Memorandum

Date: May 12, 2016

To: Honorable Chairman Jean Monestime
and Members, Board of County Commissioners

From: Carlos A. Gimenez
Mayor

Subject: Final Report on the Cooling Canal Study at the Florida Power and Light Turkey Point Power Plant - Directive 151025

Pursuant to Resolution No. R-517-15, which was adopted by the Board of County Commissioners (Board) on June 2, 2015, attached is the final Cooling Canal Study at the Florida Power and Light Turkey Point Power Plant.

The preliminary study completed by Dr. David Chin of the University of Miami was distributed to the Board and made available to the public through the County's website on February 17, 2016. Interested parties and members of the public had 30 days, through March 18, 2016, to submit written comments and questions about the study. Additionally, the preliminary study was placed on the Board meeting agenda of March 8, 2016 as item 2B1 (Legistar 160395). All comments received through March 18, 2016 were relayed to Dr. David Chin for consideration in the attached final report.

Pursuant to Ordinance No. 14-65, this memorandum and the final study report will be placed on the next available Board meeting agenda.

Should you have any questions or concerns, please contact Lee Hefty, Assistant Director, Department of Regulatory and Economic Resources, at 305-372-6754 or heftyl@miamidade.gov.

Attachment

c: Honorable Harvey Ruvin, Clerk of the Board
Abigail Price-Williams, County Attorney
Office of the Mayor Senior Staff
Lourdes Gomez, Deputy Director, Department of Regulatory and Economic Resources
Lee Hefty, Assistant Director, Department of Regulatory and Economic Resources
Charles Anderson, Commission Auditor
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UNIVERSITY OF MIAMI

The Cooling-Canal System at the FPL Turkey Point Power Station

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University of Miami

Final Report
May 2016

Executive Summary

This report was prepared under an agreement between Miami-Dade County and the University of Miami. The following issues related to the operation of the cooling-canal system (CCS) at the Turkey Point Power Station were investigated: (1) temperature variations in the CCS and associated impacts on the surrounding groundwater, (2) salinity variations in the CCS and associated impacts on the surrounding groundwater, (3) salinity control within the CCS, and (4) the effects of pumping up to 100 million gallons per day from the L-31E Canal into the CCS. The principal findings of this investigation are summarized below, with analytical details supporting the findings contained in the body of the report. Data for this study was provided by the Miami-Dade County Department of Regulatory and Economic Resources, Division of Environmental Resources Management (DERM). CCS temperature and salinity data for the four-year interval of 9/1/10 – 12/7/14 were made available for this investigation.

Temperature in the CCS. A heat-balance model was developed to simulate the temperature dynamics in the CCS. The results derived from the heat-balance model identified two distinct periods during which the heat-rejection rate from the power plant remained approximately constant. The first period corresponded to pre-uprate conditions (i.e., before February 2012), and the second period corresponded to post-uprate conditions (i.e., after May 2013). The heat-rejection rate under post-uprate conditions was found to be significantly greater than the heat-rejection rate under pre-uprate conditions. As a result of the increased heat addition to the CCS, the average temperature of water in the CCS has increased, and in the vicinity of the power-plant intake the average temperature has increased by approximately 4.7°F. This measured increase in average temperature within the intake zone is slightly greater than the increase in the maximum allowable operating temperature at the intake location of 4.0°F that was approved for the nuclear-power generating units by the Nuclear Regulatory Commission in 2014. Therefore, the increased maximum operating temperature has not reduced the probability of the intake temperatures exceeding the threshold value, which currently stands at 104°F. Since supplementary cooling of the CCS was needed in 2014, this serves as a cautionary note regarding further increases in power generation beyond 2014 levels without providing a reliable supplementary cooling system. Measured temperature data under pre-uprate conditions indicate that the thermal efficiency of the CCS has decreased between the pre-uprate and post-uprate periods. Recent efforts have been made by FPL to increase the thermal efficiency of the CCS with some tangible results. However, measured (current) post-uprate thermal efficiencies of the CCS remain below the pre-uprate levels (67% versus 77%), and the extent to which further improvements in the thermal efficiency of the CCS will be able to mitigate increased temperatures resulting from increased thermal loading is yet to be established. The assertion that higher algae concentrations in the CCS were responsible for the elevated temperatures in the CCS was investigated. A sensitivity analysis indicates that increased algae concentrations were not likely to have been responsible for the significantly elevated temperatures in the CCS recorded in the mid-summer

months of 2014. The additional heating rate in the CCS caused by the presence of high concentrations of algae is estimated to be less than 7% of the heat-rejection rate of the power plant, hence the minimal impact. Further development of a heat-balance model of the CCS is needed, since the design of any engineered system to control temperatures in the CCS must be done in tandem with heat-balance-model simulations.

Temperature impact on groundwater. Measured groundwater temperatures in some monitoring wells between the CCS and the L-31E Canal have shown higher temperatures than groundwater west of the L-31E Canal, and this occurrence can be partially attributed to limited cooling-canal water intrusion into the Biscayne aquifer. Monitoring-well measurements show that nearly all of the seasonal temperature fluctuations in the groundwater occur above an elevation of −25 ft NGVD* (about 30 ft below the ground surface). At lower elevations in the aquifer, the groundwater temperature generally remains relatively steady and in the range of 75°F – 77°F. Seasonal temperature fluctuations above −25 ft NGVD can be partially attributed to the heating and cooling of water in the L-31E Canal in response to seasonal changes in atmospheric conditions. Overall, the impact of the CCS on the temperature of the groundwater in the Biscayne aquifer can be considered as localized of not having any direct environmental consequence. However, since the density of water is inversely proportional to temperature and directly proportional to salinity, the cooling of CCS water as it penetrates the Biscayne aquifer causes an increase in density that affects the groundwater flow in the vicinity of the CCS. Hence, accounting for subsurface temperature variations in the vicinity of the CCS is essential in modeling the extent of salinity intrusion resulting from operation of the CCS.

Salinity in the CCS. There has been a steady increase in the CCS salinity of around 5‰ per decade since the CCS began operation in 1973. Recent measurements indicate that the rate of change of salinity in the CCS might be increasing. Analyses of the salinity dynamics in the CCS were performed using a salinity model previously developed by a FPL contractor. Results from this salinity model show that evaporation and rainfall are the primary drivers affecting the salinity in the CCS, with pumpage from the interceptor ditch and blowdown from the Unit 5 generating facility also having an effect. Over prolonged periods with no rainfall, the salinity in the CCS will typically increase as fresh water is evaporated and the evaporated fresh water is replaced by saline water from the surrounding aquifer. A prolonged period with no rainfall coupled with the significant inflow of saline water from the surrounding aquifer were the primary causes of the unusually high salinities (greater than 90‰) that were observed in early summer of 2014. Seepage inflow to the CCS is mostly from the east (i.e., the area adjacent to Biscayne Bay) and seepage outflow is mostly through the bottom of the CCS, thereby contributing to an increased salinity of the underlying groundwater. The short-term (seasonal) salinity fluctuations in the CCS are controlled by seasonal variations in the amount and timing of rainfall, and aperiodic spikes in salinity should be considered as being normal and expected. In the long term, barring any significant intervention, salinities in the CCS will continue to follow an upward trend, since over the long term annual evaporation exceeds annual rainfall. Recent increases in the temperatures in the CCS will certainly lead to increased evaporation, which will likely increase the rate of change of salinity in the CCS to above-historical rates of change.

Salinity impact on groundwater. Based on available documentation and data summaries contained in numerous reports prepared by FPL, SFWMD, and DERM, there is little doubt that seepage from the CCS into the Biscayne aquifer has caused salinity increases within the aquifer, and this impact extends several miles inland from the CCS. The strongest evidence for this assertion comes from measured tritium concentrations

*"NGVD" refers to the NGVD 29 datum.

in groundwater samples collected at monitoring wells in the vicinity of the CCS. Water in the CCS generally contains tritium concentrations that are significantly higher than natural background concentrations in the surrounding aquifer, and hence utilization of tritium as a tracer to identify groundwater originating from the CCS is justified. Elevated concentrations of tritium above a 20 pCi/L threshold in the deep groundwater can reasonably be attributed to the presence of water originating from the CCS. The approximate limit of the 20 pCi/L concentration contour has been reported to be 3.8 – 4.7 miles west of the CCS and 2.1 miles east of the CCS. This finding is further reinforced by USGS measurements showing that groundwater samples collected within 5.3 miles west of the CCS had elevated levels of tritium relative to normal background levels of tritium in the Biscayne aquifer. It is important to note that presence of elevated levels of tritium above natural background levels in the Biscayne aquifer is not considered to be a threat to public health and safety, since the measured concentrations are far below the federal drinking water standard of 20,000 pCi/L. Elevated levels of tritium are simply being attributed to the presence of water originating in the CCS.

Salinity control in the CCS. FPL has reached an agreement with Miami-Dade County to install a system of up to six wells to pump low-salinity water at a rate of 14 mgd from the Upper Floridan aquifer into the CCS in order to reduce salinity in the CCS. The operational goal of this system is to reduce the average-annual salinity in the CCS to approximately 34‰ within four years after the system begins operation. Based on available information, there are still some outstanding technical issues that should be addressed in developing the final design of the salinity-control system. The first issue is that the long-term addition of 14 mgd of brackish water from the Upper Floridan aquifer could be insufficient to compensate for the post-uprate evaporation-rainfall deficit that is currently around 29 mgd. This shortfall in pumping rate, if not adequately addressed in the design of the salinity-control system, would likely result in a continued steady increase in salinity within the CCS. A second issue of concern is that adding 14 mgd or more of water to the CCS is likely to significantly increase the salinity flux out of the bottom of the CCS, at least in the short term, and the extent to which this increased salinity flux will exacerbate salinity intrusion in the Biscayne aquifer still needs to be addressed. A third issue of concern is that the time-frame required for the proposed system to significantly reduce salinity levels in the Biscayne aquifer remains highly uncertain pending more definitive characterization of the subsurface hydrostratigraphy and the development of a groundwater-flow model that accounts for the effects of temperature and salinity on the flow distribution in the aquifer. The variable-density groundwater model that is being developed in support of the Biscayne Aquifer Recovery Well System (RWS) could possibly be adapted to investigate the technical issues relating to CCS salinity-control system that are identified here.

Withdrawal of 100 mgd from the L-31E Canal. Adverse impacts of pumping 100 mgd from the L-31E Canal into the CCS during June 1 – November 30 are possible under the current permitted pumping protocol. Under the current pumping protocol stipulated in the SFWMD-issued permit, the stage in the L-31E Canal will be held constant during pumping, while the stage in the CCS will generally rise as a result of pumping. This combined effect will decrease, or possibly reverse, the seaward piezometric-head gradient between the L-31E Canal and the CCS that would normally exist in the absence of pumping. A possible consequence of a reversed head gradient between the L-31E Canal and the CCS is advection of a saline plume from the CCS towards the L-31E Canal, and creation of a circulation cell in which the salinity of the water in the L-31E Canal is increased as the saline plume enters the L-31E Canal. Furthermore, according to model results provided by FPL in support of the pumping-permit application, pumping of 100 mgd into the CCS is likely to reduce the water-level differential between the L-31E Canal and the CCS to below the 0.30 ft threshold that would normally trigger the operation of the interceptor ditch salinity-control system, which, if operational, would further reduce the head gradient between the L-31E Canal and the CCS. Based on these findings, it is recommended that the permitted pumping protocol be revised prior to the 2016 pumping period. The revised protocol should include, as a minimum, real-time monitoring of the stages in the CCS and the L-31E Canal during pumping operations, specification of a threshold water-level difference between the L-31E Canal and the CCS that would limit further pumping, and real-time monitoring of the salinity in the L-31E Canal during pumping operations.

Recommended actions. The following action items would lead to better and more efficient management of temperatures and salinities within the cooling-canal system, and support the robust design of remediation systems to control CCS-induced salinity intrusion:

- Develop a calibrated heat-balance model to simulate the thermal dynamics in the CCS, and collect the data necessary to calibrate and validate the model.
- Continue present efforts to increase the thermal efficiency of the CCS, and use measured data to establish the extent to which temperature increases due to increased thermal loading are being mitigated by increased thermal efficiency.
- Develop a quantitative relationship for estimating algae concentrations in the CCS as a function of temperature, salinity, and nutrient levels.
- Develop a locally validated relationship between the evaporation rate, water temperature, air temperature, wind speed, salinity, and algae concentrations in the CCS.
- Re-assess the effectiveness of pumping 14 mgd of brackish water from the Upper Floridan aquifer into the CCS with the objective of reducing the salinity in the CCS. Under present operating conditions, a higher pumping rate will likely be necessary, since post-uprate increases in CCS operating temperatures have increased the evaporation-rainfall deficit from around 19 mgd to around 29 mgd.
- Utilize a variable-density groundwater model to better estimate the effectiveness and aquifer-response time scale of the proposed CCS salinity-control actions related to pumping 14 mgd or more from the Upper Floridan aquifer into the CCS. Based on available data, there is much uncertainty in the effectiveness and aquifer-response time scale.
- Modify the operational protocol associated with the 2015 – 2016 permit for transferring up to 100 mgd from the L-31E Canal to the CCS.

The analyses and recommendations contained in this report are offered constructively in support of the goal of achieving an environmental balance for the sustainable generation of electrical power at the Turkey Point power station.

Contents

1 Background

This investigation is primarily focused on the operation of the cooling-canal system (CCS) located at the Turkey Point power-generating station in south Miami-Dade County, Florida. The issues of concern relate to the increased temperatures and salinities that have recently been measured in the CCS, the environmental impacts of these increased levels on the quality of groundwater in the Biscayne aquifer, the need for additional engineered systems to supply supplemental cooling water to the CCS, the proposed plan to reduce salinities in the CCS, and the environmental impacts of permitted pumping of up to 100 mgd of water from the L-31E Canal to the CCS between June 1 and November 30.

Environmental concerns. Most of the environmental concerns regarding the operation of the cooling-canal system (CCS) at Turkey Point relate to: (1) the sustainability of the system in maintaining adequate temperatures to cool the power-generating units, (2) the impact that current and projected future salinities in the CCS have on the quality of groundwater in the surrounding Biscayne aquifer, and (3) the need for new supplementary sources of water and/or revised operational protocols to control the temperatures and salinities in the CCS. Specific issues of concern are as follows:

- Increased temperatures in the CCS limit the effectiveness of the CCS as a cooling-water source servicing three power-generating units. When the intake temperature in the CCS exceeds a regulatory limiting value of 104°F, either nuclear-power generation must be curtailed or supplementary cooling water must be provided to the CCS to reduce the temperature and hence keep the nuclear-power generating units in operation; the sustainability of a supplementary system to cool the water in the CCS has not yet been established.

- Increased salinity in the CCS likely contributes to increased saltwater intrusion within the Biscayne aquifer, thereby deteriorating the groundwater quality underlying nearby inland areas. This is of concern because of the proximity of the CCS to public water-supply wellfields, a commercial rockmining operation, and ecologically sensitive areas. The current salinity-control system, sometimes called the interceptor-ditch system, has not been effective in controlling the inland migration of saline water from the CCS, thereby signaling the need for revised operating strategies to manage salinity intrusion resulting from CCS operation.

- The effectiveness and environmental impact of a planned system to reduce the salinity in the CCS by pumping water from the Upper Floridan aquifer into the CCS, and the effectiveness and environmental impact of a planned system to reduce CCS-induced salinity intrusion by pumping CCS-derived hypersaline water from the Biscayne aquifer into the Boulder Zone are unresolved issues.

- The effectiveness of the permitted protocol for pumping 100 mgd from the L-31E Canal into the CCS to reduce temperatures and salinities in the CCS, and the effect of this pumping operation on saltwater intrusion in the Biscayne aquifer and water quality within the L-31E Canal are issues that are yet to be resolved.

This report summarizes what is currently known about the CCS, summarizes the key findings from previous related investigations, regulatory reports and reviews, provides new analyses, and gives suggested answers and pathways forward to resolve several issues related to the above-listed concerns.

1.1 Turkey Point Power Station

The Turkey Point Power Station consists of five power-generating units: two 404-MW oil/natural gas-fired generating units (Units 1 and 2), two 728-MW nuclear-powered units (Units 3 and 4), and a nominal 1150-MW natural gas-fired combined-cycle unit (Unit 5). The five power-generating units and support facilities occupy approximately 130 acres of the 11,000-acre Turkey Point plant. Units 3 and 4 were the first nuclear power plants constructed in Florida, and they were licensed to begin operation in 1972 and 1973, respectively. In 2002, the Nuclear Regulatory Commission (NRC) extended the operating licenses for both nuclear reactors from forty years to sixty years, extending licensed operation of Units 3 and 4 to the years 2032 and 2033, respectively. The CCS provides cooling water for Units 1 to 4, with cooling of Unit 5 accomplished by mechanical-draft cooling towers that use make-up water drawn from the Upper Floridan aquifer. Blowdown water from Unit 5 is discharged into the CCS. Since the uprate of Units 3 and 4 went into effect, Unit 2 has not been operational, with some documentation indicating that Unit 2 actually ceased operating in 2010 (Florida, 2015). With an estimated total power-station capacity of approximately 3550 MW, the Turkey Point power station has been cited as the second largest power station in Florida, in terms of generating capacity, and is the sixth largest power station in the United States (NRC, 2012).

Uprate of Units 3 and 4. In June of 2009, the Florida Department of Environmental Protection (FDEP) certified the increase in power-generating capacity (commonly called an "uprate") of Units 3 and 4 to provide an additional 250 MW of electrical power (i.e., 250 MWe). Pursuant to this uprate certification, Unit 3 has been operating at its uprated power-generation capacity since November 2012, and Unit 4 has been operated at its uprated power-generation capacity since May 2013. By increasing electrical-power generation by 250 MW, the NRC estimated that the increase in thermal loading on the CCS would be approximately 688 MW (i.e., 688 MWt). Further, in planning for the Unit 3 and Unit 4 uprates, it was anticipated that the uprate would increase the temperature of the cooling water discharged to the CCS by approximately 2.5°F, and would increase the temperature in the CCS at the power-plant intake by around 0.9°F (FPL 2011; FDEP, 2008) . It was also anticipated that the increased temperature in the CCS would result in increased evaporation, which would cause an increased CCS salinity of around 3.6‰.

Future plans. In 2014, the Florida legislature approved construction of two additional nuclear reactors at Turkey Point (Units 6 and 7), with each additional unit having an approximate electrical output of 1100 MW; approval of the additional units by the NRC is currently pending. The two additional nuclear reactors will not use the CCS for cooling.

1.2 Geohydrology

The Turkey Point power station and associated cooling-canal system (CCS) are underlain by the Biscayne aquifer. In the vicinity of Turkey Point, the Biscayne aquifer extends from land surface to a depth of approximately 106 ft below sea level (BSL), with the thickness of the aquifer decreasing towards the west. Geologic formations within the Biscayne aquifer include, from the ground surface downward, the Miami Limestone Formation, Key Largo/Fort Thompson Formations, and upper portions of the Tamiami Formation. The less-permeable units of the Tamiami Formation, and the deeper Hawthorn Group, form the confining unit between the Biscayne aquifer and the Upper Floridan aquifer. The top of the confining unit is characterized by the transition between highly permeable beds of the Fort Thompson Formation and the lower-permeability silty sands of the Tamiami Formation. The thickness of the Miami Limestone Formation is in the range of

8 – 23 ft, and the thickness of the Fort Thompson Formation is in the range of 46 – 95 ft. The bulk hydraulic conductivity of the Biscayne aquifer in the vicinity of Turkey Point is in the range of 2700 – 7300 m/day (Fish and Stewart, 1991). The regional groundwater flow direction is, on average, from the northwest to southeast, although the predominant flow direction at the coast can vary significantly between the wet and dry seasons. The water-table gradient is typically towards the coast during the wet season (May – October), but can be directed inland during the dry season (October – April). The possibility of the occurrence of an inland water-table gradient is the primary reason for utilization of the so-called "interceptor-ditch system" that is used ostensibly to control the inland migration of saline water originating from the CCS. Water-table elevations at Turkey Point are typically around 1 ft NGVD, and the magnitude of the average regional water-table gradient is typically in the range of 0.004% – 0.005%. Notably, with such small water-table gradients, small errors in measured water-table elevations can significantly impact the accuracy of the estimated gradients. Vertical piezometric-head gradients at the Turkey Point site (away from the CCS) are typically negligible, with piezometric-head differentials between shallow, intermediate, and deep zones reportedly being within hundredths of a foot. Negligible vertical piezometric-head gradients indicate that groundwater flows are predominantly in the horizontal direction (Chin, 2013).

Groundwater classification. Groundwater at the Turkey Point site was originally classified by FDEP as as G-II, which is the classification for groundwater that is of possible potable use and has a total dissolved solids content of less than 10,000 mg/L. In September 1983, at the request of FPL, the groundwater at the Turkey Point site was reclassified by FDEP as G-III, which is the classification for groundwater that has a total dissolved solids content of 10,000 mg/L or greater, or has a total dissolved solids of 3,000 – 10,000 mg/L and has no reasonable potential as a future source of drinking water. The G-III classification currently remains in effect.

1.3 The Cooling-Canal System

Background. The utilization of recirculating cooling ponds and cooling canals at thermoelectric power plants in the United States is not unique to South Florida, with approximately 85 thermoelectric power plants using such closed-loop cooling systems as of 2005 (Hughes et al., 2010). Approximately 40% of U.S. nuclear power plants use closed-cycle cooling, with the others using once-through cooling systems (EPRI, 2012). In the United States, closed-loop cooling-pond systems are more commonly utilized in arid areas where evaporation rates are high, and such systems are less commonly used in humid areas where evaporation rates are relatively low. Elevated temperatures and salinities are common features of cooling ponds and canals. Notably, elevated temperatures and salinities have opposite effects on the density of water, with elevated temperatures causing reduced densities, and elevated salinities causing increased densities. Typically, the increased density due to elevated salinities is greater than the reduced density due to elevated temperatures[†]. Therefore, the combined effect is to increase the density of the water in the cooling system relative to that of surrounding groundwater. The increased density of water within the cooling system causes the water to move downward through the surrounding aquifer. Such density-driven flows are commonly referred to as thermohaline flows, and such flows contribute to the process of salinity intrusion.

History and regulation of the Turkey Point cooling canal system. The Turkey Point cooling-canal system (CCS) is located approximately 4.5 miles southeast of Homestead, approximately 8 miles east of Florida

[†]For temperature: $\partial\rho/\partial T = -0.375$ (kg/m^3)/°C; and for salinity: $\partial\rho/\partial S = 0.75$ (kg/m^3)/‰.

City, and approximately 10 miles north of Key Largo. Construction of the CCS was approved by the Dade County Board of County Commissioners in November 1971, and became operational in February 1973. At the time of its initial operation, the CCS was approximately half-completed compared with the present system. The CCS is sometimes referred to as the Industrial Wastewater Facility (IWW), since the circulating-water system discharges saline water to the surrounding Biscayne aquifer and is regulated under the federal National Pollutant Discharge Elimination System (NPDES) and an Industrial Wastewater (IW) permit issued to FPL by the Florida Department of Environmental Protection. The CCS is also commonly referred to as the Ultimate Heat Sink (UHS) of the nuclear-reactor power-generating units (Units 3 and 4).

Current canal system. In its present state, the CCS is approximately two miles wide (east–west) and five miles long (north–south), covers an area of approximately 6100 acres, and has approximately 4370 acres of water surface. The CCS occupies more than half of the 11,000-acre Turkey Point power-station property. The CCS consists of 32 canals flowing south from the discharge location in the north, and 6 return canals flowing north to the intake location. Because the south-flowing canals are located in the western section of the CCS and the north-flowing canals are located in the eastern section of the CCS, the system is sometimes referred to as having 32 western canals and 6 eastern canals. The south-flowing (western) canals are each approximately 4 ft deep, 200 ft wide, and spaced approximately 90 ft apart; these canals range in length from 2 – 5 miles. The 4 ft depth of the canals (from ground surface) was originally chosen so as to not penetrate the less-permeable surficial Miami Oolite Formation that extends to about 4 ft below grade, thereby minimizing groundwater exchange between the CCS and the underlying Biscayne aquifer. The bottom of the canals are below the lowest water-table elevation expected in the Biscayne aquifer at Turkey Point, and therefore the canals always contain water that is directly connected to the adjacent groundwater. Cooling water leaves the three operational power-generating units (Units 1,3, and 4), flows into Lake Warren, and then into the 20-ft deep 100-ft wide feeder canal that connects to the 32 south-flowing cooling canals. Four shallow cross canals spaced 1-mile apart run east – west across the 32 south-flowing cooling canals. These cross canals contain flow-control structures that distribute water flow evenly to the canals so that each cooling canal carries a flow that is proportional to its surface area in order to optimize heat exchange with the atmosphere. At the southern end of the CCS is a collector canal that is approximately 20 ft deep and 200 ft wide. Water returns to the power-generating units from the southern collector canal via 6 north-flowing canals, the largest of which is the Grand Canal which is 200 ft wide and 20 ft deep. The average length of the circulation path between the discharge and intake locations is 13.4 miles. The 32 south-flowing cooling canals are numbered from 1 to 32, from east to west, hence, cooling-canal number 32 is the westernmost canal in the CCS.

Federally protected species inhabiting the CCS. Since 1977 an area that includes the majority of the Turkey Point site (including the CCS) has been designated as critical habitat for American crocodiles under the Endangered Species Act. Endangered American crocodiles (*Crocodylus acutus*) have inhabited the cooling canals since around 1976 (FDEP, 2008). During nesting season, more than 40 adult crocodiles have been observed in the canals, although there have been some reports that the crocodile population in the CCS is declining possibly due directly or indirectly to the increased salinities in the CCS. According to the NRC (NRC, 2014), the Turkey Point site now hosts approximately one-third to one-half of the breeding population of crocodiles in the United States.

Operational characteristics of the CCS. The canals in the CCS were designed to operate at a total flow rate of 4250 ft^3/s (2750 mgd) when all four generating units (Units 1 – 4) supported by the CCS are in full operation. Small wastewater (blowdown) flows from Unit 5 are also discharged into the CCS. Typically, the flow rate through the CCS varies with the electric load demand on the generating units, and is usually in the range of 2700 – 4250 ft^3/s (1750 – 2750 mgd) on any given day, with a typical flow depth of around 2.8 ft. Thermal energy input from the power-generating units is dissipated in CCS as water moves from north to south, with the primary heat-exchange processes being evaporation, solar radiation, and both emitted and absorbed longwave radiation. Maximum temperatures near the discharge location of the power-generating units are typically around 108°F, and maximum temperatures near intake to the power-generating units are typically around 93°F; the difference between these typical maxima is 15°F, which gives a measure of the cooling effect of the CCS. The (regulated) maximum allowable temperature at the intake location in the CCS is 104°F. The flow in the CCS is driven by 12 condenser-circulating pumps and auxiliary cooling pumps. The CCS typically contains approximately 7×10^8 ft^3 of water, and the average velocity of flow is around 0.25 ft/s in each canal. Approximately two days (44 – 48 h) are required for water in the CCS to travel from the discharge location to the intake location. Flow within the CCS is maintained by a head differential between the discharge and intake locations, with the water-surface elevation being highest at the discharge location and lowest at the intake location. Under current operating conditions, typical water surface elevations in the CCS are 1.48 ft NGVD at the discharge location, 0.95 ft NGVD at the south end, and 0.70 ft NGVD at the intake location. The water-surface elevation at south end of the CCS is usually closest to the water-surface elevation in Biscayne Bay. The water-surface elevation in the CCS is typically higher than the site-average water-table elevation in the Biscayne aquifer at the discharge (north) end of the system, approximately equal to the water-table elevation at the south end of the system, and below the water table at the intake (north) end of the system. Consequently, water generally flows out of the CCS into the aquifer near the discharge location of the CCS and water generally flows into the CCS from the aquifer near the intake location of the CCS, there is less flow interaction between the CCS and the aquifer at the southern end of the system. During very heavy rains, there can be a net inflow to the CCS from the surrounding aquifer. The CCS is approximately nontidal, and water in the CCS is typically warmer than the air temperature.

1.4 Algae in the CCS

A significant algae bloom occurred in the CCS during 2014 and algae is now perceived to be a problem in the CCS. Prior to 2013, only limited and short-term algae blooms had occurred in the CCS, typically during the early summer months. In fact, algae blooms were previously of such limited concern that routine monitoring for algae was not commonly done prior to 2014. In the summer of 2014, large-scale application of a $CuSO_4$-based algaecide was used to reduce the algae concentrations in the CCS. The applied algaecide was reported as being ineffective in reducing the algae concentrations, serving only to stabilize the existing concentrations (SFWMD, 2015).

Factors affecting algae concentrations. High concentrations of algae have been observed in the CCS with correspondingly high concentrations of nutrients being measured. The historical average algae concentration in the CCS is reported to be 50 cell/L[‡], however, in the summer of 2014 algae concentrations as high as 1600 cell/L were reported (SFWMD, 2015). The addition of nutrients from the power-generating units into the CCS is assumed to be negligible, with nutrients likely originating from allochthonous sources. Total nitrogen (TN) concentrations in the CCS have been reported in the range of 1.7 – 5.3 mg/L (Ecology and Environment, Inc., 2012). The highest reported TN concentrations in the CCS were measured at all stations

[‡]Algae concentrations are normally given in Chl*a*/L, so these units are unusual.

in March 2012, which coincided with higher turbidities and pH in the CCS. The majority of the nitrogen in the CCS appears to be in organic form (typically 80% – 90%). Total phosphorus (TP) concentrations in the CCS have been reported in the range of 4 – 73 μg/L, with an overall average concentration of 36 μg/L. Numerous measurements of TN and TP were reported between 7/2010 and 3/2015 (Ecology and Environment, Inc., 2010; 2011a; 2011b; 2012a; 2012b; 2012c; 2013a; 2013b; 2014a; 2014b; 2015), and synoptic measurements within this time period yield TN/TP values in the range of 48 – 2015 with a median value of 142. Since the measured TN/TP values generally exceed the Redfield ratio of 16, it can be inferred that TP is the controlling nutrient for algae growth in the CCS. The existence of TP-control of algae growth in saline systems is commonly attributed to the presence of nitrogen-fixing planktonic cyanobacteria which make up any short-term nitrogen deficits (Howarth and Marino, 2006). It has been reported that the cyanobacteria *Aphanothece* sp. are the predominant algae species in the CCS; these species are nitrogen-fixing and thrive under hypersaline conditions. In addition to nutrients, both temperature and salinity are known to affect the growth of algae in water bodies. For given nutrient levels, increasing temperatures usually contribute to increased algae concentrations, and increasing salinities usually contribute to decreased algae concentrations (Håkanson and Eklund, 2010). However, for the algae species commonly found within the CCS, algae concentrations have been reported to increase with increasing salinity (SFWMD, 2015). Algae concentrations are usually expressed in terms of the mass of chlorophyll-a per liter of sample volume. Synoptic measurements of chlorophyll-a (Chl$a$) concentration, salinity (S), temperature (T), and total phosphorus (TP) concentration at locations near the discharge and intake locations in the CCS between May 31, 2015 and November 13, 2015 are plotted in Figure 1. These synoptic measurements collectively show the algae

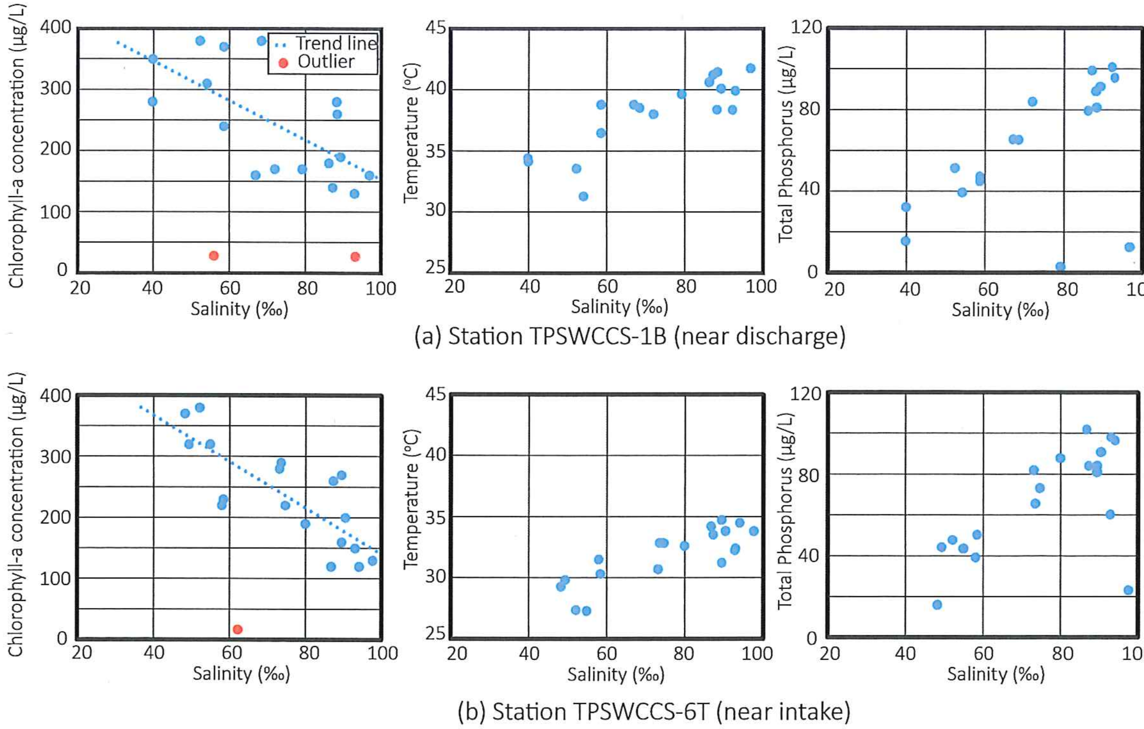


Figure 1: Chlorophyll-a levels in the CCS as a function of temperature, salinity, and total phosphorus

concentration (Chl$a$) decreasing with increasing salinity (S), decreasing with increasing temperature (T), and decreasing with increasing nutrient concentration (TP). All of these trends are contrary to the natural relationships between Chl$a$, S, T, and TP and are either anomalous or indicate the effect of an algaecide. The active ingredient of the algaecide commonly used in the CCS is $CuSO_4$, and the possible effectiveness of this algaecide can be seen by plotting the relationship between Chl$a$ and sulfate (SO_4^{2-}) concentrations; this relationship is shown in Figure 2. It is apparent from Figure 2 that algae concentrations decrease signifi-

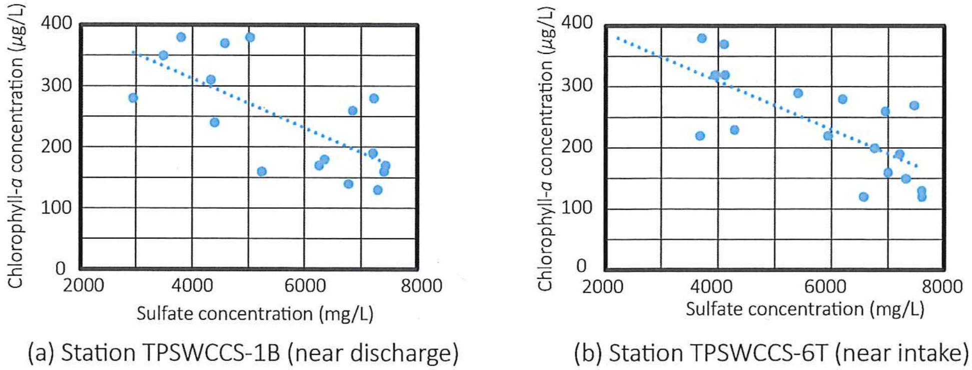


Figure 2: Chlorophyll-a levels in the CCS sulfate concentrations

cantly with increasing concentrations SO_4^{2-}, indicating that the addition of an algaecide is an effective means of reducing algae concentrations in the CCS. However, according to FPL (see Appendix A), no algaecide was applied during the period covered by Figures 1 and 2, and so the SO_4^{2-} apparently acting as an algaecide could be the residual from previous $CuSO_4$ applications. FPL has suggested an alternative hypothesis that the decreasing trend in algae concentrations during this time is attributable to salinity concentrations exceeding 70‰, since the particular algae species observed in the CCS during this time frame was not ideally suited to growing and surviving in water with salinity exceeding 70‰. Collectively, the anomalous results described here should provide a strong motivation for FPL to use measured data to develop a functional relationship between algae concentrations and the influencing independent variables of temperature, salinity, total phosphorus, and algaecide concentrations. Such a functional relationship could provide useful guidance for the control of algae within the CCS. However, it should generally be kept in mind that Chl$a$ reductions caused by any algaecide are necessarily only temporary, since the natural factors causing high levels of Chl$a$ (i.e., S, T, and TP) remain at elevated levels within the CCS. Since the system is autotrophic, reduction of autochthonous TP levels should be targeted to ultimately reduce both algae levels and the need for repeated application of algaecide(s) in the CCS.

Impact of increased algae concentrations. It has been asserted (SFWMD, 2015) that increased algae concentrations and turbidities associated with algae blooms cause more solar energy to be absorbed in the CCS, and reduces the ability of the CCS to dissipate thermal energy. The primary mechanisms by which the CCS dissipates thermal energy input by the power-generating units are by evaporation and the emission of longwave radiation. A conventional assumption made by engineers and scientists is that the evaporation rate from a water body is unaffected by the concentration of algae in the water body. There is no scientific evidence documented in any published studies showing that the rate of evaporation from a water body is reduced by high algae concentrations. Further, there are no published studies showing that the emission of longwave radiation from a water body is particularly sensitive to the concentration of algae in the water. As a consequence, the primary effect of increased algae concentrations in the CCS can be assumed to be increased absorption of solar radiation, which would increase the heating of the water and elevate the temperature of the water in the CCS. The quantitative effect of increased solar heating of the CCS due to increased algae concentrations is parameterized by a reduced albedo of the water surface, and the relationship between the reduced albedo and the corresponding increased temperature was investigated in this study using a heat-balance model described subsequently in Section 2.2 of this report. It should be noted that the "trapping" of solar energy due to increased algae concentrations would be moderated by the resulting increased evaporation which would cause increased cooling due to the extraction of the latent heat of vaporization.

1.5 Saltwater Intrusion

Definitions. The extent of saltwater intrusion in an aquifer is typically based on the chloride concentration in the groundwater. The chloride concentration in water is commonly called the chlorinity, and typical seawater has a chlorinity of around 19,000 mg/L. Contours of equal chlorinity are called isochlors. In South Florida, water with clorinity exceeding 19,000 mg/L is commonly classified as hypersaline, and the inland extent of saltwater intrusion is defined by the location of the 1000 mg/L isochlor. As a reference concentration, the (secondary) drinking-water standard for chloride concentration is 250 mg/L. Saltwater is commonly defined as water having a chlorinity greater than or equal to 1000 mg/L, and brackish water as having a chlorinity between 250 mg/L and 1000 mg/L. The South Florida Water Management District (SFWMD) defines seawater as having a chlorinity greater than 19,000 mg/L, and saline water as having a chlorinity greater than 250 mg/L. Surface-water bodies with chlorinities greater than 1500 mg/L are classified as marine waters, and surface-water bodies with chlorinities less than 1500 mg/L are classified as fresh waters (F.A.C. 62-302.200). The terms "saltwater intrusion", "saltwater encroachment", and "salinity intrusion" are used synonymously. Chlorinity is closely related to salinity, where salinity measures the concentration of total dissolved solids and chlorinity measures the concentration of dissolved chloride ions. Typical seawater has a salinity of around 35 g/kg or 35‰. Salinities are also commonly expressed in terms of the practical salinity unit (PSU), with salinities in PSU being numerically close, but not exactly equal, to salinities in ‰ (i.e., 35 PSU $\approx$ 35‰).

Saltwater intrusion in the vicinity of Turkey Point. The landward extent of the saltwater interface (i.e., the 1000 mg/L isochlor) in South Florida varies naturally in response to a variety of factors, such as seasonal variations groundwater recharge, variations in rates at which groundwater is pumped from the aquifer, and controlled water-surface elevations in coastal canals. For example, prolonged droughts or excessive water usage inland that reduce water-table elevations can cause increased salinity intrusion. The beginning of saltwater intrusion in South Florida can be traced back to the draining of the Everglades starting in the early 1900s; the motivation for draining the Everglades was to support urban development and human habitation. At the time of construction of the CCS in the early 1970s, the groundwater underlying the Turkey Point site was saline due to the proximity of the site to the coast. In fact, had the groundwater not been saline, construction of the cooling-canal system at Turkey Point would not have been permitted. The current state of salinity intrusion in the vicinity of Turkey Point can be found in Prinos et al. (2014). Since the water-table gradient (and topographic gradient) towards the coast at Turkey Point is very low, and with the location of the saltwater interface being partially controlled by the water-table gradient, even slight reductions of the water-table gradient can cause substantial landward movement of the saltwater interface. The occurrence of landward gradients during the dry season promotes inland movement of saline groundwater.

CCS impact on saltwater intrusion. It has always been recognized that construction of the CCS without any mitigating salinity-control systems would cause the saltwater interface to move further inland. This expectation was based on the assertion that construction of a CCS containing saline water one mile inland from the coast is tantamount to moving the coast one mile inland, and also moving the associated saltwater wedge around one mile inland. Since water in the CCS has a higher salinity than seawater, and is therefore denser that the water in Biscayne Bay, the effect of the CCS is actually greater than moving the coast one mile inland. The engineering consultants that originally analyzed the performance of the CCS further asserted that if the water level in the CCS were to be increased by 0.50 ft above the preconstruction water-table elevation, then the toe of saltwater wedge at the base of the Biscayne aquifer might move approximately 7.5 miles further inland during the dry season as compared to its original location during the dry season. The engineering consultants also asserted that in the wet season, an elevated water level of 0.50 ft in the CCS might move the toe of the saltwater wedge approximately 1 mile further inland compared to its original location during the wet season. Based partially on these expectations, the salinity-control system that is currently in place was designed to control the westward migration of saltwater originating in the CCS. This control system involves pumping water from a so-called "interceptor ditch" into the CCS in order to create a seaward hydraulic gradient between the L-31E Canal and the interceptor ditch, where the L-31E Canal is located to the west of the interceptor ditch. The protocol for operating this salinity-control system and the effectiveness of the system are discussed in Section 4.2 of this report.

Trituim as a tracer. Tritium is a naturally occurring radioactive isotope of hydrogen (^3H) that is produced in the atmosphere, is naturally found in very small or trace amounts in groundwater throughout the world, and has a half life of approximately 12.32 years. Tritium is also a byproduct of the production of electricity by nuclear power plants, and elevated levels of tritium are commonly found in the cooling water of nuclear power plants. Tritium has been selected by the cognizant regulatory agencies (SFWMD and DERM) as a tracer to track the movement of CCS water in the Biscayne aquifer. The drinking-water standard for tritium is 20,000 picocuries per liter (pCi/L).

Tritium concentrations in the vicinity of CCS. Data collected and analyzed by Prinos et al. (2014) showed that natural tritium concentrations in southern Miami-Dade county average around 4.2 pCi/L with a standard deviation of 2.6 pCi/L. Prinos et al. (2014) also noted that groundwater samples collected within 5.3 miles of the CCS had elevated levels of tritium, with measured tritium concentrations in this proximal area being in the range of 13 – 173 pCi/L, with an average concentration of 40 pCi/L.

Using tritium to trace the movement of CCS water in the Biscayne aquifer. Historical data from 1974 to 1975 showed tritium concentrations in the CCS to be in the range of 1556 – 4846 pCi/L, and reports submitted by FPL for the monitoring period from June 2010 through December 2011 showed CCS tritium concentrations in the range of 1260 – 14,280 pCi/L. Natural groundwater at the base of the Biscayne aquifer would be expected to have relatively low concentrations of tritium. A threshold concentration of 20 pCi/L has been used as a baseline to infer the presence of groundwater originating from the CCS. Groundwater with concentrations below 20 pCi/L are presumed not to be significantly affected by the CCS. FPL does not concur with the selection of 20 pCi/L as a threshold for background tritium concentration for surface water, pore water, or shallow groundwater. The basis of FPL's contention regarding the 20 pCi/L threshold is that multiple factors such as atmospheric deposition, vapor exchange, and errors in laboratory analysis can influence reported tritium levels. The FPL assertion is reasonable and is supported by measured data that indicate atmospheric and vapor exchange effects on tritium concentrations can be particularly significant in surface water and shallow groundwater, with significance decreasing with distance from the CCS. However, at depth, the CCS appears to be the primary source of tritium, and using tritium as a tracer in the lower elevations of the Biscayne aquifer is reasonable. Reported measurements show groundwater tritium concentrations in excess of 3000 pCi/L near the CCS, with concentrations decreasing with distance from the CCS, and found at concentrations of hundreds of pCi/L three miles west of the CCS at depth. The tritium-concentration contours derived from measurements in deep wells (within the Biscayne aquifer) surrounding the CCS were documented by Ecology and Environment, Inc. (2012c) and these contours are shown in Figure 3. The contours shown in Figure 3 support the assertion that the CCS is the source of tritium in the

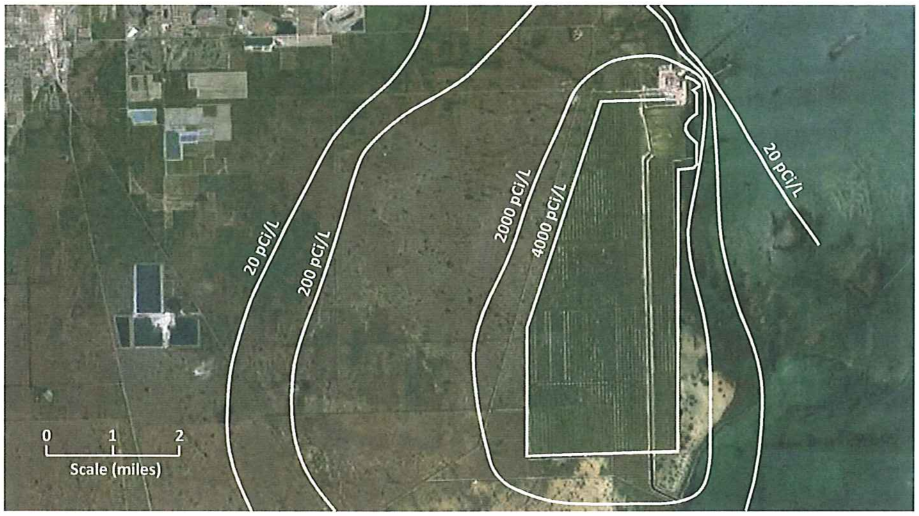


Figure 3: Tritium-concentrations derived from deep wells surrounding the CCS

groundwater at the bottom of the Biscayne aquifer, indicating that some of this groundwater originated from the CCS. The approximate limit of the 20 pCi/L concentration contour is 3.8 – 4.7 mi west of the CCS and 2.1 mi east of the CCS. Based on these data and supporting analyses, it is reasonable to conclude that operation of the CCS has impacted the salinity of the Biscayne aquifer at least within the limits of the 20 pCi/L contour. The presence of elevated levels of tritium above natural background levels in the Biscayne aquifer is not considered to be a threat to public health and safety, since the measured concentrations are far below the federal drinking water standard of 20,000 pCi/L. Elevated levels of tritium are simply being attributed to the presence of water originating in the CCS.

Groundwater flows around the CCS. Any representative model of groundwater flow in the aquifer surrounding the CCS must necessarily account for temperature and salinity effects. This approach is necessary since flows in the vicinity of the CCS are influenced by spatial variations in density, and the density distribution in the groundwater depends on both the temperature and salinity distribution. A simplified two-dimensional cross-section model of the portion of the Biscayne aquifer surrounding the CCS was developed by Hughes et al. (2010) using the SEAWAT code (Langevin et al., 2007). The focus of the Hughes et al.

(2010) model was to study the dynamics of density-driven groundwater flow and salinity transport for a variety of assumed realistic aquifer hydrogeologic properties. Results generated by Hughes et al. (2010) showed that the base of the Biscayne aquifer immediately under the CCS can be expected to have a salinity roughly equal to that of the water in the CCS, indicating a uniform salinity distribution over the 100-ft aquifer depth under the CCS. The temperature at the base of the aquifer under the CCS can be expected to have an equilibrium temperature of around 80% of the temperature of the CCS water. This combination of salinity and temperature indicates that the density of the groundwater at the base of the aquifer under the CCS is greater than the density of water in the CCS, since the density of water is inversely proportional to temperature. The Hughes et al. (2010) model showed that the extent of salinity intrusion attributable to operation of the CCS is very sensitive to the salinity of the water in the CCS. For example, increasing the salinity in the CCS from 35‰ to 70‰ (i.e., by a factor of 2) increased the extent of of salinity intrusion by a factor of 6. This result lends support to the effectiveness of a strategy of reducing CCS salinities as a means of reducing salinity intrusion caused by operation of the CCS. The Hughes et al. (2010) model also showed that the time taken for a salinity plume originating at the CCS-aquifer interface to penetrate the 100-ft depth of the aquifer could be anywhere from a few days to 5 years, depending on the hydraulic conductivity distribution over the depth of the aquifer. Since Hughes et al. (2010) investigated a range of plausible aquifer hydraulic conductivity distributions, the aforementioned result indicates that greater certainty in the subsurface hydrogeology is required in order to provide reasonably accurate estimates of the time required to arrest salinity intrusion by reducing the salinity of the water in the CCS.

1.6 L-31E Canal and Interceptor Ditch

L-31E Canal Levee L-31E and its adjacent 20-ft deep borrow canal to the west of the levee were primarily constructed as a barriers to prevent salinity intrusion to locations west of the canal. The L-31E Canal collects water from other drainage canals in the area, including Military Canal, North Canal, Florida City Canal, North Model Land Canal (C-106), and South Model Land Canal (C-107). The L-31E Canal discharges into Biscayne Bay through structures S-20 and S-20F in the vicinity of Turkey Point. The L-31E Canal was constructed in the late 1960's by the U.S. Army Corps of Engineers and the Central and Southern Florida Flood Control District (FCD); in 1972 the FCD was renamed the South Florida Water Management District (SFWMD).

Interceptor-ditch control system. The interceptor-ditch (ID) salinity-control system was designed to prevent the seepage of water from the CCS westward within the Biscayne aquifer. The ID, which is located immediately to the west of the CCS, is occasionally pumped to create a seaward water-table gradient between the L-31E Canal to the west and the ID to the east, with the basis for the effectiveness of the ID control system being that groundwater originating in the CCS will be prevented from migrating towards the west in the presence of an eastward water-table gradient between the L-31E Canal and the ID. The ID is pumped when a natural seaward water-table gradient between the L-31E Canal and the ID does not exist, and usually this is needed only during the dry season (November – April). The ID is adjacent and parallel to cooling-canal number 32 (CC-32) at the western end of the CCS, and was constructed at the same time as the CCS. The ID is approximately 18 – 20 ft deep, 30 ft wide, and 29,000 ft (5.5 mi) long. Within the ID are two pump stations, with each station containing two pumps, each capable of pumping up to 15,000 gpm (21.6 mgd). There is no mechanism to transfer water between the ID and the CCS, except for the 4 pumps at the two pump stations. The L-31E Canal, ID, and CC-32 are all approximately parallel to each other and run at an angle of approximately $17°38'$ west of south. The perpendicular horizontal distance between the

L-31E Canal and the ID is about 1000 ft. When the ID is pumped, there is a quick and measurable response in water levels in the L-31E Canal and the monitoring wells closest to the ID, indicating that there is good connectivity between the ID, L-31E Canal, and nearby monitoring wells.

Interceptor ditch operating rule (1973 – 2011). The ID operating rule that was followed from the initial date of operation of the CCS in February 1973 up until December 2011 (i.e., for 38 years) was as follows:

- Whenever the water-surface elevation in the L-31E Canal is more than 0.2 ft higher than the water-surface elevation in CC-32, there is a seaward water-level gradient and no pumping is necessary.
- If the above criterion is not met, a seaward gradient is still taken to exist if the water-surface elevation in the L-31E Canal is more than 0.3 ft higher than the water-surface elevation in the ID. Under this condition no pumping is necessary.
- If neither of the above two criteria are met, pumping of the ID is initiated and the pumping rates are adjusted to meet the 0.3-ft water-level difference criterion between the L-31E Canal and the ID.
- Pumping is terminated when the criteria for a natural water-table gradient is met (without pumping).

Although this operating rule is no longer in effect, it is still relevant to this analysis since possible westward migration of saline water from the CCS into the Biscayne aquifer could have occurred while following this operating rule. This concern is discussed subsequently.

Interceptor ditch operating rule (2011 – present). A more conservative operating rule for the ID was initiated in December 2011 that considered freshwater piezometric-head equivalents rather than measured water-table elevations. This resulted in changes to the ID operating rule, and since December 2011 the ID operating rule in effect is as follows:

- If the L-31E Canal water-surface elevation minus the CC-32 water-surface elevation is equal to or greater than 0.30 ft then no pumping of ID is necessary, and a seaward gradient exists.
- If the L-31E Canal water-surface elevation minus the CC-32 water-surface elevation is less than 0.30 ft, a natural seaward gradient might still exist if the L-31E Canal water-surface elevation minus the ID water-surface elevation is equal to or greater than 0.30 ft and the density of the water in the ID is less than or equal to 1012 kg/m^3. If a density in the ID is greater than 1012 kg/m^3, a higher elevation difference between L-31E and the ID is necessary and can be calculated by converting the surface-water levels to freshwater piezometric-head equivalents.
- If a natural seaward gradient does not exist, create an artificial seaward gradient by pumping the ID until the ID is maintained at an elevation difference of at least 0.30 – 0.70 ft between the L-31E Canal and the ID, depending on the density of the ID water.

The primary change between this revised operating rule and the previous operating rule is the increase in the L-31E/ID/CC-32 water-level difference criteria and the consideration of variable-density effects. The use of freshwater piezometric-head equivalents provides a more rigorous approach to the operation of the ID.

Effectiveness of the ID salinity-control system. Both the current and previous operating rules of the ID salinity-control system have limited salinity-control effects and do not prevent the landward migration of saline water originating from the CCS under all conditions. Following either of these operating rules, pumping of the ID reduces the water level in the ID below that in the L-31E Canal thereby creating a seaward water-table gradient and presumably precluding westward migration of groundwater originating in the CCS. However, pumping water from the ID into the CCS generally elevates the water-surface in the CCS and it is possible for the water level in the CCS to be above the water level in the L-31E Canal, which then creates the possibility that water originating in the CCS could pass under the ID even when the pumps in the ID are running to prevent this occurrence. Interestingly, this scenario was recognized in an early report prepared by the design engineers (Dames and Moore, 1971) based on results derived from an analog model of the system. The analog model showed that westward migration of the saltwater interface is possible even if the ID operating rule is followed. Further, Golder (2008) stated that operation of the ID salinity-control system would prevent westward migration of CCS water "at least in the top 18 ft of groundwater." Measurements taken during ID pumping have in fact shown several occurrences where the water level in the CCS exceeds that in the L-31E Canal during ID pump operation, thereby indicating the possible ineffectiveness of the ID salinity-control system. In actuality, the functioning of the ID salinity-control system is more accurately characterized as intercepting shallow saline groundwater adjacent to the ID that is then pumped back to the CCS when the natural gradients are low and the potential for saltwater intrusion exists. It is possible that pumping of the ID under some circumstances simply creates a shallow subsurface (groundwater) circulation in which water from the CCS flows into the ID as groundwater that is subsequently returned to the CCS as pumped water. In support of this assertion, time series plots show that there are periods during pumping of the ID when the bottom-water temperatures in the ID rose along with an increase in specific conductance in the ID (Ecology and Environment, Inc., 2014). Aside from concerns regarding the effectiveness of the ID control system in mitigating saltwater intrusion, secondary concerns have also been raised that the ID control system contributes to the deterioration of groundwater quality in that it generally pumps less-saline water from the ID into the hypersaline CCS which further contributes to increased salinity in the aquifer.

2 Temperature Variations in the Cooling Canals

The temperature in the CCS at the intake to the power-generating units affect the efficiency and power output of the generating units that use water from the CCS. Both the efficiency and the power output of the generating units decrease with higher cooling-water temperatures. The practical upper limit of the intake cooling-water temperature is determined by the characteristics of the condensers and auxiliary heat exchangers in the generating units.

Maximum-allowable intake temperature. In 2014 the Nuclear Regulatory Commission granted FPL's request to increase the maximum intake cooling-water temperature for the nuclear-power generating units from 100°F to 104°F. Under the new rule, if the intake cooling-water temperatures in the CCS were to exceed 100°F, then FPL would be required to monitor the temperature at the cooling-water intake at least once every six hours[§] as long as the intake-water temperature exceeds 100°F. If the intake cooling-water temperatures in the CCS were to exceed 104°F, then FPL would be required to transition Units 3 and 4 into at least "hot stand by" mode within 12 hours, and to "cold shutdown" mode within 30 hours. Since curtailment of power generation would adversely affect a large number of customers in the South Florida

[§]The normal monitoring interval for the intake-water temperature is 24 hours.

service region, Miami-Dade County is obliged to work with FPL to find ways to avoid cutbacks in power generation resulting from elevated temperatures in the CCS.

2.1 Results from Previous Studies

2.1.1 Temperatures in the CCS

Water temperatures in the CCS are almost always higher than synoptic temperatures of the overlying air, and temperatures in the CCS are almost always higher than temperatures in nearby Biscayne Bay. Analyses done by FPL's engineering consultants in around 2008 anticipated that the uprate of Units 3 and 4 would cause a maximum temperature increase of 2.5°F (1.4°C) in the cooling water discharged to the CCS and an increase of 0.9°F (0.5°C) in the temperature of the intake water (SFWMD, 2008). These temperature changes were predicted to result in an increase in evaporation from the CCS of around 2 – 3 mgd, and the increased evaporation was expected to increase the salinity in the CCS by 2‰ – 3‰. In contrast to the aforementioned predictions, it has been generally reported that temperatures in the CCS have actually increased by 5 – 9°F (3 – 5°C) in the post-uprate period compared with the pre-uprate period. In the summer of 2014 (during the post-uprate period), temperatures in the CCS were sufficiently elevated as to prompt concern regarding the sustainability of the CCS as an adequate source of cooling water to the power-generating units. According to FPL's consultant (Ecology and Environment, Inc., 2014), the increase in CCS water temperatures in the post-uprate period cannot be attributed to the uprate since the total heat rejection rate to the CCS from Units 1, 2, 3, and 4, operating at full capacity prior to the uprate would have been higher than the post-uprate heat rejection rate to the CCS for Units 1, 3, and 4, operating at full capacity. Unit 2 in the post-uprate period has been dedicated to operate in a synchronous generator mode and hence not producing steam heat. It is important to note that the preceding argument presented by FPL's consultant is flawed, since power-generating units do not operate at full capacity over extended periods of time, and so the actual power generation (which affects the temperatures in the CCS) should not be inferred from power-generation capacity. Furthermore, with the post-uprate switch to a higher percentage of power being generated by the nuclear units, the capacity factor of the combined generating units serviced by the CCS would almost certainly be higher in the post-uprate period compared with the pre-uprate period.

2.1.2 Thermal Efficiency of the CCS

The thermal efficiency of the CCS is a measure of the ability of the CCS to cool the discharged water down to the background air temperature. An investigation of the thermal efficiency of the CCS was performed by Lyerly (1998), and these analyses indicated that the thermal efficiency of the CCS at the time of the Lyerly (1998) study was equal to 86.4%. This efficiency was based on a 24-h average discharge temperature of 107.3°F (41.8°C), average intake temperature of 91.1°F (32.8°C), and an average air temperature of 88.6°F (31.4°C). In analyzing the temperature measurements, Lyerly (1998) noted that most of the cooling (i.e., most of the temperature decrease) occurs as the water in the CCS flows from the (north) discharge location to the (south) collector canal, with much less temperature decrease as the water flows back from the collector canal to the (north) intake location. It is expected that the thermal performance varies with flow rate and the state of the CCS, so the reported thermal efficiency should be regarded more as a snapshot of conditions at the time of the measurements than as a constant value. More recent measurements between June 2010 and June 2012 (Ecology and the Environment, 2012) show water temperatures in the CCS on the discharge side of the power-generating units being around 13.5°F (7.5°C) warmer on average than at the intake side of the power-generating units. The average temperature at the south end of the CCS was only 2°F (1.1°C) warmer than at the intake side of the power-generating units, which supports the assertion that most of the cooling in the CCS occurs as the water flows from north to south.

2.1.3 Thermal Effects on Groundwater

Measured groundwater temperatures in some wells between the ID and the L-31E Canal show higher temperatures than the groundwater west of the L-31E Canal, and this occurrence has been partially attributed to limited cooling-canal water intrusion (Dames and Moore, 1977). A "groundwater thermocline" has been reported to exist in the area west of the CCS, which shows a sudden decrease in groundwater temperature at a particular depth in the aquifer. Measurements show that nearly all of the seasonal temperature fluctuations occur above an elevation of −25 ft NGVD. Below −25 ft NGVD, the groundwater temperature generally remains in the range of 75°F – 77°F (24°C – 25°C). The seasonal temperature fluctuations above −25 ft NGVD have been attributed to the heating and cooling of water in the L-31E Canal in response to seasonal changes in atmospheric conditions. Notably there is some temperature stratification in the L-31E Canal, in part due to the canal depth and limited flow. The near-surface water temperatures in the L-31E Canal are almost always warmer than the bottom temperatures, and the surface temperatures exhibit more daily variability in response to air-temperature changes. Aside from the groundwater adjacent to the L-31E Canal, it has also been reported (Ecology and Environment, Inc., 2014) that since groundwater in monitoring wells TPGW-2M and TPGW-2D is warmer than other nearby surface waters such as Biscayne Bay or fresh groundwater, the CCS might be influencing the groundwater temperatures in those wells. Based on modeling results reported by Hughes et al. (2010), subsurface temperature variations in the immediate vicinity of the CCS are of sufficient magnitude to significantly influence the density-driven groundwater flow in the aquifer, particulary in the immediate vicinity of the CCS. As a consequence, temperature variations in the aquifer must be regarded as significant, and therefore taken into account in modeling the extent of intrusion of CCS water into the Biscayne aquifer.

2.2 Heat-Balance Model of CCS

To fully understand the temperature dynamics in the CCS, it is necessary to have a validated heat-balance model of the CCS. In reviewing the documentation made available for this investigation, all indications were that such a model does not currently exist, at least not in the public domain. Historical documentation shows that a heat-balance model was developed in the early stages of operating the CCS, as reported by Ray L. Lyerly Associates (1973), however, utilization of this model has not been subsequently reported. As described by Lyerly (1973), the heat-balance model that was developed previously took into account such key components as the heat input from the power-generating units, the net heat entering the water from shortwave solar radiation and longwave atmospheric radiation, and the latent heat transfer associated with evaporation. The input variables in the thermal model were the air temperature, relative humidity, wind speed, and the net amount of radiation; the output variable was the water temperature in the CCS.

2.2.1 Heat-Balance Model Formulation

To investigate and understand the thermal dynamics within the CCS, a preliminary heat-balance model of the CCS was developed for this study. The CCS was divided into four zones as shown in Figure 4, where water in the CCS flows sequentially through zones 1, 2, 3, and 4. The four delineated zones are the same zones that are used in salinity-balance model of the CCS developed by an engineering consultant for FPL. The measurement stations that characterize conditions within each of the four CCS zones were taken as

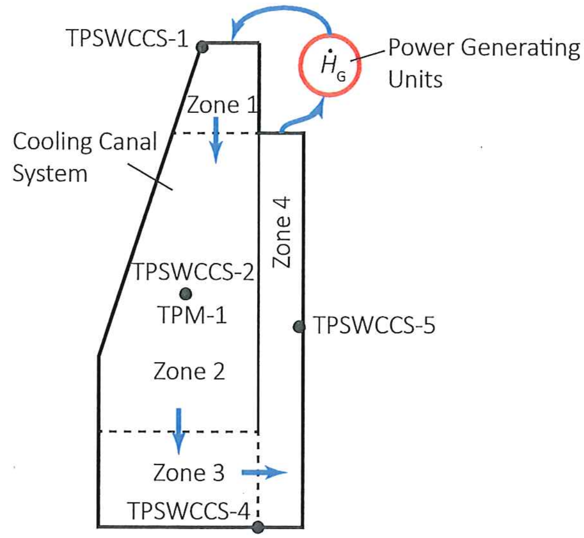


Figure 4: Cooling-canal system

TPSWCCS-1, TPSWCCS-2, TPSWCCS-4, and TPSWCCS-5, respectively, and the approximate locations of these measurement stations are shown in Figure 4. The average-daily temperature measurements within each of the CCS zones in the period 9/1/10 – 12/7/14 are shown in Figure 5. It is apparent from these

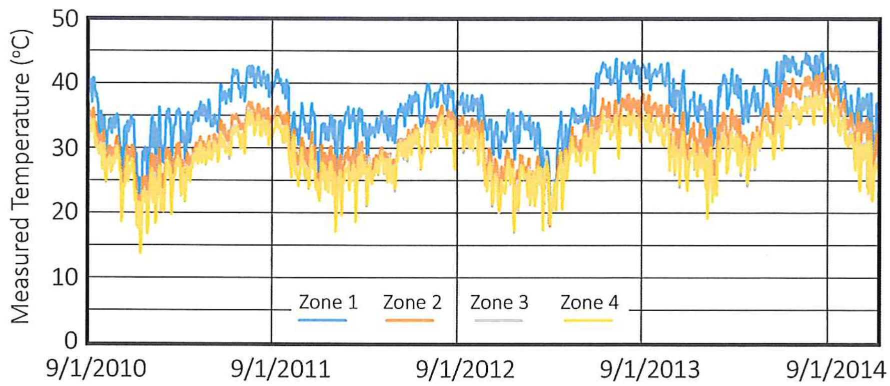


Figure 5: Temperature measurements in CCS

measurements that the temperatures in the CCS decrease noticeably from zones 1 to 3 (i.e., moving from north to south in the CCS), with much less temperature change as the water moves back to the northern (cooling-water intake) end of the CCS through zone 4. Therefore, almost all of the cooling in the CCS occurs in the south-flowing canals in the western portion of the CCS. It is further apparent from the temperature measurements shown in Figure 5 that the midsummer temperatures in the CCS in 2014 (between July and August) were higher than the midsummer temperatures in the CCS in previous years. For the period of record (9/1/10 – 12/7/14), the maximum measured daily-average temperature in Zone 1 was 113°F (44.9°C) recorded on 8/21/14, and the maximum measured daily-average temperature in Zone 4 was 101°F (38.3°C) recorded on 8/22/14. Since the maximum allowable temperature at the cooling-water intake is 104°F and measured temperatures in Zone 4 have been close to this limiting value (e.g., 101°F recorded on 8/22/14), there is cause for concern. Temperatures in Zone 4 near the 104°F limit could force curtailment of power generation by one or more of the nuclear-power generating units, and cause power outages in South Florida. Given the elevated temperatures that have been recorded in the CCS, is necessary to identify the fundamental reasons for these occurrences, and to determine whether such occurrences are expected to continue in the future without any changes in the CCS and/or power-plant operations. To fully understand the temperature dynamics in the CCS it was necessary to develop a heat[¶]-balance model of the CCS, which is described in the following section.

2.2.2 Heat-Flux Components

The heat fluxes within each of the CCS zones are illustrated in Figure 6, where the volumetric inflow rate and temperature are Q_1 and T_1, respectively, and the corresponding quantities on the outflow side are Q_2 and T_2. Within each zone, there are several sources of energy that are represented in Figure 6. These energy sources

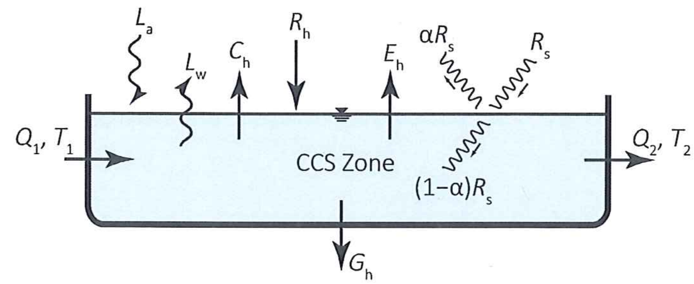


Figure 6: Energy fluxes in CCS zone

and their quantification are described below, where, for consistency with thermodynamic convention, energy added to CCS is taken as positive and energy losses are taken as negative.

Absorbed solar radiation, $(1-\alpha)R_s$. The incident solar (short-wave) radiation, which is normally available from direct measurements, is represented by R_s [$EL^{-2}T^{-1}$][‖], and the albedo (i.e., reflectivity) of the water surface is represented by α [dimensionless]. Therefore, the amount of solar radiation that is absorbed within the zone is $(1-\alpha)R_s$. The average solar radiation, R_s, for each day in the four-year study (9/1/10 – 12/7/14) was obtained from the Florida Automated Water Network (FAWN) station located on the premises of the University of Florida Tropical Research and Education Center (TREC) in Homestead, Florida. The albedo, α, of a water surface is typically on the order of 0.1 for latitudes in the range of 20° – 30° (Cogley, 1979), and a value of 0.1 was used as a reference value for this investigation. Factors such as the concentration of algae in the CCS can affect the value of α, and therefore the sensitivity of the temperature dynamics within the zone to elevated algae concentrations was investigated by varying α. The minimum value of α is equal to zero, in which case all of the

[¶]In this report "heat" and "thermal energy" are used interchangeably.

[‖]Terms in square brackets indicate dimensions: E = energy, L = length, M = mass, T = time, and Θ = temperature.

incident solar radiation is absorbed by the CCS and none is reflected. Hence, α was varied within the range of $0-0.1$.

Evaporation heat flux, E_h. Evaporation extracts heat from the CCS due to the latent heat of evaporation required to transform water from the liquid phase to the vapor phase. The evaporation heat flux, E_h [$\text{EL}^{-2}\text{T}^{-1}$], is given by

$$E_\text{h} = -E\rho_\text{f}L_\text{v} \tag{1}$$

where E [LT^{-1}] is the evaporation rate, ρ_f [ML^{-3}] is the density of fresh water, and L_v [EM^{-1}] is the latent heat of vaporization of water. The evaporation rate of water has long been known to decrease with increasing salinity (e.g., Harbeck, 1955; Salhorta et al., 1985). In the present study, daily evaporation rates, E, were calculated based on typical salinities in the CCS, measurements of water temperature, T_s [Θ], at the monitoring station within the zone, onsite measurements of air temperature, T_a [Θ] and relative humidity, RH [dimensionless] at station TPM-1, and measurements of wind speed, V_w, at station TD. The freshwater density, ρ_f, in Equation 1, was taken as 994 kg/m^3, which is the approximate density of fresh water at 35°C (95°F). The latent heat of vaporization, L_v, in Equation 1, is known to depend on both the temperature and salinity of the source (liquid) water. At a temperature of 35°C, values of L_v at salinities of 60‰ and 80‰ are 2.279 MJ/kg and 2.229 MJ/kg, respectively (Sharqawy et al., 2010), and an average of 2.254 MJ/kg was used for L_v in the energy analysis. The empirical formula used for estimating E [cm/d], from onsite meteorological measurements is

$$E = -\underbrace{C_\text{w}(0.299 + 0.11V_\text{w})}_{=f(V_\text{w})}\left[\beta e_\text{s}(T_\text{s}) - \text{RH}\, e_\text{s}(T_\text{a})\right] \tag{2}$$

where C_w [dimensionless] is a calibration constant, $f(V_\text{w}) = C_\text{w}(0.299 + 0.11V_\text{w})$ is a wind function that accounts for the effect of wind on evaporation, V_w is the wind speed in m/s, β [dimensionless] is a factor that accounts for the effect of salinity on the saturation vapor pressure of water, and $e_\text{s}(T)$ [kPa] is the saturation vapor pressure of water at temperature T. Equation 2 was used to calculate the evaporation for the sake of consistency with the previously developed salinity model of the CCS, where the constants C_w and β were taken as 0.69 and 0.885, respectively. In the salinity model, the value of C_w was determined by calibration, and the value of β was obtained from previous research on evaporation from saline water bodies reported by Salhorta et al. (1985). The evaporation formula given by Equation 2 has an uncertain functional form, particularly for the wind function $f(V_\text{w})$.

Uncertainty in the wind function. Wind functions used to estimate evaporation typically have the form $f(V_\text{w}) = a + bV_\text{w}$, where a and b are constants. Such a wind function is used in Equation 2. In artificially heated waters, vertical convection is particulary important under low-wind conditions making specification of the value of a a key parameter. The wind function used in Equation 2 was originally proposed by Williams and Tomasko (2009) for heated waters, however, alternate formulations have been proposed by others (e.g., Brady et al., 1969; Ryan and Harleman, 1973). Notably, the formulation proposed by Ryan and Harleman (1973), and subsequently supported by Adams et al. (1975), accounts for the effect of the temperature difference between the heated water and the overlying air in specifying the convection parameter a in the wind function, which is a logical relationship that is not accounted for in the other models (including the model used in this study) and could be an important consideration in accounting for convective heat transfer at low wind velocities.

Rainfall heat flux, R_h. Rainfall that is cooler than the water in the CCS extracts thermal energy from the CCS because thermal energy in the CCS water is used to warm the rainwater. The heat flux, R_h [$\mathrm{EL^2T^{-1}}$] due to rainfall directly on the CCS can be estimated using the relation

$$R_\mathrm{h} = -\rho_\mathrm{f} c_{p\mathrm{f}}\, d_\mathrm{r}(T_\mathrm{s} - T_\mathrm{r})$$

where ρ_f [$\mathrm{ML^{-3}}$] and $c_{p\mathrm{f}}$ [$\mathrm{EM^{-1}\Theta^{-1}}$] are the density and specific heat of the (fresh) rainwater, respectively, d_r is the depth of rainfall, T_s [Θ] is the temperature of the water in the CCS, and T_r [Θ] is the temperature of the rainfall. There are no direct measurements of rainfall temperature at the Turkey Point site, however, it can be estimated that during a rainfall event the ambient air can be cooled by several degrees, and the temperature of raindrops approaches that of the cooled ambient air. Cooling effects of rainfall on the ambient air have been reported to be as high as 10°C (Byers, 1949). On a global average, raindrops can have temperatures in the range of 32°F – 80°F (0°C – 27°C). For purposes of the present analysis, the temperature of the rainfall, T_r, was assumed to be 68°F (20°C), and the corresponding values of ρ_f and $c_{p\mathrm{f}}$ were taken as 998 kg/m^3 and 4.180 kJ/kg·°C, respectively. The temperature dynamics in the CCS zones are relatively insensitive to the assumed temperature of the rainfall.

Atmospheric longwave radiation, L_a. Any body of matter whose temperature is above absolute zero emits longwave radiation. Longwave radiation, L_a [W/m^2] emitted by the atmosphere can be estimated using the relation (Chin, 2013)

$$L_\mathrm{a} = \sigma(T_\mathrm{a} + 273)^4(0.6 + 0.031\sqrt{\mathrm{RH}\, e_\mathrm{s}(T_\mathrm{a})}(1 - R_\mathrm{L})$$

where σ is the Stefan-Boltzmann constant ($= 4.903 \times 10^{-9}\,\mathrm{MJ{\cdot}m^2K^{-4}d^{-1}}$), T_a [°C] is the air temperature, RH [dimensionless] is the relative humidity, $e_\mathrm{s}(T_\mathrm{a})$ [mm Hg] is the saturation vapor pressure of water at temperature T_a, and R_L is the longwave reflection coefficient that can be taken as 0.03. On cloudy days, atmospheric longwave radiation can be the greatest source of thermal energy at the water surface.

Water longwave radiation, L_w. Water in the CCS also emits longwave radiation by virtue of its temperature being greater than absolute zero. Longwave radiation, L_w [W/m^2] emitted by the water in the CCS can be estimated using the relation (Chin, 2013)

$$L_\mathrm{w} = -\epsilon\sigma(T_\mathrm{s} + 273)^4$$

where ϵ is the emissivity of water that can be estimated as 0.97 [dimensionless], σ is the Stefan-Boltzmann constant as given previously, and T_s [°C] is the temperature of the water in the CCS.

Heat interchange with surrounding aquifer, G_h. The CCS exchanges heat with the surrounding aquifer via seepage of groundwater into and out of the CCS, and conduction of heat between water in the CCS and both the groundwater and solid (limestone) matrix in the surrounding aquifer. It is to be expected that the region immediately surrounding the CCS is normally cooler than the water in the CCS, in which case there will be cooling of the CCS water due to heat conduction between the CCS and the surrounding aquifer, cooling due to seepage inflow from the surrounding aquifer into the CCS, and no cooling or heating due to seepage outflow from the CCS into the surrounding aquifer. The cooling heat flux due to conduction can be assumed to negligible compared to the heat flux due to seepage inflow. The heat flux G_h [$\mathrm{EL^{-2}T^{-1}}$] due to seepage inflow is proportional to the temperature difference between the water in the CCS and the groundwater in the surrounding aquifer and can be estimated by the relation

$$G_\mathrm{h} = -\rho_\mathrm{g} c_{p\mathrm{g}} \frac{Q_\mathrm{sg}}{A_\mathrm{s}} \Delta T_\mathrm{sg}$$

where ρ_g [ML^{-3}] and $c_{p\mathrm{g}}$ [EM$^{-1}\Theta^{-1}$] are the density and specific heat, respectively, of the groundwater surrounding the CCS, Q_sg [L^{3}T^{-1}] is the seepage inflow to the CCS from the surrounding aquifer, A_s [L^2] is the area of the CCS zone, and ΔT_sg [Θ] is the difference between the temperature in the CCS, T_s [Θ], and the temperature on the surrounding groundwater, T_g [Θ] (i.e., $\Delta T_\mathrm{sg} = T_\mathrm{s} - T_\mathrm{g}$)

Conduction heat flux, C_h. The conduction heat flux is associated with the sensible transfer of heat between the CCS water and the air above the CCS. The conduction heat flux, C_h [W/m^2] can be estimated using the empirical relation (Chin, 2013; Chapra, 1997)

$$C_\mathrm{h} = -c_\mathrm{B} f(V_\mathrm{w})\,(T_\mathrm{s} - T_\mathrm{a})$$

where c_B is Bowen's coefficient, and $f(V_\mathrm{w})$ is the wind function as defined in Equation 2. Following the guidance given in Chin (2013) and Chapra (1997), the value of c_B can be estimated as 0.063. According to Martin and McCutcheon (1998), sensible heat transfer from lakes and reservoirs to the overlying air due to conduction and convection is a relatively small component of the heat balance equation that is poorly understood, and Brown and Barnwell (1987) have noted that the conduction heat flux from lakes and reservoirs to the overlying air calculated by heat-transfer theory is normally small enough to neglect. Given the aforementioned considerations, conduction of heat between the CCS and the overlying air was neglected in this analysis.

The sum of the above-described heat-flux components gives the net heat flux into to the CCS due to the combined effects of solar radiation, evaporation, longwave radiation, seepage, and conduction. The heat dissipated by the CCS is equal to the negative of this summation.

2.2.3 Steady-State Energy Model

In terms of the component heat fluxes described in the previous section, the steady-state heat-balance equation for the CCS is given by

$$\dot{H}_\mathrm{G} = -\sum_{i=1}^{4} \Big\{ \left[(1-\alpha)R_\mathrm{s} + E_\mathrm{h} + R_\mathrm{h} + L_\mathrm{a} + L_\mathrm{w} + G_\mathrm{h}\right]_i A_i \Big\} \tag{3}$$

where $\dot{H}_\mathrm{G}$ [EL^{-2}T^{-1}], is the heat-rejection rate of the power-generating units that are serviced by the CCS, i is an index that refers to each zone within the CCS, A_i [L^2] is the area of Zone i, and the summation is over the four zones within the CCS. The average water-surface area in each CCS zone during the period 9/1/10 – 5/31/14 is given in Table 1, and the average total area of the CCS water surface during this period was approximately 1886 ha (= 4685 ac = 7.32 mi^2).

Table 1: CCS Zonal Areas in Energy and Salinity Models

Zone	Area (ha)
1	187.7
2	988.1
3	349.1
4	371.1
Total	1896.0

2.2.4 Model Application

Application of the heat-balance model given by Equation 3 consists of first calculating the the component heat fluxes in each zone of the CCS, and then summing the component heat fluxes to estimate the rate at which heat is being added to the CCS by the power-generating units. A daily time step is used in the calculations, and so daily-averaged heat-rejection rates are estimated. Two key aspects of these calculations are given below.

Cooling from ID pumpage. The heat extracted from the CCS by pumping cooler water from the ID into the CCS was calculated in a similar manner to the method used to calculate the cooling effect of rainfall, where the "effective" rainfall rate is equal to the volume of water pumped from the ID divided by the area of the CCS. Assuming (conservatively) that the temperature difference between the ID water and the CCS water is 10°C (50°F), the cooling effect of pumped ID water was found to be negligible compared with other component fluxes in the heat-balance equation.

Estimation of heat-rejection rate. The heat-balance model used in this study, given by Equation 3, assumes that on any given day the heat added to the CCS (by the power-generating units, solar radiation, and atmospheric longwave radiation) is equal to heat loss from the CCS (by evaporation and longwave radiation). It is assumed that heat storage due to stage changes on any given day is small relative to the other heat-flux terms. Since daily stage changes are typically less than 2% of the local CCS depth, the assumption of a relatively small change in heat storage over daily time scales within the CCS is justified. In cases where daily time steps are used, estimated values of $\dot{H}_{\mathrm{G}}$ given by Equation 3 might fluctuate about a mean value and be difficult to discern. In such cases, the average heat-rejection rate, $\langle \dot{H}_{\mathrm{G}} \rangle_J$, over a period of J time steps can be estimated using the relation

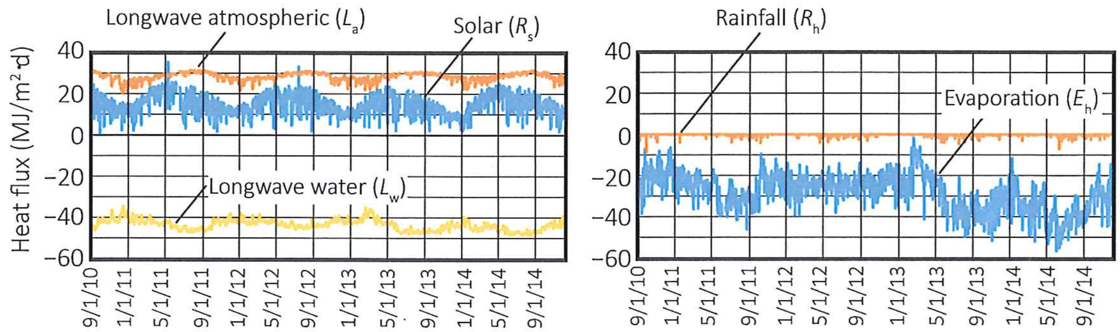
$$\langle \dot{H}_{\mathrm{G}} \rangle_J = \frac{1}{J\Delta t} \sum_{j=1}^{J} \dot{H}_{\mathrm{G}} \Delta t \tag{4}$$

where Δt is the duration of each time step. In accordance with Equation 4, a constant heat-rejection rate can be recognized by plotting the cumulative estimated heat rejection rate, $\sum_{j=1}^{J} \dot{H}_{\mathrm{G}} \Delta t$, versus time, $J\Delta t$, which would would result in a straight line of constant slope equal to $\langle \dot{H}_{\mathrm{G}} \rangle_J$. This relationship was used in this study to identify periods of constant heat rejection rate of the power-generating units that utilize the CCS.

2.2.5 Model Results

The heat-balance model was applied to each of the four zones within the CCS to determine the net heat flux into each zone, and the results from all zones were combined to determine the net heat flux into the entire CCS. The heat-balance model was applied at daily time steps for the period of record, 9/1/10 – 12/7/14. The thermal-energy dynamics within each of the CCS zones are similar, and the temporal variations of the heat-flux components in Zone 1 will be used to demonstrate the thermal-energy dynamics within each zone.

Zone 1 heat-flux components. The longwave radiation and shortwave solar energy fluxes as a function of time are shown in Figure 7(a), and the evaporation and rainfall heat fluxes as a function of time are shown in Figure 7(b). It is apparent that the shortwave and longwave energy fluxes vary seasonally, and there is much



(a) Longwave and solar energy

(b) Rainfall and evaporation energy

Figure 7: Energy fluxes in Zone 1

more seasonal variation in the shortwave solar radiation than in the longwave radiation. The net longwave radiation has a cooling effect (i.e. net negative heat flux) which contributes to a net-radiation cooling of the CCS water at night when the solar radiation is effectively zero. It is apparent from Figure 7(b) that evaporation and rainfall generally have a cooling effect, with evaporation usually having the greater cooling effect and rainfall having a lesser cooling effect. The convective heat flux between the CCS and the adjacent groundwater, G_h, is not shown in Figure 7 because the magnitude of G_h is generally much smaller that the heat flux due to rainfall, and therefore has a minimal impact on the heat balance within the CCS.

Heat rejection rate of the power-generating units. To determine the thermal dynamics in the entire CCS, the component heat fluxes were determined for each zone within the CCS, and these heat fluxes were combined in accordance with Equation 3 to determine the thermal energy that is added to the CCS by the power plant (i.e., the heat-rejection rate). The cumulative heat-rejection from the power plant as a function of time for the entire CCS is shown in Figure 8. It is apparent from Figure 8 that there are two periods during which the heat rejection rate is approximately constant. The first period, shown as Period 1 in Figure 8, covers the time interval 9/1/10 – 2/1/13, and the second period, shown as Period 2 in Figure 8 covers the time interval 7/1/13 – 12/1/14. Notably, Period 1 includes the pre-uprate period before February 2012 and Period 2 includes the post-uprate period after May 2013. During Period 1, the average heat-rejection rate is estimated to be around 2600 MW, and during Period 2 the average heat-rejection rate is estimated to be around 5300 MW. Although these estimated heat rejection rates are preliminary estimates and derived from

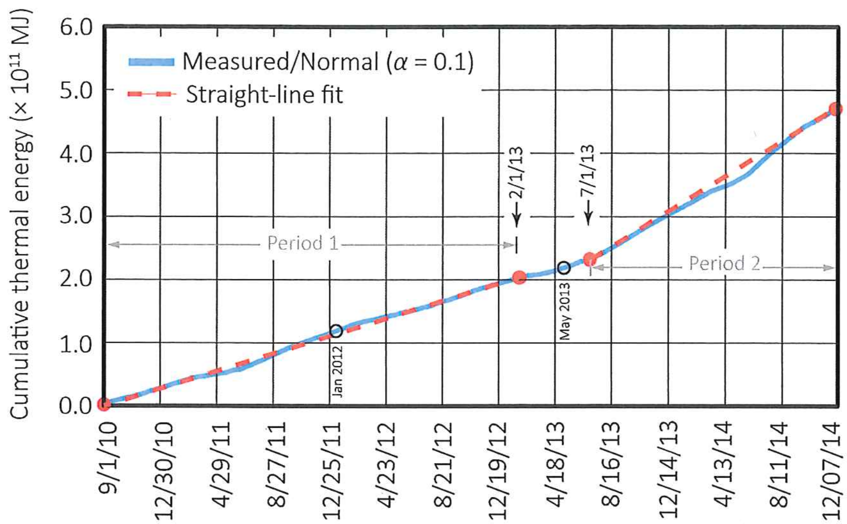


Figure 8: Cumulative heat rejection rate from the power plant

an uncalibrated heat-balance model, the distinct difference in heat-rejection rates between the two periods is clear, and the estimated magnitudes of the heat-rejection rates during these two periods are reasonable given the capacities of the power-generating units serviced by the CCS and the energy efficiencies normally associated with fossil-fuel and nuclear power plants. A logical inference from the results shown in Figure 8 is that the uprate in power-generating capacity of the two nuclear units (Units 3 and 4) has caused the total heat-rejection rate from the power plant to increase significantly. This finding is not inconsistent with the condition that the post-uprate generating capacity of the power plant served by the CCS is less than the pre-uprate generating capacity (due to Unit 2 operating in synchronous generator mode). This is so because in the post-uprate generating capacity there is a significant shift from fossil-fuel generation to nuclear-power generation, and nuclear-power units are known to have much higher heat-rejection rates to cooling water than fossil-fuel generating units, which release a significant portion of their waste heat in flue-gas emissions. In addition, nuclear units typically have much higher capacity factors than fossil-fuel generating units, which means that the actual power generation is likely to be closer to the generating capacity under post-uprate conditions than under pre-uprate conditions.

Effect of reduced flows in the CCS. According to FPL, the uprate of Units 3 and 4 between January 2012 and May 2013 resulted in reduced CCS flow rates of up to 50% for a period of approximately 16 months. If the anomalous period with reduced CCS circulation (January 2012 – May 2013) were excluded from the heat-budget analysis, this would not affect the conclusion that the post-uprate heat rejection rate to the CCS is significantly higher than the pre-uprate heat-rejection rate. This assertion is apparent from Figure 8, which shows that the heat-rejection rate prior to January 2012 is approximately the same as that asserted for the entire Period 1, and the anomalous flow period (January 2012 – May 2013) does not overlap with Period 2. Consequently, the asserted pre- and post-uprate heat-rejection rates would be approximately the same if the anomalous flow period were excluded from the analysis, and hence inclusion of the anomalous flow period does not significantly affect the heat-budget analysis and the derived conclusions.

Data supporting increased heat rejection rate. Using the uncalibrated heat-balance model, the average heat-rejection rate prior to 2/1/13 (Period 1) is estimated as 2600 MW, and after 7/1/13 (Period 2) is estimated as 5300 MW. Power-generation data for the units serviced by the CCS for the months included in Periods 1 and 2 were documented by Ecology and Environment, Inc. (2012; 2014) and Nuttle (2015a; 2015b) and these data are plotted in Figure 9. For the months within Period 1, the average power generation (shown in red in

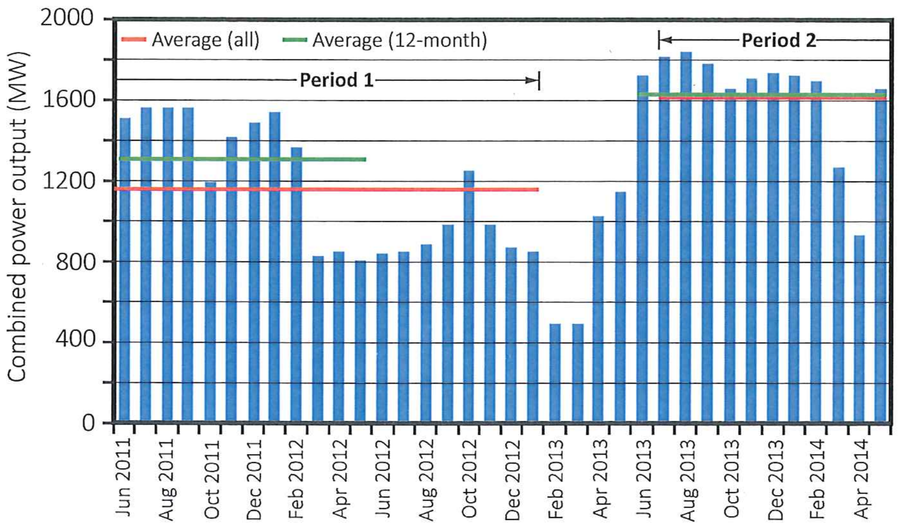


Figure 9: Power-generation in Periods 1 and 2

Figure 9) was 1160 MW, and for the months within Period 2 the average power generation (also shown in red) was 1620 MW. Using these data, the plant efficiencies during Periods 1 and 2 are approximately 31% and 23%, respectively, which are on the order of magnitude that one would expect from the mix of fossil-fuel and nuclear-power generating units being serviced by the CCS. To account for possible seasonalities in power generation, 12-month average power generation (shown in green in Figure 9) were 1307 MW and 1629 MW for Periods 1 and 2, respectively, which correspond to plant efficiencies of 33% and 24%, respectively. For both of the scenarios considered here, the estimated heat-rejection rates appear to be quite reasonable for the given power-generation rates. The results presented here are further supported by data contained in a recent report by the Electric Power Research Institute (EPRI, 2012). These data show the summer capacity of each nuclear unit as 693 MWe, with a corresponding thermal output of 2300 MWth, indicating a unit efficiency of 23% which is remarkably close to the plant efficiencies derived from the heat-balance model developed in this study.

Effect of algae. It is assumed that increased algae concentrations in the CCS affect the heat balance in the CCS by increasing the amount of solar energy that is absorbed by the CCS. Consequently, the effect of elevated algae concentrations in the CCS was investigated by reducing the albedo (i.e., reflectivity), α, of the water surface from 0.1 to 0.0 starting on January 1, 2014. An albedo of 0.1 was used in the "normal" simulations presented in Figure 8 since this is the typical value of α that is associated with water surfaces at subtropical latitudes; this corresponds to 90% of the incident solar radiation being absorbed by the water in the CCS. Assuming that the effect of algae is to retain more solar heat, then taking $\alpha = 0$ represents the extreme case where the CCS with high concentrations of algae absorbs 100% of the incoming solar radiation. The effect of reducing α from 0.1 to 0.0 on the estimated cumulative heat-rejection rate is shown in Figure 10. It is apparent from Figure 10 that the impact of the higher absorption rate of solar energy

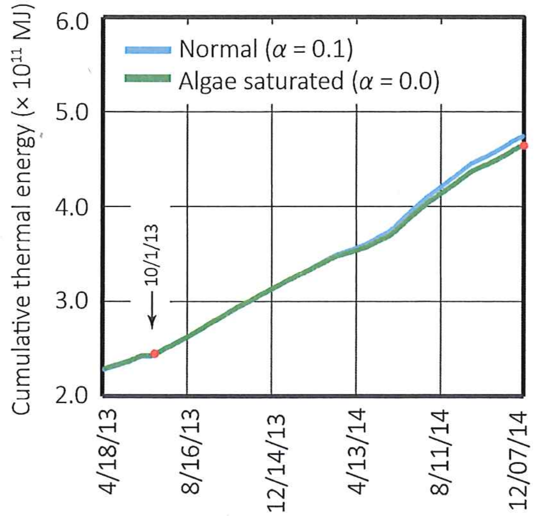


Figure 10: Estimated algae effect on estimated cumulative heat rejection rate from the power plant

attributed to high algae concentrations is relatively small compared with the heat rejection rate of the power-generating units. In quantitative terms, the increased rate of heating of the CCS due to reduced reflection of solar energy is around 400 MW, compared with a normal heat rejection rate of around 5500 MW (in 2014). This indicates that the (maximum) rate of increased heating caused by algae is only around 7% of the normal heat-rejection rate, and hence there is a relatively small heating effect caused by algae in the CCS.

Relationship between increased net heat flux and temperature. An increased heat-rejection rate would normally be expected to increase the temperature in the CCS relative to the temperature of the overlying air. Representing the temperature in the CCS as T_s, and the temperature of the overlying air as T_a, this temperature difference is $T_s - T_a$. The variation of $T_s - T_a$ as function of time for each of the four CCS zones is shown in Figure 11, where the average temperature difference during Period 1 and Period 2 are shown as horizontal lines. It is apparent from Figure 11 that the increase in the average heat-rejection rate from Period 1 to Period 2 corresponds to an increase in the average value of $T_s - T_a$. Representing the average value of $T_s - T_a$ during Period 1 as $\overline{\Delta T}_1$ and the average value of $T_s - T_a$ during Period 2 as $\overline{\Delta T}_2$, these averaged values for each CCS zone are shown in Table 2, along with the corresponding standard deviations, S_1 and S_2, respectively. These results show that in Zone 1, which accepts the cooling-water discharge, the average temperature difference between the CCS and the overlying air has increased from 9.6°C (17.3°F) to 13.1°C (23.6°F), which corresponds to an average temperature increase of 3.5°C (6.3°F). In Zone 4, which contains the cooling-water intake, the average temperature difference between the CCS and the overlying air has increased from 2.8°C (5.0°F) to 5.4°C (9.7°F), which corresponds to an average temperature increase of 2.6°C (4.7°F). These changes in average temperature can be contrasted with previous (pre-uprate) predictions made by FPL's engineering consultants in 2008 where it was anticipated that the uprate of Units 3 and 4 would cause a maximum temperature increase of 1.4°C (2.5°F) in the discharged cooling water (to Zone 1) and an increase of 0.5°C (0.9°F) in the temperature of the intake water

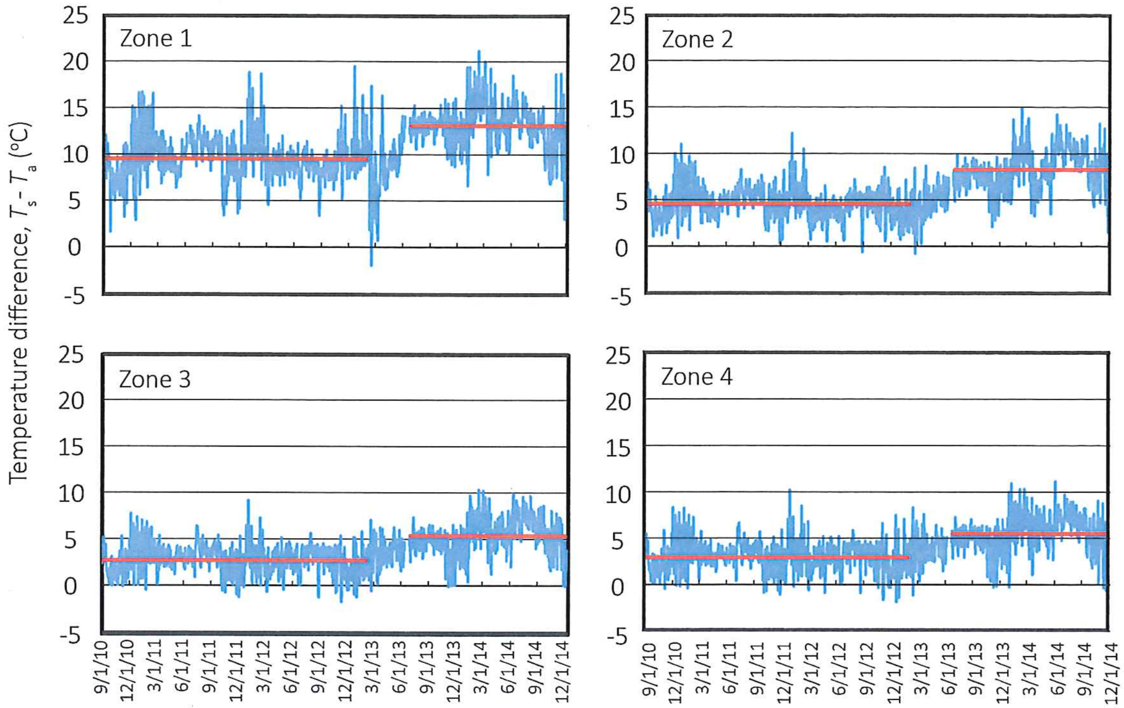


Figure 11: Temperature differences between CCS and overlying air. Horizontal lines show intervals of constant heat-addition rates.

(from Zone 4). The standard deviations of the temperature fluctuations are similar across all zones, and have shown relatively modest decreases between the pre-uprate and post-uprate periods. Of particular interest, in Zone 1 the standard deviation decreased from 3.8°C (6.8°F) to 3.3°C (5.9°F), and in Zone 4 the standard deviation decreased from 3.9°C (7.0°F) to 3.5°C (6.3°F).

Thermal efficiency. The thermal efficiency, η_t, of the CCS is a measure of the ability of the CCS to cool the water down to the background air temperature. The thermal efficiency of the CCS was previously measured by Lyerly (1998) using the relation

$$\eta_t = 1 - \frac{T_i - T_a}{T_d - T_a} \tag{5}$$

where T_d and T_i are the temperatures of the cooling water at the discharge and intake ends of the power plant, respectively, and T_a is the temperature of the ambient air above the CCS. The thermal efficiency of the CCS can be estimated using Equation 5 by replacing $T_d - T_a$ by the average value of $T_s - T_a$ in Zone 1, and replacing $T_i - T_a$ by the average value of $T_s - T_a$ in Zone 4. Using the averaged temperature differences given in Table 2 in Equation 5 gives:

$$\text{Period 1: } \eta_t = 1 - \frac{2.8}{9.6} = 0.71, \qquad \text{Period 2: } \eta_t = 1 - \frac{5.4}{13.1} = 0.59$$

These results indicate that the thermal efficiency of the CCS in Period 1 is around 70% and the thermal efficiency of the CCS in Period 2 is around 60%. Hence, the thermal efficiency of the CCS has apparently

Table 2: Temperature Statistics in CCS

	Period 1		**Period 2**			
	$\overline{\Delta T_1}$	S_1	$\overline{\Delta T_2}$	S_2	$\overline{\Delta T_2} - \overline{\Delta T_1}$	
Zone	(°C)	(°C)	(°C)	(°C)	(°C)	(°F)
1	9.6	3.8	13.1	3.3	3.5	6.3
2	4.6	3.7	8.4	3.7	3.8	6.8
3	2.9	3.9	5.5	3.6	2.6	4.7
4	2.8	3.9	5.4	3.5	2.6	4.7

decreased between Period 1 and Period 2. The reason for this decrease in thermal efficiency is not readily apparent and could be due to a variety of factors, including increased thermal loading, inefficient flow distribution, and increased algae concentrations and turbidity in the CCS. It should be noted that the thermal efficiency of 86% reported by Lyerly (1998) is not directly comparable to the values calculated here, since the additional cooling between the discharge location and the Zone 1 temperature measurement station, as well as the additional cooling between the intake location and the Zone 4 temperature measurement location are not taken into account in the present analysis.

Efforts to improve thermal efficiency. FPL has undertaken significant efforts to improve the thermal efficiency of the CCS by reducing flow restrictions (blockages) caused by elevated sediment levels and other impediments in the CCS. Sediment removal from the CCS was conducted between March and October 2015, with the intention of redistributing the flow and recovering the design flow depths in portions of CCS. FPL has reported that the thermal efficiency of the CCS was approximately 65% in August 2015 (see Appendix A). However, the extent to which the removal of blockages will contribute to increased thermal efficiency in the CCS is unknown at this time. The temporal trend in the thermal efficiency of the CCS is shown in Figure 12[**], where it is apparent that the pre-uprate thermal efficiency averaged around 77% and the post-uprate thermal efficiency is currently averaging around 67%. Under the best-case scenario, the thermal efficiency of the CCS would be improved to levels that are sufficiently greater than the pre-uprate thermal efficiency so as to compensate for the increased heat loading that is occurring under post-uprate (current) conditions. If this best-case scenario is not achieved, then post-uprate temperatures in the CCS can be expected to continue being greater than pre-uprate temperatures in the CCS. Based on the data shown in Figure 12, it is not apparent at this time that the post-uprate thermal efficiency is trending towards recovering the pre-uprate thermal efficiency. As a consequence, temperatures in the CCS are expected to continue being elevated relative to pre-uprate temperatures.

2.2.6 Conclusions

The results derived from the heat-balance model indicate that the rate of heat addition to the CCS has increased significantly during the period of record, and that the increased heat-addition rate is manifested in an increase in the average temperature in the CCS relative to the temperature of the overlying air. It appears that the most likely cause for the increased heat-addition rate is an increased heat-rejection rate from the

[**] From data contained in the FPL response to the preliminary report.

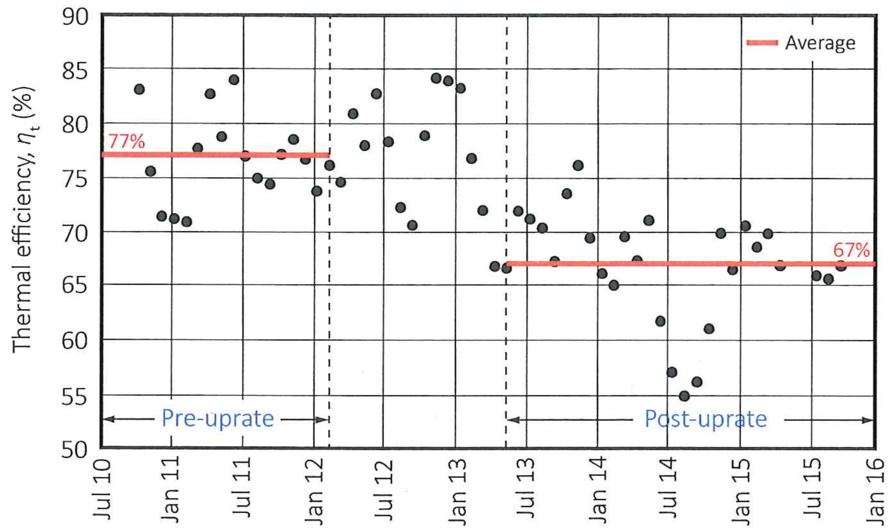


Figure 12: Thermal efficiency of the cooling canal system

power-generating units. Notably, the increased heat-addition rate began shortly after the beginning of the post-uprate period. As a result of the increased heat addition to the CCS, the average temperature in the intake zone (Zone 4) has increased by approximately 2.6°C (4.7°F). Interestingly, this measured increase in average temperature is slightly greater than the increase in the maximum allowable operating temperature at the intake location of 2.2°C (4.0°F)[††] approved for the nuclear-power generating units by the Nuclear Regulatory Commission in 2014. Therefore, the increased maximum allowable operating temperature has not reduced the probability of the intake temperatures exceeding the threshold value, and might have slightly increased the probability of exceeding the threshold temperature. This serves as a cautionary note regarding further increases in power generation beyond 2014 levels without providing a supplementary system to cool the water in the CCS. Others have cited increased algae concentrations in the CCS as being a possible reason for elevated temperatures in the CCS. However, a sensitivity analysis indicates that changes in the algae-influenced solar reflectivity of the CCS within a realistic range are unlikely to have been of sufficient magnitude to cause the observed changes in temperature, nor stimulate the sudden change in heat-addition rate that was observed almost immediately after the beginning of the post-uprate period. There are indications that the thermal efficiency of the CCS has decreased significantly between the pre-uprate and post-uprate periods. Further investigation is recommended to identify the factor(s) causing the reduced thermal efficiency.

Limitations of the heat-balance model. The heat-balance model developed for this study is based on the best estimates of all of the heat-balance components that influence the temperature in the CCS. However, the heat-balance model has not been calibrated due to lack of available data for calibration. Data required to calibrate the heat-balance model would include synoptic measurements of the flow rate and temperature differences between the intake and discharge structures of the power-generating units, and synoptic temperatures and flow rates at the inflow and outflow faces of each CCS zone. Calibration of the heat-balance

[††]From 37.8°C to 40°C (100°F to 104°F)

model would not necessarily change the key inferences that have been drawn from the uncalibrated model, namely that there has been a significant increase in the heat-rejection rate from the power-generating units during the post-uprate period, and that increased algae concentrations and increased ambient temperatures are not the most likely causes of elevated temperatures in the CCS. Further development of a calibrated heat-balance model is warranted to confirm the conclusions that have been drawn.

3 Salinity Variations in the Cooling Canals

Salinity is defined as the mass of dissolved salts per unit mass of solution, and is usually reported in units of either parts per thousand (‰) or as a dimensionless number on the practical salinity scale 1978 (PSS-78). Salinities are sometimes expressed indirectly in terms of chlorinity (mg/L chloride) or conductance (mS/cm). In this report, salinities are expressed in units of parts per thousand (‰), which gives salinities approximately equal in magnitude to salinities expressed in PSS-78. As reference points, average seawater at 25°C has a salinity of 35‰, a chlorinity of 19.84 g/L, and a specific conductance of 54.7 mS/cm. Hypersaline water is typically defined as water with a salinity greater than 40‰ or a specific conductance greater than 61.5 mS/cm, and brine is typically defined as water with a salinity greater than 50‰. These hypersalinity and brine thresholds are routinely exceeded in the CCS, and therefore water within the CCS can be properly classified either as being hypersaline or as brine.

3.1 Results from Previous Studies

There has been a continuous upward trend in salinity since the CCS began operation in August 1973, and this trend is clearly apparent in Figure 13, which shows the maximum reported salinities in the CCS since the initial NPDES report was submitted by FPL in 1973. The long-term trend of increasing salinity shown

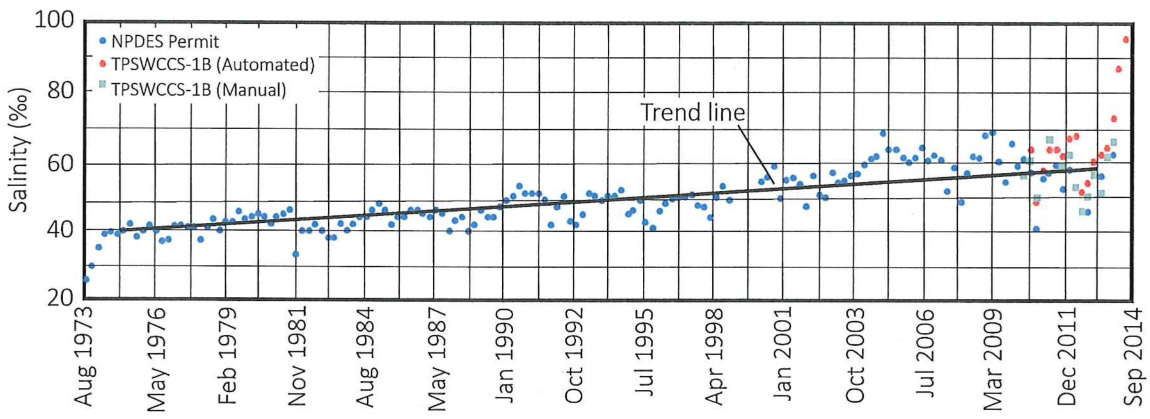


Figure 13: Maximum observed salinities in the CCS since initial operation

in Figure 13 can be approximated as being linear (as shown by the linear trend line) with a salinity increase of around 5‰ per 10 years. It is also apparent from Figure 13 that the rate of increase in salinity might have accelerated since 2013. The salinity in the CCS when it was first put into operation was around 26.5‰, with the contemporaneous salinity in Biscayne Bay being around 33‰ (Lyerly, 1973). The average CCS salinity in 1998 was reported to be in the range of 38 – 50‰ (Lyerly, 1998), and in May 2014, the salinity in the CCS was reported to be as high as 95‰.

Salinity-control processes. The key processes affecting the salinity in the CCS are: rainfall, evaporation, and groundwater exchange between the CCS and the surrounding Biscayne aquifer. Average annual rainfall at Turkey Point is approximately 60 inches, and the natural annual evaporation at Turkey Point is approximately equal to the average annual rainfall. Actual evaporation of water from the CCS exceeds natural evaporation due to the elevated temperatures in the CCS. The steady increase in salinity since operation of cooling canals began in the early 1970s (as shown in Figure 13) has been most commonly attributed to evaporation excess over rainfall.

3.1.1 Historical Chloride Levels

Chloride concentrations (i.e., chlorinities) in the CCS between June 2010 and June 2012 were in the range of 26 – 46 g/L with an average chlorinity of 33.9 g/L. The average chlorinity in Biscayne Bay during the same period was 18.9 g/L (Ecology and Environment, Inc., 2012). There is little difference (less than 10%) in chloride concentration between water samples collected near the surface or near the bottom at any given sampling location within the CCS. Chloride concentrations in the CCS during the post-uprate period were observed in range of 27 – 50 g/L, with the highest values observed in March 2014 and the lowest values in June 2013 (Ecology and Environment, Inc., 2014).

3.1.2 Historical Specific Conductance Levels

Specific conductances in the CCS between June 2010 and June 2012 were in the range of 70 – 90 mS/cm. Specific conductance in the CCS has been rising since the beginning of the dry season in 2014 and exceeded 120 mS/cm in May 2014. The average post-uprate specific conductance for all CCS stations was reported as 92.6 mS/cm, and this average value was over 15 mS/cm higher than the average value reported in the pre-uprate period.

3.2 Salinity-Balance Model of CCS

The salinity-balance model of the CCS that is currently being used to simulate salinity variations in the CCS was developed by FPL consultants. The salinity-balance model uses a finite-control-volume approach in which the control volume is defined to include the canals of the CCS and the adjacent interceptor ditch (ID). The salinity-balance model is closely related to a companion water-balance model, with both models having been developed by the same consultant and described by Ecology and Environment, Inc. (2012). For purposes of the current analyses, this previously developed model will be accepted as valid, and the relevant components of the model formulation are described in the following section.

3.2.1 Salinity-Balance Model Formulation

Component salinity fluxes into and out of the defined control volume are determined by multiplying the water (volume) flux by the corresponding salinity. The components of the water balance model are the lateral and vertical seepage into the CCS, blowdown water (i.e., additional water pumped from other units to the CCS), rainfall (including runoff from earth berms between canals), and evaporation. The key features of the salinity model are as follows:

- The base of the control volume is assumed to be the bottom of the ID and the cooling canals, whose elevations range from approximately −3 ft feet NAVD[‡‡] to approximately −30 ft NAVD. The elevation of bottom of the ID is approximately −20 ft NAVD. Sloping sidewalls of the canals in the CCS are taken into account by expressing the water-surface area as a function of the water-surface elevation in the CCS.

- Lateral seepage of water and salt between the L-31E Canal and the control volume is calculated directly from the product of the calibrated hydraulic conductivity and the difference in water-surface elevations between the L-31E Canal and the ID.

- Lateral seepage of water and salt between Biscayne Bay and the control volume is calculated directly from the product of the calibrated hydraulic conductivity and the difference in water-surface elevations between the CCS and Biscayne Bay.

- Vertical seepage of water and salt through the bottom of the control volume is calculated directly from the product of the calibrated hydraulic conductivity and the difference in the water-surface elevations in the CCS and the measured and estimated piezometric heads beneath the CCS.

- Evaporation is estimated using Equation 2, which uses meteorological data collected from meteorological stations in and immediately to the north and south of the CCS.

- Rainfall is estimated using Next Generation Weather Radar (NEXRAD) precipitation data provided by the SFWMD. Runoff into the control volume from earth berms between canals is used as a calibration parameter and is initially assumed to be 50% of the rainfall that falls on the berms.

- Added water from Units 3 and 4 are assumed to be freshwater (non-saline); Unit 5 blowdown salinities are adjusted to between 20% and 80% of seawater (35‰), with the exact percentage used as a calibration parameter.

- The ID control system is simulated to operate primarily between the months of January and June; with pumping rates as high as 50 mgd and averaging 4.5 mgd over the calibration period.

- The water-budget model is calibrated first by minimizing the errors between the simulated and observed storage in the control volume. Parameters adjusted during calibration of the water-budget model included the hydraulic conductivities in the aquifer adjacent to and beneath the CCS, an evaporation factor that adjusts the coefficients in the wind function, the amount of runoff that enters the control volume as percentage of precipitation, and the amount of Unit 5 cooling-tower water that is lost to evaporation before entering the CCS. The salinity model uses measured salinities in and around the CCS.

Calibrated values of the horizontal hydraulic conductivities in the aquifer surrounding the control volume have been found to be in the range of 500 – 950 ft/d, and calibrated values of the vertical hydraulic conductivities beneath the control volume have been found to be in the range of 0.1 – 4 ft/d. Vertical hydraulic conductivities beneath the northern discharge canals and beneath the return canals, where it is assumed deeper canals intersect highly permeable material underlying the muck and Miami Limestone Formation, were calibrated to have (higher) vertical hydraulic conductivities of 3.8 ft/d and 4 ft/d, respectively. Lower

[‡‡]"NAVD" refers to the NAVD 88 datum.

vertical hydraulic conductivities of 0.1 ft/d were calibrated for the mid- and southern portions of the discharge canals, as well as the southern portion of the return canals. Calibration of the salinity model was done entirely by the FPL consultant.

3.2.2 Previous Model Results

The model was run to simulate salinity variations both before the uprate (i.e., before February 2012) and after the uprate (i.e., after May 2013). The results of these model simulations are useful in understanding the salinity dynamics in the CCS and are described below.

Pre-uprate model results. The salinity model was calibrated for a 22-month pre-uprate period and the results showed an average volume outflow rate from the CCS of 0.62 mgd, with monthly-averaged outflow rates ranging from −46.6 mgd (October 2010) to +52.1 mgd (September 2010) (Ecology and Environment, Inc., 2012). Net flow through the bottom of the CCS was generally outward between the dry-season months of September through February, and inward during the wet-season months. Average inflow from precipitation during the wet season was more than twice that for the dry season. It was reported that vertical flows into and out of the control volume were substantially larger than lateral flows.

Post-uprate model results. A second round of salinity-model results was reported for the post-uprate period of June 2013 – May 2014 (Ecology and Environment, Inc., 2014). The results showed an average outflow rate of 3.26 mgd, with monthly-averaged outflow rates ranging from −31.1 mgd (June 2013) to +19.6 mgd (July 2013). During the pre-uprate and interim operating period, (September 2010 to May 2013), precipitation accounted for 39.4% of inflowing water to the CCS and evaporation accounted for 63.7% of the outflowing water from the CCS. There was an average rate of increase of salt in the CCS during the post-uprate period of 2.2×10^6 lb/d, which was attributed primarily to the combined effects of low rainfall and high evaporation. These model simulations were able to match the summer 2014 rise in salinity from approximately 60‰ to approximately 90‰.

3.2.3 Analysis of Salinity Dynamics

The primary drivers of salinity variations in the CCS are rainfall, evaporation, and seepage exchanges between the CCS and the surrounding aquifer. Pumpage from the ID can also influence salinity variations in the CCS, but its role is secondary to that of the aforementioned processes. Evaporation increases the salinity, rainfall and ID pumpage decrease the salinity, and seepage interchange with the surrounding aquifer can either increase or decrease the salinity depending on other factors.

Salinity variations under dry conditions. Under conditions of no rainfall (i.e., dry conditions), salinity in the CCS is primarily controlled by evaporation, and the salinity in the CCS steadily increases with time. Evaporation removes pure water from the CCS, and the volume of pure water that is evaporated is replenished by the seepage of saline water into the CCS from the surrounding aquifer. Since the CCS is directly connected to the surrounding aquifer, the water surface elevation within the CCS remains close to the water-table elevation in the surrounding aquifer which changes over relatively long time scales (viz. months) compared to the shorter time scales (viz. days, weeks) over which significant salinity variations are observed. The seepage flows between the CCS and the surrounding aquifer are proportional to the small differences between the water-surface elevations in the CCS and the piezometric heads in the surrounding aquifer. Over shorter time scales (viz. days) the evaporated volume of pure water is approximately equal to the seepage inflow volume of saline water, and the volume of water within the CCS remains approximately constant. This mechanism results in an increased mass of salt in an approximately unchanged CCS volume, and hence an increase in salinity.

Salinity variations under wet conditions. When rainfall occurs (i.e., wet conditions), salinity is primarily controlled by the difference between evaporation and rainfall. Conditions under which evaporation exceeds rainfall result in the net removal of pure water from the CCS and the dynamics of salinity variations under this condition are similar to those described previously for evaporation without rainfall. Hence, for time intervals where evaporation exceeds rainfall, the salinity in the CCS can be expected to increase. For time intervals where rainfall exceeds evaporation, there is a net inflow of (approximately) pure water into CCS that is equal to the difference between the rainfall and evaporation volumes, and this inflow is approximately balanced by the volume of saline water that seeps out of the CCS into the surrounding aquifer. The salinity of the seepage outflow is approximately equal to the salinity of the water within the CCS. This mechanism results in a decreased mass of salt in the CCS in an unchanged volume, and hence a decrease in salinity.

Salinity variations under ID pumping. Pumping water from the ID into the CCS has a relatively minor effect on the salinity in the CCS relative to rainfall and evaporation, since the volume of pumped water is relatively smaller and the difference in salinity between the pumped water and the water in the CCS is also less than for evaporation and rainfall.

3.2.4 Modeled Salinity Dynamics

The mechanism driving salinity changes in the CCS can be demonstrated using the previously calibrated salinity model. The cumulative rainfall, evaporation, seepage inflow, ID pumpage, and water storage (= net inflow) within the CCS between September 2010 and April 2014 are shown in Figure 14. It is apparent from

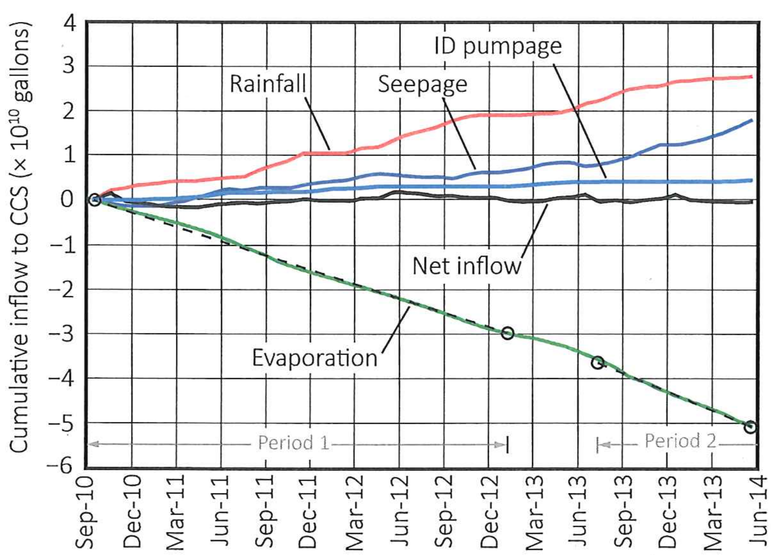


Figure 14: Water inflow into CCS

Figure 14 that evaporation and rainfall are dominant components of the water budget, and the storage in the CCS remains relatively constant compared with cumulative rainfall, evaporation, ID pumpage, and seepage inflow. Further, it can be asserted from Figure 14 that the seepage inflow adjusts to the difference between evaporation and rainfall-plus-ID-pumpage so as to keep the volume of water within the CCS approximately constant.

Post-uprate increase in evaporation. A notable feature of Figure 14 is that the evaporation rate increases during the post-uprate period (Period 2) relative to the evaporation rate during the pre-uprate period (Period 1), which is consistent with the post-uprate temperature increases shown in Figure 11. Using the evaporation and rainfall data from the heat-balance model, the average evaporation rate, average rainfall rate, and the difference between these quantities during Period 1 (9/1/10 – 2/1/13) and Period 2 (7/1/13 – 12/1/14) are shown in Table 3. It is apparent from Table 3 that the average evaporation rate in the post-uprate period

Table 3: Average Evaporation and Rainfall Rates in the CCS

Period	Evaporation (mgd)	Rainfall (mgd)	Difference (mgd)
1	34.46	15.44	19.02
2	44.20	15.52	28.68

is approximately 9.7 mgd greater than the average evaporation rate during the pre-uprate period, with the evaporation-rainfall deficit increasing by approximately the same amount. Since the long-term rate of increase in salinity in the CCS is proportional to the evaporation-rainfall deficit, these results indicate that the long-term rate of increase in CCS salinity is likely to increase if there is no intervention. It is interesting to note that pre-uprate analyses by FPL consultants predicted that the CCS evaporation rate would increase by 2 – 3 mgd and the intake temperature would increase by 0.9°F. In contrast, the actual increase in evaporation rate is around 9.7 mgd and the measured increase in the average intake temperature is 4.7°F. The post-uprate evaporation-rainfall deficit of 28.7 mgd is a key design variable for any planned system to control salinity within the CCS by pumping fresh or brackish water into the CCS from external sources.

Seepage inflow and outflow. Seepage flow to the CCS does not occur uniformly over the interfaces of the CCS with the surrounding Biscayne aquifer, and the relative volumes of seepage inflows and outflows over the CCS interfaces are shown in Figure 15. It is apparent from Figure 15 that most of the inflow is across the East interface (i.e., the interface facing Biscayne Bay), most of the outflow is across the Bottom interface, relatively lesser volume fluxes occur across of the North, South, and West interfaces, and inflows and outflows occur across all interfaces to varying degrees. The relative seepage contributions from the different faces are important inasmuch as the salinity in the aquifer adjacent to the East interface tends to be at least as high as the salinity in Biscayne Bay, the salinity in the aquifer adjacent to the Bottom interface tends to be on the same order of magnitude as the salinity in the CCS, and lesser salinities occur at the North, South, and West interfaces. Analyses have shown that, although the net seepage across of the Bottom interface is predominantly outward, seepage across the Bottom interface is not uniform within the four zones of the CCS. In particular, seepage across the Bottom interface is predominantly outward in Zone 1, predominantly inward in Zone 4, and much weaker inflows and outflows occur in Zones 2 and 3 (Nuttle, 2015a).

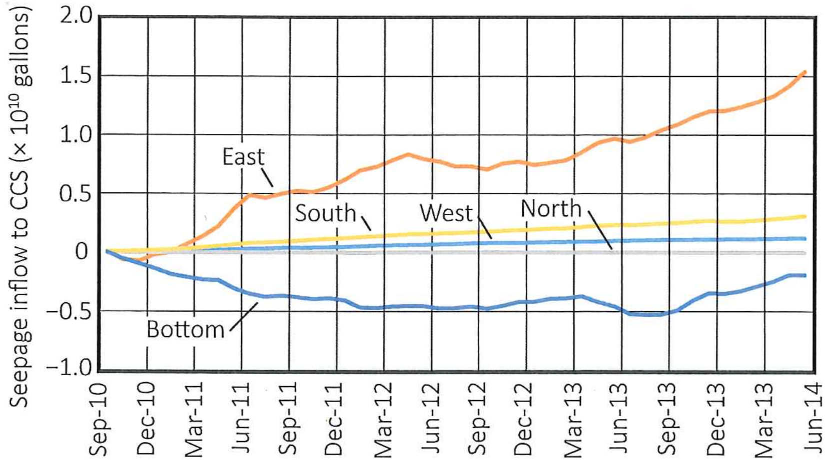


Figure 15: Seepage into CCS from aquifer

Salinity inflow and outflow. The estimated salt contributions from the CCS seepage interfaces are shown in Figure 16. It is apparent that the salt fluxes across the East and Bottom interfaces constitute the predomi-

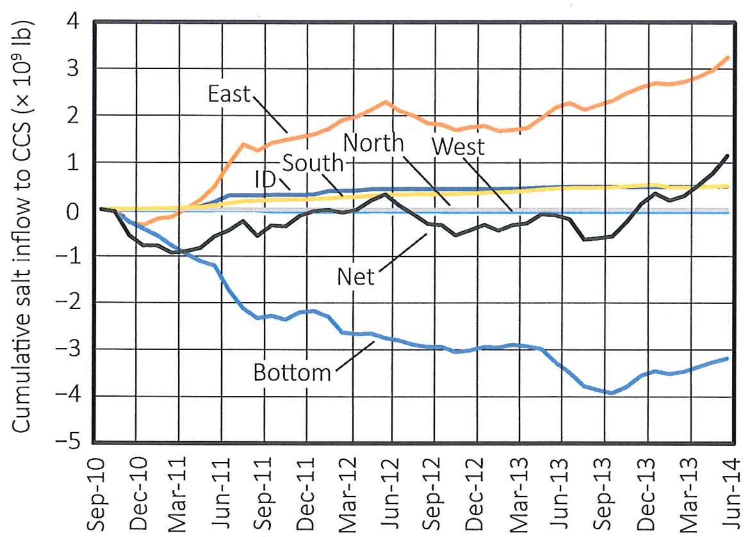


Figure 16: Salt inflow to CCS

nant components of the salt budget, with influx of salt primarily associated with the East interface and efflux of salt primarily associated with the Bottom interface; keeping in mind that both influx and efflux of salt can occur at these interfaces. Lesser but still significant salt influx occurs across the South interface and via ID pumping, with much smaller to negligible salt fluxes across the North and West interfaces. Following the same pattern as seepage fluxes, salt fluxes across the Bottom interface are predominantly outward in Zone 1 and predominantly inward in Zone 4 (Nuttle, 2015a), with the net salt flux across the Bottom interface typically being outward. It is apparent from Figure 16 that in the interval September 2013 – May 2014 the flux of salt was primarily and (almost) consistently into the CCS from both the East and Bottom interfaces and, with relatively stable water level and volume in the CCS, this yielded an (almost) consistent increase in the CCS salinity as demonstrated by the measurements shown in Figure 17. Since the seepage influx was

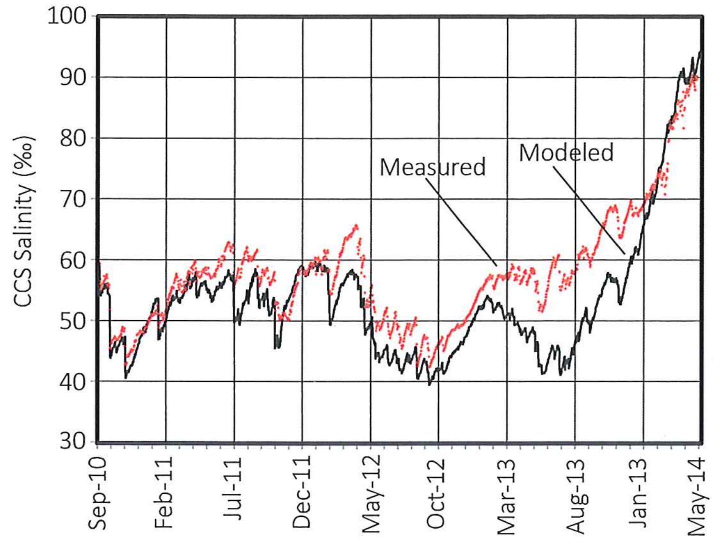


Figure 17: Measured and modeled salinity variations in CCS

driven by the deficit between evaporation and rainfall, it can be concluded that the increase in salinity in the CCS was due to the evaporation-rainfall deficit causing contemporaneous influxes of salinity from both the Bottom and East interfaces. Subsequent to the time period covered by Figure 17, salinity in the CCS during 2014 increased to a maximum daily-average value of approximately 99‰. On January 1, 2015, the average salinity in the CCS was 75‰, and by April 26, 2015, salinity levels were over 95‰. During April 27 – 28, 2015, significant rainfall over the CCS reduced the average salinity to 78‰, however, salinities subsequently began rising again in the absence of more rainfall (SFWMD, 2015).

Lessons learned. The results presented in this section clearly demonstrate that the salinity of water in the CCS can be expected to rise significantly during prolonged periods without rainfall. Furthermore, over multi-seasonal time scales, a steady increase in salinity within the CCS occurs since average evaporation rates exceed average rainfall rates. Post-uprate increases in CCS operating temperatures have increased evaporation rates compared with pre-uprate evaporation rates. In the absence on any engineered intervention, this increased evaporation rate will cause salinities in the CCS to increase at a higher rates in the future compared with the rates of salinity increase observed during the pre-uprate period. It is apparent from the results presented here that additional salinity controls are necessary in order to reduce the likelihood that the excessive salinity levels of the past will be repeated in the future.

Salinity-control and groundwater remediation plan. In October 2015, in response to chloride levels in the Biscayne aquifer exceeding water-quality standards as a consequence of the high salinities in the CCS, FPL reached an agreement with Miami-Dade County which includes the design of a system of up to six wells to pump low-salinity water from the Upper Floridan aquifer into the CCS to reduce salinity levels in the CCS. Reports indicate that the plan is to pump up to 14 mgd of water from the Upper Floridan aquifer into the CCS, with the goal of reducing the average annual salinity in the CCS to approximately 34‰ within four years of the implementation of the plan. In addition to the aforementioned plan to reduce the salinity in the CCS, FPL has agreed to remediate the hypersaline part of the saltwater plume to the west of the CCS, potentially by pumping hypersaline water from the Biscayne aquifer into the Boulder Zone. This planned remediation system is called the Biscayne Aquifer Recovery Well System (RWS) and will be designed based on simulations using a variable-density groundwater flow model that is currently under development by FPL. Initial design of the RWS will be based on a 12 mgd capacity.

Issues of concern. The analyses and modeling that were used as bases for formulating the salinity-control plan for the CCS were not made available to the author of this report, and so unanswered questions remain concerning the likelihood that the proposed plan will be successful. Three technical issues of concern are identified here. The first issue of concern is that the current (post-uprate) evaporation and rainfall rates at the CCS are 44.2 mgd and 15.5 mgd, respectively, which means that a long-term average inflow of around 44.2 mgd − 15.5 mgd = 28.7 mgd of fresh water would be required to keep the salinity in the CCS at approximately its current average-annual value. Hence, a long-term addition of only 14 mgd of brackish water from the Upper Floridan aquifer might be of insufficient volume and quality to abate the persistent increase in salinity within the CCS. A second issue of concern is that adding 14 mgd or more of water to the CCS is likely to significantly increase the salinity flux out of the bottom of the CCS (at least in the short term), and the extent to which this increased salinity flux will exacerbate salinity intrusion would need to be addressed. To properly model the effect of adding 14 mgd or more of brackish water to the CCS on salinity intrusion in the surrounding aquifer it would be necessary to use a groundwater model that accounts for density-driven flow, heat transport, and dissolved-solids transport in the portion of the Biscayne aquifer surrounding the CCS. This model could also be used to accurately describe the seepage flux of salinity into and out of the CCS at a much more sophisticated level that is currently being done with the FPL salinity-balance model. A third issue of concern is that the time-frame required for the proposed system to significantly reduce salinity levels in the aquifer remains highly uncertain pending more definitive characterization of the subsurface hydrogeology and the development of a groundwater-flow model that accounts for the effects of temperature and salinity on the flow distribution in the surrounding aquifer. Utilization of a variable-density groundwater model is essential to estimate the time scale required for the proposed actions to take effect, The need for model development in support of designing the salinity-reduction protocol is further buttressed by the modeling results reported by Hughes et al. (2010), who showed that estimation of the time scale for salinity changes in the CCS to propagate through the aquifer are significantly influenced by the certainty with which the hydrogeology in the aquifer surrounding the CCS can be specified. The model being developed in support of the RWS could possibly be adapted for this purpose.

4 Pumping Water from the L-31E Canal into the Cooling Canals

4.1 Pumping Permit and Protocols

In August 2014, SFWMD issued an Emergency Order authorizing the pumping of up to 100 mgd of freshwater from the L-31E Canal to the CCS between August and October 2014, with the primary goal of reducing the temperature in the CCS. Pursuant to this order, FPL conducted emergency pumping between September 25 and October 15, 2014, and as a result the temperature in the CCS dropped by 6.5°F, the salinity dropped from 87‰ to 75‰, and the algae concentrations reportedly dropped from 1315 cell/L on September 26, 2014 to 68 cell/L on October 27, 2014. After pumping had terminated, algae concentrations again began increasing. Also subsequent to pumping, the temperature in the CCS began to rise again. On April 27, 2015, the temperature of the CCS reached 98.2°F. A large rainfall event occurred over the CCS between April 27 and 28, 2015. The addition of freshwater inflow from rainfall reduced the temperature of the water in the CCS to 81.3°F. However, by May 17, 2015, the intake temperature had risen to 94.6°F, which was within 10°F of the maximum allowable intake temperature of 104°F. It was primarily on the basis of these conditions that FPL requested a permit to pump additional water from the L-31E Canal into the CCS.

2015 – 2016 Pumping Permit In May 2015, FPL received a permit from the SFWMD to pump up to 100 mgd from the L-31E Canal to the CCS, for the purpose of controlling the temperature in the CCS. Pumping is permitted between June 1 and November 30 in both 2015 and 2016. A limitation stipulated within this permit is that water cannot be withdrawn from the L-31E Canal on any given day until at least 504 acre-ft (2.2×10^7 ft^3) of water has been diverted from the L-31E Canal to Biscayne Bay for purposes of fish and wildlife preservation. Diversion of water from the L-31E Canal to Biscayne Bay occurs through structures S-20F, S-20G, and S-21A, which are located upstream of the CCS withdrawal location (at the "South Pumps") as shown in Figure 18. These three upstream structures open and close based on prescribed

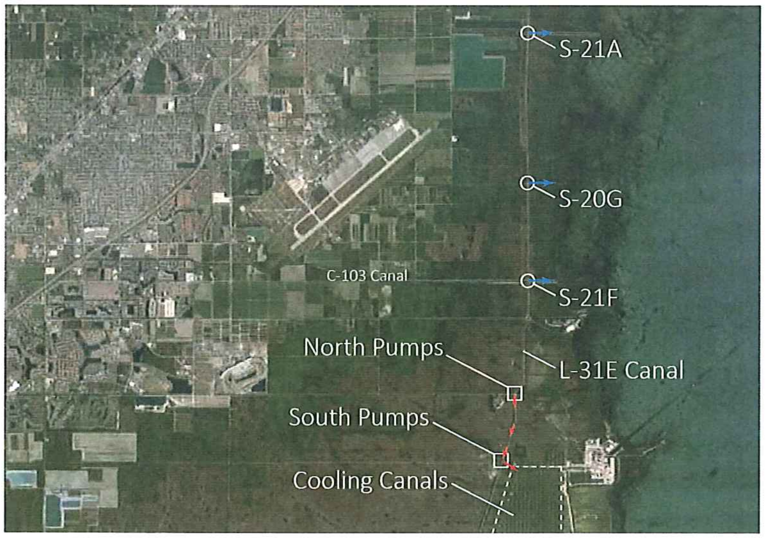


Figure 18: Pumping from L-31E Canal into Cooling-Canal System

water-surface elevations in L-31E Canal at the structure locations, and the open/close stages of these structures are given in Table 4. For example, in the wet-season period of April 30 – October 15 the S-20F, S-20G, and S-21A structures open when the L-31E Canal stage is at or above 0.67 ft NAVD and close when the stage is at or below 0.27 ft NAVD. The cumulative discharges from these structures are monitored daily, to ensure that no pumping from the L-31E Canal into the CCS is allowed until the cumulative discharges from these structures exceed the threshold of 504 acre-ft. The delivery system consists of a northern and southern pump station, where the northern pump station pumps water from the C-103 Basin into the L-31E Canal, and the southern pump station pumps water from the L-31E Canal into the CCS. The operational

Table 4: Gate Operation Rules that Affect L-31E Withdrawals

			L-31E Stage	
Gate(s)	Season	Period	Open (ft NAVD)	Close (ft NAVD)
S-20F, S-20G, S-21A	Wet	April 30 – October 15	0.67	0.27
S-20F	Dry	October 15 – April 30	−0.13	−0.53
S-20G			0.67	0.27
S-21A			−0.13	−0.53

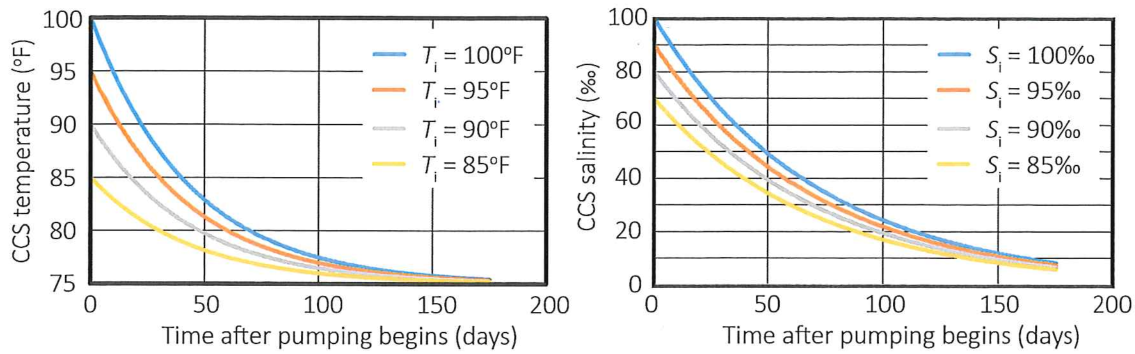
plan synchronizes northern and southern pumping operations so as to avert dewatering of wetlands between the two pump stations and adjacent to the L-31E Canal. The operational protocol requires that the northern pumps always be started at least five minutes prior to starting the southern pumps, and at the end of each day the southern pumps must be shut down at least five minutes before the northern pumps are shut down. This operational protocol for the pumps ensures that the volume of water pumped daily from the C-103 Basin into the L-31E Canal by the northern pumps exceeds the volume pumped from the L-31E Canal into the CCS by the southern pumps. A particularly important condition of the pumping permit is that FPL is required to monitor the stage in the L-31E Canal between the northern and southern pump stations to ensure that there is no drawdown in the L-31E Canal between the pump stations as a result of the pumping operations. Besides ensuring that there is no L-31N drawdown as a result of pumping, this protocol also ensures that the wetlands adjacent to the L-31N Canal are not dewatered as a result of pumping. Subsequent to beginning of pumping on June 1 2015, the salinity level in the CCS dropped to 70‰, and subsequent large rainfall events have further reduced the CCS salinity to 60‰, according to reports submitted by FPL to the SFWMD.

4.2 Quantitative Effects

This section presents a simplified analysis that is intended only to illustrate the relative impacts on temperature and salinity of pumping water from the L-31E Canal into the CCS. The change in temperature, ΔT, of the water in the CCS resulting from the addition of a volume V_a water at temperature T_a can be approximated using the relation

$$\Delta T \approx \frac{V_\mathrm{a}}{V_0 + V_\mathrm{a}} (T_\mathrm{a} - T_0) \tag{6}$$

where V_0 is the initial volume of water in the CCS, and T_0 is the initial temperature of water in the CCS. Equation 6 is a very approximate relationship which assumes that the added water is well mixed over the CCS, and it neglects the differences in density and specific heat between the saline water in the CCS and the fresh water being added. In spite of these shortcomings and in the absence of a detailed heat-balance model of the CCS, Equation 6 can be used to provide a rough estimate of how the temperature in the CCS might react to the addition water from the L-31E Canal. If 100 mgd (= 1.337×10^7 ft^3/d) is added to the CCS which has a volume of 5.746×10^8 ft^3 (assuming an average depth of 2.8 ft) and the added water has a temperature of 75°F, then Equation 6 can be applied using a daily time step to calculate the temperature in the CCS in as a function of number of days of continuous pumping for initial temperatures in the range of 85°F – 100°F. The results of these calculations are shown in Figure 19(a). In a similar manner, the change in salinity, ΔS, in the CCS resulting from the addition water at salinity S_a can be estimated using the approximate



(a) Temperature versus pumping time

(b) Salinity versus pumping time

Figure 19: Approximate effect of pumping 100 mgd on temperature and salinity in CCS

relationship

$$\Delta S \approx \frac{(V_\mathrm{a} - V_\mathrm{e})}{V_0 + (V_\mathrm{a} - V_\mathrm{e})}\,(S_\mathrm{a} - S_0) \tag{7}$$

where S_0 is the initial salinity in the CCS, and V_e is the evaporated volume. Equation 7 is an approximate relationship which assumes that the added water is well mixed over the CCS, and it neglects decreases in salinity that would be caused by rainfall. If 100 mgd is added to the CCS and the rate of evaporation is 39 mgd, then the net rate of freshwater addition to the CCS (i.e., $V_\mathrm{a} - V_\mathrm{e}$) is equal to 61 mgd (= 8.156×10^6 ft^3/d). Using the same CCS volume V_0 that is used for calculating the daily temperature changes, ΔT, and taking the salinity, S_a of the water pumped from the L-31E Canal equal to zero, Equation 7 can be used to calculate the salinity in the CCS in as a function of number of days of continuous pumping for initial salinities in the range of 70‰ – 100‰ as shown in Figure 19(b). The results in Figure 19 collectively indicate that the sustained addition of 100 mgd from the L-31E Canal to the CCS over continuous times on the order of a week to a month (30 days) would be an effective means of reducing the temperature and salinity in the CCS. The environmental effects on the surrounding environment of pumping water from the L-31E Canal to the CCS are discussed subsequently.

Context. To put a volume flow rate of 100 mgd of fresh water in a societal context, it is noted that 100 mgd is approximately the average daily drinking-water demand of one million people. In the context of the CCS, 100 mgd can be contrasted with the assumed average CCS evaporation rate of around 39 mgd and a long-term average rainfall rate on the CCS of around 21 mgd, where both of these averages are computed over the 9/1/2010 – 5/1/2014 time period using data from the FPL water-balance model. If the CCS were empty and were to be filled by supplying water at 100 mgd, it would take approximately 43 days to fill the CCS. Although 100 mgd is more than twice the evaporation rate, the cooling effect of a unit volume of evaporated water is much greater than the cooling effect of a unit volume of added liquid water. For example, a unit volume of evaporated water would cause a temperature decrease of around 50 times the temperature decrease caused by adding a unit volume of liquid water that is 20°F cooler than the CCS. Therefore, in thermodynamic terms, the addition of 100 mgd of pumped water has approximately the same cooling effect as 2 mgd of evaporated water. With regard to salinity, the salinity reduction resulting from the addition of a unit volume of fresh water exactly compensates for the salinity increase caused by a unit volume of evaporated water. Hence, 39 mgd of added water would neutralize the salinity-increase caused by 39 mgd of evaporated water, with the excess added water causing a reduction in salinity.

4.3 Model Results

The water-balance and salt-balance models used previously by FPL to simulate the pre-uprate salinity dynamics in the CCS were used by FPL to simulate the potential future scenarios with and without the L-31E water inputs in the summer of 2015 and 2016. FPL made minor revisions in the models to incorporate data up through October 2014. The model-simulation period to predict the response of the CCS to pumping water from the L-31E Canal starts on November 1, 2014, and ends on November 30, 2016. Two scenarios were simulated at multiple maximum-allowable withdrawal rates, where actual withdrawal rates were predicated on the availability of water in the L-31E Canal after providing 504 acre-ft to Biscayne Bay. Scenario A assumes that future conditions are the same as those observed between November 1, 2010 and October 31, 2012; conditions during this time frame reflected normal weather patterns. Scenario B assumes that future conditions are the same as those observed between November 1, 2013 and October 31, 2014; conditions during this time reflected dry weather patterns, and this one-year period was repeated sequentially to produce a two-year predictive simulation. In both scenarios, the conditions observed during the first November (2010, 2013) were repeated to simulate conditions for the last month (November 2016) of the 25-month predictive simulation. Scenario A and Scenario B were each run four times under different pumping scenarios: no pumping, 30 mgd-maximum, 60 mgd-maximum, and 100 mgd-maximum and for a two-year time period. Under all pumping scenarios the simulated CCS water levels increased and simulated CCS salinities decreased relative to the base case of no pumping. Greater changes were observed in response to greater pumping rates. Under all pumping scenarios, the greatest increases in CCS stage occur between June 1 and November 30.

Application of model results. The water-balance and salinity-balance modeling done by FPL in support of the application for the 2015 – 2016 pumping permit focused on the effectiveness of the L-31E pumping on reducing salinity, whereas the primary motivation for pumping from the L-31E Canal is actually to reduce temperature. Elevated temperatures in the CCS will affect power-generation while elevated salinities will not, and there is not a proportional correspondence between reduced salinity and reduced temperature, since temperatures in the CCS depend on a variety of other factors besides the volume of water pumped from the L-31E Canal.

4.4 Environmental Effects

Environmental concerns that have been raised previously by others relate to both the diversion of fresh water from other environmental restoration projects that are currently being serviced by the L-31E Canal, and the utilization of fresh water to dilute hypersaline water, which degrades the quality and utility of the fresh water. Based on available information, it appears that the only environmental projects currently being served directly by the L-31E Canal is the Biscayne Bay fish and wildlife preservation allocation of 504 acre-ft, and the maintenance seasonal water levels in support of adjacent wetlands. The permitted pumping operation will not divert the water volume previously allocated to fish and wildlife preservation, and a pumping protocol will be followed to maintain water levels at their no-pumping levels. With respect to the degradation of fresh water, this degradation will in fact occur, however, the extent of water-quality deterioration and specific deleterious impacts on existing water uses have not to date been identified. Aside from these previously raised concerns, some major additional concerns resulting from pumping up to 100 mgd from the L-31E Canal to the CCS are described below.

4.4.1 Effect of Increased Water-Surface Elevations in the CCS

Pumping water from the L-31E Canal into the CCS will elevate the average water level in the CCS relative to the water level that would exist without pumping. The magnitudes of water-level increases in the CCS were estimated by FPL using the previously developed and calibrated mass balance model of the CCS, and the results of these simulations were submitted to the SFWMD as part of the application for the 2015 – 2016 pumping permit (SFWMD, 2015). Since the water level in the L-31E Canal will be held constant during pumping operations, the increased water-surface elevations in the CCS are of concern because they will decrease the seaward piezometric-head gradient between the L-31E Canal and the CCS. Furthermore, it is likely that the piezometric-head gradient between the L-31E Canal and the CCS could be reversed from a seaward gradient to a landward gradient. This could produce landward groundwater flow between the CCS and the L-31E Canal, which would likely advect a saline plume from the CCS towards the L-31E Canal. In addition to the aforementioned outcome, elevated water levels in the CCS resulting from pumping up to 100 mgd from the L-31E Canal will increase the (seaward) piezometric-head gradient between the CCS and Biscayne Bay, resulting in the increased discharge of higher-salinity water from the CCS into the Bay via the Biscayne aquifer.

Relevant data. To quantify the effect of increased water-surface elevations in the CCS that would occur as a result of pumping, the increased water-surface elevations simulated by FPL were subtracted from historical water-level differences between the L-31E Canal and the CCS to yield possible water-level differences under the 100-mgd pumping scenario. As described previously, two scenarios were modeled, with Scenario A corresponding to "normal" conditions, and Scenario B corresponding to "dry" conditions. Each simulation covered two years (2015 and 2016), with pumping in each year from June 1 to November 30. The increases in CCS water-surface elevations over the water-surface elevations that would exist in the CCS without pumping are given in Table 5 for selected dates (about a month apart) during each of these scenarios. The values given in Table 5 were estimated from graphical plots developed by FPL as part of the permit application. It is apparent from Table 5 that water-level increases in the CCS on the order of 0.5 ft are predicted to occur as a result of pumping water at a rate of 100 mgd from the L-31E Canal into the CCS. These water-level increases can be contrasted with historical differences in the water levels between the L-31E Canal and the CCS for the pre-uprate (June 2011 – May 2012) and post-uprate (June 2013 – May 2014) periods as shown in Table 6, where a positive difference indicates that the water level in the L-31E Canal is higher than the water level in the CCS. It is apparent from Table 6 that the historical differences between the water levels in the L-31E Canal and the CCS are typically on the same order of magnitude as the expected increases in the CCS water level, and therefore a significant impact on the historical seaward water-level gradient is to be expected. This concern is further amplified when it is considered that a minimum water-level difference of 0.30 ft is required to keep an acceptable seaward water-level gradient and to keep from triggering the interceptor ditch (ID) pumps. If the ID pumps are turned on, this would further elevate the water level in the CCS and further decrease the water-level difference between the L-31E Canal and the CCS.

Demonstration of effects. The increases in the water-surface elevations in the CCS predicted by the FPL mass-balance model can be subtracted from the historical water-level differences between the L-31E Canal and the CCS to estimate the water-level differences between the L-31E Canal and the CCS that are likely

Table 5: Estimated Water Level Increases in CCS

Day-Month	Scenario	2015 (ft)	2016 (ft)
15-Jun	A	0.00	0.23
15-Jul	A	0.00	0.55
15-Aug	A	0.55	0.40
15-Sep	A	0.57	0.40
15-Oct	A	0.50	0.60
15-Nov	A	0.65	0.60
30-Nov	A	0.50	0.45
15-Jun	B	0.00	0.00
15-Jul	B	0.62	0.50
15-Aug	B	0.65	0.70
15-Sep	B	0.15	0.10
15-Oct	B	0.35	0.30
15-Nov	B	0.37	0.55
30-Nov	B	0.50	0.65

to exist as a consequence of pumping a maximum of 100 mgd from the L-31E Canal into the CCS. These expected water-level differences are summarized for the Scenario A (the "normal" condition) in Figure 20(a), and for Scenario B (the "dry" condition) in Figure 20(b). For each historical period (pre-uprate and post-uprate), and for each selected day, three water-level differences are shown: the historical difference (blue), the projected 2015 difference (orange), and the projected 2016 difference (gray). In general, the 2015 and 2016 projected water-level differences are less than the historical differences by the amounts listed in Table 5. Also shown in Figure 20 is the 0.30-ft reference line, which is the threshold water-level difference below which the ID pump system is triggered. It is apparent from Figure 20(a) that under pre-uprate water-level-difference conditions a landward water-level gradient would be created around 15-Sep and 15-Nov on which dates there were previously seaward water-level gradients; the 15-Jun data point is anomalous in that a landward gradient already existed in the historical record. It is further apparent from Figure 20(a) that under post-uprate water-level-difference conditions a landward water-level gradient would be created around 15-Jul, 15-Aug, 15-Sep, 15-Nov, and 30-Nov on which dates there were previously seaward gradients. Under both pre-uprate and post-uprate conditions shown in Figure 20(a), the difference between the water level in the L-31E Canal and the CCS would fall below the 0.30-ft threshold on all of the dates cited in Figure 20(a). Considering Scenario B (the "dry" condition) shown in Figure 20(b), the results are similar to those shown in Figure 20(a). Under pre-uprate conditions, a landward water-level gradient would be created around 15-Sep and 15-Nov, and under post-uprate water-level-difference conditions a landward water-level gradient would be created around 15-Jul, 15-Aug, 15-Sep, 15-Nov, and 30-Nov. Under both pre-uprate and post-uprate conditions, the difference between the water levels in the L-31E Canal and the CCS would fall below the 0.30-ft threshold on all dates cited in Figure 20(b). The results shown in Figure 20 collectively show that there is cause for concern that pumping 100 mgd from the L-31E Canal into the CCS could cause a landward water-level gradient where none previously existed. This concern is further exacerbated when considering that water levels at the northern end of the CCS near the discharge from the power-generating units will

Table 6: Historical Water-Level Differences Between L-31E Canal and CCS

Day-Month	Pre-Uprate (ft)	Post-Uprate (ft)
15-Jun	−0.32	0.46
15-Jul	0.57	0.37
15-Aug	0.80	0.40
15-Sep	0.42	0.48
15-Oct	0.85	0.60
15-Nov	0.51	0.49
30-Nov	0.55	0.45

be higher than the average water level in the CCS that is used in this analysis, which further decreases the seaward water-level gradient between the L-31E Canal and the CCS. Concern is further heightened when the increased density of water in (and under) the CCS is taken into account, since the difference in equivalent freshwater (piezometric) heads between the L-31E Canal and the CCS is less that the difference in water levels between the L-31E Canal and the CCS. It is actually the difference in equivalent freshwater heads that govern the flow between these bodies of water (e.g., Post et al., 2007). This latter point is particularly important since the difference in freshwater heads between the L-31E Canal and the CCS will increase with depth.

Effect of generating a landward gradient. A landward gradient in the freshwater-equivalent piezometric head between the L-31E Canal and the CCS would advect saline water from the CCS towards the L-31E Canal. Such gradients are likely to be generated under 100-mgd pumping operations. Also, since pumping would be occurring mostly during the wet season, it is likely that a seaward head gradient would exist (and be maintained) west of the L-31E Canal. As a consequence of a landward gradient in the freshwater-equivalent piezometric head east of the L-31E Canal and a seaward (freshwater) head gradient west of the L-31E Canal, it is possible that a "saline circulation cell" is developed in which water is pumped from the L-31E Canal into the CCS, water seeps out of the CCS and flows through the Biscayne aquifer back into the L-31E Canal, and then this water is pumped back into the CCS. This circulation cell would increase the salinity in the L-31E Canal, which would degrade the quality of the water in the L-31E Canal and decrease the effectiveness of the pumped water in decreasing the salinity in the CCS.

Historical anecdote. Interestingly, in 1978, engineers from the consulting firm Dames and Moore wrote a report to FPL with a specific section in their report titled "Effects of an Overall Increase in Water Level in the Cooling-Canal System Relative to the Ground Water" (Dames and Moore, 1978). In their report, the engineers at Dames and Moore specifically considered the impact of raising the water level in the CCS by 0.50 ft above the water table in the surrounding aquifer. They concluded that such an occurrence would cause the saltwater interface to move approximately one mile further inland relative to its location prior to the rise in the water level of the CCS.

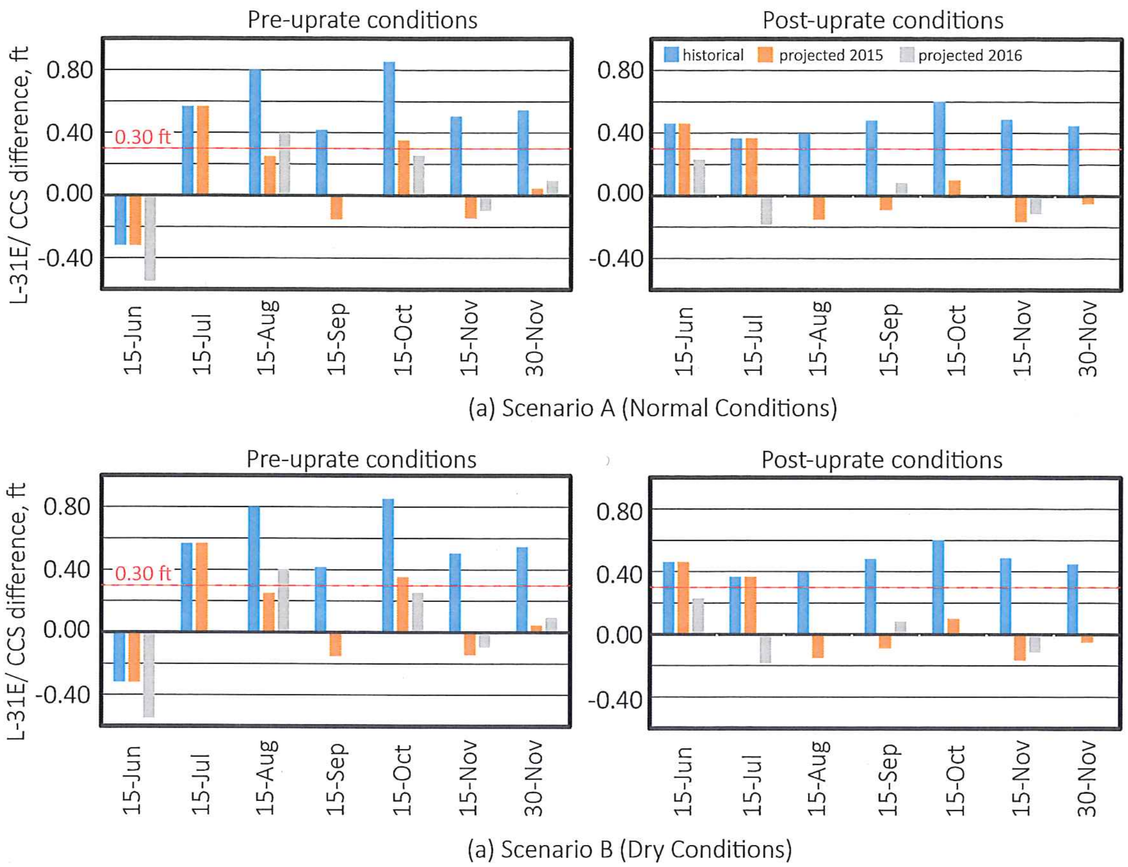


Figure 20: Differences Between L-31E Canal and CCS Water Levels. The historical difference is in blue, the projected 2015 difference is in orange, and the projected 2016 difference is in gray.

4.4.2 Suggested Permit Modifications

Based on the concerns described here, along with the supporting analyses provided, it is recommended that the pump-operation protocol associated with the 2015 – 2016 pumping permit be modified to include measurement of water levels in the CCS, and that a threshold water-level difference between the L-31E Canal and the CCS be determined by the SFWMD and added as a controlling factor in pump operations. To ensure that a subsurface circulation cell of saline water does not develop, the salinity of the water in the L-31E Canal should be monitored during pump operations.

5 Conclusions and Recommendations

This study consisted of reviewing, summarizing, and analyzing the relevant reports and data relating to the operation of the cooling-canal system (CCS) at the Turkey Point power station. The study focused on the following four primary issues: (1) the temperature dynamics in the CCS, (2) the salinity dynamics in the CCS, (3) salinity control in the CCS, and (4) the impacts and consequences of pumping a maximum of

100 mgd from the L-31E Canal into the CCS.

5.1 Temperature Dynamics

Temperature dynamics in the CCS are a concern primarily because operation of the nuclear-power generating units will be impacted if the temperature of the cooling water at the intake exceeds 104°F. Recent elevated temperatures have come close to exceeding this threshold value.

Heat balance in the CCS. Understanding the temperature dynamics in the CCS is not possible without the development of a heat-balance model of the CCS, and no such model currently exists in the public domain. As part of this study, a preliminary heat-balance model was developed and is described in this report. Using this model to simulate the heat balance in the CCS during the interval 9/1/10 – 12/7/14 showed that there were two distinct periods during which the heat-rejection rate from the power plant remained approximately constant. The first period corresponded to pre-uprate conditions (prior to February 2012) and the second period corresponded to post-uprate conditions (after May 2013). The heat-rejection rate during the post-uprate period was found to be significantly greater than the heat-rejection rate during the pre-uprate period. In the 250 MW uprate in nuclear-power generating capacity (Units 3 and 4) that was completed in 2013 and the retirement of a 400 MW standby fossil-fuel plant (Unit 2) that was done in 2010 there was a significant shift from fossil-fuel generation to nuclear-power generation that occurred between the pre-uprate and post-uprate periods. This shift towards the greater utilization of nuclear power in the units served by the CCS is significant because nuclear-power units are known to have a much higher heat-rejection rates to cooling water than fossil-fuel generating units. Hence, on a per-megawatt basis, nuclear-power units generate more heat to the CCS than fossil-fuel units. Furthermore, capacity factors of nuclear-power units are typically much higher than capacity factors of fossil-fuel units, hence the ratio of actual power generation to installed capacity can be expected to be higher during the post-uprate period compared with the corresponding ratio during the pre-uprate period.

Increased temperatures. The increased heat-rejection rate in the post-uprate period was manifested in the CCS by increased temperatures. Notably, the average temperature in the CCS discharge zone increased by about 6.3°F (3.5°C), and the average temperature in the CCS intake zone increased by about 4.7°F (2.6°C). Considering that the increased average temperature in the intake zone of the CCS is slightly greater that the increased threshold temperature of 4.0°F (2.2°C) approved by the NRC in 2014, and also considering that supplementary cooling of the CCS was needed in 2014, then caution should be exercised in further increasing power generation beyond 2014 levels without a reliable system to provide additional cooling beyond that currently being provided by the CCS. A power-generation increase would likely lead to a repeat of the need for supplementary cooling that was experienced in 2014.

Decreased thermal efficiency. The thermal efficiency of the CCS has decreased in the post-uprate period relative to the thermal efficiency in the pre-uprate period. FPL has undertaken efforts to improve the thermal efficiency of the CCS and thereby compensate for the increased thermal loading on the CCS. However, available data indicate that the average post-uprate thermal efficiency remains significantly less than the average pre-uprate efficiency (67% versus 77%). Increasing the thermal efficiency of the CCS is a possible means of mitigating the effects of increase heat loading on the CCS, but the extent of this mitigation is yet to be established and current levels of mitigation are insufficient to compensate for the increased heat loading.

Thermal effect of algae. A sensitivity analysis indicates that increased algae concentrations in the CCS and increased air temperatures are unlikely to have been of sufficient magnitude to have caused the elevated temperatures that have been measured in the CCS. In quantitative terms, the additional solar heating rate in the CCS caused by the presence of high concentrations of algae is estimated to be less than 7% of the heat-rejection rate of the power plant, hence the relatively small effect of algae-induced additional heating.

Follow-up. The preliminary findings of this study will need to be followed up by further development of the thermal model. This model will need to be calibrated within each zone of the CCS. Data required for calibration include indirect measurements of heat-rejection rates, and (ideally) flows and temperatures within the designated zones of the CCS. The development of any engineered system to control temperatures in the CCS will need to be done in tandem with thermal-model simulations.

5.2 Salinity Dynamics

Salinity in the CCS is of concern because increased salinity levels contribute to increased salinity intrusion into the Biscayne aquifer. Although an interceptor-ditch salinity-control system has been in place since initial operation of the CCS, this salinity-control system is ineffective in controlling salinity intrusion at depth, and so elevated salinities in the CCS remain a problem. This study confirms that long-term salinity increases in the CCS are primarily caused by long-term evaporation rates exceeding long-term rainfall rates. Without any intervention, the trend of increasing salinity would continue into the future, likely at an increased rate due to increased post-uprate temperatures in the CCS. Recent spikes in salinity in the CCS are a normal consequence of a prolonged rainfall deficit and can be expected to recur.

5.3 Salinity-Control Plan

FPL has reached an agreement with Miami-Dade County which includes the installation of a system of up to six wells to pump brackish water at a rate of up to 14 mgd from the Upper Floridan aquifer into the CCS. The design objective of this system is to reduce the average annual salinity in the CCS to approximately 34‰ within four years after installation of the system. The agreement with Miami-Dade County also includes remediation of the hypersaline part of the saltwater plume to the west of the CCS, potentially by pumping hypersaline water from the Biscayne aquifer into the Boulder Zone. Three issues of concern related to salinity control in the CCS are identified in this report.

Concern # 1: Pumping rate. The long-term addition of 14 mgd of brackish water from the Upper Floridan aquifer could be of insufficient volume and quality to compensate for the post-uprate evaporation-rainfall deficit that is currently around 29 mgd. This shortfall in pumping rate, if not adequately addressed in the design of the salinity-control system, would likely result in a continued steady increase in salinity within the CCS.

Concern # 2: Increased salinity flux. Adding 14 mgd or more of water to the CCS is likely to significantly increase the salinity flux out of the bottom of the CCS, at least in the short term. The extent to which this increased salinity flux will exacerbate salinity intrusion needs to be addressed.

Concern # 3: Time-frame. The time-frame required for the proposed system to significantly reduce salinity levels in the aquifer remains highly uncertain. Increased certainty is pending more definitive characterization of the subsurface hydrostratigraphy, and the development of a groundwater-flow model that accounts for density-driven flow, heat transport, and dissolved-solids transport in the portion of the Biscayne aquifer surrounding the CCS.

Model leveraging. Utilization of a variable-density groundwater-flow model is essential to accurately describe the flux of salinity into and out of the CCS, to estimate the time scale required for the proposed actions to take effect, and to account for the effects of pumping hypersaline water from the Biscayne aquifer into the Boulder Zone. The variable-density groundwater model that is being developed in support of the Biscayne Aquifer Recovery Well System (RWS) could possibly be adapted to further investigate the technical issues relating to the CCS salinity-control system that are identified here.

5.4 Pumping from the L-31E Canal

Pumping of up to 100 mgd from the L-31E Canal into the CCS is permitted between June 1 and November 30 during 2015 and 2016. Mass-balance modeling has shown that this level of pumping will likely raise the average water level in the CCS by around 0.5 ft, and since the historical water-level differences between the L-31E Canal and the CCS are also on the order of 0.5 ft, it is likely that there will be a significant reduction, or even reversal, of the historical seaward water-level gradient that would exist in the absence of pumping. It is even more likely that the water-level difference between the L-31E Canal and the CCS will be reduced below the 0.30-ft threshold that normally triggers the ID salinity-control system. Model results show a likely reversal of gradient under some circumstances, and a consequence of this reversal could be the advection of a saline plume from the CCS to the L-31E Canal which would cause in increase in the salinity in the L-31E Canal, which is undesirable since the L-31E Canal is regarded as a source of freshwater in its various environmental functions.

5.5 Recommended Action Items

Based on the aforementioned findings, the following action items should be considered:

- Develop a calibrated heat-balance model to simulate the thermal dynamics in the CCS. Essential additional measurements that are required to supplement the calibration of this model are synoptic measurements of volumetric flow rate through the power-generating units, intake temperature, and discharge temperature. Desirable additional measurements include synoptic measurements of the volumetric flow rate and temperature into and out of each CCS zone. The thermal model could be developed to simulate the effects of various supplementary cooling systems to support operation of the CCS.

- Continue efforts to increase the thermal efficiency of the CCS. Increasing the thermal efficiency of the CCS is a possible means to mitigate elevated temperatures caused by increased heat loading on the CCS. However the extent of mitigation that is possible is yet to be established.

- Develop a quantitative relationship for estimating algae concentrations as a function of temperature, salinity, and nutrient levels in the CCS. Such a relationship could be derived using data that is already being collected. The developed model could be useful in managing the CCS, since algae concentrations affect the heat balance and possibly the thermal efficiency of the CCS.

- Develop a locally validated relationship between the evaporation rate, water temperature, air temperature, wind speed, salinity, and algae concentrations in the CCS. This is justified since evaporation is the major cooling process in the CCS, and the evaporation model that is currently being used has a high uncertainty level. At present, a constant in the evaporation function is used as a calibration parameter in the salinity-balance model which is not a desirable circumstance given the importance of the evaporation process.

- Re-assess the effectiveness of pumping up to 14 mgd of brackish water from the Upper Floridan aquifer into the CCS with the objective of reducing the salinity in the CCS. Under present post-uprate operating conditions, a much higher pumping rate will likely be necessary, since post-uprate increases in CCS operating temperatures have increased the evaporation-rainfall deficit from around 19 mgd to around 29 mgd.

- Utilize a variable-density groundwater model to estimate the effectiveness and aquifer-response time scale of the proposed CCS salinity-control actions related to pumping 14 mgd or more from the Upper Floridan aquifer into the CCS.

- The operational protocol associated with the 2015 – 2016 permit for transferring up to 100 mgd from the L-31E Canal to the CCS should be modified to include: (1) measurement of water levels in the CCS to preclude a landward equivalent freshwater head gradient being developed, (2) specification of threshold water-level difference between the L-31E Canal and the CCS as a controlling factor in pump operations, and (3) monitoring of the salinity of the water in the L-31E Canal during pump operations to ensure that CCS water is not seeping into the L-31E Canal.

The recommendations made in this report are intended to facilitate the resolution of the outstanding operational issues related to the CCS. In particular, these recommendations will facilitate the design of robust engineered systems to control the temperature and salinity in the CCS, and control to some degree the extent of salinity intrusion associated with the operation of the CCS. All of the issues raised in this report can likely be resolved, with the goal of having sustainable power generation at the Turkey Point station.

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Appendices

A Response to FPL Comments

Author Comment: The author thanks FPL for providing feedback on the preliminary report. The comments and data provided by FPL were taken into consideration in the preparation of this final report. As explained subsequently in this response, most of the data and commentary provided by FPL reinforces the findings and recommendations contained in the preliminary report. The author encourages FPL to give serious consideration to several recommended actions contained in this final report.

General Comments

FPL Comment: We note that Dr. Chin's review was limited by the lack of any direct interaction with FPL engineers and scientists, or the body of data that has been developed to characterize and understand the various forces in action within the system.

Author Response: The author respectfully disagrees with the above statement. A preliminary form of this report was publicly disseminated, and FPL was formally invited to provide comments and any additional data of their choice. All comments and additional data submitted by FPL were considered in the preparation of this final report. Following this protocol, this final report does not lack direct interaction with FPL and is not limited by lack of FPL input. In conducting scientific and engineering studies that affect a variety of public interests, it is common professional practice to develop a preliminary report based on available data before disseminating the preliminary report and inviting comments and input from stakeholders; this practice was followed here. For preparation of the preliminary report, the Miami-Dade County Division of Environmental Resources Management (DERM) provided the author with an extensive amount of documentation and data that had been compiled by FPL and submitted to regulatory agencies including DERM and the South Florida Water Management District (SFWMD). These data and documentation were used in the preparation of the preliminary report, and additional data provided by stakeholders (including FPL) were also taken into consideration in the preparation of the final report. In their response to the preliminary report, FPL does not contest the accuracy of any of the data used in this study. Although more data has been collected by FPL, beyond that used in this study, the data used in this study was of sufficient length to provide a good understanding of the "various forces in action (sic) within the system." FPL has not provided any additional data that changes the fundamental understanding of the driving forces in the CCS. This latter assertion is discussed in more detail in subsequent sections of this response.

FPL Comment: "Not unexpectedly some of the assumptions employed by Dr. Chin are not consistent with our observations or practical limitations. Moreover, we regret that Dr. Chin's work does not reflect the significant results of FPLs concerted efforts undertaken in 2014 and 2015 to address degraded water quality."

Author Response: The author respectfully disagrees with the above statement. FPL states that "some of the assumptions employed by Dr. Chin are not consistent with our observations or practical limitations," and yet does not state what assumptions they are referring to and what are the observations and practical limitations that are not consistent with the assumptions made in the preliminary report. Therefore, the FPL statement is simply unsubstantiated. A review of FPL's Technical Addendum included with their response to the preliminary report indicates that FPL's statement might have resulted from their misunderstanding of some of the material in the preliminary report, and the author has endeavored to provide increased clarity in this final report. The author recognizes that FPL has done additional work and has acquired additional data beyond the data used in the present study. However, FPL has not presented any additional data that contradicts or changes any of the key findings that were contained in the preliminary report.

FPL Comment on Recommendation 1: Heat balance models are a useful tool that have been used to inform the original design and subsequent changes to system operation and remain an important part of CCS management. It is important that these models be informed with actual system data and observations of the full range of system operations, and with an appreciation for the wide range of water quality, flow distribution, and ambient conditions that affect the heat balance. Importantly, these models have been the basis of regulatory review and direction provided for system operation. Review of the system operational experience through the summer of 2015 confirms that actions taken to restore water quality and system flow have stabilized the thermal operation of the system.

Author Response: FPL states that "Heat balance models are a useful tool that have been used to inform the original design and subsequent changes to system operation and remain an important part of CCS management," yet, there is no documentation cited by FPL, no documentation submitted to regulatory agencies and made available to the author, and no documentation in the public domain that could be found by the author of any heat-balance model currently being used in the management of the CCS, particularly to guide temperature-control measures in the CCS. Any heat-balance model that is currently being used by FPL to assist in the management of the CCS should be made available to the public and outside professionals for peer review and comment. Utilization of such a model would likely have shown that algae blooms in the CCS were not of sufficient magnitude to have been the prime cause of elevated temperatures in the CCS. With this knowledge, FPL might not have made statements to regulatory agencies and the public that elevated algae concentrations were primarily responsible for elevated temperature levels in the CCS, and FPL might have been able to focus on the actual cause of elevated temperatures in the CCS. Therefore, in the absence of any documentation of a FPL heat-balance model that is being used to manage the CCS, the author stands by the recommendation that FPL should develop a calibrated heat balance model to simulate the thermal dynamics in the CCS, and collect the data necessary to calibrate and validate this model. Such a model would likely improve management of the CCS.

FPL Comment on Recommendation 2: There have been multiple reviews over the past 18 months that have identified the causative factors for the decline in thermal efficiency of the CCS. Additionally, the factors have been reviewed in three related DOAH administrative hearings, and testimony before the NRC. These factors have been confirmed, as identified by the recovery of system thermal efficiency and water quality through actions taken in late 2014 and 2015. Future actions are directed by continuing to validate and address these causative factors.

Author Response: FPL's future actions to validate and address the causative factors for the decline in thermal efficiency of the CCS are in support of Recommendation 2 in the report. Data provided by FPL that were derived from their latest efforts to improve the thermal efficiency of the CCS are plotted in Figure 12 of this final report. These data show that the thermal efficiency of the CCS under current conditions remains significantly below the thermal efficiency of the CCS under per-uprate (before Februrary 2012) conditions. Therefore, based on these data, although FPL has made some progress in improving the thermal efficiency of the CCS, the thermal efficiency has not "recovered" to pre-uprate levels and in fact remains significantly below pre-uprate levels.

FPL Comment on Recommendation 3: FPL continues a detailed data monitoring program to characterize the status and behavior of the ecology of the CCS system. This information will enable development of a longer term solution, which may include re-establishing natural filtration through managed vegetation in the system.

Author Response: FPL's data monitoring program to characterize the status and behavior of the ecology of the CCS is partially consistent with the report recommendation. However, to date FPL has not documented any quantitative relationships for estimating algae concentrations in the CCS as a function of temperature, salinity and nutrient levels. Development of such quantitative relationships, as recommended in the final report, could further assist FPL in the effective management of algae concentrations in the CCS. Furthermore, comparative evaluation of the developed relationships with published data from other sites would provide valuable technical validation and guidance to the efforts of FPL.

FPL Comment on Recommendation 4: The salt/water balance model provides a serviceable and validated tool to address the salinity objective identified in this recommendation. The model has been reviewed through regulatory processes and accepted for use in developing predictions of CCS behavior under various future scenarios. Algae and nutrient concentrations are being monitored through the efforts described above, and are the focus of longer term efforts.

Author Response: Recommendation 4 suggests that FPL develop a validated relationship between evaporation rate, water temperature, air temperature, wind speed, salinity, and algae concentrations in the CCS. The basis for this recommendation is that the evaporation process is separately measurable and is central to the management of the CCS for both temperature and salinity control. The evaporation model that is currently embedded in the salt/water balance model is unvalidated, and there is no evidence that this model yields accurate estimates of evaporation from the CCS. The fact that evaporation is adjusted during calibration of a salt/water balance model that also includes several other key unvalidated seepage process equations and associated calibration parameters (viz. hydraulic conductivities) does not validate the evaporation process equation. For example, other functional forms of the evaporation model and other functional forms of the seepage process equations with other calibration constants could provide comparable performance of the salt/water balance model. The primary importance of the evaporation process in the thermal management of the CCS and the practicality of validating the evaporation model separately are the key bases for the recommendation provided in the final report. Furthermore, having a separately validated evaporation model embedded in the salt/water balance model would provide an opportunity to improve the certainty with which the seepage processes are quantified in the salt/water balance model, and provide a more useful tool for managing and quantifying the water fluxes into and out of the CCS.

FPL Comment on Recommendation 5: The 2015 activities associated with the L-31E canal will be the subject of an After Action report by the SFWMD. This report will document the actual pumping history experienced through 2015 and make recommendations for modifications, as deemed necessary. FPL and Miami-Dade County Department of Environmental Resource Management will continue to review system operations to determine consistency with the objectives and requirements of the Consent Agreement. Any revisions to protocols warranted can be accommodated through this vehicle.

Author Response: Recommendation 5 is consistent with the preparation of the After Action report by the SFWMD. The intent of Recommendation 5 is to ensure that future actions (which might deviate from past actions) have sufficient safeguards to protect against negative and unintended environmental impacts that might not have occurred in the past.

Technical Addendum

FPL Comment, #1 Temperature in the CCS: The review apparently relies on a limited data set (2010–2014), and considers no other causative factors for an increase in average CCS temperature.

Author Response: The above statement is simply false. The report extensively documents the development of a heat balance model of the CCS and the report quantifies all of the heat sources and sinks of thermal energy in the CCS. Causative factors explicitly considered in the study include: algae in the CCS, variations in atmospheric temperature, variations in evaporation, and variations in rainfall.

FPL's observations have concluded that the temporal increase in average CCS temperature in 2014 was the result of a series of events that degraded CCS water quality and negatively affected the heat exchange capacity of the CCS.

Author Response: FPL has not produced any data or analyses showing that degraded water quality in the CCS has been responsible for increased temperatures in the CCS.

Key factors contributing to the CCS degradation were:

- Lower than average precipitation into the CCS during 2011 through early 2014 established a deficit of rainfall and reduced stage levels in the system. See Figure 1.

  Author Response: Figure 1 that is cited by FPL is simply a plot of evaporation minus rainfall which correlates to increased salinity in the CCS. However, Figure 1 does not show a reduction in CCS stage nor does it imply that the stage in the CCS is reduced since the evaporation-rainfall deficit is made up by inflowing groundwater mostly originating from Biscayne Bay (i.e., the East side of the CCS). Therefore, Figure 1 does not relate to temperature changes in the CCS. The heat-balance model used in this study uses a daily time step, and the model assumes that on any given day the heat added to the CCS (by the power-generating units, solar radiation, and atmospheric longwave radiation) is equal to heat loss from the CCS (by evaporation and longwave radiation). It is assumed that heat storage due to stage changes on any given day is small relative to the other heat-flux terms. Since daily stage changes are typically less than 2% of the local CCS depth, the assumption of a relatively small change in heat storage over sub-daily time scales within the CCS is justified.

- Beginning in 2010 Unit 2 was secured, along with its circulation water pumps, which provided approximately 17% of design CCS flow. Uprate outages required securing circulating water pumps for Units 3 and 4, sequentially, over a 17-month period beginning in January 2012 and ending in May 2013. This reduced the circulation to approximately 50% of the design flow for a period of approximately 16 months. Reduction of flow had two affects: (1) reduced flow velocities allowed increased deposition of sediments from the water column (preferentially, at the northern end of the system), and (2) higher head levels in the eastern return canals inhibiting the historic inflow of saline groundwater into the CCS based on relative tidal fluctuations.

Author Response: FPL has not provided any data or scientific analyses to show that either increased sediment deposition or higher stages in the eastern return canals have any significant effect on the temperature in the CCS. The effect of reduced seepage inflows on the heat budget is likely to be minimal. If the anomalous period with reduced CCS circulation (January 2012 – May 2013) were excluded from the heat-budget analysis, this would not affect the conclusion that the post-uprate heat rejection rate to the CCS is significantly higher than the pre-uprate heat-rejection rate. This assertion is apparent from Figure 8 of this report, which shows that the heat-rejection rate prior to January 2012 is approximately the same as that asserted for the entire Period 1, and the anomalous flow period (January 2012 – May 2013) does not overlap with Period 2. Consequently, the asserted pre- and post-uprate heat-rejection rates would be approximately the same if the anomalous flow period were excluded from the analysis, and hence inclusion of the anomalous flow period does not significantly affect the heat-budget analysis and the derived conclusions.

- Observations of CCS water quality during June 2012 noted a significant increase in turbidity and algae concentration, which was reduced upon receiving seasonal rainfall and cooler ambient temperatures in the fall of 2012. Following the dry season of 2013, CCS water quality was once again degraded, with observations of high turbidity. Below average rainfall throughout the remainder of the year contributed to increasing salinity in the CCS.

Author Response: The effects of increased turbidity and algae concentrations were taken into account in the heat-balance model by reducing the albedo to zero, which is the most extreme case in which the turbidity is so high that all of the solar radiation is absorbed. The assumption of extreme turbidity has a minimal impact on the heat balance, so it is reasonable to conclude that increased turbidity and algae concentrations were not responsible for the significant temperature increases in the CCS. Increased salinity is linked to increased temperature, since the specific heat of water decreases with increasing salinity. However, the decrease in specific heat between a salinity of 75‰ and 100‰ is only around 3%, which means that the error in assuming a constant specific heat (corresponding to a salinity of 75‰) produces a maximum error of around 3% in the predicted temperature change, which is small compared with the observed temperature changes.

- In late 2013 and early 2014, salinity increased above historically observed peak levels. High turbidity and algae concentrations were observed out of the normal seasonal occurrences. Significant rainfall did not begin until mid-July 2014. Significant canal blockages in the upper segments of the CCS were observed, particularly during periods of low stage levels prior to rainfall. See Figure 2.

> Author Response: Figure 2 provided by FPL is a plot that simply shows the salinity, turbidity, and algae concentrations increasing primarily between June 2013 and September 2014. These changes were taken into account in the heat balance model as described in the previous response.

- A review of CCS heat exchange efficiency shows a decrease from a historic level of 75% efficiency to 65% in early 2013 followed by a decrease to 55% in early 2014. Significant blockages and sediment levels were noted, principally in the northern segments of the CCS. See Figure 3.

> Author Response: Figure 3 provided by FPL shows a decrease in thermal efficiency between the pre-uprate and post-uprate time periods. The data shown in Figure 3 confirm the reported decrease in thermal efficiency contained in both the preliminary report and this final report. FPL indicates that significant blockages and sediment levels might be responsible for the decreased thermal efficiency, however, no data or analyses were provided to support this assertion. Whereas it seems reasonable to assert that blockages in the CCS are at least partially responsible for the reduced thermal efficiency in the CCS, it is equally reasonable to assert that increased temperatures in the CCS (due to increase power input from the power plant) is partially responsible for reduced thermal efficiency. The relative impacts of blockages and increased CCS temperature on thermal efficiency have not been analyzed by FPL, and therefore the extent to which removal of blockages will contribute to reduced temperatures in the CCS has not been addressed by FPL.

- Elevated temperatures in the CCS approached the Ultimate Heat Sink (UHS) Technical Specification limit of 100°F, requiring multiple power reductions to maintain compliance in the summer of 2014. The UHS Technical Specification limit was subsequently amended to 104°F.

> Author Response: The above statement is reflected in both the preliminary and final report. This statement does not relate to the cause of increased temperatures in the CCS.

- Sediment removal was conducted March through October 2015 to redistribute flow and recover design depths in portions of Section 3 and Section 1. Aerial thermography comparing August 2014 vs August 2015 conditions confirm improved cooling and flow distribution in the system. CCS heat exchange efficiency improved to approximately 65% in August 2015. This is in spite of the fact that five of the canal segments were blocked for sediment maintenance activities during this period. See Figure 4.

> Author Response: Even with an improvement of the thermal efficiency to 65%, the thermal efficiency of the CCS in the post-uprate period is still significantly below the average thermal efficiency of 77% based on measurements during the pre-uprate period. Figure 4 provided by FPL shows thermographs of temperatures on two particular days in 2014 (6/29/14) and 2015 (9/10/15), where there is obviously more cooling on 9/10/15 compared to 6/29/14. These two snapshot thermographs lend support to the hypothesis that removal of blockages improves cooling in the CCS. However, the extent to which these two snapshots represent longer-term improved

thermal efficiency cannot be determined. Multiple snapshots taken at regular time intervals (e.g., monthly) would be more useful in this regard, particularly since the latest thermal-efficiency analyses provided by FPL show that thermal efficiencies are still significantly below pre-uprate levels. It should also be noted that assessment of thermal efficiency from the thermographs provided by FPL is not possible, since the ambient temperatures of the given dates were not provided.

FPL Conclusion: The combined effect of multiple factors impacted water quality and heat exchange effectiveness to result in elevated CCS temperatures during the summer of 2014. Sediment removal activities in 2015 established improved heat exchange efficiency that reduced CCS temperatures during the summer of 2015, despite continued high salinity (average of 95 PSU) and degraded water quality. Units 3 and 4 operated continuously through the summer of 2015 with a maximum intake temperature of 98.5°F.

Author Response: For FPL to simply state that elevated CCS temperatures were the result of degraded water quality and reduced heat-exchange effectiveness without providing any supporting data and quantitative analyses is rather unscientific. Such an approach points to the urgent need for FPL to develop a validated heat-balance model to support effective management of the CCS. FPL states that sediment removal activities in 2015 established improved heat exchange efficiency that reduced CCS temperatures. However, reduced temperatures in the CCS could have been mostly due to reduced power generation and minimally influenced by sediment removal activities. The author urges FPL to perform a more complete scientific investigation of the performance of the CCS and the impact of increase thermal efficiency on the temperatures in the CCS. It is entirely plausible that FPL could be successful in significantly improving the thermal efficiency of the CCS, while at the same time post-uprate temperatures continue to exceed pre-uprate temperatures. The reason for such an occurrence is that the achievement of increased thermal efficiency in the CCS is insufficient to compensate for the increased thermal loading resulting from increased heat rejection from the power plant during the post-uprate period. For improved thermal efficiency to maintain temperatures at pre-uprate levels, the post-uprate thermal efficiency would have to significantly exceed the pre-uprate thermal efficiency. To date, there has been no data or analyses provided to indicate that this is possible, and the post-uprate thermal efficiency remains below pre-uprate levels.

FPL Comment, #2 - Quantitative Effects of Water Input (Section 4.2): The discussion of the impacts of L-31E water temperature and salinity are based on unrealistic and incorrect assumptions that are inconsistent with the observations at site. For example:

- For the calculations, the focus is on the impacts of added L-31E canal water and disregards the variations that come from groundwater exchange and ambient weather conditions (rainfall, evaporation rates, etc.). These factors tend to be significant and more influential than the impacts being hypothetically calculated.

Author Response: The author respectfully disagrees with FPL's statement that the analysis of impacts of L-31E water on temperature and salinity as described in Section 4.2 are based on unrealistic and incorrect assumptions. It appears that FPL has misinterpreted the intent of this section of the report. The intent of this section is simply to isolate the temperature and salinity effects of pumping water from the L-31E Canal into the CCS. Therefore temperature and salinity changes caused by other processes are purposely not taken into account in this section. This section of the report is <u>not intended</u> to be nor presented as a model of how the CCS will respond to water pumped from CCS over the long term (viz. months), it is just intended to illustrate the isolated impact of pumped water on temperature and salinity. Over the short term (viz. days) other effects on CCS temperature and salinity might be small and the effects of pumped water on temperature and salinity provided in this section could give a fair indication of the response of the CCS.

- The calculation assumes a 100 MGD rate of addition for over 170 days. The average daily volume during pumping operations was approximately 30 MGD. The period of active pumping began August 27, 2015 and ceased November 30, 2015–a period of 94 days. These events occurred during periods of significant rainfall, whose volumetric contributions were the predominant influence on CCS temperature and salinity during this period.

Author Response: The objective of the present study, as requested by DERM, was to "examine the effects of extracting up to 100 mgd of water from the L-31E Canal." Therefore, the calculations in this section are provided only as an example and are intended to present the maximum impact of pumping water from the L-31E Canal into the CCS. The duration of the pumping is also given as an example and is not intended to show the actual duration of pumping, but rather the duration of pumping that would be required for the temperature or salinity to reach an asymptotic value. The simple hypothetical example presented here is <u>not</u> an attempt to replicate the pumping that occurred in 2015 and assumes a period of no rainfall during pumping operations.

- In FPLs experience, L-31E water provided an input of approximately 28 MGD (or 0.6% of system volume per day) at an average temperature of 80°F. The temperature impact of this water would be less than 0.2°F degrees each day, calculable but likely not measurable.

Author Response: The author does not contest this statement, and this statement does not contradict any statement in the report.

- While FPL believes that a potential benefit of adding water is a reduction in CCS water temperature, as the report states, added water is significantly more effective at reducing CCS salinity. As the report later states, evaporation is a notably more effective means of cooling than added water. Whereas the report identifies occasions where water added to the CCS (i.e. L-31E, precipitation) has appeared to produce significant reductions in CCS water temperature, FPL wishes to identify potential inaccuracies in the cited events:
  - The report suggests that the water temperature of the CCS dropped by 6.5°F during the fall 2014 pumping of L-31E water into the CCS. However, based on uprate monitoring data, the average CCS temperature decreased from 92.8°F (September 25) to 91.4°F (October 15), a total reduction of 1.4°F.

    Author Response: The author respectfully disagrees with the statement made by FPL. The text of the Emergency Final Order (SFWMD, 2015) explicitly states that "During the term of the fall 2014 Emergency Order, the temperature of the water in the CCS dropped 6.5°F." Therefore, the statement made in the report is consistent with the understanding of the South Florida Water Management District. FPL states here that the average CCS temperature decreased from 92.8°F (September 25) to 91.4°F (October 15), a total reduction of

1.4°F. This statement is not contradicted in the report and does not affect the statements and conclusions in the report.

– The report concludes that the average temperature of the CCS dropped from 98.2°F on April 27, 2015 to 81.3°F on April 28, 2015 (a reduction by 16.9°F in one day) due to a rainfall event that occurred in that 2-day timeframe. Based on uprate monitoring data, the average temperatures for April 27 and 28, 2015 were 97.9°F and 96.8°F, respectively. The average water temperature on April 29 did drop to 90.0°F, a reduction of 6.8 degrees in one day. This reduction is likely due to a number of factors, including an approximately 5-inch rainfall on April 29 and a drop in air temperature of a similar magnitude.

Author Response: The author respectfully disagrees with the inference made by FPL. The text of the Emergency Final Order (SFWMD, 2015) explicitly states that "On April 27, 2015, the temperature of the CCS reached 98.2°F. A large rainfall event occurred over the CCS between April 27 and 28, 2014. The addition of freshwater inflow from rainfall reduced the temperature of the water in the CCS to 81.3°F." Therefore, the statement made in the report is consistent with the understanding of the South Florida Water Management District. To avoid any ambiguity, the statement in the report has been changed to be exactly the same as stated in SFWMD (2015).

Conclusion: The discussion of quantitative effects of L-31E water fail to recognize the actual experience and environment, and therefore overstate the impacts of this activity.

- The report notes that pumping from the Interceptor Ditch (ID) has produced increases in the stage of the CCS. FPL is not cognizant of data that demonstrate a relationship between ID pumping and CCS stage in an absolute or relative sense. Due to the complex nature of inflows and outflows of water from the CCS, it is impossible to isolate the effect of water additions from water additions from the ID on CCS stage.

Author Response: The author finds this statement by FPL to be very surprising, given that such data is routinely collected, analyzed, and reported subsequent to ID operation. There are multiple data collected by FPL contractors showing that when the ID system is operational and there is no rainfall the stage in the CCS increases, sometimes increasing above the state in the L-31E Canal. Such data and associated analyses relating ID pumpage, L-31E Canal stage, and CCS stage can be found, for example, in the following documents produced by FPL contractors: Golder (2008) and Ecology and Environment, Inc. (2012c). This responsive increase in the CCS stage when the ID pumps are operating would most likely be due to ID-pump operation, since they could not reasonably be caused by net seepage inflows as would be shown by FPL's own water-balance model.

- The report notes that "In October 2015...FPL reached an agreement with Miami-Dade County which includes construction and operation of six wells that would pump water from the CCS into the Boulder Zone of the Floridan aquifer so as to reduce the salinity in the CCS". The agreement between FPL and Miami-Dade County includes the design a system to pump low salinity Floridan aquifer water into the CCS via six wells for the purpose of salinity reduction. In addition, FPL has agreed to remediate the hypersaline part of the plume to the west of the CCS, potentially by pumping water from the Biscayne aquifer and injecting into the Boulder Zone.

Author Response: The author thanks FPL for this correction. During preparation of the preliminary report, the author was not provided any information on the agreement between Miami-Dade County and FPL, so the author relied on media accounts that were repeated in the preliminary report. The media accounts were apparently incorrect. The text in the report has been changed, and the replacement text in the final report is as follows: "In October 2015, in response to chloride levels in the Biscayne aquifer exceeding water-quality standards as a result of the high salinities in the CCS, FPL reached an agreement with Miami-Dade County which includes the design of a system of up to six wells to pump low-salinity water from the Floridan aquifer into the CCS to reduce salinity levels in the CCS. In addition, FPL agreed to remediate the hypersaline part of the saltwater plume to the west of the CCS, potentially by pumping hypersaline water from the Biscayne aquifer into the Boulder Zone." Subsequent to the dissemination of the preliminary report and during preparation of this final report, DERM provided the author with a copy of the Consent Agreement between FPL and Miami-Dade County relating to salinity control in the CCS and remediation of the hypersaline plume in the Biscayne aquifer. The content of this Consent Agreement is reflected in the analyses presented in this final report.

- The report states that a unit volume of evaporated water would cause a 50 times greater temperature decrease than a unit volume of added water. This means that the average 39 MGD of evaporation reduces temperature approximately 50 times the 6.8°F that is attributed (earlier in the report) to the average 43.5 MGD of L-31E water added during fall 2014. In theory, FPL agrees with the relative effectiveness of evaporation at cooling water. As such, FPL believes that comments elsewhere in the report pertaining to the cooling effects of added water to the CCS are overstated.

Author Response: FPL's interpretation of the statements in the report is grossly incorrect and taken out of context. The heat extracted from the CCS at an evaporation rate of 39 mgd is supplied by multiple sources that include solar energy and heat from the power-generating units. Hence, the latent heat of evaporation does not directly translate into a proportional decrease in temperature, but rather the heat demand of evaporation is buffered by the aforementioned heat sources.

FPL Comment, #3 - Application of Model Results (pg. 39): The review improperly characterizes that "...the primary motivation for pumping from the L-31E is actually to reduce temperature." At best this statement is an oversimplification. The input of L-31E water was conducted primarily to reduce CCS salinity by making up for evaporative losses and diluting the existing CCS salinity. This allowed for improved water quality and therefore more efficient heat exchange operation. Input of L-31E water can only occur during periods of coincident rainfall.

Author Response: The author respectfully disagrees with the above statement. The primary motivation for short-term pumping, as it relates to the public interest and the involvement of DERM and SFWMD, is that the FPL plant is not forced to shut down the nuclear-power generating units, which would deprive a significant number of FPL customers of electricity. Curtailment of nuclear-power generation is required as a result of high temperatures in the CCS, and is not required as a result of high salinities in the CCS. FPL appears to be asserting that high salinities are responsible for high temperatures, and therefore salinity reduction is the primary motivation for pumping water from the L-31E Canal. In fact, the reduction of CCS temperature by mixing colder water from the L-31E Canal with warmer water from the CCS is the "primary motivation" for pumping water from the L-31E Canal into the CCS. There is no scientific data or analyses to support the assertion that focusing on salinity reduction to improve heat exchange would be a reasonable tactic in this circumstance.

With regard to the heat balance and unit operations, the following is noted.

- Following the approval of the uprate, but prior to its execution, FPL made the decision to decommission Unit 2. Calculations have been conducted to illustrate the pre- and post-uprate maximum thermal capacity provided by operating units at the Turkey Point site. While Unit 3 and 4 electric capacity was increased by 225 MW as a result of the uprates, Unit 2 was decommissioned removing 400 MW of electric capacity. The resultant net change in thermal heat rejection capacity to the CCS was a decrease of approximately 4%. (See FPLs NRC ASLB testimony, Exhibit FPL 008, November 11, 2015).

Author Response: The author respectfully asserts that the above statement is grossly misleading. This statement, which has been made in key testimony and in the public square, implies that since the capacity of the generating units has decreased in the post-uprate period then increased power generation could not be responsible for increased temperatures in the CCS. This is simply not true. In fact, actual power generation has increased during the post-uprate period (at least in 2014 for which data is available to the author). In addition, FPL should acknowledge that switching 1 MW of power-generation capacity from a backup fossil-fuel plant (Unit 2) to 1 MW of capacity in a base-load nuclear power plant (Units 3 and 4) increases the heat rejection rate significantly for several reasons: (1) heat that used to be rejected with flue gas through stacks is now rejected into the CCS, (2) base-load units generate waste-heat most of the time, while backup units generate waste heat sporadically, and (3) Unit 2 has apparently been out of service since 2010, so the power-generating capacity serviced by the CCS in the post-uprate period is in fact greater than the immediate pre-uprate capacity serviced by the CCS. In addition to all of these facts, actual power-generation data plotted in Figure 9 of this report show unequivocally that power generation in post-uprate period was greater than power generation in the pre-uprate period.

FPL Comment, #4 - Impacts to Adjacent Water Bodies:

- Between August 27 and November 30, 2015, FPL conducted near-sustained pumping from L-31E into the CCS (approximately 30 MGD). During this time, there was no evidence of increasing salinity within even the deepest portions of L-31E adjacent to the CCS. A figure is provided that illustrates the daily averaged salinities in L-31E in the bottom sensors at stations TPSWC-1 and TPSWC-2. Inspection of this figure reveals that there is no notable increase in L-31E salinity (orange and blue lines) beyond the natural fluctuations over the prior year, between late-August and the end of November. See Figure 5.

Author Response: FPL has misinterpreted the statement in the report, which identifies the possibility of salinity increases in the L-31E Canal due to sustained pumping 100 mgd from the

L-31E Canal into the CCS. The fact that salinity increases were not observed during the previous pumping of 30 mgd does not preclude the possibility of the cited occurrence in the future.

- The seasonal inland movement of saltwater noted in the report (7.5 miles during the dry season, 1 mile during the wet season for 0.5 ft increase in CCS water levels) suggests a maximum rate of migration of 7.5 miles per 180 days (220 ft per day). This rate is significantly higher than and inconsistent with tritium-based estimates of saltwater wedge movement (400 to 500 ft per year).

Author Response: FPL has misinterpreted the statement in the report, which simply re-states previous predictions of salinity intrusion under a particular circumstance (0.5 ft increase in CCS water level). These predictions were made by engineers several years ago. FPL has also misinterpreted the meaning of the salinity intrusion predictions cited. The predictions refer to the equilibrium position of the saltwater front; there is no implication as to the rate of movement of the saltwater front as interpreted by FPL.

- While increased salinity in the CCS can contribute to increased saltwater intrusion within the Biscayne aquifer, as the report concludes, it is also true that periods of increased CCS salinity are generally coupled with depressed water levels within the CCS. These periods of time are generally characterized by predominant groundwater inflow to (and reduced seepage to Biscayne aquifer from) the CCS.

Author Response: This above analysis provided by FPL is incomplete and misleading. FPL has not produced any data or analyses to show that elevated salinities in the CCS are generally coupled with depressed stages in the CCS. This assertion is in fact not supported by available data. The report shows that salinities in the CCS have been steadily increasing over time, whereas it is clear that CCS stages have not been steadily decreasing over time. Over the shorter term, stages in the CCS roughly follow the stages in the surrounding aquifer, with stages in the CCS and surrounding aquifer both being lower in the dry season, and both being higher in the wet season. Since seepage inflow is related to the difference between the water level in the CCS and the water-table elevation in the surrounding aquifer, one cannot generally conclude that this difference is lesser under particular seasonal conditions within the CCS. Groundwater inflow and outflow from the CCS is governed by the relative elevation of water-table in the surrounding aquifer compared with the elevation of the water surface in the CCS. Since both the water-table in the surrounding aquifer and the elevation of the water surface in the CCS are likely to be simultaneously depressed (e.g., in the dry season) then one cannot generally associate depressed water levels in the CCS with increased groundwater inflow to the CCS as implied by FPL.

FPL Comment, #5 - Algae in the CCS:

- The statement by SFWMD that algaecide is ineffective at reducing algae concentrations in the CCS is contradicted by observed relationships between algaecide concentrations and algae concentrations. Dr. Chin illustrates this conclusion reasonably well in his report.

- The report speculates on the application of a $CuSO_4$-based algaecide between May 31, 2015 and November 13, 2015. FPL would like to clarify that no such algaecide was applied during this time. The decreasing trend in algae concentrations during this time are likely attributable to salinity concentrations exceeding 70 ppt. The particular algae observed in the CCS during this timeframe are not ideally suited to growing and surviving in water with salinity exceeding 70 ppt.

Author Response: The speculation on the application of a $CuSO_4$-based algaecide between May 31, 2015 and November 13, 2015 was inferred from monitoring data that showed elevated SO_4^{2-} levels during the period cited. However, in the light of the additional information provided by FPL, the text in the preliminary report has been modified in the final report, and the revised text is as follows: "The algaecide commonly used in the CCS is $CuSO_4$, and the possible effectiveness of this algaecide can be seen by plotting the relationship between Chl$a$ and sulfate (SO_4^{2-}) concentrations; this relationship is shown in Figure 2. It is apparent from Figure 2 that algae concentrations decrease significantly with increasing concentrations SO_4^{2-}, indicating that the addition of an algaecide is an effective means of reducing algae concentrations in the CCS. However, according to FPL (see Appendix A), no algaecide was applied during the period covered by Figures 1 and 2, and so the SO_4^{2-} apparently acting as an algaecide could be the residual from previous $CuSO_4$ applications. FPL has suggested an alternative hypothesis that the decreasing trend in algae concentrations during this time is attributable to salinity concentrations exceeding 70‰, since the particular algae species observed in the CCS during this time frame was not ideally suited to growing and surviving in water with salinity exceeding 70‰. Collectively, the anomalous results described here should provide a strong motivation for FPL to use measured data to develop a functional relationship between algae concentrations and the influencing independent variables of temperature, salinity, total phosphorus, and algaecide concentrations. Such a functional relationship could provide useful guidance for the control of algae within the CCS. However, it should generally be kept in mind that Chl$a$ reductions caused by any algaecide are necessarily only temporary, since the natural factors causing high levels of Chl$a$ (i.e., S, T, and TP) remain at elevated levels within the CCS."

FPL Comment, #6 - CCS Salinity:

- While the differential between evaporation and precipitation is a cause for continuing increases in salinity, as the report states, data show that evaporation is greater than precipitation during periods of relatively steady and decreasing trends in salinity (See the 2004 to 2013 timeframe in report Figure 10). For example, between June 1 and August 31, 2012 (pre-uprate period), cumulative evaporation exceeded cumulative precipitation by more than 200 MG; yet, average CCS salinity decreased by more than 6 ppt during this timeframe.

Author Response: The main point in the report is that over the long term the fact that evaporation exceeds rainfall is the primary cause for the upward trend in CCS salinity. The report also makes clear that over the short term seepage flows and ID pumpage can influence salinity levels in the CCS. In this regard, the report does not contradict the above statement made by FPL.

- In addition to evaporation and precipitation, there are other factors that affect the balance of salt in the CCS, as illustrated in the water and salt balance model. Salinity moderating factors include CCS water seepage to groundwater, inflow of lower salinity groundwater into the CCS, and additional water sources.

Author Response: See previous response.

- According to the most recent calibrated water and salt balance model (which simulates from September 2010 through November 2015), evaporation is, on average, approximately twice precipitation. During this this timeframe, the CCS has experienced periods of increasing, decreasing and relatively steady salinity.

  Author Response: See previous response.

FPL Comment, #7 - Inaccuracies Regarding the CCS:

- Card Sound Canal is not a part of the Cooling Canal System. Perhaps the author is referring to the Grand Canal.

  Author Response: Yes, this is a typographical error. "Card Sound" has been changed to "Grand."

- The report notes that typical CCS stage elevations (NGVD 29) near the discharge, CCS southern canal, and intake locations are 2.04 ft, 0.76 ft, and −0.77 ft, respectively. Based on uprate monitoring data, the average stage elevations (NGVD 29) near the discharge, CCS southern canal, and intake locations during pre-Uprate, Interim, and post-Uprate periods are summarized in the table below. These values appear to be inconsistent with the stages stated in the report, and are indicative of a CCS with a lower stage at the discharge location (lower seepage rate to groundwater) and a more moderate hydraulic gradient across the CCS (lower canal flow rate, increased water travel time through the CCS, and increased opportunity for water cooling). See Table 1.

  Author Response: The cited stages in the preliminary report were the same as those stated by Lyerly (1998), a FPL contractor, in a report on the thermal performance of the CCS. Therefore, any inaccuracies in these data can be attributed to Lyerly (1998). Nevertheless, the author assumes that the stages reported in the above comment by FPL are more authoritative, and so the stages in question have been changed in the final report. The revised text in the report now reads as follows: "Under current operating conditions, typical water surface elevations in the CCS are 1.48 ft NGVD at the discharge location, 0.95 ft NGVD at the south end, and 0.70 ft NGVD at the intake location (see Appendix A)."

B Response to SACE Comments

Author Comment: The author thanks the Southern Alliance for Clean Energy (SACE) for providing feedback on the preliminary report. The comments provided by SACE were taken into consideration in the preparation of the final report.

Cover-Letter Comments

SACE Comment: To complement and strengthen the basis of the report with additional data, SACE believes that it is important to expand the scope to include all new available information such as work from William Nuttle and baseline studies of the underlying geology of the area. As well as ensuring that Mr. Chin consult some older reliable reports to help him inform and support his analysis. There are some key reports missing from the references that were cited as well.

Author Response: The study was initiated in fall 2015 and lasted 120 days. The scope of the study was specified by the Miami-Dade County Commission, and the database for the study was that made available by DERM. Publications by Nuttle were not available to the author during the preparation of the preliminary report, and were not in the open technical literature. However, Nuttle's publications were subsequently made available to the author via DERM and were considered and referenced in the final report. The documents and data provided to the author by DERM was extensive and covered mostly up to the end of 2014. Many reports and data files were referred to during the study to gain an understanding of the CCS and the surrounding environment. The reports reviewed included many relating to the subsurface geology, and the author believes that this geology is adequately summarized in the final report at a level that is commensurate with the scope of this study. Additional data considered in the preparation of the final report was provided by FPL subsequent to their review of the preliminary report. All references cited in the final report are listed in the Bibliography, however, these references are limited to those from which either data or factual information was derived in the preparation of the final report.

SACE Comment: In addition, to the extent the report relied upon data provided by Florida Power and Light, Inc. (FPL) the owner and operator of the CSS, that data should be independently verified. We would not want anyone to assume that information now becomes factual just because it is now cited here. We know for example the water budget has at least a 30% error associated with it and that normal background levels of tritium in surface water are typically 1 – 3 pCi/L and 4 – 6 pCi/L in groundwater and it is important to realize that the 20 pCi/L threshold is only a screening tool, not a regulatory measure of any kind.

Author Response: None of the key findings or recommendations contained in the final report were based on data obtained directly from FPL. Although most of the data used in the analyses were indeed collected by FPL consultants, these data were reviewed by DERM and SFWMD prior to being used in this study. The author found no reason to question the collected and reviewed data. The author did not rely on any interpretations of these data by FPL. The study did not rely on the accuracy of the water-budget model in any of its findings. However, the report does recommend that FPL improve the water-budget model by developing a more precise evaporation process equation, noting that evaporation is a dominant yet uncertain component of the water budget. Regarding the 20 pCi/L threshold, the final report states that "A threshold concentration of 20 pCi/L has been used as a baseline to infer the presence of groundwater originating from the CCS." This wording should make it clear that the 20 pCi/L tritium concentration is used for screening only. The final report further states that "The presence of elevated levels of tritium above natural background levels in the Biscayne aquifer is not considered to be a threat to public health and safety, since the measured concentrations are far below the federal drinking water standard of 20,000 pCi/L. Elevated levels of tritium are simply being attributed to the presence of water originating in the CCS."

General Comments

1. The report appeared to give primary focus on the operations and outcomes within the CCS with much less attention given to impacts of CCS operations on the surrounding groundwater or surface water systems.

Author Response: The objective of this study as stated by the Miami-Dade County Commission was to "...look at the temporal trends in the physical and chemical characteristics of the CCS water, and to provide possible explanations for these changes." Pursuant to this objective, the focus of the investigation was on the CCS and not on the surrounding groundwater or surface water systems.

2. Temperature and Salinity data were only evaluated through 12/7/14. The report would likely benefit from focused data collection efforts instigated over the past year.

Author Response: Temperature and salinity data subsequent to 12/7/14 were not made available to the author during the period of the study. It should also be noted that to fully analyze the temperature and salinity data for the past year supporting climatic and operational data would also have been needed.

3. Review with consult (sic) William Nuttle, wnuttle eco-hydrology.com, and all of his published works and presentations. One such report dated June 8th, 2015 entitled "Review of CCS water and salt budgets reported in the 2014 FPL Turkey Point Pre-Uprate Report and Supporting Data" would be particularly helpful.

Author Response: It would not have been appropriate to consult with Dr. Nuttle during this study since he appears to be affiliated with at least one of the stakeholder groups; such a consultation could have compromised the impartiality of this investigation. Subsequent to preparation of the preliminary report, the author was provided (via DERM) with a copy of the above-referenced report. This report has been reviewed and referenced in the final report.

4. Impacts on the aquifer should be discussed, salt loading and the water budget.

Author Response: See response to Comment #1. The water and salt interchanges between the CCS and the surrounding aquifer are discussed fairly extensively in Section 3.2.4 of the report.

5. What additional data need to be collected to help correct the % error we see in the modeling of the operations? The water budget for example seems to have a percent error of +/- 30% for example how could this be corrected by informing the models with better data: additional rain gauges, flow meters, a rhodium dye study–what sampling would be most helpful?

Author Response: Improvement in the water-budget model would likely require the development of a more sophisticated water-balance model. A first step in this direction is a recommendation in the final report that FPL develop a more accurate evaporation model, since this is a dominant component of the water budget, and the current evaporation model has not been appropriately validated. In order to properly quantify the seepage fluxes to the CCS, a variable-density groundwater-flow model of the surrounding aquifer would need to be interfaced with the CCS. This would produce a quantum improvement in the water-budget model, and a much better understanding of the interaction between the CCS and the surrounding aquifer. Improved flow measurements within the CCS would be particularly helpful in validating seepage estimates.

6. Additional minor comments: We did not see a date on the report, this report does not indicate it is a draft, there was a mix of metric and English units used in the report and there was a mix of NGVD and NAVD vertical datum used in the report.

Author Response: There was no date on the report and it was not tagged as a draft. This final report is tagged as the "Final Report" and is dated. The mix of SI and American units, as well as the mix of NGVD and NAVD, reflected the variations of units that were used in other key studies cited in the report. To facilitate references to those other studies, it was decided to retain (for the most part) the units and benchmarks used in those studies.

Specific Comments

1. Page 2: Temperature in the CCS. The report makes important commentary on increasing temperature with increased power generation and the critical need for a reliable supplementary cooling system.

2. Page 3: Salinity in the CCS. Statement that period of no rainfall was primary cause of high salinities in 2014 is not supported by the data collected subsequent to 2014. In addition there were 0-1 working rain gauges to calibrate the NEXRAD data used.

Author Response: In 2014, the extended period of no rainfall was the primary cause for high salinities measured in the CCS. As shown in Figure 16 and discussed in this report, the extended period of no rainfall was associated with a net seepage inflow of saline water from both the east-side and the bottom of the CCS, and these combined (yet interdependent) occurrences resulted in a steep trend of increasing salinity in 2014. Data collected subsequent to 2014 does not change the assertion regarding salinity dynamics that led to the increasing salinity in 2014. The cause of the salinity increase in 2014 is supported by the FPL mass balance model and is a data-driven conclusion. Subsequent to 2014, other factors contributing to salinity variations might have had a more dominant influence than the absence of rainfall. This occurrence is not contrary to the mass-balance analyses in the report. The lack of working rain gages to calibrate the NEXRAD data is certainly a concern, but there is insufficient data or analyses to assess the impact of this issue on the water-budget analyses presented in the report.

3. Page 3: Salinity in the CCS. The report makes important commentary that while supplemental fresh water can mitigate CCS salinity, it will elevate water levels and likely exacerbate inland intrusion of saltwater from the CCS. But where else will it go? Preferential flow paths? How will it interact with the surrounding environment? How about a look at the geology and how the pH of the plume may be interacting with the basic limestone. Could it be making those flow paths larger? Are there other locations in the bay where the pollution is reaching the surface that are not being monitored currently? Just as historical upwelling of freshwater into Biscayne Bay from the Everglades once did. These locations are recorded in old historical sailing accounts and the National Park may actually know where some of these upwelling features are.

Author Response: Accurate estimation of the contribution of elevated stages in the CCS to salt-water intrusion and outflows to Biscayne Bay will require the utilization of a variable-density groundwater-flow model that takes into account the spatial variations in the subsurface geology, and spatial variations in groundwater densities and salinities in the aquifer surrounding the CCS. Such analyses and modeling of flow in the surrounding aquifer were beyond the scope of this study.

4. Page 3: Salinity in the CCS. The report makes important commentary that the effectiveness of the proposed hyper saline extraction system will depend upon salinity-transport dynamics within the aquifer.

5. Page 4: Withdrawal of 100 mgd from L-31E Canal. The report makes important commentary on adverse effects on groundwater gradients and groundwater salinity from pumping water from the L-31E Canal to the CCS. However, it only notes water level impacts and does not mention the complex hydrodynamics of water level and salinity within the CCS and surrounding groundwater system.

   Author Response: The impact of pumped water on the flow dynamics and the salinity distribution in the CCS was beyond the scope of this study. Such analyses would require the development of detailed hydrodynamic and mass-balance (salt) models of the CCS. An analysis of the impact of the pumpage on the flow field in the surrounding aquifer would require the use of a variable-density groundwater-flow model. Development of such models were beyond the scope of the present study.

6. Page 4: Recommended Actions. All of the recommendations appear to focus on the CCS itself with no specific recommendations on monitoring or mitigation of impacts to the surrounding groundwater or surface water systems.

   Author Response: As described previously, the scope of work for this 120-day study was only concerned with the CCS. Specifically the scope of work was "...to look at the temporal trends in the physical and chemical characteristics of the CCS water, and to provide possible explanations for these changes." Consequently, no specific recommendations on monitoring or mitigation of impacts to the surrounding groundwater or surface water systems were generated.

7. Page 8: 1.2 Geohydrology. The report correctly points out the generally low hydraulic gradients in the Biscayne aquifer and the importance of very accurate measurements of water levels. However, he does not mention the importance of density differentials and density gradients to the acquisition of accurate water level measurements or the fact that in the highly permeable Biscayne aquifer, a very small gradient change can mean very large movements of water in the aquifer.

   Author Response: The report mentions the importance of density variations in the groundwater surrounding the CCS, particularly in the context of converting water-table gradients to piezometric-head gradients when considering the elevated stages in the CCS that will result from pumping water into the CCS. The fact that the use of freshwater piezometric-head equivalents provides a more rigorous approach to the operation of the ID is mentioned on Page 17, and the fact that it is actually the difference in equivalent freshwater heads that govern the flow between the CCS and the L-31E Canal is stated on Page 49. There are a variety of factors that affect the inland movement of a saltwater front and the fact that small gradient changes can cause large changes in seepage velocity, while true, is not the only reason for the inland migration of the saltwater front.

8. Page 13: 1.5 Saltwater Intrusion. The report states that the inland extent of the saltwater interface varies naturally in response to a variety of factors but then goes on to only mention two of those factors; rainfall and groundwater pumping. Numerous studies have shown that construction and operation of the extensive canal network in SE Florida is the most critical influence and control on saltwater movement in the aquifer.

Author Response: The factors cited in the report that influence saltwater intrusion are factors that vary seasonally (e.g., rainfall) or can have inadvertent effects on salinity intrusion (e.g., groundwater pumping). The author acknowledges the role of coastal canals and salinity-control structures on salinity intrusion, however, in recent history these are highly controlled systems and are usually used to mitigate saltwater intrusion.

9. Page 13: CCS Impact on Saltwater Intrusion. The report provides a number of references to the original engineering studies completed by Dames and Moore in the 1970's as predicting the very outcomes we are observing today.

10. Page 14: Upper Paragraph. The report correctly concludes that the tritium data strongly support the conclusion that operation of the CCS has impacted salinity of the Biscayne aquifer some 4 miles west of the CCS.

11. Page 15/16: Effectiveness of the ID Salinity Control System. The report correctly points out that operating rules of the ID salinity control system have limited effects and do not prevent landward migration of saline water originating from the CCS. It further points out that pumping water into the CCS will elevate water levels in the CCS above the L-31E Canal and notes that this condition was recognized in a study by Dames and Moore in 1971 which predicted westward migration of the saltwater interface even with operation of the ID salinity control system.

12. Page 17/18: 2.1.3 Thermal Effects on Groundwater. The report discusses thermal impacts to groundwater above −25 feet NGVD with little or no observed thermal impacts below that depth. It should be noted here that a depth of 20 – 30 feet is typically the occurrence of the contact between the less permeable overlying Miami Oolite and the highly permeable underlying Key Largo/Fort Thompson formation. High porosity and strong groundwater movement within the underlying formation may be a primary control on the vertical extent of thermal impacts to the groundwater system.

Author Response: This is a possible scenario, but there is no data or analyses presented to support this assertion. The thermocline occurrence as described in the report is a measured effect that is explainable simply based on the lesser density of shallow warm water compared to deeper cool water. The influence of seepage velocities on thermocline formation is more speculative.

13. Page 31: Salinity Balance Model Formulation. It is not clear from the model descriptions that water levels are corrected for density differentials associated with varying salinity.

Author Response: Water levels in the (FPL-developed) salinity-balance model are not corrected for density differentials associated with varying salinity.

14. Page 40: Upper Paragraph. The report refers to model Scenario A from 11/2010 to 10/2012 as reflecting normal weather conditions and Model Scenario B from 11/2013 to 10/2014 as reflecting dry weather patterns. However, these periods also reflect pre and post uprate periods for power generating units 3 and 4 and therefore do not provide valid wet and dry scenarios absent of the bias created by the different operating conditions.

Author Response: Yes, there is a bias that comes from assuming that the temperature of the water in the CCS corresponds to the given external conditions during each of the scenarios. However, in order to use the FPL analysis as a basis for the analyses presented in this report, the bias was carried forward. This temperature bias likely has minimal impact on the analyses in the report, since the analyses in the report are concerned with elevated stages in the CCS due to the addition of pumped water, where the elevated stages would be minimally affected by any inherent temperature bias; the more important variables in this case being rainfall, water-table elevations, and pumpage rate. Consequently, the key findings in this report are unlikely to be sensitive to temperature biases in the assumed scenarios.

15. Page 40/41: Effect of Increased Water Elevations in the CCS. The report correctly points out that the addition of up to 100 mgd of freshwater to the CCS will raise water level elevations and increase the discharge of highly saline water from the CCS into Biscayne Bay and into the Biscayne aquifer.

16. Page 43: Demonstration of Effects. The report discusses the density differentials between the freshwater from the L-31E Canal and the hypersaline groundwater underlying the CCS as further increasing the potential for reversed gradients and increased movement of hypersaline water from the CCS to the Bay and Aquifer. However, he does not discuss that the density differential will also likely result in little to no mixing in the groundwater system.

Author Response: The report discusses differences in piezometric head in the context of flow direction, since groundwater will flow from a location of higher piezometric head to a location of lower piezometric head. The report states that groundwater density must be factored into the calculation of piezometric head and that, as a consequence of pumping water from the L-31E Canal into the CCS, water will flow from the CCS towards the L-31E Canal whenever the piezometric head at the CCS is greater than the piezometric head at the L-31E Canal. This is the undesirable consequence of pumping water from the L-31E Canal that is addressed in the report. Whereas density variations have an impact on mixing of saltwater and freshwater in the aquifer, this phenomenon is not discussed in the report since it is regarded as a separate issue. Furthermore, subsurface mixing of salt and fresh water depends on several other factors in addition to the difference in piezometric head between the CCS and the L-31E Canal. The mixing issue will certainly be a primary focus of any follow-up investigation dealing with the movement of saline groundwater originating in the CCS.

17. Page 44: Historical Anecdote. The report again provides results of early studies by Dames and Moore (1978) showing the an increase in water level of 0.5 feet in the CCS (as predicted with the addition of 100 mgd of L-31E Canal water) will result in a one-mile inland movement of the saltwater interface.

18. Page 45/46: Salinity Dynamics and Pumping From the L-31E Canal. The report's Conclusions Section provides a good summary of many of the points above.