FINAL REPORT

SALT WATER ORIENTATION IN THE BISCAYNE AQUIFER IN THE TURKEY POINT PLANT VICINITY PRIOR TO INSTALLATION OF THE COOLING CANAL SYSTEM

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1.0 INTRODUCTION

Florida Power & Light Company (FPL) and South Florida Water Management District (SFWMD) agreed to each review existing literature and to determine the orientation of the salt water within the Biscayne Aquifer in the vicinity of the Turkey Point Plant prior to installation of the Cooling Canal System (CCS, Figure 1). The purpose of these activities is to establish a baseline of the salt water orientation before installation of the CCS. This Final Report represents the culmination of that research by FPL and SFWMD. FPL and SFMWD find that this report represents, to their best scientific knowledge based on available data, the orientation of salt water prior to the installation of the CCS.

The CCS was installed according to the terms of a Consent Final Judgment dated September 10, 1971, which settled a lawsuit brought by the U.S. Department of Justice against FPL in March, 1970, and a counter-suit brought by FPL. In July, 1972, an Operating License was obtained for Turkey Point Unit 3, and cooling water for Units 1 and 2 was diverted to the 6.5-mile long canal to Card Sound during construction of the CCS. Unit 3 was placed into operation in December, 1972. By February 18, 1973, the CCS was 40% complete and was closed off from Biscayne Bay and Card Sound, i.e. the CCS commenced operating as a closed loop cooling system for Units 1, 2, and 3. In May, 1973, Unit 4 was placed into operation, also utilizing the closed loop CCS. By August, 1973, the construction of the CCS and Interceptor Ditch (ID) was complete. By December, 1973, the ID pumping system was operational.

FPL installed several sets of monitoring wells and measured conductivity levels over time at various depths in the Biscayne Aquifer. The G-Series wells and the E-Series wells were installed in compliance with the Consent Decree. FPL installed the F-Series wells under their own volition. Although conductivity was measured as a surrogate for chloride, multiple chemical analyses were performed on ground water samples taken at various depths in order to develop mathematical relationships between chloride and conductivity

The E-Series Wells Monitoring Program was initiated in April, 1972. Twenty-three monitoring wells were installed to the north, south, and east of the CCS (Figure 2). First data from the E-series wells was obtained between April and July, 1972, and were taken at depths of 20, 40, and 60 feet below the top of each well casing (TOC).

The G-Series Wells Monitoring Program was initiated in April, 1972. Thirty-eight monitoring wells were installed at twenty-three separate locations west of the CCS (Figure 3). Three existing USGS composite wells (cased with perforated PVC pipe to allow for the free flow of ground water through the well) were also incorporated into the G-wells monitoring system. Pairs of piezometers, at depths of 20 and 50 feet TOC were installed at fifteen of the twenty-three locations (G-2, G-3, G-5, G-9, G-10, G-12, G-16, G-17, G-19, G-23, G-24, G-26, G-30, G-31, and G-33). The remaining eight new wells (G-6, G-13, G-14, G-20, G-27, G-34, G-34X, and G-35) were constructed as 70-foot deep composite wells. The three existing USGS composite wells incorporated into the monitoring plan (G-7, G-21, and G-28) are located along Tallahassee Road. Conductivities were measured at depths of 20, 40, and 60 feet TOC in the composite G-series wells, and at 20 and 50 feet TOC in the G-series piezometers. Data are available for the G-series wells starting in April, 1972.

The F-Series Wells Ground Water Monitoring Program was also initiated in April of 1972. FPL installed nine F-series wells in the area south of the CCS (Figure 4). The F-series wells are composite wells about 70 feet deep. Chloride data from five of the F-series wells are available starting from July –December, 1972, at depths of 20, 40, and 60 feet TOC.

FPL and SFWMD have reviewed the available literature, determined which of the documents contain relevant information to this study, and compiled a list of those references (see Table 1). Based on that review, data from 23 E-series wells, 26 G-series wells, and 5 F-series wells, for a total of 54 wells, have been utilized to estimate the locations of relevant iso-conductivity lines and isochlors in the aquifer. The estimation technique and iso-contour line locations are presented in the remainder of this report.

The CCS was utilized in closed cycle mode beginning on February 18, 1973, prior to its completion in August, 1973. The well monitoring programs described above all began in 1972. In order to estimate conductivity values prior to operation of the CCS, all available conductivity data values for each well and depth between January 1, 1972, and February 1, 1973, have been averaged. Similarly, all available chloride data over the same period of record have also been averaged. Calculations describing exact details of the data analysis are presented in Appendix A Calculations.

2.0 ISO-CONDUCTIVITY AND ISOCHLOR LOCATION ESTIMATION TECHNIQUE

The references include limited tabulations of the actual data in references 18 through 23; however, References 3 and 4 include scaled time-history plots of the well water levels, conductivities, and temperatures, and Reference 16 includes time-history plots of well water levels, temperature, and chlorinity. The averaged conductivity data are shown in Table 2 for the E-Series wells and Table 3 for the G-Series wells. Table 4 shows the averaged chloride data which were available for the F-Series wells, and the limited chloride data which were directly available for the E-Series wells.

The values were inserted into GIS shape files, and plotted using color codes to differentiate between different ranges of conductivity levels, at depths of 20, 40, 60, and 50 feet (Figures 5, 6, 7 and 8 respectively). Conductivity values at 20, 40, and 60 feet were available for all wells; values at 50 feet were only available at the fifteen piezometer locations in the G-Series wells. Similarly, chloride values were inserted into GIS shape files, and plotted using color codes to differentiate between different ranges of chloride levels, at a depth of 20 feet (Figure 9). The resultant maps were used to draw iso-contours (isochlors for chloride and iso-conductivity for specific conductance) for each depth. Iso-contour line positions are estimated by the following methodology:

1. Beginning with the point with the highest value, draw a line to a nearby point
2. Use linear interpolation to estimate the point (or points) on the line that correspond to the selected lines to be shown
3. Repeat the process for other points around the highest point
4. Sketch a smooth curve that connects all points estimated to have the same value. Each curve must pass through any points that have its value, and must divide the map so that all points on one side have higher values and all points on the other side have lower values.
5. Sketch a curve for the next value. The second curve should be similar in shape to the first curve and must not cross it.
6. Continue drawing lines until the entire area has been covered

The resultant iso-contour lines are shown on Figures 10, 11, and 12 for conductivity at depths of 20, 40, and 60 feet TOC, respectively, and on Figure 13 for chloride at a depth of 20 feet.

The piezometer conductivity levels at the 50-foot depth TOC are not numerous enough to develop contours.

3.0 DISCUSSION

Figure 10 shows the iso-conductivity lines at the 20-foot depth. The 20,000 micro-mho per cm iso-conductivity line on figure 10 is approximately at the location of the Levee 31E. Virtually all of the area in which the CCS is built is above 30,000 micro-mho per cm, and the eastern half of that area is above 40,000 micro-mho per cm. The eastern-most portion of the area in which the CCS is built is above 45,000 micro-mho per cm, with an isolated point exceeding 50,000 micro-mho per cm. There is also another isolated point exceeding 50,000 micro-mho per cm south of the CCS.

Figure 11 shows the iso-conductivity lines at the 40-foot TOC depth. The 35,000 micro-mho per cm iso-conductivity line is west of the CCS. Conductivity levels drop off to the west, until the 1,000 micro-mho per cm line is reached near Tallahassee Road. All of the area in which the CCS is built is above 35,000 micro-mho per cm, with values exceeding 50,000 micro-mho per cm. South of the CCS, iso-conductivity levels exceed 55,000 micro-mho per cm.

Figure 12 shows the iso-conductivity lines at the 60-foot TOC depth. The distribution of the iso-conductivity lines at the 60-foot depth is similar to that shown at the 40-foot depth in Figure 11. Conductivity levels in virtually all of the area in which the CCS was built are above 35,000 micro-mho per cm, and most of that area is above 45,000 micro-mho per cm. Again, the conductivity levels drop off to the west, until the 1,000 micro-mho per cm level is reached near Tallahassee Road.

Figure 13 shows chloride values at the 20-foot depth TOC. The chloride values in Figure 13 range between 10,000 and 19,000 mg/L within the footprint of the CCS, and up to about 22,000 mg/L southwest of the CCS, in well F-4.

Figure 8 shows the conductivity values found in the 50-foot deep piezometers. The values shown in Figure 8 range between 29,500 and 43,900 micro-mho per cm.

References 2 and 15 include figures that depict what was estimated to be the measured ranges of the 1,000, 10,000, and 20,000 mg/L isochlors at the 20, 40, and 60 foot depths during the period between April, 1972, and January, 1975. This period does include time when the CCS was complete and all four units were operating; therefore, the areas shown in these figures are not directly comparable to the isochlors shown in Figure 13. However, it is of interest to compare them, as is done for the 20-foot isochlors in Figure 14. The isochlors from Figure 14 are consistent with the ranges depicted in Reference 2.

4.0 CONCLUSIONS

Based on the iso-conductivity lines developed, the entire area in the vicinity of the present location of the CCS between the coast and Tallahassee Road contained salt water prior to construction of the CCS. Florida Class I standards, and Class III fresh water standards include a numerical limit of 1275 micro-mho per cm for specific conductance. Based on Figures 11 and 12, the 1275 micro-mho per cm value is exceeded well west of the footprint of the CCS at the 40 and 60-foot depths below TOC. Based on Figure 10, the 1275 micro-mho per cm level is exceeded at the 20-foot depth below TOC well west of Levee 31E.

Based on the isochlors developed, the entire area in the present location of the CCS contained salt water prior to construction of the CCS. Although the USGS sometimes defines a "salt line" as the location where the 1,000 mg/L chloride concentration is at the bottom of the aquifer, the Drinking Water Standards provide a limit of 250 mg/L for chloride. In either case, salt water had extended in-shore to at least the 10,000 mg/L line shown on Figure 13. There were insufficient data to develop the lower value isochlors.

Based on Figure 14, it can also be concluded that the entire area between the coast and Tallahassee Road contained salt water prior to construction of the CCS. The locations of the isochlor lines developed within this report are completely consistent with the isochlor ranges published by Dames & Moore in 1975; this fact leads to the conclusion that the 1,000 mg/L range shown on Figure 14 is also accurate for the pre-CCS condition. It can further be concluded that if the Dames & Moore ranges are accurate at the 20-foot depth, they are most likely also accurate at the 40- and 60-fot depths.

Figure 15 shows the 1,000 mg/L range at a depth of 60 feet as published by Dames & Moore in 1975. The same figure includes two "salt water intrusion lines" published by the USGS, and generally described as the location of the 1,000 mg/L isochlor at the base of the aquifer. Two observations can be made:

1. The 1971 line is seaward of the 1951 line, and
2. The 1,000 mg/L line at the 60-foot depth as reported by Dames & Moore is consistent with the 1971 line.

With respect to the first observation, it should be noted that the salt line can move considerable distances because of changes in the local ground water hydraulic gradients. Likely causes of such changes include evaporation, precipitation, ground water withdrawals, and changes in ocean/Biscayne Bay water levels. Thus, while the 1971 line is seaward of the 1951 line, they are likely both located within the normal range within which the salt water intrusion line normally moved prior to installation of the CCS.

TABLES

Ref. No.	File Name	Document Title	Relevant Section	Relevance
1	1-77 semi annual report gw mon.prog2.pdf	January 1977 Semi-Annual Report , GWMP	Figure 1	locations of E, F, and G wells
1	1-77 semi annual report gw mon.prog2.pdf	January 1977 Semi-Annual Report , GWMP	Figure 2	locations of L, G, S, and ID wells
1	1-77 semi annual report gw mon.prog2.pdf	January 1977 Semi-Annual Report , GWMP	Section 2	history of monitoring wells installation and purpose
1	1-77 semi annual report gw mon.prog2.pdf	January 1977 Semi-Annual Report , GWMP	Figures 25 - 43	Chlorinity Profiles-1976-ID, L, & G-6,7,21,27,28,35, and X wells
1	1-77 semi annual report gw mon.prog2.pdf	January 1977 Semi-Annual Report , GWMP	Figures 44 - 48	10 PPT Cl Cross Sections Lines A-E
2	4-75 quart.rep.ground.pdf	April 1975 Quarterly Report GWMP	GROUNDWATER SALINITIES	description of groundwater salinities 1975
2	4-75 quart.rep.ground.pdf	April 1975 Quarterly Report GWMP	Plates 5, 6, and 7	Isochlor lines - 1, 10, 20 PPT - 4/72 to 1/75
2	4-75 quart.rep.ground.pdf	April 1975 Quarterly Report GWMP	Plates 8 and 9	5 PPT @ 20 ft, and 15 PPT @ 50 ft, isochlors near Line D - 7/72 to 6/73
3	Dames and Moore 3-final.pdf	Summary Report GWMP E-Series Wells	Figures 4, 5, and 6	12/72 - 20 PPT Isochlor @ 20 ft, 40 ft, and 60 ft depth
3	Dames and Moore 3-final.pdf	Summary Report GWMP E-Series Wells	Figures in Appendix A	Time/History Plots for E wells, starting May 1972, 20, 40, and 60 ft depth
4	Dames and Moore 5 final.pdf	GWMP G-Series Wells	Appendix	Time/History Plots for S-1 and G wells, starting 9/1/73 - 20, 40, and 60 ft depth
4	Dames and Moore 5 final.pdf	GWMP G-Series Wells	Plates 3.3.4.R through 3.3.4.Y	Isochlor maps - Figures missing from pdf file
5	data summary f-series wells.pdf	Data Summary, F-Series Wells GWMP	Figures 4, 5, and 6	Isochlor maps - 1, 10, and 20 PPT @ depths of 20, 40, and 60 feet
6	engineering design reservoir.pdf	The Engineering Design of the Turkey Point Cooling Reservoir	VII. , page VII-1 thru VII-5	Narrative discussion of salt water intrusion
6	engineering design reservoir.pdf	The Engineering Design of the Turkey Point Cooling Reservoir	VIII. , page VIII-1 thru VIII-3	Narrative discussion of surface water usage
7	fpl reservior sect 2.pdf	Florida Power & Light Company, Reservoir Concept - Appendix A:Geohydrological Conditions Related to the Construction of Cooling Ponds	Plate 1	Plate 1 shows 1,000 ppm isochlor at base of aquifer
7	fpl reservior sect 2.pdf	Florida Power & Light Company, Reservoir Concept - Appendix A:Geohydrological Conditions Related to the Construction of Cooling Ponds	Table 1	Table 1 shows chloride in L-31E borrow canal ranged from 520 to 650 ppm during November, 1970.
8	intensive mon.prog..pdf	Intensive Monitoring Program, Turkey Point Site	Table 3	Table 3 shows chloride values in some E- and G- wells, including G-28, at 20, 40, and 60 feet during Nov/Dec 1972
9	letter to der.pdf	Letter from FDER to W.J. Barrow, dated 9/6/83	Figures 3 - 7	Time-History Plots of Cl in ID wells, @ depth of 20, 40, and 60 feet below top of casing--11/73 through 5/82 (pp. 12-16 of 96)
9	letter to der.pdf	Letter from FDER to W.J. Barrow, dated 9/6/83	Figure 1	Location of wells X-1 and X-2 (p. 10 of 96)
9	letter to der.pdf	Letter from FDER to W.J. Barrow, dated 9/6/83	Figure 8	Estimated Levels of Cl in wells G-21, G-13, E-8, and E-9 with cooling canals(p. 17 of 96)
9	letter to der.pdf	Letter from FDER to W.J. Barrow, dated 9/6/83	Table 1	Weekly Salinity in cooling canals, 1981 (p. 20 of 96)
9	letter to der.pdf	Letter from FDER to W.J. Barrow, dated 9/6/83	un-numbered table	Salinity in cooling canals, Sept-Nov, 1982 (p. 23 of 96)
10	NPDES DIS. MON. REP 95-98.pdf	NPDES DMRs	1995,1996, 1997, & 1998 sampling reports	Salinity in cooling canals, 1995-1998
11	REPORT JULY 1978 SEMI ANNUAL REPORT GROUND WATER MONITORING PROGRAM TURKEY POINT FLORIDA FLORIDA POWER AND LIGHT COMPANY.pdf	Report, July 1978, Semi-Annual Report, GWMP	pages 169 and 170	Time-History Plots Wells X-1 and X-2 April, 1974--June, 1978
12	summary report of cool sys..pdf	A Summary Report of the Turkey Point Cooling Canal System	Chapter VII Salinity and Table VII-1	Salinities in CCS and Biscayne Bay/Card Sound 5/73 - 11/73
12	summary report of cool sys..pdf	A Summary Report of the Turkey Point Cooling Canal System	Chapter X	Narrative description of Salinity in E wells
12	summary report of cool sys..pdf	A Summary Report of the Turkey Point Cooling Canal System	Chapter XI	Biscayne Aquifer under CCS was normally saline prior to construction of CCS;ID design was to "intercept any cooling canal seepage and prevent it from flowing to the west."
12	summary report of cool sys..pdf	A Summary Report of the Turkey Point Cooling Canal System	Chapter XI	G-wells consist of 11 composite wells and 30 piezometers at 26 locations, Piezometers are co-located two to a location
13	SUMMARY SALINITY EVALUATIONS TURNKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY.pdf	SUMMARY SALINITY EVALUATIONS TURKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY	Figures 2 - 4	Cl values for pairs of wells east, west, and south of CCS at 40 ft depth
13	SUMMARY SALINITY EVALUATIONS TURNKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY.pdf	SUMMARY SALINITY EVALUATIONS TURKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY	page 2	Natural sea water intrusion has occurred throughout the area

Ref. No.	File Name	Document Title	Relevant Section	Relevance
13	SUMMARY SALINITY EVALUATIONS TURNKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY.pdf	SUMMARY SALINITY EVALUATIONS TURKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY	Figure 6	Fresh Water - Salt Water Interface Under Original Ground Water Conditions
13	SUMMARY SALINITY EVALUATIONS TURNKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY.pdf	SUMMARY SALINITY EVALUATIONS TURKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY	Figure 7	Fresh Water - Salt Water Interface Under Projected Ground Water Conditions - shows brackish water in L-31E Canal
13	SUMMARY SALINITY EVALUATIONS TURNKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY.pdf	SUMMARY SALINITY EVALUATIONS TURKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY	Text of report	Discussion of causes of salt water intrusion in this area.
13	SUMMARY SALINITY EVALUATIONS TURNKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY.pdf	SUMMARY SALINITY EVALUATIONS TURKEY POINT PLANT FLORIDA POWER AND LIGHT COMPANY	Last page entitled "Figures"	Mentions that this summary is based on a more detailed report dated 12/15/77
14	therm perf cool sys 1988.pdf	Thermal Performance of the Turkey Point Cooling Canal System In 1988	Figure 4	Infrared Photograph of CCS
14	therm perf cool sys 1988.pdf	Thermal Performance of the Turkey Point Cooling Canal System In 1988	Figure 5	Flow rates in individual Canals
15	1-75 quart. rep.pdf	January 1975 Quarterly Report, GWMP	Ground Water Salinity pp 12-14 of 122	description of groundwater salinities 1974
15	1-75 quart. rep.pdf	January 1975 Quarterly Report, GWMP	Plates 5, 6, and 7 pp 24 - 26	Isochlor lines - 1, 10, 20 PPT - 4/72 to 10/74
15	1-75 quart. rep.pdf	January 1975 Quarterly Report, GWMP	Plates 8 and 9 pp 27 - 28	5 PPT @ 20 ft. and 15 PPT @ 50 ft. isochlors near Line D - 7/72 to 6/73
16	1-79 semi annual report gw mon. prog.pdf	January, 1979 Semi-Annual Report GWMP	pages 173-177	Time-History Plots Wells F-3, F-4, F-6, F-7, and F-8
17	NPDES DISCHARGE 91-94.pdf	DMRs for 1/91 through 6/94	monthly DMR salinity tables	max, average, and min monthly salinities in CCS 1/91 through 6/94
18	EPA Turkey Point Wells.pdf	Storet LDC--Detailed Data Report	all	Specific conductance for E-Wells for 7/31/72 at 20', 40' and 60' depths
19	E-Series_Wells-Dec-11-1972.pdf	Groundwater Monitoring Data--Report Sequence #6	all	Specific conductance for E-Wells for 12/5/72 and 12/6/72 at 20', 40' and 60' depths
20	E-Series_Wells-Jan-8-1973.pdf	Groundwater Monitoring Data--Report Sequence #7	all	Specific conductance for E-Wells for 1/2/73 and 1/4/73 at 20', 40' and 60' depths
21	E-Series_WQ-Oct-18_1972.pdf	Groundwater Monitoring Data--Water Sample Analyses	all	TDS and Chlorides for E-Wells for 10/72 at 20' and 40' (E-1 only) depth
22	E-Series_WQ-Nov-14-1972.pdf	Groundwater Monitoring Data--Water Sample Analyses	all	TDS and Chlorides for E-Wells for 11/72 at 20' depth
23	E-Series_WQ-Dec-18-1972.pdf	Groundwater Monitoring Data--Water Sample Analyses	all	TDS and Chlorides for E-Wells for 12/72 at 20' depth

Table 2
Average Conductivity[1] (micro-mhos per cm) in E-Series Wells

Well	Cond @ 20 '	Cond @ 40 '	Cond @ 60 '
E-1	39,100	46,600	47,800
E-2	42,200	46,900	47,900
E-3	30,900	48,200	49,100
E-4	37,800	50,100	52,700
E-5	43,200	47,300	49,300
E-6	41,900	48,700	51,600
E-7	47,900	49,900	52,200
E-8	44,100	48,900	51,500
E-9	48,600	54,100	54,700
E-10	48,800	51,000	52,900
E-11	48,200	51,200	52,400
E-12	50,200	50,300	51,700
E-13	49,600	49,900	50,400
E-14	46,900	48,700	49,400
E-15	45,000	49,400	50,700
E-16	41,200	49,000	50,100
E-17	45,700	50,900	51,500
E-18	43,400	50,000	51,100
E-19	32,800	45,800	46,800
E-20	35,100	44,600	46,200
E-21	44,500	53,100	54,200
E-22	50,000	55,600	56,400
E-23	49,900	55,700	56,200

Note 1: Period of Record is 4/1/1972 through 2/1/1973

Table 3
Average Conductivity[1] (micro-mhos per cm) in G-Series Wells

Well	Cond @ 20 '	Cond @ 40 '	Cl @ 50 '	Cond @ 60 '
G-2	25,300		43,100	
G-3	27,000		43,100	
G-5	14,800		42,800	
G-6	7,800	28,600		40,500
G-7	900	900		900
G-9	27,900		43,900	
G-10	18,700		45,000	
G-12	7,500		42,700	
G-13	5,900	37,800		41,300
G-14	1,000	1,100		1,000
G-16	17,500		42,800	
G-17	15,100		40,900	
G-19	6,100		37,600	
G-20	5,900	30,100		31,200
G-21	1,200	1,100		1,300
G-23	19,500		31,500	
G-24	19,800		32,600	
G-26	7,000		29,500	
G-27	3,500	26,200		26,100
G-28	3,000	16,600		26,300
G-30	30,800		40,200	
G-31	31,300		39,300	
G-33	18,600		35,800	
G-34	6,500	29,500		29,600
G-34X	4,700	17,000		22,600
G-35	1,100	4,400		27,700

Note 1: Period of Record is 4/1/1972 through 2/1/1973