Chapter 2B: Water and Climate Resilience Metrics

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Snail kites flying over a canal.

Highlights

In this year's Water and Resilience Metrics chapter, the following metrics are discussed:

- Tidal Elevations at Coastal Structures
- Minimum Flows and Minimum Water Levels (MFLs) – Biscayne Aquifer
- Flood Occurrences

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TIDAL ELEVATIONS AT COASTAL STRUCTURES

Tidal water level data collected at 32 South Florida Water Management District (SFWMD)-operated gravity coastal structures (**Figure 2B-1** later in the document) between 1967 and 2022 exhibit statistically significant upwards trends, with even more rapid increases occurring over the past 20 years. To address these risks, SFWMD, in partnership with federal, state, and local governments and local water management districts in South Florida, are actively engaged in comprehensive flood resiliency studies, conducting monitoring and modeling exercises to assess system vulnerabilities, and developing adaptive strategies to ensure the resilience and effectiveness of the Central and Southern Florida Project water management system and its coastal gravity structures under changing climatic conditions.

MINIMUM FLOW AND MINIMUM WATER LEVELS (MFLS)

Water levels in primary canals discharging to tide at 11 coastal structures (**Figure 2B-3** later in the document) are monitored as part of the Biscayne Aquifer MFL in the Lower East Coast water supply planning area. The Biscayne Aquifer MFL prevention strategy includes minimum operation levels upstream of the structures established to help recharge the Biscayne aquifer and maintain the water level in the aquifer needed to counter inland movement of salt water into the aquifer. Data analysis reveals a total of three instances at two structures where canals did not meet the minimum operating levels since the MFL was established. Yet groundwater quality monitoring indicates that saltwater intrusion is occurring at the base of the aquifer in some areas. Continued and enhanced monitoring as well as analysis that considers sea level rise are recommended to inform water supply planning and adaptation in the context of resiliency.

FLOOD OCCURRENCES

Flood occurrence data collected in South Florida's urban areas between 1991 and 2022 identified an initial set of 25 flood prone areas within the SFWMD region. These flood prone areas were used to pinpoint data gaps and highlight areas for future data collection efforts. Ongoing efforts to collect flood observations using the Document the Floods survey will be used to inform satellite and radar imagery acquisition to provide more comprehensiveness and quantitative information about flood occurrence and extent. These data will contribute to flood risk management, adaptive strategies, and incident response and help better inform regional and local governments and water managers on flood occurrence within primary, secondary, and tertiary systems.

www.sfwmd.gov/our-work/district-resiliency

SUMMARY

The South Florida Water Management District (SFWMD) continues to be strongly committed to addressing the impacts of land development, population growth, and climate change. SFMWD's resiliency efforts focus on assessing how sea level rise and extreme events, including flood and drought events, happen under current and future climate conditions, and how they affect water resources management. In this context, resiliency is the capacity for natural and man-made systems to cope with and adapt to acute and chronic stressors, now and in the future, as climate conditions evolve.

SFWMD is making significant infrastructure adaptation investments that are needed to successfully implement its mission of safeguarding and restoring South Florida's water resources and ecosystems, protecting communities from flooding, and ensuring an adequate water supply for all of South Florida's needs. Working to ensure the region's water resources and ecosystems resiliency, now and in the future, is part of everything SFWMD does.

As part of its resilience initiatives, SFWMD has established an initial set of water and climate resilience metrics to track and document trends and shifts in water and climate monitored data. This data assessment supports the enhanced understanding of the current and predicted impacts of climate change on South Florida's ecosystems and water resources, informs modeling scenario formulation, adaptation planning, operational decisions, and the resiliency projects prioritization.

In this year's chapter, the following metrics are examined:

- Tidal Elevations at Coastal Structures
- Minimum Flows and Minimum Water Levels (MFLs) – Biscayne Aquifer
- Flood Occurrences

The chapter includes discussions and explorations of the drivers influencing the observations of the selected metrics, delves into their relevance to resiliency in water management, and also addresses next steps in ongoing data analysis efforts.

TIDAL ELEVATIONS AT COASTAL STRUCTURES

To assess the effects of sea level rise on stormwater discharge capacity and saltwater intrusions risks in South Florida, the tidal elevation at SFWMD's coastal structures is examined as part of the Water and Climate Resilience Metrics. This data, combined with flood protection level-of-service performance data, helps identify limitations and deficiencies in flood control infrastructure.

Tidal water level data collected at 32 SFWMD-operated gravity coastal structures between 1967 and 2022 exhibit statistically significant upwards trends, with even more rapid increases occurring over the past 20 years. To address the risks associated with these upward trends in tidal water levels at coastal gravity structures, SFWMD, in partnership with federal, state, and local governments and local water management districts in South Florida are actively engaged in comprehensive flood resiliency studies, conducting monitoring and modeling exercises to assess system vulnerabilities and developing adaptive strategies to ensure the resilience and effectiveness of the Central and Southern Florida Flood Control Project (C&SF Project) water management system and its coastal gravity structures under changing climatic conditions.

MINIMUM FLOWS AND MINIMUM WATER LEVELS (MFLS) – BISCAYNE AQUIFER

MFLs are defined as the minimum flows or minimum water levels for selected water bodies at which further permitted water withdrawals would be significantly harmful to the water resources or ecology of the area. MFLs are adopted by the SFWMD Governing Board pursuant to Sections 373.042 and 373.0421, Florida Statutes, and are an integral part of water resource management in South Florida. MFLs ensure the long-term viability of water resources and the protection of natural systems. SFWMD has a statutory obligation to identify key water bodies for which an MFL should be developed where there is the existence of, or potential for, significant harm (> 2 years recovery period) to the water resources or ecology within the SFWMD boundaries and includes water bodies that are experiencing or may reasonably be expected to experience adverse impacts over a 20-year planning horizon. Adopted MFLs in the SFWMD and their criteria are contained in Chapter 40E-8, Florida Administrative Code (F.A.C.).

Water levels in primary canals discharging to tide at 11 coastal structures are monitored as part of the Biscayne Aquifer MFL along the Lower East Coast water supply planning area. Minimum operation levels were established to maintain sufficient water levels (stages) in these 11 coastal canals to recharge the Biscayne aquifer and maintain the water level in the aquifer needed to meet the MFL. Data reveal a total of three occurrences at two structures where the minimum operation levels were not met since the MFL was established. Yet groundwater quality monitoring indicates that saltwater intrusion is occurring at the base of the aquifer in some areas. Continued and enhanced monitoring as well as analysis that considers sea level rise are recommended to inform water supply planning and adaptation strategies in the context of resiliency.

FLOOD OCCURRENCES

Flooding is a shared concern in both natural and urban areas of South Florida. Natural areas are affected by water levels that influence ecological dynamics, driven by hydrology, while urban areas face potential consequences affecting communities and residents. For resilience planning, the analysis of historical and current flood patterns is essential for water management operations, providing a foundation for informed decision-making and risk reduction in flood prone areas in South Florida. By leveraging historical data, water managers and resilience planners can proactively plan, adapt, and respond to flood events, ensuring the resilience of the water management system that safeguards communities, infrastructure, and the environment against flooding amid evolving climate conditions, changing in land use, and population growth.

Flood occurrence data collected in urban areas between 1991 and 2022 in South Florida identified an initial set of 25 flood prone areas within the SFWMD region and pinpointed gaps in data sources, highlighting areas for improvement in future data collection efforts. Ongoing efforts to collect flood observations will be used to inform satellite and radar imagery acquisition to provide more comprehensive and quantitative information about flood occurrence and extent. These data will contribute to flood risk management, adaptive strategies, and incident response and help to better inform regional and local governments and water managers on flood occurrence within the primary, secondary, and tertiary water management systems.

BACKGROUND

As part of its resilience initiatives, the South Florida Water Management District (SFWMD) has established an initial set of water and climate resilience metrics to track and document trends and shifts in the water and climate data it monitors. This collaborative effort is led by the SFWMD internal Water and Climate Resilience Metrics Workgroup, comprising technical staff from various bureaus. Reporting the latest information about SFWMD’s water and climate resilience metrics ensures scientific findings are memorialized to preserve institutional knowledge and disseminated to stakeholders, the public, and partner agencies to support local and regional resilience strategies.

The analysis of these data is essential for understanding the current and predicted impacts of climate change on South Florida’s ecosystems and water resources. While uncertainties persist regarding climate change, evaluating changes in climate variables like rainfall, temperature, evapotranspiration, and sea level as well as their consequences on sea level rise, saltwater intrusion, groundwater elevation, and ecosystem dynamics is crucial. These assessments provide the foundation for more robust infrastructure planning, operational decisions in water management and ecosystem restoration projects, ensuring SFWMD’s resilience planning is grounded in the best available science.

The comprehensive approach supports SFWMD’s mission and resiliency goals, ensuring ecosystem restoration, flood protection, and water supply mission while considering current and future climate conditions.

INTRODUCTION

As part of its resilience initiatives, the SFWMD implemented an initial set of water and climate resilience metrics to track and document shifts and trends in SFWMD-monitored water and climate data. **Table 2B-1** summarizes key aspects of the water and climate resilience metrics. Each metric is categorized as a climate metric or a resilience metric. Climate metrics are the primary drivers of observed changes in climate conditions that impact the hydrologic cycle, while resilience metrics represent the observed consequences of changing climate conditions and can be directly or indirectly managed or mitigated through operation of the water management system or implementation of adaptation strategies.

The selected statistical approaches for consistent analyses across the set of initial metrics includes linear regression analysis and seasonal and non-seasonal Mann-Kendall tests, complemented by GIS analyses for identifying spatial patterns of specific metrics, and the findings in this chapter are presented and based on this approach, recommended by the Water and Climate Resilience Metrics Workgroup. More detailed information on the selection of the initial set of metrics and approaches to data analysis can be found in the *Water and Climate Resilience Metrics Phase I Final Report* (SFWMD 2021).

This chapter, introduced in Volume I of the *2022 South Florida Environmental Report* (SFER), aims to continuously advance water and climate data analysis and deepen the understanding of the influence of climate change and other determinant factors on observations and findings. It includes additional technical analysis and scientific considerations for three key water and climate resilience metrics:

- Tidal Elevations at Coastal Structures
- Minimum Flows and Minimum Water Levels (MFLs)
- Flood Occurrences

Examining the factors that influence resilience metrics is crucial for correlating trends and identifying potential relationships between climate factors and resilience outcomes. Analyzing how changes in one factor may impact resilience metrics supports informed decision-making and prioritization of interventions to enhance overall resilience.

Monitoring these factors also supports the observation of any shifts in established trends over time and enables water managers to adapt and respond to changing conditions, ensuring resilience strategies remain effective and relevant in the face of dynamic challenges.

Understanding and tracking these factors can lead to the development and implementation of novel indicators for monitoring resilience, providing more comprehensive insights into the system's ability to withstand and recover from disturbances. New and previously unused measurements would contribute to a more nuanced and holistic understanding of complex interactions and can help address limitations in existing metrics.

The influencing factors of each analyzed metric are outlined in this chapter to provide a comprehensive understanding of the underlying drivers shaping resilience trends. This approach supports the development of well-informed and effective strategies to enhance resilience in South Florida's regional water management system.

The following sections provide background information for each metric, outline the findings of these three metrics, and discusses influencing factors, recommended enhancements to data monitoring, and additional analyses that can aid in distinguishing between climate and non-climate driven change. Evaluating these metrics is an important step in planning for the future. The observed trends in long-term water and climate data shed light on the consequences of a changing climate, guiding water management and resiliency priorities.

Table 2B-1. Summary of the water and climate resilience metrics.

Metric	Type of Metric	SFWMD Role	Use (What It Is & What It Is Used For)	Application (How Observed Trends Inform Resilience Efforts)
Rainfall	Climate	Rainfall intensity, duration, extension, and frequency cannot be controlled by SFWMD.	Rainfall is used to estimate the water budget, forecast inflows to the system, plan the management of water resources, and determine water management operations.	Annual trend analysis provides insights about average rainfall. Regional trend analyses on daily maxima, daily minima, and peaks over/under thresholds for selected return frequencies and durations are necessary to fully understand the impacts of rainfall on flooding, water supply, and ecosystem restoration.
Evapotranspiration (ET)	Climate	ET cannot be controlled by SFWMD.	Together with rainfall, ET drives the hydrologic cycle and water budget.	ET is projected to increase in a warming climate and impact seasonal patterns and trends in precipitation. Increasing ET might contribute to increasing demand on the water management system (due to associated canal levels, flooding, etc.). During drought events, ET might deplete already limited water supplies. ET data trends inform SFWMD operation and planning efforts.
Tidal Elevations at Coastal Structures	Climate	Tidal elevations cannot be controlled by SFWMD. Tidal elevations at coastal structures can be partially influenced by SFWMD operations. Activities of other jurisdictional agencies cannot be controlled by SFWMD.	Headwater (freshwater canal levels) and tailwater (tidal levels) elevations are the drivers of stormwater discharge operations. Coastal structures must be opened to release stormwater as part of flood control operations and closed during high tailwater conditions to prevent saltwater intrusion inland.	Long-term data trends, combined with flood level-of-service performance data, inform SFWMD on the limitations and deficiencies of flood control infrastructure. This information provides guidance on the priority investments where resources are most needed for adaptation planning and mitigation strategies. For instance, coastal structures are a vital component of the prevention strategy for the Biscayne aquifer MFL.
High Tide Events	Climate	Tidal stages and high tide events cannot be controlled by SFWMD.	High tide events represent extreme values of the tidal stages used to assess trends in sea level rise and identify potential flooding hazards, risks to water supply, and impacts to structural design standards.	Long-term data trends in tidal stages and high tide events and level-of-service performance inform SFWMD on the limitations and deficiencies of natural and structural assets. This information provides guidance on where SFWMD might allocate resources for adaption strategies and planning.
Groundwater Levels/Elevations/ Stages	Resilience	Groundwater levels can be indirectly controlled by SFWMD via operation of water control structures and pump stations along canals of the C&SF Project. Higher sea levels that increase hydrostatic pressure and allow inland movement of seawater into aquifers cannot be controlled by SFWMD.	Groundwater level data are used to monitor water supply, as inputs to surface water and groundwater modeling, for the establishment of and compliance with MFL criteria, and for compliance and permitting reviews. Groundwater levels at key sites are evaluated weekly as indicators of potential water shortages.	Trends in groundwater level data inform a broader understanding of the impacts of sea level rise in terms of timing and extent of groundwater stages during the wet season, threats to water supply, the need for additional monitoring, urgency of mitigation strategies, and places the need for communicating risks through visualization at the forefront of resilience planning. Data are available for long-term groundwater level trends for the surficial, intermediate, and Floridan aquifer systems. Data also are available through the United States Geological Survey (USGS) Water Level and Salinity Analysis Mapper online tools, showing trends over the past 20 years.

Table 2B-1. Continued.

Metric	Type of Metric	SFWMD Role	Use (What It Is & What It Is Used For)	Application (How Observed Trends Inform Resilience Efforts)
Saltwater Intrusion/ Saltwater Interface – Chloride Levels	Resilience	The saltwater interface can partially be controlled by SFWMD. The water management system has limited/variable capacity to maintain higher elevations in inland canal systems to impede saltwater intrusion.	Analytical chloride data from groundwater wells are used to monitor salinity in freshwater aquifers and map the inland movement of saltwater.	Historical and projected movement of saltwater inland and current water use data and future water use projections identify vulnerabilities to public supply utilities. Saltwater intrusion has a large impact in water use permitting as an increased number of wells/wellfields/ utilities are vulnerable to loss of supply or reduced availability during droughts.
MFLs – Exceedances/ Violations	Resilience	SFWMD adopts MFL criteria for key water bodies where there is the existence of, or potential for, significant harm to the water resources or ecology within SFWMD boundaries. When establishing an MFL, SFWMD considers structural changes and alterations to the watersheds of MFL water bodies and the effects and constraints of these changes and alterations on their hydrology. SFWMD monitors exceedances and violations of adopted MFLs to determine compliance and to develop recovery or prevention strategies, respectively. Through water management, operational, and regulatory practices, SFWMD may achieve adequate MFL status. MFL rules and criteria contained in Chapter 40E-8, F.A.C., are based on the best available information, and are periodically reevaluated and revised by SFWMD as appropriate.	MFL criteria are the minimum flows or water levels at which water resources, or the ecology of the area, would experience significant harm from further permitted water withdrawals. MFL criteria are developed individually for the affected water bodies and define the minimum flow or minimum water level for surface water bodies, or minimum water level for groundwater in aquifers. Flow and water level data are used to ensure water bodies are in compliance with their minimum requirements and to identify the occurrence of exceedances and violations.	MFL monitoring data identify threats to water supply sources and ecosystems, and the need to develop recovery or prevention strategies in cases where a water body currently does not or will not meet adopted MFL criteria. The MFL program supports SFWMD's regional water supply planning process, and involves the consumptive use permitting program, and the environmental resource permitting program. Applications for consumptive use permits for water uses that directly or indirectly withdraw water from MFL water bodies must meet the requirements of the recovery or prevention strategy at the time of permit issuance. MFL data are also used in assessments of water supply sources and declarations of water shortages.
Flooding Events	Resilience	SFWMD has the capacity and mission to control and protect communities from flooding events through effective operation and maintenance of its water management system and through infrastructure investments to implement flood adaptation and mitigation strategies.	Flood data are used to assess and monitor (pattern, extent, and depth) flooding events that occur after storms, heavy rainfall, and extreme tides.	Comprehensive analysis of flood event data identifies where investments and reinforcements in flood control systems are necessary. Formally tracking trends of reported flooding and comparing to other trends, such as rainfall, will help determine if observed changes are part of a long-term trend or represent a shift in climate.

Table 2B-1. Continued.

Metric	Type of Metric	SFWMD Role	Use (What It Is & What It Is Used For)	Application (How Observed Trends Inform Resilience Efforts)
Water Temperature	Resilience	SFWMD can indirectly control water temperature in the system through operational and management decisions, and through coordination with state and local agencies as part of basin management action plan (BMAP) implementation.	Water temperature is used to monitor water supply and aquatic and marine ecosystems.	Water temperature informs effective water management practices and helps assess restoration efforts. Resilience-driven interventions may reduce the impacts of poor water quality in critical areas and help identify areas that require implementation of restoration strategies.
Dissolved Oxygen (DO)	Resilience	SFWMD can indirectly control DO in the system through operational and management decisions, and through coordination with state and local agencies as part of BMAP implementation.	DO is used to monitor water supply sources and availability for uptake in aquatic and marine ecosystems.	DO informs effective water management practices and helps assess restoration efforts. Resilience-driven interventions may reduce the impacts of poor water quality in critical areas and help identify areas that require implementation of restoration strategies.
pH	Resilience	SFWMD can indirectly control pH in the system through operational and management decisions, and through coordination with state and local agencies as part of BMAP implementation.	Water pH is an indicator of the chemical state and changes within a water body. Water pH is used to monitor water supply sources and aquatic and marine ecosystems.	Water pH informs effective water management practices and helps assess restoration efforts. Resilience-driven interventions may reduce the impacts of poor water quality in critical areas and help identify areas that require implementation of restoration strategies.
Specific Conductance	Resilience	SFWMD can indirectly control specific conductance in the system through operational and management decisions, and through coordination with state and local agencies as part of BMAP implementation.	Specific conductance is used to monitor water supply sources and aquatic and marine ecosystems. Analyses of specific conductance allow for the removal of altering variables and accounts for fluctuations in water temperature. High specific conductance values indicate a high amount of substances and chemicals dissolved in water. Conductivity may also be used as a conservative tracer to monitor the movement of water and contamination.	Specific conductance informs effective water management practices that promote resilience and helps assess restoration efforts. This identifies critical areas that require implementation of restoration strategies.
Estuarine Inland Migration – Everglades	Resilience	SFWMD can partially control the extent of estuarine inland migration through water management by maintaining higher freshwater levels inland.	Estuarine inland migration is used to monitor shifts in species composition in freshwater marshes. Trends in estuarine inland migration provide insights to the impacts of sea level rise in coastal areas and the Everglades.	Estuarine inland migration informs SFWMD on the efficacy of water management practices in creating favorable conditions for marshes and mangroves to keep up with sea level rise. Information on estuarine inland migration provides guidance to align/plan practices to adapt and mitigate for sea level rise and other climate change impacts.

Table 2B-1. Continued.

Metric	Type of Metric	SFWMD Role	Use (What It Is & What It Is Used For)	Application (How Observed Trends Inform Resilience Efforts)
Soil Subsidence	Resilience	SFWMD can partially control the extent of soil subsidence through water management by maintaining higher freshwater levels inland and improving the physical and biological processes that promote accretion and subsurface root and peat accumulation.	Soil subsidence, or expansion, is the result of elevation change minus accretion rate, incorporating both surface and subsurface processes. SFWMD has been studying mangrove environments in northeastern Florida Bay and Taylor River to determine soil subsidence at non-flooded, frequently flooded, and permanently flooded areas. The main objective of the study is to determine whether mangrove soil surface elevation can keep pace with increasing sea level rise.	The rate of soil subsidence informs SFWMD on the effectiveness and benefits of Everglades restoration. This information guides water management practices that aim to uplift land to reduce the impacts of sea level rise and promote the seaward migration of coastlines (i.e., increasing freshwater input into the salinity transition zone of Taylor Slough).
Salinity in the Everglades	Resilience	SFWMD can partially control salinity through water management by maintaining higher freshwater levels inland.	Salinity is used to monitor water quality and evaluate the effectiveness of restoration strategies.	Salinity informs SFWMD on the effectiveness and benefits of Everglades restoration and guides water management practices.

TRENDS IN TIDAL ELEVATIONS AT COASTAL STRUCURES IN SOUTH FLORIDA

BACKGROUND

The regional water management system, known as the Central and Southern Florida (C&SF) Project water management system, was designed over 70 years ago and serves multiple project purposes including flood control measures, water supply components, environmental restoration components, and navigation improvements. Since then, population growth, land development, and changing climate conditions have reduced the system's overall performance. Changing rainfall patterns, rising sea levels, and fluctuations in groundwater levels are further impacting the system's performance.

SFWMD relies on coastal gravity structures, including culverts, weirs, and spillways, as essential components of the region's water management system. These structures are operated to manage inland water levels and control water discharges to tide. The coastal structures are part of a tiered and interconnected drainage system, consisting of a primary system (SFWMD canals and natural waterways, and respective water control structures) and secondary and tertiary systems (local county or city drainage systems and neighborhood drainage features, respectively).

To assess the effects of sea level rise on the overall system's discharge capacity and saltwater intrusion risks in South Florida, the tidal elevation monitoring data at SFWMD's coastal structures is examined as part of the Water and Climate Resilience Metrics. Coastal structures included as part of the metrics analyses are shown in **Figure 2B-1**. This data, combined with the Flood Protection Level of Service (FPLOS) Program assessments and performance metrics results, helps identify vulnerabilities in flood control infrastructure.

The FPLOS performance metrics (PMs) quantify the level of flood protection provided within a watershed under current and future conditions. There are 6 PMS, PMs 1through 4 assess performance of the regional drainage systems, while PMs 5 and 6 assess impacts to local flooding frequency and duration within the communities the drainage systems serve. For additional details on the FPLOS Program performance data, visit https://www.sfwmd.gov/our-work/flood-protection-level-service.

- PM 1: Maximum stage in primary canals
- PM 2: Maximum daily discharge capacity through the primary canals
- PM 3: Tidal structure flow performance – effects of sea level rise
- PM 4: Peak storm runoff – maximum conveyance capacity of the watershed
- PM 5: Frequency of flooding – stage-based level-of-service for sub-watersheds
- PM 6: Duration of flooding – effects of sea level rise

By analyzing long-term trends in tidal water levels at coastal structures, SFWMD gains additional insights into where investments are most needed for adaptation and mitigation strategies. The analysis presented in this section is based on historical instantaneous water level data collected and stored in SFWMD's hydrometeorological and water quality database, DBHYDRO.

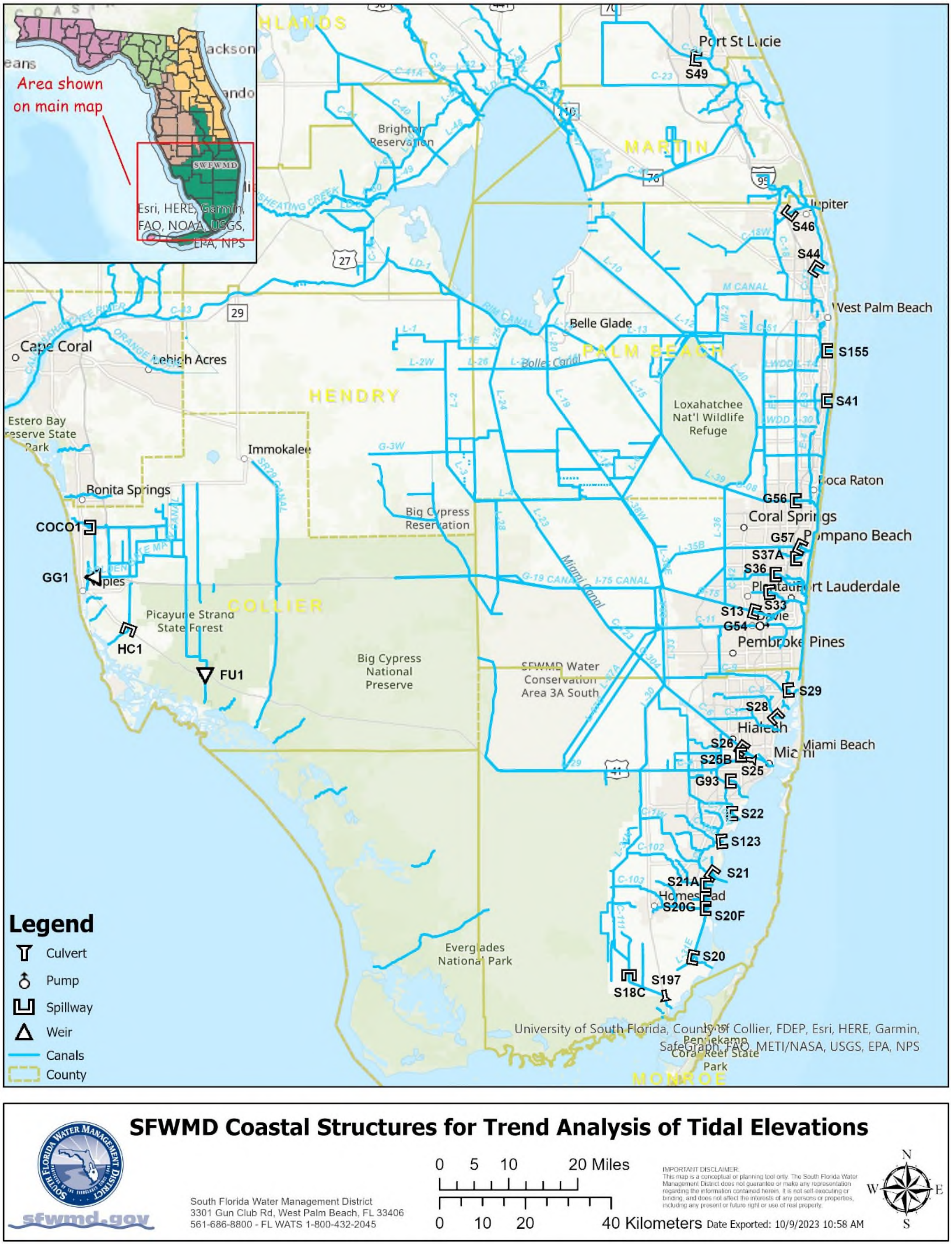


Figure 2B-1. Locations of the 32 SFWMD-operated coastal structures used in the analysis.

DRIVERS AND INFLUENCING FACTORS

South Florida's coastal structures face a complex and interrelated set of challenges, where both coastal and inland areas are susceptible to flooding, while coastal aquifers remain vulnerable to saltwater intrusion. This predicament is further exacerbated by several factors:

- **Sea level rise:** As global sea levels continue to rise, coastal gravity structures face increased pressure to prevent saltwater intrusion into freshwater systems. Rising sea levels can also lead to higher downstream water levels in canals and estuaries, making it more challenging to maintain the necessary balance between salt and fresh water.
- **Changes in precipitation patterns and extreme events:** As climate conditions evolve, South Florida may experience altered precipitation patterns, relative to historical observations, including more extreme rainfall and extreme drought occurrences, along with shifts in dry and wet season duration and averages. These scenarios will impact the overall water levels, discharges, and flow capacity at the coastal gravity structures, requiring adaptive management strategies to cope with the changed environment.
- **Storm Surge:** South Florida is prone to hurricanes and tropical storms, along with storm surges. These surges can lead to destructive flooding and erosion, potentially damaging or compromising coastal infrastructure.
- **Gulf Stream Effects**: The Gulf Stream, a strong and fast-moving ocean current off the coast of Florida, may contribute to local tidal levels in South Florida. Though it is important to note that the interaction between the Gulf Stream and local tidal levels in South Florida is complex, involves several global mechanisms, and varies temporally. Its influence on local tidal levels can vary depending on factors such as the Gulf Stream's distance from the coast, its strength, and the characteristics of the coastline. Additionally, other local factors, such as winds and atmospheric pressure, can also influence tidal levels in conjunction with the Gulf Stream. Understanding the complex interactions between the Gulf Stream and local tidal levels is essential for coastal planning, management, and hazard mitigation in Florida.

The region's stormwater management system operates within pre-determined, and seasonally varying, operational ranges to maintain canal reaches and facilitate water movement through coastal structures via gravity. This necessitates sufficient hydraulic gradient between the inland canal elevation (fresh headwater) and tidal elevation (saline tailwater). During wet conditions, coastal structures are opened to discharge stormwater to tide and prevent flooding. Conversely, during dry conditions, coastal structures are closed to conserve water and prevent saltwater intrusion.

However, increasing tidal elevations, due to rising sea levels, pose a significant challenge by reducing the freshwater gradient and consequently decreasing discharge capacity at coastal structures, as depicted in **Figure 2B-2**. This reduction in discharge capacity significantly impacts the structures' ability to provide effective flood control, increasing the risks of inland flooding during wet conditions and contamination from saltwater intrusion during dry conditions.

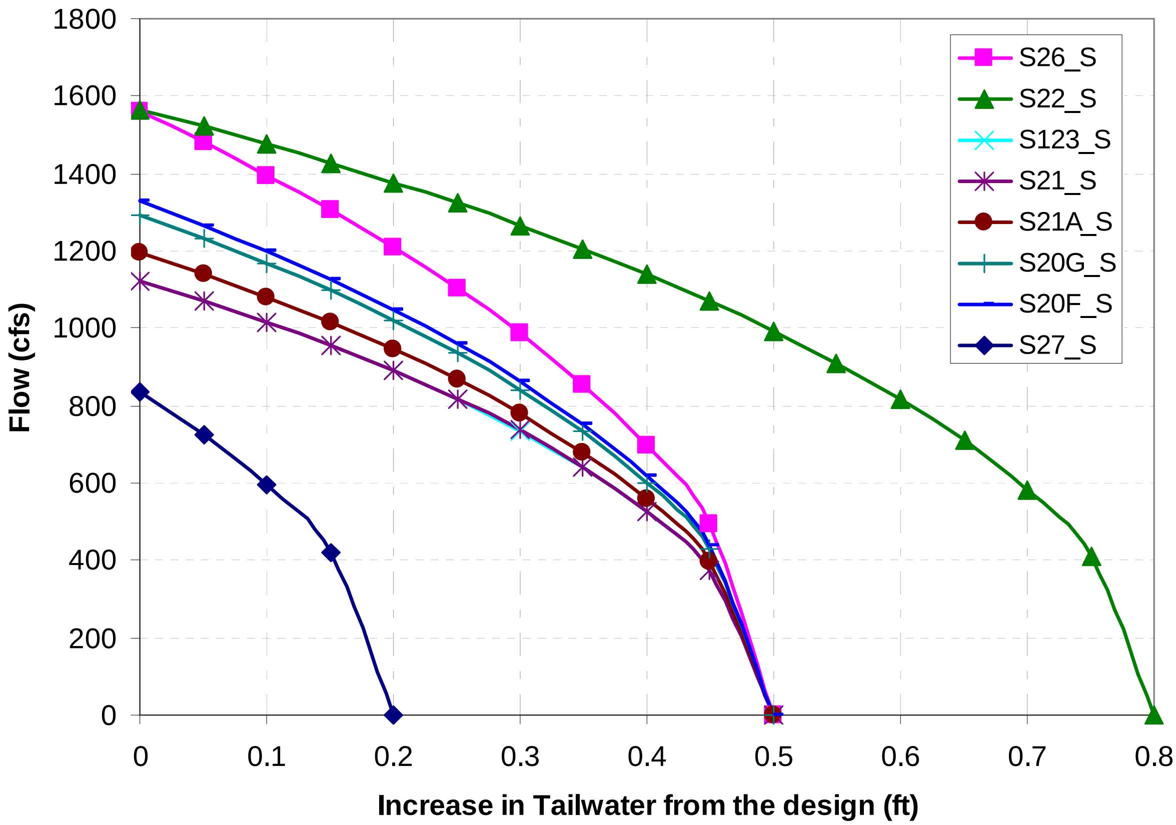


Figure 2B-2. Correlation between reduction in discharge capacity and the corresponding increase in tailwater levels based on specific design conditions. (Note: cfs – cubic feet per second and ft – feet.)

TIDAL WATER LEVEL DATA AND TREND ANALYSES

SFWMD maintains an extensive hydrological monitoring network, which includes coastal structures to effectively support the day-to-day operation of the water management system. This network serves multiple purposes, including meeting reporting requirements, supporting hydrologic and hydraulic modeling, and facilitating future project planning and design. Water level data is collected and archived in SFWMD's hydrometeorological and water quality database, DBHYDRO. Historical water level data at downstream locations of coastal structures, also referred to as tailwater stations, are accessible within DBHYDRO. Historical water level data collected downstream of coastal structures (tailwater stations) were recently analyzed to identify potential trends over time (Cortez et al. 2022).

Overview of Previous Assessment

The initial analysis of tidal elevations at coastal structures was presented in the 2022 SFER chapter on SFWMD's water and climate resilience metrics (Cortez et al. 2022) and focused on specific of groups of coastal structure along South Florida's east and west coasts. For that study, annual average trend analyses were conducted using data from the start of the period of record (POR), which varies by site, through 2021. The 15 selected sites for analysis included three locations on the west coast (FU1, GG1, and HC1), four sites on the upper east coast (S49, S44, S155, and S41), and eight sites on the lower east coast (G57, S33, G54, S13, S29, S28, S27, and S25B). The data analysis determined the average annual rate of change and employed a linear regression approach, with time as the independent variable and tidal elevations as the dependent variable, to determine a trend. The application of linear regression allowed for a systematic examination of the relationship between these variables over the POR.

During the analysis, the coefficient of determination, denoted as R-squared (R^2), was calculated to assess the strength of the relationship between time and tidal elevations at the respective sites. The R^2 values serve as valuable indicators of how well time can explain the observed changes in tidal elevations at the selected sites. The analysis provided insights into the nature and magnitude of these relationships, facilitating a more refined understanding of the patterns and trends in water level data over the specified timeframe.

Overall, average annual tidal elevations at the selected coastal structures were trending upward and the rate of increase in average annual tidal elevation ranged between 3.41 and 7.94 millimeters per year (mm/yr). The R^2 values obtained fell within a range of 0.40 to 0.89, with a value closer to 1.0 indicating a significant trend. The range signified varying degrees of correlation, spanning from weak ($0.25 < r < 0.50$) to moderate ($0.5 < r < 0.75$) and strong ($r > 0.75$) relationships between the independent variable (time) and the dependent variable (tidal elevations).

The results of the linear regression analyses for each site in the groups, along with annual rate of change and R-squared values indicating the strength of the relationship between time and tidal elevations, were presented in the 2022 SFER chapter on SFWMD's water and climate resilience metrics (Cortez et al. 2022). The initial analysis provided valuable insights into the dynamics of water level fluctuations within specific groups of sites along South Florida's east and west coasts. The findings presented in the 2022 chapter also explored the factors influencing tidal elevations needed to support informed decision-making for resilience planning and management in the region.

Current Refined Assessment and Results

The analysis presented in this chapter enhances the overall understanding of the tidal elevation at coastal structures metric by evaluating and refining the previous analysis. This assessment analyzes the individual tidal elevation data (also called tailwater level or tidal water level) for all 32 SFWMD operated coastal structures (**Figure 2B-1**) and provides a statistical summary of the observed data over the last 20 years.

To assess trends in tidal elevation data, the Mann-Kendall test was utilized to determine if there is a statistically significant trend in average annual tidal elevation for each coastal structure, and Kendall Tau's correlation coefficient was employed to determine the direction of the trend. For the analysis, average annual tidal elevation data were averaged by calendar year. The data were treated as independent, and the analysis did not require that the data be normally distributed or linear. Any missing values were disregarded during the analysis.

The test was performed using a 95% confidence band around the trend slope for the available tidal elevation data. A trend is considered statistically significant if the probability value is lower than the significance level of 0.05, which allows for rejection of the null hypothesis, that there is no significant trend in the data, and confirms that there is indeed evidence of a trend. Conversely, a probability value above 0.005, indicates that there is no significant trend detected in the data within the 95% confidence level.

The trend analyses of long-term tidal elevation data observed at SFWMD's 32 coastal structures reveal annual average tidal water levels are on the rise (**Table 2B-2**), with all results detecting a statistically significant upward trend in the data (all probability values below 0.05). While not a direct comparison due to variations in the POR at each site, this analysis characterizes overall trends on the available data from all the coastal structures. Appendix 2B-1 of this volume provides the plotted average annual tailwater stage and trendline at each of the 32 SFWMD-operated coastal structures. The figures provide visual representations of the trends observed in the tidal elevation data of over the analyzed POR.

Table 2B-2. Summary of statistics of individual annual average water level data at SFWMD's 32 coastal structures for the full POR. The POR differs for each site.

Structure	POR Start Year	POR End Year	Mann-Kendall-Test Probability Value (p-value)	R^2	Annual Rate (mm/yr)
COCO1	1995	2022	0.001	0.31	4.31
FU1	1987	2022	<0.0001	0.60	5.24
G-54	1991	2022	0.001	0.24	3.48
G-56	1992	2022	0.030	0.12	2.35
G-57	1992	2022	<0.0001	0.50	5.69
G-93	1993	2022	<0.0001	0.52	5.09
GG1	2005	2022	0.002	0.63	5.99
HC1	2004	2022	<0.0001	0.89	7.84
S-123	1980	2022	<0.0001	0.83	5.19
S-13	1987	2022	<0.0001	0.68	5.96
S-155	1987	2022	<0.0001	0.72	4.79
S-18C	1967	2022	<0.0001	0.63	5.41
S-197	1971	2022	<0.0001	0.84	3.81
S-20	1968	2022	<0.0001	0.30	2.04
S-20F	1986	2022	<0.0001	0.70	4.53
S-20G	1985	2022	<0.0001	0.72	4.36
S-21	1987	2022	<0.0001	0.71	3.97
S-21A	1975	2022	<0.0001	0.70	4.19
S-22	1984	2022	<0.0001	0.75	5.30
S-25	1977	2022	<0.0001	0.65	3.52
S-25B	1980	2022	<0.0001	0.76	5.36
S-26	1986	2022	<0.0001	0.73	5.06
S-27	1986	2022	<0.0001	0.44	3.40
S-28	1981	2022	<0.0001	0.71	4.43
S-29	1987	2022	<0.0001	0.54	3.70
S-33	1992	2022	<0.0001	0.53	4.11
S-36	1987	2022	<0.0001	0.51	4.57
S-37A	1986	2022	0.003	0.24	2.46
S-41	1987	2022	<0.0001	0.75	6.52
S-44	1978	2022	<0.0001	0.58	4.02
S-46	1996	2015	0.018	0.40	5.09
S-49	1995	2022	0.001	0.47	4.67

Notes:

1. The trend analysis consistently concludes in 2022 across all sites, except for S-46, acknowledging variations in the start of their respective periods of record.
2. All sites with a period of record ending in 2022 are currently active. It is important to note 2022 denotes the endpoint of data considered in the analysis, not the discontinuation of ongoing monitoring efforts at these locations.
3. The period of record at S-46 concluded in 2015 due to the relocation of the tailwater monitoring station. Originally positioned downstream of the coastal structure, a new weir was installed downstream of the coastal structure but upstream of the monitoring station in 2016. This weir was strategically placed to influence and regulate tailwater flow towards the coastal structure. As a result, the monitoring station was relocated between the coastal structure spillway and the new weir. While this new location captures water levels downstream of the coastal structure for operational purposes, it no longer provides tidal data. Despite this change, data from the original monitoring location remains relevant, demonstrating a statistically significant upward trend in tidal water levels during the recorded period.

A closer examination of the data from the last two decades indicates that the rate of increase in tidal levels has become more rapid during the last twenty years. Between 2003 and 2022, the rates of increase in annual average tidal elevation at SFWMD's coastal structures ranged between 5.0 and 10.4 millimeters per year (mm/year) with an annual average of 8.2 mm/year. **Table 2B-3** summarizes the combined annual average tidal water level statistics at SFWMD's 32 coastal structures over the last 20 years.

Table 2B-3. Summary of statistics of increasing rates of annual average tidal water level data at SFWMD's 32 coastal structures for the past 20 years (2003–2022).

Summary Rates	Water Level (mm/yr)
Lowest increasing rate in annual average tidal water level	5.0
Average increasing rate in average annual tidal water level	8.2
Greatest increasing rate in average annual tidal water level	10.4

These results have been validated by various types of data sources and independent analyses, which consistently demonstrate an overall increase in sea levels and a notable acceleration in more recent years. A local analysis of four South Florida National Oceanic and Atmospheric Administration (NOAA) tide gauges (Naples, Key West, Key, and Virginia Key) provided additional evidence of accelerating sea level rise rates. The average rate of sea level rise increased from 3.9 mm/yr between 1900 and 2021 to 6.5 mm/yr between 2000 and 2021 and 9.4 mm/yr between 2010 and 2021 (Parkinson and Wdowinski 2022). Additionally, a global analysis of global mean sea level, combining satellite altimeter data and in situ data collection, such as ocean temperature and thermal expansion data and field survey observations like glacier melt and expansion data, reported global sea level rise is accelerating each decade (Blunden 2022, Lindsay 2022).

RELEVANCE TO RESILIENCY IN WATER MANAGEMENT

Monitoring tidal water level data, along with inland levels, is crucial for resilience planning and management for several reasons:

- **Flood Risk Assessment:** Water level data helps assess the risk of flooding, especially in low-lying areas and areas near rivers or lakes. Tidal water level data specifically in directly and indirectly tidally influenced areas, is essential for coastal regions as it provides critical information about the potential for flooding from rainfall and extreme weather events, such as hurricanes or tropical storms, high tides and king tides, and high groundwater levels and storm surge, both inland (upstream) and along coastal areas (downstream). Capturing and understanding these flood drivers allow for comprehensive assessments of flood risks in the region.

- **Saltwater Intrusion Monitoring:** In coastal areas, tidal water level data is essential for understanding the movement of seawater into freshwater sources. This is particularly relevant in localized areas where groundwater wellfields are at risk of contamination, which can have severe consequences.

- **Resilience Planning:** Continuously monitoring and assessing tidal water levels aids in identifying patterns and trends related to flooding. This information is vital for developing effective resilience plans and strategies to mitigate the impacts of flooding on communities, infrastructure, and the environment.

- **Infrastructure Management:** Many critical infrastructures, such as roads, bridges, and drainage systems, are susceptible to flooding. Monitoring tidal water levels helps ensure that these structures are designed/enhanced and maintained to withstand potential flood events, thereby enhancing their resilience.

- **Emergency Response and Preparedness:** Timely and accurate tidal water level data allows for better emergency response during flooding events. This data enables agencies to issue timely warnings to residents, activate flood control measures, and allocate resources effectively to protect communities and property.
- **Environmental Protection:** Understanding the implications of changing water levels is vital for preserving natural habitats and ecosystems. Proper management of tidal water levels helps maintain the balance between freshwater and saltwater environments, protecting fragile ecosystems and water resources.

COMMENTS AND RECOMMENDATIONS

Monitoring tidal water level data, along with inland water levels, is essential for making informed decisions and implementing effective resilience strategies. These measures are essential to safeguard communities, infrastructure, and the water resources and ecosystems from the risks posed by various climate-related factors, such as sea level rise, changing rainfall patterns and extreme events, such as storm surge.

All observed trends in tidal elevation at SFWMD’s 32 coastal structures (**Figure 2B-1**), located along South Florida’s east and west coasts, show statistically significant upward trajectories. These trends are supported by multiple sources of data and analyses, consistently reinforcing increased rates of sea levels in the last century and accelerating rates in more recent years. It is crucial, however, to approach the interpretation of specific values with careful consideration, as different studies adopt varying analytical approaches, site selections, number of sites, periods of record, and analysis periods.

As evident upward trends due to sea level rise, understanding how contributing factors and conditions will continue to evolve in the future becomes increasingly important. Increasing flood occurrences and saltwater intrusion risks will demand continuous investments in resilience adaptation.

To address these risks, SFWMD and other water management agencies in South Florida are actively engaged in comprehensive flood resiliency studies, conducting modeling exercises to assess system vulnerabilities, and developing adaptive strategies to ensure the resilience and effectiveness of coastal gravity structures under changing climatic conditions.

TRENDS IN MINIMUM FLOWS AND MINIMUM WATER LEVELS IN SOUTH FLORIDA

BACKGROUND

Minimum flows and minimum water levels (MFLs) are defined as the minimum flows or minimum water levels for select water bodies, at which further permitted water withdrawals would be significantly harmful to the water resources or ecology of the area. MFLs are adopted by the SFWMD Governing Board pursuant to Sections 373.042 and 373.0421, Florida Statutes, and are an integral part of water resource management in South Florida. MFLs ensure the long-term viability of water resources and the protection of natural systems. SFWMD has a statutory obligation to identify key water bodies for which an MFL should be developed where there is the existence of, or potential for, significant harm to the water resources or ecology of the state or region and includes water bodies that are experiencing or may reasonably be expected to experience adverse impacts. The establishment and implementation of MFLs are essential tools for maintaining the resilience of aquatic ecosystems and supporting adaptive water management practices amid changing climate conditions and associated environmental challenges. Adopted MFLs for water bodies within SFWMD boundaries, and their criteria, are contained in Chapter 40E-8, F.A.C.

Minimum flows refer to the minimum amount of water flow that must be maintained in a water body, such as rivers, streams, and estuaries to ensure the ecological health and well being of the ecosystem. These flows are essential to sustain the natural functions of the water body, support the habitat of aquatic species, and prevent environmental degradation. Similarly, minimum water levels refer to the minimum water elevation required in lakes, wetlands, and aquifers to preserve their ecological integrity and support associated ecological communities. MFLs are based on scientific studies and data analysis conducted by water management agencies to determine the necessary water quantities needed to support and prevent significant harm in the ecosystems and the associated plant and animal species.

Setting MFLs is a complex process that involves scientific assessments, data collection, stakeholder input, and consideration of various ecological and hydrological factors. SFWMD evaluates the needs of different water bodies and their ecological systems to determine the appropriate MFLs. MFLs help prevent over-extraction of water by permitted users and promote sustainable water management practices in the region.

SFWMD develops and adopts recovery or prevention strategies simultaneously with MFL rule adoption. Recovery or prevention strategies include the development of additional water supplies and other actions, consistent with the authority granted in statute to achieve recovery to the established minimum flow or minimum water level as soon as practicable; or prevent the existing flow or water level from falling below the established minimum flow or minimum water level. These MFL recovery or prevention strategies can consist of multiple components, including capital projects (water control, conveyance, storage), environmental projects (habitat enhancements, operational changes), regulatory measures and requirements, water shortage measures, and other research and monitoring. MFL prevention and recovery strategies are monitored and updated, when necessary, as part of SFWMD’s five-year regional water supply plan update process and rulemaking, as appropriate.

In this initial analysis of MFL criteria for selected water bodies, the presented monitoring serves to introduce the method of identifying and tracking exceedances and violations, while also exploring the interactions that underlie the observation of MFL criteria.

Biscayne Aquifer MFL

The Biscayne aquifer, located in southeastern Florida, is a crucial groundwater resource supporting millions of residents, agriculture, and industries in Miami-Dade, Broward, and Palm Beach counties and is designated as a sole source of drinking water by the United States Environmental Protection Agency (USEPA). However, it faces an ongoing threat of saltwater intrusion, which necessitates the maintenance of adequate freshwater levels within the aquifer to prevent inland migration of saline water.

Beginning in 1939, the aquifer experienced inadequate water levels, leading to high chloride concentrations in over 10,000 water supply wells, and led to the partial loss of five major wellfields (Parker et al. 1955). Since then, various measures have been implemented to protect public and private wellfields from saltwater intrusion, such as constructing coastal water control structures in the 1950s, improving monitoring efforts, and establishing the SFWMD Consumptive Use Permitting program in the 1970s.

To safeguard the Biscayne Aquifer and its associated ecosystems, an MFL with a prevention strategy (Subsection 40E-8.421(3), F.A.C.) was adopted in 2000. The MFL was based on analyses of the relationships between groundwater and canal water levels, and the potential for saltwater intrusion without considering sea level rise. The preservation of the Biscayne aquifer primarily revolves around its function as a water supply source. As a result, the definition of significant harm to this function is based on the extent of movement of the saltwater interface into the vicinity of, and eventually into existing and future water supplies:

> *"The minimum level for the Biscayne aquifer is the level that results in movement of the saltwater interface landward to the extent that ground water quality at an established withdrawal point is insufficient to serve as a water supply source. A MFL violation occurs when water levels within the aquifer produce this degree of saltwater movement at any point in time."* (Subsection 40E-8.231, F.A.C.).

The prevention strategy includes maintaining coastal canal stages, constraints in water use permits, monitoring, research, and water resource and water supply development projects. These components aim to strike a balance between meeting human water demands and preserving the aquifer's ecological health and function. The Lower East Coast regional water supply plan, updated every 5 years, contains the details of the prevention strategy (SFWMD 2018).

The Biscayne aquifer's significance is underscored by the three key water resource functions considered as part of MFL development: (1) providing a primary water supply, (2) supplying base flow to coastal estuaries, and (3) preventing saltwater intrusion. Addressing saltwater intrusion is a principal concern in developing MFL criteria for the aquifer. Ensuring sufficient water levels in coastal canals is vital for recharging the aquifer, maintaining fresh groundwater levels to counter inland movement of saltwater into the aquifer, and meeting the MFL requirements.

For this analysis, technical documents are consulted to reference the established threshold rules, and the water supply plans where needs are identified and projects to address, maintain, or remediate water bodies are characterized. These technical documents are reviewed every five years to gauge compliance and make necessary adjustments.

DRIVERS AND INFLUENCING FACTORS

Biscayne Aquifer MFL

The factors that influence and drive compliance with the Biscayne Aquifer MFL include a combination of natural factors and human activities. Proper management of these factors is essential to preserve the aquifer's ecological health and prevent further saltwater intrusion.

- **Rainfall:** Groundwater levels within the Biscayne aquifer are influenced by local rainfall. Increased rainfall contributes to higher groundwater levels, while drought conditions can lead to lower groundwater levels.
- **Canal Operations:** The canals and structures operated by SFWMD play a significant role in determining the elevation of freshwater levels in the Biscayne aquifer across South Florida.
- **Distance from Canals:** Groundwater dynamics are more influenced by canals and less by rainfall as one moves closer to the primary canal network. The aquifer becomes more rainfall-driven and less canal-dependent as distance from the canals increases.
- **Secondary and Tertiary Canals:** Local canals and water storage in the secondary and tertiary canal systems also play a significant role in influencing groundwater dynamics and the Biscayne aquifer's water levels.
- **Wellfield Pumpage:** Pumping water from wellfields for various purposes, including municipal water supply and irrigation, affects groundwater levels in the aquifer. High pumpage can lead to lower groundwater levels and increased potential for saltwater intrusion.
- **Seasonal Variations:** Short-term variations in groundwater levels can temporarily affect the position of the saltwater interface but it typically retreats to its former position once groundwater levels return to normal ranges.

- **Long-Term Low Water Levels:** Historical data indicate that when water levels in the canals and aquifer remain low for an extended period, significant inland migration of the freshwater-saltwater interface may occur, and it could potentially result in permanent movement of the interface even after water levels return to normal or above normal conditions.
- **Saltwater Intrusion:** As the aquifer experiences increased freshwater withdrawals or faces prolonged shortages in inland water levels or drought conditions, the saltwater interface can advance inland, threatening the aquifer's freshwater quality. Over time, the intrusion may cause permanent displacement of the freshwater-saltwater interface, even after water levels return to normal or above-normal conditions.
- **Water Supply Management:** Water supply releases from regional storage sources, such as the Everglades Water Conservation Areas (WCAs), are utilized to achieve dry season drought management targets, which, in turn, influence the adjacent dry season groundwater elevations within the Biscayne aquifer.
- **Consumptive Use Permits:** The consumptive use permit conditions for coastal users aim to maintain a groundwater divide between the withdrawal point and the source of saline water, further protecting the Biscayne aquifer from saltwater intrusion.

SALINITY DATA AND TREND ANALYSIS

Biscayne Aquifer MFL

The Biscayne Aquifer MFL was established based on an analysis of the relationships between groundwater levels, canal stages, chloride concentrations in monitor wells, and the potential for saltwater intrusion. The SWICHA model, a finite-element solute transport flow model, capable of simulating saltwater intrusion in the South Florida area (SFWMD 2000a), was part of the analysis. SWICHA model results showed historical water levels that ranged between the mean (50^{th} percentile) and one standard deviation from the mean (84^{th} percentile) represented the most appropriate levels that would restrict movement of the saline interface without adversely affecting flood control (SFWMD 2000a). Twenty-two years later, canal stage and groundwater chloride or conductivity concentration information has been collected and analyzed again to see what changes have occurred. The initial period of record used was the 20 years from 1980 to 1999. The reanalysis period is from January 2000 to June 2023.

Minimum operating levels (upstream canal stages) are specified at eleven primary canal/water management salinity control structures; C-51/S-155, Lake Worth Drainage District (LWDD) C-16/S-41, LWDD C-15/S-40, Hillsboro/G-56, C-14/S-37B, C-13/S-36, North New River/G-54, C-9/S-29, C-6/S-26, C-4/S-25B, and C-2/S-22 (**Figure 2B-3**). At the time of MFL rule development, the 'Turnpike aquifer' was considered part of the Biscayne aquifer, which is why S-155 is one of the selected structures. The canal water levels that are equivalent to the 84^{th} percentile (**Table 2B-4**) were used to establish the minimum canal operating levels at the structures selected for this MFL. According to the prevention strategy, in order to protect against MFL violations, canal stages cannot fall below the specified levels for more than 180 days, and the average annual stage must be sufficient to allow water levels and chloride concentrations in the aquifer to recover to levels that existed before a drought or discharge event occurred (SFWMD 2000a). Note in **Figure 2B-3**, there are four additional salinity control structures in southern Miami-Dade County—S-123, S-21, S21A and S20F—shown as grey structures; these are not included in the Biscayne aquifer MFL. It was recommended, but never implemented, that an MFL for the portion of the Biscayne aquifer in southern Miami-Dade County be developed concurrently with the development of MFLs for Biscayne Bay, Florida Bay, Card Sound, and Barnes Sound (SFWMD 2000a).

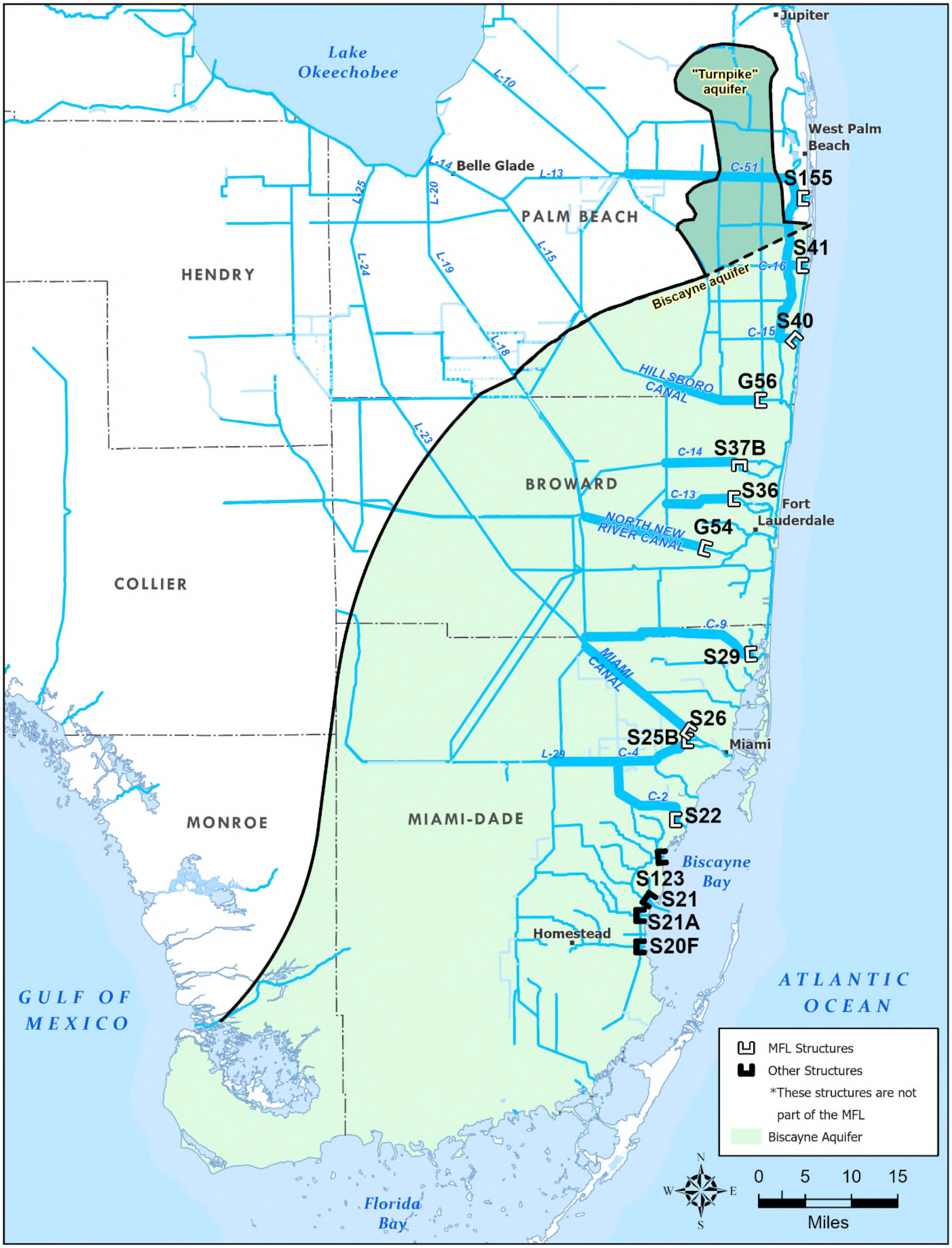


Figure 2B-3. Salinity control structures with Biscayne aquifer MFL minimum operating levels.

Table 2B-4. Summary of statistics for the structures of the Biscayne Aquifer MFL.

A	B	C	D	E	F	G	H
Canal/Water Management Structure	**1980–1999 84th Percentile Stage [a] (ft NGVD29) [b]**	**MOL [c] for MFL Prevention Strategy (ft NGVD29)**	**Number of Times MOL Not Met since Inception [d]**	**1980–1999 Percent of Days below MOL**	**2000–2023 Percent of Days below MOL**	**Structure Optimum Headwater Elevation [e] (ft NGVD29)**	**1980–1999 Average Annual Stage (ft NGVD29)**
C-51/S-155	7.74	7.80	0	16%	13%	8.0	8.14
C-16/S-41	7.72	7.80	0	13%	13%	8.2	8.17
C-15/S-40	7.59	7.80	0	23%	22%	8.2	8.05
Hillsboro/G-56	6.75	6.75	0	19%	17%	7.5	7.11
C-14/S-37B	6.6	6.50	0	7%	25%	7.0	6.87
C-13/S-36	4.15	4.00	0	8%	16%	4.5	4.44
North New River/G-54	3.28	3.50	0	27%	18%	4.0	3.69
C-9/S-29	1.9	2.00	0	25%	28%	2.0	2.10
Miami C-6/S-26	2.07	2.50	1	38%	46%	2.5	2.41
C-4/S-25B	1.95	2.50	2	53%	47%	2.8	2.35
C-2/S-22	2.04	2.50	0	22%	23%	2.9	2.82

A	I	J	K	L	M	N	O
Canal / Water Management Structure	**2000–2023 Average Annual Stage (ft NGVD29)**	**2000–2023 Average Annual Wet Season Stage (ft NGVD29)**	**2000–2023 Average Annual Dry Season Stage (ft NGVD29)**	**2000–2004 Average Stage Tidal [f] (ft NGVD29)**	**2018–2022 Average Stage Tidal [f] (ft NGVD29)**	**2000–2004 Average Stage Difference between Canal and Tidal (feet)**	**2018–2022 Average Stage Difference between Canal and Tidal (feet)**
C-51/S-155	8.14	8.03	8.21	0.78	1.19	7.49	6.91
C-16/S-41	8.04	7.99	8.08	0.91	1.30	7.22	6.67
C-15/S-40	7.97	7.97	7.97	0.74	1.21	7.37	6.71
Hillsboro/G-56	7.36	7.09	7.56	1.06	1.41	6.15	6.33
C-14/S-37B	6.79	6.69	6.86	3.55	3.82	3.28	2.97
C-13/S-36	4.41	4.28	4.50	1.00	1.43	3.29	3.13
North New River/G-54	3.97	3.81	4.09	1.24	1.41	2.55	2.51
C-9/S-29	2.13	2.00	2.22	0.82	1.18	1.31	0.98
Miami C-6/S-26	2.32	2.14	2.46	1.00	1.34	1.33	1.08
C-4/S-25B	2.40	2.14	2.59	1.01	1.36	1.25	1.18
C-2/S-22	2.74	2.63	2.82	0.78	1.30	2.11	1.30

a. Calculate 1 standard deviation (84th percentile) and then subtract from the mean (50th percentile) stage.
b. NGVD29 – National Geodetic Vertical Datum of 1929.
c. MOL – Minimum Operating Level.
d. Not met when canal headwater stage remains below MOL for more than 180 days.
e. 'Normal' optimum for structure. Structure information updated for Palm Beach and Broward counties in 2022, and Miami-Dade in 2020.
f. Downstream stage at all structures except S-37B is tidal.

Information on stages at the eleven structures is presented in **Table 2B-4**. Column C lists the minimum operating levels and column B provides the information (i.e., 84^{th} percentile values) used to establish the minimum operating levels. Column D lists the number of times that minimum operating level was not met for more than 180 days in a year since the MFL was established. Daily stage data for the 1980–1999 period, which was the initial analysis period prior to the MFL, and data for the 2000–2022 period since the MFL was established, was used to calculate the percent of days the upstream canal stages were below the minimum operating levels (columns E and F). Each structure operates to maintain an optimum headwater elevation (column G) with seasonal variability, which helps water levels in the aquifer to recover to levels that existed before a drought or discharge event occurred. The average annual stage in the 1980–1999 period is in column H while column I, the 2000–2022 period average annual stage, can be compared to the structure's optimum headwater elevation and compared to column H to understand how average annual stage may have changed in the following 22 years. The average annual stage should be at or above the minimum operating level. The average annual stage for the 2000–2022 period is subdivided into wet season (column J) and dry season (column K) canal stages to view seasonal operational changes. Note dry season stages meet the minimum operating level at all structures, which is when the aquifer is most vulnerable to the effects of saltwater intrusion and is therefore a positive result. Finally, columns L and M show how average tidal elevations have changed from the initial 5 years of MFL development and adoption (2000–2004) to the most recent 5 years (2018–2022) and columns N and O provide the difference between the upstream canal stage and downstream tidal stage at each structure for the two time periods. Note that downstream of S-37B is not tidal. Discussion of observations at each structure are provided below and summarized in the following *Results and Discussion* subsection.

The SFWMD saltwater interface monitoring and mapping program was established to evaluate the extent of seawater encroachment into aquifers along the South Florida coastline with the exception of Miami-Dade County, which has retained the United States Geological Survey (USGS) to conduct its mapping (Prinos, et. al 2014, Prinos 2017). SFWMD began mapping the approximate location of the saltwater interface in its coastal aquifers in 2009, with updated maps every 5 years (2014 and 2019 to date). The 2019 SFWMD saltwater interface maps are available on SFWMD's webpage at https://www.sfwmd.gov/documents-by-tag/saltwaterinterface and are due to be updated in 2024.

Electromagnetic (EM) induction logs record the electrical conductivity of the rocks and water within the borehole (well). Higher values indicate higher salinity. A value of 60 to 70 microSeimens/second (µS/s) bulk conductivity is usually correlated to approximately 1,000 milligrams per liter (mg/L) of chloride concentration, although the full range that correlates is 30 to 250 µS/s bulk conductivity (Prinos and Valderrama 2016). Annual logs of select monitor wells are combined to show the progressive changes in conductivity over time for the entire depth of the well.

The following discussion provides data and analyses in the vicinity of each of the 11 salinity control structures associated with the Biscayne aquifer MFL. Evidence of sea level rise at each structure is presented along with a local saltwater interface map and nearby monitoring well data. The monitor well with electronic induction logs, closest to the MFL structure, where available, is presented for discussion purposes for all 11 structures. The map itself shows that the position of the interface can be greatly affected by the wellfield location, such that intrusion can occur at distance from the control structure. Average upstream and downstream stages in the following descriptions are the most recent 5-year average (2018–2022) from columns I and M of **Table 2B-4**.

Salinity Control Structure S-155 (West Palm Beach C-51 Canal)

The SFWMD C-51 canal minimum operation level is 7.8 feet (ft) National Geodetic Vertical Datum of 1929 (NGVD29) (green line) and the average headwater stage in the canal is 8.1 ft NGVD29, which is more than seven ft higher than the downstream tidal stage of 1.2 ft NGVD29 (**Figure 2B-4**). Groundwater levels are also supported by the canals of the Lake Worth Drainage District, which extend to within 1.5 miles of the coast and provide recharge to the aquifer and reduce the threat of saltwater intrusion. Monitor well PB-1723 is in the general vicinity of the S-155 salinity control structure. Based on the induction logs (**Figure 2B-5**), salinity at this location has steadily increased at the base of the aquifer below 270 ft below land surface (bls) (i.e., the most recent induction log, April 19, 2022, shows the highest bulk conductivity values). It has shown some increases near land surface where it is influenced by tidal canals east of the control structure. There has been some decrease in salinity between 170 and 260 ft bls. This is also shown on the map as the 2019 saltwater interface position (red line) eastward of the 2014 and 2009 positions (green and black dashed lines). The City of Lake Worth Beach reduced withdrawals east of I-95 and added Floridan aquifer system supply wells as an alternative water supply source in 2012, which resulted in the interface retreating towards the coast in the area.

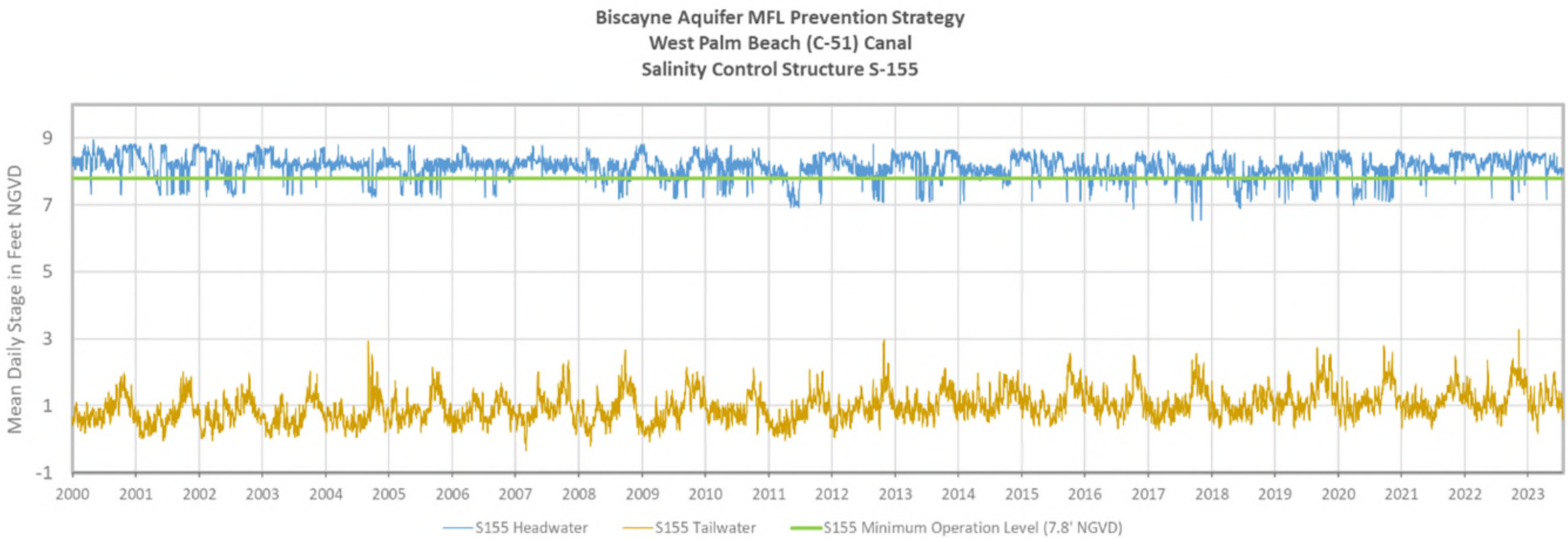


Figure 2B-4. Structure S-155 headwater and tailwater plotted relative to the minimum operation level. (Note: NGVD – National Geodetic Vertical Datum of 1929.)

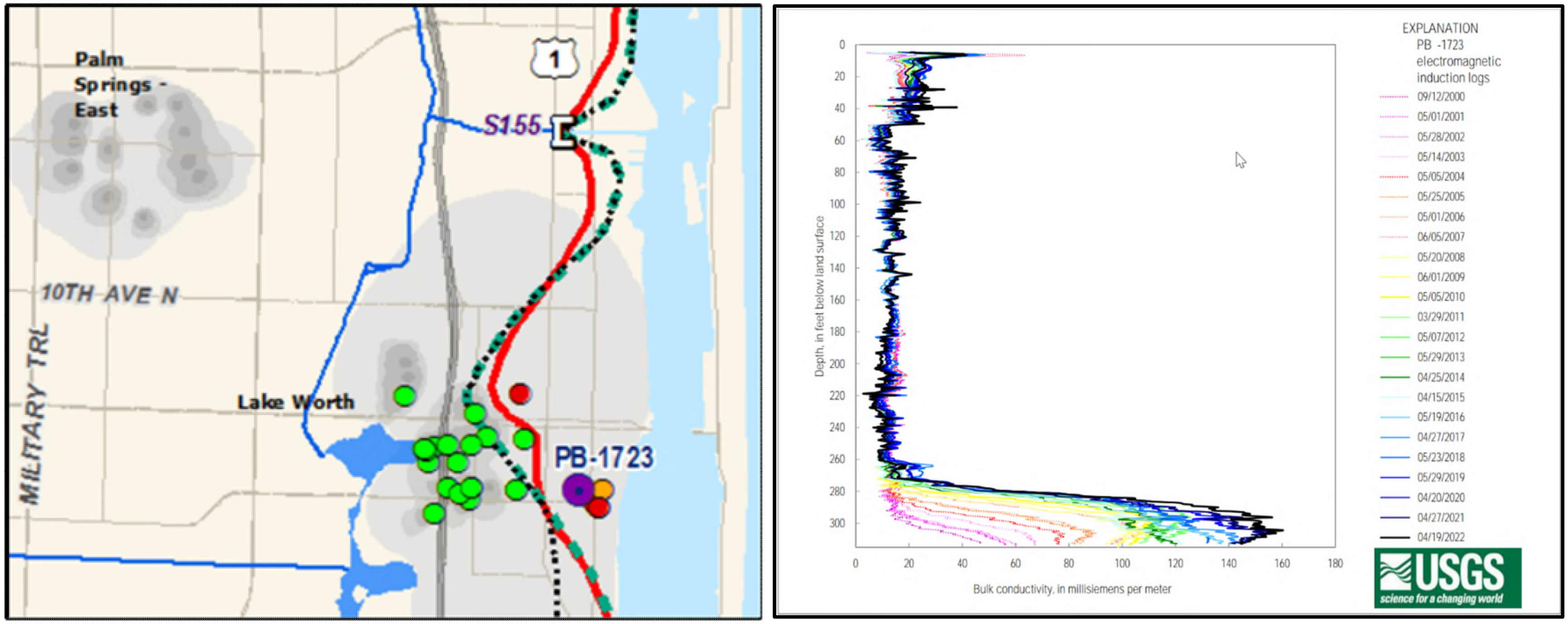


Figure 2B-5. Saltwater interface (left panel; SFWMD 2019[4]) and induction logs (right panel; USGS 2023) for monitor well PB-1723 (318 ft deep) in Lake Worth Beach near structure S-155.

[4] https://www.sfwmd.gov/sites/default/files/documents/PalmBeach_%20Isochlor_2019RR%2836X64%29.pdf.

Salinity Control Structure S-41 (C-16 Canal)

The C-16 Canal minimum operation level is 7.8 ft NGVD29 (green line) and the average headwater stage in the canal is 8.0 ft NGVD29, which is more than 6 ft higher than the downstream tidal stage of 1.3 ft NGVD29 (**Figure 2B-6**). Groundwater levels are also supported by the canals of the Lake Worth Drainage District, which extend to within 1.5 miles of the coast and provide recharge to the aquifer and reduce the threat of saltwater intrusion. While the minimum operation level is being met at the salinity control structure, the Boynton Beach public supply wellfield, not being in the same place as the structure, is affecting the interface position due to pumpage. The induction logs for monitor well PB-1195 (**Figure 2B-7**, right panel), near the public supply wellfield, indicate steady increases in salinity below 200 ft bls (i.e., the most recent induction log, September 15, 2022, shows the highest bulk conductivity values). There was a decrease in salinity, especially between 110 and 150 ft bls, from 2000 to 2011, with slight increases from 2012 to 2017. Changes in the eastern Boynton Beach public supply wellfield operations, addition of an aquifer storage and recovery (ASR) well, and use of reclaimed water reduced demand and therefore improved salinities in groundwater shallower than approximately 200 ft bls shown on the map in **Figure 2B-7** (left panel) as the 2019 saltwater interface position (red line) eastward of the 2014 and 2009 positions (green and black dashed lines).

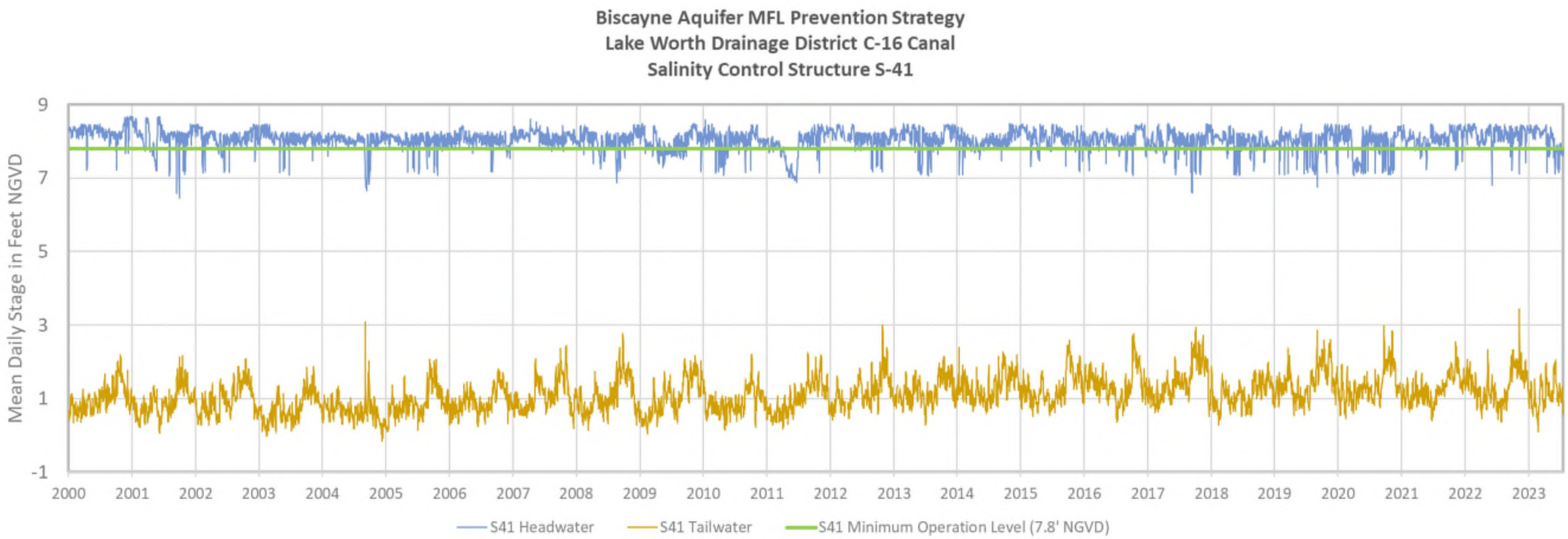


Figure 2B-6. Structure S-41 headwater and tailwater plotted relative to the minimum operating level.

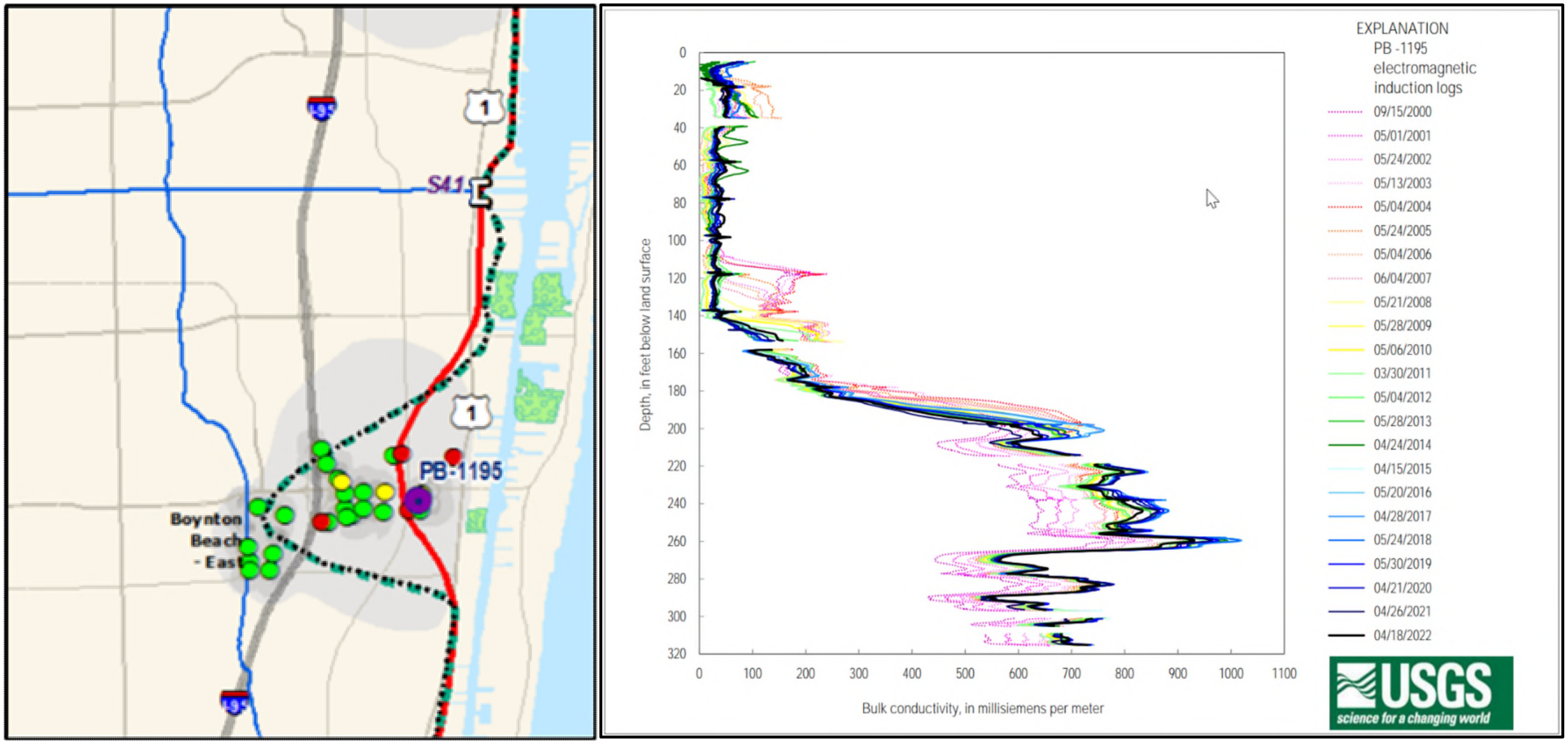


Figure 2B-7. Saltwater interface (left panel; SFWMD 2019[5]) and induction logs (right panel; USGS 2023) for monitor well PB-1195 (325 ft deep) in Boynton Beach near structure S-41.

[5] https://www.sfwmd.gov/sites/default/files/documents/PalmBeach_%20Isochlor_2019RR%2836X64%29.pdf.

Salinity Control Structure S-40 (C-15 Canal)

The C-15 Canal minimum operation level is 7.8 ft NGVD29 (green line) and the average headwater stage in the canal is 8.0 ft NGVD29, which is more than 6 ft higher than the downstream tidal stage of 1.2 ft NGVD29 (**Figure 2B-8**). Groundwater levels are also supported by the canals of the Lake Worth Drainage District, which extend to within 1.5 miles off the coast and provide recharge to the aquifer and reduce the threat of saltwater intrusion. While the minimum operation level is being met at the salinity control structure, the Delray Beach public supply wellfield, not being in the same place as the structure, is affecting the interface position due to pumpage. The induction logs for monitor well PB-1714R (**Figure 2B-9**, right panel), in the vicinity of the public supply wellfield, tell a mixed story. They indicate increases in salinity 20 to 35 ft bls and slight increases below 140 ft bls (i.e., the most recent induction log, April 20, 2022, shows the highest bulk conductivity values). Reductions in salinity are noted above 20 ft bls and in the 40 to 120 ft bls range. The public supply wells in the Eastern wellfield range from 36 to 100 ft bls. Delray Beach began moving the primary public supply withdrawals further west from the coastal saline water in the 1980s. This monitor well is located near the tidal Intracoastal Waterway, influenced by sea level rise and freshwater recharge at ground surface (**Figure 2B-9**, left panel). The change in the position of the saltwater interface in 2019 (red line) was due to new data points, which allowed a more refined interpretation of it.

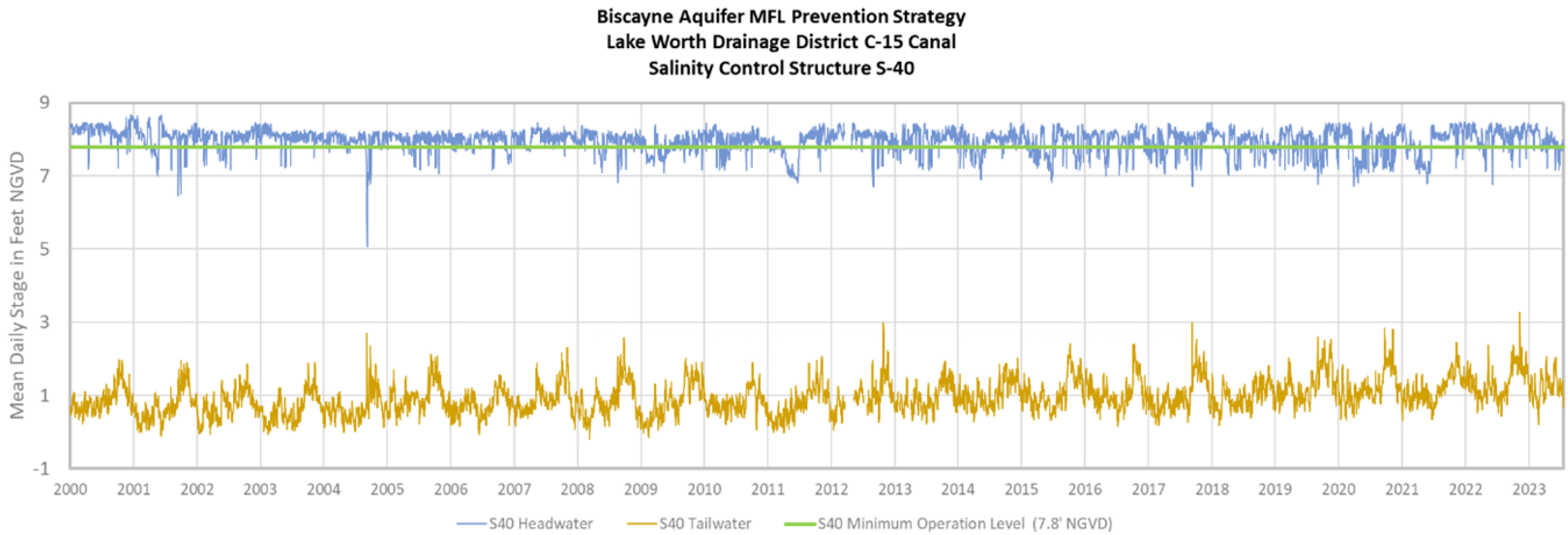


Figure 2B-8. Structure S-40 headwater and tailwater plotted relative to the minimum operation level.

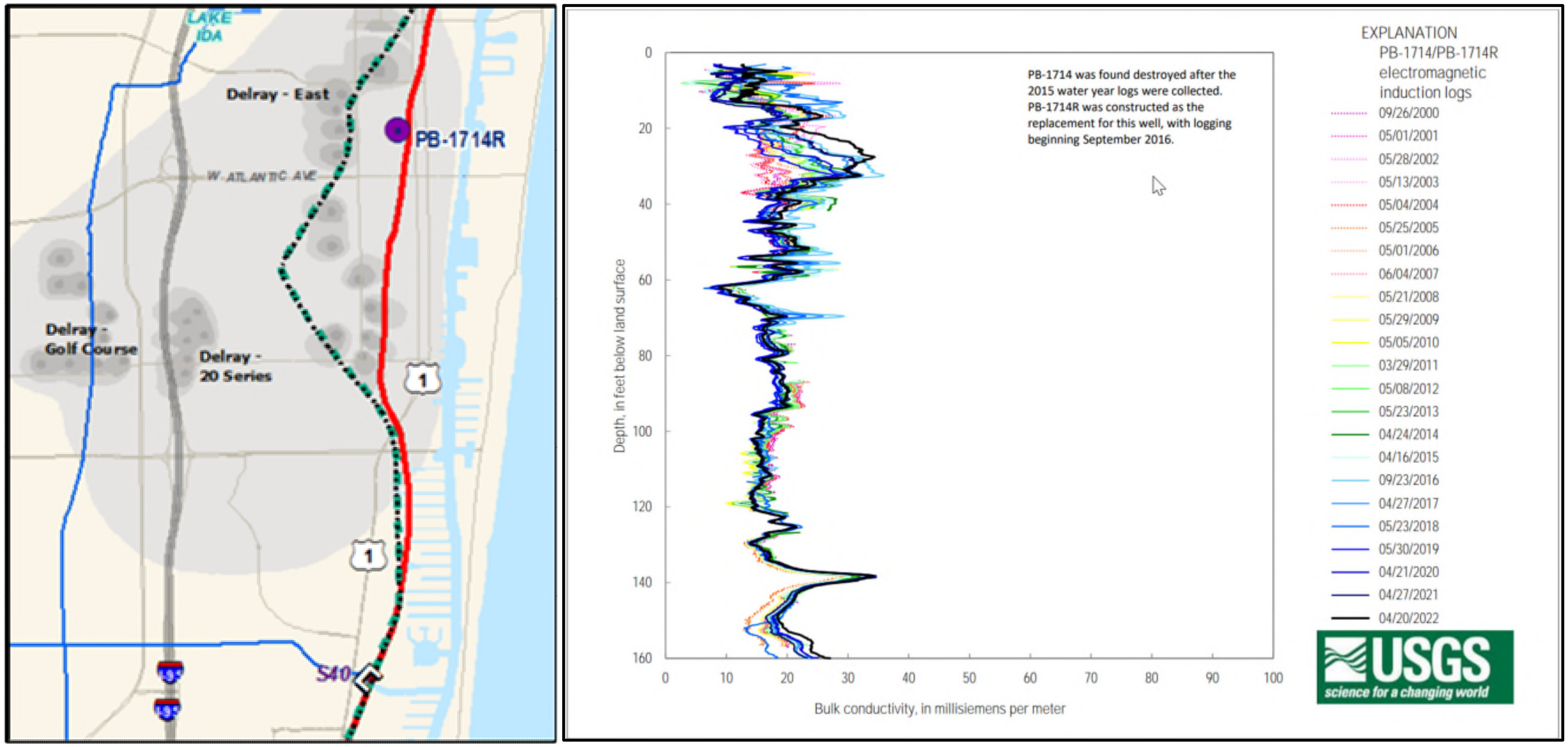


Figure 2B-9. Saltwater interface (left panel, SFWMD 2019[6]) and induction logs (right panel; USGS 2023) for monitor well PB-1714R (screened interval; 151 to 161 ft bls) in Delray Beach located 3 miles north of structure S-40.

[6] https://www.sfwmd.gov/sites/default/files/documents/PalmBeach_%20Isochlor_2019RR%2836X64%29.pdf.

Salinity Control Structure G-56 (Hillsboro Canal)

The SFWMD Hillsboro Canal minimum operation level is 6.75 ft NGVD29 (green line) and the average headwater stage in the canal is 7.4 ft NGVD29, which is more than 5 ft higher than the average downstream tidal stage of 1.4 ft NGVD29 (**Figure 2B-10**). The headwater stage increased beginning in 2012 and a gradual increase in tailwater stage can also be noted. Groundwater levels are also supported by the canals of the North Broward County Recharge System, which extend to within 2.5 miles of the coast and provide recharge to the aquifer and reduce the threat of saltwater intrusion. While the minimum operation level is being met at the salinity control structure, the Deerfield Beach public supply wellfields, seaward of the structure, are affecting the interface position due to pumpage. The saltwater intrusion map (**Figure 2B-11**, left panel) indicates a change in the position of the saltwater interface in 2019 (red line); however, this is due to new data which allowed a more refined interpretation of the position. The induction logs for G-2893 (**Figure 2B-11**, right panel), located south of the G-56 salinity structure on the eastern side of U.S. Highway 1 between Deerfield Beach and Hillsboro Beach, indicate reduced salinity from 10 to 40 ft bls, which corresponds to the timeframe when the Hillsboro Canal began operating with higher stages. Salinity is fairly stable in the 40- to 120-ft depths, which correspond to the Deerfield Beach public supply Eastern wellfield depths of 60 to 100 ft. However, increasing salinity is occurring below 120 ft bls, within the zone of the Deerfield Beach Western wellfield (60 to 200 ft bls) with more rapid increases below 160 ft bls (i.e., the most recent induction log, April 19, 2022, shows the highest bulk conductivity values).

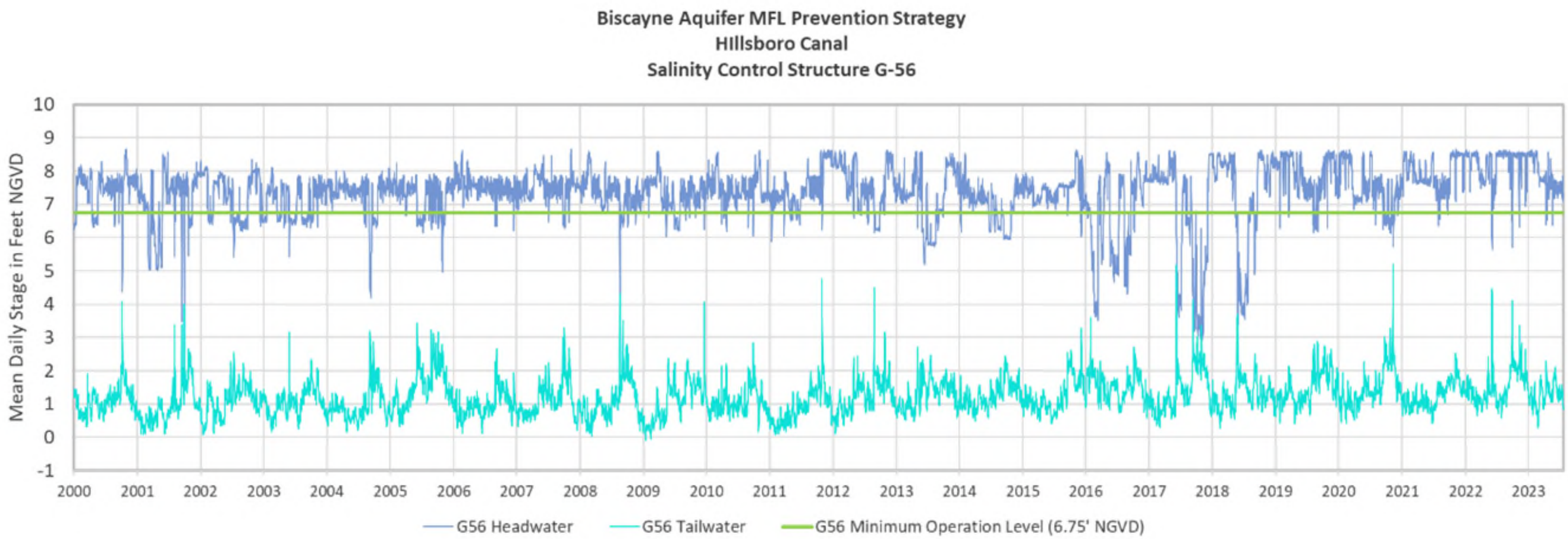


Figure 2B-10. Structure G-56 headwater and tailwater plotted relative to the minimum operation level.

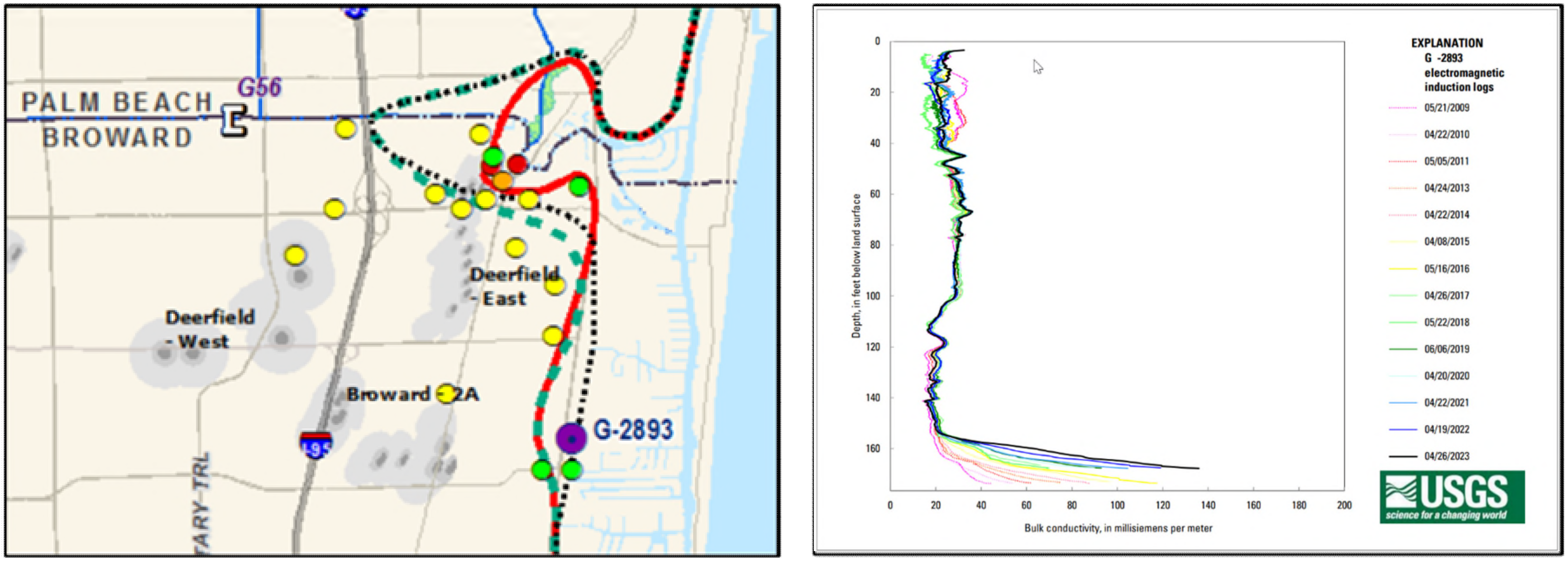


Figure 2B-11. Saltwater interface (left panel; SFWMD 2019[7]) and induction logs (right panel; USGS 2023) for monitor well G-2893 (177 ft deep) near Hillsboro Beach and structure G-56.

[7] https://www.sfwmd.gov/sites/default/files/documents/Broward_%20Isochlor_2019R.pdf.

Salinity Control Structure S-37B (Cypress Creek C-14 Canal)

The SFWMD Cypress Creek canal minimum operation level is 6.5 ft NGVD29 (green line) and the average headwater stage in the canal is 6.8 ft NGVD29, which is 3 ft higher than the average downstream stage of 3.8 ft NGVD29 (**Figure 2B-12**), which is not tidal until downstream of S-37A. The headwater stage increased beginning in mid-2011 and a gradual increase in tailwater stage can also be noted. While the minimum operation level is being met at the salinity control structure, the Pompano Beach Airport wellfield is seaward of the structure and affecting the interface position due to pumpage. The saltwater intrusion map (**Figure 2B-13**, left panel) indicates that the 2019 saltwater interface position has moved inland towards the Pompano Beach public supply wellfields compared to the 2014 and 2009 positions (green and black dashed lines). The movement of the saltwater interface through monitor well G-2896 as the wedge of saltwater moves inland can be seen in the chlorides versus time graphic presented in **Figure 2B-13** (right panel). Note the proximity of this well to the tidally influenced canals on **Figure 2B-13**.

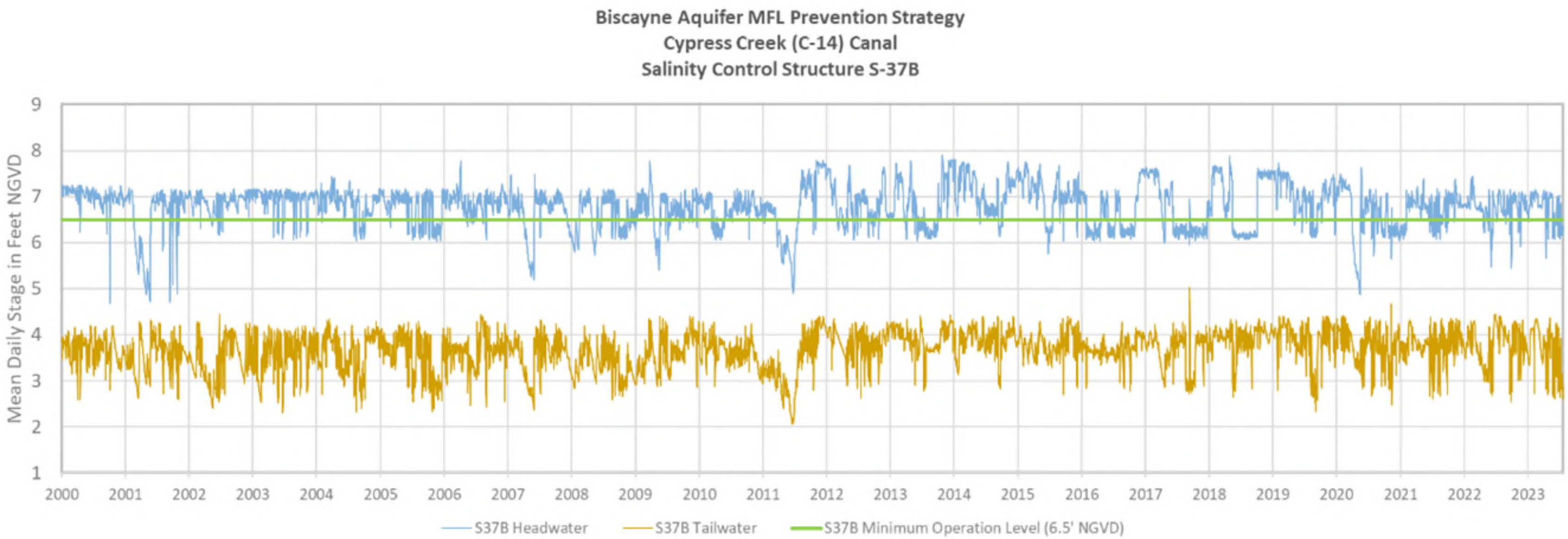


Figure 2B-12. Structure S-37B headwater and tailwater plotted relative to the minimum operation level.

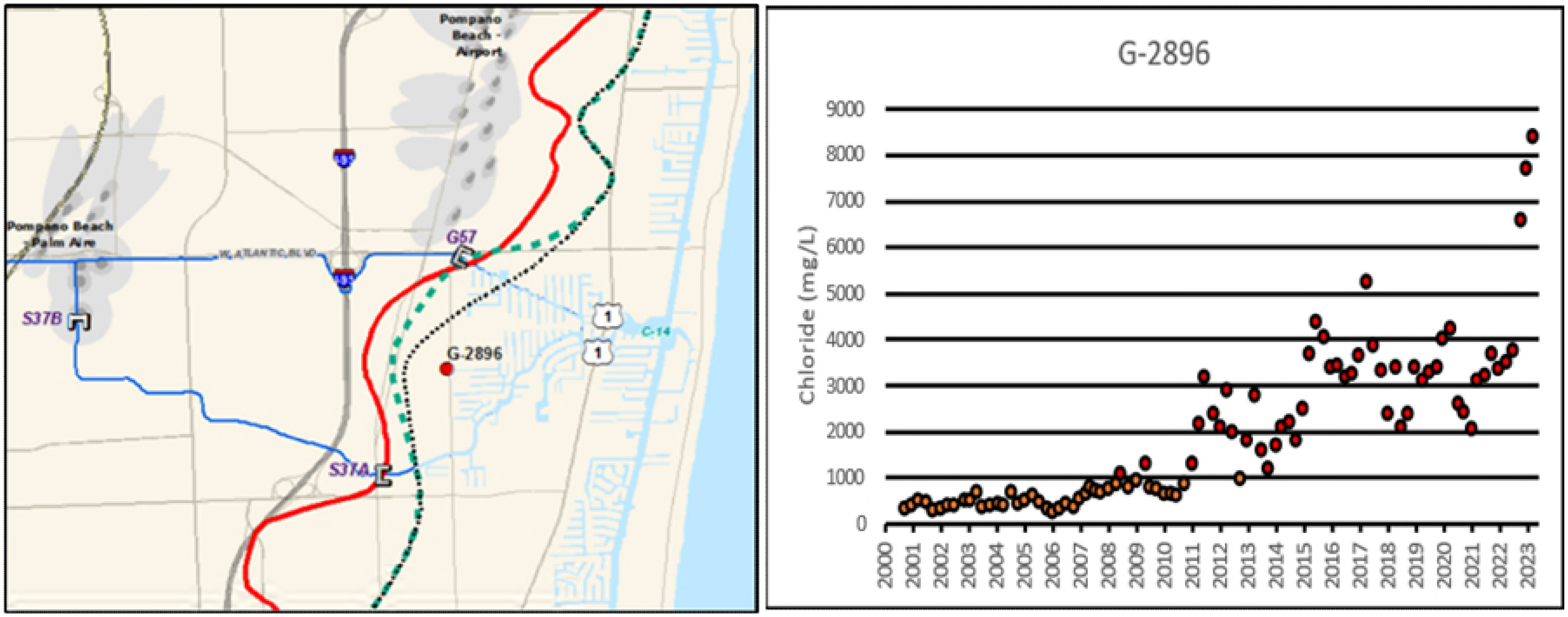


Figure 2B-13. Saltwater interface in Pompano Beach (left panel, SFWMD 2019[8]) and time series plot of chloride concentration in monitor well G-2896 (101 ft bls) near structure G-57 (right panel).

[8] https://www.sfwmd.gov/sites/default/files/documents/Broward_%20Isochlor_2019R.pdf.

Salinity Control Structure S-36 (Middle River C-13 Canal)

The SFWMD Middle River Canal minimum operation level is 4.0 ft NGVD29 (green line) and the average headwater stage in the canal is 4.4 ft NGVD29, which is approximately 3 ft higher than the average downstream tidal stage of 1.4 ft NGVD29 (**Figure 2B-14**). A gradual increase in average tailwater stage can be noted. While the minimum operation level is being met at the salinity control structure, the Fort Lauderdale public supply Prospect wellfield and Lauderhill wellfields, not being proximal to the structure, are able to affect the interface position due to pumpage. The saltwater intrusion map (**Figure 2B-15**, left panel) indicates that the 2019 saltwater interface position (red line) has moved inland from the 2014 and 2009 positions (green and black dashed lines). Monitor well G-2897, 2.25 miles east of the S-36 structure, records a steady increase in chloride concentration since it began being monitored in 2000 (**Figure 2B-15**, right panel), indicating continued inland movement of saline water.

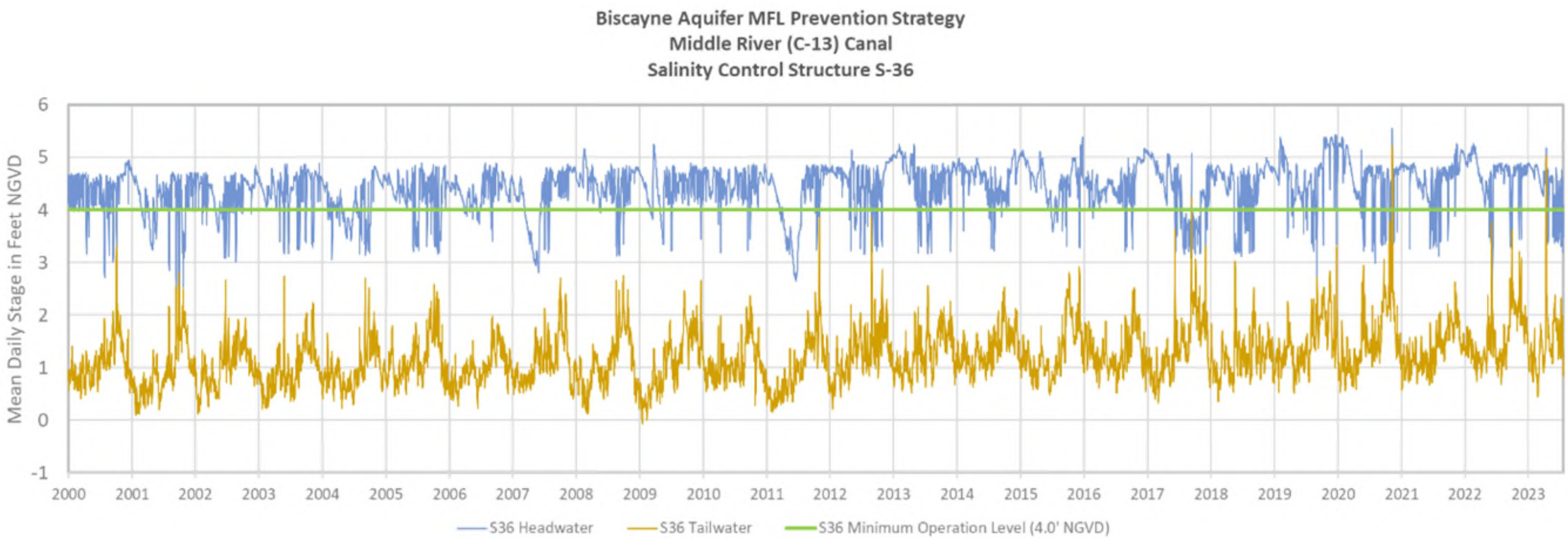


Figure 2B-14. Structure S-36 headwater and tailwater plotted relative to the minimum operation level.

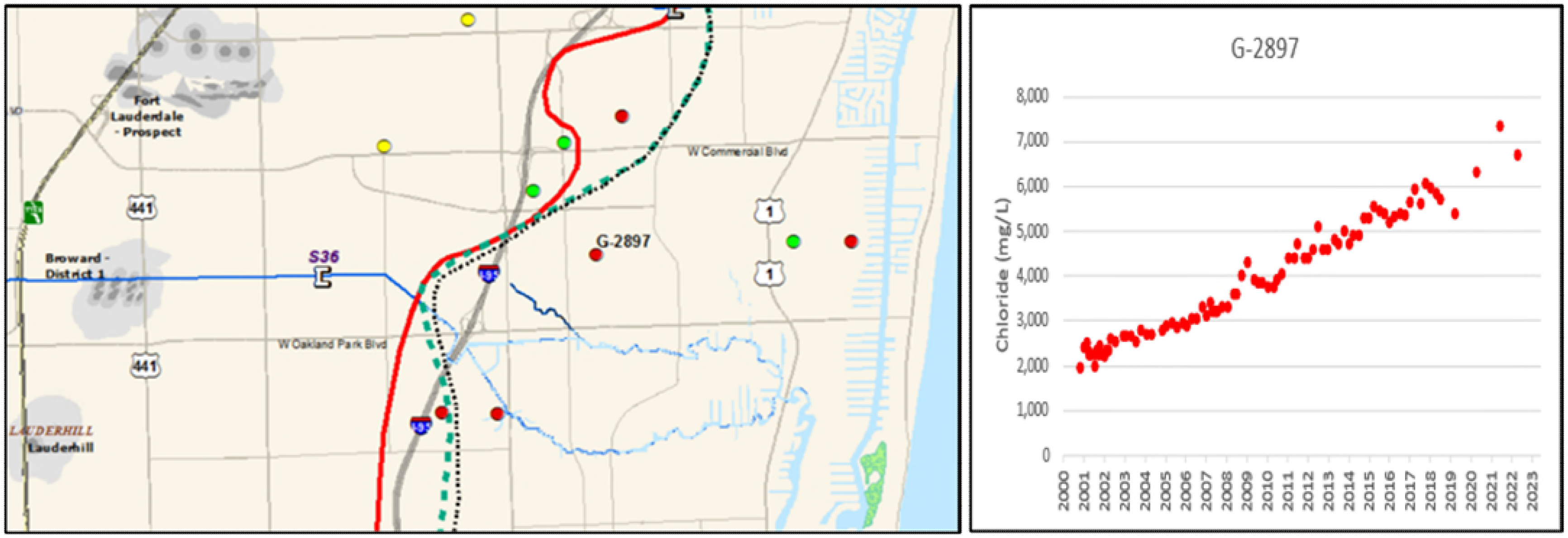


Figure 2B-15. Saltwater interface in Oakland Park (left panel; SFWMD 2019[9]) and time series plot of chloride concentration in monitor well G-2897 (135.5 ft bls), 2 miles east of structure S-36 (right panel).

[9] https://www.sfwmd.gov/sites/default/files/documents/Broward_%20Isochlor_2019R.pdf.

Salinity Control Structure G-54 (North New River Canal)

The SFWMD North New River Canal minimum operation level is 3.5 ft NGVD29 (green line) and the average headwater stage in the canal is 3.97 ft NGVD29, which is approximately 2.5 ft higher than the average downstream tidal stage of 1.4 ft NGVD29 (**Figure 2B-16**). An increase in the upper limit of the headwater stage can be seen after 2008 and a gradual increase in average tailwater stage can be noted. While the minimum operation level is being met at the salinity control structure, the Fort Lauderdale, Tindall_Hammock, and Davie public supply wellfields are seaward of the structure and affect the interface position due to pumpage. The saltwater intrusion map (**Figure 2B-17**, left panel) indicates that the 2019 saltwater interface position (red line) has moved inland near Ft. Lauderdale's Peele-Dixie wellfield from the 2014 and 2009 positions (green and black dashed lines, respectively). The large, apparent movement of the interface between 2009 and 2014 south of the North New River Canal is mostly due to additional monitoring points that allowed a more accurate interpretation (i.e., the interface was likely in the 2014 position in 2009). The induction logs for USGS well G-2921 (**Figure 2B-17**, right panel) near Davie indicate the saltwater interface has been steadily moving inland between 65 and 200 ft bls, with a zone of higher salinity water at approximately 115 ft bls (i.e., the most recent induction log, April 27, 2017, shows the highest bulk conductivity values). Davie's public supply wells are approximately 4 miles west of well G-2921 and range from 100 to 150 ft bls. The saltwater interface is approaching the town's North (southwest of Tindall Hammock public supply) and South wellfields, especially in the more transmissive zone around 115 ft bls. Water quality is monitored by the Town of Davie at four locations between the saltwater interface and the public supply wellfields.

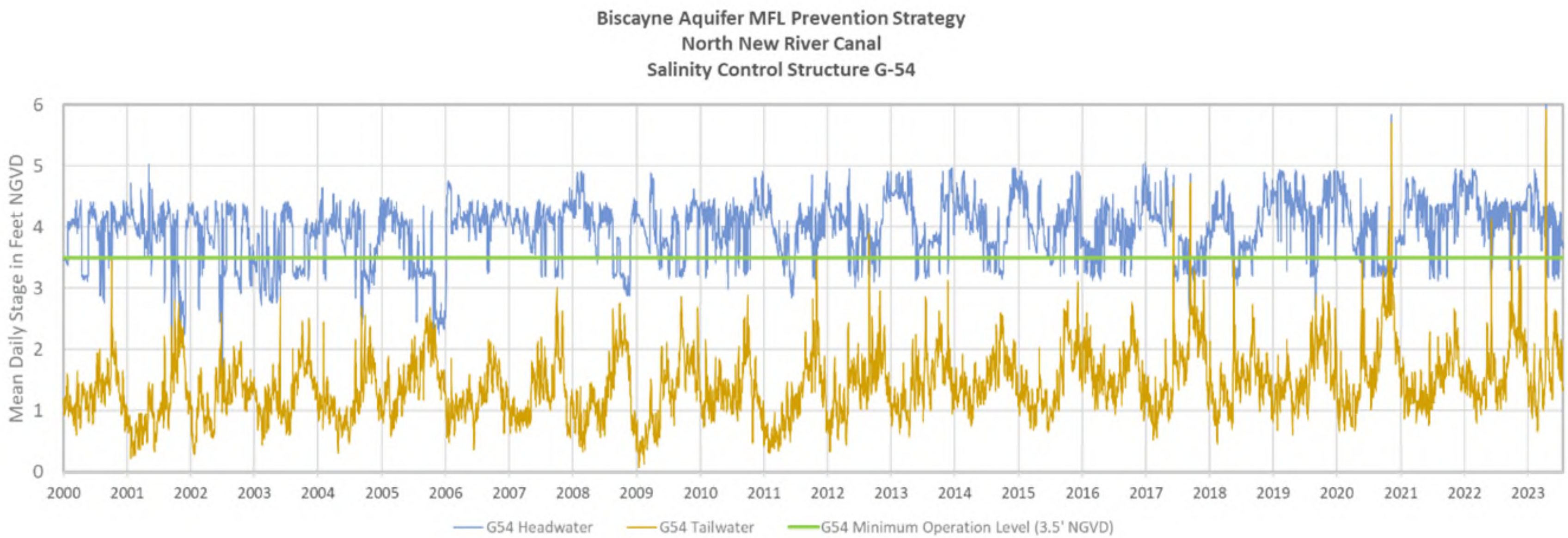


Figure 2B-16. Structure G-54 headwater and tailwater plotted relative to the minimum operation level.

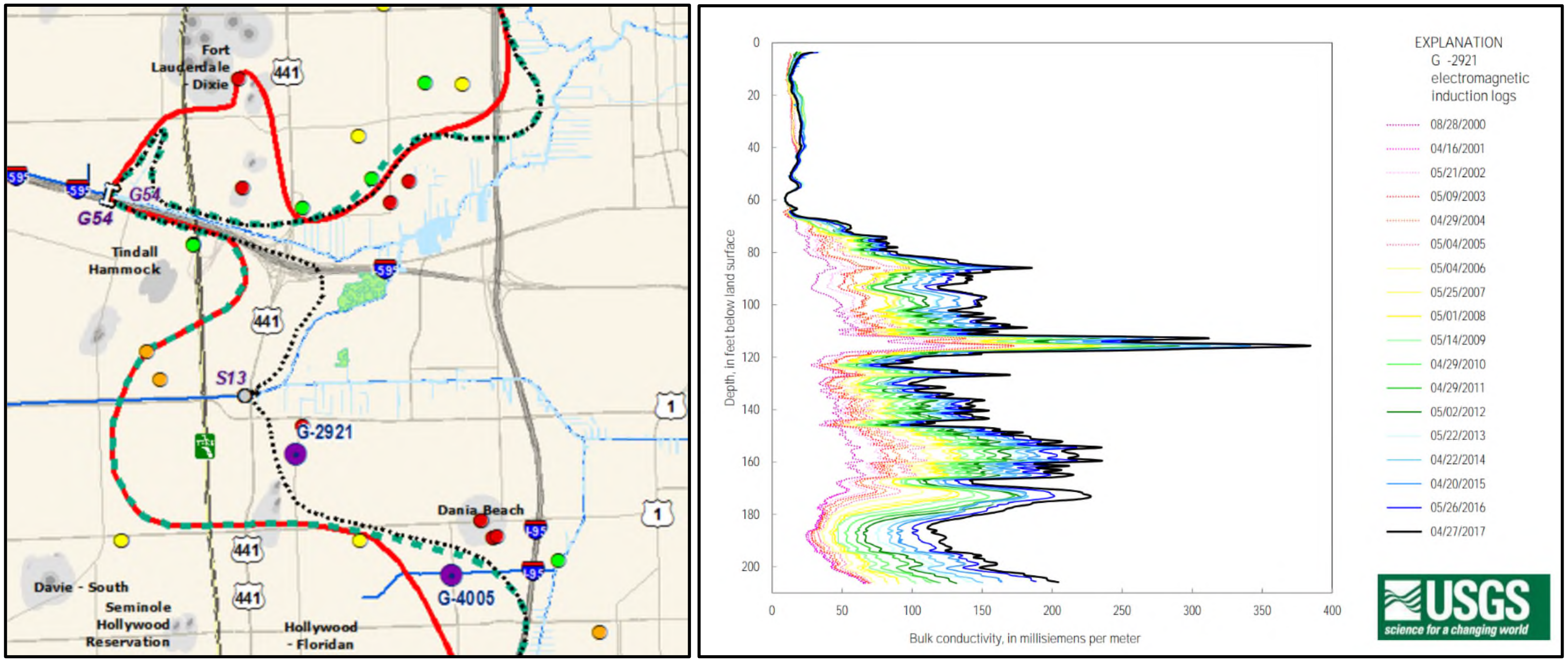


Figure 2B-17. Saltwater interface (left panel; SFWMD 2019[10]) and induction logs (right panel; USGS 2023) for monitor well G-2921 (210 ft deep) near Davie and structure G-54.

[10] https://www.sfwmd.gov/sites/default/files/documents/Broward_%20Isochlor_2019R.pdf.

Salinity Control Structure S-29 (Royal Glades C-9 Canal)

The SFWMD Royal Glades Canal minimum operation level is 2.0 ft NGVD29 (green line) and the average headwater stage in the canal is 2.1 ft NGVD29, which is approximately 1 ft higher than the average downstream tidal stage at the S-29 structure of 1.2 ft NGVD29 (**Figure 2B-18**). A slight increase in the maximum values of the headwater stage can be seen after 2013 and a gradual increase in average tailwater stage can be noted. As the sea level rises, the tailwater and headwater stages sometimes are similar. The 2016 saltwater interface position (red line) on the saltwater interface map (**Figure 2B-19**, left panel) shows minor inland movement from the 2011 and 2009 positions (green and black dashed lines, respectively). It appears that meeting the minimum operation level and the inland location of the North Miami Beach public supply wellfield near the C-9 Canal is helping limit saltwater intrusion. However, the induction logs for well G-3949D suggest the saltwater interface is steadily moving inland below 155 ft bls (i.e., the most recent induction log, April 11, 2022, shows the highest bulk conductivity values) (**Figure 2B-19**, right panel). The City of North Miami Beach's public supply wells are screened from 50 to 100 ft bls where water quality has remained stable and one well is 100 to 131 ft bls. The city's wells are operated to minimize upward movement of the brackish water below and city monitor wells are deeper than the public supply wells to facilitate that operation. The G-3949D induction log below approximately 275 ft bls does not indicate changes in conductivity because it is a low transmissivity unit of the Tamiami Formation below the Biscayne aquifer.

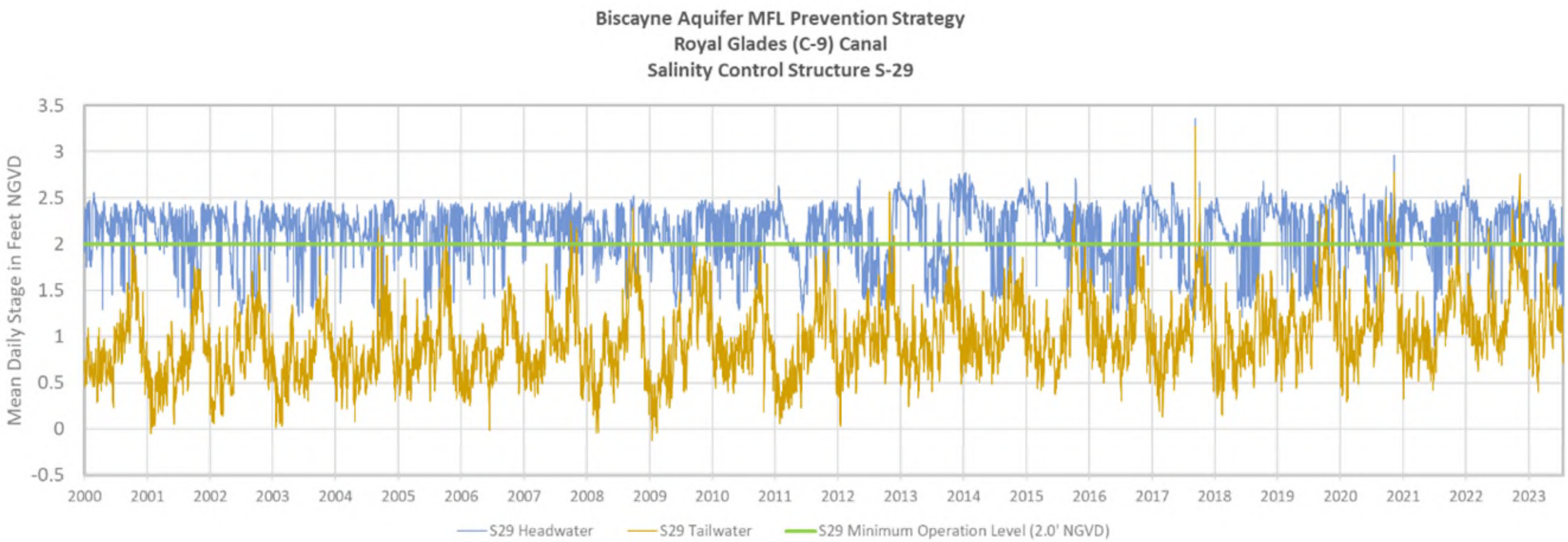


Figure 2B-18. Structure S-29 headwater and tailwater plotted relative to the minimum operation level.

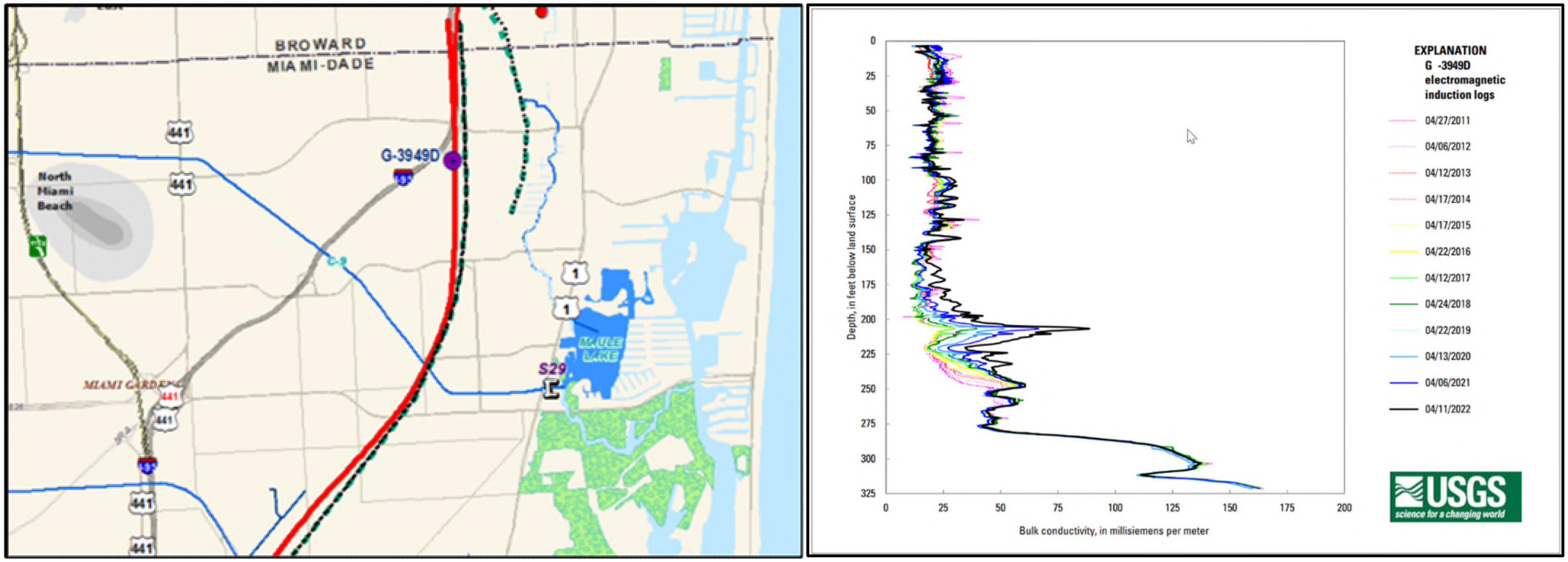


Figure 2B-19. Saltwater interface (left panel; Prinos, et. al 2014, Prinos 2017) and induction logs (right panel; USGS 2023) for monitor well G-3949D (325 ft bls) near North Miami Beach and structure S-29.

Salinity Control Structure S-26 (Miami C-6 Canal)

The SFWMD Miami Canal minimum operation level is 2.5 ft NGVD29 (green line) and the average headwater stage in the canal is 2.3 ft NGVD29, which is approximately 1 ft higher than the average downstream tidal stage of 1.3 ft NGVD29 (**Figure 2B-20**). A gradual increase in average tailwater stage can be noted. The saltwater interface **(Figure 2B-21**) in the vicinity of the S-26 structure moved inland past the S-26 and S-27B structures by 2016 (red line). The average difference between headwater and tailwater has decreased from 1.3 to 1.0 ft (**Figure 2B-22**, left panel). As sea level rises, the tailwater and headwater stages sometimes are similar. Monitor well G-3964 is adjacent to the S-26 salinity control structure. The induction logs for well G-3964 suggest the saltwater interface is steadily moving inland below 100 ft bls (i.e., the most recent induction log, April 7, 2022, shows the highest bulk conductivity values) (**Figure 2B-22**, right panel). The Miami-Dade Hialeah-Preston and Miami Springs wellfields are upstream of the salinity control structure adjacent to the Miami Canal, withdrawing from 80 to 115 feet bls and limited to withdrawals of 70 million gallons per day. The small difference between upstream stages and tidal stages provides minimal aquifer recharge and significant wellfield withdrawals can influence the saltwater interface position.

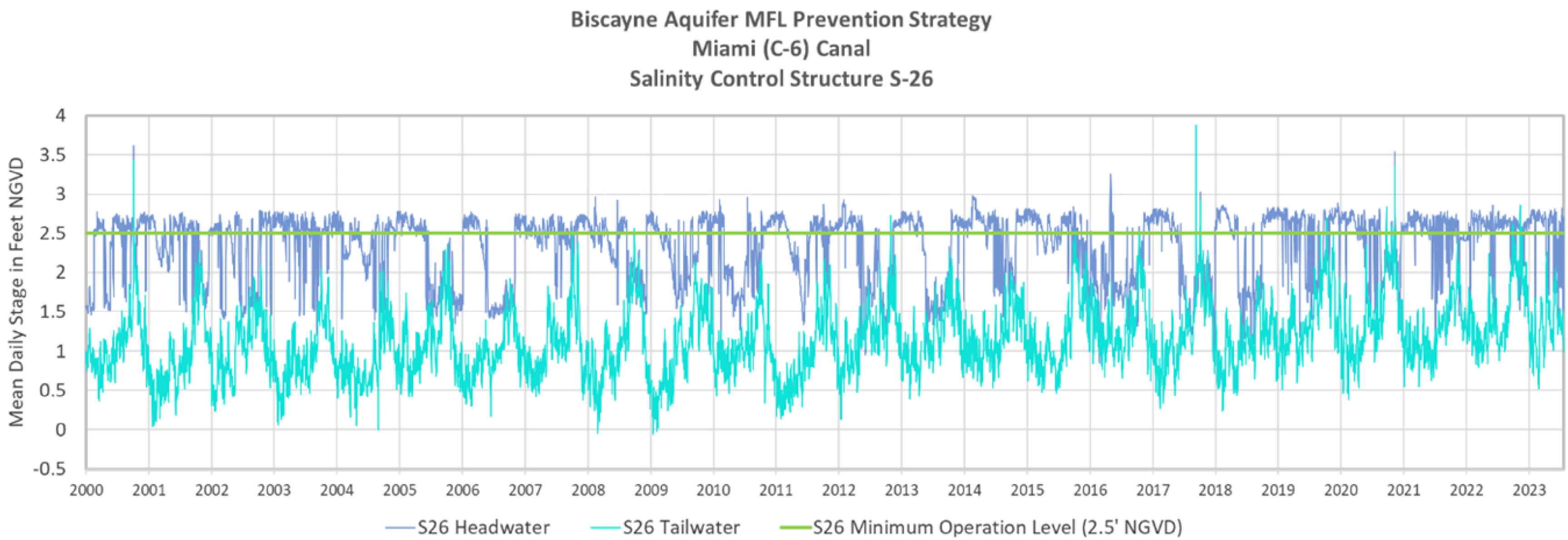


Figure 2B-20. Structure S-26 headwater and tailwater plotted relative to the minimum operation level.

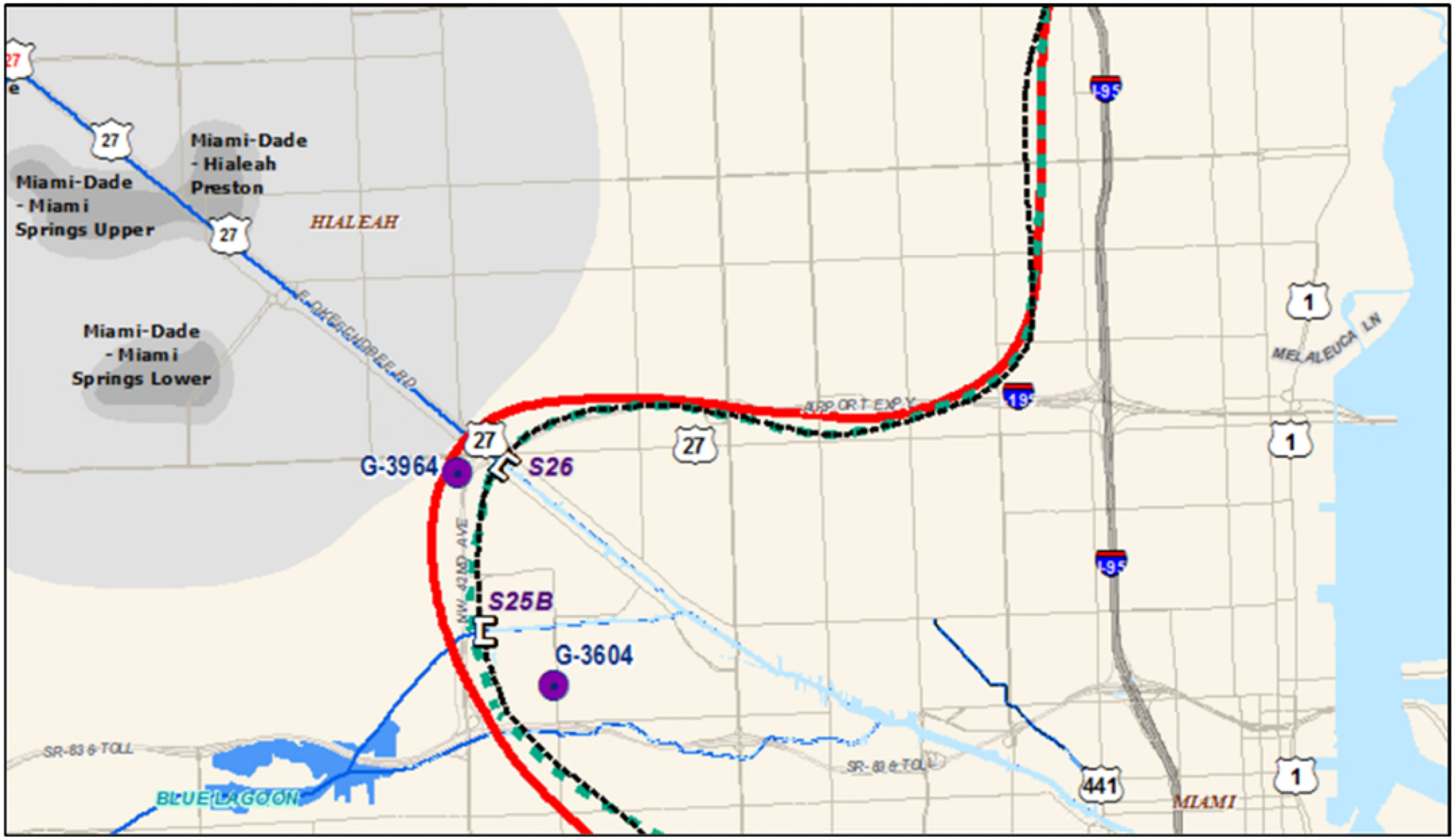
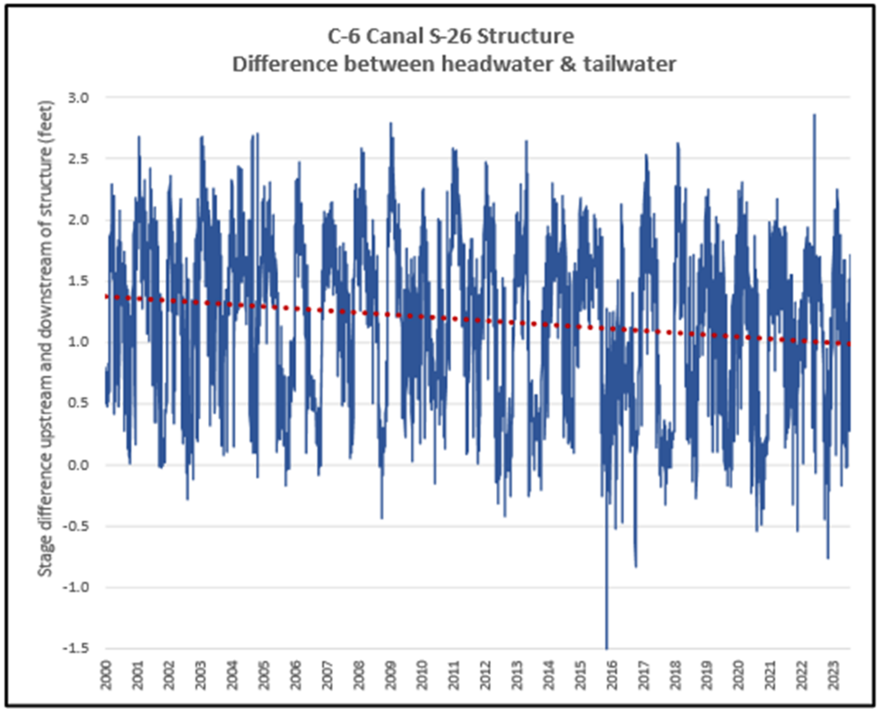


Figure 2B-21. Saltwater interface near structures S-26 and S-25B (Prinos, et. al 2014, Prinos 2017).



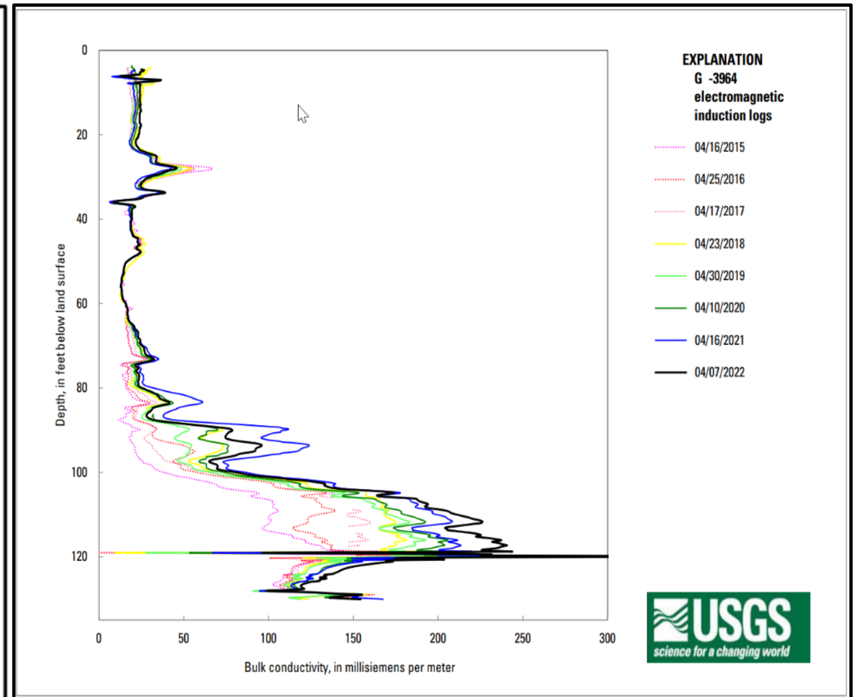


Figure 2B-22. Difference between headwater and tailwater at structure S-26 (left panel) and induction logs for monitor well G-3964 (130 ft bls) in the C-4 Basin near structure S-26 in Miami Springs (right panel) (USGS 2023).

Salinity Control Structure S-25B (Tamiami C-4 Canal)

The SFWMD Tamiami Canal Minimum Operation Level is 2.5 ft NGVD29 (green line) and the average headwater stage in the canal is 2.4 ft NGVD29, which is approximately 1 ft higher than the average downstream tidal stage of 1.4 ft NGVD29 (**Figure 2B-23**). A gradual increase in average tailwater stage can be noted. The average difference between headwater and tailwater has decreased from 1.25 to 1.00 ft. (**Figure 2B-24**, left panel). The saltwater interface (**Figure 2B-21**) in the vicinity of the S-25B structure moved inland past the structure by 2016 (red line). As sea level rises, the tailwater and headwater stages occasionally overlap. Monitor well G-3604 is nearby the S-25B salinity control structure. Based on the induction log for G-3604, salinity at this location has steadily increased below 95 ft bls (i.e., the most recent induction log, April 12, 2022, shows the highest bulk conductivity values); however, in 2010, chloride concentrations began to increase at shallower depths, and by 2021, inland movement of the saltwater interface was observed at approximately 85 ft bls (**Figure 2B-24**, right panel). The Miami-Dade Hialeah-Preston and Miami Springs wellfields are upstream of the salinity control structure adjacent to the Miami Canal, withdrawing from 80 to 115 feet bls and limited to withdrawals of 70 million gallons per day. The small difference between upstream stages and tidal stages provides minimal aquifer recharge and significant wellfield withdrawals are influencing the saltwater interface position.

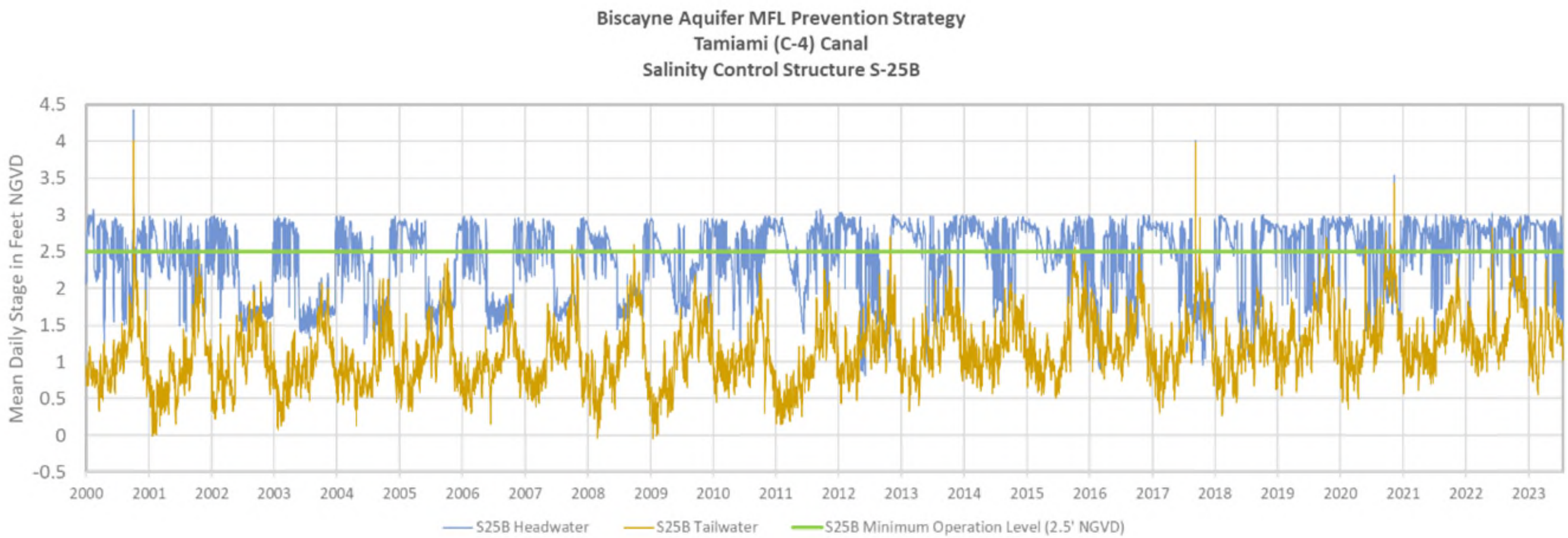


Figure 2B-23. Structure S-25B headwater and tailwater plotted relative to the minimum operation level.

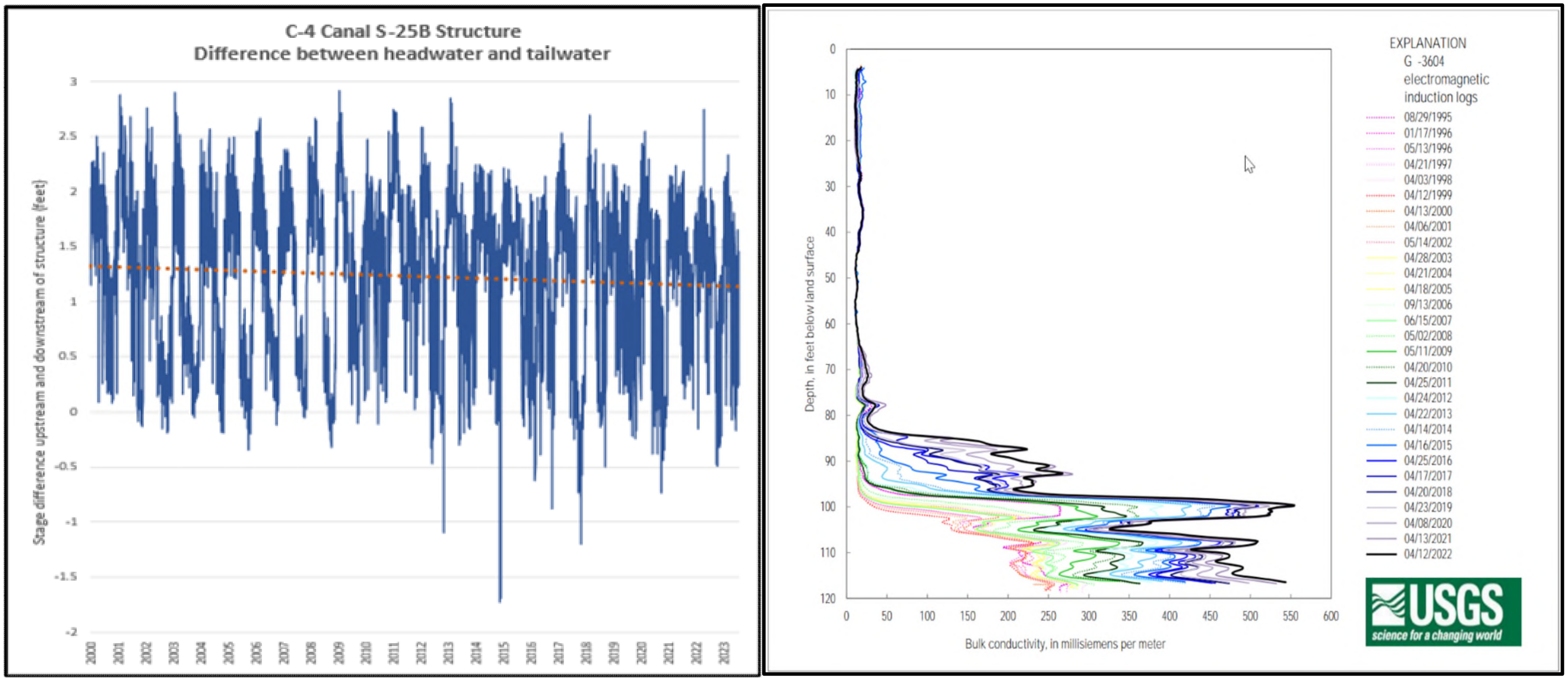


Figure 2B-24. Difference between headwater and tailwater level at structure S-25B (left panel) and induction logs for monitor well G-3604 (120 ft bls) in the C-4 Basin near structure S-25B in Miami Springs (right panel, USGS 2023).

Salinity Control Structure S-22 (Snapper Creek C-2 Canal)

The SFWMD Snapper Creek Canal minimum operation level is 2.5 ft NGVD29 (green line) and the average headwater stage in the canal is 2.7 ft NGVD29, which is slightly more than one ft higher than the average downstream tidal stage of 1.3 ft NGVD29 (**Figure 2B-25**). A decrease in headwater stage is seen after 2014 and a gradual increase in average tailwater stage can also be noted. The average difference between headwater and tailwater has decreased from 2.1 to 1.3 ft (**Figure 2B-25**). As sea level rises, the tailwater and headwater stages occasionally overlap. The saltwater interface (**Figure 2B-26**, left panel) in the vicinity of the S-22 structure by 2019 (red line) had moved slightly further inland than the 2009 (green line) and 2011 (black dashed line) positions. The induction log for G-3608, located one mile north of the S-22 salinity control structure, is east of the Miami-Dade Water and Sewer Department's Alexander Orr and Snapper Creek public supply wellfields. Salinity is stable above 50 ft bls (i.e., the most recent induction log, April 2, 2022, shows similar bulk conductivity values as previous logs). Salinity has fluctuated over time, with water quality improvements since 2005 in the 40 to 70 ft bls range but increases below that depth (**Figure 2B-26**, right panel). The Miami-Dade public supply wells range from 40 to 100 ft bls. While there is evidence of steady increases in salinity below 70 ft bls, the toe of a saltwater wedge at the base of the aquifer is not evident and may be deeper than the well.

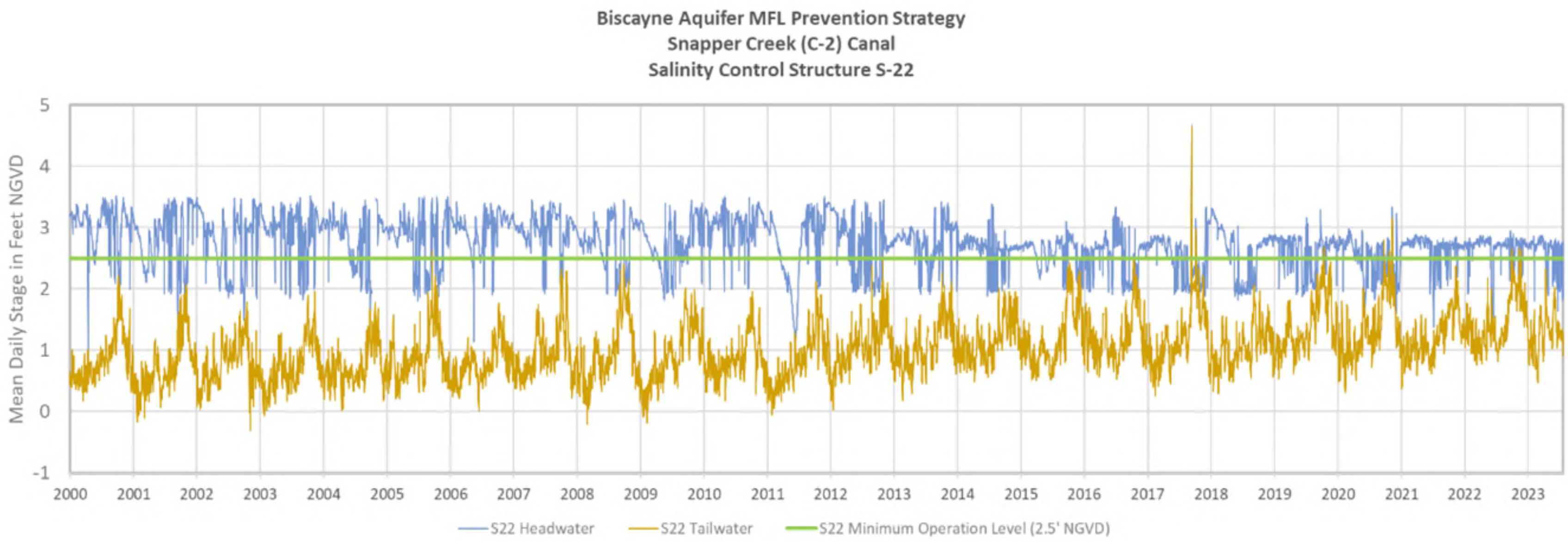


Figure 2B-25. Structure S-22 headwater and tailwater plotted relative to the minimum operation level.

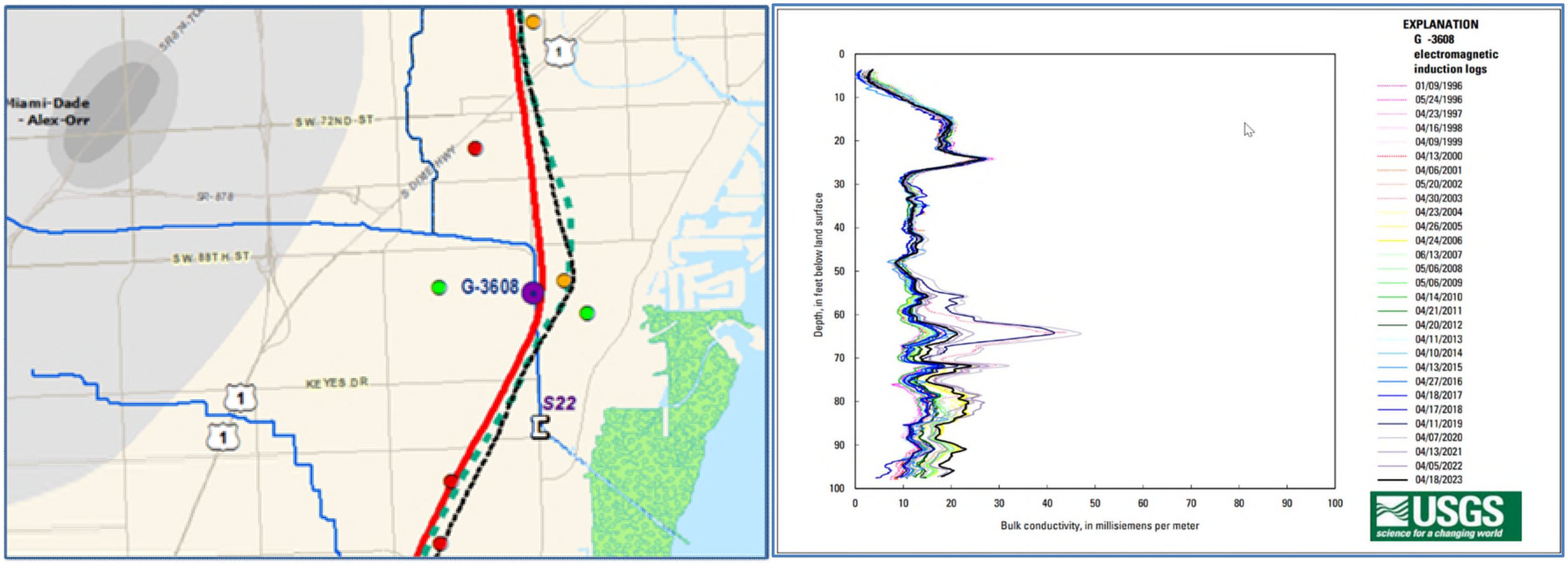


Figure 2B-26. Saltwater interface (left panel; Prinos, et. al 2014, Prinos 2017) and induction logs (right panel, USGS 2023) for monitor well G-3608 (100 ft bls) in the C-2 Basin in South Miami, near structure S-22.

Results and Discussion

Water levels along coastal Miami-Dade, Broward, and Palm Beach counties are largely controlled by SFWMD's primary canal system where structures are located close to the coast. Regionally, these canal systems have great influence on the position of the saltwater interface. However, the canals are not evenly spaced and the salinity control structures are not located an equal distance from the coast.

To meet the requirements of the MFL prevention strategy, canal stages cannot fall below the minimum operating levels shown on **Table 2B-4** for more than 180 days, and the average annual stage must be sufficient to allow water levels and chloride concentrations in the aquifer to recover to levels that existed before a drought or discharge event occurred (SFWMD 2000b). Data from 20 years before the MFL was established (1980–1999) was compared to the 22 years since MFL inception in 2001 (**Table 2B-4**). Only two structures, S-26 and S-25B, have on three occasions not met the minimum operating level. Two structures in Broward County, S-36 and S-37B, and two in Miami-Dade County, S-26 and S-29, have increased the percentage of days below their minimum operating levels. Looking at the 2000–2023 data, the percent of time headwater stage elevations were below the minimum operating level at structures S-26 and S-25B is near 50%. Average annual stages have not substantially changed pre- and post-2000 although G-56 and G-54 have increased by 0.25 and 0.3 ft, respectively. While the average annual headwater stages at S-26 and S-25B are below the minimum operating level, average dry season stages are near or exceed the minimum, respectively. Therefore, upstream stages at the 11 structures overall are meeting the established minimum operating levels as outlined in the MFL prevention strategy. The 2018–2022 period average annual stages are within 0.2 ft, usually lower, of the structure optimum headwater elevations, except S-25B at 0.4 ft lower. While each structure is operated to maintain an optimum headwater elevation in alignment with its designated purpose according to SFWMD manuals, the establishment of minimum operating levels set in the prevention strategy is grounded in the goal of meeting the MFL requirements. Average annual dry season stages are higher than wet season stages at all structures.

The ability for water managers to manipulate canal water levels as a means to control saltwater intrusion is greatly reduced in areas of Miami-Dade and Broward counties that have low ground level elevations and maintain flood protection. Tidal stage has increased at all stations by an average of 0.4 ft from the early 2000s to the most recent 5 years. As sea level rises, the difference between headwater and tailwater stage at each structure except G-56 is diminishing. Data from the early years (2000–2004) since MFL adoption indicated there was more than two ft of head difference at eight of the 11 MFL structures and a minimum of at least 1.25 ft at the other three structures. In the most recent five years (2018–2022), the difference between the canal stage and the tidal stage at the four southernmost MFL structures has declined to at or near one ft of head difference (**Table 2B-4**). This difference is not adequate to help prevent inland movement of the saltwater front.

While review of headwater stage data at the salinity control structures indicates only three instances where the minimum operating levels (prevention strategy) were not met for 180 days over the period of record, that should not be construed to indicate that saltwater intrusion is not occurring. First, the original rule is limited to the locations of salinity control structures and the associated canals, and there are not regularly spaced canals and salinity control structures over the entire coast. Second, wellfields are not co-located with these structures, so saltwater intrusion has occurred (e.g., City of Lake Worth Beach, see **Figure 2B-5**) even when the closest structure (S-155 in West Palm Beach) shows compliance with the minimum operating stage for the MFL prevention strategy. In this case, the effects of wellfield pumpage overwhelm the beneficial effects of the headwater stage a few miles to the north. Third, the effects of sea level rise were not contemplated when the original MFL rule was developed (2000). Increases in tailwater stage at the structures due to sea level rise will result in the MFL headwater stage being less preventative than originally envisioned.

RELEVANCE TO RESILIENCY IN WATER MANAGEMENT

Established MFLs play a crucial role in supporting the resilience of South Florida's water resources and ecosystems by ensuring their ability to withstand and recover from disturbances while maintaining their essential functions and structures.

Biscayne Aquifer MFL

The Biscayne Aquifer MFL accomplishes the following:

- **Groundwater Recharge:** The MFL ensures that sufficient water remains in surface and subsurface water bodies (i.e., aquifers), promoting groundwater recharge. Groundwater acts as a buffer during dry spells, helping communities and ecosystems withstand prolonged droughts.
- **Water Quality:** The MFL helps protect water quality by preventing excessive permitted water withdrawals and maintaining the dilution capacity of water bodies. Water resources can act as natural purifiers, enhancing water quality for both human consumption and agricultural use.
- **Regulatory and Management Framework:** The MFL provides a clear and objective standard for water management and decision-making. It serves as a reference point for evaluating proposed water use permits and development projects, ensuring that new activities do not compromise the viability of water bodies.
- **Drought Mitigation:** The MFL can act as a buffer against the impacts of droughts, where established levels help prevent water levels from dropping too low, supporting water supply.
- **Adaptation to Changing Conditions:** As water bodies face stressors, like changing rainfall patterns and anthropogenic impacts, the establishment of the MFL provides a framework for adaptive management. It allows for adjustments in response to changing conditions, ensuring that water bodies can cope with these shifts and maintain their functionality.
- **Climate Change Resilience:** As climate change intensifies, the frequency and severity of extreme weather events, such as droughts and floods, may increase. The MFLs act as safeguards by maintaining sufficient water levels in varying climate scenarios. During droughts, the MFL ensures there is enough water to sustain the aquifer, reducing the impact of prolonged dry spells.

COMMENTS AND RECOMMENDATIONS

The challenges of sea level rise-driven change in groundwater levels and saltwater intrusion in South Florida are complex. MFLs are an integral part of water resource management in South Florida. MFLs ensure the long-term viability of water resources and the protection of natural systems, mitigating for flood and drought and supporting adaptive management amid changing conditions.

Biscayne Aquifer MFL

As sea level rises, the ability to operate salinity control structures with a sufficient headwater/tailwater difference to prevent saltwater intrusion while providing adequate flood protection will be physically challenging. Capturing, storing, and redistributing water to recharge the Biscayne aquifer provides a hydraulic means of resisting the inland movement of the saltwater interface. Currently, water from Lake Okeechobee and the WCAs provides a backup source to help maintain the coastal canal stages, mainly during the dry season. There are several Comprehensive Everglades Restoration Plan (CERP) storage projects proposed that have the potential to also contribute to recharging the Biscayne aquifer. These include the C-111 Spreader Canal, C-9 and C-11 impoundments, and excess water from the C-9, C-12, and C-13 canal basins pumped into the coastal canal systems to maintain canal stages at optimum levels. Additionally, the ongoing Central and Southern Florida (C&SF) Flood Resiliency Study, which is assessing coastal structures along the southeast coast, will recommend improvements to enhance the system's capacity. SFWMD will continue to monitor headwater and tailwater stages at the coastal structures.

Since the time of MFL implementation, SFWMD has implemented more direct measures to evaluate saltwater intrusion including increased chloride monitoring of wells, electromagnetic induction logs in select wells, and regional saltwater interface mapping efforts. In addition, density-dependent groundwater models are being developed to more explicitly simulate saltwater intrusion and the effects of sea level rise and climate change. Compared to the original rule, these technological advances will enable SFWMD to better protect the resource by proactively identifying areas of concern, providing time to manage wellfield operations and identify alternative water supply sources to meet future water demands. As a result, future operational strategies may be developed.

MONITORING TRENDS IN FLOOD OCCURRENCES IN SOUTH FLORIDA

BACKGROUND

SFWMD operates and maintains the regional (primary) water management system made up of canals and natural waterways connected to community drainage districts (secondary) and hundreds of smaller neighborhood systems (tertiary). As a result of this interconnected drainage system, effective flood control in South Florida is a shared responsibility between SFWMD, the county and city governments, and local drainage districts (also known as 298 districts for the chapter of Florida Statutes that outlines their responsibilities) that maintain and operate the secondary system and homeowners' associations and residents who maintain and operate the tertiary system.

Flooding is a concern in both natural and urban areas of South Florida. Natural areas are affected by water levels that influence ecological dynamics, driven by hydrology, while urban areas face potential consequences affecting communities and residents. Evaluating flood occurrence information and augmenting the understanding of flood patterns and the systems' responses to changing hydrological conditions ensures water managers and resilience planners can proactively plan, adapt, and respond to flood events, ensuring the resilience of the water management system that safeguards communities, infrastructure, and the environment against flooding amid evolving climate conditions, changes in land use, and population growth.

To advance the analysis of the flood occurrence metric and assess the response of the water management system to extreme rainfall, major storm, storm surge, high tide, and/or compound flooding events, SFWMD is adopting a phased approach to compiling historical documentation and collecting new flood observations to document flood occurrence and gain a better understanding of which areas have flood recurrence.

An initial step was taken to compile sources of information that could be used both to identify events in South Florida that resulted in flooding and to locate areas where flooding occurred. Web resources were identified to be most valuable sources for this type of information along with NOAA storm reports and agency after action technical reports and materials. A qualitative analysis was performed using these data to identify areas with documentation of recurrent flooding. These flood prone areas will be further refined as more observations are gathered and used for informed decision-making and risk reduction in South Florida.

This section provides an overview of the flood-related data and information collected from internal and external reports, open data repositories, crowd-sourced information, and other resources. This information was used to located flood observations or delineate areas impacted by flooding and to evaluate the availability of hydrological data to document water levels before, during, and after an event. This collection of information was used to identify an initial set of flood prone areas that will be used in identify monitoring gaps and refine the understanding of flood patterns within these areas.

Information collected is being consolidated into a flood repository information system. Efforts are being made to standardize collected information to facilitate development of reporting tools and to support future use of this information in the evaluation of other observed trends, such as rainfall, enabling the discernment of whether observed changes in flooding represent long-term trends and/or indicate a shift in climate dynamics. This critical insight will inform effective flood management strategies and adaptive planning to bolster water management resilience in South Florida. While this initial analysis concentrates on urban areas, future efforts can be expanded to encompass natural areas.

DRIVERS AND INFLUENCING FACTORS

In South Florida, the occurrence of flooding is influenced by several factors specific to the unique geographical and climatic characteristics of the region. The following are the key factors that influence flooding in the region:

- **Low-lying Topography:** South Florida is characterized by its low elevation and flat topography, particularly in coastal areas. This makes the region highly susceptible to flooding, as there is limited natural drainage and water can easily accumulate on the surface during rainfall and high tide events.
- **Hydrological Connectivity:** In South Florida, a crucial factor influencing flooding is the extensive hydrological connectivity between various water bodies, including the surface water in upper Kissimmee, Lake Okeechobee, estuaries, and lower system, as well as the ground water, especially the surficial aquifer. The region's hydrology is intricately connected, forming a complex system of water flow and surface and sub-surface interactions.
- **High Water Table:** Groundwater levels in South Florida are relatively close to the surface and the region is characterized by its porous limestone geology. As a result, heavy rainfall and storm surges, associated with high water tables, can lead to rapid and widespread flooding especially in low-lying areas.
- **Rainfall and Tropical Storms:** South Florida experiences heavy rainfall events especially during the wet season and tropical storm seasons. These intense rainfall events, especially the ones above design conditions or limitations in current conditions, can overwhelm the tiered drainage system and lead to widespread flooding if they exceed.
- **Storm Surge:** South Florida's extensive coastline is vulnerable to storm surges during hurricanes and tropical storms, which can inundate coastal and some inland areas.
- **High Tides and King Tides:** Along with rainfall and storm surge, high tide events also contribute to flood risks in South Florida. The variation in strength and direction of the gravitational pull of the moon, especially during the new and full moon phases in the Fall, contributes to King Tide occurrences, the greatest tides of the year which can result in flooding in coastal areas, especially when combined with heavy rainfall or storm surges.
- **Urbanization and Impervious Surfaces:** Urbanization, mainly in coastal regions has altered natural drainage patterns and disrupted the natural flow of water, affecting how water moves through the landscape. Impervious surfaces can accelerate surface runoff,

directing water into drainage systems and canals above the design capacity for intensity of stormwater runoff into the tiered drainage systems, which can exacerbate flooding in urban areas.

- **Canal and Drainage System Capacity:** South Florida relies on an extensive and tiered network of canals and drainage systems to manage water flow. During heavy rainfall, the capacity of these systems may be overwhelmed leading to urban flooding.
- **Sea Level Rise:** With approximately 700 miles of shoreline and 40+ gravity coastal structures upstream of tidally influenced canals, the SFWMD's water management mission is influenced by sea levels. As sea levels rise, the region may experience increased coastal flooding due to the limitations in the performance of its gravity system, along with saltwater intrusion into freshwater sources.

FLOOD OCCURRENCE DATA AND SPATIAL TRENDS ANALYSIS

SFWMD utilizes diverse methods to collect flood occurrence data, which serves multiple purposes from immediate event response to fulfilling stakeholder briefing requests. While pre-existing efforts and operational activities have established methods with mapped internal protocols, there are also various untapped sources of data and information, such as reports, presentations, and photographs, that have not been integrated into a unified data set. By combining these internal and external flood observation sources with available historical information, an initial understanding of local and regional flood occurrence patterns is facilitated.

To systematically incorporate these varied data sources and identify flood prone areas under current and future climate and hydrological conditions, a phased data collection approach is being implemented. This approach aims to document and track patterns of flood occurrence, supporting spatial analyses and aiding in distinguishing patterns of spatial extent, magnitude, and frequency of flood occurrences. The analysis presented in this chapter details the initial effort to compile flood occurrence records.

SFWMD Established Flood Occurrence Data Sets

SFWMD has used a range of tools over the years to track and report major flooding events, usually associated with hurricanes and tropical storm events.

- Public reports by phone (also known as the Citizen's Information Line, which was decommissioned in 2017).
- Public reports by e-mail used since 2017 to update an internal editable we map created in 2017 (available for the public to submit local flooding concerns online via sfwmd.gov/contact, which is being decommissioned in 2024).
- Survey (web application for local drainage districts, internal SFWMD staff, and other partner agencies to report flooding, which was deployed in 2023 and can be accessed at www.sfwmd.gov/floodingapp. This survey is being opened to the public in 2024.)
- Environmental Conditions Team (deployed when the Emergency Operations Center is activated during major weather events)
- High Water Mark Tool (used by SFWMD staff to mark high water on buildings, trees, and along debris lines for future collection of flood elevation information)

Data Compilation and Integration for Historical Flood Occurrence Analysis

The initial effort involved identifying and compiling information from internal and external after action technical reports and materials that documented flooding locations and the water management system response to extreme rainfall, major storm, storm surge, high tide, and/or compound flooding events impacting the primary, secondary, and/or tertiary systems. These inventories were used to delineate flood-impacted areas.

Agency employees were asked to reflect on past storm experiences and identify technical memoranda, PowerPoint presentations, and other materials documenting events and related flooding stored within business archives. Additional information was collected from publicly available sources to supplement internal flood observations. Event data, including photographs, were used to estimate and delineate impacted areas in a geographic information system (GIS) layer. This GIS layer will be incorporated into the flood information system repository being compiled to house flood documentation and facilitate spatial analyses.

The list below outlines the data sources reviewed to identify historically flood impacted areas:

- *South Florida Hydrology and Water Management* chapters in Volume I of historical SFERs (www.sfwmd.gov/SFER)
- SFWMD's Internal Photo Database
- National Hurricane Center Tropical Cyclone Reports (https://www.nhc.noaa.gov/data/tcr/)
- National Weather Service Event Index (www.weather.gov/mfl/events_index)

Agency flood event documentation dates back as far as the 1960s. However, this phase of review focused on documentation from 1990 to early 2023 which is considered an adequate historical context considering land use change within the period and a long enough period of record for the analysis.

Results and Discussion

Based on the review of the listed historical flood documentation, the following areas, listed in descending order of the number of documented events, were identified as the most impacted areas. This list does not include all impacted areas.

1. City of Miami – 8 events
2. Key West – 5 events
3. Florida Keys – 4 events
4. City of Fort Lauderdale – 4 events
5. City of Boca Raton – 4 events
6. City of Lake Worth Beach– 4 events
7. City of Port St. Lucie – 4 events
8. City of North Miami – 4 events
9. City of Boynton Beach – 4 events
10. City of Homestead – 3 events
11. City of Fort Pierce – 3 events
12. Fort Lauderdale - Hollywood International Airport – 3 events
13. City of Pembroke Pines – 3 events
14. Town of Jupiter – 2 events
15. City of West Palm Beach – 2 events
16. Palm Beach International Airport – 2 events
17. Village of Wellington – 2 events
18. City of North Miami Beach – 2 events
19. Fort Lauderdale Executive Airport – 2 events
20. City of Delray Beach – 2 events
21. City of Pompano Beach – 2 events
22. City of Florida City – 1 event

23. Princeton (a census-designated place and unincorporated community in southwest Miami-Dade County) – 1 event
24. Village of Royal Palm Beach – 1 event
25. City of Lauderhill – 1 event

The events identified encompassed a broad range of event types regardless of their severity. They signify instances of localized flooding resulting in temporary disruptions or, in some cases, more widespread impacts and disruptions over larger areas. In addition to the list of events with flood occurrences, a set of extreme rainfall, major storm, storm surge, high tide, and compound flooding events occurring concurrent to the documented period of record were also identified. This second set of events were characterized by recorded rainfall, tidal levels, and surge data, indicating their severity and potential to cause significant flood concerns. These two sets of events were cross-referenced to assess the availability of flood observations for each set.

Figure 2B-27 visually represents the difference in availability of flood observations for known major events based on severity characteristics (left) and events from findings in historical documentation (right). In the Venn diagram's central section, depicting the overlap between the sets of events, both major and other events for which historical flood documentation were available is shown. This intersection aids in considering a broader picture and understanding of varying scenarios, highlighting the importance of investigating the underlying factors and distinctive characteristics that render specific areas more susceptible to flooding based on their capacity to manage water. Additionally, it underscores the importance of acknowledging unreported flood occurrences that may have gone undocumented or were not readily accessible at the time of this analysis, potentially leading to an incomplete understanding of the overall flood risk landscape.

The primary objective of this initial project phase was to assess the individual and combined contributions of each data source to enhance the characterization of flood occurrences. This involves applying knowledge of the water management system and using topographic data to identify flood prone areas and closely examining contributing events, and considering factors such as flood intensity, frequency, duration, and extent. The map in **Figure 2B-28** shows impacted areas identified based on the historical flood occurrence documentation compiled and examined during this initial phase. The map in **Figure 2B-29** shows flood prone areas delineated based on compiled flood occurrence documentation and constitutes the current version of South Florida's flood-prone areas.

This initial summary is based on best available information from the SFWMD databases, open sources, and some partner agencies. This analysis likely does not capture all flood occurrences, depths of flooding, extents of rainfall, or event types. Therefore, no formal conclusions or major decisions should be made based solely on this sample. It is acknowledged some flood prone areas may not be shown on the map or listed above, either because flooding occurrences were not reported, formally documented, or known about at the time of this analysis. This summary serves as starting point and should be considered preliminary in nature.

In the context of this report, flood prone areas are defined as locations where recurrent flood occurrences are observed as a result of rainfall, extreme rainfall, major storm, storm surge, high tide, and /or compound flooding events. This designation is based on information compiled from observations and historical documentation that allowed impacted areas to be delineated. These boundaries and delineations along with the compiled historical data, reports, and other available information are being consolidated into a flood information repository. In subsequent phases, flood observations derived from satellite/radar imagery, water level and flood sensor data, high water marks, and other sources will be incorporated, and the scope will be extended to characterizing flood occurrences based on extent, magnitude, and frequency of occurrence.

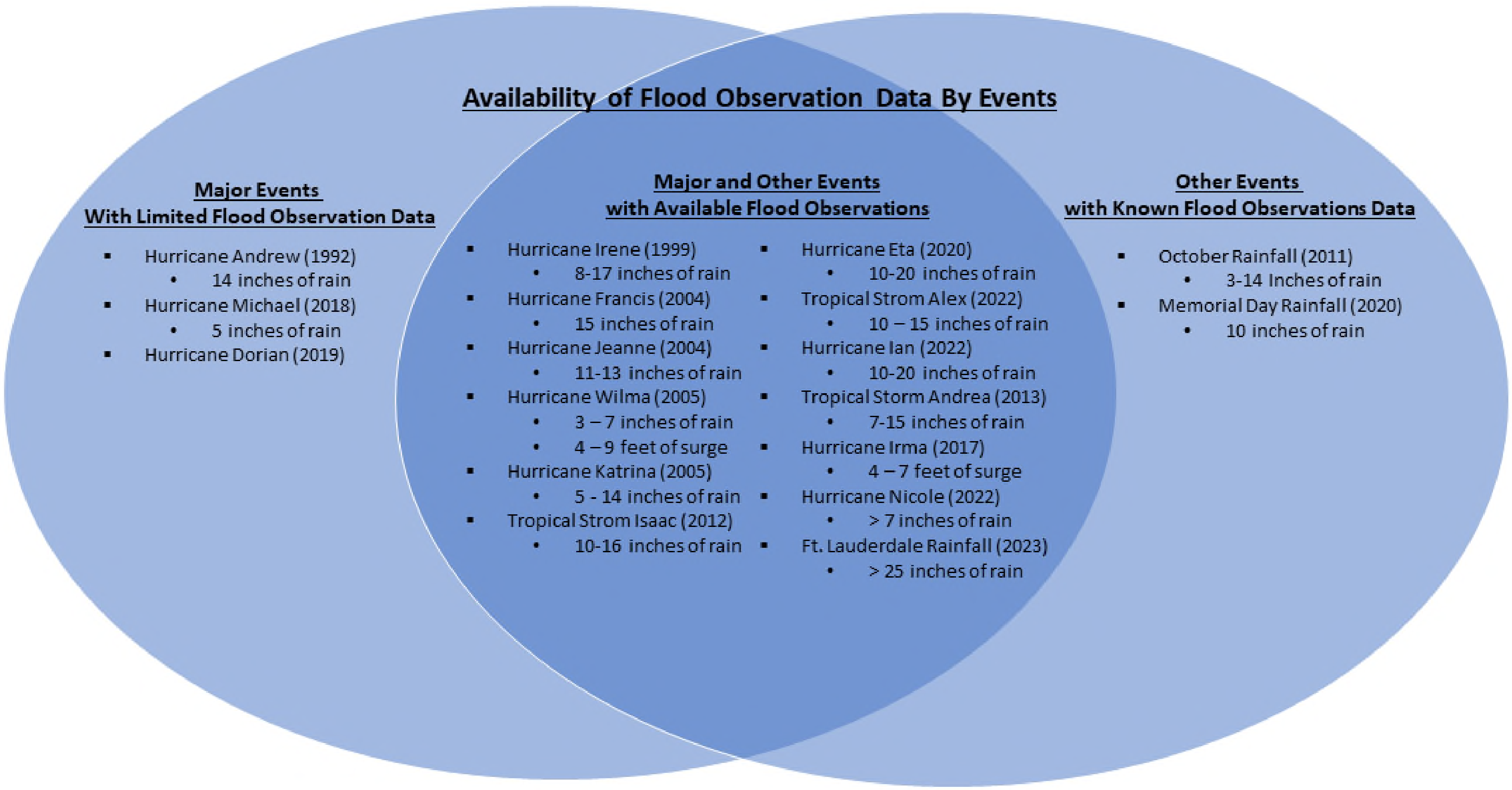


Figure 2B-27. Diagram showing difference in availability of flood observations for known major events-based characteristics (left), events for which flood observations based solely historical documentation compiled were available (right), and the overlap between the sets of events (center).

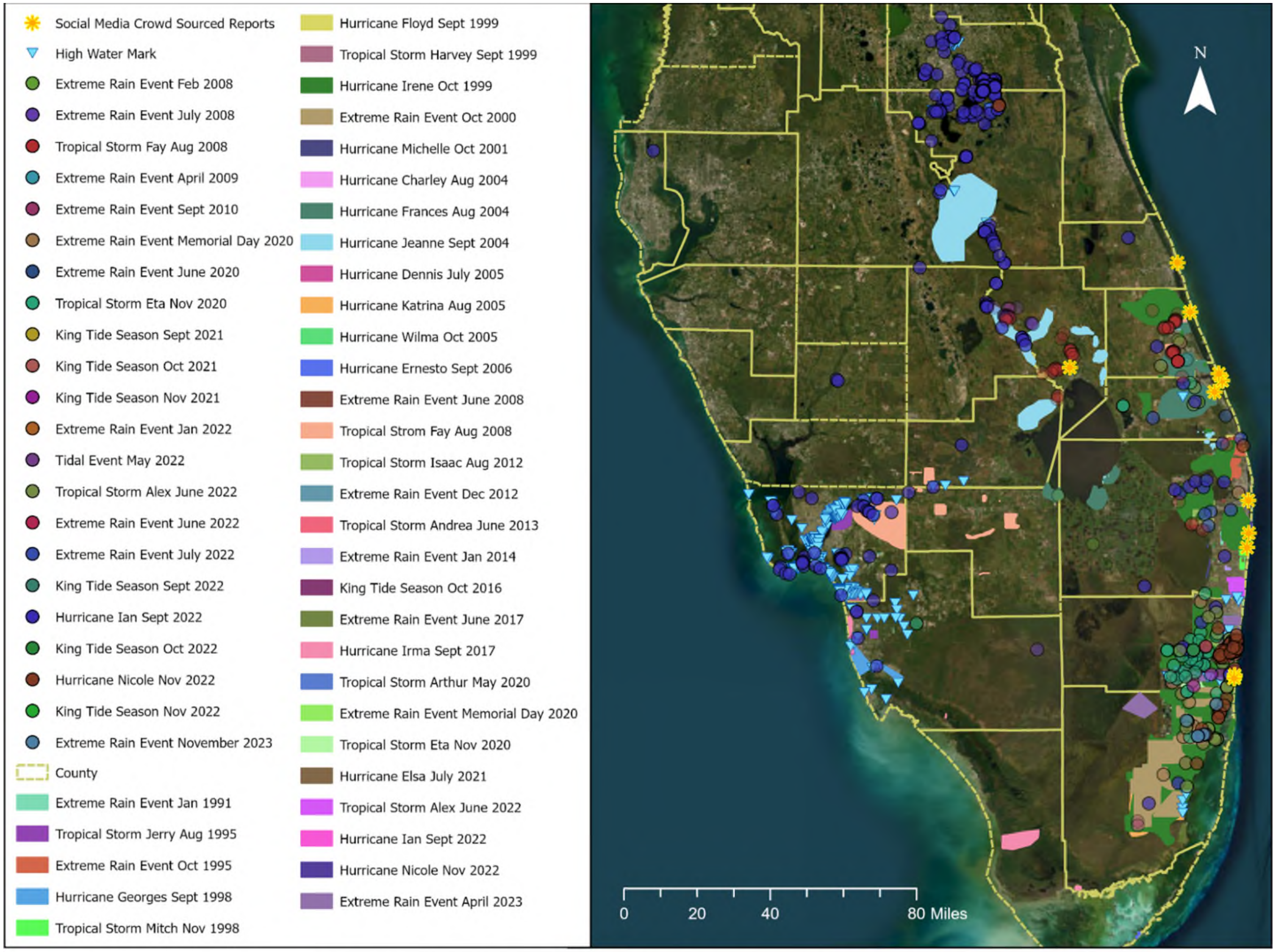


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Figure 2B-28. Map of impacted areas identified based on available historical flood occurrence documentation examined.

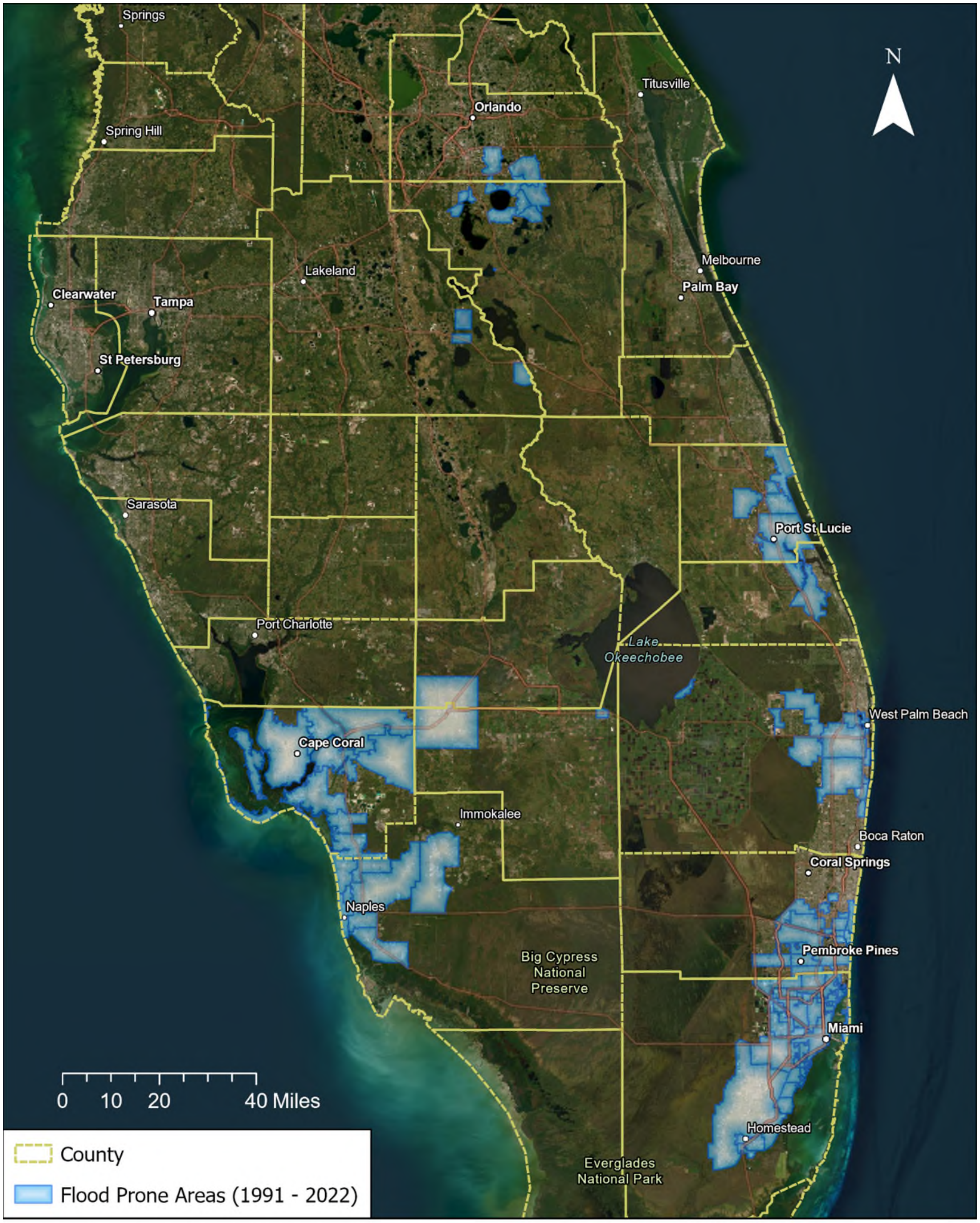

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Figure 2B-29. Map of flood prone areas based on established data sets and historically impacted areas combined.

RELEVANCE TO RESILIENCY IN WATER MANAGEMENT

Understanding flooding occurrence is needed to characterize how the water management system responds to rainfall, storm surge, and extreme tides. This understanding is important for the following reasons:

- **Anticipating Long-Term Trends:** Monitoring trends in reported flood occurrence in association with trends in contributing factors will support understanding increasing flood risks.
- **Enhancing Resilience Planning:** Understanding current and future flood risks is critical to prioritizing areas for resilience planning and determining how best to mitigate for and adapt to those risks based on the unique topographic and other physical characteristics of flood prone areas.
- **Calibrating and Validating Flood Models:** Understanding the system's response based on antecedent and event conditions supports planning initiatives. This provides the information necessary to identify the best mitigation strategies for different flooding events, supporting the formulation of proactive measures to enhance resilience, and ensuring that communities can withstand and recover quickly from floods. As significant investments are being directed towards characterizing flood vulnerabilities, using the latest and greatest modeling tools, it is important that calibration and validation of inundation levels and flood extent, resulting from these hydrology and hydraulic models, are supported by strong observation data sets. A robust flood observations data set ensures the accuracy, reliability, and relevance of modeled flood risks.
- **Identifying Vulnerabilities:** Monitoring flood events allows for the identification of vulnerable areas within the region’s communities. This information is vital for developing targeted adaptation and mitigation strategies to protect those areas from future flooding impacts.
- **Assessing System Performance:** By tracking and analyzing flood occurrence, SFWMD can evaluate how well the existing flood control system performs during different events. Understanding how the system responds to varying conditions helps identify its strengths and weaknesses, enabling targeted improvements and investments to enhance its effectiveness.
- **Developing Adaptation Strategies:** With the increasing impacts of climate change, including rising sea levels and extreme storm events, monitoring flood occurrence will inform adaption strategies designed to address the challenges of changing climate conditions and protect communities from heightened flood risks.
- **Guiding Infrastructure Investments:** Spatial insight provided by flood impact location documentation informs comprehensive analysis of flood event data and insights into where and when infrastructure investments are needed to reinforce flood control systems. This data-driven approach ensures that investments are directed to areas most at risk, optimizing resource allocation.
- **Improving Emergency Response:** Real-time monitoring of flood occurrence will enhance and inform the agency’s response activities. Identification of emerging conditions will facilitate and focus agency and partner collaboration and response activities, supporting timely mobilization of resources, issuance of warnings, and coordination of evacuation measures.

COMMENTS AND RECOMMENDATIONS

The analysis of flooding occurrences, driven by extreme rainfall, major storm, storm surge, high tide, and compound flooding events, is a crucial metric for supporting resilience efforts in South Florida. Formally tracking trends in observed flooding and comparing them with other relevant trends, such as rainfall patterns and water levels, will support a better understanding of flood risks and enhance adaptation planning.

The analysis of historical information in legacy flood occurrence documentation identified event impacted areas and identify an initial set of flood prone area. It will be used to identify data gaps for future data collection efforts. Gathering reports, pictures, high water marks and other information about local flooding supplements monitoring data and supports validation of model results and remotely sensed flood observations. Where quantitative measurements are available, they can be used in combination with high-resolution elevation data to estimate flood extent and depth. In areas without quantitative data, crowd-sourced observation locations can be used to guide reconnaissance efforts to collect high water marks while submitted depth estimates can be used to estimate extent. The establishment of a centralized repository for consolidating flood information in formats that can be used for spatial analyses and reporting will make these information available to water managers, planners, modelers, and stakeholders to make data-driven decisions to support operational response, water management practices, and resilience planning. This repository will also consolidate recommended tools for use in collection of observations, high water marks and other event documentation designed to support data-driven decisions, analyses, and regional coordination. This initiative reinforces SFWMD’s regional role in collaboration with local governments and other partner agencies, such as USGS, the Federal Emergency Management Agency (FEMA), and the Florida Department of Emergency Management (FDEM) and will further enhance data integration and reporting for flood risk management and SFWMD’s regional role in building a more resilient South Florida.

CONCLUSIONS

The future of successful water resource management in South Florida will be influenced by understanding of how climate-related long-term trends and other associated changing conditions are impacting SFWMD’s mission and the region’s ability to provide flood protection, water supply, and ecosystem restoration. The continuous assessment and availability of water and climate resilience metrics established as part of this effort will be essential in achieving this understanding.

This chapter detailed the data and analyses, potential influencing factors, and future monitoring considerations for one climate and two resilience metrics related to sea level and hydrology—tidal elevations at coastal structures, MFLs, and flood occurrence—to identify trends for specific water bodies, enhance previous analyses, and develop an understanding of influencing factors to begin differentiating the influences of climate and non-climate factors. The evaluation of these metrics and correlation with other metrics may be required to determine if observed changes are associated with identifiable climatic changes or other influencing factors.

Overall findings for each of the three metrics included in this chapter are presented below:

- Tidal water level data collected at 32 SFWMD-operated gravity coastal structures between 1967 and 2022 exhibit statistically significant upwards trends, with even more rapid increases occurring over the past 20 years. To address associated risks, mainly flooding, SFWMD, in partnership with federal, state, and local governments and other water management districts in South Florida, is actively engaged in comprehensive flood resiliency studies, conducting modeling exercises to assess system vulnerabilities, and developing adaptive strategies to ensure the resilience and effectiveness of the C&SF Project water management system and its coastal gravity structures under changing climatic conditions.

- Analysis of water levels at 11 coastal structures monitored as part of the Biscayne Aquifer MFL along the Lower East Coast water supply planning area reveals a total of three instances at two structures where canals did not meet the minimum operating levels since the MFL was established. Yet groundwater quality monitoring indicates that saltwater intrusion is occurring at the base of the aquifer in most areas. Continued and enhanced monitoring as well as analysis that considers sea level rise are recommended to inform water supply planning and adaptation in the context of resiliency.
- The integration of recently compiled historical flood impact documentation, along with existing flood occurrence data sets for South Florida's urban areas from 1990 to 2022, has identified an initial set of flood prone areas within the SFWMD region. This data will be integrated into a GIS-based repository and will aid in pinpointing data gaps, highlight additional monitoring needs, support standardizing current and future data collection, and support subsequent project development. Ongoing work includes refining flood event data collection through the *Document the Floods* survey and expanding the project scope to include the use of satellite and radar imagery, supplementary water level and flood sensor data in areas lacking such data, and the inclusion of additional flood information sources. These enhancements will expand the flood prone areas project to include the ability to discern patterns of spatial extent, magnitude, and frequency of flooding occurrences. These combined efforts will contribute to more effective flood risk management, better adaptive strategies, prompt incident response, and inform regional and local governments and water managers responsible for the operation of the primary, secondary, and tertiary systems.

The inaugural Water and Climate Resilience Metrics chapter in the 2022 SFER (Cortez et al. 2022) detailed the trend analyses of rainfall and ET in South Florida, tidal trends at select coastal structures, and the four selected water quality metrics in Lake Okeechobee. The 2023 SFER chapter (Cortez et al. 2023), detailed spatial trends in saltwater intrusion, and trends in the three ecological metrics: salinity in estuaries, soil accretion/subsidence, and estuarine inland migration. This chapter details the refined analysis of tidal elevations at coastal structures and introduces the new analyses for MFLs, starting with the Biscayne Aquifer MFL, and flood occurrence.

In future SFERs, the Water and Climate Resilience Metrics chapter will present developments on these and other water and climate resilience metrics, quantification of influencing factors, and correlation with other selected metrics. Future chapters will also explore expanded resiliency monitoring requirements. These efforts provide a means to evaluate the significance of water and climate observations, and how they compare to historical trends as climate conditions evolve.

Additionally, the links between major findings in Chapter 2A: South Florida Hydrology and Water Management of this volume and this chapter will continue to support the understanding of how the observations summarized in Chapter 2A are part of long-term trends or represent evolving conditions documented in Chapter 2B, and how these long-term trends or shifts may be associated with climate change.

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