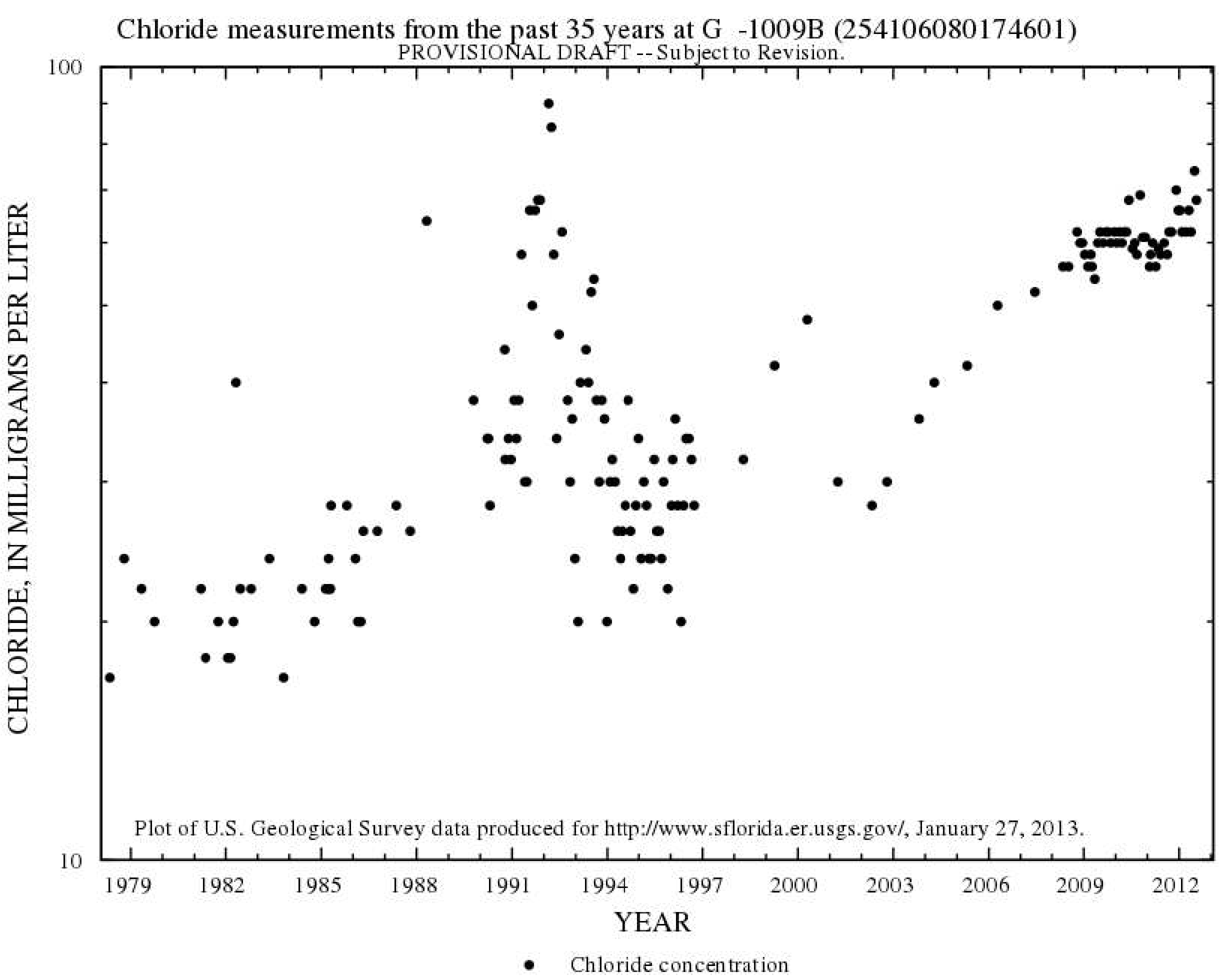
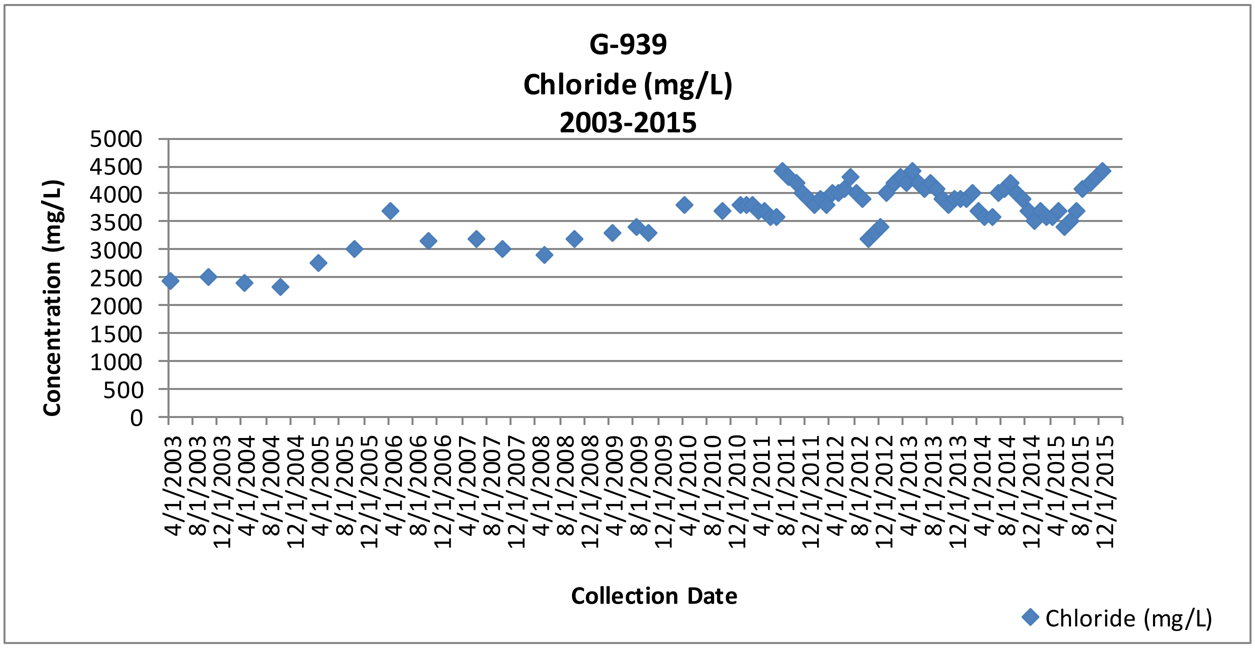
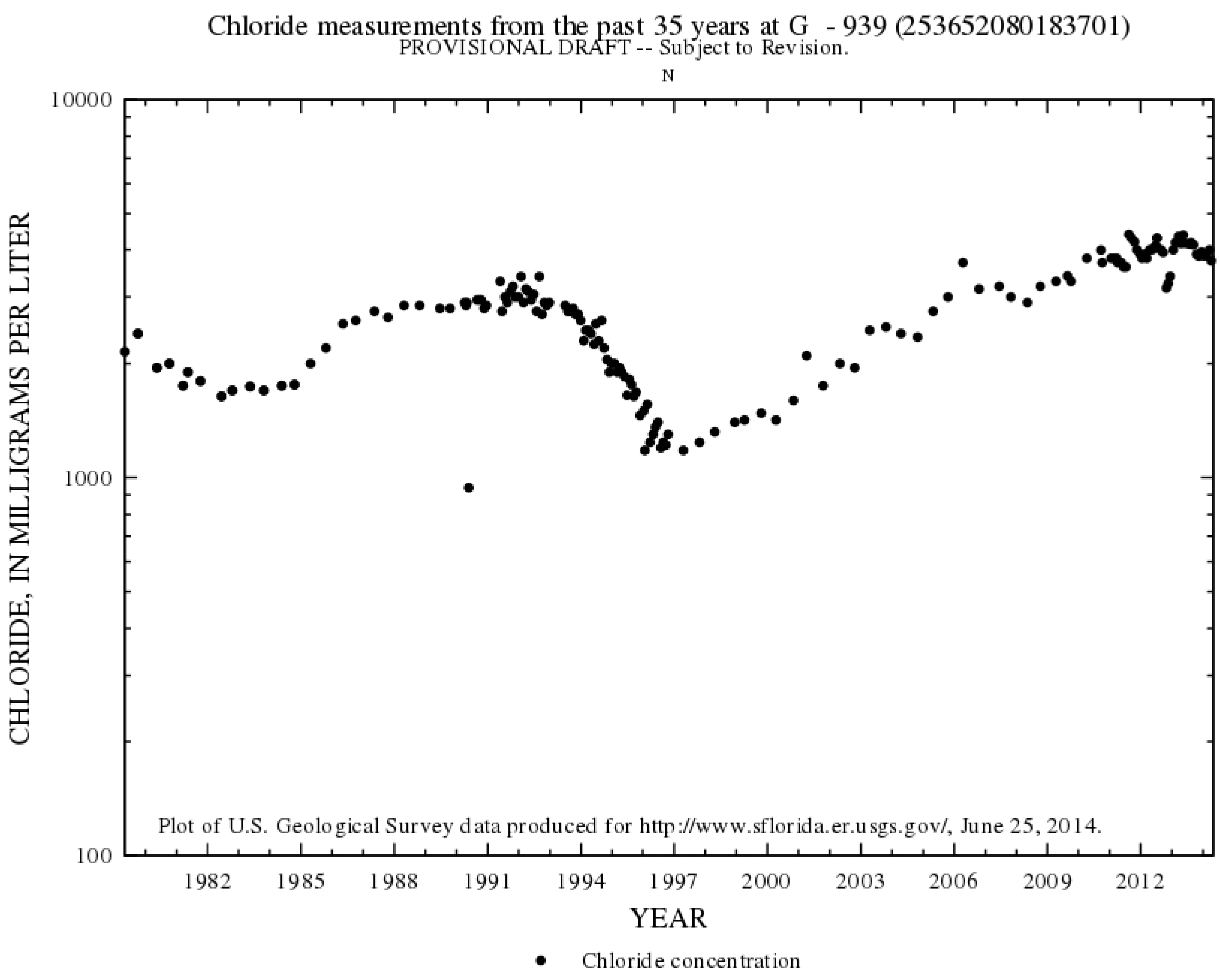
9/9/2014
1/9/2015
5/9/2015
9/9/2015
1/9/2016

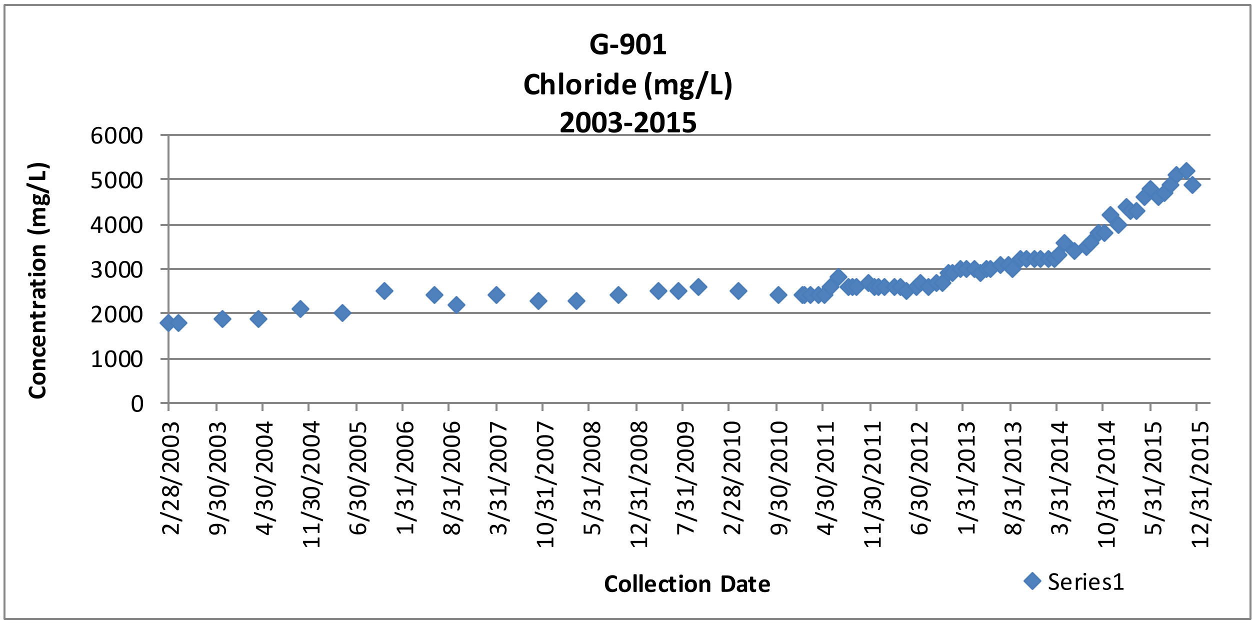

Chloride measurements from the past 35 years at G -1180 (252947080235301)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
100
10
1
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

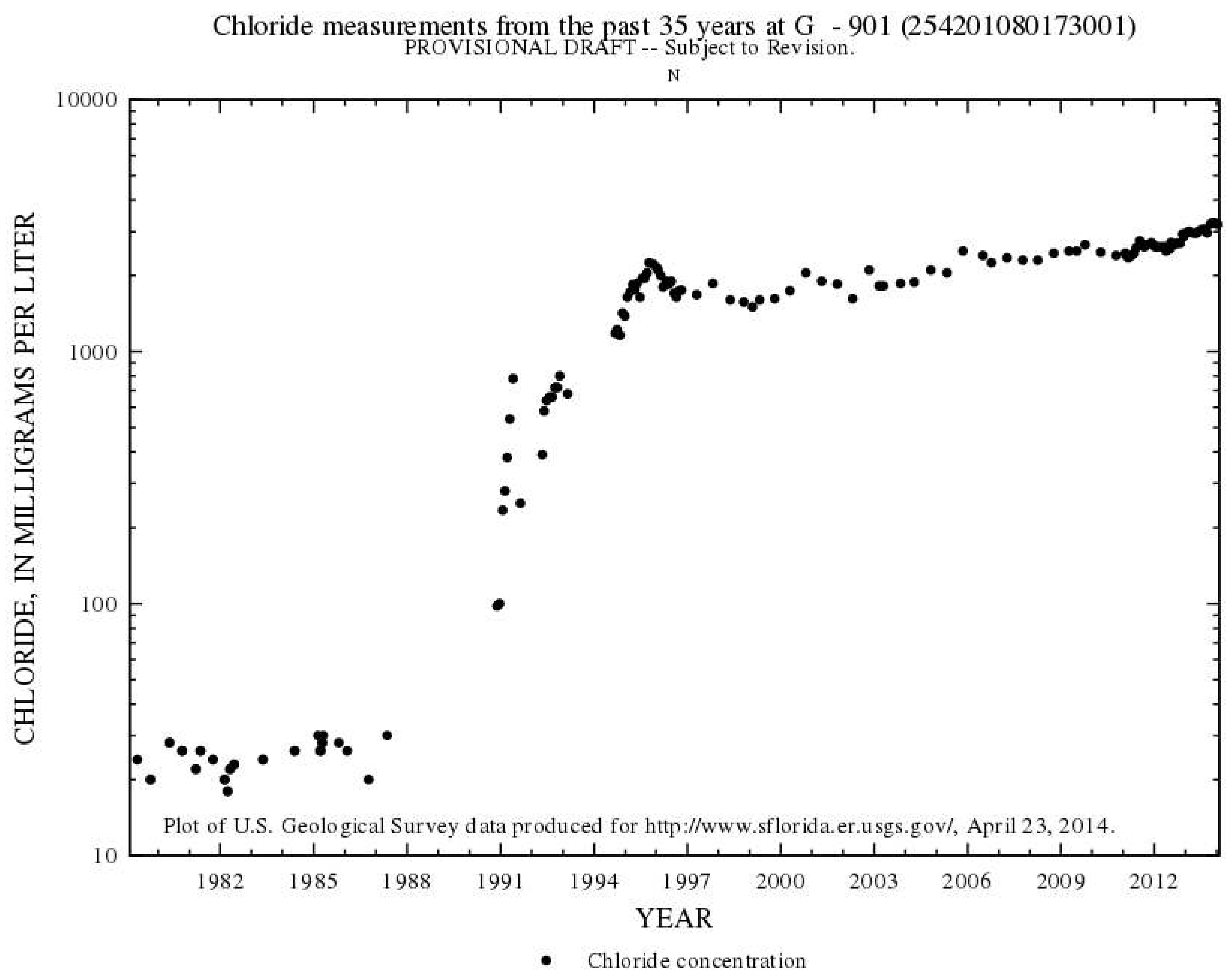

G-1009B
Chloride (mg/L)
2003-2015
Concentration (mg/L)
180
160
140
120
100
80
60
40
20
0
Collection Date
Chloride (mg/L)

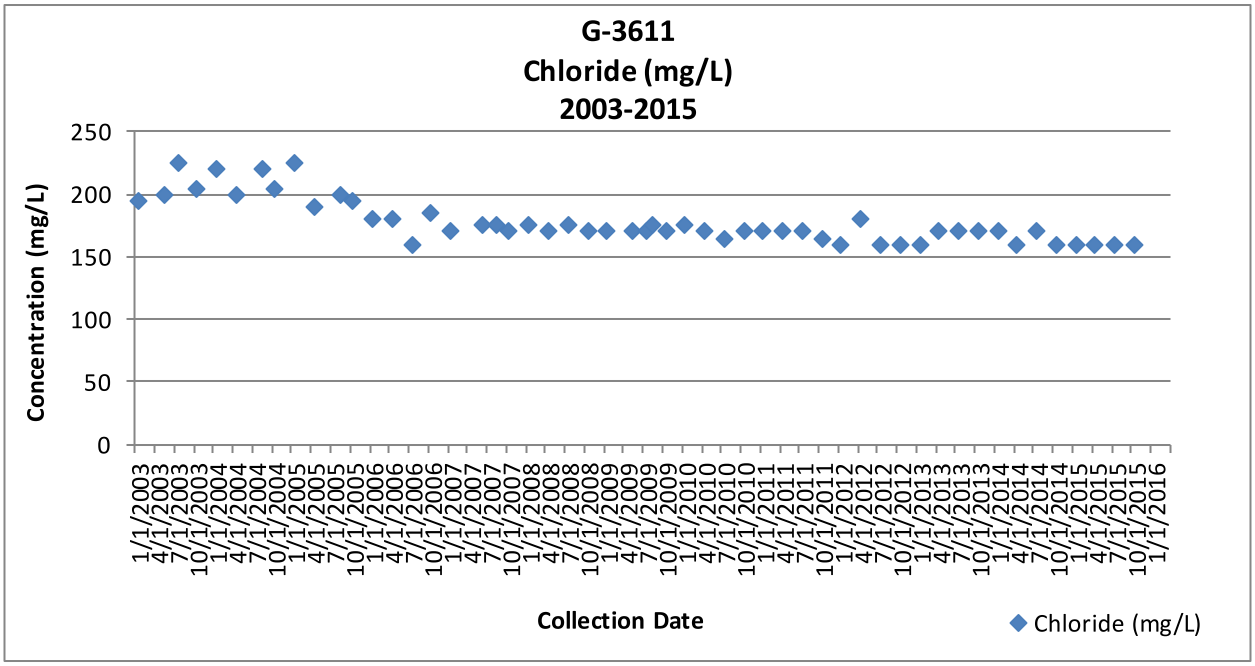

Chloride measurements from the past 35 years at G -1009B (254106080174601)
PROVISIONAL DRAFT -- Subject to Revision.
CHLORIDE, IN MILLIGRAMS PER LITER
100
10
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, January 27, 2013.
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

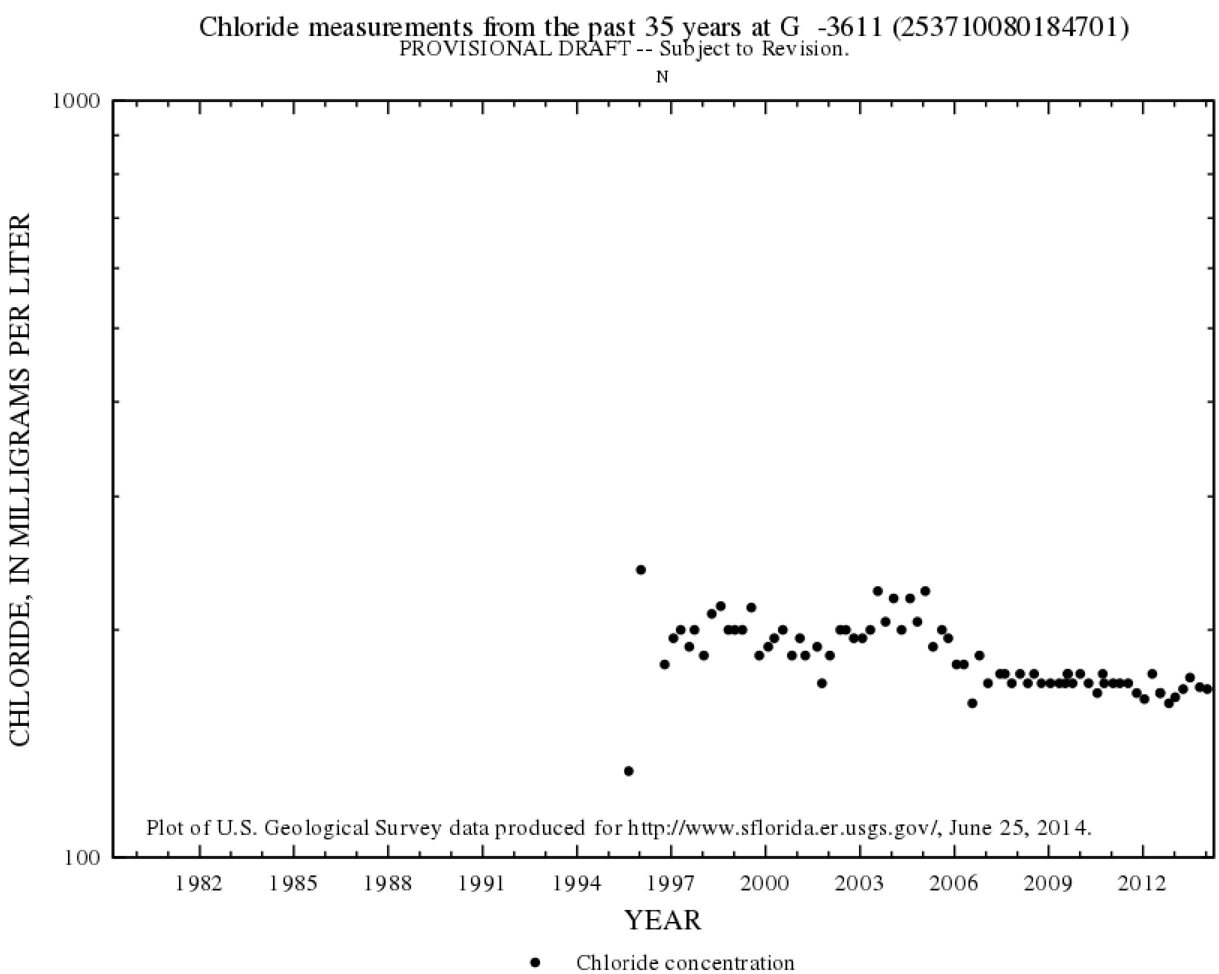

G-939
Chloride (mg/L)
2003-2015
Concentration (mg/L)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
4/1/2003
8/1/2003
12/1/2003
4/1/2004
8/1/2004
12/1/2004
4/1/2005
8/1/2005
12/1/2005
4/1/2006
8/1/2006
12/1/2006
4/1/2007
8/1/2007
12/1/2007
4/1/2008
8/1/2008
12/1/2008
4/1/2009
8/1/2009
12/1/2009
4/1/2010
8/1/2010
12/1/2010
4/1/2011
8/1/2011
12/1/2011
4/1/2012
8/1/2012
12/1/2012
4/1/2013
8/1/2013
12/1/2013
4/1/2014
8/1/2014
12/1/2014
4/1/2015
8/1/2015
12/1/2015
Collection Date
Chloride (mg/L)

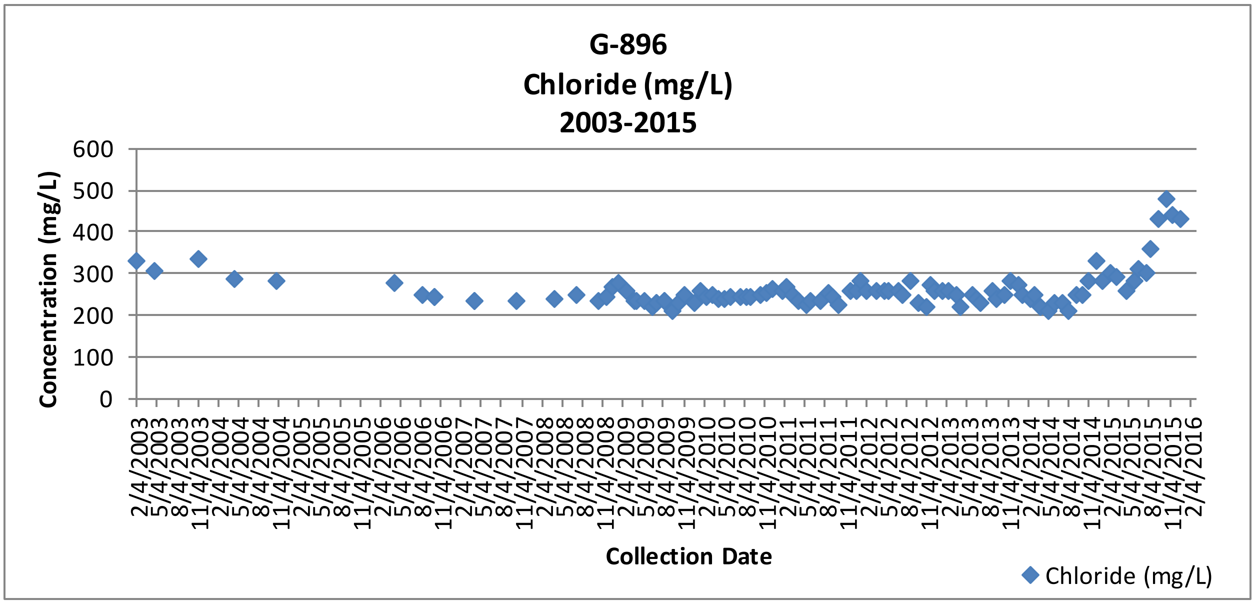

Chloride measurements from the past 35 years at G - 939 (253652080183701)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
10000
1000
100
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

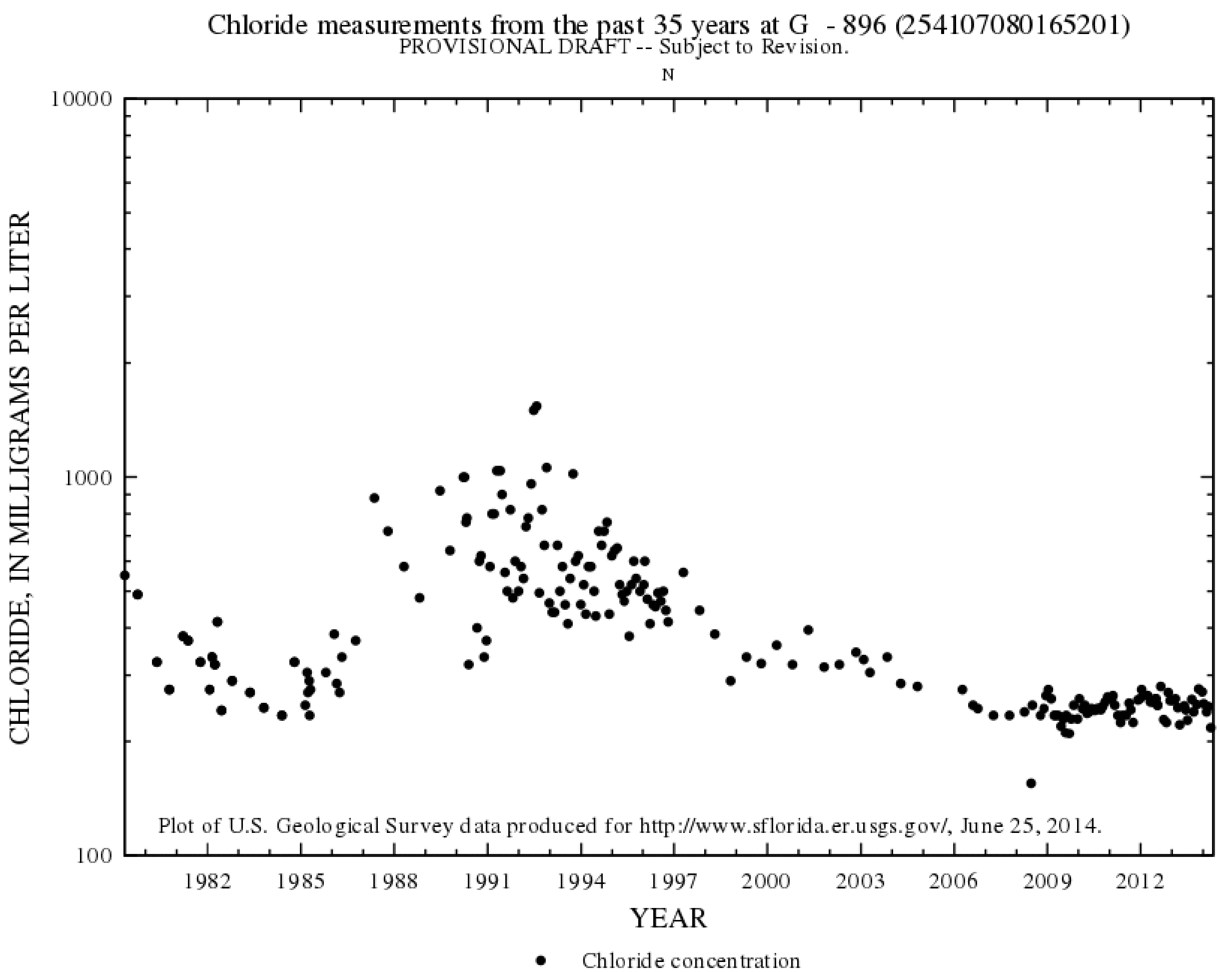

G-901
Chloride (mg/L)
2003-2015
Concentration (mg/L)
6000
5000
4000
3000
2000
1000
0
2/28/2003
9/30/2003
4/30/2004
11/30/2004
6/30/2005
1/31/2006
8/31/2006
3/31/2007
10/31/2007
5/31/2008
12/31/2008
7/31/2009
2/28/2010
9/30/2010
4/30/2011
11/30/2011
6/30/2012
1/31/2013
8/31/2013
3/31/2014
10/31/2014
5/31/2015
12/31/2015
Collection Date
Series1

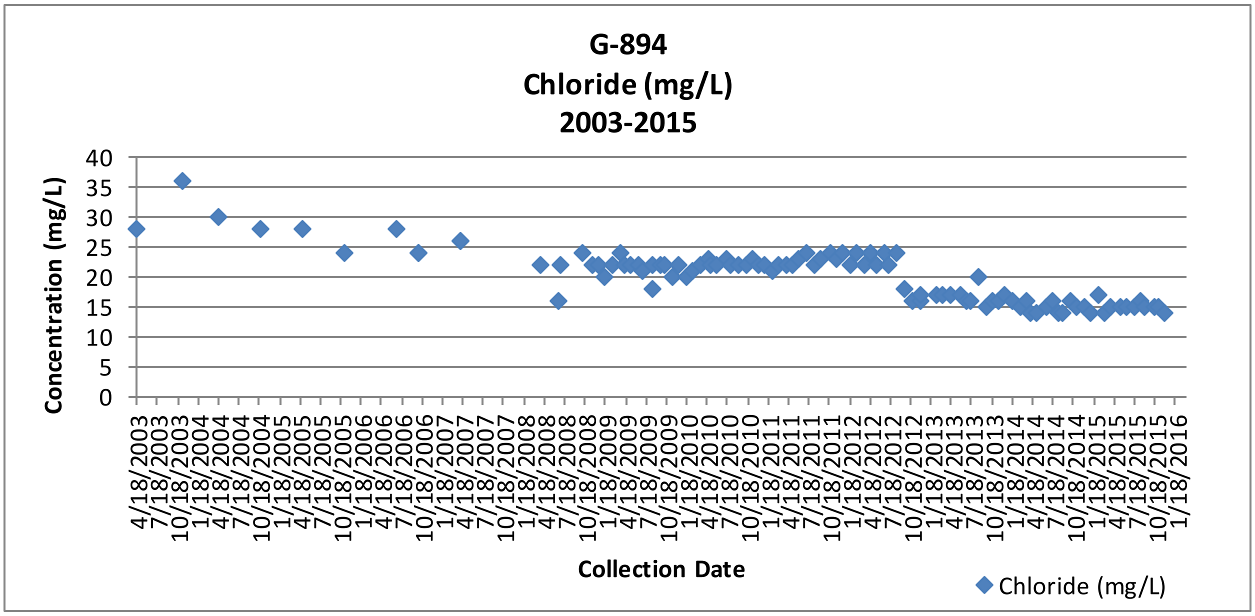

Chloride measurements from the past 35 years at G - 901 (254201080173001)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
10000
1000
100
10
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, April 23, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

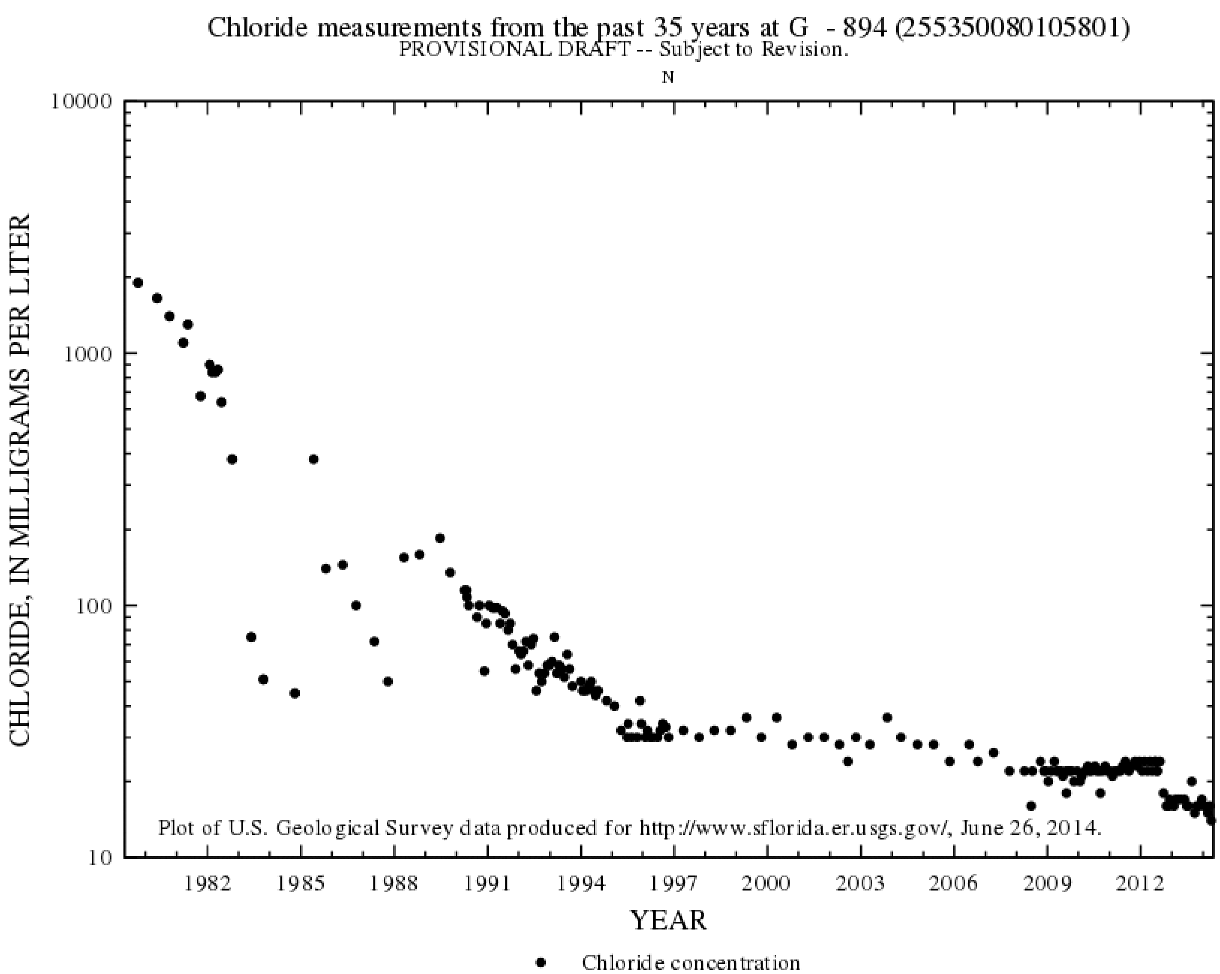

G-3611
Chloride (mg/L)
2003-2015
Concentration (mg/L)
250
200
150
100
50
0
Collection Date
Chloride (mg/L)

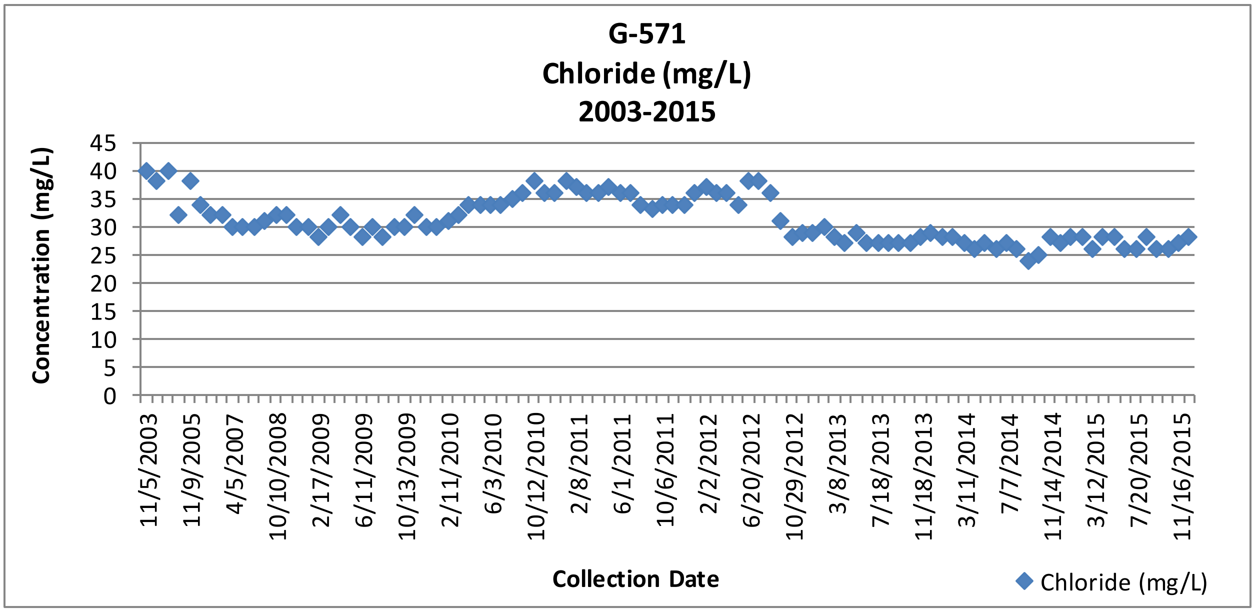

Chloride measurements from the past 35 years at G -3611 (253710080184701)
PROVISIONAL DRAFT -- Subject to Revision.
N
1000
100
CHLORIDE, IN MILLIGRAMS PER LITER
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
Chloride concentration

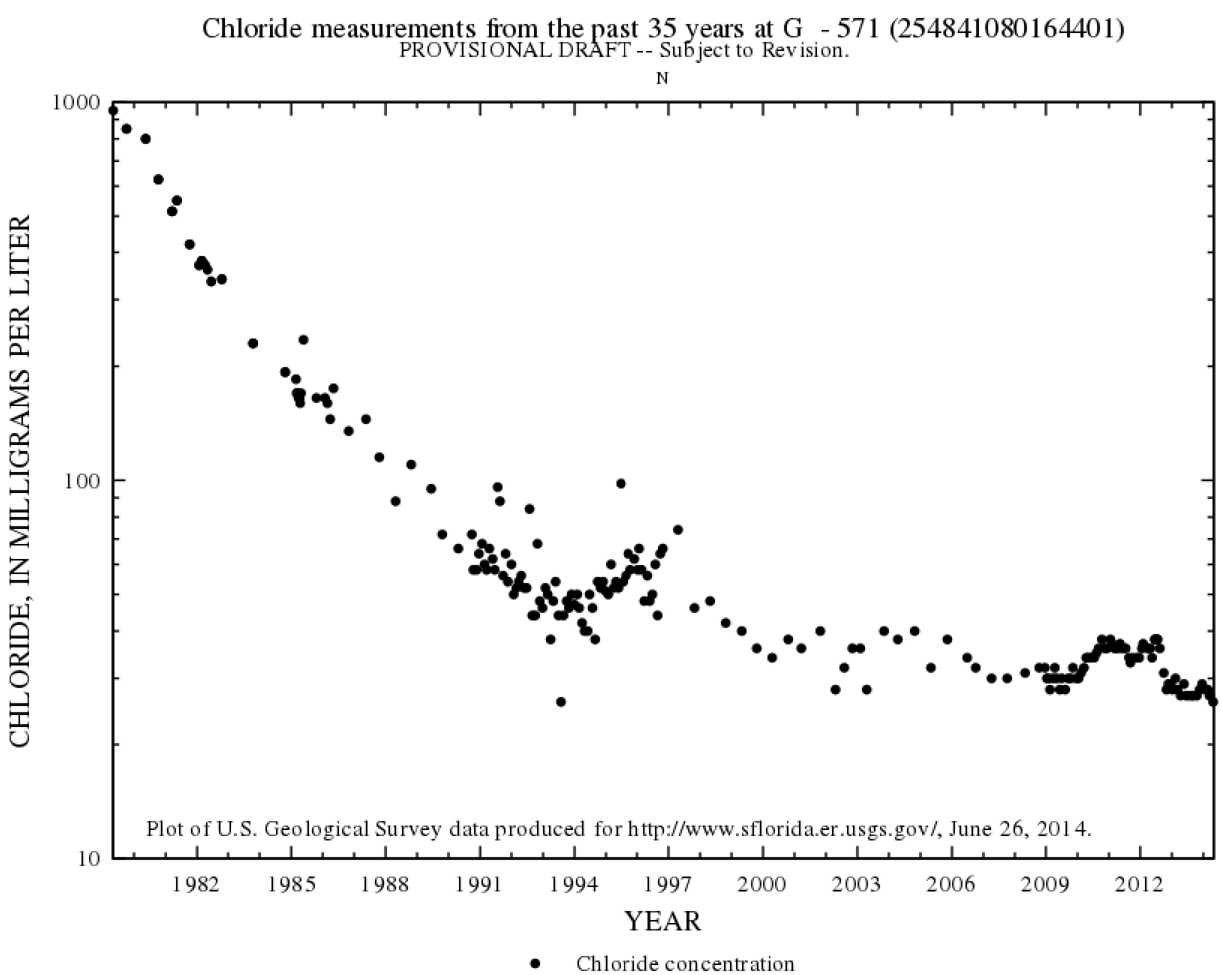

G-896
Chloride (mg/L)
2003-2015
Concentration (mg/L)
600
500
400
300
200
100
0
2/4/2003
5/4/2003
8/4/2003
11/4/2003
2/4/2004
5/4/2004
8/4/2004
11/4/2004
2/4/2005
5/4/2005
8/4/2005
11/4/2005
2/4/2006
5/4/2006
8/4/2006
11/4/2006
2/4/2007
5/4/2007
8/4/2007
11/4/2007
2/4/2008
5/4/2008
8/4/2008
11/4/2008
2/4/2009
5/4/2009
8/4/2009
11/4/2009
2/4/2010
5/4/2010
8/4/2010
11/4/2010
2/4/2011
5/4/2011
8/4/2011
11/4/2011
2/4/2012
5/4/2012
8/4/2012
11/4/2012
2/4/2013
5/4/2013
8/4/2013
11/4/2013
2/4/2014
5/4/2014
8/4/2014
11/4/2014
2/4/2015
5/4/2015
8/4/2015
11/4/2015
2/4/2016
Collection Date
Chloride (mg/L)

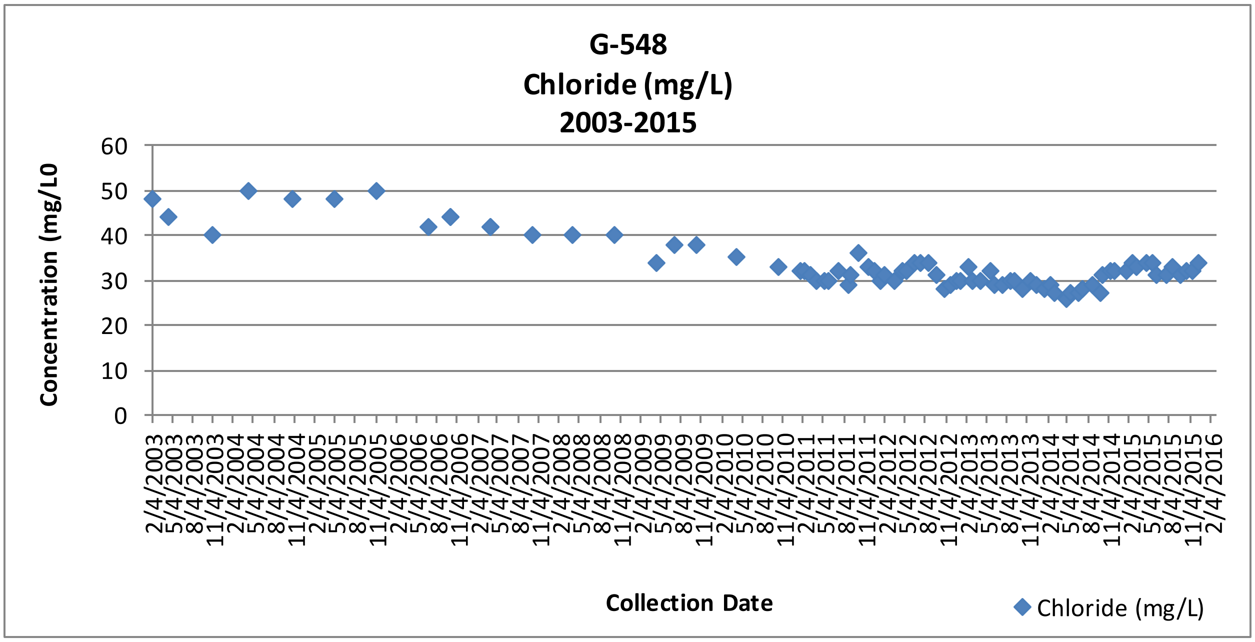

Chloride measurements from the past 35 years at G - 896 (254107080165201)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
10000
1000
100
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

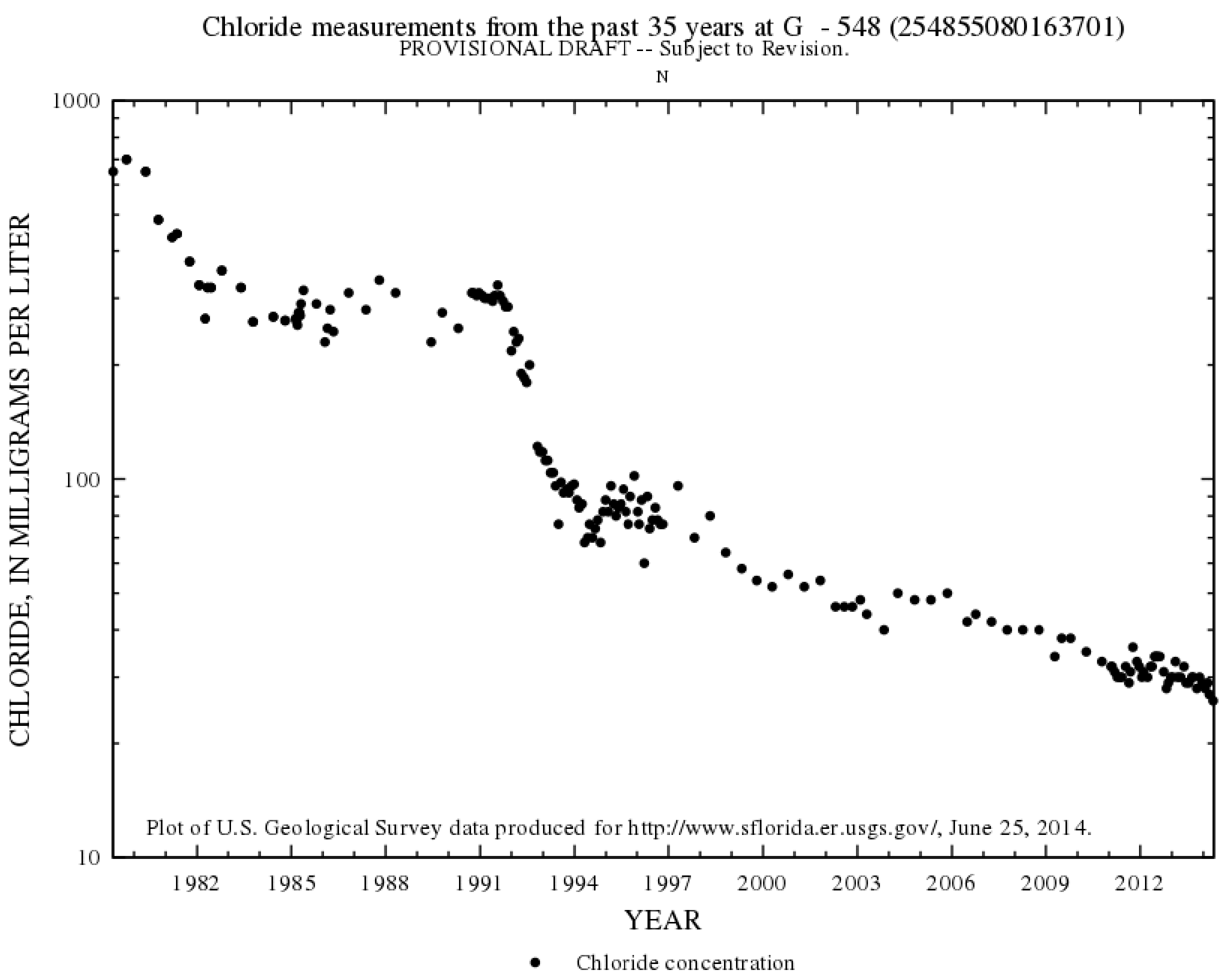

G-894
Chloride (mg/L)
2003-2015
Concentration (mg/L)
0
5
10
15
20
25
30
35
40
4/18/2003
7/18/2003
10/18/2003
1/18/2004
4/18/2004
7/18/2004
10/18/2004
1/18/2005
4/18/2005
7/18/2005
10/18/2005
1/18/2006
4/18/2006
7/18/2006
10/18/2006
1/18/2007
4/18/2007
7/18/2007
10/18/2007
1/18/2008
4/18/2008
7/18/2008
10/18/2008
1/18/2009
4/18/2009
7/18/2009
10/18/2009
1/18/2010
4/18/2010
7/18/2010
10/18/2010
1/18/2011
4/18/2011
7/18/2011
10/18/2011
1/18/2012
4/18/2012
7/18/2012
10/18/2012
1/18/2013
4/18/2013
7/18/2013
10/18/2013
1/18/2014
4/18/2014
7/18/2014
10/18/2014
1/18/2015
4/18/2015
7/18/2015
10/18/2015
1/18/2016
Collection Date
Chloride (mg/L)

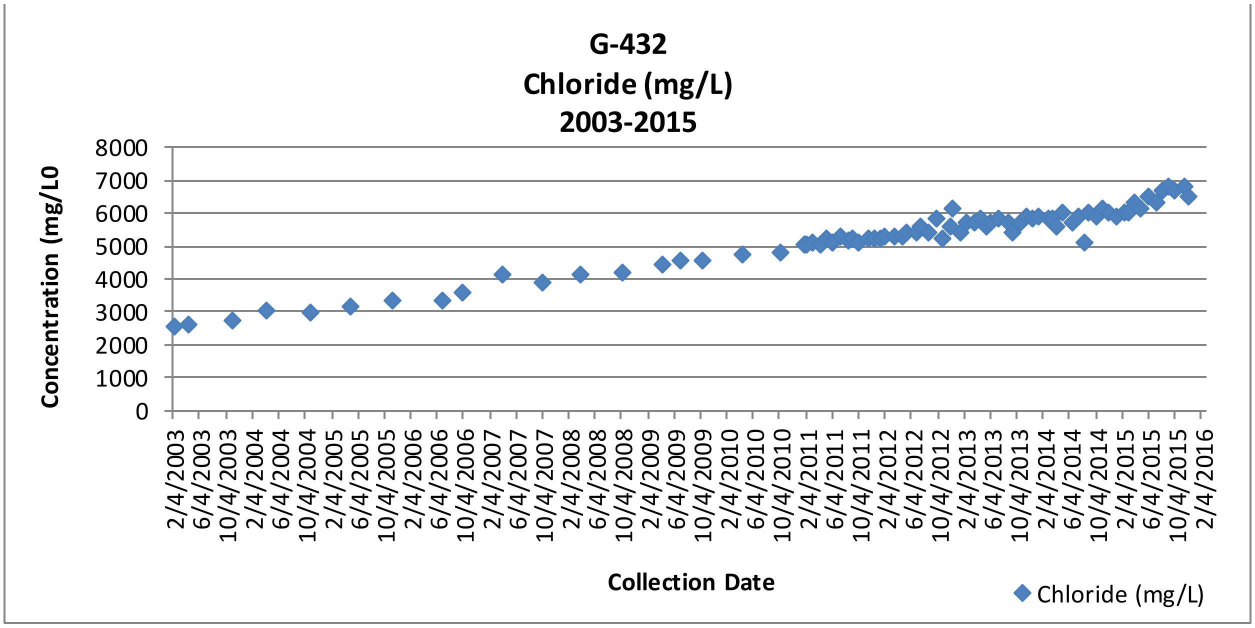

Chloride measurements from the past 35 years at G - 894 (255350080105801)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
10000
1000
100
10
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 26, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

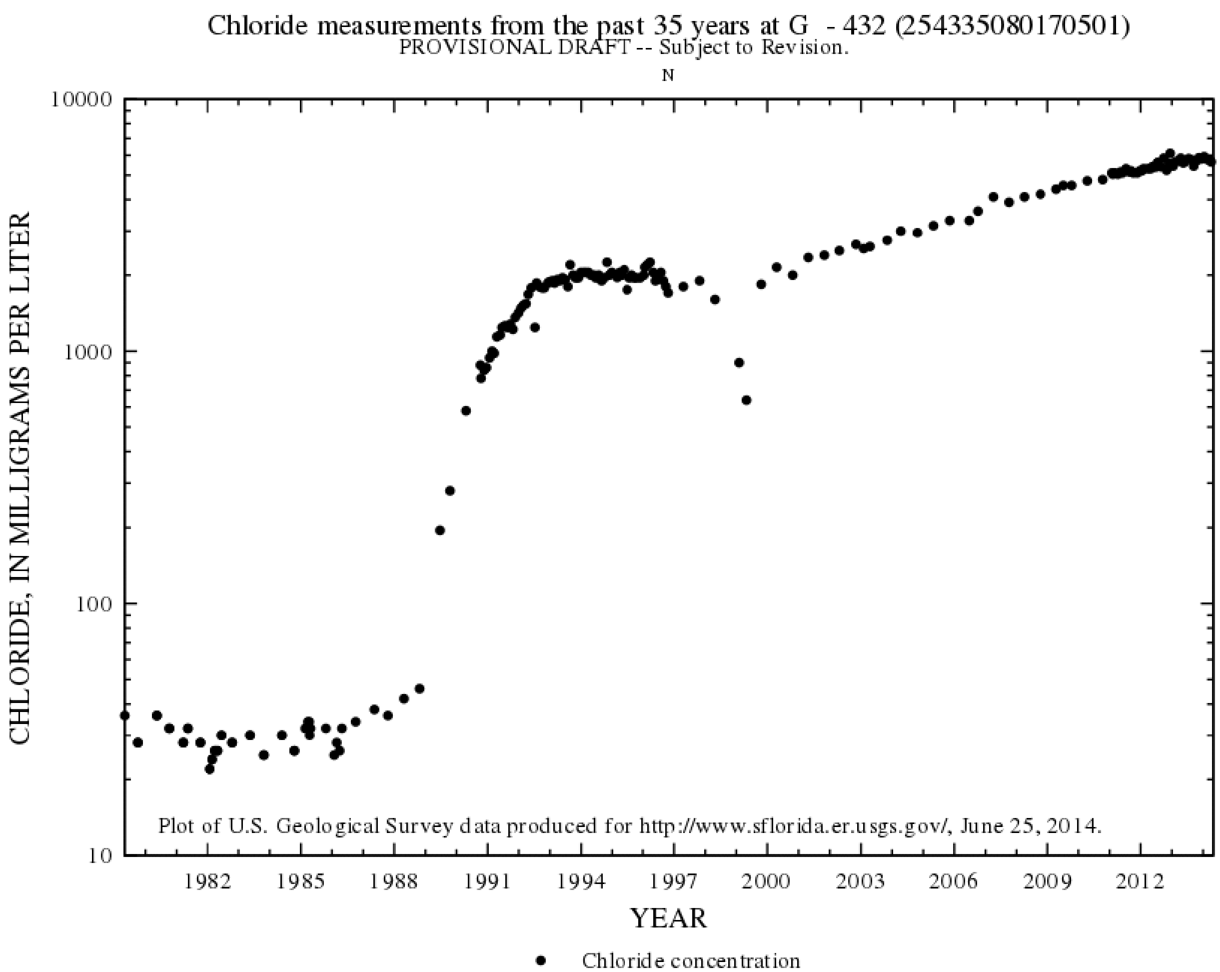

G-571
Chloride (mg/L)
2003-2015
Concentration (mg/L)
45
40
35
30
25
20
15
10
5
0
11/5/2003
11/9/2005
4/5/2007
10/10/2008
2/17/2009
6/11/2009
10/13/2009
2/11/2010
6/3/2010
10/12/2010
2/8/2011
6/1/2011
10/6/2011
2/2/2012
6/20/2012
10/29/2012
3/8/2013
7/18/2013
11/18/2013
3/11/2014
7/7/2014
11/14/2014
3/12/2015
7/20/2015
11/16/2015
Collection Date
Chloride (mg/L)

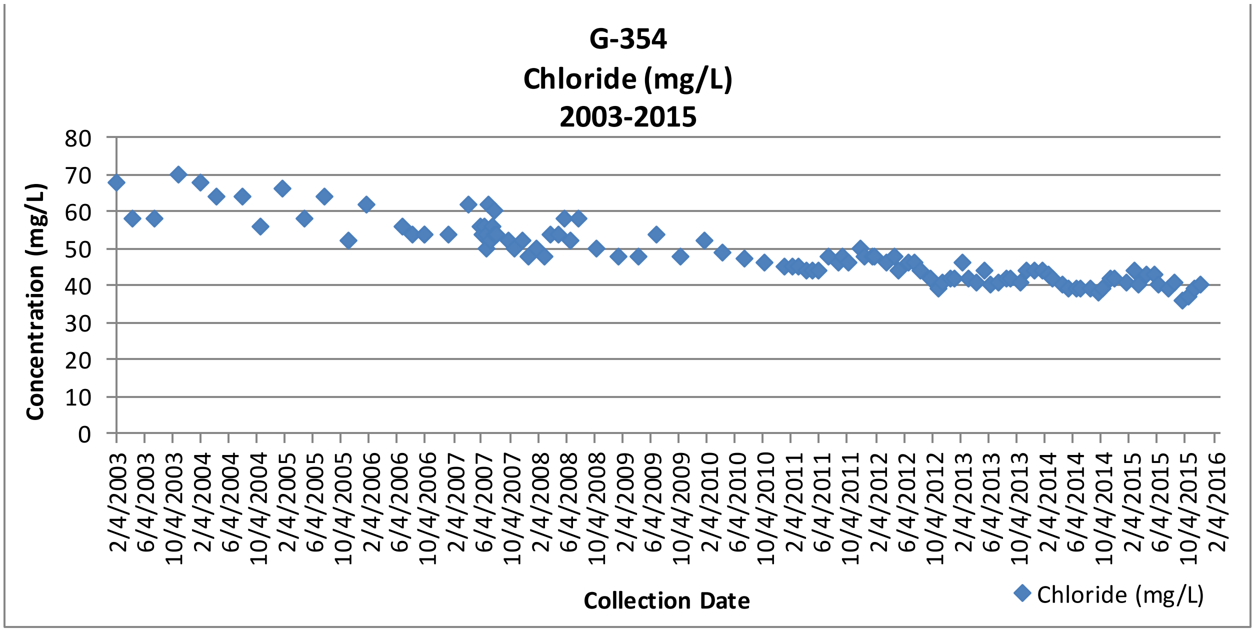

Chloride measurements from the past 35 years at G - 571 (254841080164401)
PROVISIONAL DRAFT -- Subject to Revision.
N
1000
100
10
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 26, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

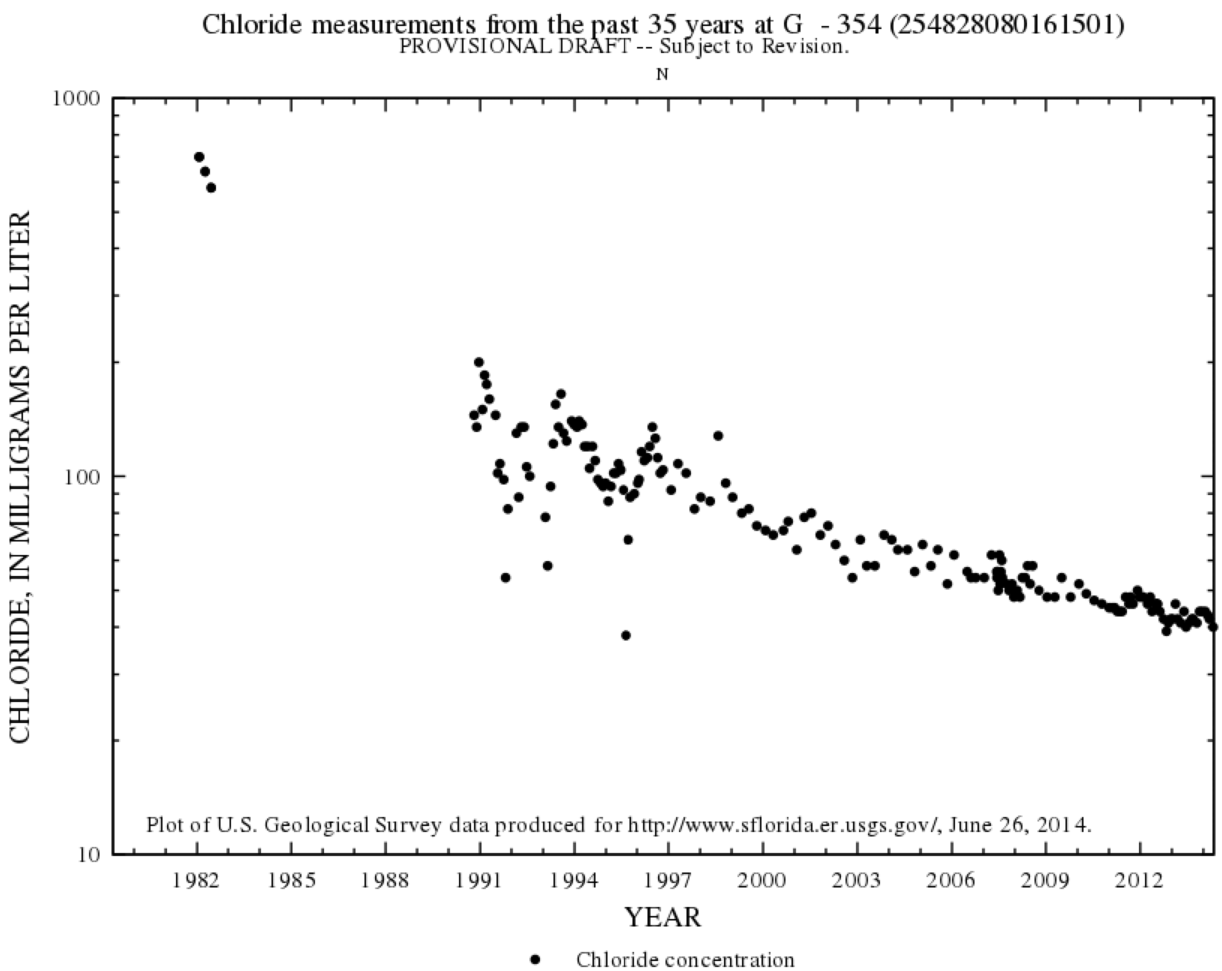

G-548
Chloride (mg/L)
2003-2015
Concentration (mg/L0
60
50
40
30
20
10
0
2/4/2003
5/4/2003
8/4/2003
11/4/2003
2/4/2004
5/4/2004
8/4/2004
11/4/2004
2/4/2005
5/4/2005
8/4/2005
11/4/2005
2/4/2006
5/4/2006
8/4/2006
11/4/2006
2/4/2007
5/4/2007
8/4/2007
11/4/2007
2/4/2008
5/4/2008
8/4/2008
11/4/2008
2/4/2009
5/4/2009
8/4/2009
11/4/2009
2/4/2010
5/4/2010
8/4/2010
11/4/2010
2/4/2011
5/4/2011
8/4/2011
11/4/2011
2/4/2012
5/4/2012
8/4/2012
11/4/2012
2/4/2013
5/4/2013
8/4/2013
11/4/2013
2/4/2014
5/4/2014
8/4/2014
11/4/2014
2/4/2015
5/4/2015
8/4/2015
11/4/2015
2/4/2016
Collection Date
Chloride (mg/L)

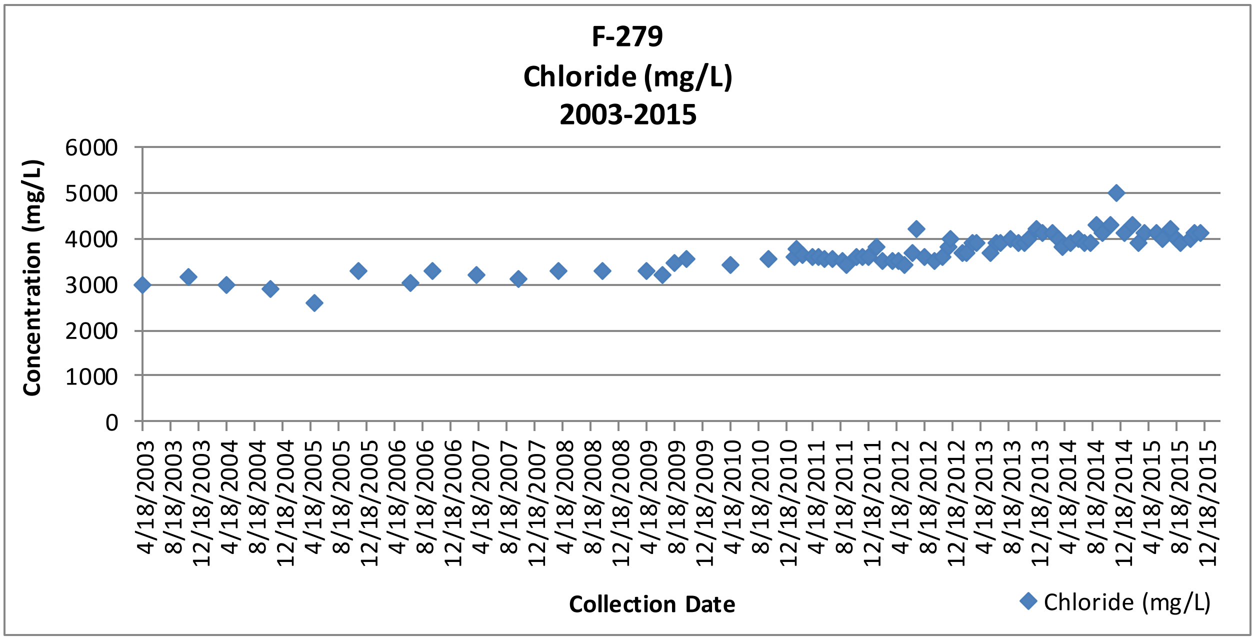

Chloride measurements from the past 35 years at G - 548 (254855080163701)
PROVISIONAL DRAFT -- Subject to Revision.
N
1000
100
10
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

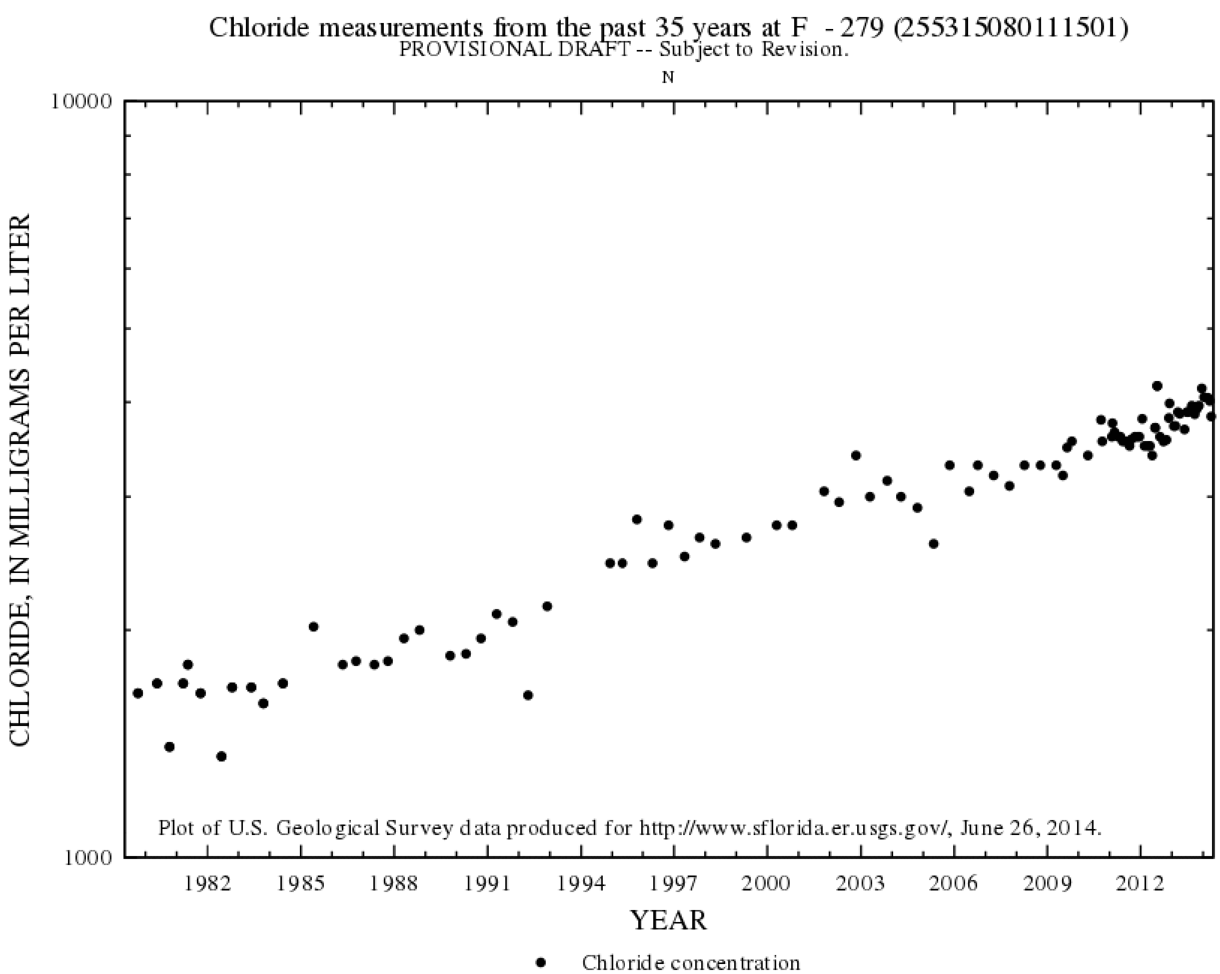

G-432
Chloride (mg/L)
2003-2015
Concentration (mg/L0
8000
7000
6000
5000
4000
3000
2000
1000
0
Collection Date
Chloride (mg/L)

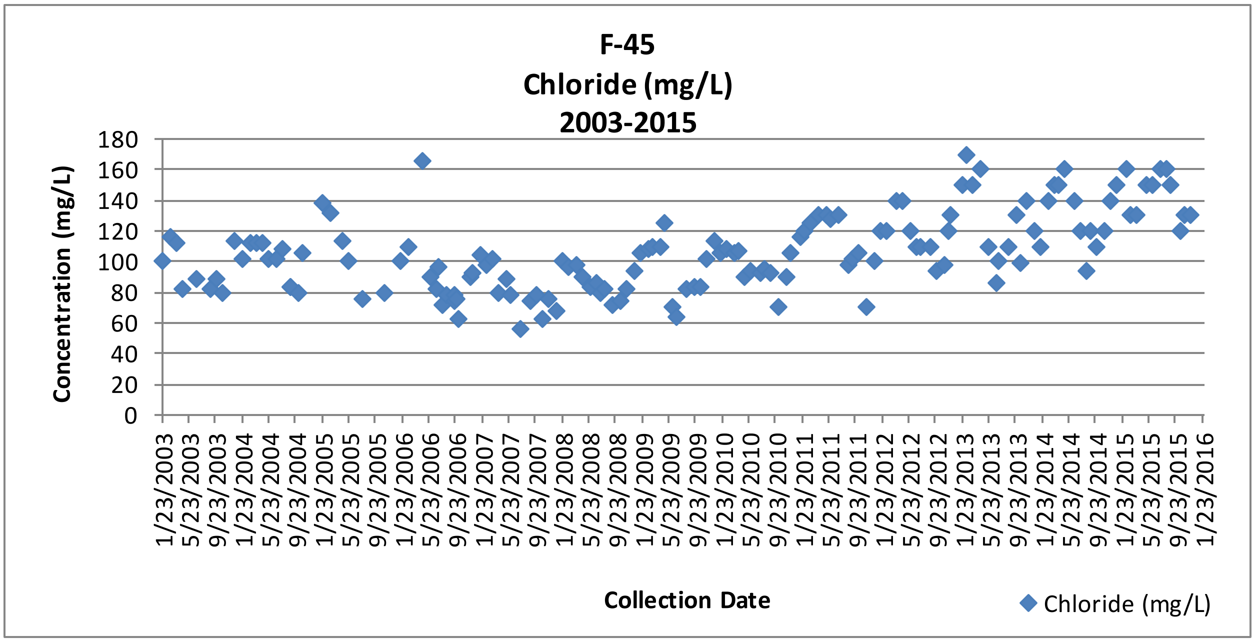

Chloride measurements from the past 35 years at G - 432 (254335080170501)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
10000
1000
100
10
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 25, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

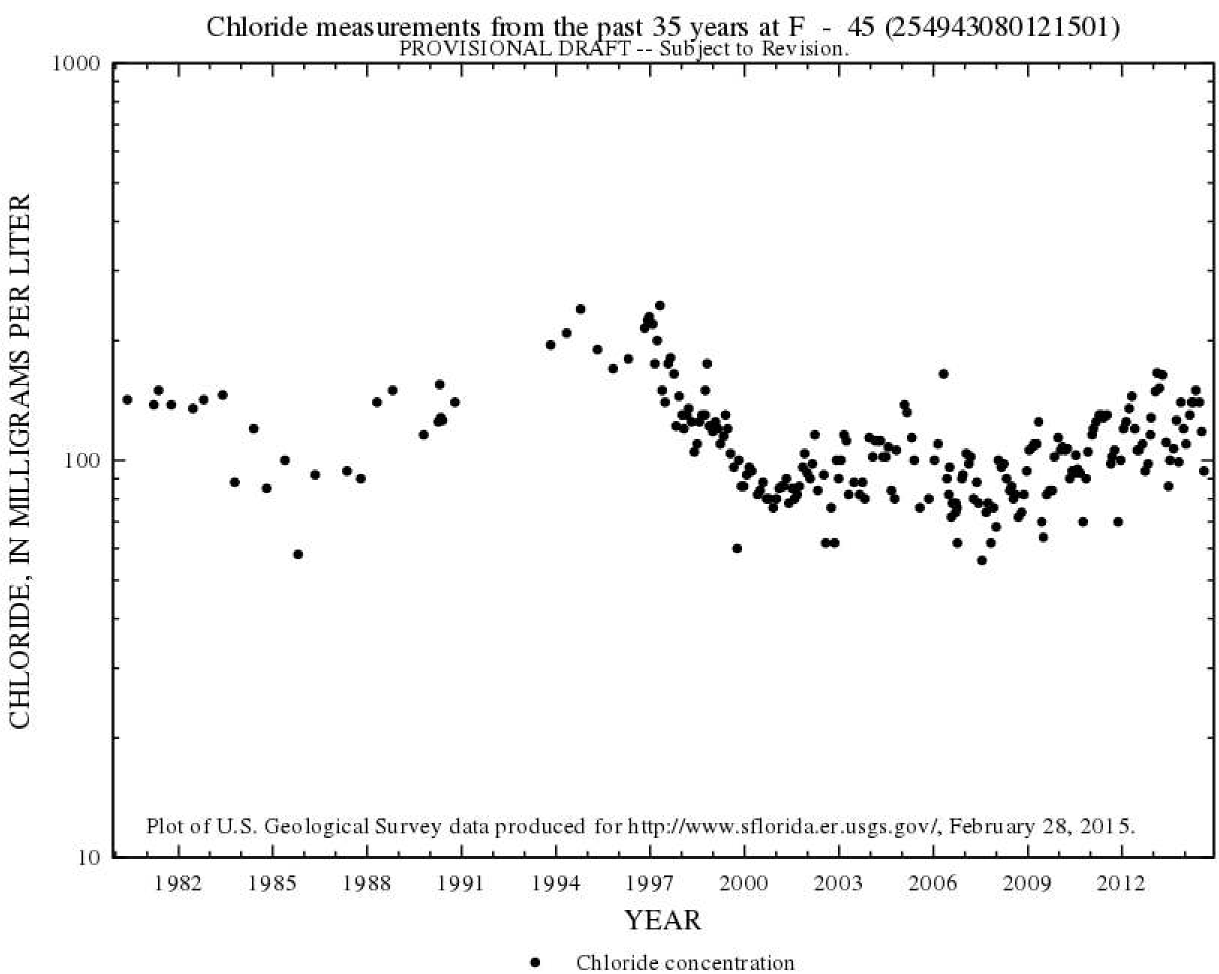

G-354
Chloride (mg/L)
2003-2015
Concentration (mg/L)
0
10
20
30
40
50
60
70
80
2/4/2003
6/4/2003
10/4/2003
2/4/2004
6/4/2004
10/4/2004
2/4/2005
6/4/2005
10/4/2005
2/4/2006
6/4/2006
10/4/2006
2/4/2007
6/4/2007
10/4/2007
2/4/2008
6/4/2008
10/4/2008
2/4/2009
6/4/2009
10/4/2009
2/4/2010
6/4/2010
10/4/2010
2/4/2011
6/4/2011
10/4/2011
2/4/2012
6/4/2012
10/4/2012
2/4/2013
6/4/2013
10/4/2013
2/4/2014
6/4/2014
10/4/2014
2/4/2015
6/4/2015
10/4/2015
2/4/2016
Collection Date
Chloride (mg/L)

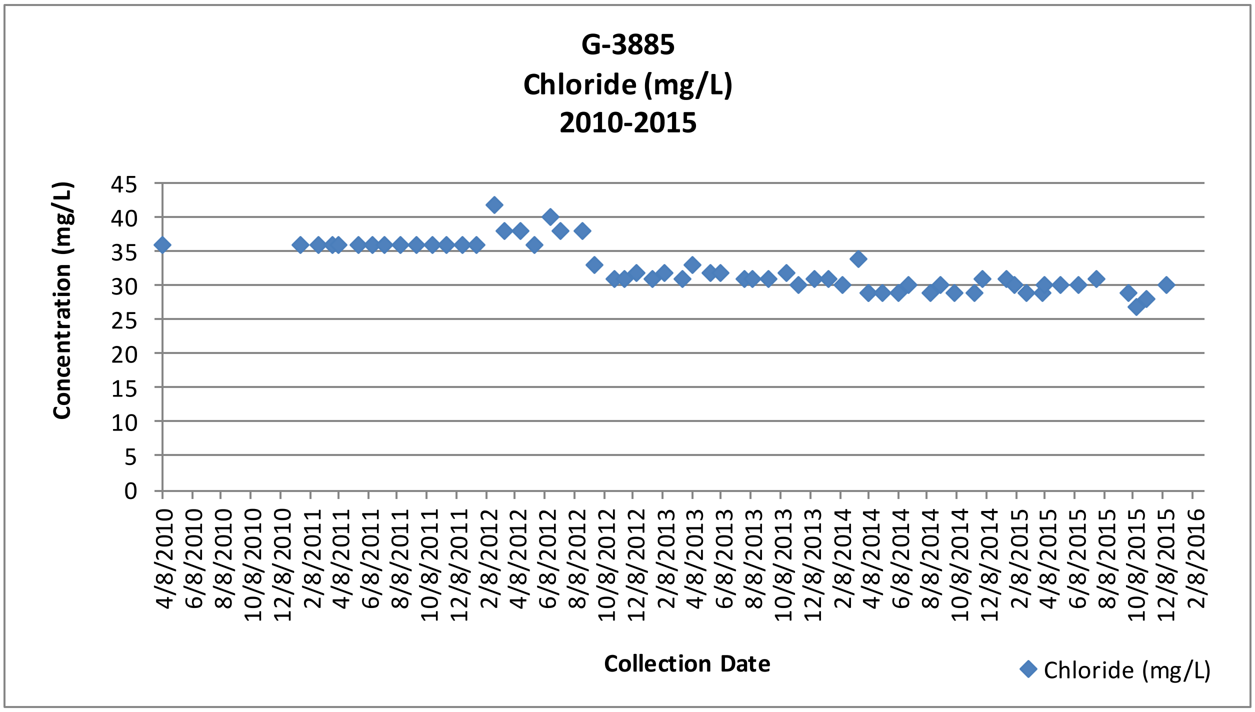

Chloride measurements from the past 35 years at G - 354 (254828080161501)
PROVISIONAL DRAFT -- Subject to Revision.
N
CHLORIDE, IN MILLIGRAMS PER LITER
1000
100
10
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 26, 2014.
Chloride concentration

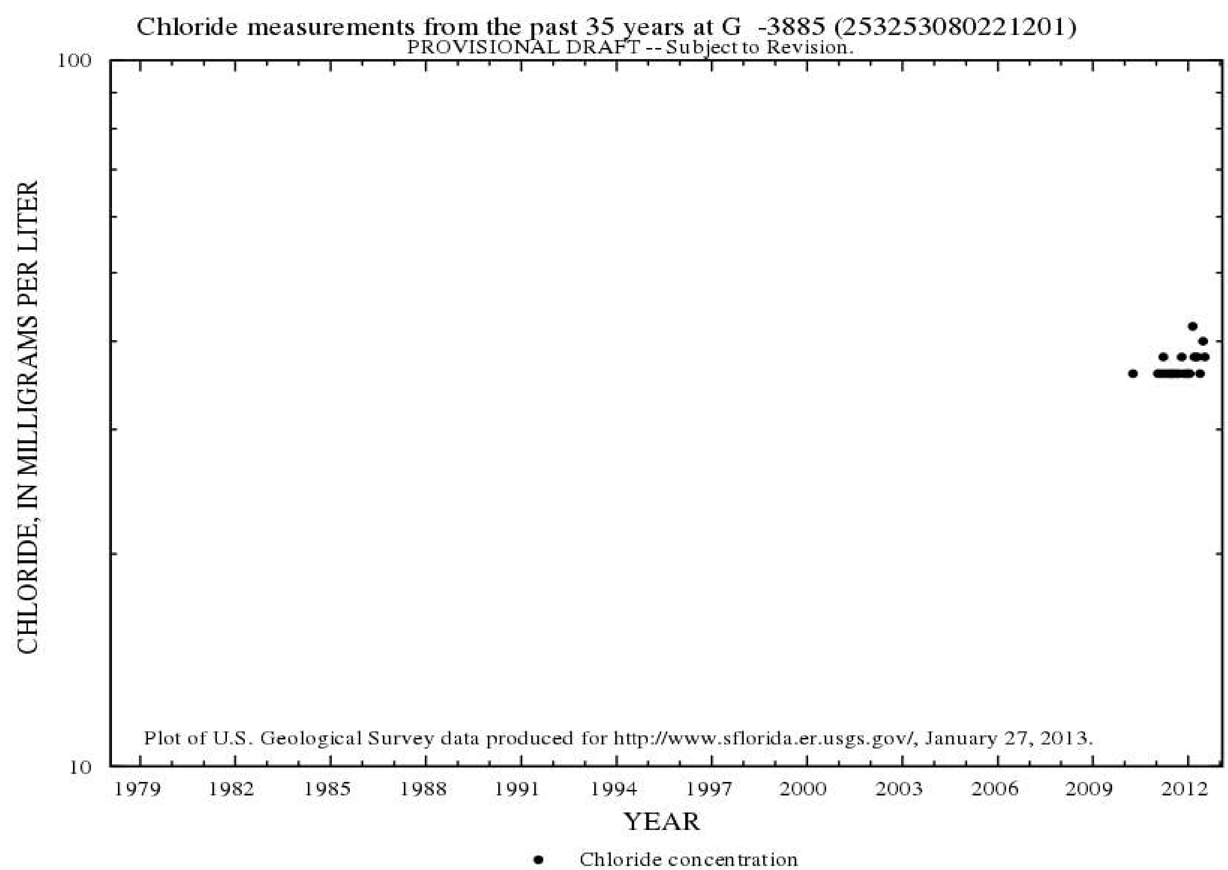

F-279
Chloride (mg/L)
2003-2015
Concentration (mg/L)
6000
5000
4000
3000
2000
1000
0
4/18/2003
8/18/2003
12/18/2003
4/18/2004
8/18/2004
12/18/2004
4/18/2005
8/18/2005
12/18/2005
4/18/2006
8/18/2006
12/18/2006
4/18/2007
8/18/2007
12/18/2007
4/18/2008
8/18/2008
12/18/2008
4/18/2009
8/18/2009
12/18/2009
4/18/2010
8/18/2010
12/18/2010
4/18/2011
8/18/2011
12/18/2011
4/18/2012
8/18/2012
12/18/2012
4/18/2013
8/18/2013
12/18/2013
4/18/2014
8/18/2014
12/18/2014
4/18/2015
8/18/2015
12/18/2015
Collection Date
Chloride (mg/L)

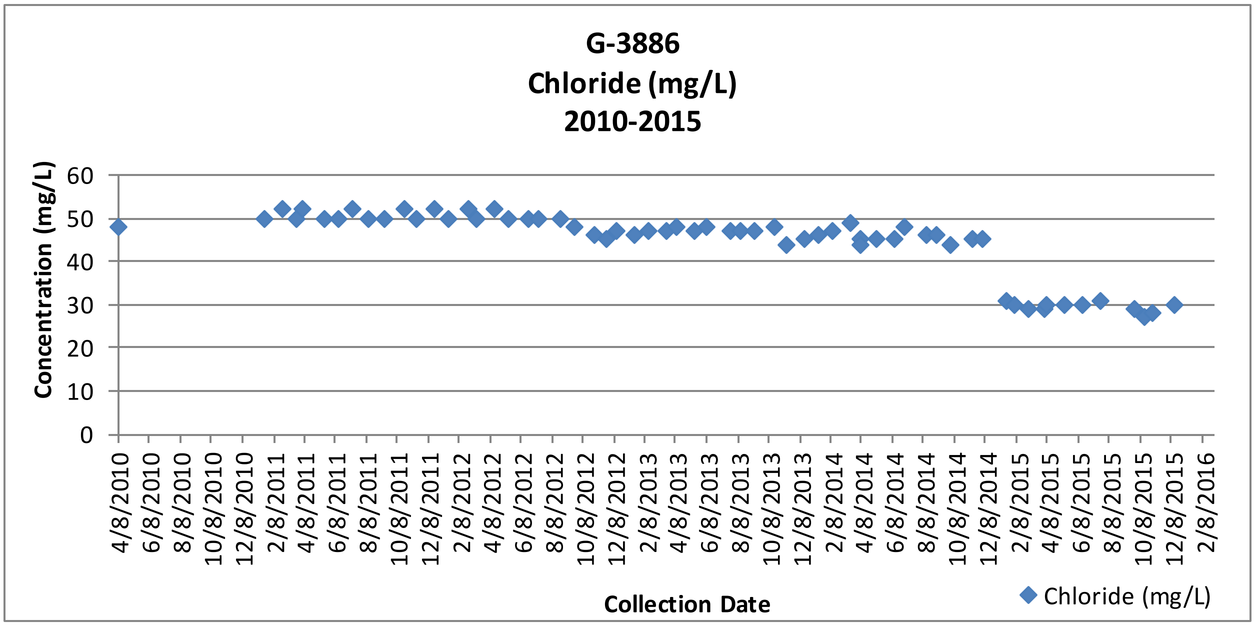

Chloride measurements from the past 35 years at F - 279 (255315080111501)
PROVISIONAL DRAFT -- Subject to Revision.
N
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, June 26, 2014.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

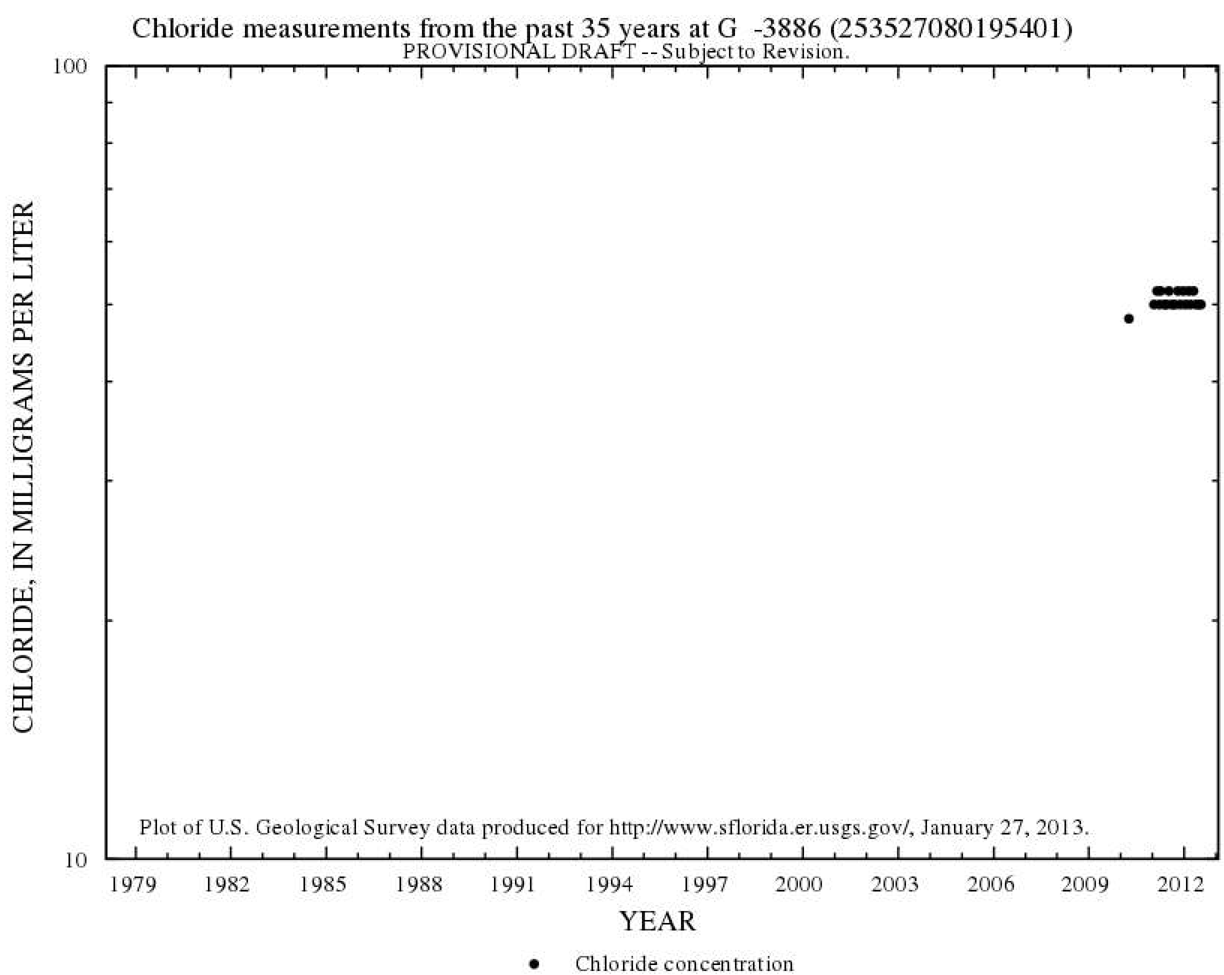

F-45
Chloride (mg/L)
2003-2015
Concentration (mg/L)
180
160
140
120
100
80
60
40
20
0
1/23/2003
5/23/2003
9/23/2003
1/23/2004
5/23/2004
9/23/2004
1/23/2005
5/23/2005
9/23/2005
1/23/2006
5/23/2006
9/23/2006
1/23/2007
5/23/2007
9/23/2007
1/23/2008
5/23/2008
9/23/2008
1/23/2009
5/23/2009
9/23/2009
1/23/2010
5/23/2010
9/23/2010
1/23/2011
5/23/2011
9/23/2011
1/23/2012
5/23/2012
9/23/2012
1/23/2013
5/23/2013
9/23/2013
1/23/2014
5/23/2014
9/23/2014
1/23/2015
5/23/2015
9/23/2015
1/23/2016
Collection Date
Chloride (mg/L)

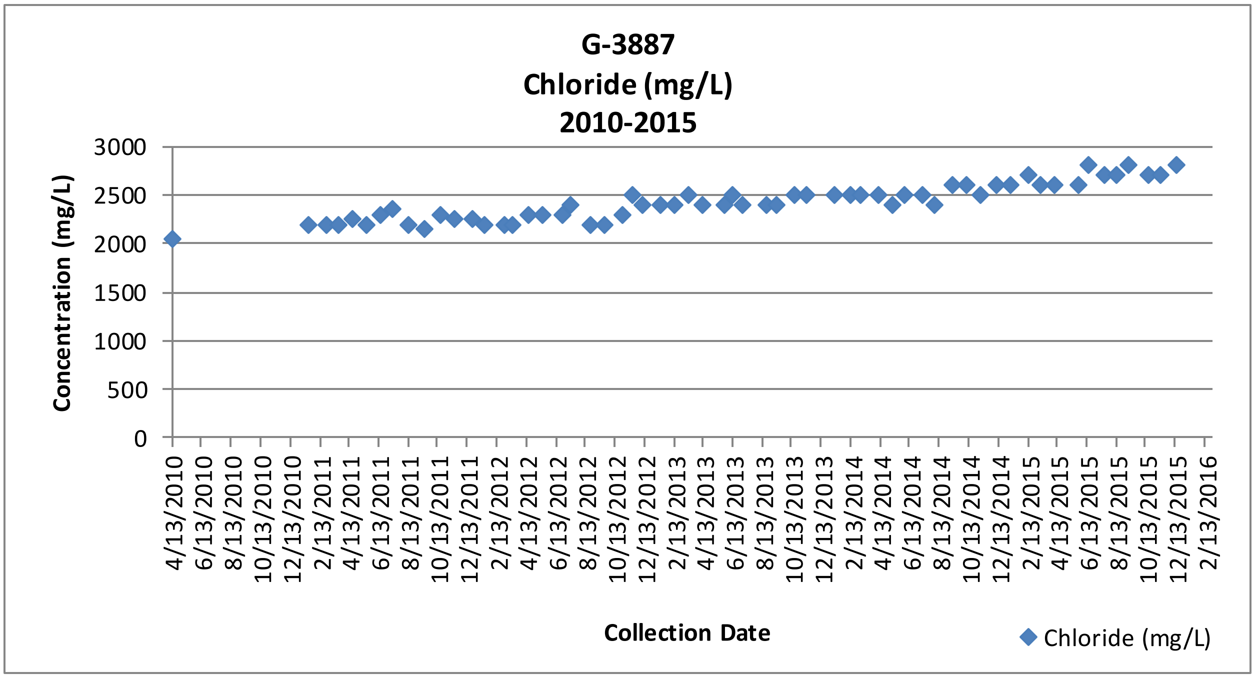

Chloride measurements from the past 35 years at F - 45 (254943080121501)
PROVISIONAL DRAFT -- Subject to Revision.
1000
100
10
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, February 28, 2015.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

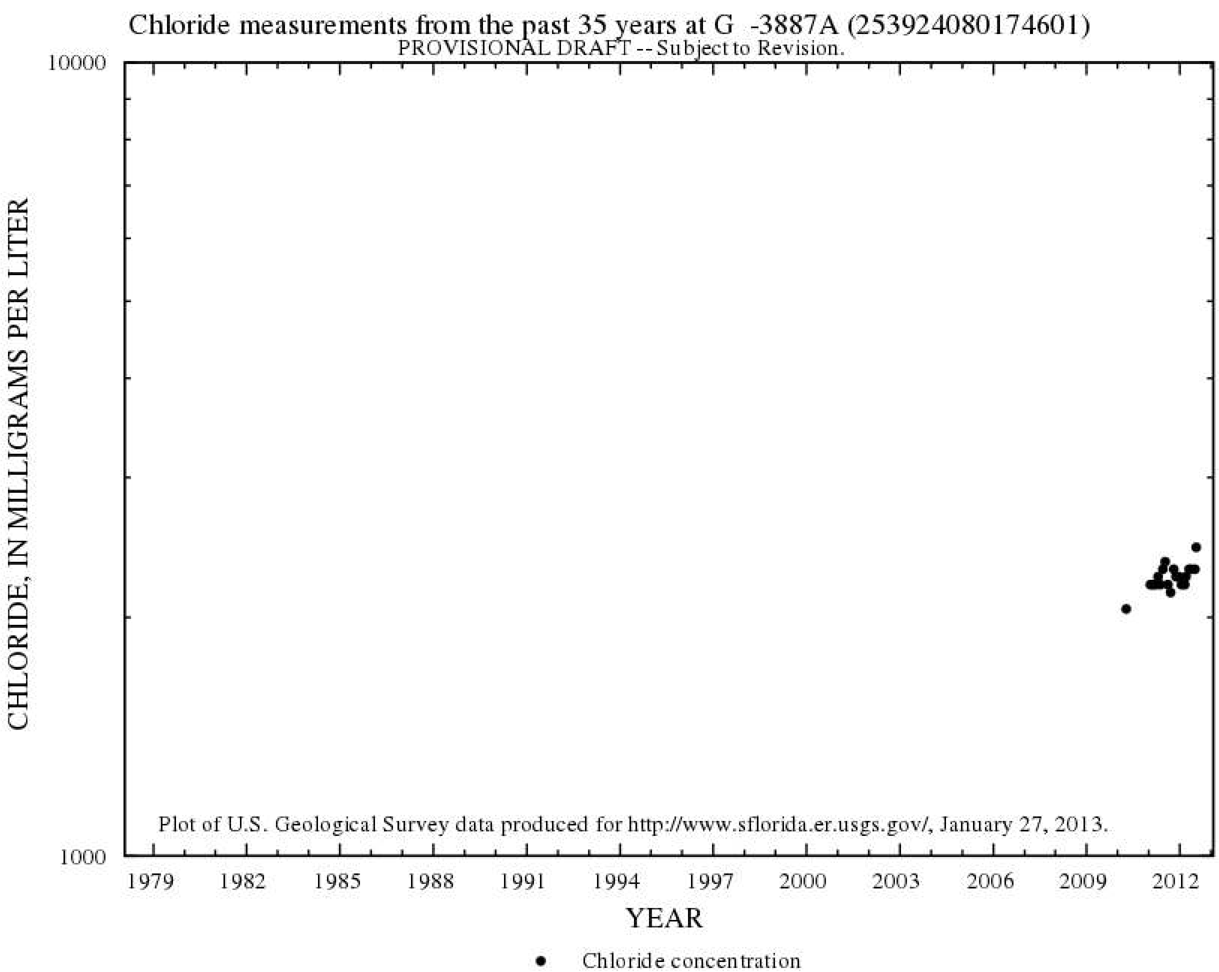

G-3885
Chloride (mg/L)
2010-2015
Concentration (mg/L)
45
40
35
30
25
20
15
10
5
0
4/8/2010
6/8/2010
8/8/2010
10/8/2010
12/8/2010
2/8/2011
4/8/2011
6/8/2011
8/8/2011
10/8/2011
12/8/2011
2/8/2012
4/8/2012
6/8/2012
8/8/2012
10/8/2012
12/8/2012
2/8/2013
4/8/2013
6/8/2013
8/8/2013
10/8/2013
12/8/2013
2/8/2014
4/8/2014
6/8/2014
8/8/2014
10/8/2014
12/8/2014
2/8/2015
4/8/2015
6/8/2015
8/8/2015
10/8/2015
12/8/2015
2/8/2016
Collection Date
Chloride (mg/L)

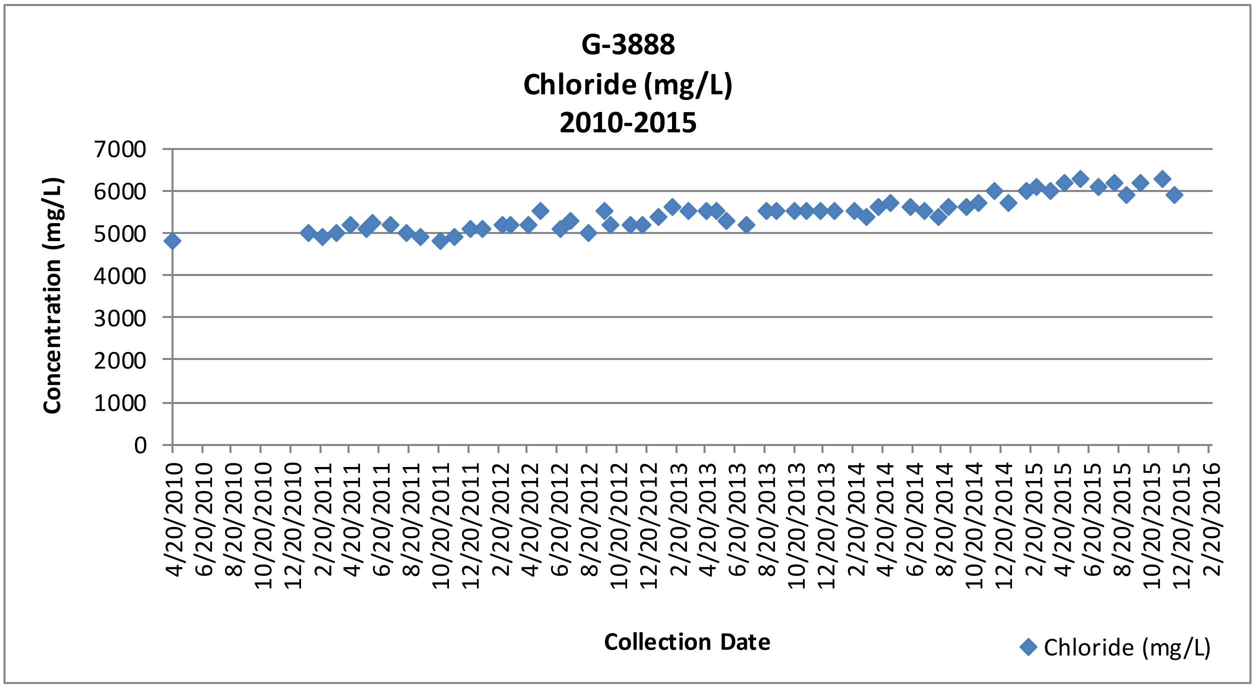

Chloride measurements from the past 35 years at G -3885 (253253080221201)
PROVISIONAL DRAFT -- Subject to Revision.
100
10
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, January 27, 2013.
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

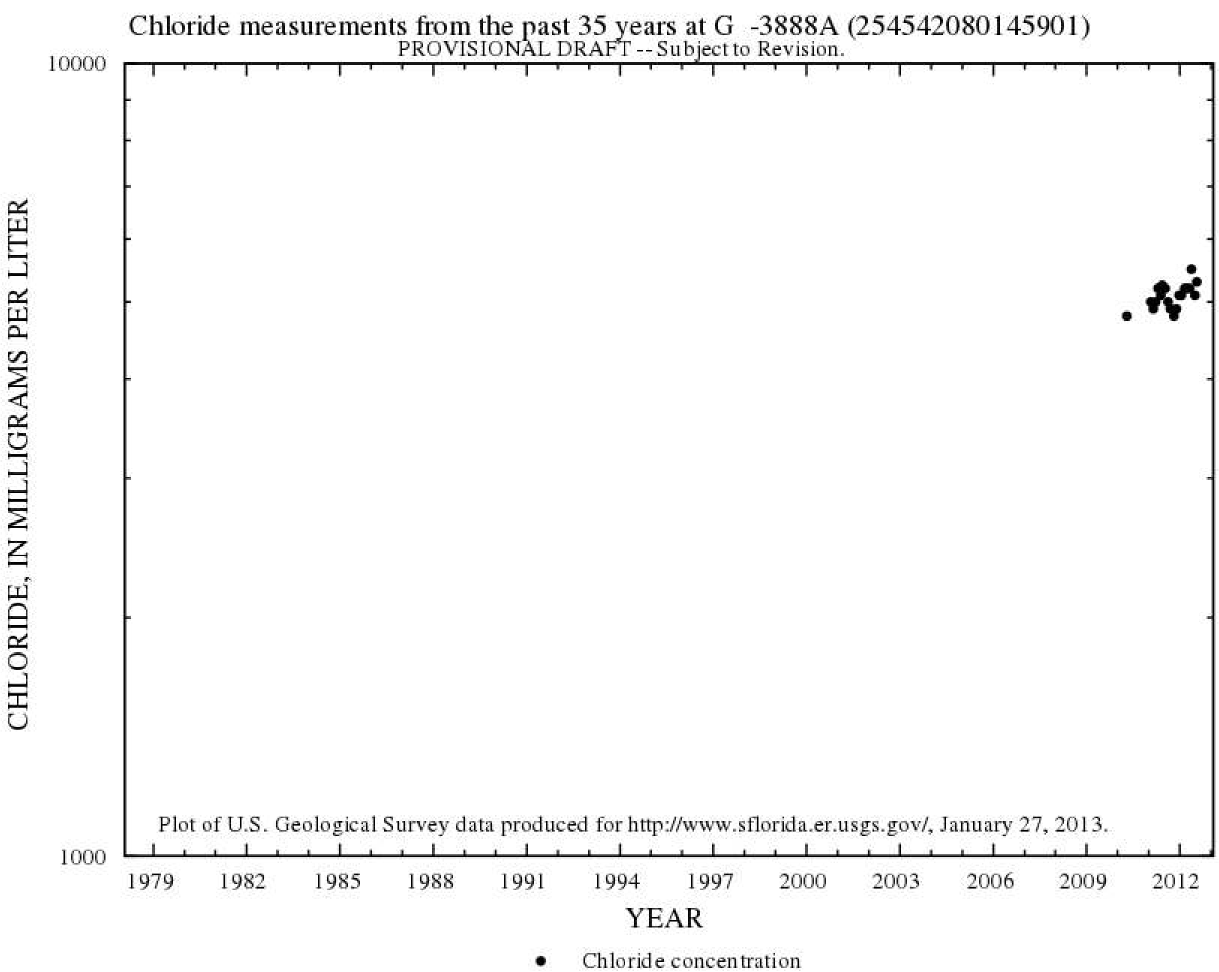

G-3886
Chloride (mg/L)
2010-2015
Concentration (mg/L)
60
50
40
30
20
10
0
4/8/2010
6/8/2010
8/8/2010
10/8/2010
12/8/2010
2/8/2011
4/8/2011
6/8/2011
8/8/2011
10/8/2011
12/8/2011
2/8/2012
4/8/2012
6/8/2012
8/8/2012
10/8/2012
12/8/2012
2/8/2013
4/8/2013
6/8/2013
8/8/2013
10/8/2013
12/8/2013
2/8/2014
4/8/2014
6/8/2014
8/8/2014
10/8/2014
12/8/2014
2/8/2015
4/8/2015
6/8/2015
8/8/2015
10/8/2015
12/8/2015
2/8/2016
Collection Date
Chloride (mg/L)

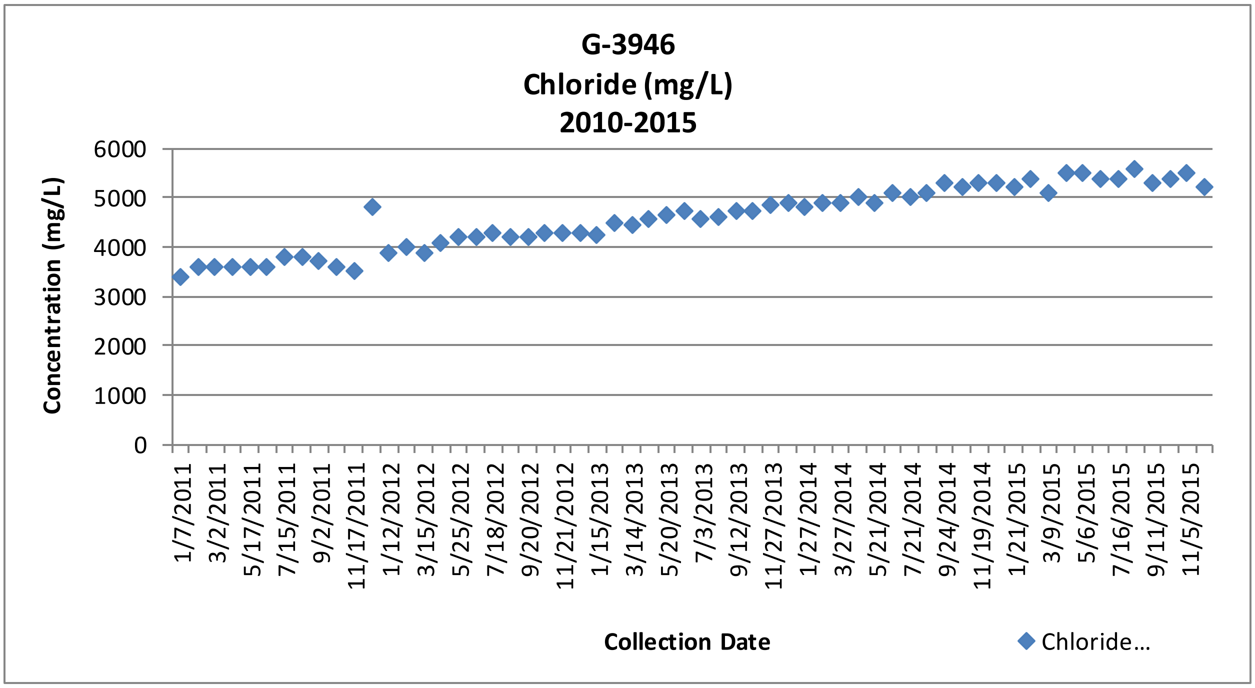

Chloride measurements from the past 35 years at G -3886 (253527080195401)
PROVISIONAL DRAFT -- Subject to Revision.
100
10
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, January 27, 2013.
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

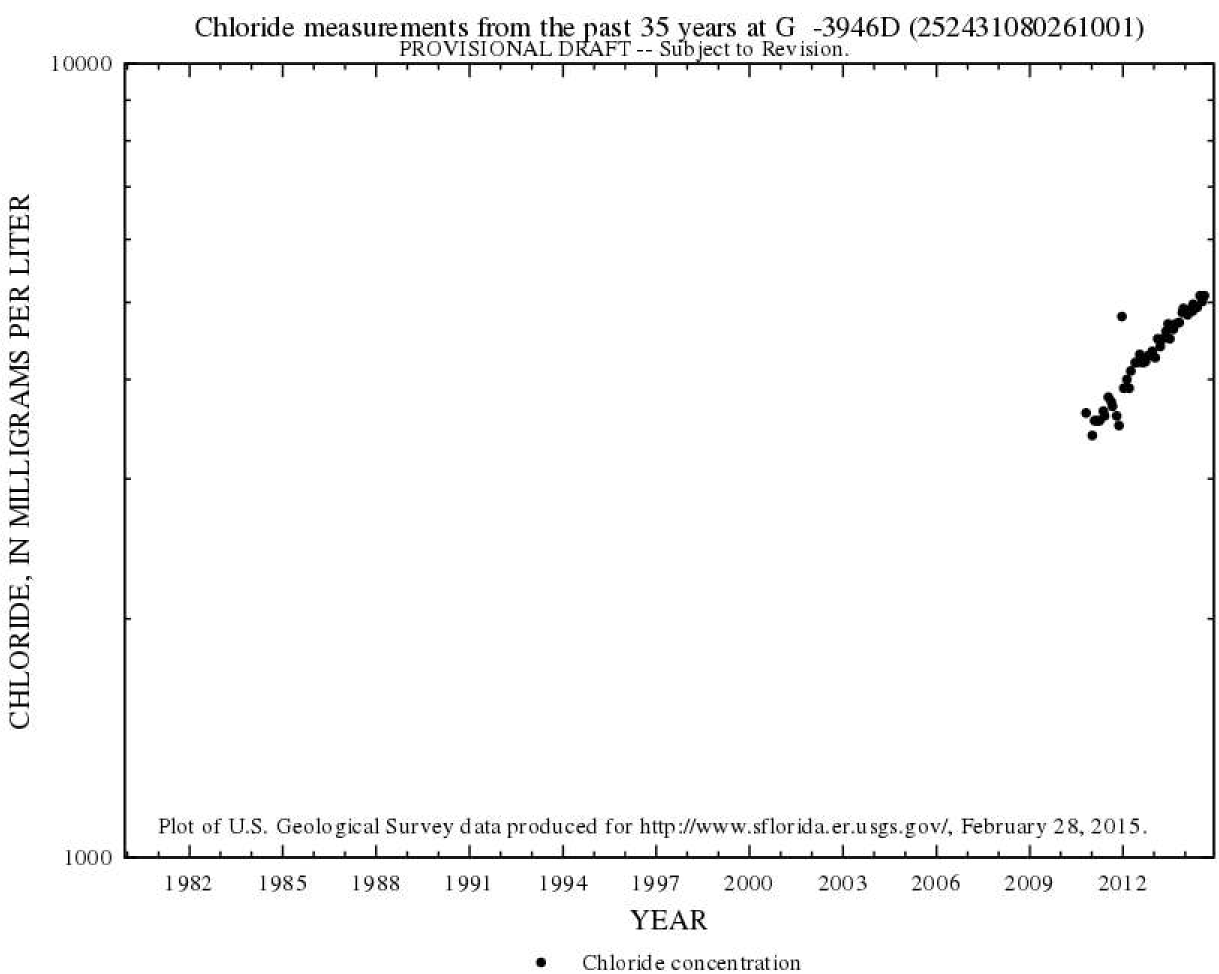

G-3887
Chloride (mg/L)
2010-2015
Concentration (mg/L)
3000
2500
2000
1500
1000
500
0
4/13/2010
6/13/2010
8/13/2010
10/13/2010
12/13/2010
2/13/2011
4/13/2011
6/13/2011
8/13/2011
10/13/2011
12/13/2011
2/13/2012
4/13/2012
6/13/2012
8/13/2012
10/13/2012
12/13/2012
2/13/2013
4/13/2013
6/13/2013
8/13/2013
10/13/2013
12/13/2013
2/13/2014
4/13/2014
6/13/2014
8/13/2014
10/13/2014
12/13/2014
2/13/2015
4/13/2015
6/13/2015
8/13/2015
10/13/2015
12/13/2015
2/13/2016
Collection Date
Chloride (mg/L)

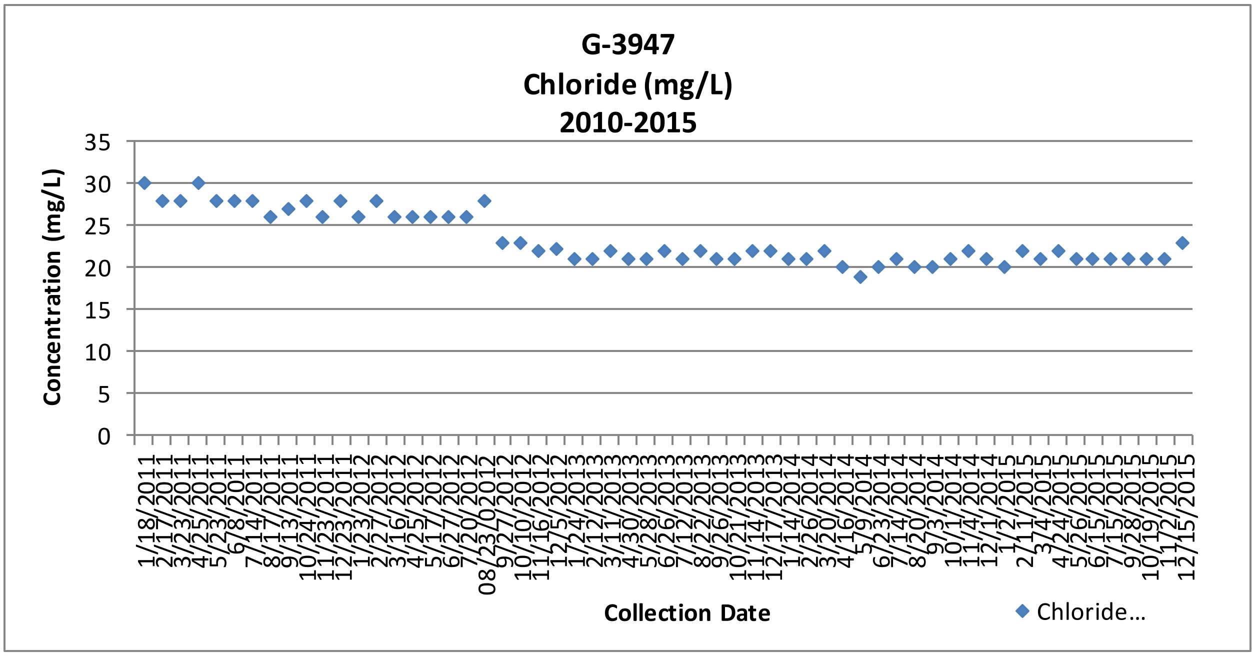

Chloride measurements from the past 35 years at G -3887A (253924080174601)
PROVISIONAL DRAFT -- Subject to Revision.
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, January 27, 2013.
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

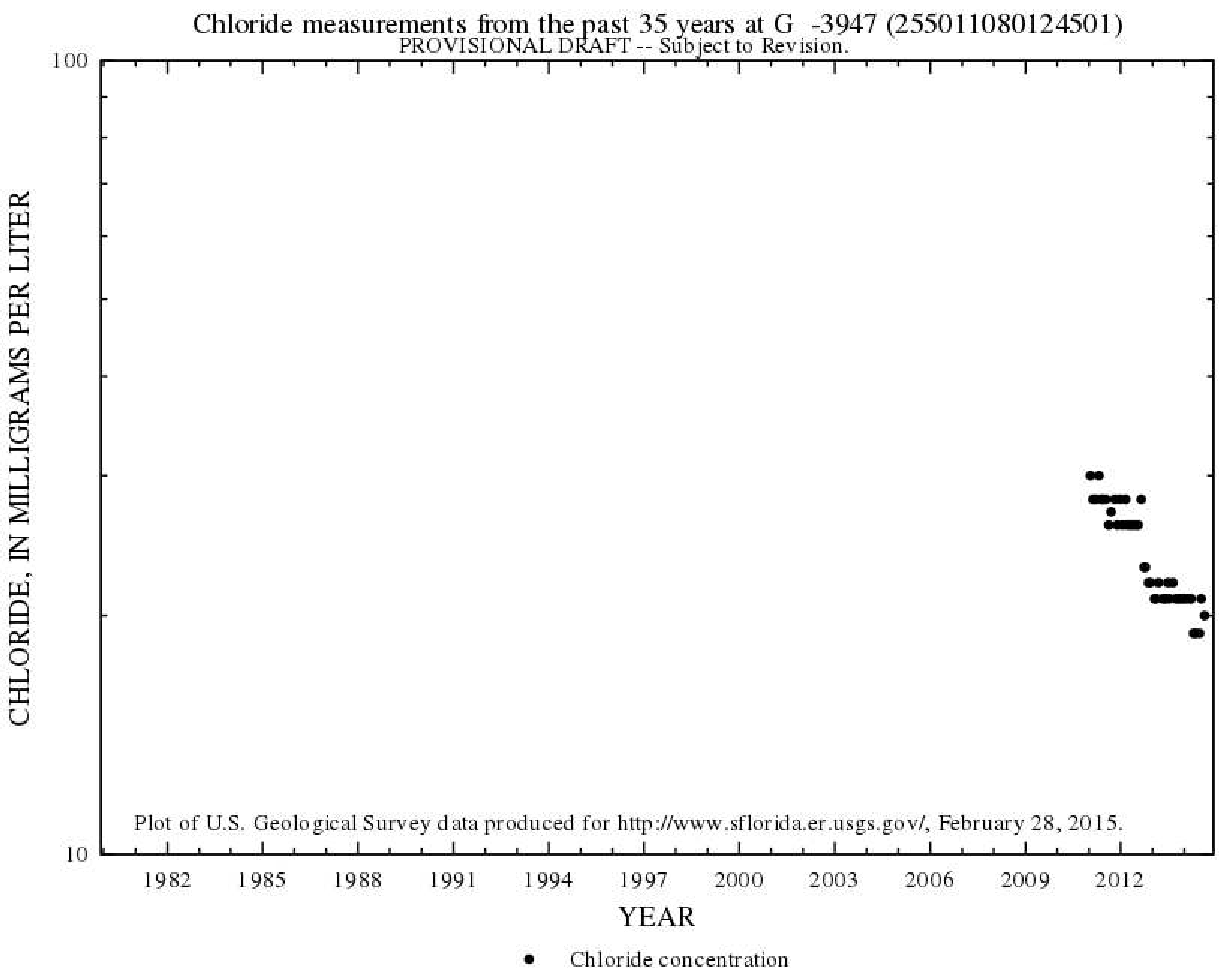

G-3888
Chloride (mg/L)
2010-2015
Concentration (mg/L)
7000
6000
5000
4000
3000
2000
1000
0
4/20/2010
6/20/2010
8/20/2010
10/20/2010
12/20/2010
2/20/2011
4/20/2011
6/20/2011
8/20/2011
10/20/2011
12/20/2011
2/20/2012
4/20/2012
6/20/2012
8/20/2012
10/20/2012
12/20/2012
2/20/2013
4/20/2013
6/20/2013
8/20/2013
10/20/2013
12/20/2013
2/20/2014
4/20/2014
6/20/2014
8/20/2014
10/20/2014
12/20/2014
2/20/2015
4/20/2015
6/20/2015
8/20/2015
10/20/2015
12/20/2015
2/20/2016
Collection Date
Chloride (mg/L)

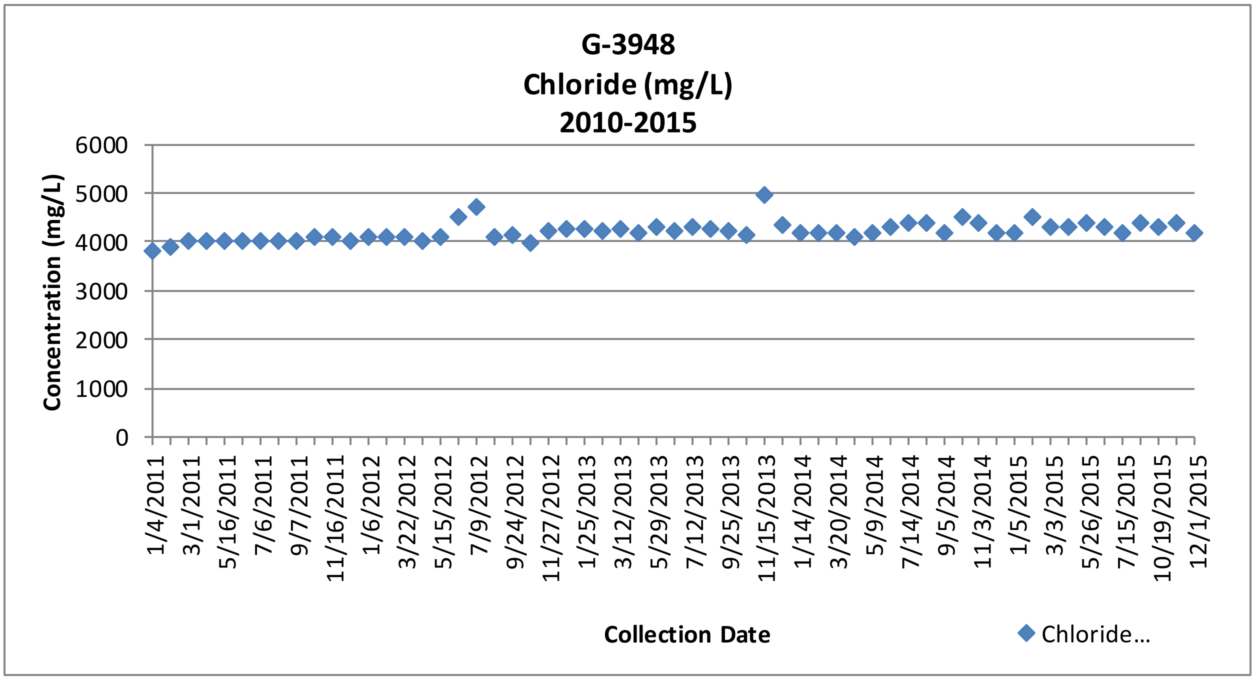

Chloride measurements from the past 35 years at G -3888A (254542080145901)
PROVISIONAL DRAFT -- Subject to Revision.
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, January 27, 2013.
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

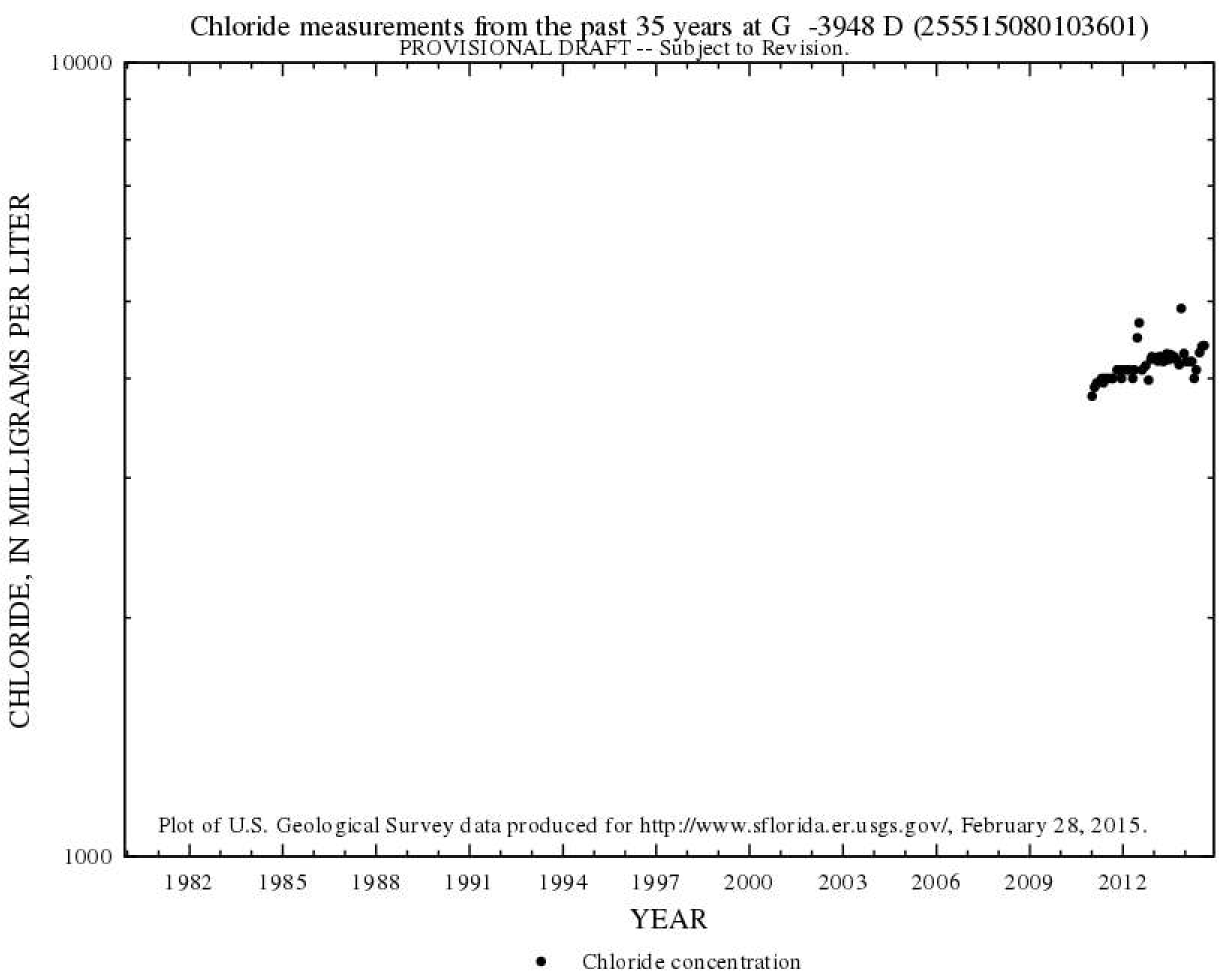

G-3946
Chloride (mg/L)
2010-2015
Concentration (mg/L)
6000
5000
4000
3000
2000
1000
0
1/7/2011
3/2/2011
5/17/2011
7/15/2011
9/2/2011
11/17/2011
1/12/2012
3/15/2012
5/25/2012
7/18/2012
9/20/2012
11/21/2012
1/15/2013
3/14/2013
5/20/2013
7/3/2013
9/12/2013
11/27/2013
1/27/2014
3/27/2014
5/21/2014
7/21/2014
9/24/2014
11/19/2014
1/21/2015
3/9/2015
5/6/2015
7/16/2015
9/11/2015
11/5/2015
Collection Date
Chloride...

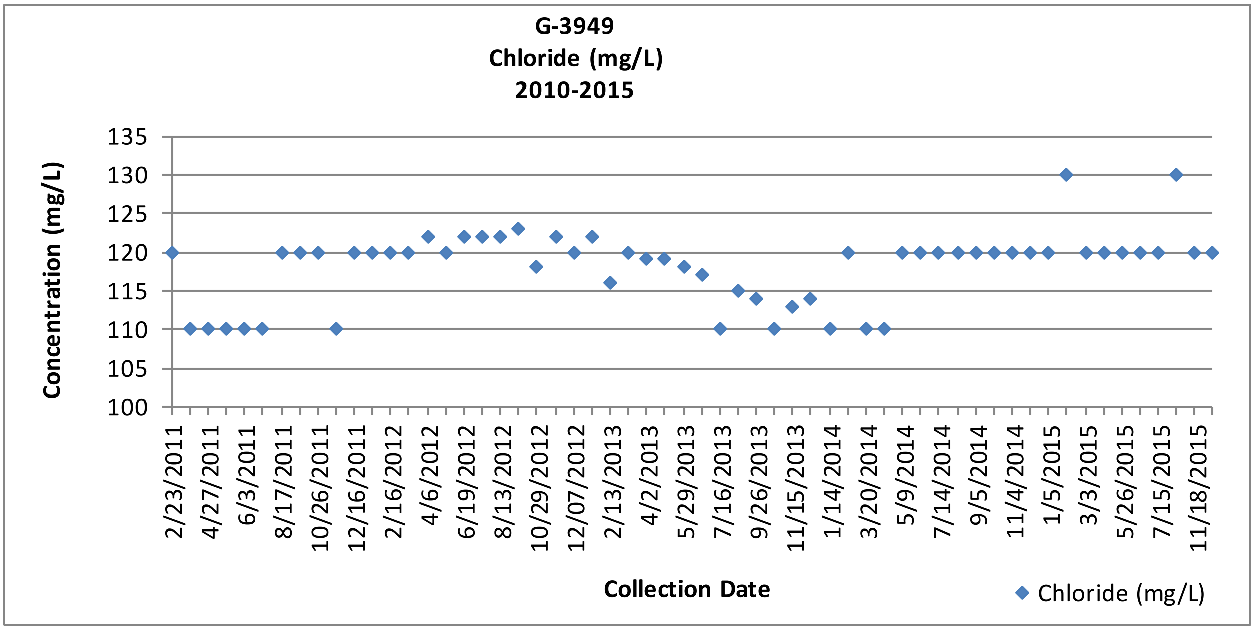

Chloride measurements from the past 35 years at G -3946D (252431080261001)
PROVISIONAL DRAFT -- Subject to Revision.
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, February 28, 2015.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration

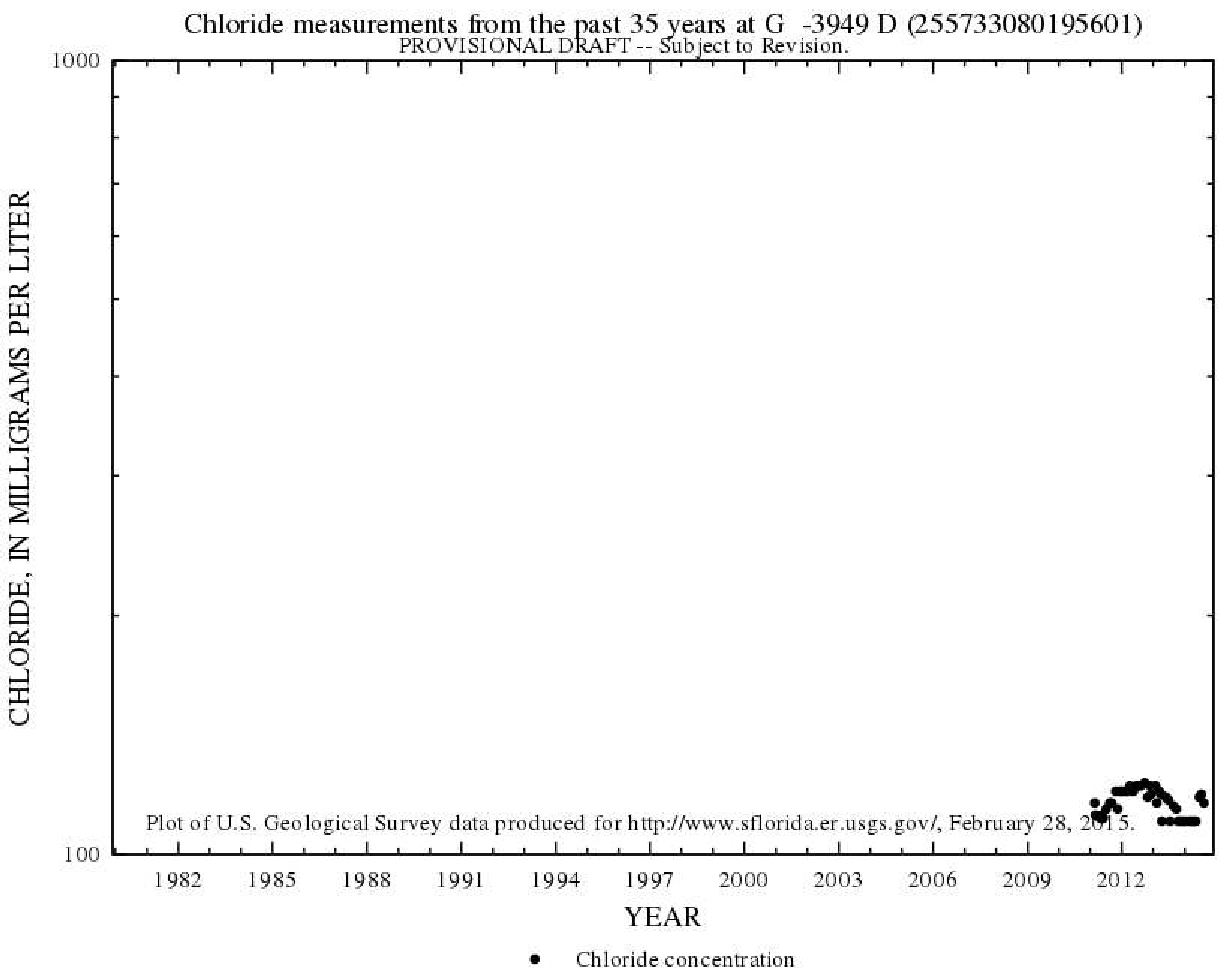

G-3947
Chloride (mg/L)
2010-2015
Concentration (mg/L)
35
30
25
20
15
10
5
0
1/18/2011
2/17/2011
3/23/2011
4/25/2011
5/23/2011
6/8/2011
7/14/2011
8/17/2011
9/13/2011
10/24/2011
11/23/2011
12/23/2011
1/23/2012
2/27/2012
3/16/2012
4/25/2012
5/17/2012
6/27/2012
7/20/2012
08/23/2012
9/27/2012
10/10/2012
11/16/2012
12/5/2012
1/24/2013
2/12/2013
3/11/2013
4/30/2013
5/28/2013
6/26/2013
7/12/2013
8/22/2013
9/26/2013
10/21/2013
11/14/2013
12/17/2013
1/14/2014
2/26/2014
3/20/2014
4/16/2014
5/9/2014
6/23/2014
7/14/2014
8/20/2014
9/3/2014
10/1/2014
11/4/2014
12/1/2014
1/2/2015
2/11/2015
3/4/2015
4/24/2015
5/26/2015
6/15/2015
7/15/2015
9/28/2015
10/19/2015
11/2/2015
12/15/2015
Collection Date
Chloride...


Chloride measurements from the past 35 years at G -3947 (255011080124501)
PROVISIONAL DRAFT -- Subject to Revision.
100
10
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, February 28, 2015.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration


G-3948
Chloride (mg/L)
2010-2015
Concentration (mg/L)
6000
5000
4000
3000
2000
1000
0
1/4/2011
3/1/2011
5/16/2011
7/6/2011
9/7/2011
11/16/2011
1/6/2012
3/22/2012
5/15/2012
7/9/2012
9/24/2012
11/27/2012
1/25/2013
3/12/2013
5/29/2013
7/12/2013
9/25/2013
11/15/2013
1/14/2014
3/20/2014
5/9/2014
7/14/2014
9/5/2014
11/3/2014
1/5/2015
3/3/2015
5/26/2015
7/15/2015
10/19/2015
12/1/2015
Collection Date
Chloride...


Chloride measurements from the past 35 years at G -3948 D (255515080103601)
PROVISIONAL DRAFT -- Subject to Revision.
10000
1000
CHLORIDE, IN MILLIGRAMS PER LITER
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, February 28, 2015.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration


G-3949
Chloride (mg/L)
2010-2015
Concentration (mg/L)
135
130
125
120
115
110
105
100
2/23/2011
4/27/2011
6/3/2011
8/17/2011
10/26/2011
12/16/2011
2/16/2012
4/6/2012
6/19/2012
8/13/2012
10/29/2012
12/07/2012
2/13/2013
4/2/2013
5/29/2013
7/16/2013
9/26/2013
11/15/2013
1/14/2014
3/20/2014
5/9/2014
7/14/2014
9/5/2014
11/4/2014
1/5/2015
3/3/2015
5/26/2015
7/15/2015
11/18/2015
Collection Date
Chloride (mg/L)


Chloride measurements from the past 35 years at G -3949 D (255733080195601)
PROVISIONAL DRAFT -- Subject to Revision.
CHLORIDE, IN MILLIGRAMS PER LITER
1000
100
Plot of U.S. Geological Survey data produced for http://www.sflorida.er.usgs.gov/, February 28, 2015.
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
YEAR
Chloride concentration