TurkeyPointCEm Resource

From: Haber, Matthew S. [MSHaber@miamigov.com]
Sent: Friday, May 22, 2015 6:55 PM
To: TurkeyPointCOLEIS Resource
Cc: TurkeyPoint@usace.army.mil; Williamson, Alicia; Comar, Manny; Mendez, Victoria; Weisman, Robert
Subject: City of Miami's Official Comments on Draft Environmental Impact Statement (NUREG 2176) (NRC-2009-0337)
Attachments: image003.jpg; City of Miami - Comments on Draft Environmental Impact Statement NUREG 2176 - small.pdf

Hello,

Attached, please find the City of Miami's comments on the draft Environmental Impact Statement.

Thank you.

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May 22, 2015

Cindy Bladey,
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RE: NUREG-2176 – Letter from Mayor Regalado, City of Miami (NRC-2009-0337)

Dear Ms. Bladely:

Thank you for the opportunity to comment on the draft Environmental Impact Statement ("DEIS") for Turkey Point Nuclear Plant Units 6 & 7. Attached to this letter, please find the City of Miami's comments prepared by the Office of the City Attorney.

I am concerned for the future of my community. We are confronted by sea-level rise and a diminishing drinking water supply. FPL's project, as proposed, may needlessly endanger our sole source of freshwater by exacerbating saltwater intrusion. If approved, the project will also destroy mangrove and seagrass populations that perform vital ecosystem services, including maintaining our water quality and protecting our shoreline. There are ways to generate electricity, some of which are explored in the DEIS, that do not create these problems. Given South Florida's limited sources of freshwater, FPL's project seems to be a shortsighted investment.

Ultimately, I fear that Miami residents will be left to shoulder the costs of this project and its long-term consequences. Securing new supplies of drinking water and protecting coastal lands will be an expensive and difficult task. Moreover, the transmission line FPL plans to run through Miami will not be built to Florida hurricane safety standards. In a storm, the ten-story poles could collapse onto homes or the Metrorail.

I am asking you to do everything in your power to protect Miami from these risks.

Sincerely,

Tomás Regalado,
Mayor of the City of Miami

City of Miami

Victoria Méndez
City Attorney

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May 22, 2015

Cindy Bladey,
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Division of Administrative Services, Office of Administration,
Mail Stop: OWFN-12-H08,
U.S. Nuclear Regulatory Commission,
Washington, DC 20555-0001
Sent via e-mail: TurkeyPoint.COLEIS@nrc.gov

RE: NUREG-2176 – City of Miami's Comments on Draft Environmental Impact Statement for Combined Licenses (COLs) for Turkey Point Nuclear Plant Units 6 & 7 (NRC-2009-0337)

Dear Ms. Bladely:

The City of Miami ("the City" or "Miami") appreciates the opportunity to submit these comments on the draft Environmental Impact Statement ("DEIS") for the Turkey Point Nuclear Plant Units 6 & 7 application, published in February 2015.

The City believes that the license for the project should not be approved as currently proposed. The Turkey Point Nuclear Plant Units 6 & 7 application should be viewed in context of a region facing the enormous water quality and land use related challenges imposed by climate change.

Therefore, the final Environmental Impact Statement ought to consider not only the direct impact of this project to a region currently under threat, but also how the project's operations will constrain investments made to manage future challenges and correct a history of destabilizing influences. In sum, the region is confronted with a deteriorating baseline and will need to adapt.

The City's comments focus on seven components of the DEIS' analysis: (1) the site selection process, (2) impacts to the Biscayne Aquifer and the nearby national parks, (3) consideration of sea-level rise, (4) foreseeable emergencies, (5) disposal of wastewater, (6) the need for power, and (7) transmission line impacts. These comments are submitted in addition to the "Concerns" document that the City presented to the U.S. Nuclear Regulatory Commission in late 2014.

Clarify Rationale for Selecting Turkey Point as the New Reactor Site

The DEIS outlines the legal framework for the alternative site selection process and describes some of the criteria used in selecting the final site for the new reactors. The site selection criteria included:

- Avoidance of high-population areas
- Avoidance of ecologically sensitive and special designation areas
- Avoidance of special dedicated land uses (e.g., national parks)
- Proximity to target transmission/load centers
- A minimum size of 5,000 acres, etc.

At first glance, the Turkey Point site does not rate highly on these measures. The site itself is within 25 miles of Miami, the densest population center in Florida and the second most populous city in the state. Likewise, the site is sandwiched between two national parks and sits atop the Biscayne Aquifer, the sole source of drinking water for most of Miami-Dade and Broward Counties.

Instead, the text of the DEIS suggests that Turkey Point was chosen as the site for the new reactors primarily to satisfy the company's business objectives. The DEIS states:

> Of the original 21 potential sites FPL selected the top 8 ranked sites, and **even though they ranked below these 8 sites**, FPL also retained the Turkey Point and St. Lucie sites "based on the fact that they are existing, operating nuclear power plant sites within the ROI," and FPL's determination that the sites fall within "the special case (described above) for licensed nuclear power plant sites."

DEIS at 9-39. The DEIS goes on to conclude that "FPL selected the Turkey Point site as its proposed site based on this ranking and its determination that the site was the preferred site for meeting FPL's overall business objectives." DEIS at 9-40.

Comment 1: The final Environmental Impact Statement should clarify the Nuclear Regulatory Commission's assessment of the site selection analysis conducted by FPL.

Tables 9.3-5 and 9.3-6 of FPL's Environmental Report compare Turkey Point with the alternate sites across a range of criteria. As noted above, the DEIS describes some of these criteria. Within Table 9.3-6, entitled "Candidate Site Rankings," the Technical Analysis Composite Rating/Score for each candidate site is compared against several categories, all of which appear to be given equal weight. These categories included land acquisition, site layout, public acceptance, and political considerations. However, the score that matters most within this framework, the reliability of electrical generation, is also the metric on which Turkey Point scored the lowest compared to all alternative sites.

Generating additional and reliable baseload power is the primary motivation for constructing the additional reactors. Hence, the final Environmental Impact Statement, as a decision-making tool, should clarify the rationale for proceeding with the Turkey Point site despite the low score on reliability of electrical generation.

Comment 2: The final Environmental Impact Statement should expand its discussion of the criteria that make Turkey Point a suitable site in comparison to the alternatives considered by FPL.

As noted above, the Turkey Point site does not appear to rate highly on many of the site selection criteria specifically mentioned in the DEIS.

From the City's perspective, Turkey Point is a poor site for the placement of two nuclear reactors that will presumably operate for the majority of the 21st Century. Turkey Point's proximity to large population centers, two national parks, the comparably few evacuation routes available to nearby residents, its location atop a single source aquifer, and the site's vulnerability to extreme storm surges are only the most obvious reasons to question FPL's choice. In addition:

- The existing power plant infrastructure has demonstrably impacted the Biscayne Aquifer already,
- The cooling canals' continuing problems with salinity, temperature increases, and algae blooms reveal the difficulties of operating a power plant at Turkey Point while minimizing environmental damage, and
- FPL's requests to divert large amounts of freshwater to Turkey Point come within the context of a region that currently lacks sufficient freshwater resources for Everglades restoration and faces a diminishing supply for public consumption.

Since FPL has not stated that it intends to replace the existing reactors with the new reactors contemplated in this application, it is likely that placing additional reactors at the site will only constrain efforts to resolve these issues.

In contrast, the Glades alternative site is:

- Located further from major population centers,
- Would experience fewer impacts from sea-level rise or extreme storm surge,
- Near only a small portion of Big Cypress National Preserve,
- Could draw its cooling water from a groundwater source that is generally not used for other purposes due to the salinity of that water.

DEIS at 9-57. The primary drawbacks to placing the reactors at this site appear to be that it would impact unique farmland and it would require a variance from the local comprehensive plan. DEIS at 9-53 and 9-55. Compared to the problems presented by operating additional reactors near the critical and protected ecosystems at Turkey Point, these issues seem minor.

Therefore, the final Environmental Impact Statement would benefit from an expanded discussion of the criteria that led to Turkey Point's selection as the final site for the new reactors. For example, FPL has stated that using reclaimed water provided by Miami-Dade County as the primary source of cooling water is a beneficial feature. This may be a compelling reason to place the new reactors in Miami-Dade County; however, if that is the case it should be explained more directly and thoroughly.

On this point in particular, it is worth noting that Miami-Dade County has begun efforts to supplement its freshwater supply with desalinated water from the Upper Floridan Aquifer. Additional saltwater intrusion will only force local governments to impose stricter water conservation measures. Hence, the amount of reclaimed water available from Miami-Dade County will decline over time and will not be available for use as cooling water for much of the operating life of Turkey Point Nuclear Plant Units 6 & 7.

Comment 3: The final Environmental Impact Statement should expand the site selection scoring criteria to include sea-level rise resilience.

Extreme storm surges made possible by sea-level rise and intense storms can affect saltwater intrusion into groundwater resources, thereby affecting the regional availability of freshwater. There are obvious safety implications for storm surges near the reactor site as well. For these reasons, resilience against problems associated with sea-level rise should be incorporated into the site selection scoring criteria.

Prioritize Avoiding Potential for Impacts to the Biscayne Aquifer and National Parks

Radial collector wells located on the Turkey Point peninsula are planned to supply backup cooling water for the proposed reactors. The installation of this backup system "would involve drilling of lateral collector wells in the Biscayne aquifer beneath Biscayne Bay." DEIS at 4-28.

According to its state license, FPL is authorized to operate the radial collector wells for 60 days each year and withdraw a maximum volume of over 7 billion gallons of water during that time, the equivalent of 124 million gallons per day. If constructed, the radial collector wells would likely become the largest wells in Florida by daily permitted volume when pumping. The majority of pumped water is projected to come from Biscayne Bay rather than the Biscayne Aquifer itself. Even so, the radial collector wells may put the City at risk because the "Biscayne aquifer is the sole source of potable water in Miami-Dade County, Florida." ML14287A481. However, the determination that the backup radial collector well system will have "minor impacts on groundwater users is based on the reliability of the [primary cooling] water supply," and not the prudence of drilling radial collector well laterals into a sole source aquifer. DEIS at 7-12.

Comment 4: The final Environmental Impact Statement should include an analysis of alternatives to the radial collector well backup cooling system that are less likely to adversely impact the Biscayne Aquifer.

The DEIS acknowledges that "[r]emoving relatively large volumes of water from the inland aquifer could lower the water table in the inland portion of the aquifer, affecting existing water-supply wells and increasing saltwater intrusion to the Biscayne aquifer." DEIS at 5-13. In addition, it states that "the volume of water that would be removed [by the radial collector wells] from the inland aquifer is difficult to predict with certainty because it depends on several hydrogeologic features and parameters that are incompletely quantified." DEIS at 5-14.

According to the DEIS, the highest estimated "volume of groundwater that could be removed from the Biscayne aquifer is 4,500 gpm during [radial collector well] operation . . . ." DEIS at 5-15. This amounts to about 6.48 million gallons of water per day from the Biscayne Aquifer during radial collector wells operation and about 388,800,000 gallons annually.

During the proposed project's lifetime, Miami will likely face dwindling supplies of potable water as well as further difficulties preventing flooding and saltwater intrusion during wet and dry seasons respectively. Considering these challenges, 388,800,000 gallons appears to be a relatively large withdrawal of water from the Biscayne Aquifer. FPL's most recent filings before Florida's Public Service Commission indicate that the new reactors are now planned to enter service closer to 2027. Around that time, Miami-Dade County's Water and Sewer Department projects that demand for water will be much closer to capacity. *See* SFWMD Individual Use Permit for MDWASD Permit Number 13-00017-W (Exhibits 8A, 9, and 23). Therefore, the increased demand placed on the Biscayne Aquifer reserves by the radial collector wells could adversely impact both supply and management of this scare resource in the coming decades. *See* DEIS at 2-176.

Moreover, withdrawing water from the Biscayne Aquifer is not a necessary consequence of siting the new reactors at Turkey Point. The goal of the final Environmental Impact Statement is to balance the need to implement an action against its impacts on the surrounding environment. In this instance, that need is for additional baseload power, and not for any specific facility contemplated in FPL's application. For example, Work Order #2, Task 1, Initial Water Source Alternative Technical Review Report, Section 5.0 (pages 3-4) indicated that operating the radial collector wells for use as a backup cooling system ranked fourth in FPL's analysis of cooling options. In contrast, drawing cooling water from the "Boulder Zone" (a South Florida injection zone) ranked second in this report. FPL's response to NRC RAI Number EIS 9.4-2 (RAI 5770) indicated that this option was not selected because the Boulder Zone is planned for use as an injection zone for wastewater. However, this does not address why the third ranked option was not selected or vetted further.

Likewise, limiting the analysis in the DEIS to only the proposed radial collector wells as a backup cooling system is not the "hard look" required by the National Environmental Policy Act (NEPA). This backup cooling system is easily one of the most concerning parts of the Turkey Point Nuclear Plant Units 6 & 7 application. Since the final Environmental Impact Statement must independently assess the impacts of the Environmental Report submitted by FPL, it should also consider other approaches to providing cooling water to the reactors. The DEIS has already accomplished this task for some of the inland alternative sites by assessing potential cooling systems other than those proposed. The final Environmental Impact Statement must do the same for Turkey Point.

Comment 5: The final Environmental Impact Statement should give greater weight to the potential for adverse impacts to environmentally significant resources in its risk analysis.

Operation of the radial collector wells would remove water from Biscayne Bay, the FPL industrial wastewater facility (also referred to as cooling canals), and the Biscayne Aquifer in an area adjacent to Biscayne National Park. DEIS at 2-27. It is also worth noting that there is a plume of hypersaline water in the portion of the Biscayne Aquifer underneath the FPL industrial wastewater facility. The DEIS acknowledges this fact and predicts that some of the hypersaline water would be drawn into the radial collector well system, which "may change the area affected by the hypersaline plume." DEIS at 5-15.

Therefore, the most direct risk of operating the radial collector wells would be an increase in the amount of saltwater intrusion caused by removing groundwater from the inland portion of the Biscayne Aquifer. DEIS at 5-27.

Similarly, the intermittent usage of the backup cooling system "could result in an increase of hypersaline flow into the aquifer beneath the bay that could migrate into the bay when the [radial collector well system] is not operating." DEIS at G-29. The introduction of this hypersaline water into Biscayne Bay may irreparably damage or destroy local seagrass beds, a critical habitat for several endangered species. A similar pattern occurred in the fall of 1987, causing an abrupt and widespread mortality event in the Florida Bay seagrass community. *See* http://tinyurl.com/SeagrassHabitatRestoration2013 at 11-12, 14-15. Seagrass mortality continued due to hypersaline conditions in Florida Bay through 1995 and had negative consequences for a variety of marine life. *Id.*

The DEIS also notes that there is the potential for adverse effects on threatened species, including American crocodile, that inhabit the FPL industrial wastewater facility due salt drift and deposition from cooling-tower operation while the radial collector wells are being used. DEIS at 5-54. Furthermore, there is the potential for the entrainment of microscopic organisms and larvae.

Due to the myriad risks presented by the radial collector wells and the vulnerable nature of the surrounding ecosystem, the final Environmental Impact Statement should place additional emphasis on avoiding the potential for adverse impacts to, and place additional weight on protecting, environmentally significant resources.

Comment 6: The final Environmental Impact Statement should update its analysis, in the USGS model and elsewhere, to include the effects of flooding FPL's industrial wastewater facility/cooling canal system with additional water from the L-31E canal and other sources.

After the completion of the DEIS, the South Florida Water Management District (SFWMD) issued an order authorizing FPL to divert 100 million gallons of water per day from the L-31E canal to the industrial wastewater facility. SFWMD Order No. 2015-020-DAO-WU.

Florida's Department of Environmental Protection (FDEP) has also begun a process that would entitle FPL to draw an additional 14 million gallons of water per day from the Floridan Aquifer into its industrial wastewater facility. *See* http://tinyurl.com/TP3-5ConditionsDraftMod.

Although both actions are being challenged, the former by the City and the latter by Miami-Dade County, the final Environmental Impact Statement should account for the presence of this additional water flow because its ostensible purpose is to flush hypersaline water out of FPL's facilities. As the SFWMD noted in late 2013, the consequences of flooding the FPL industrial wastewater facility are far from certain. *See FPL Turkey Point Cooling Canal System Salinity Reduction Proposal Review*, attached to these comments as **COM - A**.

Likewise, the USGS model described by the DEIS in Appendix G would need to account for this additional water flow. In addition, "'[b]ecause the [USGS] model conserves mass, withdrawal of groundwater results in water being drawn from other sources to replace it, and the freshening in this region could be due to predicted inflow from either freshwater or marine waters." DEIS at G-35. Hence, the assumption appears to be that there will be a recharge of freshwater. The final Environmental Impact Statement should address this assumption more directly.

The final Environmental Impact Statement should also update the USGS model to account for sea-level rise over the radial collector well system's operating life and address:

- The possibility that flushing the FPL industrial wastewater facility with additional water from the L-31E canal (in a manner that does not prevent evaporation or the resulting salinity increases) will push saltier water underground,
- The effect on the inland aquifer of seawater releases from the radial collector wells into the FPL industrial wastewater facility, and
- The potential for increased salinity levels in the inland aquifer resulting from future sea-level rise and storm surge hazards at the Turkey Point site, as well as the effects of this increased salinity on South Florida's freshwater resources.

Moreover, the City echoes Miami-Dade County's concerns related to the area across which the USGS model predicts average salinities over Biscayne Bay. The model should include an analysis that more narrowly focuses on southern Biscayne Bay. The broad focus of the USGS model obscures the true potential impacts of operating the radial collector wells in a fragile aquatic ecosystem.

The decision of the Nuclear Regulatory Commission, and cooperating agencies, of whether or not to approve the Turkey Point Nuclear Plant Units 6 & 7 application will likely rely on the findings of this model. The final Environmental Impact Statement, or a Supplemental Environment Impact Statement, should address these issues by refining the USGS model.

Comment 7: The final Environmental Impact Statement should examine and clarify how the operation of the Turkey Point Nuclear Plant Units 6 & 7 project, as currently proposed, might constrain attempts to adapt to climate change and to remedy the history of destabilizing uses and impacts the regional ecosystem has already suffered.

The DEIS contemplates that demand for water by all users will increase significantly in Miami-Dade County before the new reactors begin operating. *See* DEIS at 2-176. Similarly, "[t]hermoelectric demand for power use is projected to increase from 2.1 Mgd (four-tenths of one percent of total demand) to 69.8 Mgd (about 10 percent of total demand) from 2005 to 2025, respectively." *Id*. At the least, this information should be updated to include the water being diverted to the FPL industrial wastewater facility.

Moreover, the DEIS concludes that the "[a]dditional extraction of groundwater by [Miami-Dade County] to meet plant requirements for potable and service water is negligible compared to the current demand. Therefore, the [DEIS] concludes that operational groundwater-use impacts would be SMALL, and mitigation beyond the FDEP final Conditions of Certification would not be warranted." DEIS at 5-26. The conclusion that groundwater-user impacts would be small stands in contrast to the projection that thermoelectric demand will grow to 10 percent of all water demand in Miami-Dade County. The relationship between these determinations should be explained more directly in the final Environmental Impact Statement.

To the extent that an Environmental Impact Statement is a decision-making tool, it should also clarify the tradeoffs of pursuing the Turkey Point Nuclear Plant Units 6 & 7 project as currently proposed. As has been made clear, FPL facilities consume large volumes of water in a region that already has extremely limited freshwater resources. Any conflicts presented by the operation of the new reactors with investments in the Comprehensive Everglades Restoration Plan (CERP), protecting the Biscayne Aquifer from saltwater intrusion, or the consumption of potable water by the public should be made clear, not only in the body of the final Environmental Impact Statement, but also in the executive summary.

As an additional matter, any decision based on the final Environmental Impact Statement would benefit from an examination of how the placement of the new reactors at Turkey Point might affect regional adaptation strategies. As sea levels rise, saltwater intrusion intensifies, and drinking water becomes more expensive, the South Florida region will be required to pursue a variety of adaptation strategies. The majority of these adaptations will be forced to occur during the operating life of the new reactors. The need for power identified in the DEIS is predicated on assumptions that may not be in line with these adaptive strategies and potential inconsistencies should be explored further.

Expand Consideration of Sea-Level Rise Scenarios and Related Impacts

Turkey Point is a low-lying peninsula bordered by a shallow bay to the east and the Everglades to the west. The proposed site of the new reactors is a mud island southwest of the current plant that is surrounded by the industrial wastewater facility and borders Biscayne Bay. DEIS at 3-2. The proposed site will be raised with fill to a finished grade elevation of 25.5 ft North American Vertical Datum 1988 (NAVD88). *Id.*

As noted by the DEIS, the U.S. Global Change Research Program rates the vulnerability of the Turkey Point area to sea-level rise as "high" to "very high." DEIS at I-3. The DEIS further acknowledges that:

> Sea-level rise also is expected to "…accelerate saltwater intrusion into freshwater supplies from rivers, streams, and groundwater sources near the coast" and agricultural areas around Miami-Dade County "…are at risk of increased inundation and future loss of cropland with a projected loss of 37,500 acres in Florida with a 27-inch sea level rise." Water demand in southeastern Florida is projected to increase by more than 50 percent by 2060, relative to 2005, based on combined changes in population, socioeconomic conditions, and climate.

Id. However, the DEIS merely acknowledges these issues as a matter distinct from the rest of its analysis. It does not incorporate the consequences of climate change into its broader review of the cumulative impacts that may be associated with the siting of new reactors at Turkey Point.

Comment 8: The final Environmental Impact Statement should incorporate higher sea-level rise projections and local measurements of sea-level rise rates into its analysis of the risks presented by the Turkey Point Nuclear Plant Units 6 & 7 project.

The DEIS states that "[s]ea level is projected to rise 1 to 4 ft. globally by 2100." DEIS at I-3. This figure comes from the U.S. Global Change Research Program, which is the only source for sea-level rise projections cited in the DEIS.

In contrast, the National Oceanic and Atmospheric Administration (NOAA) has stated that "[n]o widely accepted method is currently available for producing probabilistic projections of sea level rise at actionable scales (i.e.

regional and local)." http://tinyurl.com/NOAA-SLR at 1. Furthermore, there is broad uncertainty regarding the specific effects that glacial melting and thermal expansion of the oceans will have on rising sea levels. *See id.* at 2.

"[O]ne of the functions of a NEPA statement is to indicate the extent to which environmental effects are essentially unknown . . . . Reasonable forecasting and speculation is thus implicit in NEPA, and we must reject any attempt by agencies to shirk their responsibilities under NEPA by labeling any and all discussion of future environmental effects as 'crystal ball inquiry.'" *Scientists' Inst. for Pub. Info., Inc. v. Atomic Energy Comm'n*, 481 F.2d 1079, 1092 (D.C. Cir. 1973); *see also N. Plains Res. Council, Inc. v. Surface Transp. Bd.*, 668 F.3d 1067, 1079 (9th Cir. 2011) (same). Therefore, when data is incomplete or uncertain as with sea-level rise projections, "reasonably foreseeable" includes "**impacts which have catastrophic consequences, even if their probability of occurrence is low**, provided that the analysis of the impacts is supported by credible scientific evidence, is not based on pure conjecture, and is within the rule of reason." 40 CFR § 1502.22 (emphasis added).

Based on the above, the final Environmental Impact Statement should account for multiple sea-level rise projections, including those with the highest projected sea-levels. In 2012, NOAA released four sea-level rise planning scenarios, the highest of which projected 6.6 feet of sea-level rise by 2100. Concerning these scenarios, NOAA recommended:

> The Highest Scenario should be considered in situations where there is little tolerance for risk (e.g. new infrastructure with a long anticipated life cycle **such as a power plant**).

http://tinyurl.com/NOAA-SLR at 2 (emphasis added); *see id.* at 12 and 15. Moreover, scientists at the University of Miami have measured sea-level rise locally, finding even higher rates than predicted:

> [O]ver the past 15 years, the average annual increase [in sea level] is roughly 0.27"/year, but over just **the past 5 years, it's about 0.97"/year**.

http://www.rsmas.miami.edu/blog/2014/10/03/sea-level-rise-in-miami/ (emphasis added). Using this information and modeling from the National Hurricane Center, the City of Miami and the Village of Pinecrest commissioned a sea-level rise assessment for the proposed site of the new reactors. That assessment is attached to these comments as **COM – D**. It accounts for SLOSH MOM scenarios, the planned increases in elevation for the new facilities, and uses storm surge data for southern Biscayne Bay. The findings of this assessment demonstrate that even by the year 2030, storm surges could isolate the reactor site and inundate the industrial wastewater facility. It is important to note that this assessment displays information for mean tides only. The effects of a storm surge would be greater in a hurricane at high tide.

Due to the uncertain nature of the data presented in the DEIS and the new reactors' low tolerance for risk, NEPA requires that the final Environmental

Impact Statement consider greater potential sea levels based on existing credible scientific evidence. Additionally, the final Environmental Impact Statement should include existing, local measurements of rates of sea-level rise and account for more than static sea-level rise, which by itself does not reveal risks associated with more frequent and severe flooding.

Comment 9: In addition to Appendix I, the final Environmental Impact Statement should integrate subsections related to sea-level rise throughout its review.

Appendix I of the DEIS contains the majority of the discussion on climate change and sea-level rise. Sea-level rise was likely relegated to a single appendix for ease of reference and to consolidate discussion on a complicated problem. Nevertheless, it is not the kind of problem that should be acknowledged separately from the rest of the environmental review.

Instead, the potential consequences of sea-level rise should be incorporated into, and analyzed at, every stage of the review process. For example, the section discussing the transportation of radiological materials would benefit from its own analysis of how rising sea-levels might affect this particular process.

Comment 10: The final Environmental Impact Statement should examine how the Turkey Point Nuclear Plant Units 6 & 7 project's adverse environmental impacts are likely to undermine efforts at sea-level rise adaptation.

The DEIS notes that, among other problems caused by climate change, "[s]ea-level rise will also push the freshwater–seawater interface further inland. This will put further stresses on freshwater resources inland." DEIS at I-5. These problems are likely to occur due to sea-level rise regardless of future activities at the Turkey Point site.

However, the U.S. Environmental Protection Agency (EPA) has stated, in its April 2015 letter to the U.S. Army Corps of Engineers (USACE), that FPL's project "may result in substantial and unacceptable impacts to mangrove wetlands, sawgrass marshes and [submerged aquatic vegetation], which we consider to be [aquatic resources of national importance]." Attached as **COM – B**.

These environmental resources are significant not only in the context of the Clean Water Act, but also to the discussion concerning sea-level rise impacts. The problem of saltwater intrusion cannot be separated from sea-level rise, storm surge, and other threats to the public's potable water supply. Even without extreme rises in sea-level, storm surges can exacerbate saltwater intrusion. In contrast, mangrove roots stabilize shorelines and enhance water clarity. Sawgrass marshes function as natural water filtration systems. Placing the new reactors at Turkey Point threatens 300 acres of mangrove wetlands and 40 acres of sawgrass marshes. Hence, Miami agrees with the EPA's requests for additional analysis and its conclusion that the project should not be approved as currently proposed.

Moreover, as these environmental resources provide important benefits related to water quality, the final Environmental Impact Statement should examine how their loss will exacerbate the consequences of sea-level rise and limit efforts at successful adaption.

Similarly, NRC RAI EIS 7.2-3 (RAI No. 5768 Revision 2) requests from FPL a discussion of adaptions being considered to account for changes in environmental impacts due to sea-level rise up to the year 2050. This discussion should also be included in the final Environmental Impact Statement.

Comment 11: The final Environmental Impact Statement's analysis should include worst case and plausible scenarios.

The DEIS notes that:

> Climatological changes might affect the average environmental risks of severe accidents because of changes in either severe accident probabilities or associated consequences. While the potential severity of storms and other natural phenomena might increase, nuclear power plants must be designed to withstand all creditable natural events at the site of concern. Increases in the severity of hurricanes with associated storm surges could increase the chance that a challenged safety system may not function. However, the core damage frequencies (CDFs) for the Advanced Passive 1000 (AP1000) pressurized water reactor design are very low and climate change is unlikely to change the CDFs appreciably. Therefore, even if consequences change as a result of climate change, severe accident risk is likely to remain SMALL because CDFs are so low.

DEIS at I-13. It further states that "as long as floodwaters did not rise to the level of the plant grade, there would be no contribution to CDF. More detail [sic] evaluation of external flooding at Turkey Point site also confirmed that the flood level at probable maximum precipitation will be below the plant grade." DEIS at 5-130.

These statements in the DEIS raise three questions that should be addressed in the final Environmental Impact Statement:

- What sea-level rise projection was used to generate the maximum probable storm-surge contemplated above?
- What operational lifetime was projected for the new reactors?
- Was the worst case scenario hurricane drawn from a proper sample of storms?

The first question does not require additional explanation.

Concerning the second question, the U.S. Nuclear Regulatory Commission's Office of Nuclear Regulatory Research has confirmed that it is investigating the possibility of licensing reactors to operate for a total of 80 years and that it expects the first applications for these licenses to be submitted in the next couple years. Currently, nuclear reactors may not be licensed beyond a total of 60 years.

FPL's most recent filings before the Florida Public Service Commission show that it plans to delay operation of the new reactors to the late 2020s. If the new reactors were eventually approved for a total of 80 years, it would extend their operation up to the year 2100, when NOAA's projections contemplate 6.6 feet of sea-level rise. Therefore, the final Environmental Impact Statement should account for an 80 year operating life of the proposed reactors when analyzing the potential impacts of sea-level rise near Turkey Point.

Concerning the third question, new research into deeper climate histories suggests that, due to natural variability, the storm hazard profile of the recent era could be lower than what might be experienced in the future. *See* Donnelly and Woodruff, attached to these comments as **COM - C**. In short, it is possible that the intensity of future storms is being underestimated.

Deeper Examination of Foreseeable Emergencies

As noted in the previous section, the DEIS acknowledges the potential that "[c]limatological changes might affect the average environmental risks of severe accidents," however it concludes that the core damage frequencies of the relevant reactor design are low enough that this is an unlikely problem. DEIS at I-13. This does not appear to be a thorough analysis. Simply stating, without further discussion or support, that the reactor design standards are sufficient to protect from future climate harm, does not satisfy NEPA.

Comment 12: The final Environmental Impact Statement should incorporate a full analysis of the potential for severe accidents related to climate change or cite to relevant research.

Although the DEIS does acknowledge that there is the potential for a severe accident resulting from climatological changes, it does not discuss specific scenarios or estimated probabilities. The final Environmental Impact Statement should include a full analysis to better demonstrate the nature and likelihood of the risks acknowledged in the DEIS.

Comment 13: The final Environmental Impact Statement should examine impacts related to the loss of the backup cooling system.

The radial collector well system may be unable to operate for a variety of reasons. The environmental impacts of losing this system should be

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examined by the final Environmental Impact Statement to meet the "hard look" imposed by NEPA.

For example, the radial collector wells are not able to operate with water that is more than 1.5 times the salinity of Biscayne Bay. As has been noted previously, there is already a plume of hypersaline water in the aquifer beneath FPL's industrial wastewater facility. Since, the radial collector wells will be drawing water from this groundwater source, the final Environmental Impact Statement should examine and disclose how entrainment of the hypersaline water by the radial collector wells will impact the surrounding aquifer and operation of the nuclear plant.

Likewise, the final Environmental Impact Statement should examine and disclose what outcomes will result if the primary source of cooling water is still unavailable after FPL has exhausted the 60 days during which it is allowed to operate the radial collector well system.

Clarify Uncertainties Related to the Deep Injection of Wastewater

The application plans for disposal of waste by use of deep injection wells. The purpose of this system is to diffuse waste water with aquifer water over the long term by sending it beneath the "Boulder Zone" (a South Florida injection zone). At present, the formation of this injection zone is not fully understood by geologists and little data exists on its lateral flow capabilities. Moreover, the proposed discharge method for the disposal of treated liquid radioactive waste is not practiced by any other power plant in the U.S.

Comment 14: The final Environmental Impact Statement should disclose uncertainties related to the deep injection of wastewater and the probable final disposition of the waste.

The final Environmental Impact Statement should "indicate the extent to which environmental effects are essentially unknown . . . ." *Scientists' Inst. for Pub. Info., Inc. v. Atomic Energy Comm'n*, 481 F.2d 1079, 1092 (D.C. Cir. 1973). Hence, to the extent that such information is known, the final Environmental Impact Statement should disclose where effluent from the nuclear plant might migrate.

Similarly, although the east-west tidal forces on groundwater are not well understood, the final Environmental Impact Statement should discuss the probability that the north-south shallower slope of the dolomite in the Boulder Zone will push the wastewater north of the injection site.

Clarify Analysis of Need for Power and Population Projections

NEPA requires that a final Environmental Impact Statement discuss the purpose of and need for the action "to which the agency is responding in proposing the alternatives including the proposed action." 40 CFR § 1502.13. In particular, Chapter 8 of the Nuclear Regulatory Commission's Environmental Standard Review Plan provides a review and analysis of the 'need for power'. Through this section, the Nuclear Regulatory Commission may weigh the benefits of the power plant against the environmental impacts of construction and operation of a nuclear power reactor.

Comment 15: The final Environmental Impact Statement should assess and explain projections of future demand for electricity in South Florida.

The Florida Bureau of Economic and Business Research (BEBR) at the University of Florida released a Florida Detailed Population Projection for the years 2015-2040 in 2014. http://tinyurl.com/BEBR2015-2040. This study projects that the rate of population growth in Miami-Dade County will continue to rise until 2020. At that point, the rate of population growth will begin to decrease and level off. The DEIS acknowledges this projection and states that "high rates of population growth are anticipated from 2014 until 2018 and then level off after 2018." DEIS at 8-6.

Moreover, BEBR produced a Florida Estimates of Population analysis in 2014. *See* http://tinyurl.com/BEBR2014. This analysis shows that the rate of population growth has decreased from 16.3% to 4.7% in Miami-Dade County from 1990 to 2014. *See id.* at Table 3. The previous study suggests that this rate will continue to decline to 3.1% by the year 2040. Similarly, the SFWMD decreased water allocation from the Biscayne Aquifer in a 2015 water use permit for Miami-Dade County's Water and Sewer Department "due to water conservation measures and updated population projections showing a lower population growth rate through 2033." *See* SFWMD Individual Use Permit for MDWASD Permit Number 13-00017-W (Description 4-5). Thus, Miami-Dade County has updated its future demand projections with the availability of new population data, thereby reducing the total amount of water required to meet the needs of Miami-Dade County. Accordingly, the demand for power will likely decrease as the rate of population growth in Miami-Dade continues to decrease and then stabilizes over the coming decades.

Therefore, the final Environmental Impact Statement should include a discussion of whether or not a decrease in the rate of population growth in Miami-Dade County will affects the projected demand for electricity.

Comment 16: The final Environmental Impact Statement should include distributive models of energy generation in its review.

FPL has stated that "without the proposed action, nuclear power generation would decline to 16% of its portfolio by 2021 and cause FPL to rely on natural gas power generation for up to 75% of its power generation." DEIS at 8-7. This statement assumes that natural gas, or even centralized energy generation, is the only alternative to a nuclear power plant.

In contrast, the final Environmental Impact Statement should assess distributive, or "rooftop," solar power generation options. Although the DEIS assess solar farms, it does not include an assessment of distributive options. With this in mind, the City of Miami used data from the Florida

Solar Energy Center at the University of Central Florida to compare the output of a limited distributive generation scenario with nuclear power.

For simplicity's sake, the City focused only on solar water heaters. Solar water heaters use solar energy to heat water and hold that hot water in reserve for consumer use. This brief analysis showed that the same energy needs can be met more efficiently with less power output. Not only is solar hot water heating a reasonable renewable energy option, it is also more efficient than traditional electricity generation for the purposes of heating water.

Other economic considerations must be incorporated in this analysis, however, the City of Miami believes that if a simple change such as adopting widespread use of solar hot water heaters can result in such an impact in energy demand, this type of scenario should be considered in the final Environmental Impact Statement's analysis of the determination of need for Turkey Point Nuclear Plant Units 6 & 7.

Equations, Variables, & Givens
$P_{kw} = E_{kwh} \div t_{hr}$ P = Power in kilowatts E = Energy in kilowatt hours t = Time in hours
Hours in a year = 8, 765.81 hours For a family of four, typical hot water usage is 25,550 gal/yr at 3,990 kwh/yr to heat electrically. Solar hot water heaters save between 50 - 85% of energy expenditure. For the purposes of a conservative analysis, the City assumed that solar hot water heaters use 1,995 kwh/yr (or, 50% of 3,990 kwh/yr). FPL has 4.7 million customers. Of these, the average number of rural and residential customers is 4,230,063. *See* FPL 10 year site plan.

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Comparison Point A: Calculating Yearly Power from One Solar Hot Water Heater
P_{kw} = 1,995 kwh ÷ 8, 765.81 hours = .227 kw
.227 kw = 227 w
227 w/hr × 24 hours/day = 5,448 w/day
5,448 w/day × 365 days/yr = 1,988,520 w/yr
1,988,520 w/yr × (1.0×10^{-6}) MW/w = 1.98852 MW/yr
1.98852 MW/yr = power from one solar hot water heater

Comparison Point B: Calculating Yearly Power from Turkey Point Nuclear Plant Units 6 & 7
FPL's Target Capacity for Proposed Units 6 & 7 = 2,200 MW/hr
2,200 MW/hr × 24 hr/day = 52,800 MW/day
52,800 MW/day × 365 days/yr = 19,272,000 MW/yr
19,272,000 MW/yr = total projected power generated from Units 6 & 7

Conclusion Based on a Limited Population of Adopting Ratepayers: Amount of Power Produced from Solar Hot Water Heaters from FPL Rural and Residential Customers
If one solar water heater produces 1.98852 MW/yr of power, then:
1.98852 MW/yr × 4,230,063 rural and residential customers = 8,411,565.88 MW/yr
8,411,565.88 MW/yr = Amount of power produced in one year if FPL rural and residential customers were required to have a solar hot water heater.

Conclusion Based on Adopting by All Ratepayers: Amount of Power Produced from Solar Hot Water Heaters from all FPL customers
If one solar water heater produces 1.98852 MW/yr of power, then:
1.98852 MW/yr × 4,700,000 total customers = 9,346,044 MW/yr
9,346,044 MW/yr = Amount of power produced in one year if all of FPL customers were required to have a solar hot water heater.

Based on this scenario, the City found that almost half of the projected power output of the new reactors can be generated using a distributive power generation model even under conservative circumstances. Moreover, the final Environmental Impact Statement should assess whether the energy needs anticipated by FPL can be met more efficiently with less power output.

Expand Consideration of Transmission Line Impacts

The DEIS notes that "[t]ransmission-line construction would fragment habitat and permanently affect pine rocklands that are designated as critical habitat for listed species." DEIS at 10-5. However, the impacts of FPL's proposed transmission lines are not limited to construction-related disruptions.

Comment 17: The final Environmental Impact Statement should disclose risks related to transmission lines not built to Florida hurricane safety standards.

The transmission lines associated with this project will not be constructed to conform to Florida's Building Code, which specifically accounts for the high velocity hurricane zones common throughout South Florida. Instead, the transmission lines will be erected according to an industry-created minimum safety standard known as the National Electrical Safety Code (NESC).

In short, structures built using NESC standards are significantly less hurricane resistant than structures built to Florida Building Code standards. The NESC is too large to attach to these comments. However, it is contained in the Site Certification Application that FPL submitted to the State of Florida. NESC Table 253-1 shows the load factors for the highest velocity winds contemplated under that code. The table lists the relevant load factor as 1.00. Essentially, a load factor is a safety factor that accounts for construction error and establishes the amount of additional stress from wind, and related swaying, that the structure is able to withstand; **designs using this standard will have 60% less loading, and less reliability**, than required by building codes which account for high velocity hurricanes.

This is a significant concern when many of the transmission poles proposed in the Turkey Point Nuclear Plant Units 6 & 7 application are over ten-stories tall.

In conclusion, the City reiterates its belief that the Turkey Point Nuclear Plant Units 6 & 7 application should not be approved as currently proposed.

To the extent that certain of these comments are determined to be outside the scope of the environmental review, the City requests that those comments be addressed through the safety review process or the review undertaken by the U.S. Army Corps of Engineers.

Thank you for this opportunity to submit comments.

Sincerely,

Matthew Haber for

Victoria Méndez,
City Attorney

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Alicia Williamson, Alicia.Williamson@nrc.gov
Manny Comar, Manny.Comar@nrc.gov

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City of Miami
Comments on DEIS
COM - A

FPL Turkey Point Cooling Canal System Salinity Reduction Proposal Review

October 2013

Jeff Giddings

Resource Evaluation Section

Water Supply Bureau

South Florida Water Management District
West Palm Beach, Florida

1.0 Executive Summary

Hypersaline conditions exist within and beneath the Cooling Canal System (CCS) located at Florida Power and Light's (FPL) Turkey Point Power Plant in southern Miami-Dade County. To address these hypersaline conditions, FPL is proposing to dilute the existing CCS waters with 14 million gallons per day (mgd) of additional fresh and/or brackish water from the SFWMD L-31E canal or from the Floridan aquifer in order to reduce and maintain a salinity of 35 practical salinity units (psu) in the CCS canals. It is FPL's position that as a result of reducing the CCS water salinity to match that of Biscayne Bay combined with the CCS water levels associated with routine operations of the cooling system, the hypersaline groundwater and the associated effects on the inland position of CCS saline groundwater will stabilize and the inland extent of the saline groundwater wedge will retreat eastward from its current position over the next 30 years. FPL has developed a two-dimensional, cross-sectional, density-dependent groundwater model through the study area within the Biscayne aquifer -- with associated documentation along with a water budget spreadsheet model used to estimate the volume of Floridan Aquifer System water needed to reduce CCS salinity levels to 35 psu -- to support its proposal.

The purpose of this technical memorandum is to (1) evaluate FPL's groundwater model and associated documentation, (2) correct assumptions and data and conduct revised simulations, (3) reevaluate FPL's proposal and associated conclusions based on the revised simulations and (4) conduct additional simulations – including use of another model to evaluate effects of groundwater withdrawals from the Floridan aquifer system -- to address other concerns and scenarios not included in FPL's submittal.

District staff review of FPL's 2-D groundwater model identified three areas where additional evaluation was warranted: (1) model data and values with inconsistent datums, (2) specified heads which deviate from average elevations calculated from District databases and (3) more appropriate choice of canal for the western boundary condition (C-111). Regarding Item 1, it is apparent that data used in FPL's model inadvertently switched between two datums; that is the National Geodetic Vertical Datum (NGVD) of 1929 and the National American Vertical Datum (NAVD) of 1988. Because NAVD is approximately 1.5 feet higher than NGVD and the hydraulic gradient is rather flat in south Florida, these datum discrepancies can have a large effect on simulated hydraulic gradients and model interpretations and conclusions. Regarding Item 2, SFWMD downloaded data from SFWMD's DBHYDRO database and FPL's submitted monitoring data regarding water level elevations and used this data to evaluate model sensitivity to small changes in specified head elevations. Regarding Item 3, SFWMD tested the model responses to stage elevations from the C-111 Canal as a more appropriate western boundary condition -- rather than the L-31W canal used in the FPL model -- because the C-111 is the controlling canal for water levels in the area. Two additional sensitivity runs were conducted by the District; one was to evaluate the potential impact of increasing the stages in the CCS by 0.25 feet on the inland position of saline groundwater (possible increase due to adding 14 mgd to the system); the second was to assess the possible impacts associated with a hypothetical increase in sea level of 0.25 feet.

Results from FPL's original model runs were compared with the adjusted water level data set and the additional sensitivity runs developed by the District to evaluate the proposed 14 mgd addition of fresh/brackish groundwater to the CCS. Results of these simulations were generally consistent with FPL's model; that is, that the freshening of the CCS with 14 mgd of fresh/brackish water will serve to return the CCS to a saltwater concentration similar to Biscayne Bay. However, FPL's model indicates that the proposed action will not only reduce the salinity of the CCS water, but will also reverse the western movement of the hypersaline plume. In contrast, SFWMD's model does not indicate such a reversal in the inland groundwater movement. In fact, SFWMD's model indicates a continued increase in the western movement of the hypersaline plume. Slight differences of several hundred feet were noted in the position and orientation of saline groundwater west of the CCS when comparing whether or not the stage in the CCS was raised an additional 0.25 feet. There was also no significant change in the inland position and orientation of saline groundwater associated with an increase in sea level of 0.25 feet, which may be due to the higher water level elevations that occur in the discharge side of the CCS.

In an attempt to gain insights into the significance of the continued potential westward movement of saline groundwater, two additional model simulations were run by the District. In the first, a 'no action' simulation was run in which the hypersaline conditions within the CCS remain unchanged for 30 years. The second scenario capped the salinity of the CCS at 35 psu from 1972 through 2043, representing a hypothetical condition where the CCS never became hypersaline. The model calculated groundwater salinity distributions were then compared with the model runs representing the CCS becoming hypersaline and then being managed at a salinity of 35 psu for 30 years. Results suggest that the inland position and orientation of saline groundwater for the proposed 14 mgd scenario rests between the no action and constant sea water salinity scenarios.

FPL's analysis did not include an assessment of the potential impacts of withdrawing 14 mgd on existing legal uses of the Floridan aquifer. To provide insight into this question, the District utilized the regional East Coast Model to estimate drawdowns resulting from the proposed withdrawals. The results of the effects of the 14 mgd withdrawals on the Floridan aquifer indicated a 40-foot drawdown at the site, but only a few feet of drawdown at existing, adjacent legal users of the Floridan aquifer such as Florida Keys Aqueduct Authority in Florida City, Miami-Dade Water and Sewer Department and the Ocean Reef Club in Key Largo.

2.0 Introduction

In 1972, following a law suit brought against Florida Power and Light (FPL) by the United States of America, the predecessor of the South Florida Water Management District (SFWMD or the District) entered into an agreement with FPL for the construction and operation of a cooling canal system (CCS) at the Turkey Point Power Plant in southern Miami-Dade County. The purpose of this agreement was to restrict the direct discharge of heated water from the plant into Biscayne Bay and instead use a closedloop system, which would allow the water to cool and be reused by FPL on their property. At that time, it was identified that the construction of a series of saline cooling canals within the Model Lands area of Miami-Dade County could potentially impact the Biscayne aquifer. As a result, the agreement required the construction of a seepage control system (i.e., Interceptor Ditch) designed to limit the loss of freshwater and to restrict the westward migration of saline water west of the L-31E canal beyond which would occur naturally. Monitoring of surface water and groundwater was also required. Amendments to the original agreement were made four separate time's mainly addressing monitoring requirements and the seepage control operation. A fifth agreement between FPL and SFWMD was reached in 2009 following the uprate approval of the nuclear Units 3 and 4 in 2008. This agreement required FPL, in part, to revise the Interceptor Ditch seepage control system operations, to enhance the existing monitoring program, and to mitigate, abate or enact other remedial measures to control the migration of the saline interface caused by the operation of the CCS.

In 2012, FPL provided the SFWMD with a Turkey Point Pre-uprate report, which identified that the hypersaline water originating from the CCS had migrated into the Biscayne Aquifer to varying degrees and distances surrounding the CCS. To address this, FPL is considering an option of reducing the salinity levels within the CCS to those of seawater (35 psu) and conducted some preliminary evaluations of the concept. The studies, which consisted of a technical document discussing their findings, a spreadsheet model addressing the salt balance within the CCS, and a 2-D cross-sectional density-dependent solute-transport groundwater model, were sent to the District for review and approval.

District technical staff reviewed the reports and models sent by FPL to the required Agencies and District leadership. This report is compiled to document the procedures and findings of the District's technical review of FPL's proposal. District staff was tasked with documenting the finding of the review and the submittal of the findings along with FPL's and the District's work to FPL, District leadership, the Florida Department of Environmental Protection (FDEP) and Miami-Dade County to aid of their joint exploration of CCS salinity management options.

3.0 Approach

In August 2013, FPL provided the District with a proposal for reducing the salinity within the CCS to levels consistent with Biscayne Bay and the Atlantic Ocean. The District, working in conjunction with FDEP and Miami-Dade County (Agencies), elected to provide the initial technical evaluation of the FPL proposal and then share its findings with the Agencies and FPL. Upon receipt of the proposal, District staff used the following procedure for review:

3.1 Water Budget Analysis:

FPL's spreadsheet analysis was sent to the District's contract water budget expert for review and analysis. A copy of the assessment and findings are included as **Appendix E** of this report.

3.2 Two Dimensional Density-Dependent Solute-Transport Groundwater Model

FPL provided the District with a technical memorandum prepared by their contractor Tetra Tech that documents the model structure data and assumptions. In addition, FPL made available all model datasets, which enabled the District to better understand the model setup, data and to conduct sensitivity runs. District staff reviewed the FPL technical memo and model data sets initially to determine data consistency. In that review, two issues were identified. The first involved data values which were based on a different datum (NGVD and NAVD). The second observation was that some of the specified head values were slightly different than calculated values produced from District databases (example, Biscayne Bay stage and Stage data for District canals L-31E, L-31N and C-111). The values used by FPL may have been based on data from different monitor stations (as was the case in Biscayne Bay) or from different data-bases or periods of record. In any case, the differences were on the order of a few tenths of a foot but could be sufficient to produce different results. Accordingly, it was decided to evaluate the sensitivity of the model to see how robust the calculated location and orientation of saline groundwater was to small changes in water levels.

A series of model sensitivity runs were identified as listed in the table below. Results from these sensitivity runs are described below.

3.3 Floridan Aquifer Withdrawal Assessment:

FPL's scope of study did not include an assessment of the impact of withdrawing 14 mgd from the Floridan aquifer on existing legal uses. This was an important consideration of the proposed project so the District elected to use the LECFAS model to assess potential impacts

Figure 1 – Site Map with Monitor Well Locations

4.0 Review and Findings of the FPL Submittals

4.1 Cooling Canal System Water Budget

FPL used a CCS water and salt budget model developed for and under review by the District and documented in the pre-uprate report (FPL 2012) to estimate the volume of water needed for dilution. Using this water budget model, FPL concludes that the addition of 14 mgd of low salinity water from the either the Floridan aquifer or L-31E canal north of the plant site and discharged into the CCS would reduce the salinity concentration in the CCS to approximately seawater within 1 year of continuous operation. The analysis also suggests that the added 14 MGD of water would increase levels in the CCS by approximately 0.25 ft.

The water and salt budgets used are described in the Pre-uprate report (2012), and the calculations and results of the volume necessary were included in the FPL Cross-Sectional Model of Turkey Point Cooling Canal System report (2013). The general methodology used was:

a. Review and analyze FPL submitted documentation and model data sets.
b. District staff to review the FPL submittals in order to provide an independently evaluation of the data, assumptions, methods and findings for accuracy and correctness.
c. Correct errors within the model or conduct independent assessments if needed to address omissions.
d. Conduct sensitivity evaluations in order to gain an understanding of how changes to the area hydrology could affect results.

District staff contracted with an outside water budget expert to evaluate and conduct an independent, spreadsheet budget calculation and review of the work submitted by FPL and to validate the assumption that 14 MGD was sufficient to reduce the CCS to saline conditions. The result of this work is documented in a tech memo provided to the District and included in this report as **Appendix E**. The analysis require some changes to the water and salt budget model submitted by FPL but the results of the calculations show that the addition of an inflow of 14 mgd of brackish water from the Floridan aquifer is sufficient to reduce the long-term average salinity in the CCS to near or below the target value of 35,000 mg/l TDS and is consistent with the FPL conclusion. Temporal variability will remain and seasonal and year-to-year variation in rainfall and, to a lesser extent, evaporation will drive fluctuations in salinity on similar time scales. More detailed model calculations are required to fully describe the effect that the additional input of Floridan aquifer water would have on salinity in the CCS.

While 14 mgd of FAS water appears to be a reasonable estimate of the volume of water needed to reduce the CCS salinity, no evaluation of the potential impacts that could be associated with the withdrawal of 14 mgd from the FAS was included in the report for District evaluation. This issue will be discussed in **Section 5**.

4.2 2-Deminsional, Cross-Sectional Density-Dependent Solute-Transport Groundwater Model

FPL provided the District with a proposal for reducing the hypersaline conditions within the CCS at the FPL Turkey Point facility. The submittal included a report and data sets that were reviewed by District staff. Documentation of FPL's methods, assumptions, and findings can be found in their report (2013).

Hypersaline conditions exist within the CCS because water quality at the surface becomes hypersaline as a result of evaporation and plant operations and its lack of direct surface water interaction with adjacent water bodies. The result is that hypersaline water sinks beneath the CCS to the base of the aquifer because it is denser, potentially contributing to the inland migration of the saline interface in southern Miami-Dade County. To address the hypersaline conditions at the site, FPL is proposing to dilute the existing CCS with 14 mgd of additional fresh and/or brackish water from the SFWMD L-31E canal or from the Floridan aquifer.

To support their proposal, FPL provided a two-dimensional groundwater flow and density-dependent transport model of the Biscayne aquifer to the SFWMD using the USGS computer code known as SEAWAT (2003). This USGS 2-D model was originally developed by Hughes (2009) and subsequently modified by FPL (2013) to address specific issues relating to the CCS at the FPL Turkey Point Power Plant. The model is a two-dimensional cross-sectional model through the Biscayne aquifer across southern Miami-Dade County in a general east/west direction beginning on the west in the C-111 basin and terminated on the east off-shore of old Rhodes Key. The primary modifications made by FPL (2013) to the original USGS model are adjustments to the FPL cooling canal systems, internal boundary conditions, and changes to aquifer properties based upon recent aquifer performance tests conducted at the facility**. Figure 1** provides the project location.

This two-dimensional model modified from Hughes (2009) allows for a simple and quick method for evaluating proposed changes and provides reasonable results for a rudimentary assessment of possible alternatives. This model can be run and processed in a short period of time and has significant cost and time advantages compared to the development of a full 3-D solute transport model of the aquifer system. However, the geometry of the CCS and its plume are poorly represented at the regional scale by the 2-D model. The 2-D model also lacks essential features of regional hydrology that can affect the behavior of the plume. Recharge from rainfall and water loss from the aquifer due to evaporation and well withdrawals are not accounted for. Neither are the interaction between the aquifer and canals outside of the immediate area of the CCS, which can function both as sources of recharge and discharge from the aquifer. Limitations of using a 2-D versus a 3-D model are numerous because of the overly simplified hydrology, inherent constraints in 2-D flow and transport fate when applied to a 3-D problem and accordingly, results provided on saline movement in the region derived from the 2-D model should be considered as a very generalized representation of what could be expected.

The model provided by FPL is a cross-sectional model through the Biscayne aquifer with the vertical discretization divided into 31 layers each 3 feet thick. **Figure 2** shows the horizontal hydraulic conductivity with depth. The hydraulic conductivity does not vary laterally within an individual layer. The high hydraulic conductivity occurring at a depth of approximately -27 feet NGVD is a very productive unit of the Key Largo Limestone. Note that this is the same zone that the proposed radial collector wells are targeting as described in FPL's Site Certification Application proposed for Units 6 and 7.

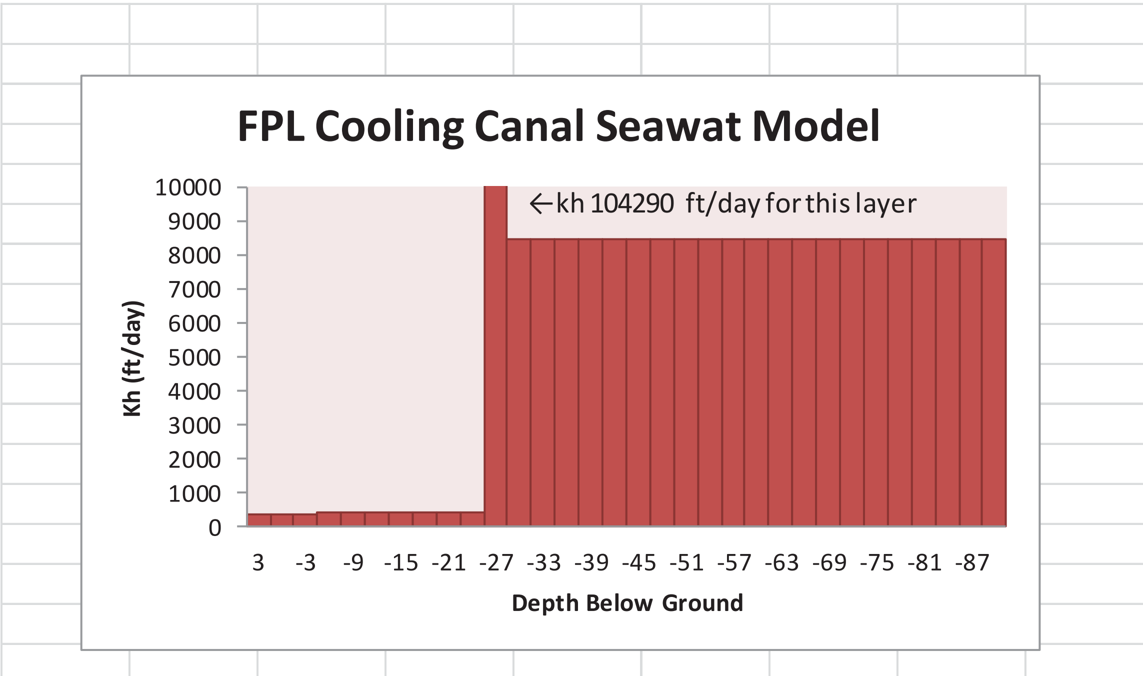

Figure 2. Hydraulic Conductivity of the FPL Biscayne aquifer model.

The use of a constant thickness and constant hydraulic conductivity for each layer of a model that stretches 136,000 feet across the Biscayne aquifer is a highly simplified representation of the groundwater system. FPL states that "No attempt was made to approximate the thinning of the aquifer to the west as it was believed that thickness changes would have an insignificant effect on model transmissivity given variability in hydraulic conductivity". This simplifying assumption of constant aquifer thickness over the model domain is incorrect and may influence the advective flow component of the model and the associated movement of saline water within the aquifer. The assumption that the hydraulic conductivity does not change across the model and that the highly transmissive zone of the Key Largo Limestone is laterally contiguous at -27 feet NGVD is also questionable. Modification of the model to more accurately reflect the area hydrogeology would require the model to be recalibrated.

4.2.1 Datum Inconsistencies

Besides the inherent problems identified above by using a simplified 2-diminsional model, another key inconsistency was identified in the FPL report. It appears that the data used to simulate the canal stages had mixed datum reference points. FPL provided two model simulations, a historical model simulation which has the CCS operating at it's historically did from 1975 through the present. A second simulation, called the salinity reduction simulation, assumes the 14 mgd inflow of brackish water into the CCS and simulates a period of 30 years beginning in 2015. In the historical simulation, FPL assumed all canals and ocean levels were referenced to NGVD. However, for the salinity reduction simulation, they assumed that the canals and ocean on the east use a NAVD datum while the west remains at a NGVD datum. This creates a series of problems because the difference between NAVD and NGVD is 1.53 feet, with NGVD being the higher datum. Basically, by keeping the western boundary at NGVD levels for the salinity reduction run and changing the eastern canals and ocean to reflect NAVD levels, an additional 1.5 foot west-to-east head gradient is artificially introduced into the simulation. Furthermore, the salinity reduction run uses the heads and concentrations from the historical operations run which means the heads are starting out 1.5 feet higher than they should be.

The topography of southern Miami-Dade County is only several feet above sea level in most of the area except along the Atlantic Coastal ridge. Due to the low topographic and hydrologic gradients of the area, deviations on the order of approximately 1.5 feet could significantly alter local groundwater flow and salinity migration rates and directions. **Figures 3 and 4** show the heads at various points that FPL used in their simulations. The mixing of NAVD and NGVD vertical datums is apparent. Correction of the FPL data to a single datum was needed to assess the effects of FPL's proposed CCS salinity reduction proposal and for the basis of comparison to the historical run and against the sensitivity model runs proposed by District staff.

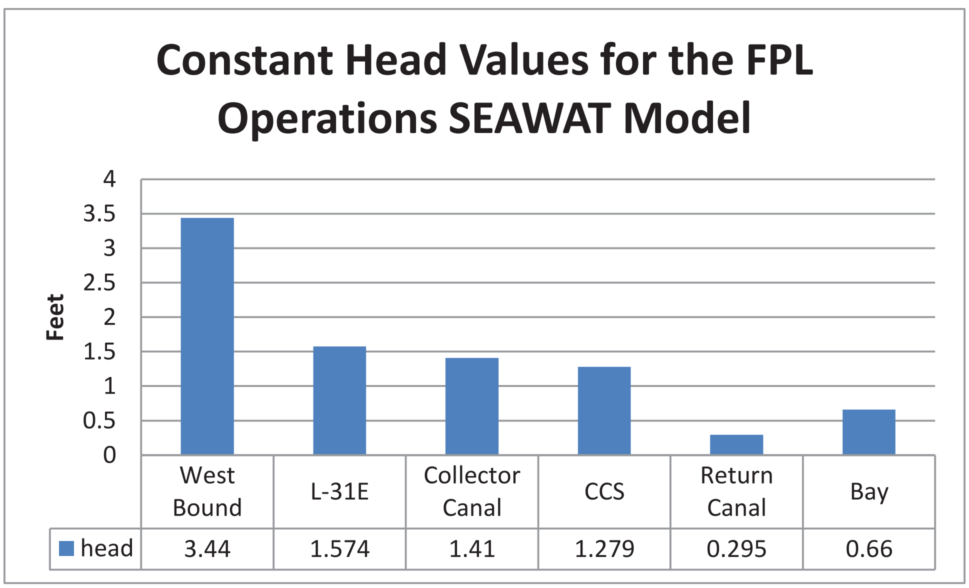

Figure 3. FPL Canal Stages for the Operations Model submitted to SFWMD.

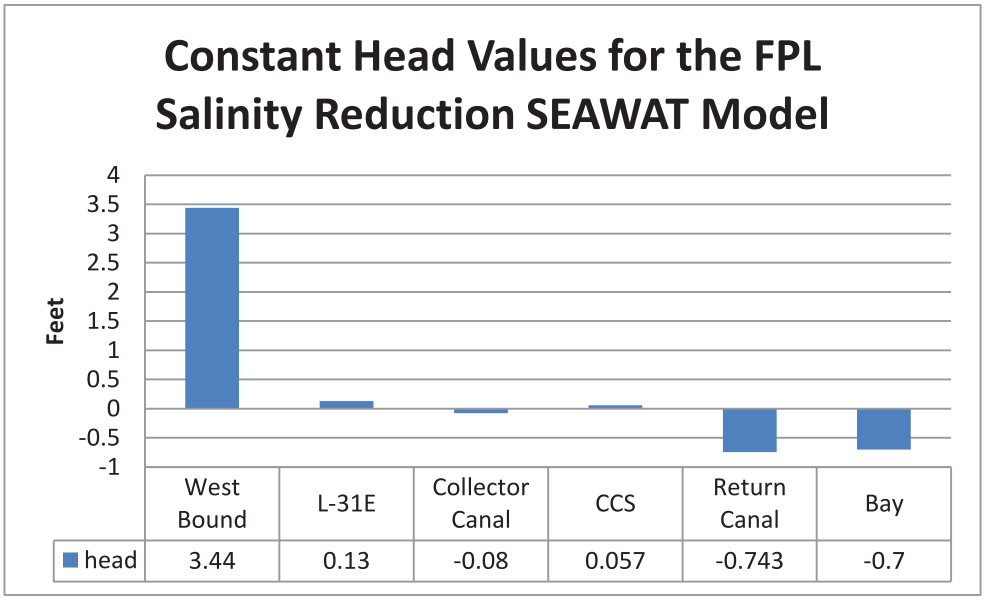

Figure 4. FPL Canal Stages for the Salinity Reduction Model submitted to SFWMD.

4.2.2 Canal, Biscayne Bay and Atlantic Ocean Specified Head Values

Water levels in the model at maintained surface water features are simulated using constant heads. These boundary conditions are the Atlantic Ocean and Biscayne Bay on the east, the C-111 basin on the west, and the SFWMD L-31E canal and the CCS in the center. Water levels within the CCS are maintained at different elevations and can be divided into the interceptor canal, the discharge canals and the return canals. The L-31E and CCS canals have varying depths ranging from several feet upwards of 30 feet deep. For each individual simulation, water levels are maintained at a fixed level throughout the simulation at each individual canal, but may have different levels between canals.

The values used by FPL for certain specified-head conditions are not non-unique and do not match long term averages calculated from District data-base time series. There is a potential that these differences, albeit small, may be significant to affect the model's representation of saline groundwater occurrence and movement. Corrections to these boundary conditions, and standardized to NGVD, were conducted for District simulations and are required to properly assess the proposed salinity reduction scenario.

5.0 SFWMD Model Scenarios Conducted Under this Review

5.1 Model Simulations and Revisions

In order to provide an independent review of the FPL proposal, SFWMD conducted a series of model simulations to evaluate groundwater conditions. These included 9 simulations using the revised 2-D Biscayne aquifer model and 3 simulations with the SFWMD East Coast Floridan Model. Several additional recalibration model runs and target-specific sensitivity runs were also conducted but not included in **Table 1**. The nine simulations using the 2-D Biscayne aquifer model are listed in **Table 1**. A detailed discussion of each run is provided in **Section 5.4**.

Table 1. SFWMD CCS simulations.

2-D Flow /Transport Steady State Biscayne Aquifer Model	
Model Run	**Description**
HIS_FPL	Original FPL Historical Operations Simulation.
HIS_SFWMD	Historical Operations Simulation with SFWMD modifications
SR_FPL_V1	Original FPL Salinity Reduction simulation with mixed NAVD and NGVD canal stages.
SR_FPL_V2	Original FPL Salinity Reduction simulation with FPL canal stages all referenced to NGVD.
SR_SFWMD	Salinity Reduction Simulation with SFWMD modifications.
SENS_SFWMD_SLR	Sensitivity simulation with combined HIS_SFWMD and SR_SFWMD run with Sea Level Rise of 0.25 feet.
SENS_SFWMD_SEA	Sensitivity simulation with combined HIS_SFWMD and SR_SFWMD run with CCS salinity held at ocean water levels.
SENS_SFWMD_NC	Sensitivity simulation with combined HIS_SFWMD and SR_SFWMD run without the 14 mgd Floridan water added. A no change simulation.
SENS_SFWMD_NI	Sensitivity simulation with combined HIS_SFWMD and SR_SFWMD run. Assumes 14 mgd added to the CCS but it does not increase stages an additional 0.25 feet.

5.2 Floridan Aquifer Model Simulations

FPL did not provide an evaluation of the potential impacts of withdrawing 14 mgd either from the L-31 Canal/Biscayne aquifer or from the Floridan aquifer. For this analysis, it was assumed that the 14 mgd would be withdrawn from the upper Floridan aquifer. The Floridan aquifer at Turkey Point is approximately 1,000 feet below land surface and is not hydraulically connected to the Biscayne aquifer. As a result, a withdrawal of this magnitude does not require an evaluation of potential impacts to Everglades National Park and other wetland features, nor does it need to address the SFWMD regional water availability rule.

To evaluate potential impacts to the Floridan aquifer system, the SFWMD's East Coast Floridan Model (Giddings et. al., 2013) was used. This model is a three-dimensional flow and transport model that encompasses the entire southeast coast of Florida from Sebastian Inlet to the north extending midway between Florida and the Cay Sal Banks in the Florida Straits to the south. The model simulates the three primary production intervals with usable water in the Floridan aquifer system. Three scenarios were simulated with this tool and are provided in **Table 2**.

Table 2. SFWMD Floridan aquifer model scenarios.

ECFM 3-D Flow /Transport 1989 - 2010 Transient Floridan Model	
Model Run	**Description**
ECFMNP	ECFM – No groundwater withdrawals.
ECFMPER	ECFM – Permitted demands. Groundwater withdrawals north of Miami Dade County set at calibration rates. Miami-Dade and Monroe County Floridan users at permitted allocations. FPL Unit 5 withdrawals at 12.6 mgd.
ECFMFPL	Permitted users simulation plus the proposed 14 mgd Upper Floridan FPL wellfield for CCS dilution.

5.3 Floridan Aquifer Simulation Results

Figure 5 provides the estimated location for the proposed FPL 14 mgd Upper Floridan aquifer wellfield. The wellfield was simulated along the northern boundary of the CCS and adjacent to the existing Unit 5 wellfield. The projected drawdown for the proposed 14 mgd wellfield is provided in **Figure 6,** which shows the cumulative impact of all permitted Floridan users in southern Miami-Dade County including the Florida Keys Aqueduct Authority (FKAA) near Florida City, the Ocean Reef Country Club on Key Largo, Miami Dade Water and Sewer Departments proposed South Miami Heights wellfield and the existing FPL Unit 5 wellfield at the Turkey Point facility plus the proposed 14 mgd for the CCS.

As shown in **Figure 6**, the cumulative cone of influence from the users in the area is confined to the southern Miami-Dade and eastern Monroe county area. **Table 3** provides the estimated additional drawdowns at the wells of existing legal users. Drawdowns between 1 and 3 feet are predicted to occur at the FKAA wellfield and the Ocean Reef wellfield. Water levels in the Upper Floridan aquifer in southern Miami-Dade and eastern Monroe County general range around 40 feet above sea level were not locally influenced by wellfield withdrawals. The projected drawdown of several feet on the existing legal users should not have an adverse impact.

Table 3. Projected drawdowns at existing legal users.

ECFM 3-D Flow /Transport 24 year Simulation		
Existing Legal User	**Permitted UFA Allocation**	**Projected Drawdown**
FPL Unit 5 (2009 Power Plant Certification)	12.6 mgd	40.4 feet
Florida Keys Aqueduct Authority SFWMD permit 13-00005-W	6.97 mgd	1.1 feet
Ocean Reef Country Club SFWMD permit 44-00001-W	0.58 mgd	2.3 feet
Ocean Reef Country Club SFWMD Permit 44-00002-W	1.42 mgd	2.6 feet
Miami Dade Water and Sewer Department SFWMD Permit 13-00017-W (South Miami Heights Wellfield)	23.3 mgd	0.3 feet

FPL Turkey Point - Estimated Floridan Well Locations

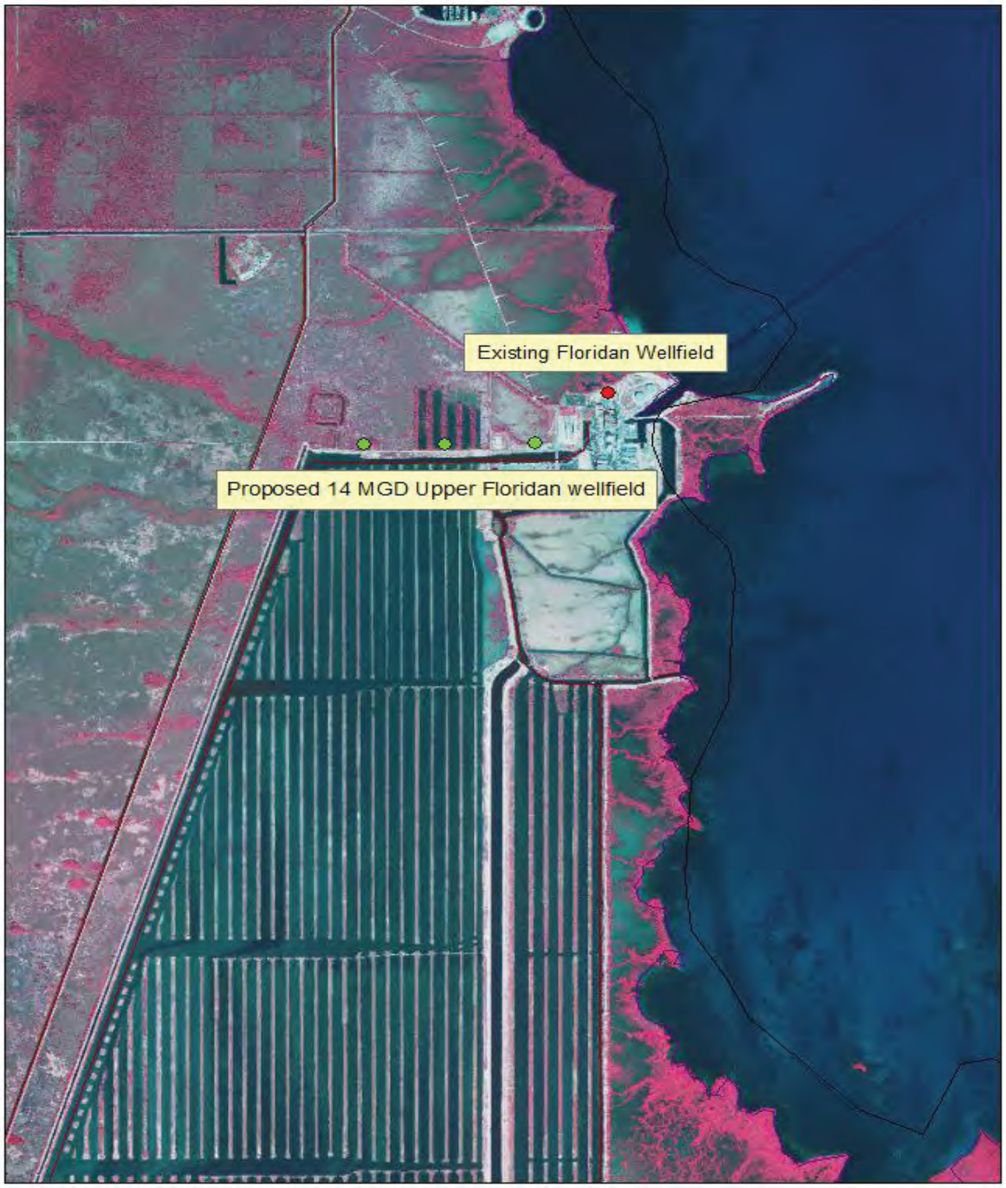

Figure 5. Estimated Location of the proposed FPL 14-mgd CCS wellfield.

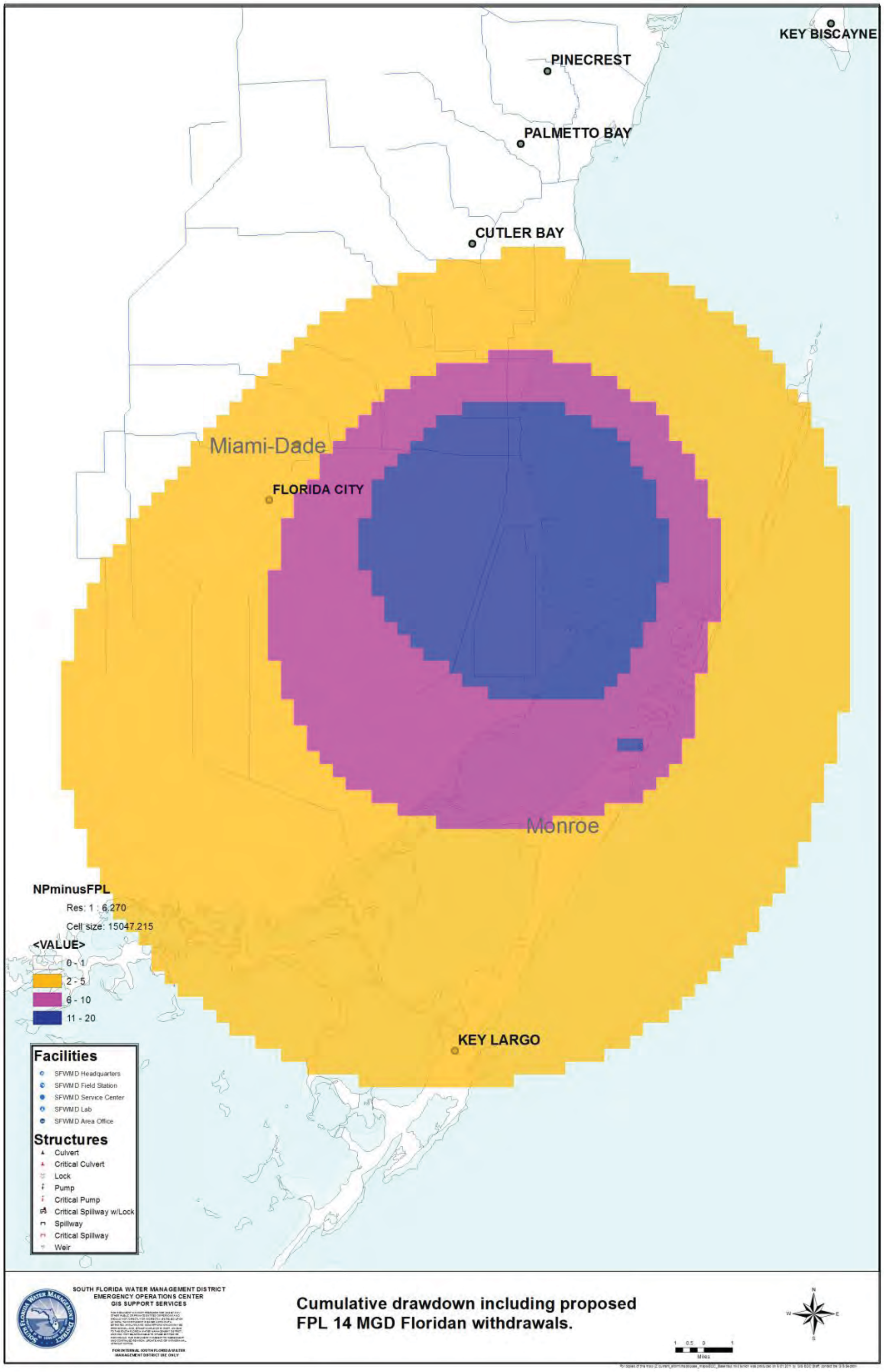

Figure 6. Upper Floridan aquifer cumulative drawdown for permitted users in south Miami-Dade County plus the proposed FPL 14 MGD demand.

5.4 CCS Historical Simulation Results

The historical simulation obtained from FPL was run in its existing condition. The situation concerning the datum is not an issue for this simulation because FPL referenced all data to NGVD in their original model submittal. This simulation is termed **HIS_FPL**.

Because of issues identified during the review of the FPL submittal and discussed in Section 4, SFWMD staff modified the model submitted by FPL to reflect these concerns. The thickness of the aquifer, which was constant in the original model, was modified to reflect the thickening of the Biscayne aquifer eastward from the edge of Everglades National Park on the west to Biscayne National Park on the east. Several other lessor modifications were also incorporated and were primarily associated with model stability. However, modifications of the model to more accurately reflect the area hydrogeology, other than the thinning of the aquifer to the west, would require the model to be significantly recalibrated. Such modifications were not consistent with the scope of review conducted here but can be introduced if needed.

In addition to changes to the model structure, stages used in the model to simulate existing and future canal and ocean/bay stages had to be adjusted to represent observed field values. Stages used for the simulations were obtained from the SFWMD DBHYDRO data base and the FPL monitoring network and all referenced to a consistent NGVD datum. Although the western boundary of the model extends to the L-31W canal, stages in the C-111 canal were used for the western boundary because it is the controlling canal for water levels in that area of the model. **Table 4** provides the levels and source for each of the canal and ocean boundary conditions simulated in all SFWMD simulations unless specifically stated. The revised SFWMD version of the historical simulation is termed **HIS_SFWMD**.

Table 4. Canal/boundary stages used for the SFWMD Biscayne aquifer model simulations.

2-D Flow /Transport Steady State Biscayne Aquifer Model		
Canal/Boundary	**Stage**	**Source**
Atlantic Ocean	0.78 ft. NGVD	DBHYDRO S-20F downstream gage
Biscayne Bay	0.78 ft. NGVD	DBHYDRO S-20F downstream gage
C-111/L-31W	3.44 ft. NGVD	DBHYDRO S-176 downstream gage
L-31E	1.75 ft. NGVD	DBHYDRO S-20 upstream gage
FPL Interceptor Ditch	1.41 ft. NGVD	FPL ID monitoring network I.D. gage
FPL discharge canals	1.63 ft. NGVD	FPL ID monitoring network C-32 gage
FPL return canals	0.71 ft. NGVD	FPL Power UprateTPSWCCS-5 gage

The calibration results are provided in the following figures. Each graph shows the observed data, the simulated FPL run, and the simulated SFWMD run for water levels or concentrations. Salinity is expressed in practical salinity units (psu), parts per thousand (ppt), or mg/L. Seawater is approximately 35 psu, 35 ppt, 35 g/L, or 35,000 mg/L. For this discussion Total Dissolved Solids (mg/l) and psu of sea water (expressed in mg/l) are considered approximately equal. **Figure 7** shows the water quality concentrations at well G-21 Deep. Both the **HIS_FPL** and **HIS_SFWMD** runs provide a good fit to the observed values, but this is misleading. The **HIS_FPL** run assumes that the levels in the CCS are at 1.27 feet NGVD while the **HIS_SFWMD** run assumes levels in the CCS are at 1.55 feet NGVD, which is consistent with observed data. This 0.27 foot head difference is significant and results in a noticeable inland migration of the saline interface if that level was used in the original **HIS_FPL** run as shown in **Figure 8** for the same G-21 Deep well. This is one of the primary reasons why District staff modified and partially recalibrated the 2-D model including the need to vary the aquifer thickness across the model domain.

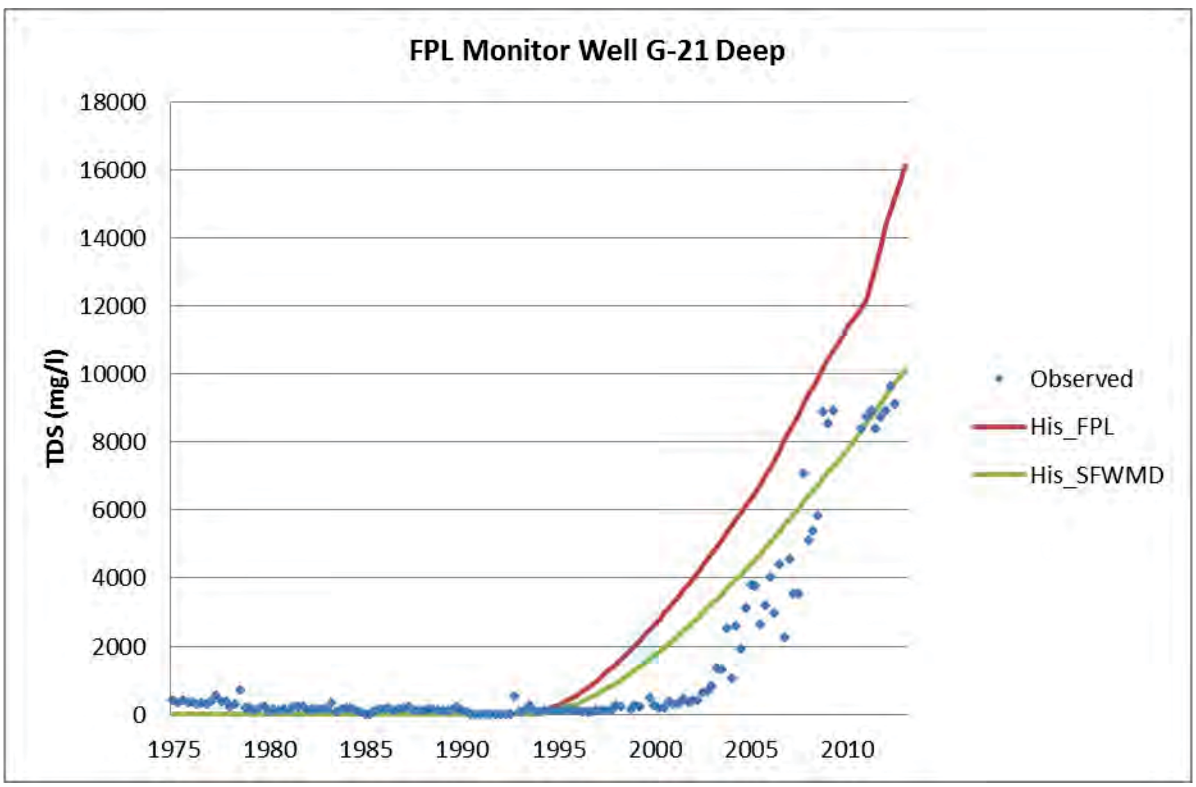

Figure 7. Simulated and observed water quality concentrations for well G-21 Deep.

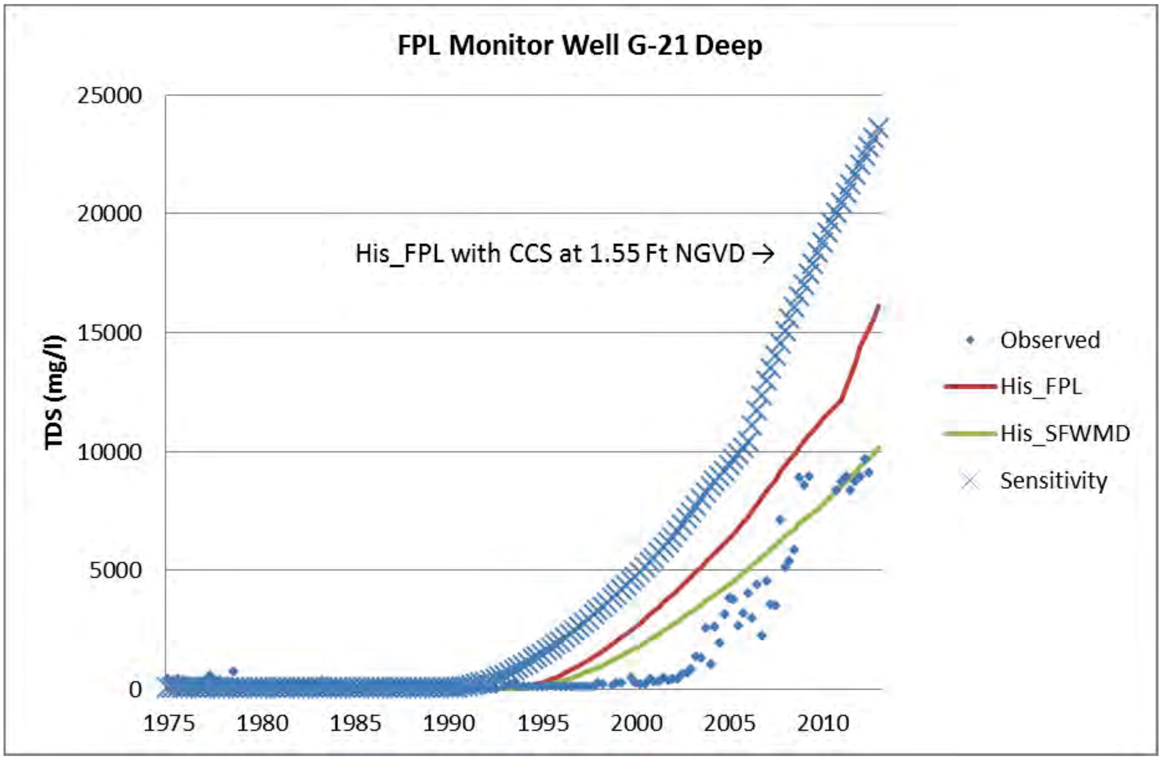

Figure 8. Water quality concentrations for well G-21 Deep including CCS stage revisions.

While the FPL report does compare historic salinity monitoring data to the model-calculated response, there is no information to describe whether the model reasonably represents groundwater stage and gradients. Comparison of groundwater stage data using monitoring data from wells located along the model transect to model-calculated stage data would provide valuable insights into the reasonableness of the models result in representing area hydrology. District staff included this analysis and water levels at well G-21 are shown in **Figure 9**. The observed and simulated water levels are significantly different, with both simulations having water levels approximately 1.0 feet higher than the observed values. This demonstrates the limitations of both models because they do not reflect changes in local hydrology included drainage canals, groundwater withdrawals, rainfall and other factors.

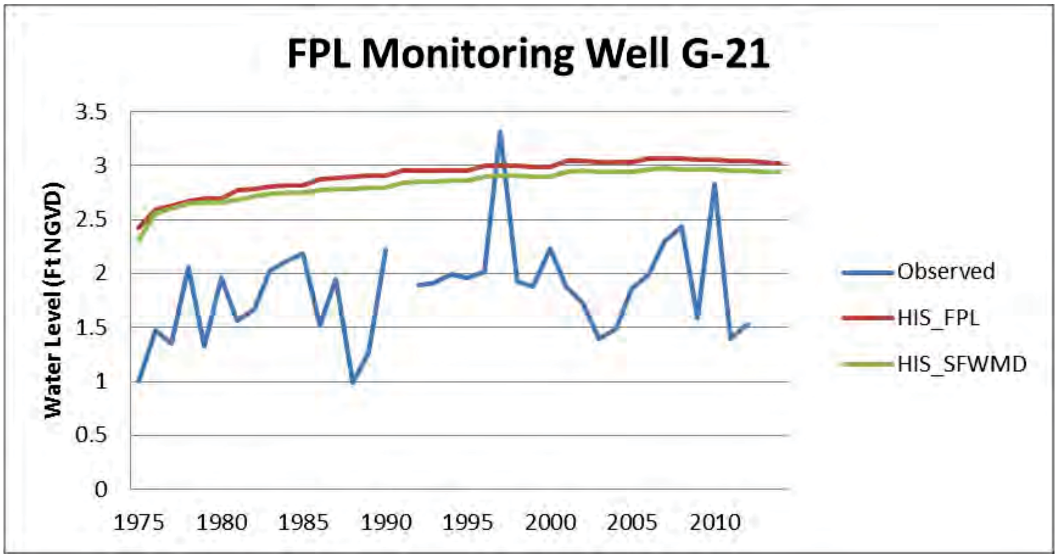

Figure 9. Water levels at well G-21.

To further illustrate this issue with the model's inability to accurately simulate water levels in the western 1/3 of the model, water levels obtained from the SFWMD South Dade Model' which is a subset of the Lower East Coast Subregional (LECsR) Model (Giddings et. al., 2006), were plotted along the model transect and compared against the results from both the **HIS_FPL** and **HIS_SFWMD** simulations. The LECsR model is a highly calibrated model and includes all hydrologic aspects of the system. It is simulated on a daily basis and the results presented here are the average water levels from 1985 through 2000 for the calibration period. **Figure 10** provides the comparison between models.

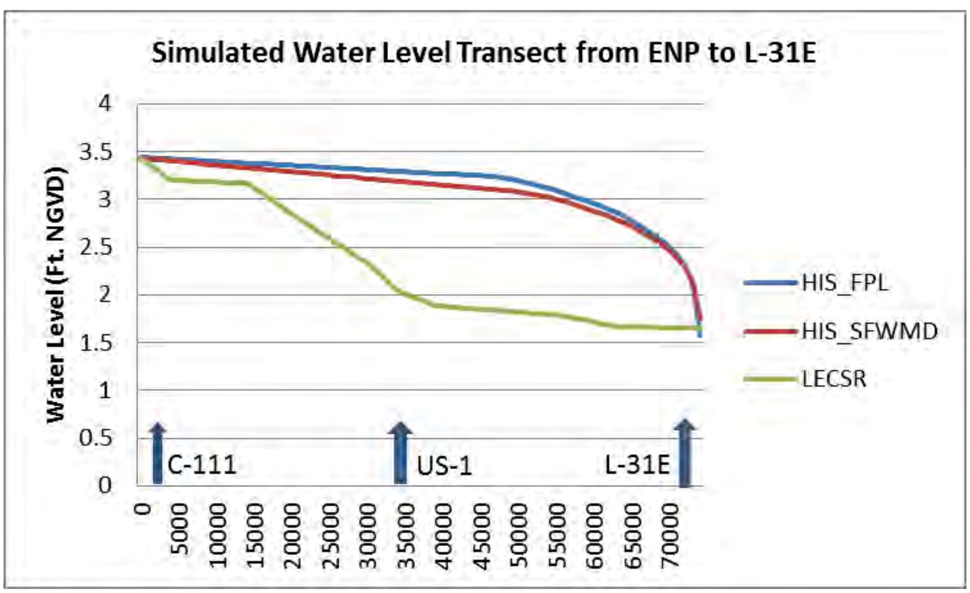

Figure 10. Water levels along the model transect.

To correct the model to more accurately simulate observed water levels would require wholesale changes to the model parameters and incorporation of packages which simulate actual conditions (i.e., wellfields). **Figure 11** provides the results of concentrations at well G-21 Deep for a sensitivity run where water levels in the western portion of the model were reduced 1.0 feet to represent more realistic water level conditions in the south Miami-Dade agricultural region. As shown in **Figure 11**, the salt water interface becomes highly unstable and suggests that the interface should have passed well G-21 Deep many years before actually being observed. This illustrates the limitations of the 2-D model and would require additional calibration and possibly a full 3-dimenisional model to accurately simulate conditions in southern Miami-Dade County.

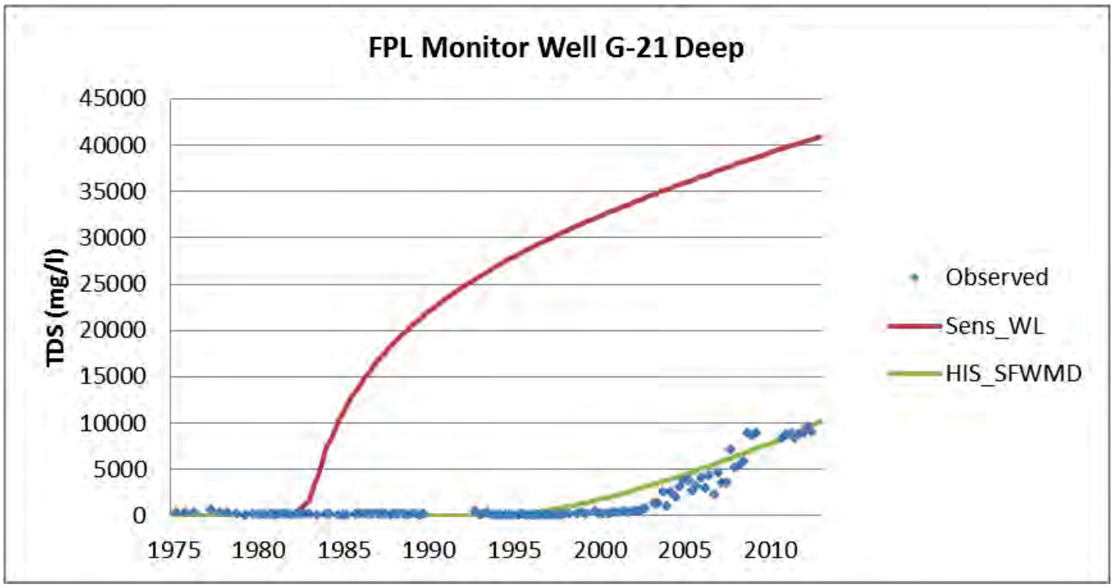

Figure 11. Sensitivity model run with observed water level conditions in south Miami-Dade County.

Calibration plots for TDS concentrations at wells L-3 Shallow, L-3 Deep, G-21 Shallow, G-12 Deep and G-1264, and water levels for wells FKS-9, G-21 and L-3 can be found in **Appendix A**. In general, the **HIS_SFWMD** model provides a reasonable calibration of the concentrations at the wells but does not do a good job simulating water levels at G-21, BBCW6GW1 or FKS-9, and the entire western portion of the model. It was also observed that water levels take up to 25 years to stabilize from the pre-development conditions in areas of the model, which is also indicative to the models lack of simulated evapotranspiration and rainfall.

5.5 CCS Future Simulation Results

Three future simulations were analyzed. These include the original FPL salinity reduction run (**SR_FPL_V1**) which includes the mixing of NAVD and NGVD datums, a revised FPL salinity reduction run which corrects FPL levels to NGVD but does not correct the canal stages to those observed in the field (**SR_FPL_V2**), and a SFWMD run, which uses the **HIS_SFWMD** model which includes the modifications to the FPL model and also uses the observed water levels at all canals (**SR_SFWMD**). Each of the graphs presented includes the previous historical simulation plus the future simulation on one graph. That is, the simulation period shown on the graphs is from 1975 through 2040 with the historical simulation represented on each graph as the period from 1975 – 2014 and the future simulation represented on the graph from 2015 through 2040. **SR_FPL_V1** and **SR_FPL_V2** use the **HIS_FPL** historical simulation and the **SR_SFWMD** use the **HIS_SFWMD** simulation.

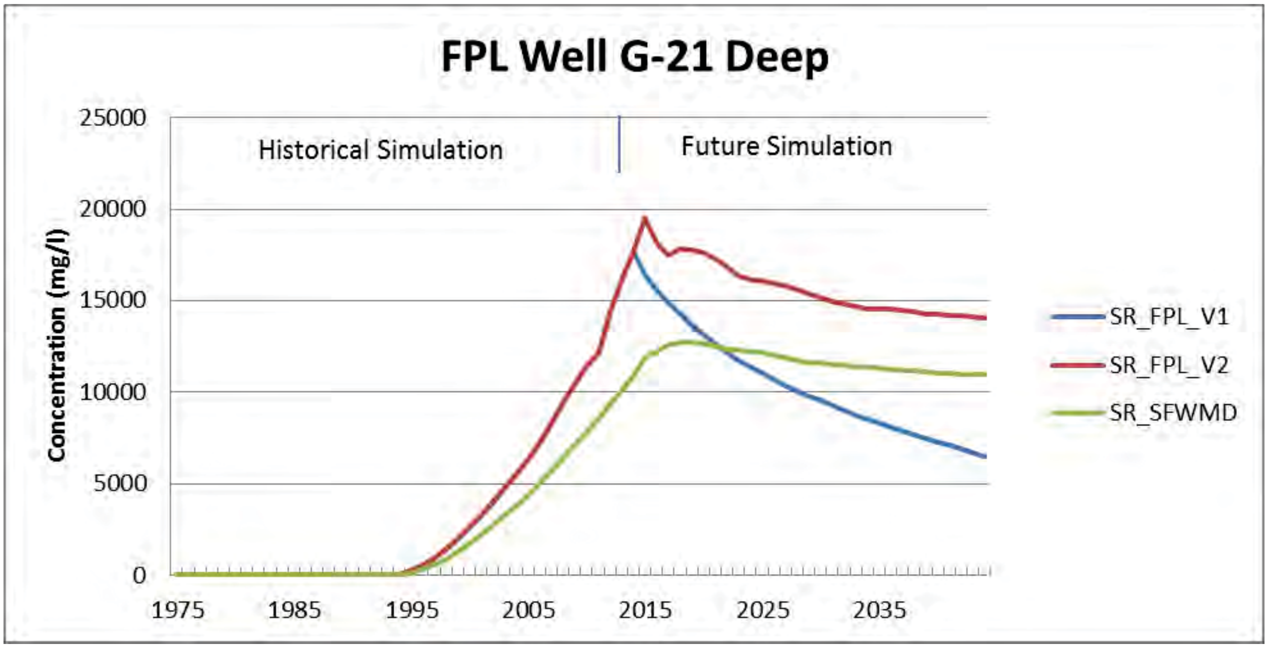

Figure 12. Salinity concentrations at well G-21 Deep.

Figure 12 provides the TDS concentration results for well G-21 Deep for the future scenarios. The rapid decrease in water quality for the **SR_FPL_V1** run is a result of the mixing of NGVD and NAVD datum assignments to the western boundary. Because the difference between the two is approximately 1.5 feet, the result for this run is that the western boundary is 1.5 feet higher than should be simulated. As a result, this higher freshwater head pushes the salt water interface further eastward than the other runs. This point is further illustrated in **Figure 13,** which shows the abrupt change in water levels for **SR_FPL_V1** at the historical and future simulation divide but is not evident in the other two simulations. The remaining two simulations are similar in trend, with the difference being that the **SR_SFWMD** does a better job of estimating the observed concentrations at the end of the historical simulation period where the **SR_FPL_V2** run tends to overestimate the TDS concentration at this well. However, both of these runs suggest that the addition of the 14 MGD of Floridan water begins to stabilize the interface at this location and aquifer depth.

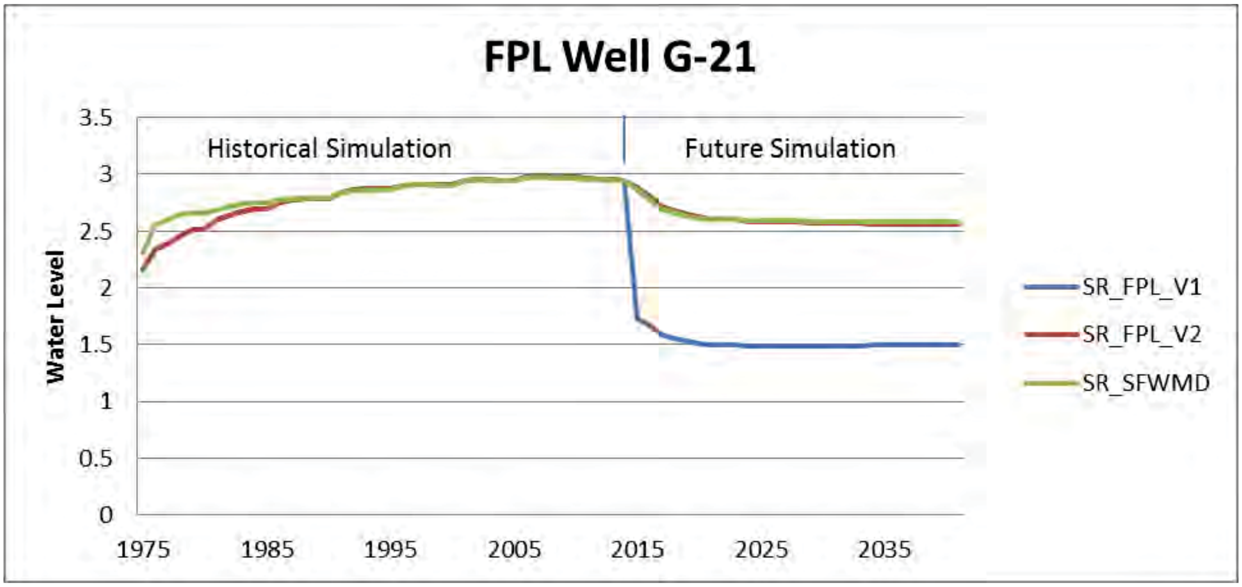

Figure 13. Water Levels at well G-21.

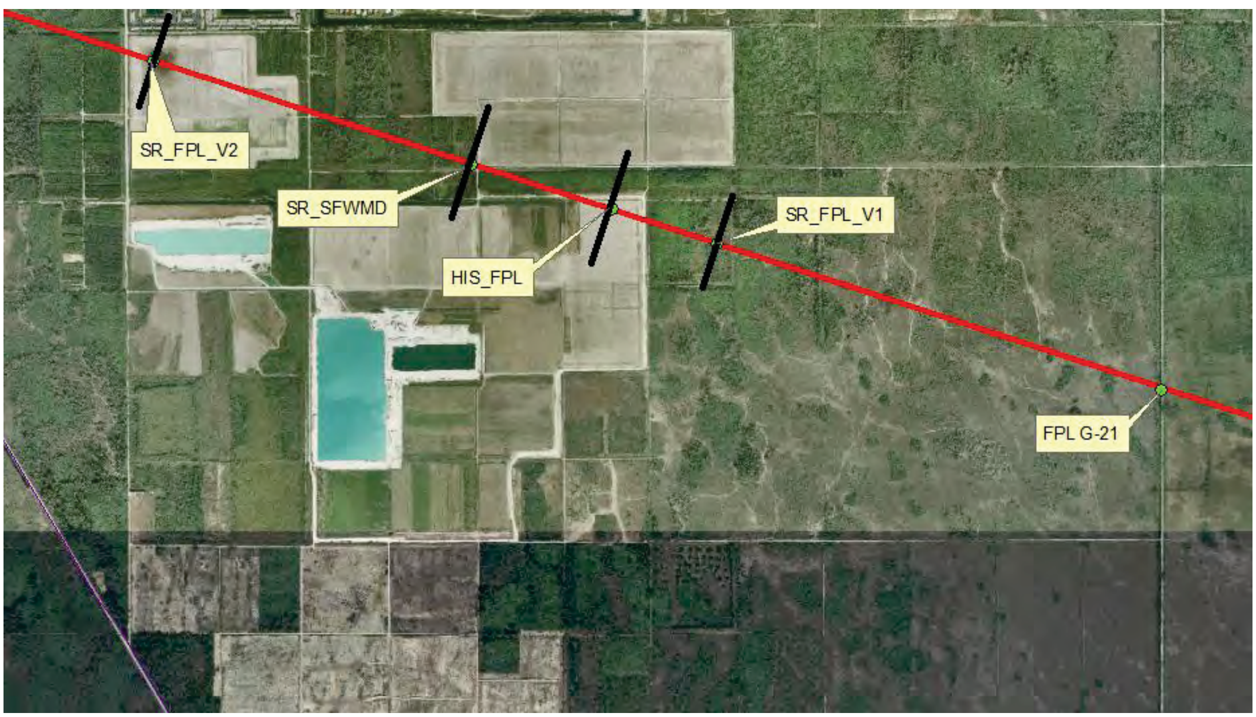

Figure 14. Location of the 10,000 mg/l TDS line at the base of the Biscayne aquifer for the FPL simulations.

Figure 14 provides the estimated location of the 10,000 mg/l TDS interface at the base of the Biscayne aquifer for the three FPL simulations. In the documentation provided by FPL, it was concluded that the salt water interface would move eastward as a result of the proposed addition of 14 mgd of fresh/brackish water to the CCS. This is shown by comparing the position of the **HIS_FPL** and **SR_FPL_V1** lines. The position of the **SR_FPL_V1** has the incorrect head for the western boundary which gives an inaccurate conclusion. Correcting the head on the western boundary actually results in a westward movement of the interface even with the salinity reduction proposal as shown by the position of the interface at point **SR_FPL_V2**. Also note that the position of the interface as predicted by the **SR_SFWMD** run is eastward of the **SR_FPL_V2** run.

Water quality beneath the CCs was also analyzed to determine the fate of the hypersaline water once the CCS was reduced to sea water conditions with the introduction of the Floridan aquifer water. Results presented here are for the SFWMD revised simulations. **Figure 15** shows the development of the hypersaline conditions underneath the CCS at present and is consistent with the results provided by FPL. As noted, water quality not only deteriorates vertically downward with time but also expands inland and seaward from the facility. The simulation suggests that the base of the salt water interface has migrated approximately 10,000 feet westward since 1985.

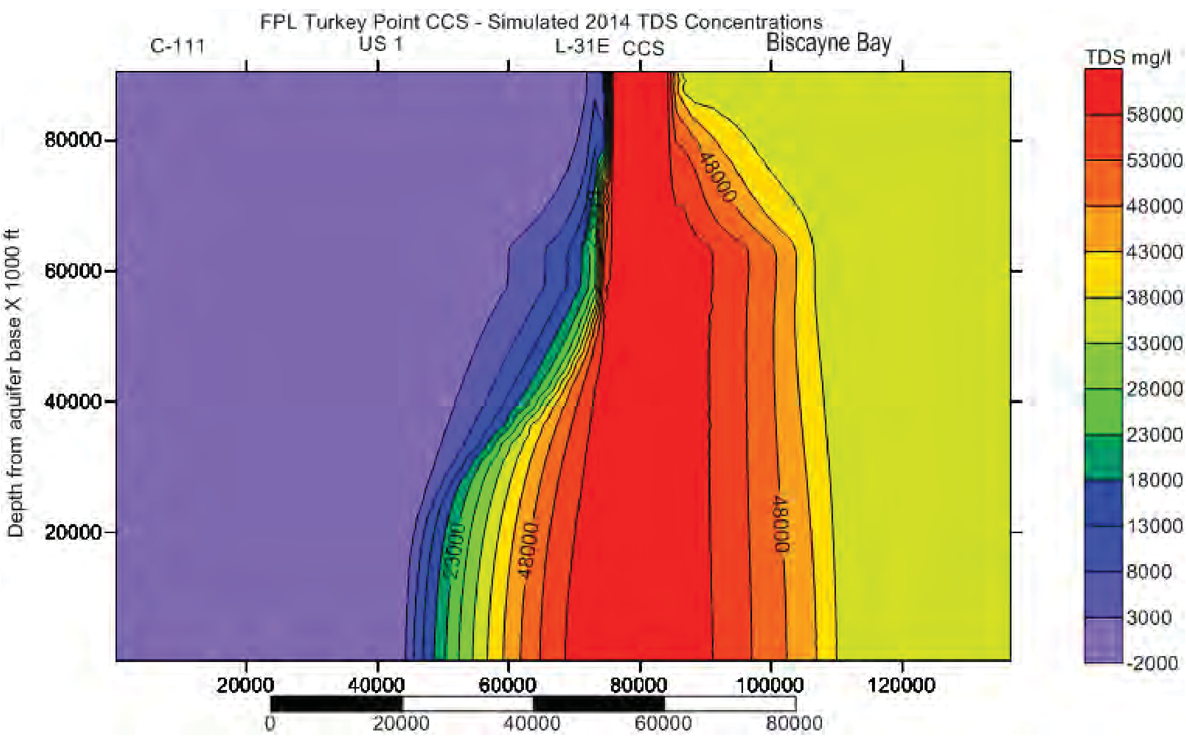

Figure 15. Simulated 2014 TDS concentrations in mg/l.

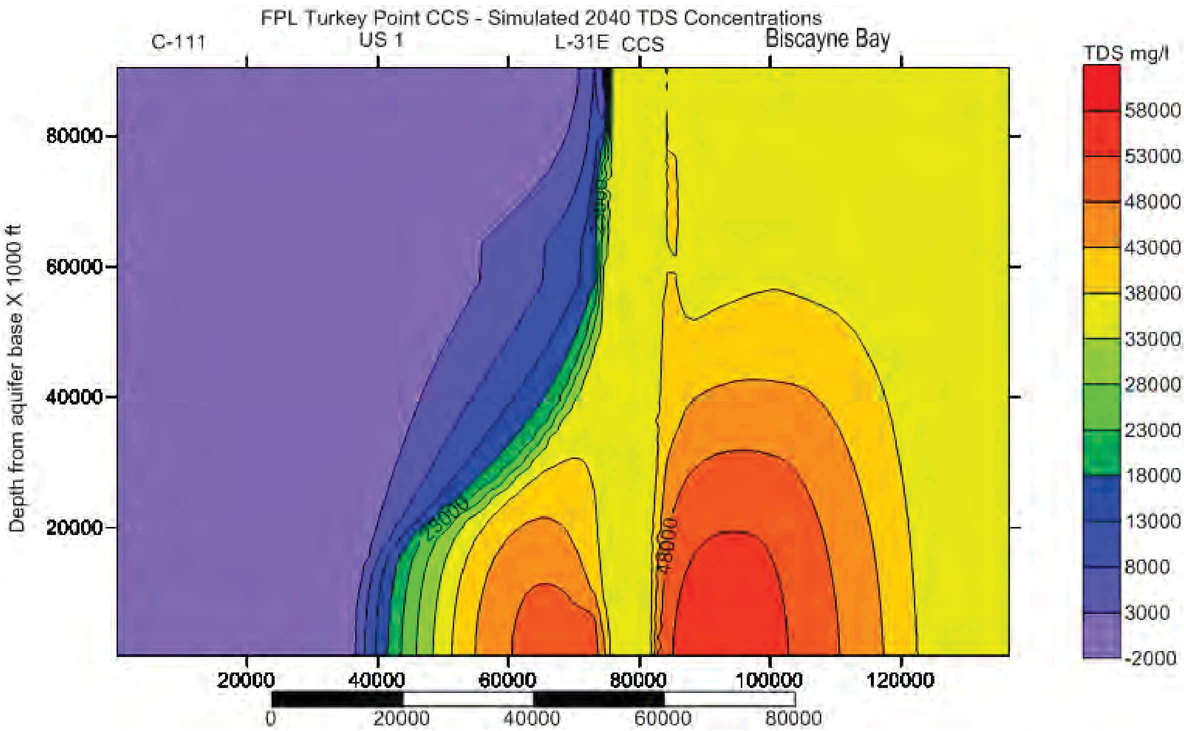

Figure 16. Simulated 2040 TDS concentrations in mg/l.

Figures 16 is the simulated water quality in the future with the introduction of the brackish water into the CCS. As shown, the introduction of the brackish water into the CCS changes the TDS concentration from approximately 60,000 to 35,000 mg/l at the surface within a short period of time. However, the denser, hypersaline water continues to remain at the base of the aquifer where it mixes and continues to radiate outward.

6 Discussion of the FPL Salinity Reduction Proposal for Turkey Point

Modeling provided by FPL, and verified by SFWMD staff, indicates that the addition of the 14 mgd of brackish water from the Floridan aquifer should help to reduce the hypersaline conditions experienced at the CCS. Water quality near the surface and beneath the site begins to change to near sea water conditions within several years after the addition of the Floridan aquifer water and continues to improve with time. However, the hypersaline water becomes trapped near the base of the aquifer and slowly mixes with the relatively fresher water surrounding it. The results provided by FPL do show potential for addressing the hypersaline conditions at the site but FPL did not provide a discussion on the future position of the saline interface in southern Miami-Dade County with or without their proposal.

As discussed previously in this report, the 2-dimensional density-dependent solute transport groundwater model developed has its limitations. It does, however, allow for an initial look at the development of water quality conditions at the site through time and management options that could potentially be implemented, which previously was missing. While the FPL report does discuss the improvements the model suggests may occur at and below the CCS, it does not address several additional concerns including how much this remediation proposal further-mitigates the migration of the saline interface landward as a result of FPL's operations.

To address questions regarding the position of the saline interface and quantify the improvements the proposed introduction of 14 mgd of Floridan aquifer water may have on the system, several additional model simulations were conducted using the SFWMD revised version of the model. These include an evaluation of a 0.25 foot rise in sea level, not allowing the CCS water quality to exceed that of sea water from 1975 through 2040, and a no change simulation, which continues to operate the CCS at hypersaline conditions through 2040. These simulations should provide a general understanding on conditions at the site through time under various operational strategies.

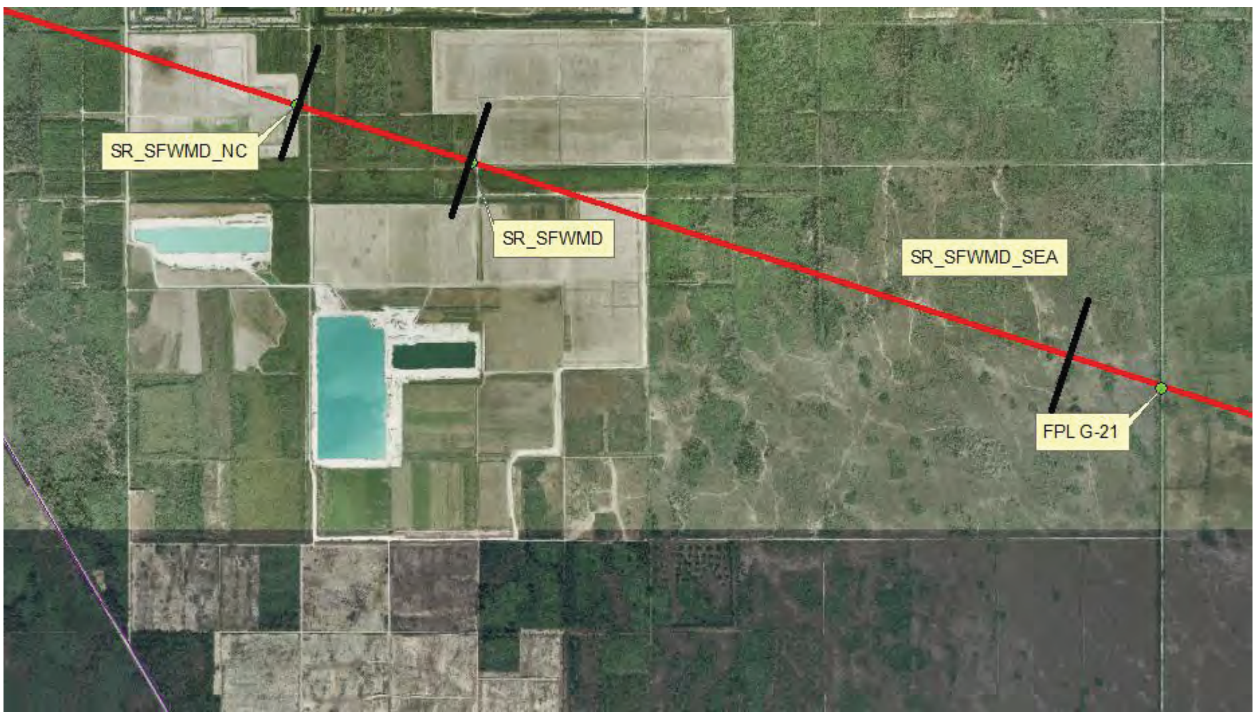

Figure 17. The position of the saline interface (10,000 mg/l TDS) at the base of the Biscayne Aquifer for the future SFWMD simulations.

Figure 17 provides the location of the interface at the base of the Biscayne aquifer for these future simulations. When the 14 md of Floridan aquifer water is added to the CCS, the position of the saline interface (**SR_SFWMD**) is seaward of the predicted position of the interface if it was not added (**SR_SFWMD_NC**). This suggests that the addition of the 14 mgd of Floridan aquifer water would have a net benefit to the Biscayne aquifer if implemented compared to existing conditions and operations. However, the proposal does not fully mitigate the last 40 years of the CCS operating at sea level to hypersaline conditions because it does not move to a position in the vicinity of the **SR_SFWMD_SEA** simulation line, which is the approximate position of the saline interface if the CCS had been not been allowed to become hypersaline.

7 Conclusions

Modeling provided by FPL, and verified by SFWMD staff, indicates that the addition of the 14 mgd of brackish water from the Floridan aquifer should help to reduce the hypersaline conditions experience in the CCS at the site. Water quality near the surface and beneath the site begins to change to near sea water conditions within several years of the implementation of the proposal and continues to improve with time. Additional modeling conducted by District staff also shows that the FPL proposal improves conditions in the Biscayne aquifer eastward of the CCS compared to if FPL continues their current operations. The proposal does not move the western extent of the saline interface back to a position if the CCS would not have been allowed to exceed sea water concentrations.

5.0 References

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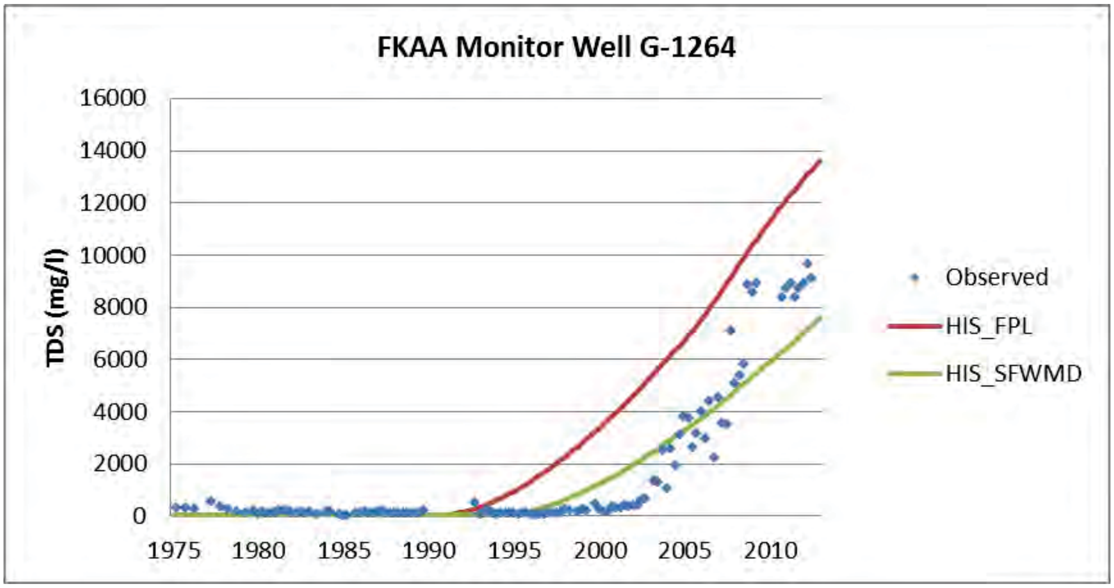
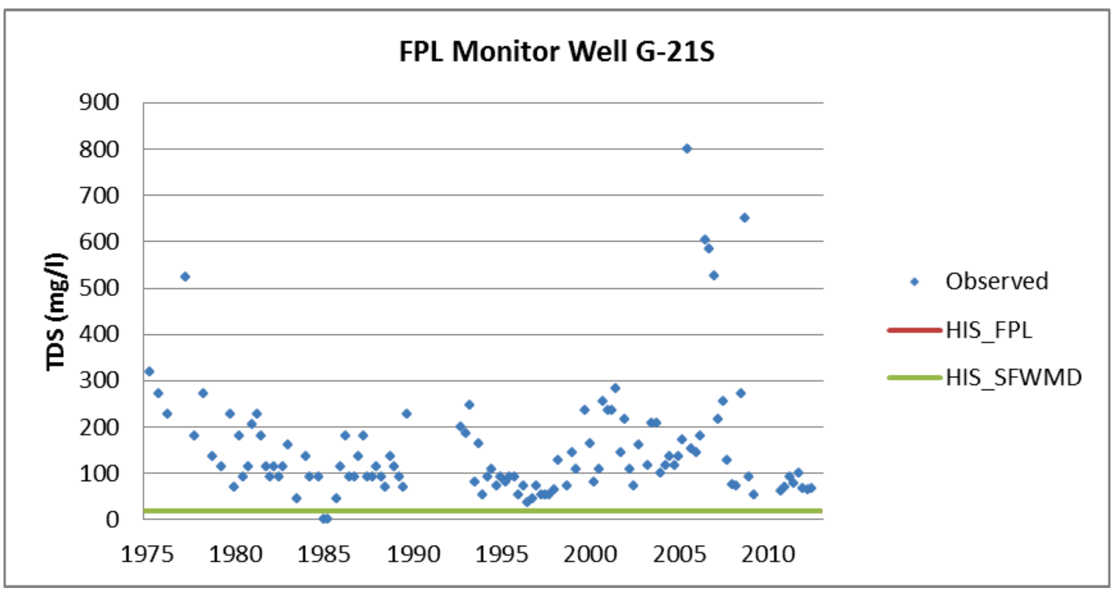
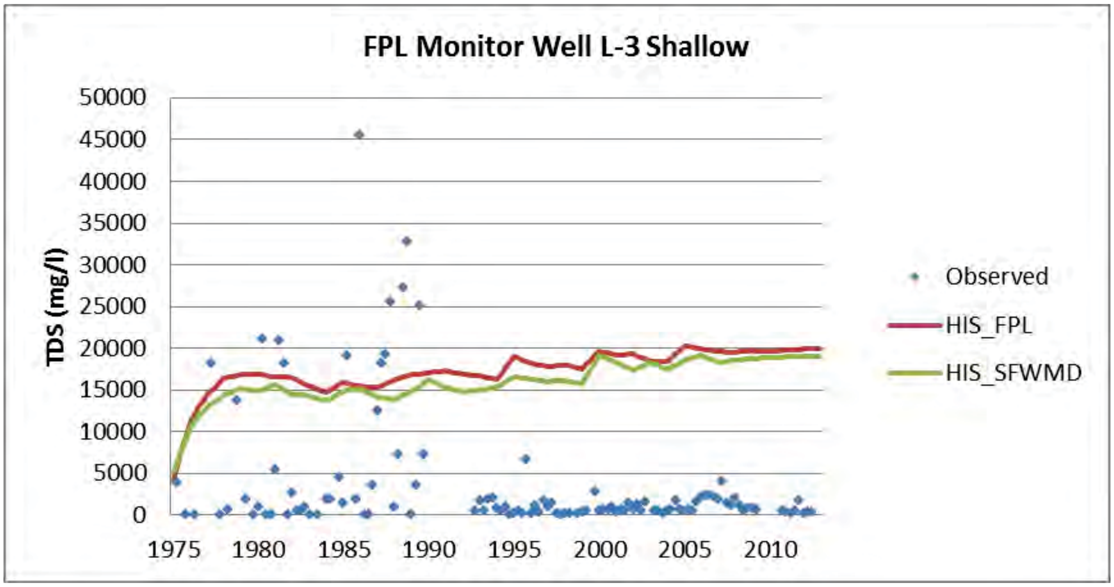
Langevin, C.D., W. B. Shoemaker, and W. Guo, 2003. MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model—Documentation of the SEAWAT-2000 Version with the Variable-Density Flow Process (VDF) and the Integrated MT3DMS Transport Process (IMT): USGS Open-File Report 03-426, 43 p.

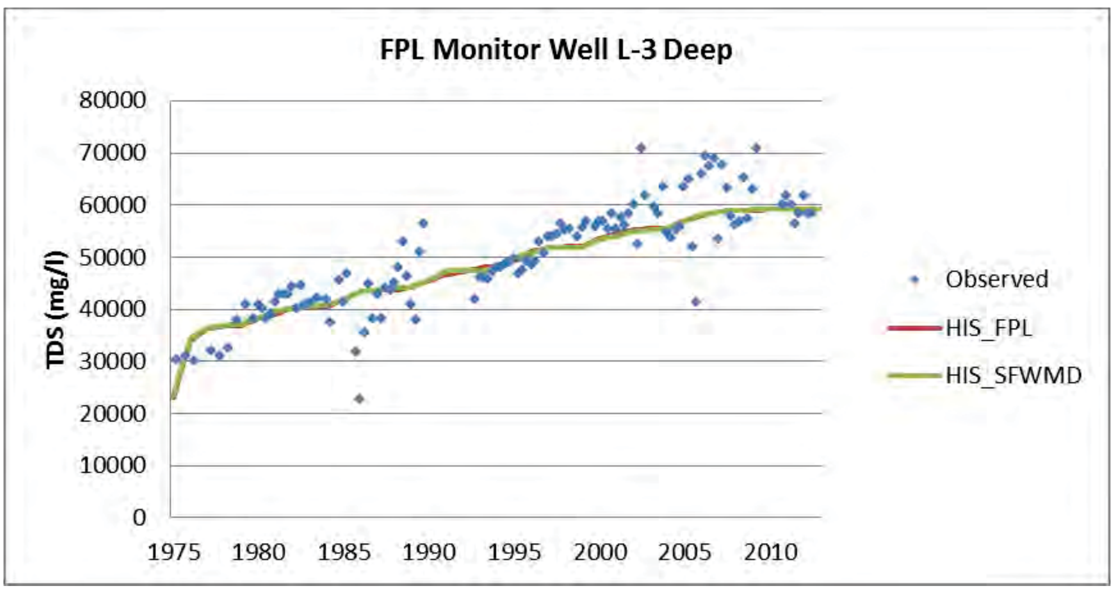
6.0 Appendices

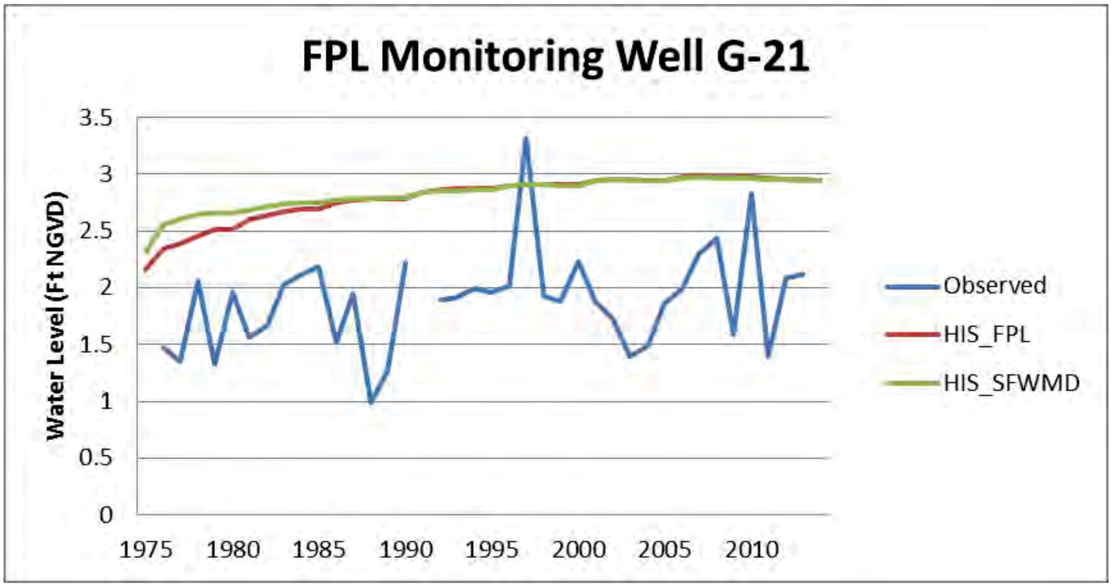
Appendix A: Calibration Plots

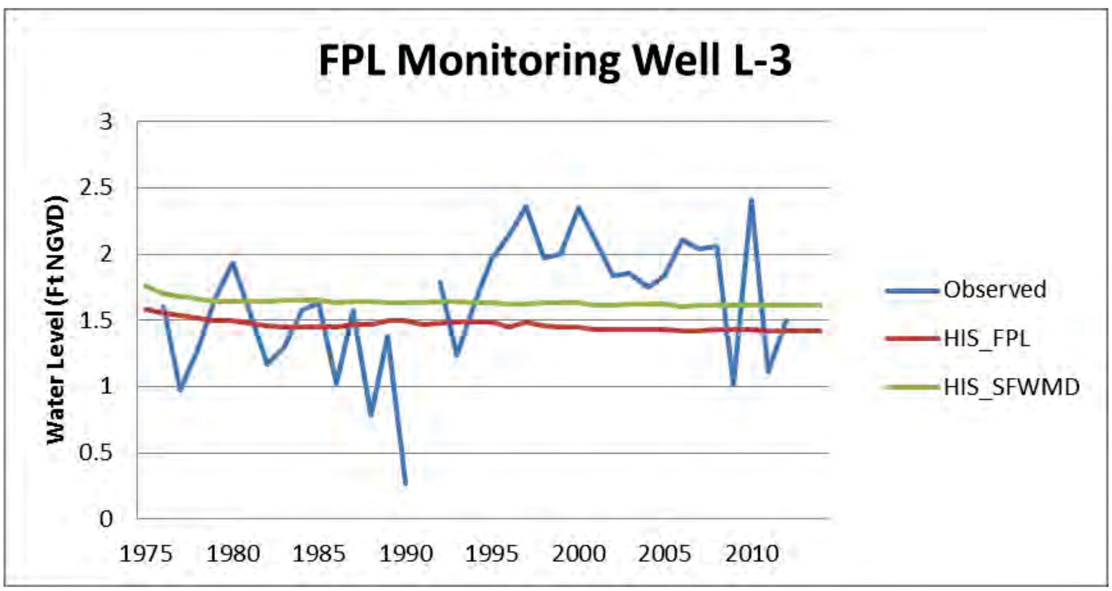


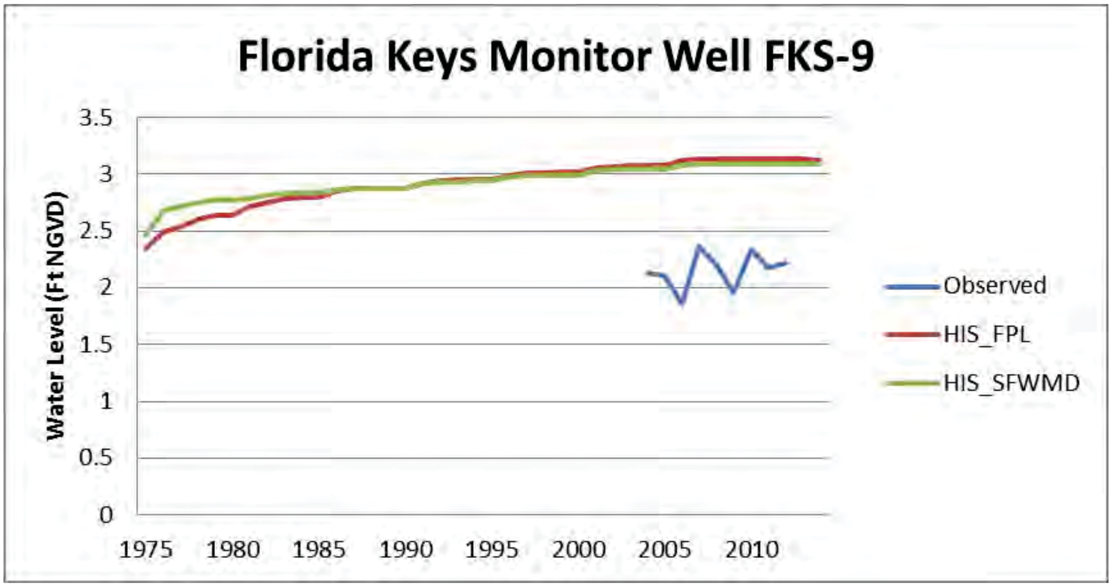


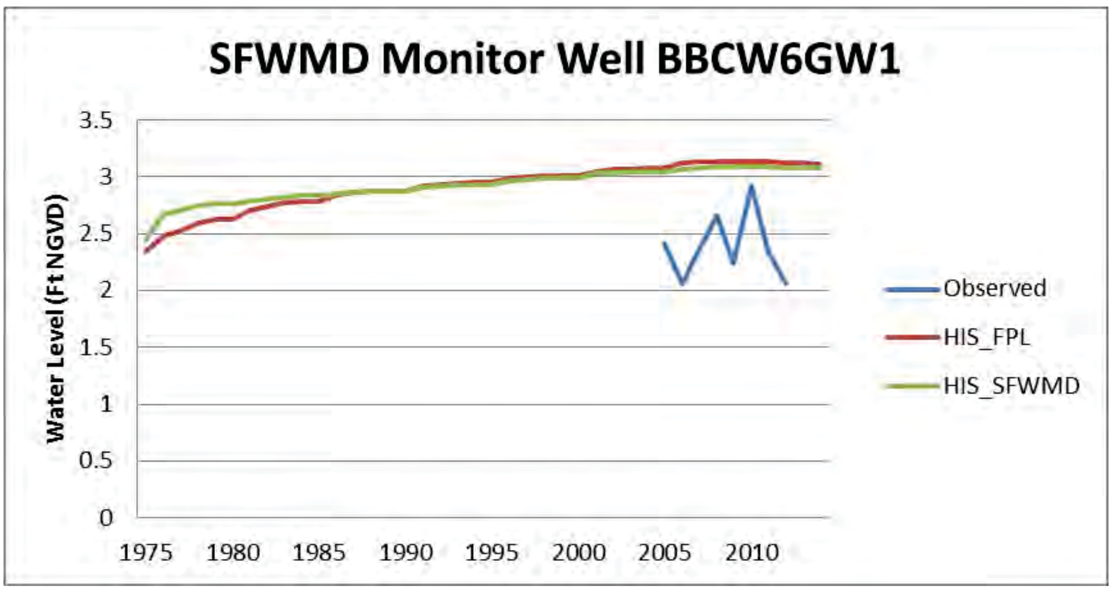

FPL Monitor Well L-3 Shallow
TDS (mg/l)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1975
1980
1985
1990
1995
2000
2005
2010
Observed
HIS_FPL
HIS_SFWMD


FPL Monitor Well L-3 Deep
TDS (mg/l)
80000
70000
60000
50000
40000
30000
20000
10000
0
1975
1980
1985
1990
1995
2000
2005
2010
Observed
HIS_FPL
HIS_SFWMD

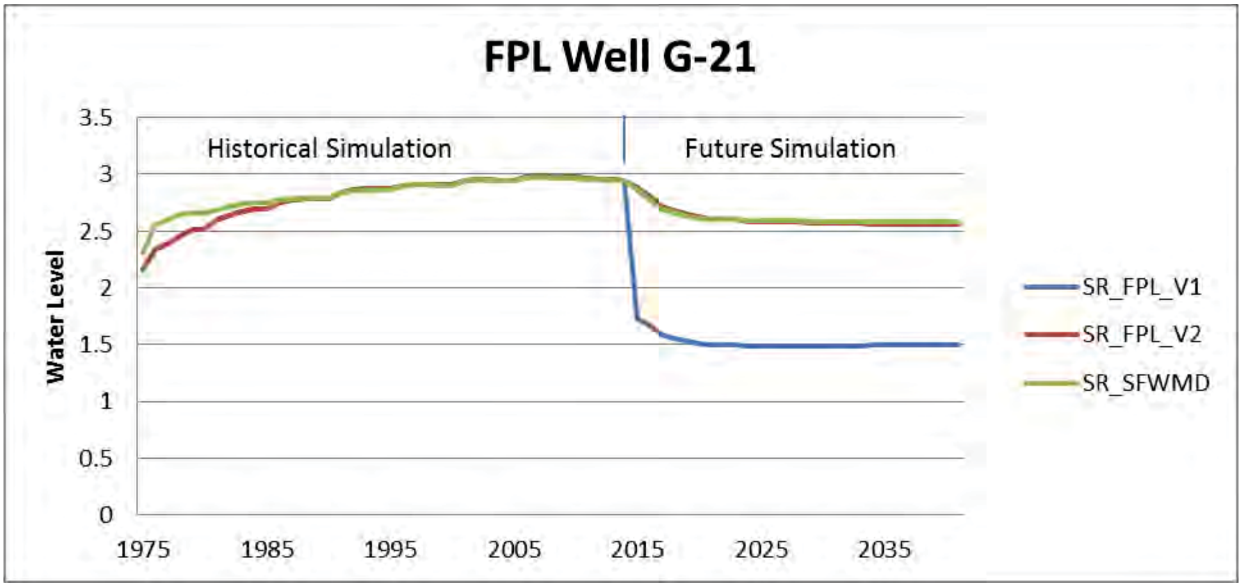

FPL Monitoring Well G-21
Water Level (Ft NGVD)
3.5
3
2.5
2
1.5
1
0.5
0
1975
1980
1985
1990
1995
2000
2005
2010
Observed
HIS_FPL
HIS_SFWMD

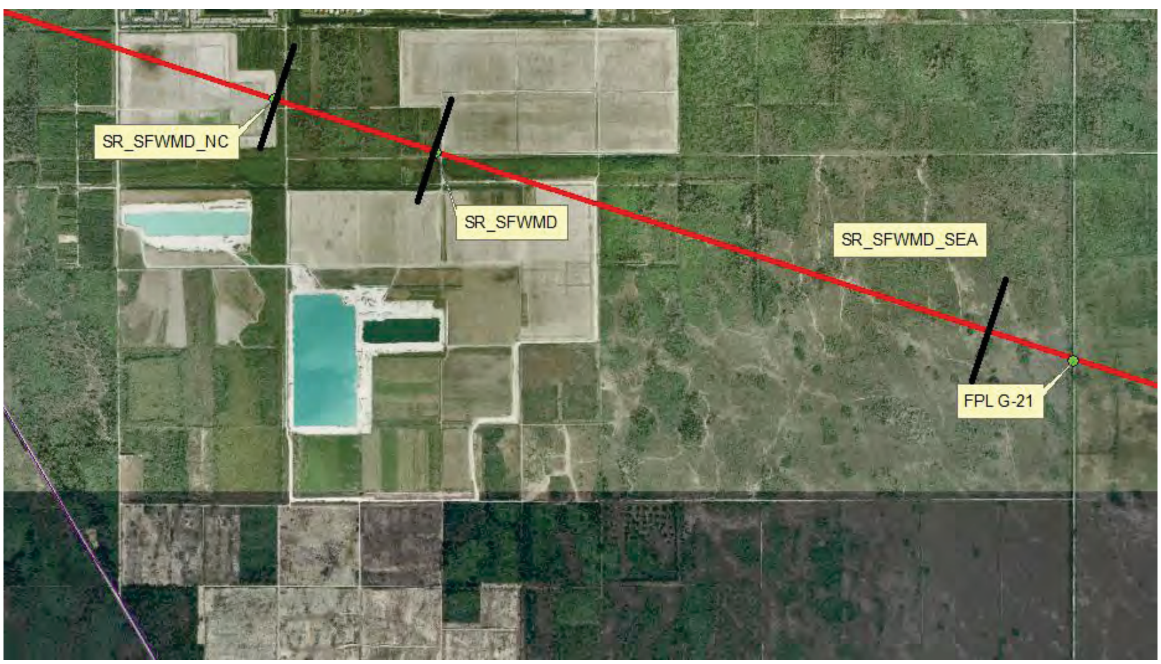

FPL Monitoring Well L-3
Water Level (Ft NGVD)
3
2.5
2
1.5
1
0.5
0
1975
1980
1985
1990
1995
2000
2005
2010
Observed
HIS_FPL
HIS_SFWMD

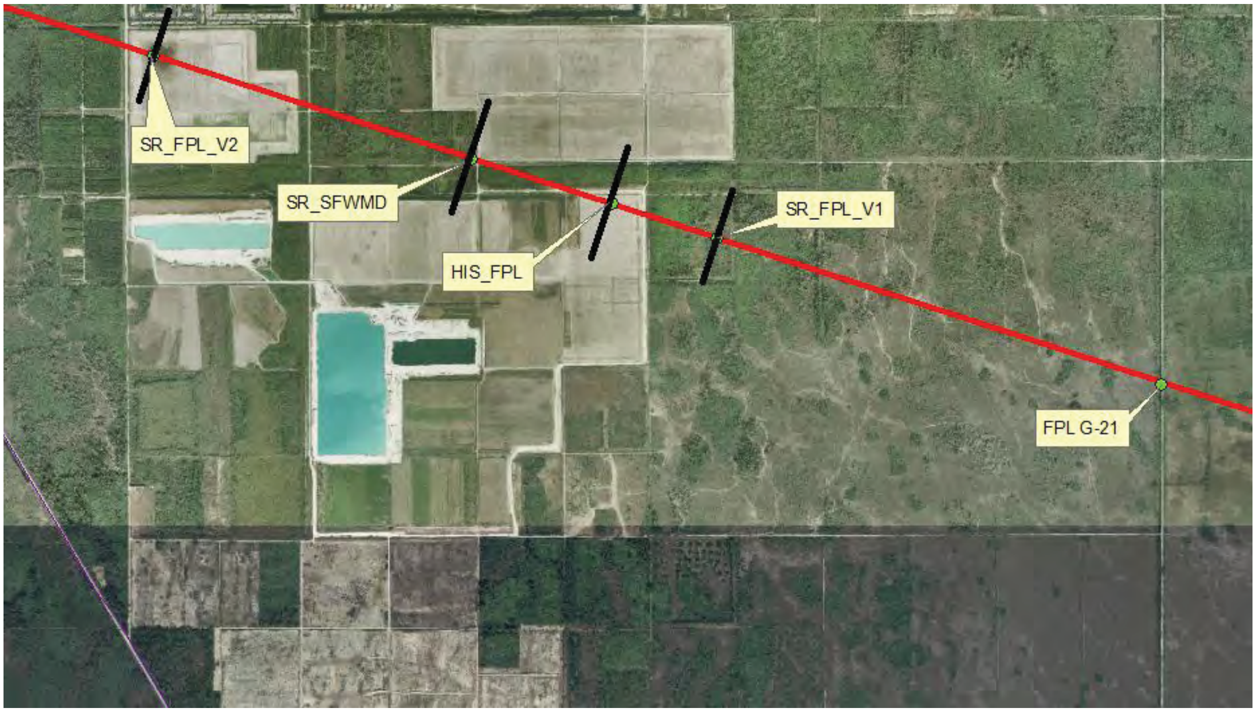

Florida Keys Monitor Well FKS-9
Water Level (Ft NGVD)
3.5
3
2.5
2
1.5
1
0.5
0
1975
1980
1985
1990
1995
2000
2005
2010
Observed
HIS_FPL
HIS_SFWMD

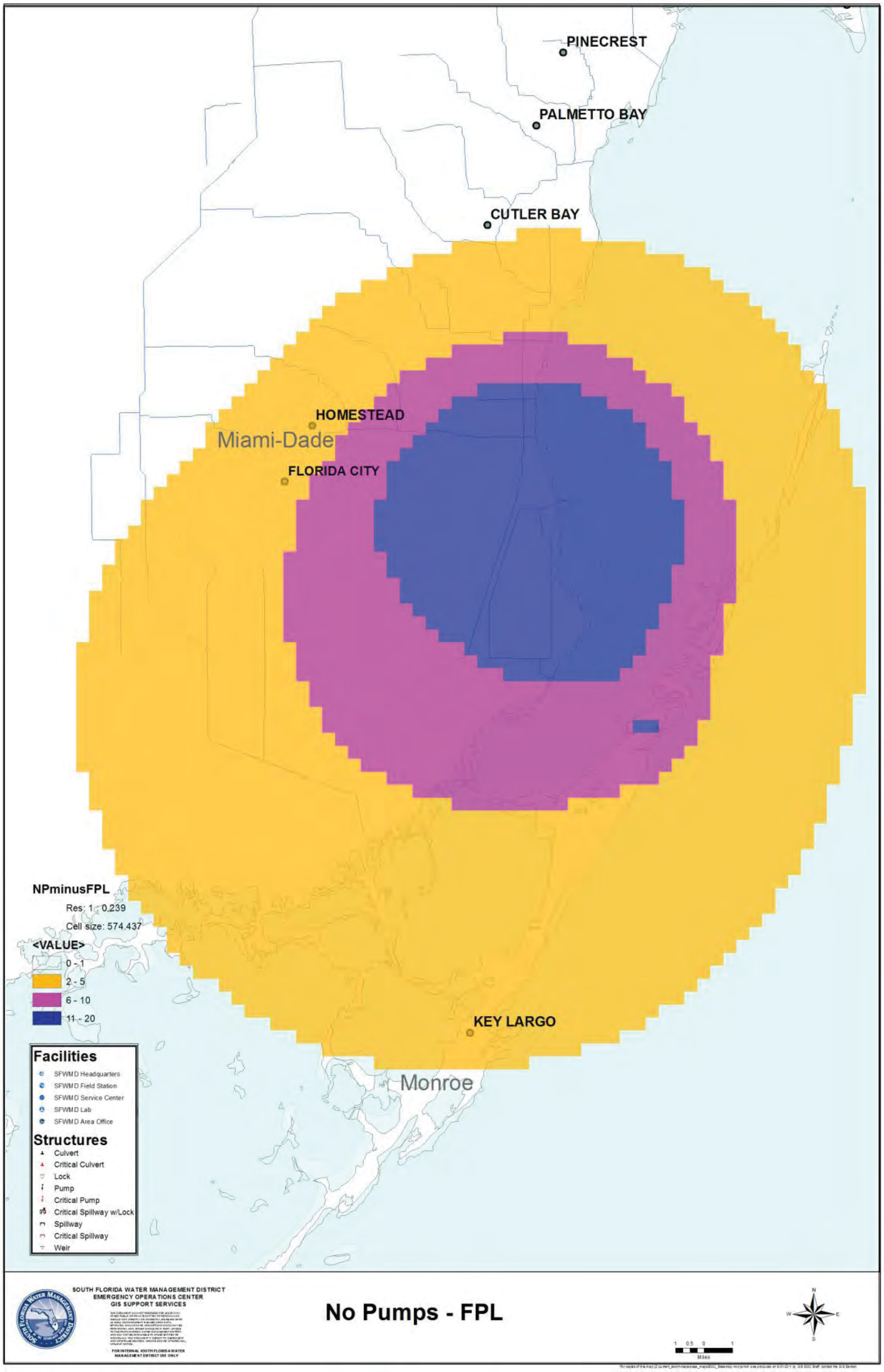

SFWMD Monitor Well BBCW6GW1
Water Level (Ft NGVD)
3.5
3
2.5
2
1.5
1
0.5
0
1975
1980
1985
1990
1995
2000
2005
2010
Observed
HIS_FPL
HIS_SFWMD

Appendix B: Simulation Plots

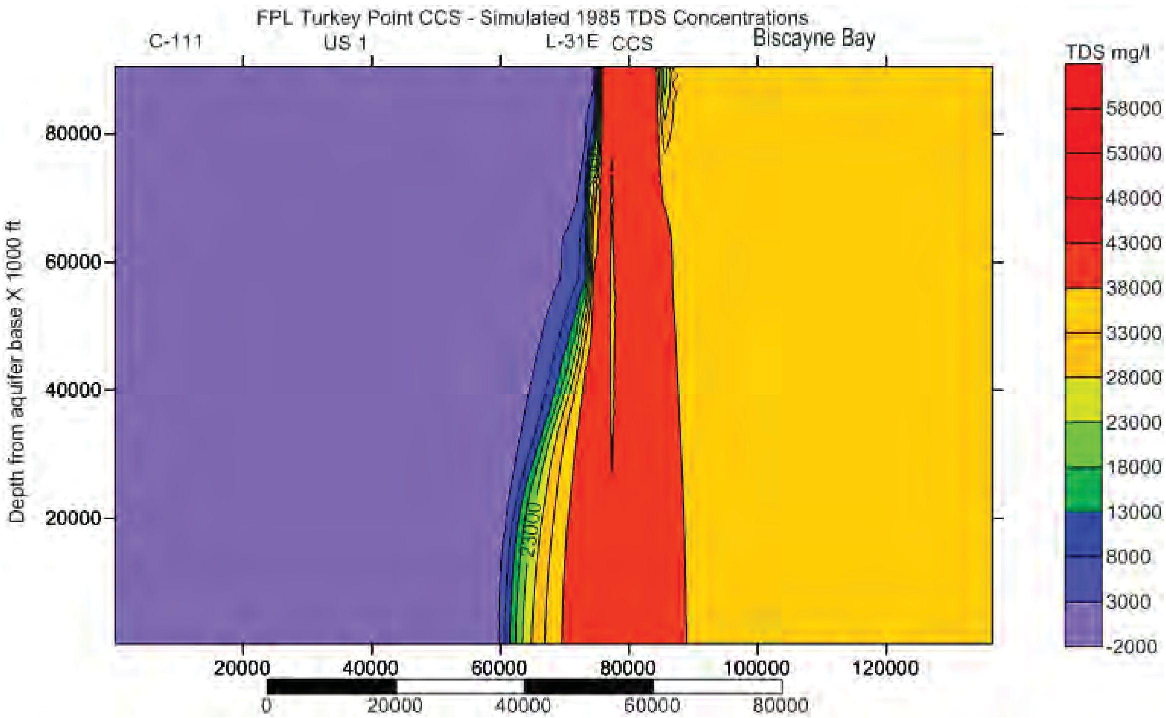




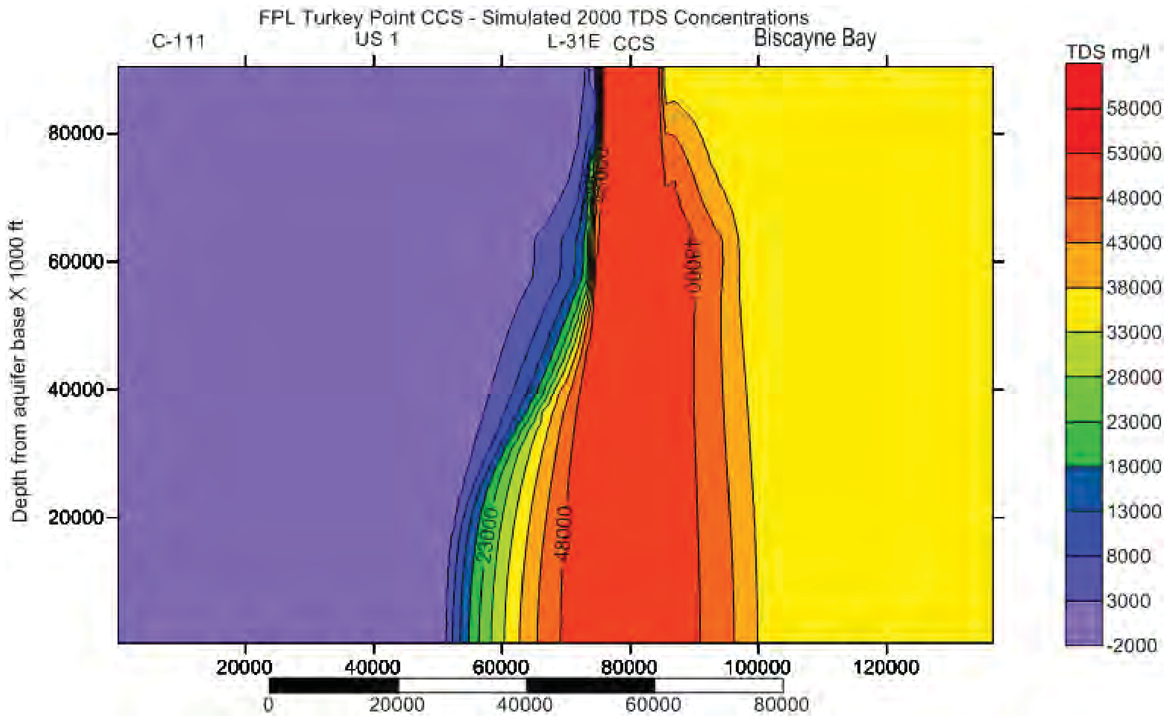

SR_FPL_V2
SR_SFWMD
HIS_FPL
SR_FPL_V1
FPL G-21


PINECREST
PALMETTO BAY
CUTLER BAY
HOMESTEAD
Miami-Dade
FLORIDA CITY
KEY LARGO
Monroe
NPminusFPL
Res: 1 : 0.239
Cell size: 574.437
<VALUE>
0 - 1
2 - 5
6 - 10
11 - 20
Facilities
SFWMD Headquarters
SFWMD Field Station
SFWMD Service Center
SFWMD Lab
SFWMD Area Office
Structures
Culvert
Critical Culvert
Lock
Pump
Critical Pump
Critical Spillway w/Lock
Spillway
Critical Spillway
Weir
SOUTH FLORIDA WATER MANAGEMENT DISTRICT
EMERGENCY OPERATIONS CENTER
GIS SUPPORT SERVICES
No Pumps - FPL
Miles

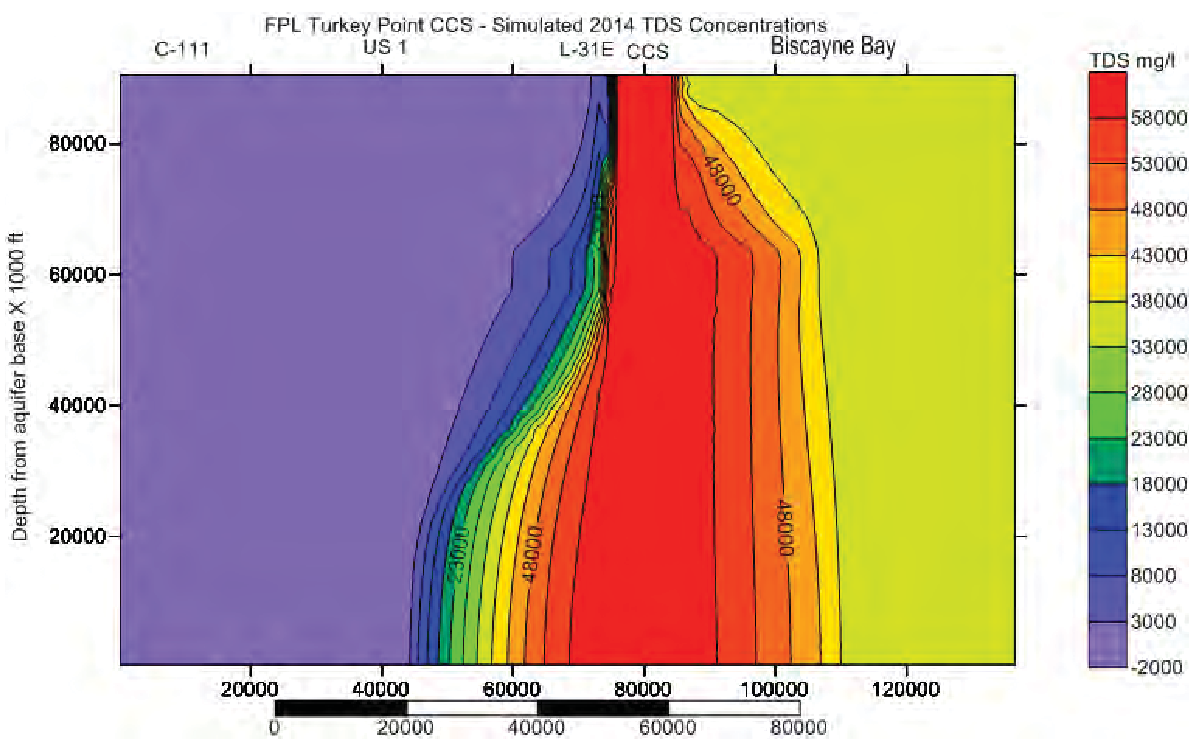
Appendix C: Cross Section Plots



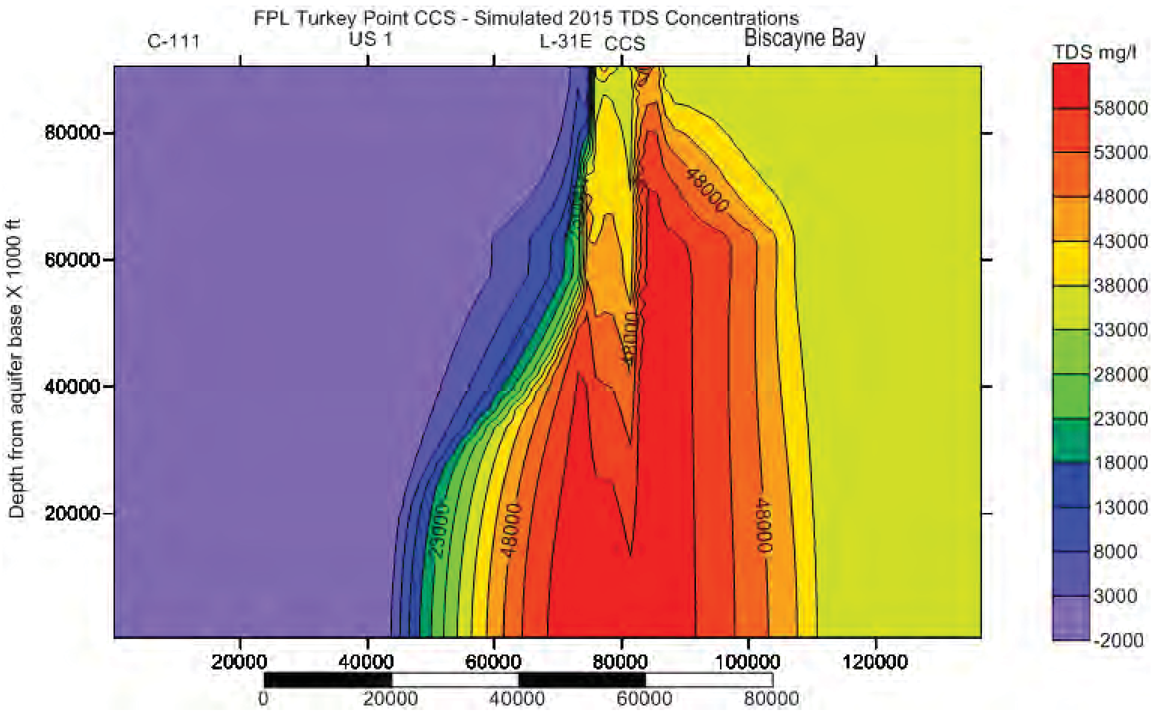
Simulated 1985 TDS concentrations in mg/l.



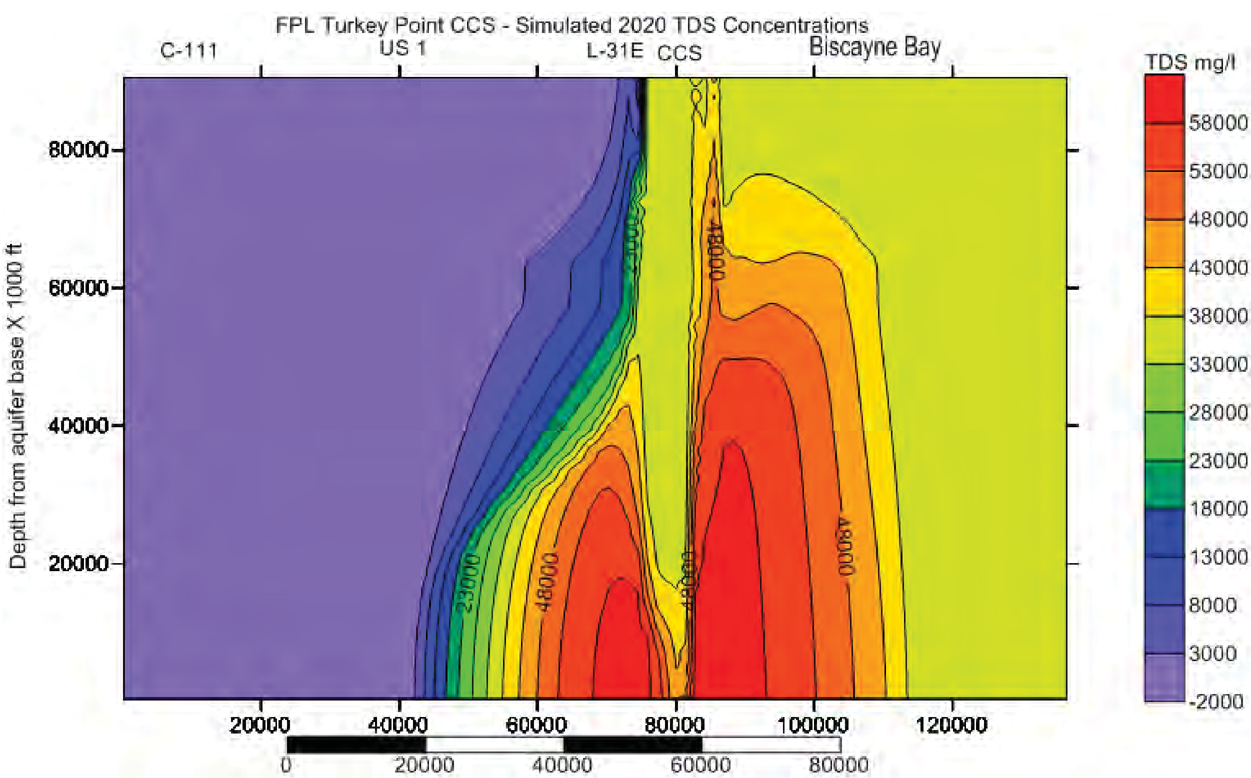
Simulated 2000 TDS concentrations in mg/l.



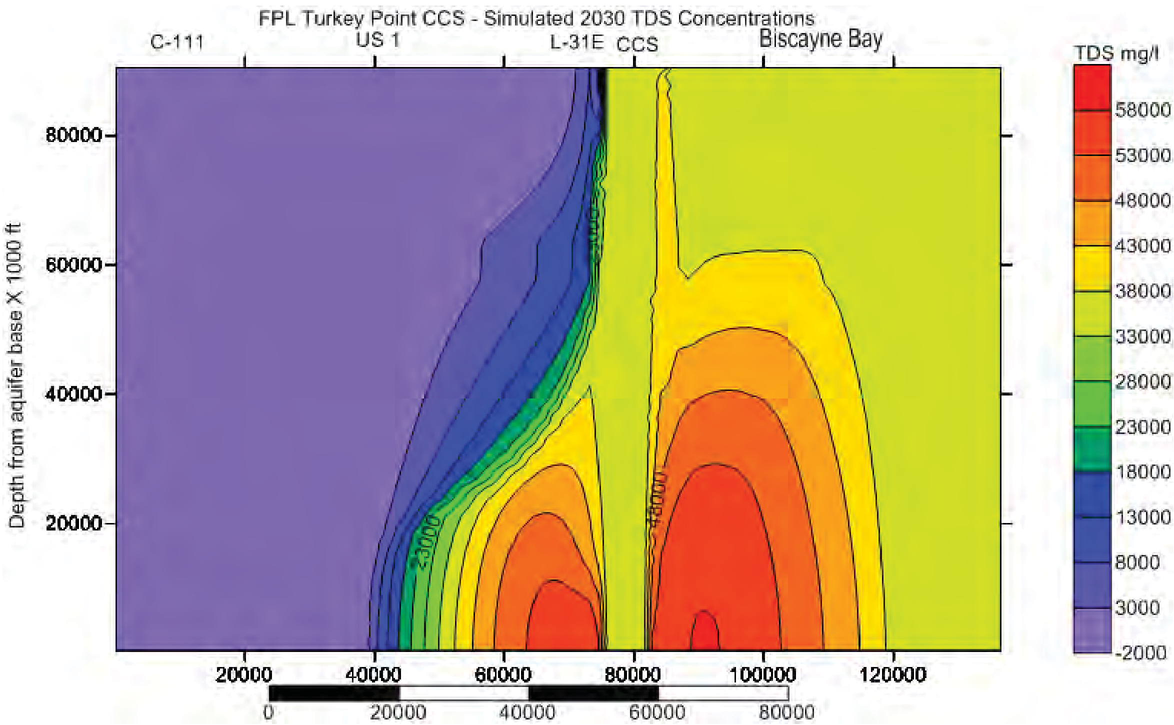
Simulated 2014 TDS concentrations in mg/l.



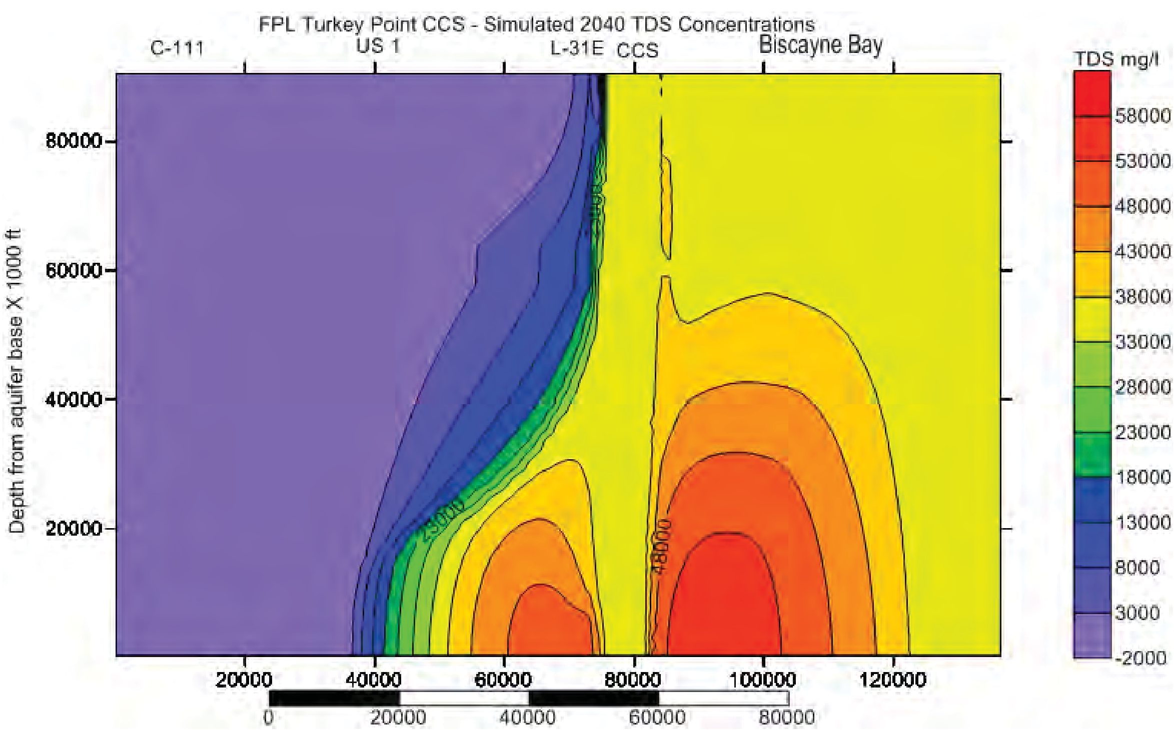
Simulated 2015 TDS concentrations in mg/l.



Simulated 2020 TDS concentrations in mg/l.



Simulated 2030 TDS concentrations in mg/l.



Simulated 2040 TDS concentrations in mg/l.

Appendix D: DBHYDRO Data

Column1	Column2	Column3	Column4
Period of Record Statistical Summary by Year			
DBKEY	Station	Year	Mean
-----	--------	----	-------- -
13037	S20_H	1990	1.955
13037	S20_H	1991	1.772
13037	S20_H	1992	1.695
13037	S20_H	1993	1.804
13037	S20_H	1994	1.909
13037	S20_H	1995	1.877
13037	S20_H	1996	1.711
13037	S20_H	1997	1.877
13037	S20_H	1998	1.802
13037	S20_H	1999	1.83
13037	S20_H	2000	1.835
13037	S20_H	2001	1.726
13037	S20_H	2002	1.694
13037	S20_H	2003	1.735
13037	S20_H	2004	1.519
13037	S20_H	2005	1.66
13037	S20_H	2006	1.564
13037	S20_H	2007	1.871
13037	S20_H	2008	1.695
13037	S20_H	2009	1.689
13037/87490	S20_H	2010	1.888
87490	S20_H	2011	1.557
87490	S20_H	2012	1.789
87490	S20_H	2013	1.557
		Average	1.750458333

DBHYDRO Data for S20_H (Used for L-31E in the model).

Column1	Column2	Column3	Column4
Period of Record Statistical Summary by Year			
DBKEY	Station	Year	Mean
-----	--------	----	-------- -
6570	S20F_T	1985	0.629
6570	S20F_T	1986	0.765
6570	S20F_T	1987	0.707
6570	S20F_T	1988	0.71
6570	S20F_T	1989	0.721
6570	S20F_T	1990	0.754
6570	S20F_T	1991	0.828
6570	S20F_T	1992	0.761
6570	S20F_T	1993	0.753
6570	S20F_T	1994	0.744
6570	S20F_T	1995	0.793
6570	S20F_T	1996	0.627
6570	S20F_T	1997	0.713
6570	S20F_T	1998	0.669
6570	S20F_T	1999	0.921
6570	S20F_T	2000	0.864
6570	S20F_T	2001	0.777
6570	S20F_T	2002	0.81
6570	S20F_T	2003	0.71
6570	S20F_T	2004	0.756
6570	S20F_T	2005	0.849
6570	S20F_T	2006	0.77
6570	S20F_T	2007	0.898
6570	S20F_T	2008	0.864
6570	S20F_T	2009	0.812
6570	S20F_T	2010	0.836
6570	S20F_T	2011	0.839
6570	S20F_T	2012	0.978
6570	S20F_T	2013	0.874
		Average	0.783862069

DBHYDRO Data for S20F_T (used in model for Biscayne Bay and Atlantic Ocean).

Column1	Column2	Column3	Column4
Period of Record Statistical Summary by Year			
DBKEY	Station	Year	Mean
-----	--------	----	-------- -
12288	S176_T	1988	3.33
12288	S176_T	1989	2.979
12288	S176_T	1990	3.047
12288	S176_T	1991	3.034
12288	S176_T	1992	3.32
12288	S176_T	1993	3.454
12288	S176_T	1994	3.631
12288	S176_T	1995	3.563
12288	S176_T	1996	3.425
12288	S176_T	1997	3.449
12288	S176_T	1998	3.519
12288	S176_T	1999	3.646
12288	S176_T	2000	3.591
12288	S176_T	2001	3.32
12288	S176_T	2002	3.542
12288	S176_T	2003	3.762
12288	S176_T	2004	3.268
12288	S176_T	2005	3.606
12288	S176_T	2006	3.515
12288	S176_T	2007	3.465
12288	S176_T	2008	3.37
12288	S176_T	2009	3.393
12288	S176_T	2010	3.74
12288	S176_T	2011	3.064
12288	S176_T	2012	3.662
12288	S176_T	2013	3.758
		Average	3.4405

DBHYDRO Data for S176_T (Used in model for C-111)

Appendix E: Dr. William Nuttle Report

Memorandum

To: Steve Krupa, South Florida Water Management District

From: William Nuttle

2 September 2013

RE: Comments on Proposed FPL Turkey Point CCS Abatement Measure

This memorandum provides my review and analysis of the abatement measure proposed by FPL to lower surface water salinity in the Turkey Point CCS and the simulation modeling of the effect this will have on the future development of the plume of CCS water in the Biscayne aquifer. To reduce salinity in the CCS, FPL proposes to supplement the current water budget by the addition of 14 mgd of either freshwater from the L31W canal, or brackish water (3 gm/l) from the Floridan aquifer. Simulations suggest that reducing salinity in the CCS surface water will cause a rapid (within years) reduction of salinity in the aquifer beneath the CCS and, over a longer period (decades), a repositioning of the saltwater wedge eastward of its current position in the aquifer.

My review and analysis addresses following specific issues of concern to the District:

1) Will the addition of 14 MGD of freshwater reduce salinity in the CCS to 35 gm/l or below, as claimed by FPL in their presentation to the District?

2) Will this reduction in salinity of the CCS suffice to eliminate the driver that is the cause of the development of the plume of CCS water in the Biscayne aquifer and its migration westward in the aquifer?

Summary Findings

1) My calculations indicate that the figure of 14 mgd is the right order of magnitude for the addition of water from the Floridan aquifer to reduce surface water salinities to 35 gm/l, even allowing for uncertainty in the estimated evaporation rate.

2) The results of the model simulations showing a repositioning of the saltwater wedge eastward of its current position are at odds with observed behavior of the saltwater wedge since 1951, twenty years before construction of the CCS. The Tetratech technical memorandum includes the comment that the calculated position of the saltwater wedge is sensitive to assumptions made in setting the hydraulic

head on the west boundary of the model domain. More information is needed about the degree of sensitivity in this behavior exhibited by the model in order to correctly interpret the simulation results.

3) In the near-term, decisions of how to proceed have to be made without the benefit of model predictions of the future behavior of the plume. The results of the model simulations are instructive as a proof of concept exercise. However, the value of this model as a source of information for management decisions is compromised by absence of any detail relating to the regional hydrology in which the CCS plume resides. Tetratech reviewed existing regional hydrologic models that cover this part of the Biscayne aquifer and finds that none takes account of the impact of CCS operations. Substantial time and effort (years) will be required to produce the type of information that regional hydrologic models might be able to provide about the future fate of the plume of CCS water.

Verification of the 14 mgd figure

I verified the 14 mgd figure by altering the long-term water budget calculations, described in my 5 April 2013 report, to take account of this new input. My approach uses a control volume similar to the control volume used in the analysis by Golder Associates[1], Figure 1. The inputs and outputs to this control volume are evaporation Q_E, rainfall Q_R, seepage of Biscayne Bay water Q_{BB}, net seepage to/from the aquifer Q_L, and seepage of fresh groundwater into the interceptor ditch Q_F. The measured water flux due to interceptor ditch pumping Q_{ID} is internal to the control volume, but it is used in the analysis to estimate Q_F. The results of the FPL water budget reported in the 2012 annual report[2] indicate that plant blowdown does not contribute significantly to either the water or salt balance, so its value is assumed to be zero for purposes of the following analysis.

Taking account of the addition of a new input of water Q_{NEW} with salinity S_{NEW}, the long-term mass balance equations for the alternative control volume are as follows: for water,

$$Q_L+E+P+Q_F+Q_{BB}+Q_{NEW}=0, \quad \text{Eq. 1}$$

and for salt,

$$Q_L S_{CCS}+Q_{BB}S_{BB}+Q_{NEW}S_{NEW}=0, \quad \text{Eq. 2}$$

in which S_{CCS} and S_{BB} are the average salinity values for the CCS and Biscayne Bay, respectively. In writing these equations, it is assumed that changes in the amount of water and salt contained in the CCS do not contribute to the respective mass balances over the long-term.

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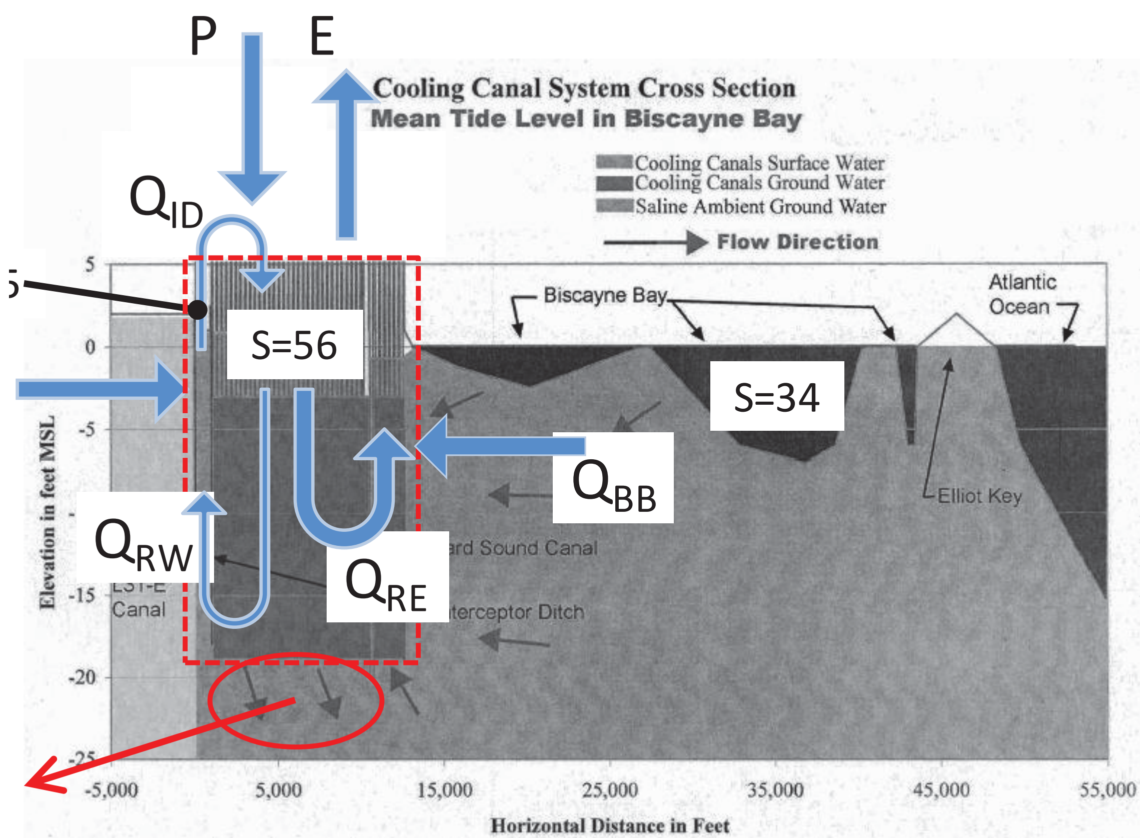
[1] Golder Associates, Inc., Cooling Canal System Model Report. January 13, 2008.

[2] FPL Turkey Point Comprehensive Pre-Uprate Monitoring Report for Units 3 & 4 Uprate Project. October 2012.

Figure 1: Alternative control volume for the calculation of Q_L, the net loading by seepage from the CCS into the aquifer. Average salinity values are shown for the interceptor ditch (average only for days when pumps operated), the CCS, and Biscayne Bay. Fluxes due to pumping from the interceptor ditch, Q_{ID}, and bottom seepage fluxes that are recaptured as inflow back into the CCS, Q_{RW} and Q_{RE}, are internal to this control volume.



ginal figure from Golder Assoc. , January 2008; notations in

I investigated the sensitivity of the calculations to uncertainty in the water budget by varying the magnitude of the evaporation flux. Evaporation is the largest flux in the long-term water budget. The magnitude of uncertainty in the estimated evaporation flux can be judged from the comparison between the average value calculated by the FPL methodology, -4.2E6 cfd, and the average value for evaporation from the CCS calculated by Golder Associates, -6.0E6 cfd. Results reported below use both the average evaporation rate reported in the FPL 2012 annual report and the higher rate used in the Golder Associates study.

In applying the new inflow, I increase the seepage loss and adjust CCS salinity values as needed to balance the water and salt budgets. In doing so, I make the assumption that none of the other terms will change as a result of this change in operations. Rainfall input is determined entirely by climate. The decrease in CCS salinity will affect evaporation, but only slightly. The addition inflow of water will affect seepage fluxes, by increasing the volume and average water levels in the CCS. This can be expected to increase the seepage loss to the aquifer, which is accounted for in these calculations, and decrease the net seepage into the CCS from Biscayne Bay, which is not accounted for in these calculations. A decrease in the inflow of Biscayne Bay water would have the effect of reducing the long-term inflow of salt to the CCS and thus salinity. By ignoring this effect, the result of these calculations are conservative in that they under estimate the reduction in salinity that can be expected to result from a given rate of inflow of new water.

Results of the calculations show that the addition of an inflow of 14 mgd of brackish water from the Floridan aquifer (3 gm/l salinity) is sufficient to reduce the long-term average salinity in the CCS to near or below the target value of 35 gm/l. Calculations reported in Table 1 show the base case water budget under current operations, with Q_{NEW} set to zero, for both the lower and higher values of evaporation. Calculations reported in Table 2 show the results of balancing the water and salt budgets including the input of 14 mgd of water with a salinity of 3 gm/l. The addition of freshwater (0 gm/l) results in a slightly greater reduction in CCS salinity.

The addition of a constant input of 14 mgd of brackish water will reduce the long-term average of CCS salinity; however considerable temporal variability will remain. The range of variation in several components of the water and salt budgets exceeds 14 mgd (1.9E6 cfd), Table 3. Seasonal and year-to-year variation in rainfall and, to a lesser extent, evaporation will drive fluctuations in salinity on similar time scales. More detailed model calculations are required to fully describe the effect that the additional input of Floridan aquifer water would have on salinity in the CCS and thus on the salinity of the seepage loading to the Biscayne aquifer.

Table 1: Base case water and salt budgets for evaporation reported in FPL 2012 annual report and for the higher evaporation from Golder Associates (2008)

Base case

Inflows	ft3/day	mgd	salinity	salt flux
Rainfall (average)	3.20E+06	24	0	0.00E+00
Inflow from Biscayne B (Qbb)	1.40E+06	10	34	4.77E+07
Fresh inflow from aquifer (Qf)	4.49E+05	3	0	0.00E+00
New water source	0.00E+00	0	3	0.00E+00
Total Inflow	5.05E+06			4.77E+07
Outflows				
Evaporation (average)	-4.20E+06	-31	0	0.00E+00
Seepage loss to aquifer (Ql)	-8.52E+05	-6	56	-4.77E+07
Total Outflow	-5.05E+06			-4.77E+07
CCS Salinity			56	

Inflows	ft3/day	mgd	salinity	salt flux
Rainfall (average)	3.20E+06	24	0	0.00E+00
Inflow from Biscayne B (Qbb)	5.98E+06	45	34	2.03E+08
Fresh inflow from aquifer (Qf)	4.49E+05	3	0	0.00E+00
New water source	0.00E+00	0	3	0.00E+00
Total Inflow	9.63E+06			2.03E+08
Outflows				
Evaporation (average)	-6.00E+06	-45	0	0.00E+00
Seepage loss to aquifer (Ql)	-3.63E+06	-27	56	-2.03E+08
Total Outflow	-9.63E+06			-2.03E+08
CCS Salinity			56	

1 ft3 = 7.480519 gallons

Table 2: Water and salt budgets with additional inflow from Floridan aquifer for evaporation reported in FPL 2012 annual report and for the higher evaporation from Golder Associates (2008)

14 mgd Floridan aquifer

Inflows	ft3/day	mgd	salinity	salt flux
Rainfall (average)	3.20E+06	24	0	0.00E+00
Inflow from Biscayne B (Qbb)	1.40E+06	10	34	4.77E+07
Fresh inflow from aquifer (Qf)	4.49E+05	3	0	0.00E+00
New water source	1.87E+06	14	3	5.61E+06
Total Inflow	6.92E+06			5.33E+07
Outflows				
Evaporation (average)	-4.20E+06	-31	0	0.00E+00
Seepage loss to aquifer (Ql)	-2.72E+06	-20	20	-5.33E+07
Total Outflow	-6.92E+06			-5.33E+07
CCS Salinity			20	

Inflows	ft3/day	mgd	salinity	salt flux
Rainfall (average)	3.20E+06	24	0	0.00E+00
Inflow from Biscayne B (Qbb)	5.98E+06	45	34	2.03E+08
Fresh inflow from aquifer (Qf)	4.49E+05	3	0	0.00E+00
New water source	1.87E+06	14	3	5.61E+06
Total Inflow	1.15E+07			2.09E+08
Outflows				
Evaporation (average)	-6.00E+06	-45	0	0.00E+00
Seepage loss to aquifer (Ql)	-5.51E+06	-41	38	-2.09E+08
Total Outflow	-1.15E+07			-2.09E+08
CCS Salinity			38	

1 ft3 = 7.480519 gallons

Table 3: Comparison of the different magnitudes of water fluxes involved in the CCS water budget. Fluxes included in the FPL water budget calculations are indicated in bold.

	ft3	mg	
CCS Volume	6.303E+08	4715	Average for Sep 2010 through June 2011

Water Flux	ft3/day	mgd	Comment
CCS surface discharge	2.42E+08	1810	Average for Sep 2010 through June 2011
Max 1-day rainfall	**1.72E+08**	**1289**	Data from Sep 2010 through June 2012
N-S difference in measured CCS discharge (underflow)	2.91E+07	218	Average for Sep 2010 through June 2011
Daily change in CCS Vol	**1.19E+07**	**89**	FPL report, standard deviation of daily vol change Sep 2010 through June 2011
Evaporation (average)	**-4.16E+06**	**-31**	FPL report, data from Sep 2010 through June 2012
Rainfall (average)	**3.24E+06**	**24**	FPL report, data from Sep 2010 through June 2012
Bottom seepage (Zone A)	**-1.14E+06**	**-8**	FPL report, data from Sep 2010 through June 2012
Long-term seepage loading to aquifer	-1.00E+06	-7	W.K. Nuttle report to SFWMD
Side seepage (East)	**6.32E+05**	**5**	FPL report, data from Sep 2010 through June 2012
ID pumping	**6.13E+05**	**5**	FPL report, data from Sep 2010 through June 2012
Bottom seepage (Zone D)	**5.57E+05**	**4**	FPL report, data from Sep 2010 through June 2012
Blowdown (inflow to CCS)	**1.66E+05**	**1**	FPL report, data from Sep 2010 through June 2012
Side seepage (South)	**9.88E+04**	**1**	FPL report, data from Sep 2010 through June 2012
Side seepage (West)	**6.78E+04**	**1**	FPL report, data from Sep 2010 through June 2012
Bottom seepage (Zone C)	**4.45E+04**	**0**	FPL report, data from Sep 2010 through June 2012
Bottom seepage (Zone B)	**2.41E+04**	**0**	FPL report, data from Sep 2010 through June 2012
Side seepage (North)	**-3.59E+02**	**0**	FPL report, data from Sep 2010 through June 2012

1 ft3 = 7.4805195 gallons

Review of results of the simulation model

The technical memorandum from Tetratech to FPL, dated 15 July 2013, provides results obtained in simulations using a 2-d, variable density groundwater and salt transport numerical model. These simulations follow and extend the earlier investigation by Hughes et al. (2009)[3] of the intrusion of hypersaline CCS water into the Biscayne aquifer following initiation of the operation of the CCS. Where the focus of Hughes et al. (2008) is on early development of the plume in the vicinity of the CCS, the simulation modeling by Tetratech seeks to reproduce the development of the groundwater plume over the operating lifetime of the CCS, up to the present day, and simulate future conditions in the aquifer following a reduction in salinity of the CCS from 60 gm/l to 35 gm/l.

Tetratech claims success in calibrating the model to reproduce the historical development of the plume. And, based on this success they claim that simulations of future conditions represent development of the plume in response to salinity reduction in the CCS, all other factors being held constant. Results provided in Figure 5 show that "[t]he CCS salinity reduction alternative appears to be very effective at reducing concentrations regionally and in arresting the westward movement of the saltwater front." Moreover, "the CCS salinity reduction scenario causes a repositioning of the saltwater wedge, where by year 30 it has receded eastward of its current position

Results showing a displacement of the saltwater wedge eastward of its current position are at odds with its observed behavior. The saltwater wedge has remained more or less fixed in the vicinity of well G-12 for the period 1951 through 2008 (c.f. Figure 5.2-23 of FPL 2012 annual report). The position of the saltwater wedge was relatively static for 20 years prior to construction of the CCS, and it has remained unchanged during 40 years of CCS operations. From this one might reasonably expect that if the CCS operations were curtailed entirely, and the site returned to its original condition, the position of the saltwater wedge would still remain unchanged from what it was before the CCS was constructed.

Rather than curtail operations, the actions to reduce salinity in the CCS will, if anything, increase the seepage loading of CCS water into the aquifer at the coast, albeit water with much lower salinity. One might reasonably expect that the salinity in some parts of the plume will decrease as a result of the infiltration of lower salinity water, but it is not credible to expect that decreasing the salinity of the seepage loading to the aquifer with alter the position of the saltwater wedge in the aquifer, assuming that all other factors are held constant. In fact, the model simulation of future conditions does not hold other factors constant.

The behavior of the saltwater wedge in the model simulations likely is connected with an issue concerning selection of head boundary conditions identified on comments by Jeff Giddings (SFWMD). Values of hydraulic head applied to the model boundaries corresponding to Biscayne Bay and the CCS are reduced by about 1.4 feet in the "predictive simulations" relative to values used in the "simulations prior to and during CCS operation." The claim is made that this is done to better reflect values of head measured during the monitoring program. However, the head value on the western boundary of the model was not similarly adjusted. The net effect of making this adjustment is to increase the regional

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[3] Hughes, J.D., C.D. Langevin, L. Brakefield-Goswami, 2009. Effect of hypersaline cooling canals on aquifer salinization. Hydrogeology Journal, DOI 10.1007/s 10040-009-502-7.

hydraulic gradient that drives freshwater flow to the coast. The regional head gradient is increased by about 40% by the adjustments made, and this has the effect of similarly increasing the amount of freshwater flow from the west toward the coast in the simulation of future conditions compared with the flow calculated during the historical period, which is used to calibrate the model.

The authors are apparently aware of this issue, as their conclusions include the observation that "the head and head changes on the western boundary may affect migration of the saltwater wedge as much or more than the salinity reductions." However, the technical memorandum provides no information on the results of model calculations in which they explore the sensitivity of the position of the saltwater wedge to changes in regional hydraulic gradient.

The simulation of future conditions alters two factors that affect the behavior of the plume at the same time, by altering the head values in the vicinity of the CCS while keeping the head on the western boundary unchanged and reducing the salinity in the CCS. Therefore, one cannot claim that the resulting dissipation of the plume is the result of only reducing CCS salinity. To substantiate this claim, more information must be provided about the current head values applicable to the western boundary, assumptions made in selecting the value of head applied in the model calculations, and the degree of sensitivity in the resulting position of the saltwater wedge exhibited by the model.

Ultimately, this model has limited utility as a source of information for decisions regarding managing the fate of the CCS plume. Simulations with this model are useful for developing an understanding of some of the factors that control the plume's behavior. However, limitations inherent in the model design prevent the effects of other important factors from being included. These include the following:

3-D geometry – The geometry of the CCS and its plume are poorly represented at the regional scale by the 2-D grid used in the model. Using the 2-D grid makes sense for the investigation by Hughes et al. into phenomenon related to the infiltration of CCS water into the aquifer below and in the immediate vicinity of the CCS.

Regional hydrology – Essential features of regional hydrology that can affect the behavior of the plume are missing from the model. Recharge from rainfall and water loss from the aquifer due to evaporation and well withdrawals are not accounted for. Neither are the interaction between the aquifer and canals, which can function both as sources of recharge and areas of discharge from the aquifer to surface water. Several studies have documented the role that canals have played in enhancing the inland migration of saltwater into the Biscayne aquifer (c.f. Parker et al 1955)[4]. It is likely that rock mining also affects conditions in the aquifer, but I am not aware of any studies on this topic.

Sea level rise – The rate of sea level rise has accelerated to the point where the effects of increased sea level must be taken into account when planning for more than a few years into the future. In South Florida sea level is projected to rise by between 0.5 and one foot over the next 30 years.[5] This will have two effects that can influence the fate of the CCS plume. First, a rise in sea level decreases the regional

[4] http://sofia.usgs.gov/publications/papers/wsp1255/
[5] http://southeastfloridaclimatecompact.org/pdf/Sea%20Level%20Rise.pdf

hydraulic gradient that drives freshwater flow in the aquifer, which will influence the position of the saltwater wedge as discussed above. Second, the shoreline of Biscayne Bay will retreat as sea level increases. Analysis of detailed LIDAR elevation data for Miami-Dade County, by Pete Harlem (FIU) and others, indicates that with a rise of one-foot the shoreline will retreat to a point west of the CCS.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
ATLANTA FEDERAL CENTER
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APR 09 2015

Colonel Alan M. Dodd
District Engineer
Department of the Army
Jacksonville District Corps of Engineers
Attn: Megan Clouser
9900 Southwest 107th Avenue, Suite 203
Miami, Florida 33176

Subject: Florida Power and Light Company; 2009-02417(SP-MLC)

Dear Colonel Dodd:

This letter is in response to permit application number 2009-02417(SP-MLC) submitted by Florida Power and Light Company (FPL). The applicant proposes to impact 1000 acres of tidal and freshwater wetlands for the purpose of constructing two new 1,100 megawatt nuclear generating units (Units 6 & 7) at the existing Turkey Point facility. Other components of the project consist of: (1) east and west transmission line routes; (2) road expansion; (3) construction of a reclaimed water facility, four radial collector wells and twelve deep-injection wells; (4) installation of reclaimed and potable water pipelines; (5) and the expansion of an existing boat basin. The wetlands proposed for impact consist of mangrove swamp, sawgrass marsh, mixed wetland hardwoods, seagrass, freshwater and saltwater marsh, and wetland shrub. However, the public notice (PN) did not provide a detailed breakdown of wetland impacts by community type. The Turkey Point facility is located at the eastern terminus of Palm Drive, adjacent to Biscayne Bay, in Sections 33 and 34, Township 57 South, Range 40 East, Miami-Dade County, Florida.

The U.S. Environmental Protection Agency Region 4 has completed its review of this project from information contained in the PN and the Draft Environmental Impact Statement (DEIS) for Turkey Point Nuclear Units 6 and 7. This letter summarizes the EPA's position on the project based on the Clean Water Act (CWA) Section 404(b)(1) Guidelines, which prohibit avoidable or significant adverse impacts to the aquatic environment.

The proposed project will have a direct impact on approximately 300 acres of high quality, tidal mangrove wetlands. Mangrove wetlands located within south Florida form a vital component of the estuarine and marine environment, providing a major organic detrital base to the aquatic food chains, significant habitat for arboreal, intertidal and subtidal organisms, nesting sites, cover and foraging grounds for birds, and habitat for reptiles and mammals. Mangroves provide protected nursery areas for fishes, crustaceans, and shellfish. Mangrove systems are one of the most biologically productive ecosystems in the world. Mangroves also serve as storm buffers by functioning as wind breaks and through prop root baffling of wave action. Mangrove roots stabilize shorelines and fine substrates, reducing turbidity, and enhancing water clarity. Mangroves improve water quality and clarity by filtering upland runoff and trapping waterborne sediments and debris. However, the cumulative loss of this habitat has reduced overall water quality and fisheries production within the south Florida ecosystem. For these reasons, the EPA considers these mangrove wetlands to be aquatic resources of national importance (ARNI).

In addition, the proposed project would impact approximately 40 acres of sawgrass marshes which provide principal environmental values related to water quality and quantity. They serve as filter systems for water and protect natural bodies of water from eutrophication. Numerous birds can be found in this community year-round or for over-wintering. They also provide habitat for frogs, snails, and crayfish, which serve as food sources for larger protected animals that are found in this region. Protected animals that can be found in and around sawgrass marsh systems include the Everglades mink (*Mustela vison evergladensis*), Florida panther (*Felis concolor coryi*), snail kite (*Rostrhamus sociabilis*), wood stork (*Mycteria americana*), and American alligator (*Alligator mississippiensis*). Therefore, the EPA considers sawgrass marshes to be ARNI.

Lastly, the proposed project would impact approximately one acre of submerged aquatic vegetation (SAV), which includes *Ruppia maritima, Thalassia testudinum,* and *Halodule wrightii*. Fin and shell fish commonly associated with this species include Florida crawfish, stone crab, blue crab, penaeid shrimp, sea trout, gray snapper, red drum, pinfish, mullet, and flounder. Moreover, SAV provides attachment sites for periphyton which in turn increases food value for the base of marine and estuarine food webs. SAV aids in stabilizing the shallow water submerged land which promotes water quality. SAV also performs important nutrient uptake functions which assist in the maintenance of water quality. For these reasons, the EPA also considers SAV to be ARNI.

The EPA requests that the applicant provide information on measures that have been taken to avoid and minimize onsite, freshwater and tidal wetland impacts. The project as proposed will impact 1000 acres of tidal and freshwater wetlands which include ARNI. According to the CWA Section 404(b)(1) Guidelines, 40 CFR § 230.91(c), and the February 6, 1990, Memorandum of Agreement between the U.S. Army Corps of Engineers and the EPA regarding the Determination of Mitigation under the Clean Water Act Section 404(b)(1) Guidelines, an applicant must demonstrate avoidance and minimization of wetland impacts before compensatory mitigation can be considered. The CWA Section 404(b)(1) Guidelines, 40 CFR Subpart H, describes several (but not all) means of minimizing impacts of an activity. The EPA recommends that the applicant consider installing the reclaimed and potable waterlines at deep enough elevations which would allow herbaceous wetlands to remain at the surface. In addition, we recommend that all lay down areas used during construction be restored to their natural wetland community type.

In order to evaluate the proposed project, the EPA requests that the applicant provide a colored copy benthic survey of the boat basin, radial collector well locations, and the Unit 6 & 7 site. The benthic survey should extend a radius of 50 feet around submerged lands of these locations. The benthic survey should include a description of the protocol used to complete the survey, sampling dates, and a map that illustrates the density and location of each SAV found at the site. The benthic survey submitted for review should be conducted between the months of June and September to ensure the survey is conducted during the active growing season. The benthic survey is necessary for the EPA to determine the extent of SAV impacts that will occur due to the proposed project.

The new nuclear reactor Units 6 and 7, including cooling towers, makeup water reservoir, new substation and associated facilities, would be built on a filled "218 acre island" enclosed by a stabilized earth wall to the north, east, and west. A reinforced concrete wall would be constructed to the south. The elevation within the fill island would range from 19 feet to 26 feet North American Vertical Datum of 1988. With the threat of sea level rise in the foreseeable future, the EPA has concerns about what effect this may have on the surrounding infrastructure to this created island. Please provide information which would support construction of the project considering the fact that even though the power units will be constructed on this island, the surrounding landscape may be impacted by sea level rise or storm surges that may affect the feasibility of the project given the project purpose.

The proposed project includes construction of a nine mile pipeline from the Miami-Dade County South Waste Water Treatment Plant to the newly constructed wastewater treatment facility at the Turkey Point facility. The purpose of the waste pipeline is to supply reclaimed water for use in the wet-cooling system for Units 6 & 7. When reclaimed water is not available in sufficient quantity or quality for the wet-cooling system, makeup water would be provided by four radial collector wells installed in Biscayne Bay. Under the Florida Department of Environmental Protection final condition of certification, the radial collector wells may only be used for 60 days per year. It is not clear what contingency plan will be implemented should the 60 day limitation be exhausted and the reclaimed water supply is not available. Please provide a detailed explanation of the contingency plans.

The PN states that the applicant proposes to offset project impacts by conducting permittee responsible mitigation and purchasing credits at the FPL Everglades Mitigation Bank and Hole-in the-Donut in-lieu-fee program. The EPA preference for mitigation is the use of a federally approved mitigation bank or in-lieu fee program, if available, rather than permittee-responsible mitigation. Since avoidance and minimization have not been adequately demonstrated, it is premature for the EPA to consider any type of mitigation plan. In the event that onsite wetland impacts are reduced and avoidance and minimization are demonstrated in the future, the EPA requests that the applicant provide the following information regarding any proposed mitigation. This information is necessary in order to ensure the proposed mitigation for impacts associated with the project are in compliance with the Federal Compensatory Mitigation Rule, dated April 2008.

- Detailed mitigation and maintenance plan
- The responsible party for the long-term management of the mitigation area
- Assurance for the long-term protection of the mitigation area (such as a perpetual conservation easement)
- Detailed performance standards to achieve mitigation success
- Detailed monitoring requirements
- Detailed long-term management plan
- Detailed adaptive management plan
- Documented financial assurance to ensure the mitigation site is maintained in perpetuity
- Detailed description of the net benefit the proposed mitigation will provide to the environment
- Objectives
- Site selection criteria
- Baseline information
- Credit determination methodology

The EPA requests that the applicant provide Uniform Mitigation Assessment Method scores for the proposed impact and mitigation sites. Technical rationale for each score should also be included.

The EPA requests that the applicant provide a cumulative impact analysis for other commercial projects that have proposed tidal and freshwater wetland impacts in Miami-Dade County, Florida. It is essential that we have a clear understanding of the potential direct, secondary, and cumulative environmental impacts these projects will have on aquatic resources. This should include all mangrove, sawgrass marsh and SAV parcels located in Miami-Dade County, Florida.

In conclusion, the EPA believes that the permit for the project should not be approved as currently proposed, because it does not comply with the CWA Section 404(b)(1) Guidelines. We believe that the proposed project may result in substantial and unacceptable impacts to mangrove wetlands, sawgrass marshes and SAV, which we consider to be ARNI. This letter follows the field level procedures outlined in the August1992 404(q) Memorandum of Agreement between the EPA and the Department of the Army, Part IV, Paragraph 3(a).

Thank you for providing an opportunity for the EPA to comment on this authorization. At this time, the EPA requests additional information to facilitate our evaluation of this project. We look forward to receiving more information from you. If you have any questions, please contact Ron Miedema at 400 North Congress Avenue, Suite 120, West Palm Beach, Florida 33401, or by telephone at 561-616-8741.

Sincerely,

James D. Giattina
Director
Water Protection Division

cc: Ms. Victoria Foster, FWS, Vero Beach, Florida
Ms. Barbara Conmy, SFWMD, West Palm Beach, Florida
Ms. Jocelyn Karazsia, NMFS, West Palm Beach, Florida

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Earth's Future

RESEARCH ARTICLE

10.1002/2014EF000274

Climate forcing of unprecedented intense-hurricane activity in the last 2000 years

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Key Points:
- Significant variability in the frequency of intense-hurricanes has occurred
- Prehistoric intense-hurricane frequency often exceeded historic levels
- Regional sea-surface temperature warming contributed to active intervals

Supporting Information:
- EFT2_61_SuppInfo.pdf

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Abstract How climate controls hurricane variability has critical implications for society is not well understood. In part, our understanding is hampered by the short and incomplete observational hurricane record. Here we present a synthesis of intense-hurricane activity from the western North Atlantic over the past two millennia, which is supported by a new, exceptionally well-resolved record from Salt Pond, Massachusetts (USA). At Salt Pond, three coarse grained event beds deposited in the historical interval are consistent with severe hurricanes in 1991 (Bob), 1675, and 1635 C.E., and provide modern analogs for 32 other prehistoric event beds. Two intervals of heightened frequency of event bed deposition between 1400 and 1675 C.E. (10 events) and 150 and 1150 C.E. (23 events), represent the local expression of coherent regional patterns in intense-hurricane–induced event beds. Our synthesis indicates that much of the western North Atlantic appears to have been active between 250 and 1150 C.E., with high levels of activity persisting in the Caribbean and Gulf of Mexico until 1400 C.E. This interval was one with relatively warm sea surface temperatures (SSTs) in the main development region (MDR). A shift in activity to the North American east coast occurred ca. 1400 C.E., with more frequent severe hurricane strikes recorded from The Bahamas to New England between 1400 and 1675 C.E. A warm SST anomaly along the western North Atlantic, rather than within the MDR, likely contributed to the later active interval being restricted to the east coast.

1. Introduction

Climate controls the characteristics of tropical cyclone populations by providing the environmental conditions that influence their genesis, intensity, and path [*Emanuel et al.*, 2004; *Gray*, 1968; *Kossin and Vimont*, 2007]. Resolving how climate and tropical cyclone activity co-evolve has critical implications for society and is poorly understood. A link between human-induced climate warming and intense tropical cyclones has been suggested [*Emanuel*, 2005; *Webster et al.*, 2005], but an alternative view proposes that the recent increase in the frequency of North Atlantic tropical cyclones (Atlantic tropical cyclones with sustained winds exceeding 33 m/s are referred to as hurricanes) is related to natural oscillations in sea surface temperature (SST) [*Goldenberg et al.*, 2001]. However, the short duration and unreliability of the observational record [*Landsea et al.*, 2006] has made testing these hypotheses challenging.

Significant disagreement exists between model projections for how Atlantic hurricane activity will respond to future anthropogenic forcing, though there is some consensus that hurricane intensity will increase [*Knutson et al.*, 2010; *Villarini and Vecchi*, 2013]. Downscaling approaches indicate that warming SST may cause both more frequent and intense hurricanes in the western North Atlantic over the coming decades [*Bender et al.*, 2010; *Emanuel*, 2013]. Unfortunately, little is known regarding the sensitivity of past variability in hurricane activity to changing SST due to the limited observational record.

Coarse-grained, storm-induced deposits preserved in coastal lakes and marshes [*Boldt et al.*, 2010; *Brandon et al.*, 2013; *Donnelly and Woodruff*, 2007; *Lane et al.*, 2011; *van Hengstum et al.*, 2013; *Wallace et al.*, 2014] provide a means to extend our observational knowledge to climate regimes outside of those observed historically, and potentially provide analogs for future climate scenarios. However, modest sedimentation rates at these sites (often less than 1 mm/year) can limit the temporal resolution of many paleo-hurricane archives. Further, challenges emerge because insufficient fine-grained sediment deposition between consecutive storm layers preclude delineation of individual events, or subsequent overwash events erode and re-work previously deposited sedimentary material [*Woodruff et al.*, 2008a]. Thus, the number of discrete storm deposits within these low-resolution records likely under-represents the total number of intense-hurricane events affecting the site.

Fortunately, a new array of high-resolution sedimentary proxy records from deep coastal basins with high sedimentation rates and low potential for post-depositional reworking are transforming our ability to detect individual hurricane-induced event beds and analyze the underlying climatic forcing of changes in hurricane activity over the last several millennia [*Brandon et al.*, 2013; *Denommee et al.*, 2014; *Lane et al.*, 2011; *van Hengstum et al.*, 2013]. Determining the spatial and temporal pattern of this past hurricane activity, and the climatic forcing mechanisms responsible for modulating intense-hurricane landfalls, is critical to assess our future risk because these past hurricane patterns may be analogs for future climate scenarios.

In this work we present a near annually resolved 2000 year record of intense-hurricane–related event beds preserved within the sediment recovered from a coastal pond (Salt Pond) in Falmouth, MA, USA (Figure 1). In combination with other previously published reconstructions from the western North Atlantic, we assess geographic patterns of intense-hurricane activity and associated climate forcings. We find that regional changes in North Atlantic SST contributed to historically unprecedented levels of intense-hurricane activity. Warm SST throughout the main development region (MDR; Figure 1a) contributed to high levels of intense-hurricane activity across the western North Atlantic for much of the first millennium Common Era (C.E.). Later, a warm SST anomaly in the western North Atlantic at the onset of the Little Ice Age (ca. 1400–1675 C.E.), coincident with a southerly shift in the Intertropical Convergence Zone (ITCZ) potentially leading to increased hurricane genesis off the southeast coast of the United States, likely contributed to an active interval of intense-hurricane activity restricted to the North American east coast, when sites in the Caribbean and Gulf of Mexico experienced low levels of intense-hurricane activity. The correspondence of active intense-hurricane regimes with regional warm sea-surface temperature anomalies,lends support to model projections of future increases in hurricane intensity associated with sea-surface warming related to greenhouse-gas emissions.

2. Methods

2.1. Study Site and Field Methods

The site of our newly developed reconstruction (Salt Pond) is a brackish coastal pond connected to the ocean via a tidal inlet with a approximately 1.3–1.8 m high (above mean high water [MHW]) coastal barrier (Figure 1). Salt Pond formed from an ice block depression (kettle) in glacial outwash sediments a few hundred meters south of the Buzzards Bay recessional moraine. Salt Pond is approximately 26 ha in area and has a relatively small total catchment area of about 70 ha. The surface of the outwash plain surrounding the pond is gently sloping with a gradient of approximately 6° and there are no significant surface water and sediment inputs from the surrounding landscape into the pond. Nearly all freshwater flux is through groundwater infiltration through the stratified coarse grained outwash sediments. Mean tidal range on the open coast is approximately 0.5 m (http://tidesandcurrents.noaa.gov/), limiting the influence of stage of astronomical tide on susceptibility of the barrier to overwash during storms. We used an Edgetech 3100 Chirp subbottom sonar system with a 4–24 kHz fish floating at the water surface to map the bathymetry and sub-bottom stratigraphic architecture of Salt Pond (Supporting Information Figure S1). Core locations were based on bathymetry and sub-bottom data. Water column salinity and temperature profiles were taken with a portable YSI Castaway CTD (Supporting Information Figure S2). We collected a series of hand driven vibracores from a raft. In each case we collected a series of replicate vibracores in an effort to maximize the total sediment recovered. In addition, we collected a replicate drive between 1 and 2 m long using a 7.5 cm diameter polycarbonate piston core at each core location to ensure we recovered an intact sediment/water interface (preserving the most recent portion of the record) at each coring location.

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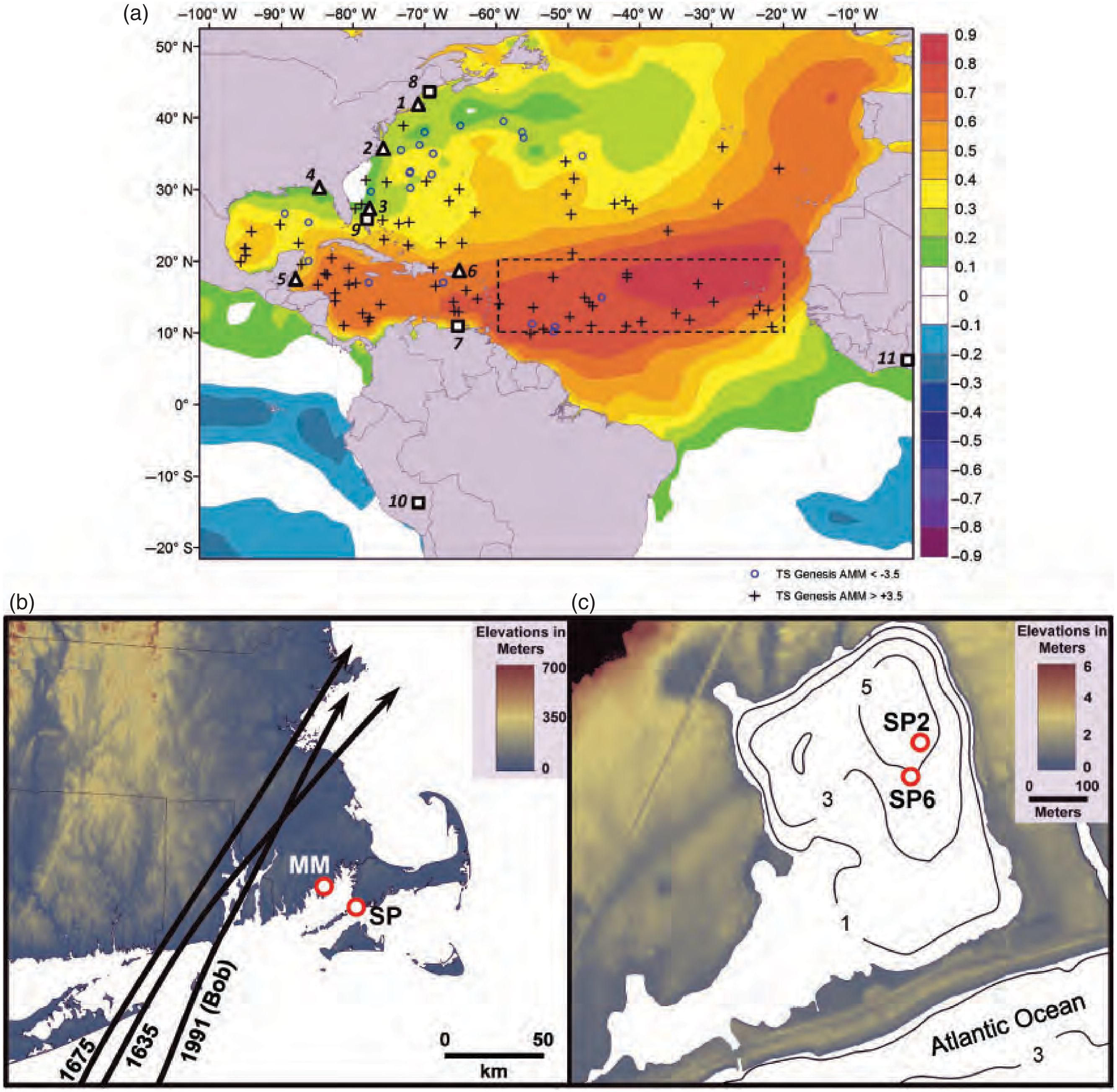


Figure 1. Location maps. (a) Correlation map of boreal summer SST and AMM. SSTs are warmer during positive AMM. Triangles show locations of paleo-hurricane reconstructions presented here (*1*—Salt Pond [this study] and Mattapoisett Marsh [*Boldt et al.*, 2010]; *2*—Outer Banks inlets [*Mallinson et al.*, 2011]; *3*—Thatchpoint Blue Hole [*van Hengstum et al.*, 2013], *4*—Mullet Pond [*Lane et al.*, 2011] and Spring Creek Pond [*Brandon et al.*, 2013]; *5*—Lighthouse Blue Hole [*Denommee et al.*, 2014]; *6*—Laguna Playa Grande [*Donnelly and Woodruff*, 2007]). The MDR for North Atlantic tropical cyclones is noted in the dashed box. Locations of additional paleoclimate proxy records presented in Figures 4 and 5 are noted with squares (*7*—Cariaco Basin [*Wurtzel et al.,* 2013; *Haug et al.*, 2001]; *8*—Gulf of Maine SST [*Wanamaker et al.*, 2008]; *9*—Bahamas SST [*Saenger et al.*, 2009]; *10*—Quelccaya Ice Cap [*Thompson et al.*, 2013]; *11*—Lake Bosumtwi [*Shanahan et al.*, 2009]). Genesis locations for hurricanes forming in the most positive AMM (+) and most negative AMM (o) years are shown. Note the increase in genesis off the North American east coast in negative AMM. (b) Location of Salt Pond (SP) and Mattapoisett Marsh (MM) [*Boldt et al.*, 2010] in southeastern New England and approximate tracks of historical hurricanes thought to have left a coarse event bed in Salt Pond sediments. (c) Map of Salt Pond showing core locations (SP2, SP6) and bathymetry and topography in meters.

2.2. Laboratory Analysis

Cores were transported to the laboratory, sectioned, split and described. Archived core halves were scanned on the ITRAX X-ray fluorescence (XRF) scanner at Woods Hole Oceanographic Institution (WHOI). X-ray radiography was measured simultaneously with elemental chemistry at 200 μm resolution. We focused our analysis on cores collected from the deepest region of the basin (i.e., SP2 and SP6; Figure 1c). In core SP2 and for the upper 50 cm of core SP6 we measured the organic content of the sediment using loss on ignition [*Dean*, 1974] (LOI) every contiguous half centimeter. Following the LOI process, we sieved the remaining ash at 32 μm and then 63 μm and dried and weighed the residual to determine the percentage of these fractions relative to the total dry weight of the sediment. Weighing errors of ±0.002 g result in percent coarse uncertainities of ±0.25% (at 95% confidence).

2.3. Chronology

We use several isotopic and stratigraphic dating methods to establish age control. The activity of ^{137}Cs within sediments provides stratigraphic markers associated with nuclear weapons testing. The beginning of ^{137}Cs deposition occurred in 1954, followed by peaks in 1959 and 1963 C.E. [*Dunphy and Dibb*, 1994]. The ^{137}Cs activity of selected subsamples from cores SP2 and SP6 were measured at WHOI using a high-resolution Canberra gamma detector.

Pollution horizons preserved in the sediments can also provide a dated stratigraphic marker. For example, lead pollution introduced to the atmosphere beginning at the onset of the industrial revolution quickly precipitated out of the atmosphere and was rendered immobile in anoxic sediments [*McCaffrey and Thomson*, 1980]. Records of lead pollution preserved in sediments can provide a stratigraphic marker that dates to the late-1800s [*Donnelly et al.*, 2001] and when lead was removed from gasoline in the 1970s and 1980s [*Wu and Boyle*, 1997; *McConnell et al.*, 2002]. We used lead levels from XRF scans to examine temporal trends in lead content of the sediment.

Regional alteration of terrestrial flora as documented by fossil pollen records also provides chronostratigraphic markers. We took 1 cm^3 samples at 20 cm intervals (40 year resolution) throughout SP2 for pollen analysis. Samples were processed using standard techniques [*Faegri and Iverson,* 1989] and pollen was identified and counted to over 400 arboreal taxa per level. The increase of native and introduced weeds (ragweed [*Ambrosia sp.* L.] and sorrel [*Rumex sp.* L.], respectively) associated with European-style clearance in the northeastern United States is well represented by pollen data, providing a well-dated stratigraphic marker [*Russell et al*., 1993]. Opaque spherules were also identified and counted in all pollen samples, where a 1900 C.E. rise in the northeast United States has been associated with industrial activities [*Clark and Patterson*, 1985].

Terrestrial macrofossils preserved within core SP2 were dated by accelerator mass spectrometry (AMS) radiocarbon techniques at the National Ocean Sciences Accelerator Mass Spectrometer (NOSAMS) facility at WHOI (Figure 2b; Supporting Information Table S1). Radiocarbon results were calibrated for secular changes in atmospheric radiocarbon concentrations (IntCal13 [*Reimer et al.*, 2013]). Age models and associated 95% uncertainties were computed using BACON (Bayesian accumulation histories for deposits) software [*Blaauw and Christen*, 2011] for SP2 and previously published sites used for comparison: Thatchpoint Bluehole [*van Hengstum et al.*, 2013], Laguna Playa Grande, Vieques [*Donnelly and Woodruff*, 2007], and the Cariaco Basin SST record [*Wurtzel et al.*, 2013; from original radiocarbon results in *Black et al.,* 1999]. Thus, the age models for Thatchpoint and Vieques are updated from the originally published versions (Supporting Information Figure S3), which were simple linear interpolated segments between dated index points.

2.4. Determining Event Bed Threshold

In order to determine a cutoff for what constitutes an event bed at Salt Pond we calculated the cumulative distribution of coarse fraction that exceeded 99% of the data over the historical interval in core SP2 (last 393 years), or 1.34%. In turn, we define events over the entirety of the 2000 year SP2 record based on those coarse fraction peaks that exceed 1.34% coarse fraction (Figure 2a). In order to filter out the multiyear to decadal variability in coarse fraction, we subtract an 11-point moving average from the data that excludes coarse fraction values that exceed 5%. By excluding the large peaks in coarse fraction from the moving average, we prevent the filter from screening coarse fraction peaks

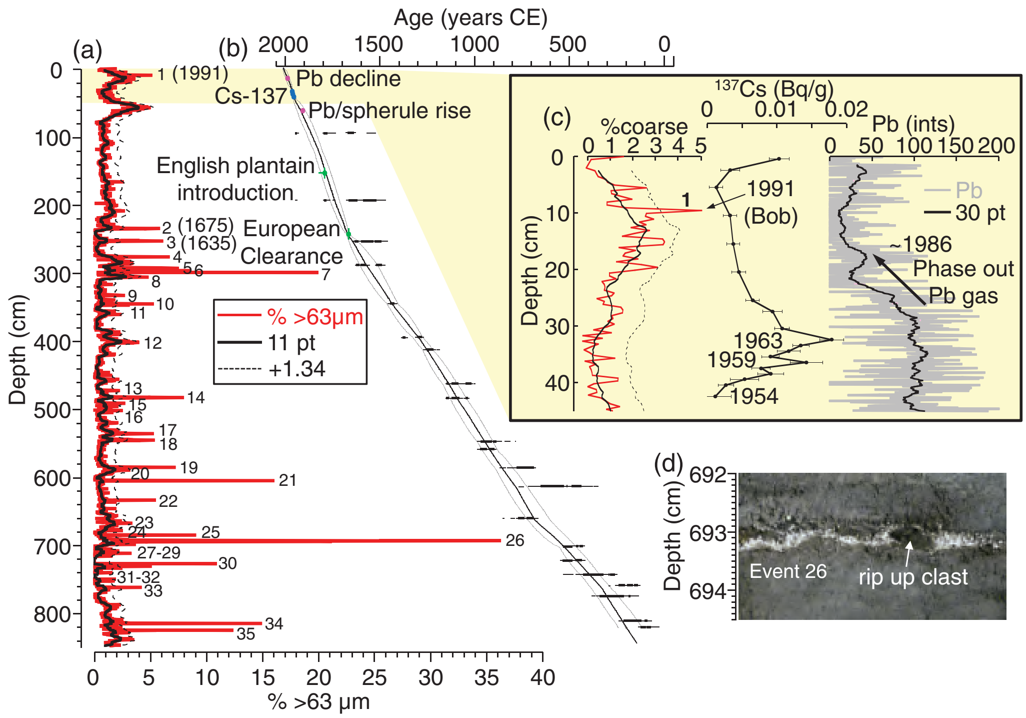


Figure 2. Overwash event record from Salt Pond, MA. (a) Percent sand fraction (>63 μm) results (red) from core collected from the deepest part of the basin (SP2) with 11-point running mean filter that excludes coarse fraction values exceeding 5% (black). Dashed line is event threshold of >1.34%. Events are numbered 1–35. (b) Age model derived from radiocarbon (2σ ranges thin bars and 1σ ranges thick bars; 95% confidence bounds shown around mean age; Supporting Information Table S1) and stratigraphic dates, including pollen evidence (green) of European land clearance and agriculture in the late seventeenth century and the introduction of English plantain in the early nineteenth century (Supporting Information Figure S5). ^{137}Cs activity provides ages related to nuclear weapons testing in the middle twentieth century (blue). Pb pollution and opaque spherules provide ages related to industrialization (purple). (c) Blow up of the upper 45 cm of percent sand fraction data with ^{137}Cs and bulk Pb pollution chrono-horizons. The event bed attributed to Hurricane Bob is noted. This portion of the record is replicated in core SP6 (Supporting Information Figure S6). (d) Photograph of event bed 26 at 693 cm.

adjacent to large peaks in coarse fraction that in other parts of our record would be well above our event threshold of 1.34%.

2.5. Determining Event Frequency

We follow the approach by *Lane et al*. [2011] and generate an event frequency per 100 years for the SP2 record by applying a sliding 162 year window, the same duration of the historic best-track data set, through the event data. This facilitates comparisons between storm frequency in the instrumental record (1851–2013 C.E.) and event frequency in the paleorecord. Moving averages of event frequency were obtained using the average occurrence rate of significant coarse fraction anomalies per year within the sliding 162 year window.

The frequency plot for Mullet Pond follows that originally published by *Lane et al*. [2011]. However, the frequency plot for Spring Creek Pond [*Brandon et al.*, 2013] was created by applying a D90 threshold of 325 μm for defining intense-hurricane event beds (roughly equivalent to modeled category 3 intensity) and then applying the 162 year moving window as above. For the Laguna Playa Grande record from Vieques (LPG4) [*Donnelly and Woodruff*, 2007], a 31-point moving average was subtracted from the data to filter out long-term variations in mean grain size and then we applied a threshold of 12 μm for event beds. A moving average of event frequency was obtained using the average occurrence rate of significant coarse fraction anomalies per year within the sliding 162 year window as above. For the Lighthouse Bluehole [*Denommee et al.*, 2014] frequency plot we converted the events per 20 year data provided by Denommee et al. to events per century with a 162 year moving average.

2.6. Calculating Expected Frequency Based on Observational Record

To calculate an estimate of modern return rate (λ) for the Salt Pond Site we used the frequency of category 2 or greater hurricanes in the northeastern United States over the past 162 years (the interval of the NOAA Best Track dataset), which is the approximate threshold event based on historic event bed deposition (see results below). Seven events with sustained winds over 43 m/s (≥CAT 2 intensity) made landfall in southern New England since 1851 C.E. (Supporting Information Figure S4) resulting in a probability of 4 storms per century for the entire southern New England coast. The maximum impact from surge and waves is typically felt within the radius of maximum winds to the east of the storm track in New England as the storms translate northwards. As a result we divide the 325 km of southern New England by the mean radius of maximum winds at this latitude of 65 km [*Boldt et al.*, 2010; *Kossin et al.*, 2007] and divide the probability of a category 2 or greater landfall in southern New England by that value. Thus, $\lambda = ([7\ \text{events}/162\ \text{years}]*100)/[325\ \text{km}/65\ \text{km}] = 0.9$ events per century/65 km of the southern New England coast. Implicit in this estimate is the assumption that the probability of a category 2 or greater hurricane strike is equal along the entire southern New England coast.

As a result of the stochastic nature of hurricane landfalls, the number of storms impacting a specific site might vary from one sampled period to the next even if the statistics of Atlantic hurricanes were stationary through time. Thus, some portion of the variability in local flooding frequency may be due to chance alone, while the remainder may have resulted from actual changes in hurricane climate. We calculate the cumulative Poisson probability (P) of equaling or exceeding 0, 1, 2, 3, 4, and 5 events per century (X) given the expected probability (λ):

$$P(x, \lambda) = 1 - \sum_{k=0}^{x} \frac{e^{-\lambda}\lambda^k}{k!}$$

3. Results and Discussion

3.1. Salt Pond Reconstruction

3.1.1. Event Beds and Chronology

The 5.5 m deep basin in the northeast corner of Salt Pond, about 400 m from the current shoreline (Figure 1), has rapidly filled with sediment over the last two millennia (sedimentation rates between 4 and 7 mm/year; Figure 2). Core SP2 is 840 cm long and numerous quartz sand (>63 μm) event beds punctuate the otherwise fine-grained, organic-rich sediments (Figures 2a and 2d). Salinity stratification (Supporting Information Figure S2) results in anoxic bottom water preserving annual laminations throughout much of the archive. As described above, we define event beds as those coarse fraction peaks that exceed 99% of the cumulative distribution of coarse fraction over the historical interval (last 393 years), or >1.34% coarse fraction (Figure 2a). Based on this criterion we identify 35 event beds in core SP2 (Figure 2a).

A combination of radiocarbon dates on plant macrofossils and chronostratigraphic markers provide age control for core SP2 (Figure 2b). We interpret the increase in total herbs and the appearance of cereal rye (*Secale cereal* L.) pollen in the record at 235–236 cm in SP2 as the onset of European land clearance and agriculture in the late 1660s and 1670s [*Geoffrey*, 1930] (Figure 2b; Supporting Information Figure S5). The appearance of English plantain (*Plantago lanceolata* L.) pollen at 144–145 cm provides evidence of the introduction of this non-native species in the first half of the nineteenth century (1800–1850 C.E.) [*Clark and Patterson*, 1985]. The dramatic increase in opaque spherules at 59–60 cm (Figure 2b; Supporting Information Figure S5) is coincident with the rise in lead pollution and likely dates to the industrial revolution in the late 19th and early 20th centuries [*Donnelly et al.*, 2001]. ^{137}Cs activity provides dated markers associated with nuclear weapon testing [*Dunphy and Dibb*, 1994] with the initial rise at 39.5 cm dating to 1954 C.E., and peaks in activity at 36.5 and 32.5 cm dating to 1959 and 1963 C.E., respectively (Figure 2c). The decrease in lead levels that occurs between approximately 28 and 18 cm (Figure 2c) is diagnostic of reduced lead accumulation related to its removal from gasoline in the 1970s and 1980s [*Wu and Boyle*, 1997].

3.1.2. Event Attribution

The most recently deposited coarse-grained event bed (#1) occurs at about 10 cm depth and based on our age model dates to between 1982 and 2005 C.E. at 95% confidence (Figures 2b and 2c; Supporting Information Figure S6). This event bed was likely deposited by Hurricane Bob in 1991 C.E., the only category 2 or greater storm since 1851 C.E. [*Landsea et al.*, 2004] to pass within 100 km to the west of Falmouth (Supporting Information Figure S4). Hurricane Bob passed about 60 km west of Salt Pond (Figure 1b) with maximum sustained winds of 45 m/s, causing a storm tide approximately 1.6 m above MHW in Falmouth [*Boldt et al.*, 2010] and maximum offshore wave heights of approximately 4 m [*Cheung et al.*, 2007]. Washover fans across the western portion of the barrier fronting Salt Pond evident in aerial photographs taken immediately following Hurricane Bob indicate overtopping by the combination of surge and wave runup (Supporting Information Figure S7). Historically, severe winter storms and tropical cyclones that either pass offshore or make landfall to the east have failed to produce storm tides capable of overtopping the barrier fronting Salt Pond (see Supporting Information) [*Boldt et al.*, 2010]. Conversely, hurricanes that made landfall further west than Bob in the middle part of the twentieth century (e.g., 1938, 1944 C.E.) produced storm tides capable of overtopping the Salt Pond barrier [*Boldt et al.*, 2010], yet these events did not leave coarse event bed in Salt Pond. The lack of distinct event beds related to these more distal hurricane strikes suggests that local wind speeds in Falmouth were insufficient to generate waves large enough to transport sediment the more than 400 m to the deep basin in the northeast corner of Salt Pond. For example, 1-min sustained wind speeds associated with the 1938 Hurricane at Edgartown, 20 km southeast of Salt Pond, were only 33 m/s [*Brown*, 1939] (using a conversion factor of 1.07 from 5-min to 1-min sustained winds). Similarly, the closest maximum sustained wind observation for the 1944 hurricane of 27 m/s comes from Nantucket (57 km to the southeast of Salt Pond) [*Sumner*, 1944]. In contrast, maximum sustained winds in Falmouth during Hurricane Bob were measured at 38 m/s, with gusts reaching 56 m/s [*Mayfield*, 1991].

Deeper in core SP2, two event beds at 253 and 235 cm depth, date to 1614–1660 C.E. (mean = 1639 C.E.) and 1668–1695 C.E. (mean = 1679 C.E.) at 95% confidence, respectively (Supporting Information Figure S5). These event beds were most likely deposited by well-documented severe hurricane strikes in 1635 and 1675 C.E. [*Ludlum*, 1963]. The first of these is the Great Colonial Hurricane of 25 August 1635, which passed across southeastern New England and caused widespread damage consistent with a category 3 hurricane [*Boose et al.*, 2001]. Hindcast surge modeling indicates surge likely reached about 3.5 m at Salt Pond [*Boldt et al.*, 2010]. Both the track and impact of the 1675 (7 September) hurricane were similar to the Great Colonial Hurricane of 1635 in southeastern New England [*Ludlum*, 1963].

The hurricane-induced event beds preserved in the historic sediments at Salt Pond indicate a similar frequency of severe hurricane impacts compared to those derived from our approach using the Best Track data that we discuss above. Specifically, three events in 393 years (1620–2013 C.E.) yields a frequency of 0.8 events per century compared to a value of 0.9 events per century derived from the approach using category 2 or stronger storms making landfall in all of southern New England since 1851 C.E. and dividing by the mean radius of maximum winds.

3.1.3. Changes in Event Frequency

The Salt Pond record indicates considerable changes in the frequency of event beds over the last 2000 years, with historically unprecedented intervals of event-bed deposition. A total of 35 event layers were deposited over the last 2000 years (Figures 2a and 3a); the highest frequencies were reached at 1420–1675 C.E. (10 event beds, #2–11) and 150–1150 C.E. (23 event beds, #13–35). Assuming hurricane landfall occurrence follows a Poisson process we can estimate the probability of exceeding the number of events expected by random chance alone. For example, using 0.9 events per century as the expected rate (λ) (derived from the 162 year NOAA Best Track Dataset, Supporting Information Figure S4), the probability of experiencing three or more events in any one century is 0.06 (6%). Several intervals in the 4–7th centuries, eleventh century, and 15th to early 17th centuries exceed this frequency (Figure 3a). The probability of experiencing one or more events in any one century is 0.6 (60%). However, the probability of experiencing 10 consecutive centuries with one or more events per century, as recorded at Salt Pond between ca. 150 and 1150 C.E., is quite low at 0.006 (0.6%). Similarly, the probability of experiencing two or more events in two consecutive centuries, as reconstructed in Salt Pond between ca. 1440 and

1640 C.E. (Figure 3a), is only 0.04 (4%), and in fact event bed frequency exceeds three events per century through most of this interval. Hence, compared to modern event frequencies in the region, significant portions of the 2000 year Salt Pond record exceed what would be expected based on random event occurrence alone.

3.1.4. Event Intensity

Given that sedimentary archives only preserve evidence of events that exceed the local intensity threshold necessary to transport and deposit coarse grained material to sediment depo-centers, archives such as Salt Pond are likely to record the passage of more intense storms. As a result, the temporal patterns in event bed deposition may reflect changes in the frequency of only the more intense storms that are capable of producing event beds. The populations of storms that can locally produce event deposits likely have varying characteristics (e.g., track, intensity, size) [*Lin et al.*, 2014]. In the case of Salt Pond, less intense historical events (minor tropical cyclones, extratropical storms, and more distal intense storms) have been unable to generate local surge, wave heights and currents sufficient to transport sand-sized material more than 400 m from the barrier to the location of SP2. The last 350 years of sediment accumulation at Salt Pond indicates that only relatively intense hurricanes making a close landfall (~100 km) to the west of the site have left event beds. Given modest increases in sea level over the last 2000 years in the region [*Donnelly*, 1998] (~2 m), the barrier fronting Salt Pond has likely transgressed landward with time, with recent historical shoreline retreat rates of approximately 10 m per century [*Thieler et al*., 2013]. As a result of this landward barrier translation, older event beds recorded in SP2 were likely transported greater distances than recent ones, which may point to even greater local intensities for prehistoric events relative to Hurricane Bob in 1991 C.E.

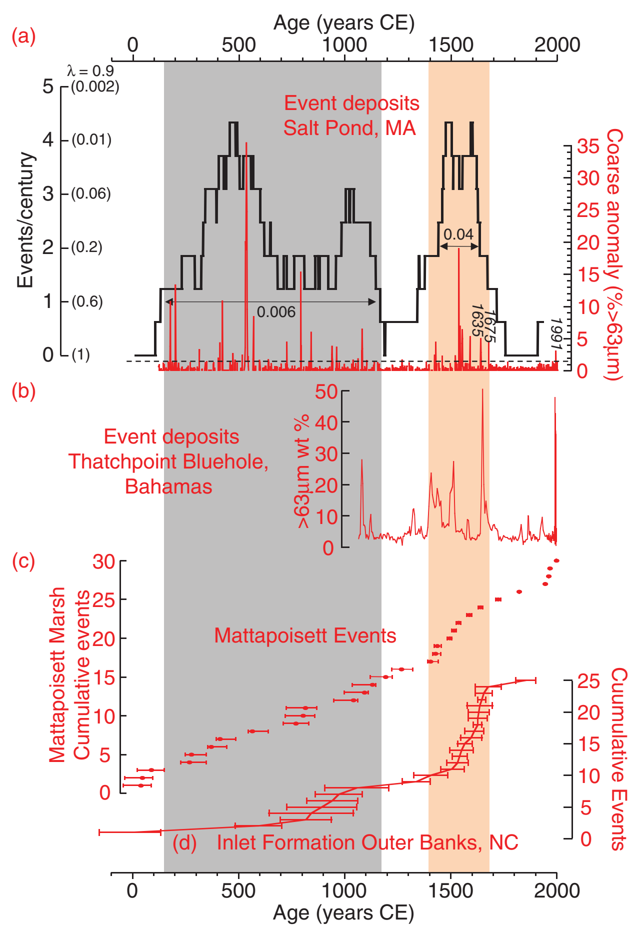


Figure 3. Comparison of hurricane proxy records from North American east coast. (a) Coarse anomaly plot from Salt Pond with event bed threshold of 1.34% coarse shown as dashed line. Historical hurricane strikes attributed to event beds are noted. Gray is event frequency with associated Poisson probabilities of occurrence assuming 0.9 events per century (i.e., modern climatology). Arrows are continuous centuries with more than 1 event per century and 2 events per century and their associated probabilities under modern climatology. (b) Event beds from a sediment core from Thatchpoint blue hole in The Bahamas [*van Hengstum et al.*, 2013]. (c) Cumulative event frequency of overwash events preserved in Mattapoisett Marsh, MA [*Boldt et al.*, 2010]. Mattapoisett Marsh is a backbarrier salt marsh 18 km to the northwest of Salt Pond. (d) Cumulative frequency plot of inlet formation from the Outer Banks of NC [*Mallinson et al.*, 2011]. Shading is intervals (150–1150 C.E. and 1400–1675 C.E.) when Salt Pond records heightened intense-hurricane–related event beds.

Out of the 32 prehistoric event beds 12 beds contain more coarse sediment than that deposited by the Great Colonial Hurricane in 1635 C.E. (event bed #3), despite likely being transported a greater distance due to barrier transgression related to sea-level rise. The largest coarse anomaly peak occurs at 693 cm (event bed #26, Figure 2) and dates to ca. 540 C.E.. A rip-up clast of fine-grained organic sediment incorporated in the ca. 540 C.E. quartz sand deposit further attests to the layers origin from a high-energy event (Figure 2d). While the amount of coarse fraction transported is only one metric for ascertaining the local intensity of an event [*Brandon et al.*, 2013; *Woodruff et al.*, 2008b], these large coarse fraction peaks suggest that the competence of local event driven waves and currents to transport sand-sized particles was greater during recent prehistory than experienced over the last ca. 400 years. This implies that many of the prehistoric hurricanes may have locally been more intense than those impacting the region historically.

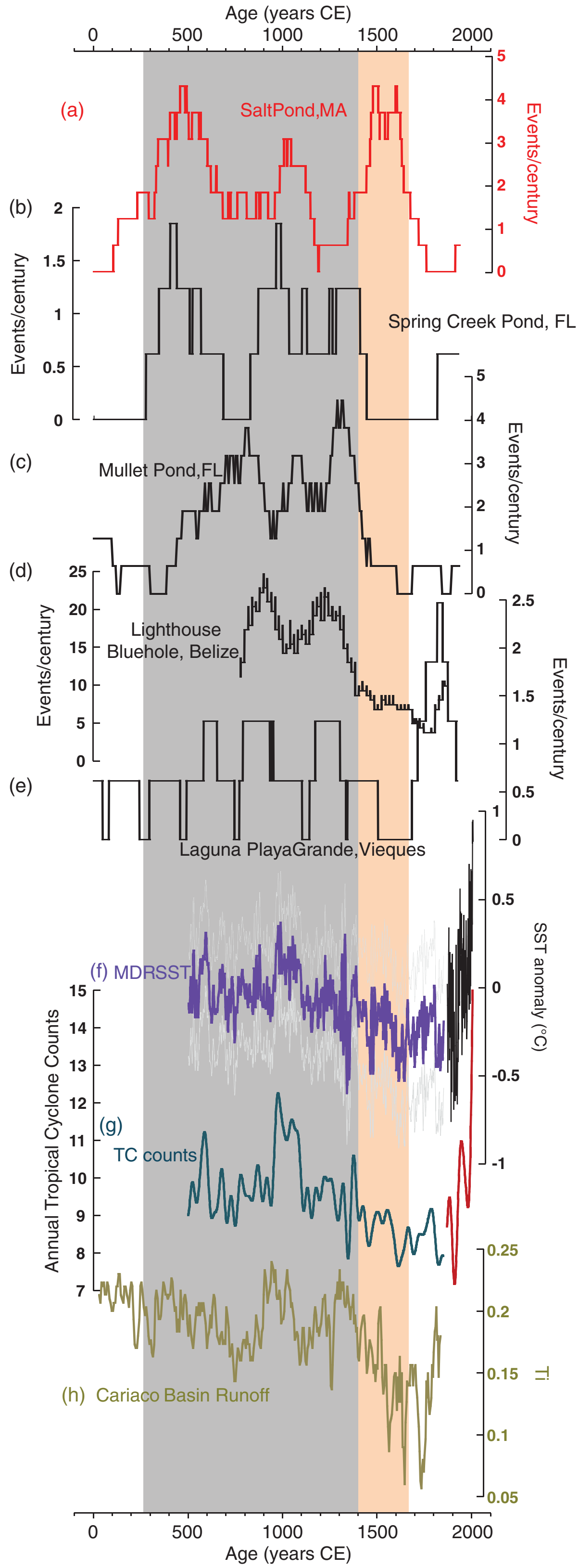
3.2. Regional Patterns

While the Salt Pond record provides only a local archive of intense-hurricane occurrence, basin-wide, or regional changes in hurricane climate can potentially be inferred by examining reconstructions from different regions [*Kozar et al.*, 2013]. One of the most active intervals at Salt Pond consists of 10 event beds between 1420 and 1675 C.E. (Figure 3a), with five of these events occurring between 1500 and 1600 C.E. Several additional lines of evidence suggest that the North American east coast (hereafter east coast) experienced heightened intense-hurricane activity at this time. Reconstructions of hurricane-induced event beds from Thatchpoint Bluehole in the Bahamas [*van Hengstum et al.*, 2013] and Mattapoisett Marsh, MA [*Boldt et al.*, 2010] reveal similar sequences of event beds attributed to hurricanes over the last millennium, with the most event beds between 1400 and 1675 C.E. (Figures 3b and 3c). Further, increased frequency of inlet formation along the Outer Banks of North Carolina [*Mallinson et al.*, 2011] (Figure 3d) and extensive erosion events in Connecticut salt marshes [*van de Plassche et al.*, 2006] between 1400 and 1675 C.E. also point to increased intense storminess.

The strong correspondence between event beds at Thatchpoint Bluehole in The Bahamas and Salt Pond further supports that the event beds at Salt Pond are related to hurricanes. Unfortunately, the record at Thatchpoint currently only extends back 1000 years, but the two events there that date to close to 1100 C.E. appear to correspond to the very end of the earlier active interval at Salt Pond (Figure 3). Mattapoisett Marsh [*Boldt et al.*, 2010] provides the closest confirmation of the period of heightened activity recorded at Salt Pond, 18 km to the southeast. Though a much lower resolution archive than Salt Pond, Mattapoisett Marsh likely records many of the same hurricane events as Salt Pond, including a cluster of eight events between 1400 and 1675 C.E. (Figure 3). In the historical period, event beds associated with hurricanes in 1991 C.E. and 1635 C.E. are recorded at both locations, unlike Salt Pond to the southeast, however, Mattapoisett Marsh also records the series of hurricane strikes that made landfall further west in Long Island NY in the mid-twentieth century (1938, 1954 – Carol, 1960 – Donna, 1815, 1727 C.E.). Given their close proximity and the overlapping ages of event beds at both sites, many of the same prehistoric events recorded at Salt Pond are likely also present at Mattapoisett Marsh. Similar to the historical interval, however, Mattapoisett Marsh also likely records some hurricanes making landfall further west.

Increased frequency of barrier island breaching along the Outer Banks of North Carolina provides further evidence of enhanced storminess along the east coast between 1400 and 1675 C.E. [*Mallinson et al.*, 2011] (Figure 3d). At least 15 barrier-beach breaches occurred in this interval, which is in stark contrast to the preceding and following two centuries when only one or two breaches occurred. Earlier, at least seven inlets were cut in the Outer Banks between 500 and 1100 C.E. when Salt Pond also showed heightened event bed deposition. Only one inlet breach was documented prior to 500 C.E., but the low preservation potential of older inlets as the barriers transgress landward with sea-level rise likely limited the length of this archive.

Taken together, the four different reconstructions provide evidence of a synchronous interval of heightened intense-hurricane activity along the east coast between 1400 and 1675 C.E. However, when one compares these records to reconstructions from the Gulf of Mexico (GoM) (Figures 4b and 4c) and Caribbean (Figures 4d and 4e) a more complex pattern emerges. For example, the interval between 1400 and 1675 C.E. appears to be one of relatively low intense-hurricane activity in the GoM and Caribbean, as reconstructions from Vieques [*Donnelly and Woodruff*, 2007], Belize [*Denommee et al.*, 2014], and Apalachee Bay, FL [*Brandon et al.*, 2013; *Lane et al.*, 2011] all preserve relatively few event beds at this time (Figures 4b – 4e). Thus, the interval of elevated intense-hurricane activity between 1400 and 1675 C.E. appears to have been restricted to the east coast.



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The earlier period of heightened event bed deposition at Salt Pond from 150 to 1150 C.E. is one where other overwash proxy records from the western North Atlantic also reveal frequent event bed deposition, though the timing of peaks in activity sometimes vary (Figure 4). These records suggest that the entire North Atlantic basin experienced more frequent intense-hurricane strikes over much of this interval. However, the reconstructions from the Caribbean and GoM all remain active until about 1400 C.E., while the east coast is quiescent between 1150 and 1400 C.E.. This suggests that, either storms failed to track up the east coast and/or conditions were not favorable for intense hurricanes to maintain their strength off the east coast at this time.

For example, an archive of the coarsest grained event deposits from Spring Creek Pond on the Florida Panhandle [*Brandon et al.*, 2013] indicates heightened intense-hurricane frequency between 250 and 1400 C.E., save a short interruption in the eighth century (Figure 4b). Large coarse grained deposits from nearby Mullet Pond [*Lane et al.*, 2011] are also more frequent between about 400 and 1400 C.E. (Figure 4c). A reconstruction of hurricane event beds from Lighthouse Bluehole in the western Caribbean [*Denommee et al.*, 2014] dating back to 700 C.E. also indicates higher incidence of events between 750 and 1400 C.E. relative to the last 600 years (Figure 4). Even the lower resolution Laguna Playa Grande record [*Donnelly and Woodruff*, 2007] from Vieques, Puerto Rico (Figure 4e), where storm undercounting is a significant issue due to the slow prehistoric sedimentation rate there (see discussion in [*Woodruff et al.*, 2008a]), suggests heightened intense-hurricane activity between 250 and 1400 C.E.

Like the reconstructions from Spring Creek Pond and Mullet Pond (Figure 4), the Salt Pond sediments record few intense events over the last century. Only one event is recorded at Salt Pond (Bob in 1991) during this time, however, the lack of recent event beds may simply reflect that Falmouth was relatively fortunate in the twentieth century and largely avoided severe hurricane impacts. In contrast, were Salt Pond located a short distance to the west (like Mattapoisett Marsh), the site would have more severely experienced three hurricane strikes in the middle of the twentieth century (e.g., 1938, 1954, and 1960) that could potentially have left event beds. Conversely, the reconstructions from Belize (Figure 4d), Vieques (Figure 4e), and The Bahamas (Figure 3b) record recent increases in event bed frequency, but interestingly the increase at Vieques appears to predate the twentieth century. With the exception of Vieques, where the identification of more event beds in the historical interval may be related to an increase in sedimentation rate [*Woodruff et al.*, 2008a], the remaining reconstructions examined here suggest the early portion of the historic interval (ca. 1700–1900 C.E.) was relatively quiescent with respect to intense hurricanes when compared to the last two millennia.

3.3. Climatic Forcing

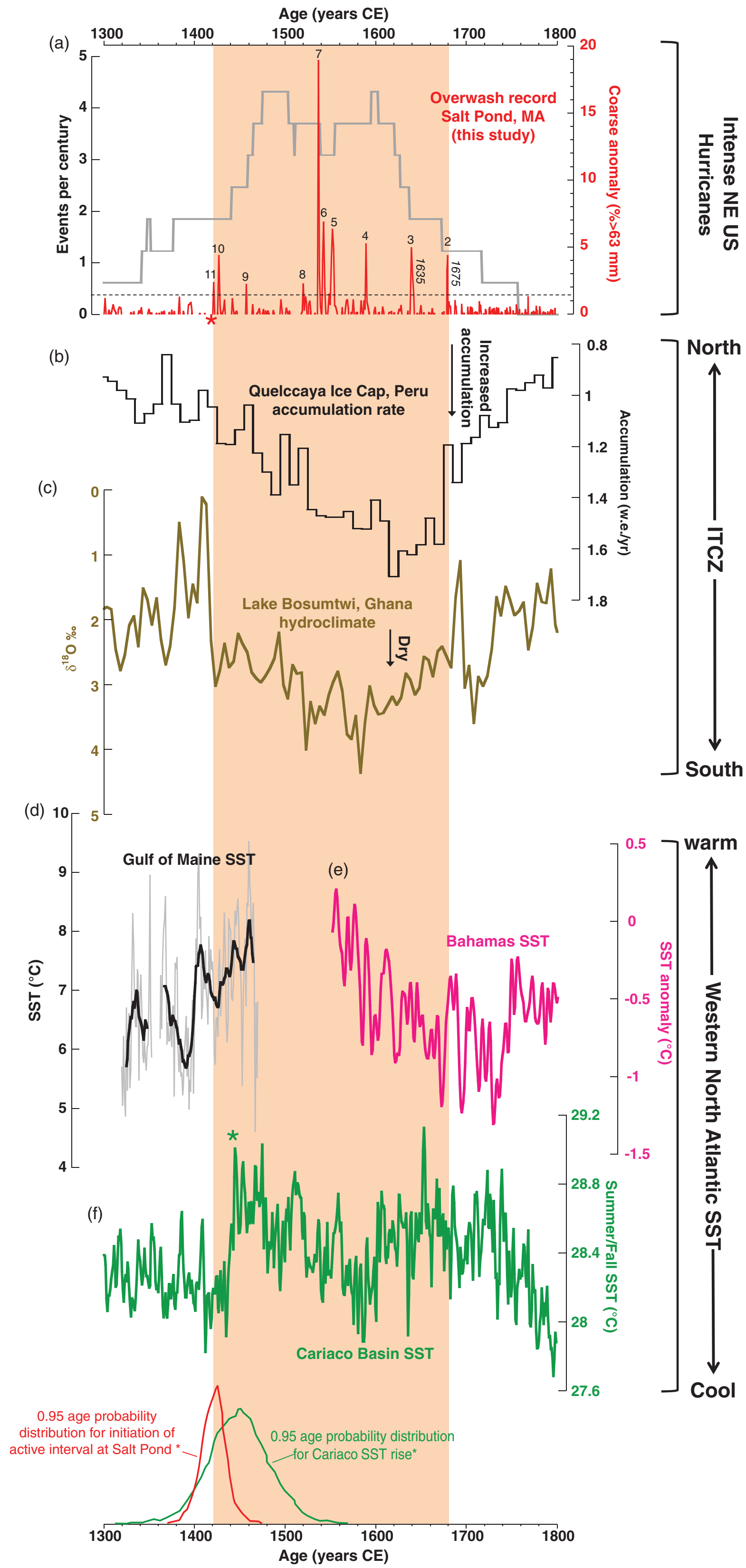
As described above, available high-resolution and well-dated reconstructions from the western North Atlantic reveal coherent patterns of intense-hurricane activity on multi-centennial time scales over the last 2000 years. While some geographic variability exists in the timing of peaks in activity, most reconstructions indicate that much of the first millennium C.E. was more active than that experienced historically. The interval between 1150 and 1400 C.E. is one in which only the Caribbean and GoM see increased activity, while the east coast is inactive. The reconstructions from the Caribbean and GoM all see a dramatic decrease in event bed frequency around 1400 C.E., when the east coast becomes active until the late seventeenth century.

Warm SST in the MDR of the tropical North Atlantic, coincident with a more northerly position of the ITCZ, promotes cyclogenesis and potential tropical cyclone intensity in the MDR by increasing low-level vorticity, and decreasing vertical wind shear and sea-level pressure [*Kossin and Vimont*, 2007]. The relationship between Atlantic hurricane activity and warm MDR SST and northerly ITCZ position has been documented on inter-annual [*Kossin and Vimont*, 2007] (Supporting Information Figure S8) to multi-decadal timescales [*Goldenberg et al.*, 2001; *Zhang and Delworth*, 2006]. The location of the ITCZ also impacts precipitation patterns across the tropics (Supporting Information Figure S9), explaining why twentieth century rainfall in the Sahel region of Africa correlates well with hurricane activity [*Gray*, 1990]. Similar centennial-scale shifts in ITCZ position and MDR SST may explain the strong anti-correlation observed between Ecuadoran extreme precipitation [*Moy et al.*, 2002] with the coarsely resolved intense-hurricane record from Vieques, Puerto Rico over the last five millennia [*Donnelly and Woodruff*, 2007].

While high-resolution proxy reconstructions of SST directly from the MDR (Figure 1a) are limited by slow rates of pelagic sedimentation and the absence of suitable corals, statistical reconstructions based on networks of proxy data are available. The Mann et al. (hereafter M09) reconstruction of MDR SST is shown in Figure 4f and documents decadal to centennial scale variations in MDR SST over the last 1500 years [*Mann et al.*, 2009].

In modern climate, La Niña conditions typically favor increased tropical cyclone genesis in the MDR [*Kossin et al.*, 2010] and indices of MDR SST and El Niño/Southern Oscillation are good predictors of historical Atlantic hurricane trends [*Kozar et al.*, 2012]. Statistical modeling of basin-wide activity over the last 1500 years by M09, based primarily on MDR SST and Niño3 temperatures, predicts relatively higher levels of basin-wide hurricane activity between 500 and 1400 C.E. (Figure 4g), when MDR SST is relatively warm. Consistent with the M09 model result, the coastal sediment records indicate heightened

Figure 4. Comparison of Salt Pond reconstruction with Caribbean and GoM hurricane proxy records, reconstructed MDR SST, modeled hurricane activity, and Cariaco Basin runoff. (a) Event bed frequency at Salt Pond, MA (as in Figure 3). (b) Intense-hurricane event bed frequency from Spring Creek Pond, FL [*Brandon et al.*, 2013]. (c) Intense-hurricane event bed frequency from Mullet Pond, FL [*Lane et al.*, 2011]. (d) Event bed frequency from Lighthouse Bluehole, Belize [*Denommee et al.*, 2014]. (e) Event bed frequency at Laguna Playa Grande, Vieques [*Donnelly and Woodruff*, 2007]. (f) MDR SST anomaly reconstruction (purple) with 95% uncertainty envelope (gray) [*Mann et al.*, 2009]. NOAA ERSST MDR SST data for 1870–2006 (black) [*Mann et al.*, 2009]. (g) Smoothed modern annual Atlantic tropical cyclone counts (red) and statistical model estimates of basin-wide tropical cyclone counts from 500–1850 C.E. (blue) [*Mann et al.*, 2009]. (h) Ti record from Cariaco Basin sediments thought to reflect changes in terrestrial runoff and the position of the ITCZ [*Haug et al.*, 2001]. Gray shading is interval between 250 and 1150 C.E. when all sites have heightened intense-hurricane–related event beds. Diagonal gray shading is interval between 1150 and 1400 C.E. when Caribbean and GoM sites have heightened intense-hurricane–related event beds and the North American east coast is inactive. Beige shading is interval between 1400 and 1675 C.E. when only the North American east coast is active (Figure 3).



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intense-hurricane activity across much of the western North Atlantic basin between ca. 250 and 1400 C.E. (Figures 4b–4e). ITCZ proxy records also show very similar variability over this time as well. For example, sedimentary Ti influx into the Cariaco Basin has been interpreted as a terrestrial runoff proxy and used to infer past changes in ITCZ position [*Haug et al.*, 2001] (Figure 4h). Higher levels of Ti are thought to represent more terrestrial runoff from increased precipitation in Venezuela from a more northerly mean position of the ITCZ. The Cariaco Basin Ti record closely mirrors the M09 MDR SST reconstruction, which provides further support for a close correspondence between MDR SST and ITCZ position over the last few millennia.

The lack of evidence of intense-hurricane activity along the east coast between 1150 and 1400 C.E., when sites in the Caribbean and GoM remain active (Figure 4), suggests that the trajectory of storms may have shifted away from this region. Alternatively or concurrently, conditions may have been unfavorable for hurricanes to make landfalls at sufficient intensities to leave a geological record of their occurrence. In fact, relatively cool SST off the east coast between 1150 and 1400 C.E. [*Cronin et al.*, 2010; *Keigwin*, 1996; *Wanamaker et al.*, 2008] may have limited hurricane potential intensity, reducing intense-hurricane activity there while the Caribbean and GoM remained active. Alternatively, or in combination with relatively cool SSTs off the east coast, more southerly storm genesis and/or more westerly storm trajectories may have limited intense-hurricane activity along the east coast at this time.

The reorganization of atmospheric and oceanic circulation at the transition from the Medieval Climate Anomaly to the Little Ice Age [*Haug et al.*, 2001; *Kreutz et al.*, 1997], around 1400 C.E., brought cooler MDR SST and a more southerly ITCZ (Figure 4h), resulting in conditions much less favorable for intense-hurricane activity generated in the MDR. Correspondingly, the M09 statistical modeling of basin-wide activity predicts relatively quiescent conditions should have prevailed (Figure 4g) [*Mann et al.*, 2009], and indeed reconstructions from the Caribbean and GoM show a dramatic decrease in event beds at this time. Yet paradoxically, the east coast becomes active at this time based on evidence of increased frequency of intense-hurricane landfalls from The Bahamas to New England between 1420 and 1675 C.E. (Figure 3).

Regional oceanic conditions and/or shifting genesis locations may have played an important role in facilitating intense-hurricane activity along the east coast between 1420 and 1675 C.E., when for example 10 events (#2–11) are recorded at Salt Pond (Figure 5a). Hydroclimate proxies from around the tropical Atlantic indicate a significant shift in tropical precipitation that suggest a southward shift in the ITCZ [*Haug et al.*, 2001], at this time, with drought evident in the tropical northern hemisphere [e.g., *Hodell et al.*, 2005; *Shanahan et al.*, 2009] and increased precipitation in the tropical southern hemisphere [e.g., *Bird et al.*, 2011; *Thompson et al.*, 2013]. In the annually constrained archives from Lake Bostumtwi, Ghana [*Shanahan et al.*, 2009] and the Quelccaya Ice Cap, Peru [*Thompson et al*., 2013] the hydroclimate changes consistent with a more southerly ITCZ also initiated close to 1420 C.E. and persisted until the late seventeenth century (Figures 5b and 5c). Examining high-resolution SST reconstructions available from the western North Atlantic margin (Figures 5d–5f) reveals that much of this interval is also one of relatively warm SST along the east coast. A Gulf of Maine reconstruction [*Wanamaker et al.*, 2008] appears to capture the onset of this warm SST anomaly indicating a rapid approximately 2°C increase around 1400 C.E. (Figure 5b), which they attribute to increased influence of the Gulf Stream. However, reservoir age uncertainties currently hamper precisely dating this floating chronology [*Wanamaker et al.*, 2013]. An annually dated Bahamian coral-derived temperature reconstruction dating back to 1550 C.E. [*Saenger et al.*, 2009] captures a warm interval and the subsequent cooling (Figure 5e). Reconstructed summer/fall SSTs from the Cariaco Basin

Figure 5. Climatic drivers of increased east coast intense-hurricane activity between 1400 and 1675 C.E. (a) Salt Pond events and event frequency (same as Figure 3a) for the interval 1300–1800 C.E. Shaded area is interval with ten event beds from 1420 to 1675 C.E. (b) Accumulation rate (decadal average; meters of water equivalent per year (m.w.e./yr)) of the Quelccaya Ice Cap in Peru [*Thompson et al.*, 2013]. (c) δ^{18}O-derived lake level proxy (5 year average) from Lake Bosumtwi in West Africa [*Shanahan et al.*, 2009]. (d) δ^{18}O-based SST reconstruction from three *Arctica islandica* samples from the Gulf of Maine (annual data in gray; 11 year moving average in black) [*Wanamaker et al.*, 2008]. (e) Coral-based SST reconstruction from the Bahamas [*Saenger et al.*, 2009]. (f) Mg/Ca-derived *Globigerinoides ruber* summer/fall SST reconstruction from the Cariaco Basin [*Wurtzel et al.*, 2013]. 95% probability distributions (bottom) for the initiation of the active interval at Salt Pond ca. 1420 C.E. (red) and the rise in summer/fall SST in the Cariaco Basin (green). Asterisks (red for Salt Pond; green for Cariaco Basin) indicate interval that relates to the age probability distribution shown.

[*Wurtzel et al*., 2013] also capture a warm excursion at this time, though here it persists into the eighteenth century (Figure 5f). Comparing the probability distributions (95% confidence) of the onset of the active hurricane interval at Salt Pond with that of the onset of warmer summer/fall SSTs in the Cariaco Basin archive indicates that they may be nearly synchronous within age uncertainties (Figure 5).

SST warming at approximately this time is also evident in more coarsely resolved and poorly dated SST records from the Bermuda Rise [*Keigwin*, 1996] and Chesapeake Bay [*Cronin et al.*, 2010] and coincides with increased transport in the upper 100 m of the Florida Current [*Lund et al.*, 2006]. The combination of increased Florida Current transport and a warm SST anomaly along the east coast could be related to an increase in Atlantic meridional overturning circulation (AMOC) at this time. This potential association of AMOC strengthening and a southerly shift in ITCZ is contrary to some model results, which indicate a southerly migration of the ITCZ is associated with AMOC weakening [*Srokosz et al.*, 2012].

In the modern climate, hurricanes that impact only the east coast develop from prior extratropical disturbances off the southeastern coast of the United States in the subtropical western North Atlantic (i.e., tropical transition) [*McTaggart-Cowan et al.*, 2008]. Therefore, paleoclimate conditions that increased tropical transition cyclogenesis could enhance east coast hurricane activity. For example, the southward shift in the ITCZ (Figures 4h, 5b and 5c) [*Thompson et al.*, 2013; *Shanahan et al.*, 2009] at the onset of the Little Ice Age (ca. 1400–1600 C.E.), which is likely the result of high latitude cooling [*Broccoli et al.*, 2006] and expanding northern hemisphere ice cover [*Chiang and Bitz*, 2005; *Miller et al.*, 2012], could have shifted the track of extratropical disturbances southward, and thus facilitated more hurricane genesis via tropical transition. Examining hurricane genesis with the Atlantic Meridional Mode (AMM), which is an index that captures the interannual variability of the ITCZ and MDR SST (Figure 1a), points to increased hurricane genesis off the southeastern U.S. coast during the most negative phase of AMM (more southerly ITCZ and relatively cool MDR SST) [*Kossin and Vimont*, 2007; *Kossin et al.*, 2010]. In addition, high latitude cooling in combination with the warm SST anomaly in the western North Atlantic would have increased meridional temperature gradients and enhanced atmospheric baroclinicity, which in turn could have increased tropical transition cyclogenesis. Over the period of instrumental data, hurricanes forming via tropical transition in this region do not become as intense as their counterparts that form in the MDR [*McTaggart-Cowan et al.*, 2008], but the warm SST event in the western North Atlantic may have contributed to significant intensification of hurricanes forming off eastern North America during the 15th and 16th centuries.

Compared to the 1500 year model prediction of M09, Atlantic hurricane activity increased significantly over the last century (Figure 4g) in association with warming MDR SST. Most of this increase in hurricane activity occurred in the middle decades of the twentieth century and then the last two decades. However, only Thatchpoint, Bahamas (Figure 3b), Mattapoisett Marsh, MA (Figure 3c), and Lighthouse Bluehole, Belize (Figure 4d) provide evidence of an increase in event bed frequency in the twentieth century. The lack of a coherent pattern of increased hurricane activity across sites may reflect the stochastic nature of landfalling hurricanes and the relatively short interval of warm SST in the MDR. More time in the current regime of relatively warm MDR SST and a greater distribution of sedimentary archives of these events are necessary to better evaluate any recent trends in hurricane activity with sedimentary archives.

4. Conclusions and Implications

Our study reveals that periods of frequent intense-hurricane landfalls that exceeded historical levels occurred over the last 2000 years. Many prehistoric hurricane events beds contain more coarse sediment than historical events, which suggests prehistoric events may have also achieved greater intensity relative to historical hurricanes. As a result, risk assessments based solely on historical evidence may significantly underestimate hurricane threats to coastal communities. Centennial-scale shifts in MDR SST and associated migration of the ITCZ played an important role in driving basin-wide changes in intense-hurricane activity. Persistently warm MDR SST drove heightened levels of intense-hurricane activity across much of the western North Atlantic between ca. 250 and 1400 C.E., however activity along the east coast was suppressed between 1150 and 1400 C.E. A shift in intense-hurricane activity from the Caribbean and GoM to the east coast occurred at the onset of the Little Ice Age (ca. 1400 C.E.). The ensuing interval of heightened intense-hurricane activity confined to the east coast between about 1400 and 1675 C.E. may have been driven by a combination of increased tropical transition cyclogenesis and elevated SSTs off the east coast. While some sediment-based reconstructions point to modest recent increases in hurricane landfalls in the last century when MDR SST has warmed, others like Salt Pond do not. However, the lack of a coherent recent increase in intense-hurricane event beds may simply reflect the stochastic nature of hurricane landfalls and the relatively short period of recent warm MDR SST.

Future anthropogenic warming will likely be focused in the northern hemisphere, and as a result the ITCZ will occupy a more northerly position [*Broecker and Putnam*, 2013], potentially leading to increased hurricane genesis in the MDR [*Kossin and Vimont*, 2007; *Merlis et al.*, 2013]. More cyclogenesis in the MDR will likely also significantly impact influence the intensity of storms impacting the highly populated western North Atlantic margin, as these long-lived storms tend to become more intense. Thus, intervals with historically unprecedented intense-hurricane activity over the past two millennia provide important analogs for evaluating future hurricane risk. AMOC is projected to weaken over the 21st century due in to greenhouse gas warming [Stocker *et al.,* 2013], but natural variability could result in AMOC strengthening at times. Reduced heat transport via AMOC could cool the higher latitude North Atlantic and potentially offset anthropogenic warming and thus limit future intense-hurricane activity off the east coast. Unfortunately, significant uncertainties exist in the future AMOC variability [*Srokosz et al.*, 2012]. From the perspective of the last two millennia, the magnitude of threat of intense-hurricane landfalls along the North American east coast is likely sensitive to SST both in the MDR as well as along the western North Atlantic margin. Our results confirm modern observations [*Emanuel*, 2005; *Goldenberg et al.*, 2001] and theoretical studies [*Emanuel et al.*, 2004] that link increased hurricane activity with intervals of warmer SST, and provide important context for examining projections of future hurricane activity.

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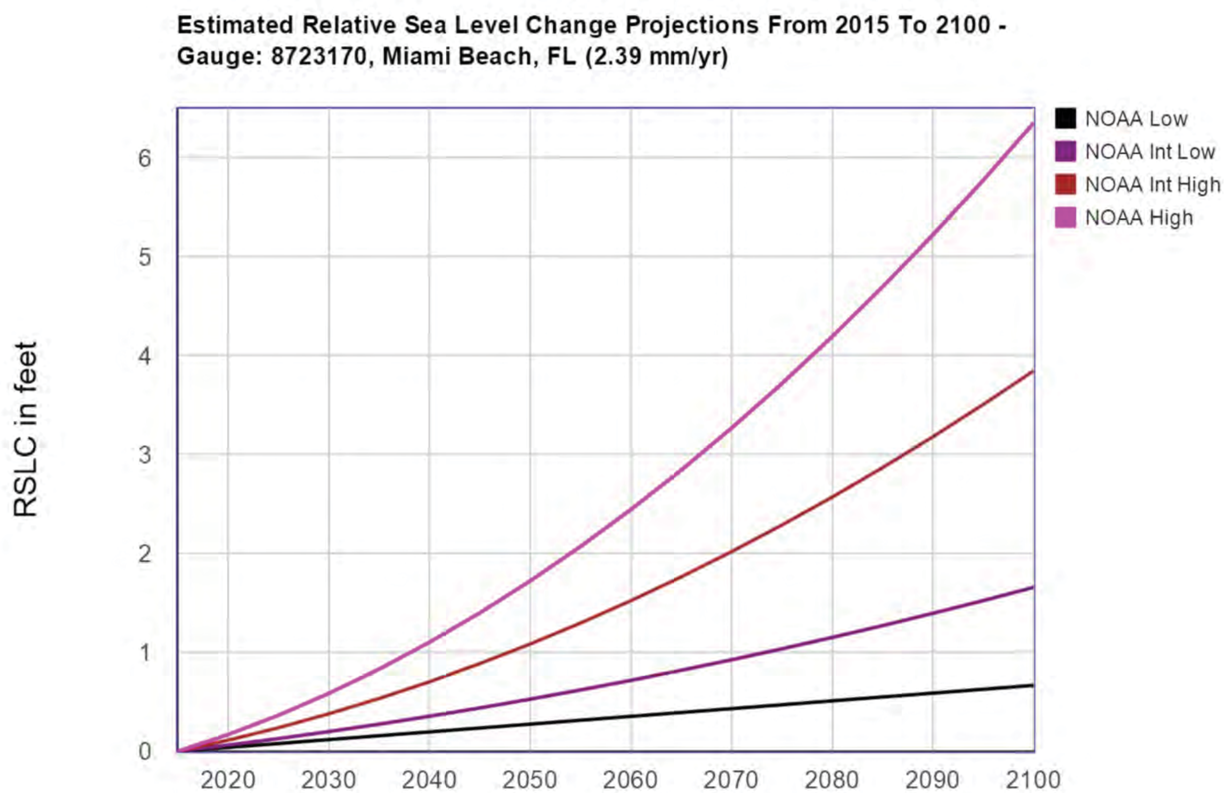

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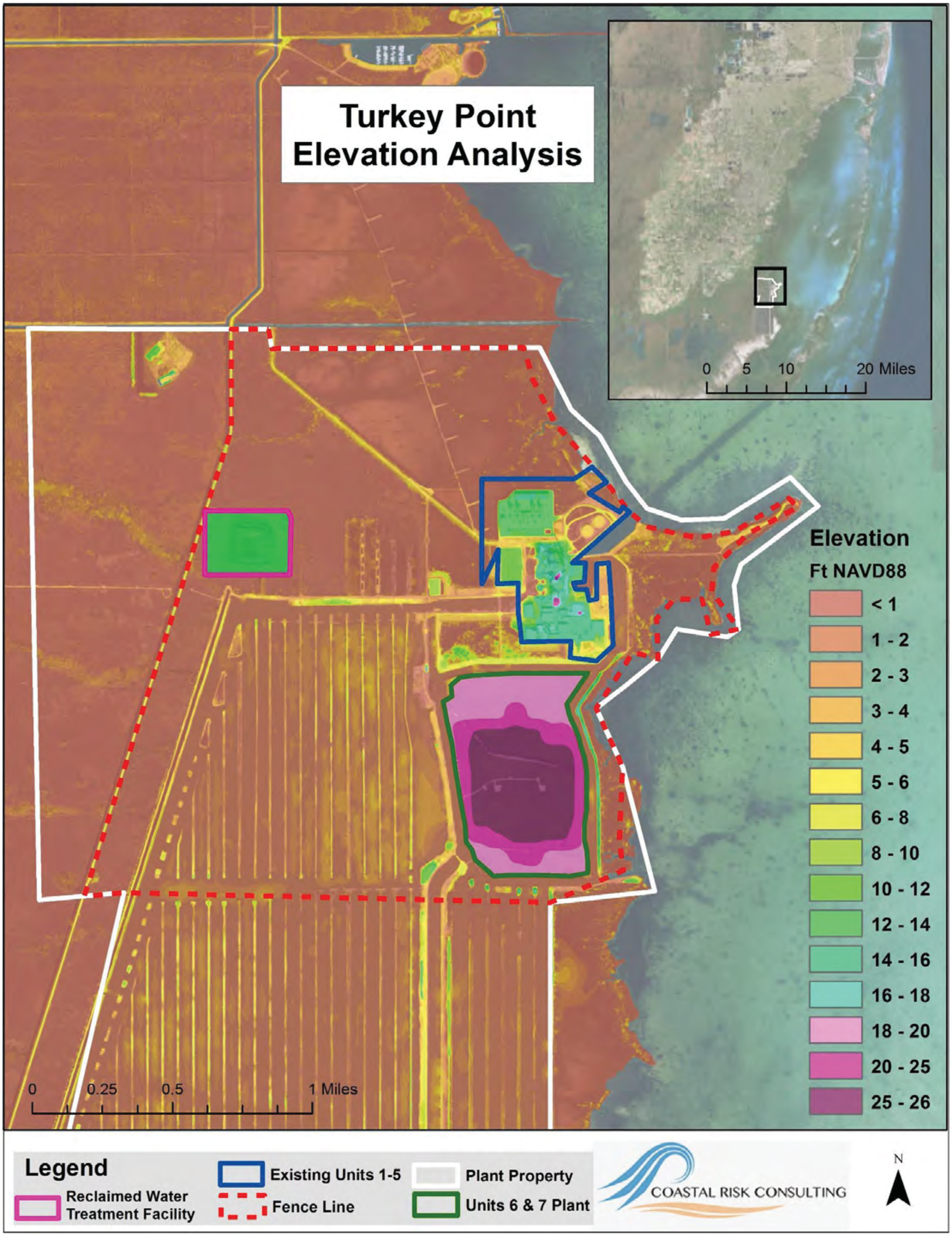
Turkey Point
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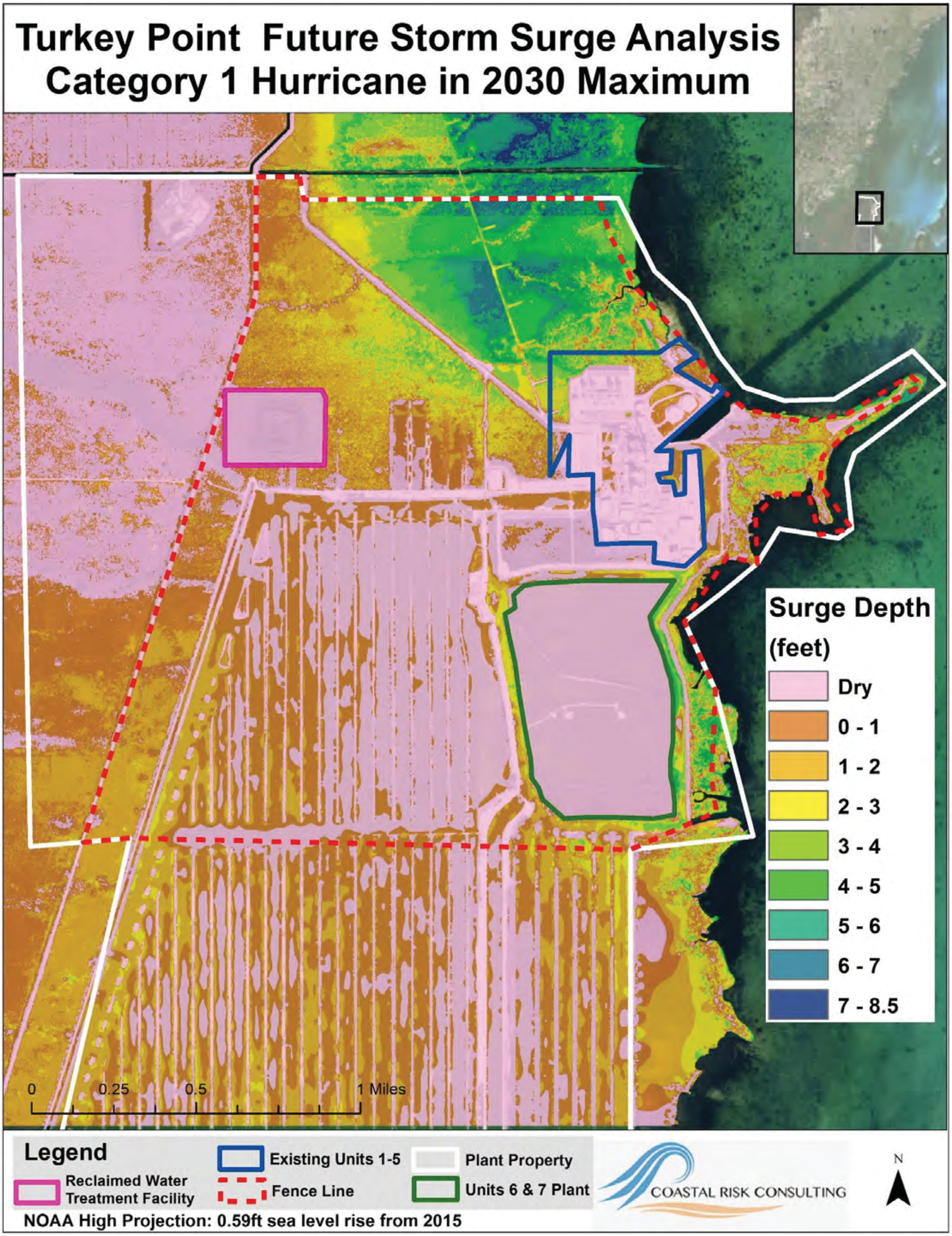
Turkey Point Future Storm Surge Analysis
Category 1 Hurricane in 2030 Maximum
Surge Depth (feet)
Dry
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1 - 2
2 - 3
3 - 4
4 - 5
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6 - 7
7 - 8.5
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1 Miles
Legend
Reclaimed Water Treatment Facility
Existing Units 1-5
Fence Line
Plant Property
Units 6 & 7 Plant
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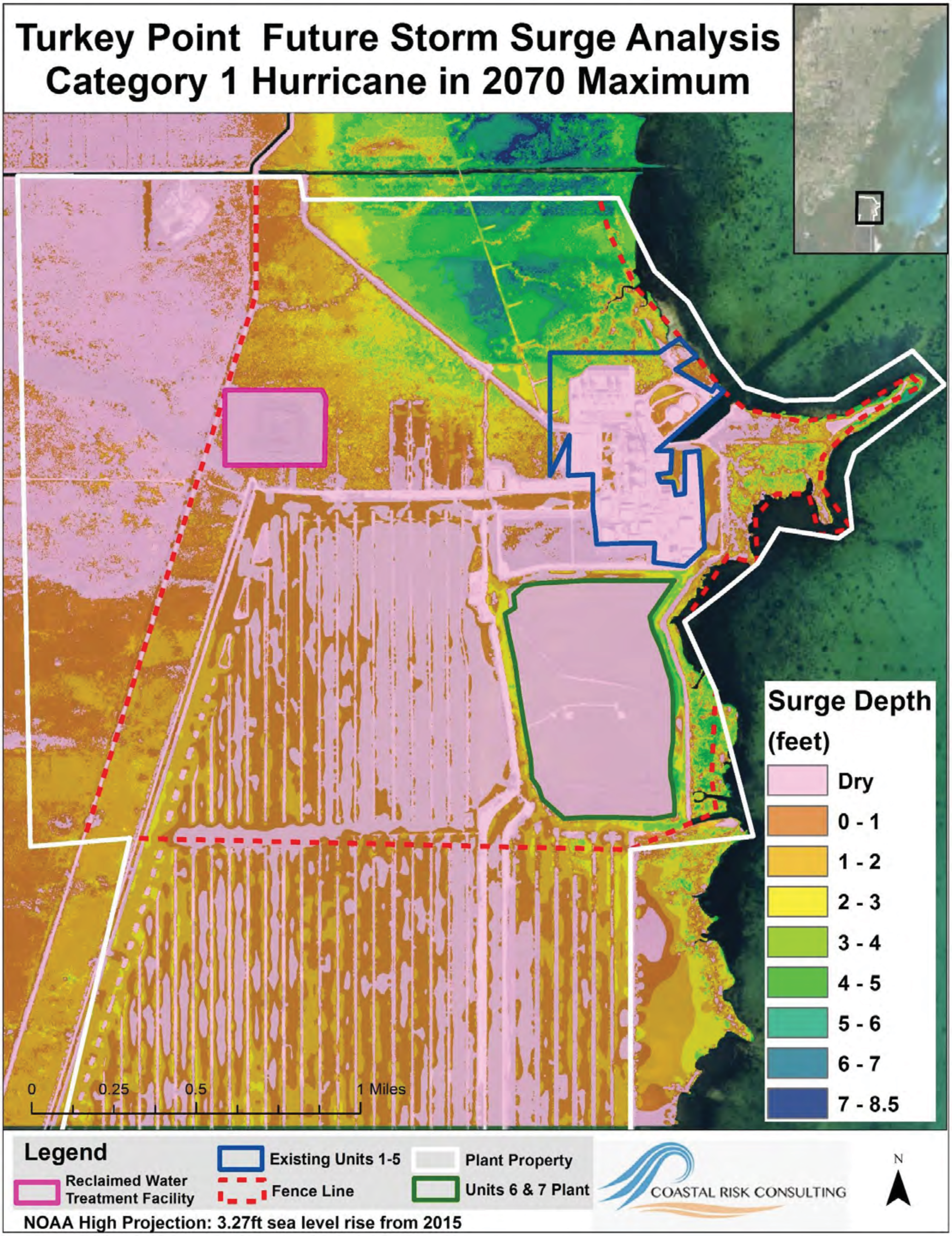
NOAA High Projection: 0.59ft sea level rise from 2015



Turkey Point Future Storm Surge Analysis
Category 1 Hurricane in 2070 Maximum
Surge Depth (feet)
Dry
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8.5
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0.25
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1 Miles
Legend
Reclaimed Water Treatment Facility
Existing Units 1-5
Fence Line
Plant Property
Units 6 & 7 Plant
COASTAL RISK CONSULTING
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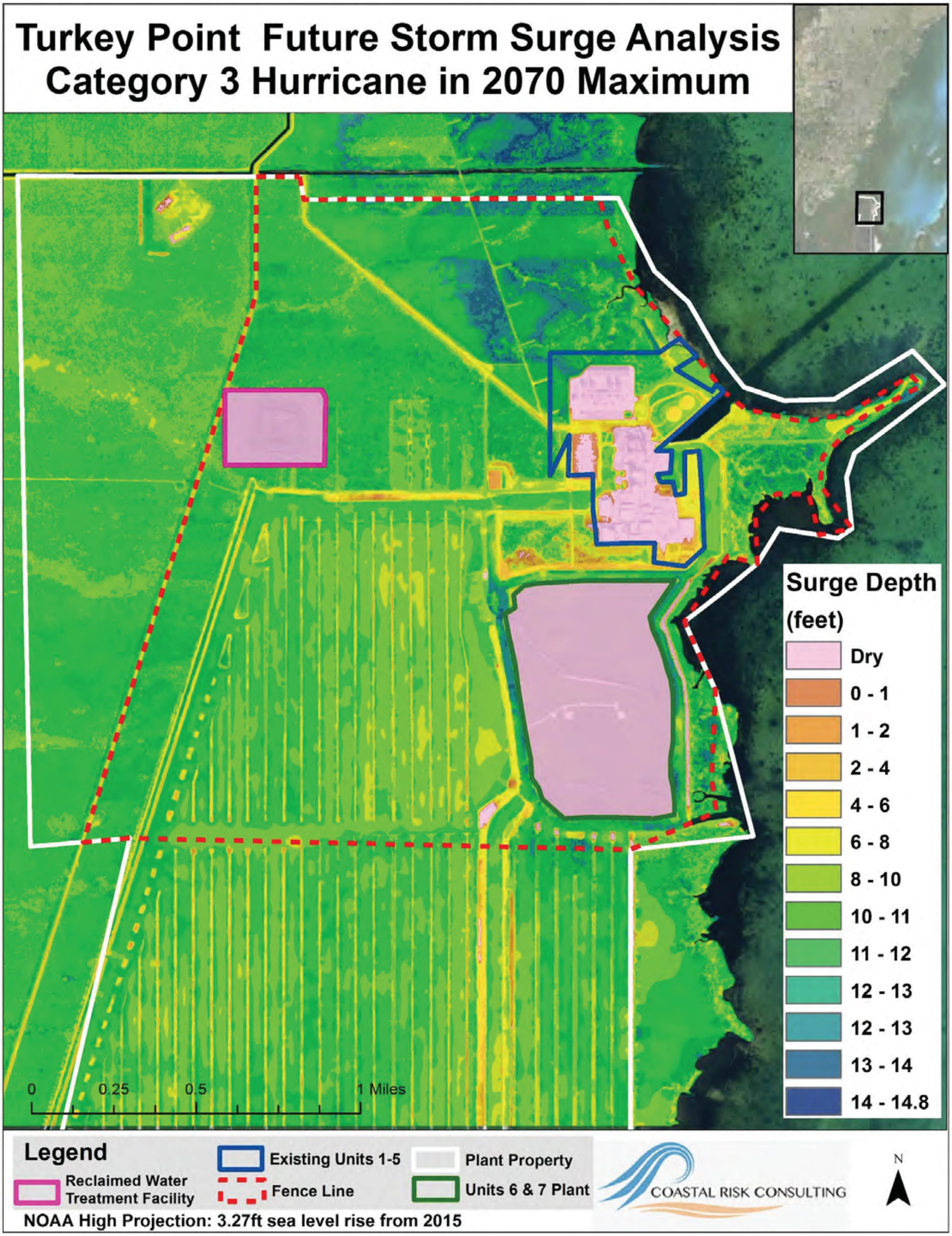
NOAA High Projection: 3.27ft sea level rise from 2015

Turkey Point Future Storm Surge Analysis
Category 3 Hurricane in 2030 Maximum


Turkey Point Future Storm Surge Analysis
Category 3 Hurricane in 2070 Maximum
Surge Depth
(feet)
Dry
0 - 1
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2 - 4
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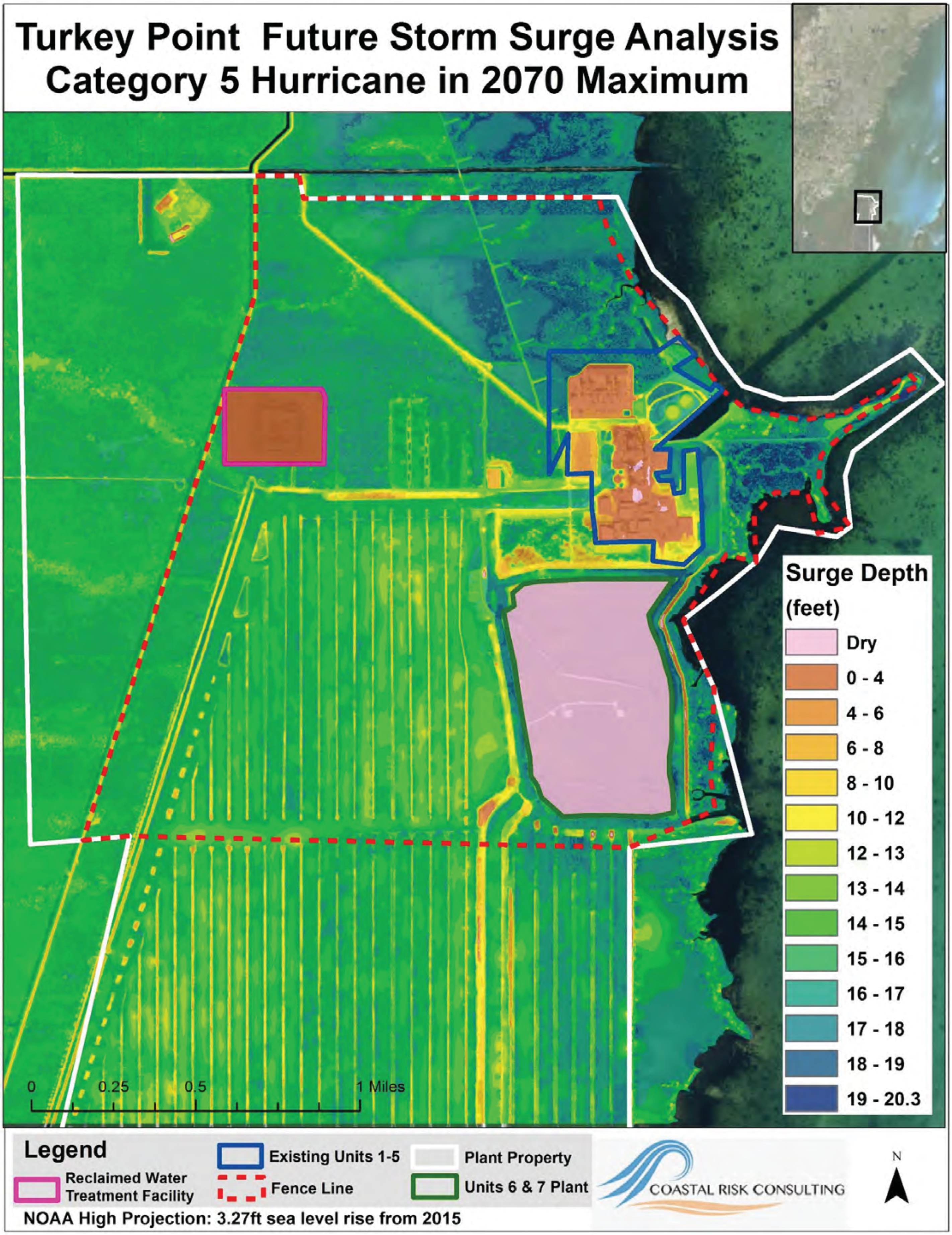
10 - 11
11 - 12
12 - 13
12 - 13
13 - 14
14 - 14.8
0
0.25
0.5
1 Miles
Legend
Reclaimed Water Treatment Facility
Existing Units 1-5
Fence Line
Plant Property
Units 6 & 7 Plant
COASTAL RISK CONSULTING
N
NOAA High Projection: 3.27ft sea level rise from 2015


Turkey Point Future Storm Surge Analysis
Category 5 Hurricane in 2030 Maximum
Surge Depth
(feet)
Dry
0 - 1
1 - 2
2 - 4
4 - 6
6 - 8
8 - 10
10 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17.6
0
0.25
0.5
1 Miles
Legend
Reclaimed Water Treatment Facility
Existing Units 1-5
Fence Line
Plant Property
Units 6 & 7 Plant
COASTAL RISK CONSULTING
N
NOAA High Projection: 0.59ft sea level rise from 2015


Turkey Point Future Storm Surge Analysis
Category 5 Hurricane in 2070 Maximum
Surge Depth (feet)
Dry
0 - 4
4 - 6
6 - 8
8 - 10
10 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20.3
0
0.25
0.5
1 Miles
Legend
Reclaimed Water Treatment Facility
Existing Units 1-5
Fence Line
Plant Property
Units 6 & 7 Plant
COASTAL RISK CONSULTING
N
NOAA High Projection: 3.27ft sea level rise from 2015