APPENDIX 2CC

GROUNDWATER MODEL DEVELOPMENT AND ANALYSIS

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ABBREVIATIONS

cm/s	centimeters per second
ft/day	feet per day
gpm	gallons per minute
bgs	below ground surface
MSL	mean sea level
Ref.	Reference

ACRONYMS

ASR	Aquifer Storage and Recovery
ER	Environmental Report
FPL	Florida Power and Light
FSAR	Final Safety Analysis Report
GMG	Geometric Multigrid
NED	National Elevation Database
NAVD 88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
RMS	Residual Mean Squared
SEGS	Southeastern Geological Society
SFWMD	South Florida Water Management District
USGS	United States Geological Survey

EXECUTIVE SUMMARY

A groundwater flow model of the Florida Power & Light (FPL) Turkey Point plant property has been developed in support of the Final Safety Analysis Report (FSAR) Subsection 2.4.12, and Environmental Report (ER) Subsections 2.3.1, 4.2, and 5.2 for the Units 6 & 7 Combined Operating License (COL) application. The objectives of the modeling effort are to simulate the localized effects of construction dewatering, construction of Units 6 & 7 (site grade increase and use of diaphragm walls for groundwater control), and operation of the radial collector wells.

The model is a steady-state, constant-density, three-dimensional representation of the Biscayne aquifer developed using the numerical code MODFLOW 2000 developed by the U.S. Geological Survey (USGS), as it is implemented in the user-interface software Visual MODFLOW developed by Schlumberger Water Services. This model extends beyond the Turkey Point plant area to establish representative flows into the localized areas of interest.

Hydrostratigraphic layer elevations are developed from geotechnical borings for Units 6 & 7, from borings for the initial proposed cooling pond, pumping wells from the on-site Upper Floridan aquifer study, from additional on-site borings and well logs, and from logs for off-site wells in the Florida Geological Survey Lithologic database.

Hydraulic conductivity values are based on results from three historical onsite pumping tests in the Biscayne aquifer, regional groundwater models that include Turkey Point within their domain, and onsite pumping tests within the Units 6 & 7 plant area.

The interaction between surface water and groundwater is simulated by including in the model Biscayne Bay, the cooling water canals, L-31E Canal, Card Sound Canal, and Model Land Canal (C-107).

Spatially-variable groundwater recharge and evapotranspiration is considered based on land use classification.

Calibration was approached with a multi-faceted methodology. Initially the model was run to steady-state and groundwater levels and flow directions compared to published data. Next, a qualitative comparison of calculated groundwater discharge/recharge between cooling water canals and groundwater beneath Biscayne Bay to results from surface water modeling was performed. Finally the response to pumping at test well PW-7L was simulated.

The conclusion from model simulations of construction dewatering indicate that high flow rates (approximately 9000 gpm per excavation) are required to provide dry working conditions in the reactor footprint excavations. The model simulations assume the excavations are dewatered simultaneously. Unit 6 draws water predominantly from Biscayne Bay while Unit 7 draws predominantly from the discharge side of the cooling water canals.

Particle tracking for the radial collector wells at the point in Biscayne Bay indicate that over 95 percent of the water pumped from the radial collector wells originates in Biscayne Bay. Within the bounds of the sensitivity analysis, the percentage of water originating from the bay is within the range of 92 percent to 100 percent.

Post-construction simulations indicate that the maximum potentiometric head under Units 6 & 7 is approximately –0.59 feet NAVD 88 and –0.49 feet NAVD 88 respectively.

1.0 OBJECTIVE & SCOPE

The objective of this report is to document the development, calibration, and simulation results of a groundwater flow model for the Biscayne aquifer within the Turkey Point plant property. The model was developed in support of the Final Safety Analysis Report (FSAR) Subsection 2.4.12 and the Environmental Report (ER) Subsections 2.3.1, 4.2, and 5.2. A three-dimensional multiple-layer groundwater model was used to simulate steady-state, constant-density groundwater flow in the Biscayne aquifer. This model extends beyond the Turkey Point plant area to establish representative flows to simulate the localized effects of construction dewatering, construction of Units 6 & 7 (site grade increase and use of cut-off walls for groundwater control), and operation of the radial collector wells.

2.0 AQUIFER DESCRIPTION & AVAILABLE DATA

2.1 Site Overview

Turkey Point plant property is located in Miami-Dade County, Florida, approximately 25 miles south of Miami and approximately 9 miles southeast of Homestead (Figure 2.4.12-201). It is bordered on the east by Biscayne Bay, on the west by the FPL Everglades Mitigation Bank, and on the northeast by Biscayne National Park. The 5900-acre industrial wastewater facility (approximately 2 miles wide and 5 miles long), of which 4370 acres is water (approximately 75 percent), is a predominant feature within the Turkey Point plant property (Figure 2.4.12-210).

The Units 6 & 7 plant area covers an area of approximately 218 acres and is situated south of Units 1 through 5. The units occupy a relatively small portion of the Turkey Point plant property. The preconstruction ground surface in the Units 6 & 7 plant area is generally flat, with elevations ranging from –2.4 to 0.8 feet NAVD 88.

Surface waters are a dominant feature of the Turkey Point plant property and surrounding region given that the plant is located between Biscayne Bay and the Everglades. A network of regional canals surround the site boundary and provides storm water drainage for areas west of the Turkey Point plant property. The Units 6 & 7 plant area is surrounded by the cooling canals that return water back to the intake structures for Units 1 through 4.

2.2 Regional Hydrostratigraphy

As discussed in FSAR Subsection 2.4.12, the hydrostratigraphic framework of Florida consists of a thick sequence of Cenozoic sediments that comprise three main units (Reference 1):

- The surficial aquifer system, containing the Biscayne aquifer and the semi-confining Tamiami Formation.
- The intermediate confining unit, referred to as the Hawthorn Group.
- The Floridan aquifer system.

In southern Florida, the surficial aquifer system consists of the Tamiami, Caloosahatchee, Fort Thompson, and Anastasia Formations; the Key Largo and Miami Limestones; and undifferentiated sediments. The thickness of the surficial aquifer ranges from approximately 20 feet to 400 feet and is approximately 115 feet under the Units 6 & 7 site.

The intermediate confining unit separates the Biscayne aquifer from the underlying Floridan aquifer system. It is characterized regionally by a sequence of relatively low hydraulic conductivity, largely clayey deposits but can locally contain transmissive units that act as an aquifer system. The SEGS define the intermediate confining unit as “all rocks that lie between and collectively retard the exchange of water between the overlying surficial aquifer system and the underlying Floridan aquifer system.” This unit is also referred to as the Hawthorn Group, with a thickness of approximately 900 feet in southern Florida.

Beneath the intermediate aquifer system/confining unit is the Floridan aquifer system which underlies all of Florida. The system formally consists of three hydrogeologic units: the Upper Floridan aquifer, the middle confining unit, and the Lower Floridan aquifer. The Upper Floridan aquifer is a major source of potable water in Florida, however, in the southeastern portion of the state (including Miami-Dade County) the water is brackish.

Hydrostratigraphic columns are presented in Figures 2.4.12-202 and 2.4.12-204.

2.3 Biscayne Aquifer

The surficial aquifer system within the Turkey Point plant property does not contain all of the units identified regionally. Those units identified within the plant property as a result of the 1971 (Reference 2) and 2008 (Reference 3) investigations are summarized as:

- Muck — This is identified as an organic soil with an average thickness of 3 feet in the plant area (Reference 3).
- Miami Limestone — Miami Oolite was identified beneath the muck layer and is a marine carbonate limestone consisting predominantly of oolitic facies of white to gray limestone with numerous fossils (mollusks, bryozoans, and corals).
- Key Largo Limestone — The upper portion of the Fort Thompson Formation has a high hydraulic conductivity and is identified as the “Key Largo Limestone” by Parker and others (Reference 4).
- Freshwater Limestone — A freshwater limestone facies of the Fort Thompson Formation was identified as a thin unit (up to 9 feet thick) during the 2008 investigation at a depth of approximately 50 feet (Reference 3). This unit was identified during the 1971 investigation of the proposed cooling pond and termed the “Fort Thompson Freshwater Limestone.”
- Fort Thompson Formation — Beneath the Freshwater Limestone is the Fort Thompson, which continues until its contact with the Tamiami Formation. The thickness of this unit varies between 55 feet and 88 feet.
- Tamiami Formation — The Tamiami Formation was identified below the Fort Thompson Formation and represents a semi-confining unit.

The Key Largo Limestone and the more permeable portions of the Miami Limestone are considered the “Upper Monitoring Zone.” The underlying Fort Thompson is designated the “Lower Monitoring Zone.”

The geology is shown in the following cross sections:

- Plan and hydrostratigraphic cross section in the vicinity of the Units 6 & 7 as shown in Figures 2CC-201 and 2CC-202 (Reference 2)
- Geologic cross section across in the vicinity of the Units 6 & 7 (Reference 5) as shown in Figure 2CC-203

- Plan of nuclear island and cross sections parallel to and across Units 6 & 7 as shown in Figures 2CC-204, 2CC-205, and 2CC-206 (Feasibility Geological Investigation).

The following list summarizes the stratigraphic picks for the top of each stratum identified above from geotechnical boring logs and well logs:

- Stratigraphic picks from geotechnical boring logs for Units 6 & 7 (B-601 to B-639, B-701 to B-739, and B-802 to B-814)
- Stratigraphic picks from boring logs for the original cooling pond study (Reference 2), L-1 through L-6, and GH-1 through GH-15
- Stratigraphic picks from Upper Floridan aquifer study pumping wells (Reference 2), GB-1 and GB-2
- Geotechnical boring logs from the Feasibility Geological Investigation borings B-1000 through B-1003
- Additional water well logs available from Florida Geological Survey Lithologic database and the USGS

Ground surface was prepared by combining the USGS 30m NED dataset (Reference 6), the 30m NOAA bathymetry dataset (Reference 7), and the cooling canal depths from Lyerly (Reference 8).

2.4 Groundwater Levels

During the 2008 subsurface investigation for Units 6 & 7, 22 monitoring locations were installed within the Units 6 & 7 plant area. Ten observation wells were installed in the Key Largo and Miami Limestone (referred to as the Upper Monitoring Unit) and ten were installed in the Lower Fort Thompson Formation (referred to as the Lower Monitoring Unit). Two geotechnical piezometers were installed in the Tamiami Formation, one at each proposed reactor site. The 20 observation wells were installed as 10 well pairs, enabling the determination of the vertical gradient between the upper and lower monitoring units. A description of the field activities and groundwater level data evaluation are presented in MACTEC (Reference 3).

Figure 2.4.12-209 shows the 22 monitoring locations within the Units 6 & 7 plant area. The observation wells are named in three series, which represent the location and screened intervals as described below:

- OW-600 series wells are located in the Unit 6 power block area and include “U,” ”L,” and “D” suffix wells monitoring the Key Largo and Miami Limestone, the lower Fort Thompson Formation, and the upper Tamiami Formation.
- OW-700 series wells are located in the Unit 7 power block area and include “U,” “L,” and “D” suffix wells monitoring the Key Largo and Miami Limestone, the lower Fort Thompson Formation, and the upper Tamiami Formation.
- OW-800 series wells are located outside of the power block areas and include “U” and “L” suffix wells that monitor the Key Largo and Miami Limestone and the lower Fort Thompson Formation.

The U and L observation wells are equipped with pressure transducers and have been recording hourly water level measurements since June 2008. Some of the transducers malfunctioned in the field, provided erratic readings, or recorded values that were not consistent with manually recorded water levels. As a result of this, data from the following observation wells were rejected:

- OW-606L
- OW-706L
- OW-721U
- OW-802U

Potentiometric surface maps for the upper and lower monitoring units were constructed with data from 2008 and 2009. Separate maps were prepared for both high and low tide in each of the monitoring zones and are presented in Figures 2.4.12-221 through 2.4.12-228.

Vertical hydraulic gradients were computed for the well pairs on the site and are presented in Table 2.4.12-204. In general well pairs indicate an upward hydraulic gradient. Vertical hydraulic gradients are similar during high and low tides.

Two regional historic Biscayne aquifer potentiometric surface maps are also available. They cover the following months:

- May 1993, Figure 2.4.12-219
- November 1993, Figure 2.4.12-220

2.5 Surface Water

Surface water features around the Turkey Point plant property are shown on Figure 2.4.12-210 and include the following:

- Biscayne Bay — This feature is located east of Units 6 & 7 and is a shallow, subtropical lagoon along the southeastern coast of Florida. The Biscayne Bay is a fairly recent geological feature and has been modified and dredged with average depths ranging from 6 feet to 10 feet. Surface water flow into Biscayne Bay is primarily controlled by the system of canals, levees, and control structures maintained by the South Florida Water Management District (SFWMD). The National Oceanic and Atmospheric Association (NOAA) maintain a tidal water level and meteorological data collection station (#8723214) on Virginia Key in Biscayne Bay. The station is located on a pier just to the southwest of the causeway that connects Virginia Key to Key Biscayne (Reference 8). Station 8723214 is the closest active station to the study area. The diurnal range, difference in height between mean higher high water and mean lower low water for the station is approximately 2.24 feet.

- Cooling Canals — The cooling canals are a closed system and do not directly discharge to adjacent surface water, however, the canals are unlined and hence the cooling water interacts with groundwater.

    — After cooling water passes through the Units 1 through 4 condensers and gains heat, the cooling water is discharged to the northern end of the 32 westernmost canals. These westernmost canals are approximately 3 feet deep and oriented north-south. The warm water flows towards the southern end of the westernmost canals where it is collected and flows eastward across the southern end of the canals to the seven easternmost canals. These easternmost canals provide the cooling water return, and the circulating pumps are located on the return side, in the northeastern corner of the closed loop system. The pumps in the northeastern corner maintain a drawdown of about three feet relative to the discharge location. This head difference is the driving force for circulation through the system.

    — The head differential created by the circulating water pumps is maintained despite or in addition to the tidal fluctuations. The head differential is a maximum at the northern end of the system; the highest imparted head is in the northern end of the westernmost canals and the lowest imparted head is in the northern end of the easternmost canals. The discharge of warm water to the northern end of the cooling canals means that the water level in the westernmost canals is always higher than the water level in Biscayne Bay when the units are operating. The intake of return water from the easternmost canals; by the circulating pumps, means that the water level in the easternmost canals is always lower than that of Biscayne Bay when the units are operating. At the southern end of the system, the influence of the enforced head differential is relatively lower and water levels are approximately equal to the water level in Biscayne Bay.

- L-31E (SFWMD Salinity Structure) — The L-31E Canal (shown in Figure 2.4.12-210) provides a salinity barrier which prevents saltwater moving inland along the regional system of canals surrounding the Turkey Point Plant.

- Interceptor Ditch (Turkey Point Cooling Canals) — The Interceptor Ditch was constructed in conjunction with the cooling canals to prevent cooling water from moving inland from the cooling canals. This ditch is about 30 feet wide, 19 feet deep, and has a total length of approximately 29,000 feet. The Interceptor Ditch is located about 1000 feet to the southeast of the L-31E canal. Operation of the interceptor ditch prevents seepage from the industrial waste water facility from moving landwards towards the L-31E Canal in the upper portion of the aquifer and therefore helps to maintain existing groundwater quality in the Biscayne aquifer west of the interceptor ditch.

2.6 Recharge and Evapotranspiration

The net infiltration, or groundwater recharge, accounts for the rate of net gain of the groundwater system resulting from surface infiltration. Recharge to the Biscayne aquifer is controlled by land use, and in southern Florida the recharge occurs mainly through wetland areas. Figure 2CC-207 indicates major land use classifications used by Langevin (Reference 9) for a regional model of the Biscayne aquifer. Corresponding values of extinction depth for these land use designations are also provided by Langevin (Reference 9) and are presented in Table 2CC-201.

Based on land use and the Turkey Point facility-related surface conditions, three recharge/evapotranspiration zones are considered for the model domain:

- Surface water bodies such as Biscayne Bay, cooling canals, and regional canals

- Areas of wetland
- Buildings and paved areas, with no recharge

2.7 Hydraulic Conductivity

The following sections describe the results from pumping tests and slug tests to evaluate hydraulic conductivity for the Biscayne aquifer.

2.7.1 Pumping Tests

Pumping tests performed within the footprints of Units 6 & 7 power block are summarized as follows:

- PW-6U (Key Largo Limestone) — This pumping test was performed in March 2009, with the test well pumped at an average rate of 5103 gpm for eight hours. The test well is located in the footprint of the Unit 6 reactor building. The hydraulic conductivity was estimated to be 3.3 cm/s.
- PW-7U (Key Largo Limestone) — This pumping test was performed in February 2009, with the test well pumped at an average rate of 4181 gpm for approximately nine hours. The test well is located in the footprint of the Unit 7 reactor building. The hydraulic conductivity was estimated to be 4.3 cm/s.
- PW-6L (Fort Thompson Formation) — This pumping test was performed in March 2009, with the test well pumped at an average rate of 3342 gpm for eight hours. The test well is located in the footprint of the Unit 6 reactor building. The hydraulic conductivity was estimated to be 0.1 cm/s.
- PW-7L (Fort Thompson Formation) — This pumping test was performed in March 2009, with the test well pumped at an average rate of 3403 gpm for nine hours. The test well is located in the footprint of the Unit 7 reactor building. The hydraulic conductivity was estimated to be 0.2 cm/s.

Onsite aquifer pumping tests in the Biscayne aquifer have been performed in three test wells (Reference 2). Figure 2CC-201 shows locations of test wells GH-11B, GH-14A, and GH-14B.

Pumping test results are summarized as follows:

- GH-14A (Miami Oolite) — This pumping test is located to the southeast of L-31E, adjacent to the northwest portion of the cooling canals. The test was performed in June 1971, with the test well pumped at 1386 gpm for four hours. The hydraulic conductivity was estimated to be 7.9E-02 cm/s.

- GH-11B (Key Largo Limestone) — This pumping test is located between Model Land Canal and L-31E. The test was performed in June 1971, with the test well pumped at 1386 gpm for four hours. The hydraulic conductivity was estimated to be 5.1 cm/s.

- GH-14B (Fort Thompson Formation) — This pumping test is located to the southeast of L-31E adjacent to the northwest portion of the cooling canals. The test was performed in June 1971, with the test well pumped at 1386 gpm for two hours. The hydraulic conductivity was estimated to be 1.6 cm/s.

Several off-site pumping tests have been conducted by other parties. Pumping tests performed in geological units that were not tested onsite include:

- The geometric mean value of hydraulic conductivity for the Freshwater Limestone was calculated to be 0.17 cm/s based on results of two well tests conducted in Dade County (Reference 10).

- Pumping tests conducted in twelve wells completed in the Tamiami Formation during an investigation by Fish and Stewart (Reference 10) indicate a geometric mean hydraulic conductivity value of 5.6E-02 cm/s.

2.7.2 Muck Hydraulic Conductivity

Several investigations of the Biscayne aquifer have provided estimates for the hydraulic conductivity and anisotropy of the muck layer. The hydraulic characteristics of this material are particularly important, as it will be a controlling factor on the rate at which water can reach the radial collector wells. A summary of these values and observations is listed below:

- Langevin (Reference 9) undertook a modeling study to evaluate simulation of groundwater discharge to Biscayne Bay. In his numerical model, a horizontal hydraulic conductivity of 3.5E-03 cm/s was assigned to the upper layer to represent the peat and marl units comprising the upper part of the Biscayne Aquifer. An anisotropy ratio of 100:1 was selected to represent the ratio of horizontal hydraulic conductivity to vertical hydraulic conductivity.

- Merritt (Reference 11) developed a transient model to simulation water-table changes in the Biscayne aquifer. In areas where calcitic mud or Everglades peat was present a horizontal hydraulic conductivity of 3.5E-03 cm/s was assigned to represent the semi-confining nature of the materials. The vertical hydraulic conductivity was an order of magnitude less than the horizontal value.

- Parker et al. (Reference 4) note that: “The organic soils of the Everglades have a comparatively low coefficient of permeability. Water moves through them very slowly under the low gradients existing there. In a test pit 5 feet square and 3 feet deep, with the water table standing only about 1 foot below land surface, the ground water seeped in so slowly that the pit could be emptied by slow bailing with a pint can.”

- Sonenshein (Reference 12) undertook a study to evaluate seepage beneath Levee 30 in Miami-Dade County. Hydraulic conductivity values of 3.5E-03 cm/s, 1.8E-02 cm/s, and 3.5E-02 cm/s were assigned to levee, wetland peat, and soil material respectively. Vertical hydraulic conductivity values were an order of magnitude lower than horizontal values.

2.8 Salinity

The Turkey Point plant property sits along the coastline in southern Florida. Consequently, it is located on the interface between saline ocean waters and fresh waters originating inland that flow to the sea. The freshwater/saltwater interface was identified in 1999 as a line extending 1 to 2 miles inland further north of Turkey Point to greater than 5 miles inland west of Units 6 & 7 as illustrated in Figures 2.4.12-207.

2.8.1 Onsite Salinity Observations

Water quality data were collected during groundwater sampling conducted May and June 2008 (Reference 3). Water quality data indicates that all samples exhibit elevated chloride concentrations compared to seawater, with a geometric mean of 31,055 mg/L for the Key Largo Limestone and 26,970 mg/L for the Fort Thompson Formation. An expanded Durov plot of the major ion chemistry is illustrated in Figure 2CC-208.

Salinity and chloride concentration can be estimated from specific conductance. Dames and Moore (Reference 2) measured specific conductance data at ten-foot depth intervals in monitoring wells. Only limited data and general conclusions are available from this investigation; elevated chloride levels were reported at depth and in locations closer to the Bay, with the highest reported concentrations above 26,000 parts per million (ppm) total chloride.

The water level in the interceptor ditch is controlled by pumping to maintain a seaward hydraulic gradient between itself and the L-31E Canal, thereby preventing inland movement of cooling canal water in the upper portion of the aquifer. A summary of findings from a groundwater investigation which obtained groundwater quality data from monitoring wells collected prior to 2007 is as follows:

- Monitoring wells L-3 and L-5, adjacent to L-31E Canal suggest a freshwater layer in the area with saline water present below depths of 20 feet below ground surface.
- Monitoring wells G-21 and G-28, located about 1 mile west of Canal L-31E indicate fresh water. However, in G-28, brackish water is present below a depth of approximately 25 feet.

A subsequent study presents salinity data for the cooling water canals measured from 2000 to 2002. This study documented a range of salinity between 38,000 and 59,000 ppm and also provided monthly averages of salinity concentration in Biscayne Bay from 1998 to 2002. The salinity concentration ranged from 26,000 to about 37,000 ppm.

2.8.2 Off-Site Salinity Observations

Langevin (Reference 9) conducted modeling studies to simulate aquifer characteristics in terms of discharges to the Biscayne Bay. As part of these studies, chloride concentrations were analyzed at three transects across the model area. These transects provide information on the extent of saltwater intrusion into the Biscayne Aquifer.

2.9 Water Wells

No water supply wells are screened in the Biscayne aquifer within the plant property. Three production wells (PW-1, PW-2, and PW-4) are located in the Upper Floridan aquifer (Figure 2.4.12-211) and provide process water for Units 1 and 2, and process and cooling tower makeup water for Unit 5. The average production of these wells is approximately 180 million gallons per month.

The Biscayne aquifer at Turkey Point Units 3 & 4 is also used for disposal of domestic wastewater. A single Class V, Group 3 gravity injection well is used to dispose of up to 35,000 gallons per day of domestic wastewater at the Turkey Point Units 3 & 4 wastewater treatment plant. The well, designated IW-1, is open from 42 to 62 feet bgs and is 8-inches in diameter. Due to the low injection rate (up to 24 gpm) this well is not included in the numerical model.

3.0 MODEL DEVELOPMENT

3.1 Conceptual Hydrogeologic Model

Based on the aquifer description in Section 2.3, the Biscayne aquifer is conceptualized as consisting of six layers. The base of the model (bottom of the Tamiami Formation) is designated as a no-flow boundary as leakage through the confining Hawthorn Formation is assumed to be negligible.

Recharge to the Biscayne aquifer occurs primarily in areas of wetland. Discharge from the Biscayne aquifer occurs to Biscayne Bay, the cooling water canals, and the regional series of canals. The cooling water canals are the dominant stress within the Turkey Point plant property, while evapotranspiration is also a dominant stress on the groundwater system.

The model domain was selected to minimize the impact of assumptions regarding boundary conditions at model sides. The boundaries of the model domain were placed where reasonable assumptions regarding local conditions could be made. Figure 2CC-209 shows the model domain. The model area extends several miles beyond the plant property and covers a total area of 48,540 feet by 37,340 feet (about 65 square miles).

The northern and southern model boundaries were extended several miles beyond the plant property, however they do not coincide with any hydrogeologic features. The eastern model boundary extends into Biscayne Bay, and the western boundary was extended beyond the L-31E canal.

3.2 Numerical Model

3.2.1 Numerical Code

The conceptual hydrogeologic model is developed into a three-dimensional multiple-layer numerical groundwater model using the code MODFLOW-2000 (Reference 13). MODFLOW solves the three-dimensional groundwater flow equation using a finite-difference method. This code is widely used in the industry since its development by the USGS (References 14 and 15).

MODFLOW has a modular structure that allows the incorporation of additional modules and packages to solve other equations that are often needed to handle specific groundwater problems. Over the years several such modules and packages have been added to the original code. MODFLOW 2000 is major revision of the code that expands upon the modularization approach that was originally included in MODFLOW.

The modeling pre-processor Visual MODFLOW (Reference 16) is used to facilitate the development of the FPL groundwater flow model. Visual MODFLOW is developed by Schlumberger Water Services.

3.2.2 Numerical Solver

The GMG solver in Visual MODFLOW produces converged solutions for the model, and is used for all simulations presented. The GMG solver uses two convergence criteria, the head change between successive outer iterations and the residual criterion which is based on the change between successive inner iterations. The model uses the default values of 0.01 feet for the head change criterion and 0.01 feet for the residual criterion.

3.2.3 Model Grid

Figure 2CC-210 show the model grid for the power block area. At its finest, the model grid spacing is 20 feet by 20 feet within the plant area for Units 6 & 7, and expands to 200 feet by 450 feet at the model perimeter.

3.2.4 Model Layers

The model is bounded by the ground surface and bottom of Biscayne Bay on top and the bottom of the Tamiami Formation at the model bottom. The ground surface used in the model is based on NOAA bathymetry data for Biscayne Bay and USGS National Elevation Database (NED) data for the remainder of the model domain.

Six model layers are included as follows:

- Model Layer 1 — Organic soils, referred to as muck and marl.
- Model Layer 2 — Marine limestone, referred to as the Miami Limestone.
- Model Layer 3 — Marine limestone, referred to as the Key Largo Limestone.
- Model Layer 4 — Freshwater limestone, referred to as the Freshwater Limestone.

- Model Layer 5 — Marine limestone, referred to as the Fort Thompson Formation.
- Model Layer 6 — Marine limestone or sandstone, referred to as the Tamiami Formation.

Elevations are assigned to each model cell based on the results of the SURFER gridding of stratigraphic picks. Figures 2CC-211 and 2CC-212 show cross sections of the model with relevant features highlighted.

3.2.5 Boundary Conditions

The model incorporates several types of boundary conditions, including constant head cells, river cells, recharge cells, evapo-transpiration cells, general-head cells, and no-flow cells. A brief description of boundary conditions as they are used in the model is provided below:

- River Boundary — (1) Cooling Canals, (2) L-31E, (3) C-107, (4) Card Sound Canal, and (5) Florida City Canal: The river boundary condition allows leakage into the model or leakage out of the model based on (1) specified surface water elevation in the canal, (2) simulated groundwater elevations in adjoining grid cells, and (3) soil conductance at the bottom of the canals. River cells are employed in lieu of constant head cells to allow flexibility to adjust the conductance between the canals and the Biscayne aquifer during calibration.
- Constant Head Boundary — (1) Biscayne Bay: The constant head boundary condition fixes the groundwater level in grid cells coinciding with Biscayne Bay for model layer 1. The specified head is based on the average level from tidal monitoring at Virginia Key for the period of calibration.
- Recharge Boundary — Model Layer 1: The recharge boundary condition is applied at the ground surface (top of model layer 1) and simulates the effect of infiltration from precipitation (before evapotranspiration losses).
- Evapotranspiration Boundary — Model Layer 1: The evapotranspiration boundary condition is applied at the ground surface (top of model layer 1) and simulates the effects of plant transpiration, direct evaporation, and seepage at the ground surface by removing water from the saturated groundwater regime.
- General Head Boundary — Model Sides: General-head boundary conditions are assigned to the perimeter of all layers where constant-head cells representing Biscayne Bay are not present. The general-head boundary

represents the influence of conditions beyond the model area. Flow through the general-head boundary is an area head dependent flux.

- No-Flow Boundary — Bottom of Model: The bottom of the model is designated a no-flow boundary because water levels in the Biscayne aquifer are expected to be negligibly affected by upward leakage through the Lower Tamiami Formation and Hawthorne Group, which is several hundred feet thick and acts as a confining layer.

3.3 Assumptions

The model development includes the assumptions described below.

3.3.1 Hydrostratigraphic Units

Assumption: The Freshwater Limestone is assumed to have a minimum thickness of 1 foot.

Rationale: Depending on the method of drilling, it is possible that this layer may be missed during logging and therefore it is considered to be laterally continuous.

3.3.2 Boundary Conditions

Assumption: Upward leakage through the Hawthorn Group to the Biscayne aquifer is assumed to be sufficiently small that it will have negligible effect on flow paths within the Biscayne aquifer, so the bottom of the Tamiami Formation is assumed to be a no-flow boundary for this model.

Rationale: The Hawthorn Group has a relatively low hydraulic conductivity and is approximately 900 feet thick beneath Units 6 & 7.

Assumption: The cooling water canals and regional canals can be modeled by the MODFLOW River Package.

Rationale: The River Package can be used to simulate the influence of surface water bodies that can either contribute water to the groundwater system, or act as groundwater discharge zones, depending on the hydraulic gradient between the surface water body and the groundwater system.

Assumption: Biscayne Bay has a surface water elevation of –0.55 feet NAVD 88 in the model.

<u>Rationale:</u> This value is the average of the monthly average surface water elevation between June 2008 and December 2008, the same period that is used for groundwater level calibration targets.

<u>Assumption:</u> The head drop between discharge and intake structures of the cooling canals is assumed to be 3 feet.

<u>Rationale:</u> Site information indicates that the water level on the east or intake side of the cooling canals is drawn down about 3 feet lower than the water level on the west or discharge side of the cooling canals. Field observations in 2009 also provide a similar number for the head drop.

<u>Assumption:</u> The three feet head drop between discharge and intake structures of the cooling canals can be equally distributed between the south flowing cooling canals and the north flowing cooling canals. Based on the surface water elevation for Biscayne Bay, the following water levels are assigned to the intake and discharge sides for Units 1 through 4:

— Discharge side of Units 1 though 4 is 0.95 feet NAVD 88.

— Loch Rosetta (intake structure) is –2.05 feet NAVD 88.

<u>Rationale:</u> The flowpath length for the discharge and return canals is approximately equal.

<u>Assumption:</u> Water level at the southern end of the cooling water canals is assumed to be equal to the water level in Biscayne Bay/Card Sound.

<u>Rationale:</u> Site information indicated that at the southern end of the cooling canals the water level is approximately equal to the water level in Biscayne Bay.

<u>Assumption:</u> A thickness of 0.1 feet of sediment is assumed to have built up in the cooling water canals.

<u>Rationale:</u> Negligible silt build up is assumed to occur because of the scouring action of the water and the high hydraulic conductivity of the Miami Limestone.

<u>Assumption:</u> Water level in:

— L-31E is 0.37 feet NAVD 88.

— Interceptor Ditch is 0.11 feet NAVD 88.

— Westernmost discharge cooling canal is 0.73 feet NAVD 88 at northern end dropping linearly to -0.55 feet NAVD 88 at the southern end.

Rationale: Water level in the interceptor ditch is maintained (by pumping) at a certain level to induce a seaward hydraulic gradient, ensuring that water from the cooling canals does not move inland in the upper portion of the aquifer.

3.3.3 Steady-State Condition

3.3.3.1 Water Levels

Assumption: The average groundwater levels measured between June 2008 and January 2009 are assumed to represent steady-state conditions for the Units 6 & 7 site and can therefore be used as the calibration targets for a steady-state simulation.

Rationale: The 2008 water year is considered an average year for the aquifer system. Total precipitation for the 2008 water year was 45.47 inches, compared to 45.77 inches for the long term average between October, 1968 and December, 2008. In addition, the cumulative departure from the mean precipitation for water year 2008 is zero and has been fluctuating around this value for five years. Water levels in the eastern return canals are always maintained lower than the water level, while water levels in the western discharge canals are always maintained higher than the water level in Biscayne Bay.

3.3.3.2 Groundwater Flow

Assumption: The cooling water canals have been previously modeled and are assumed to be in steady-state. Figure 2CC-213 presents the balance of flows as documented in a previous study. This balance assumes that the plant is operating at maximum capacity.

Rationale: Previous modeling of the cooling water canals assumed the system was in chemical equilibrium and hence steady state.

3.3.4 Hydraulic Conductivities

Assumption: The anisotropy ratio prior to beginning model calibration is assumed to be 1:1 for all layers (Kh:Kv).

Rationale: Anisotropy was estimated from the central tendency of Figure 2.4.12-238. This figure presents the results of a USGS study of horizontal and vertical air permeability measurements on core samples from the Biscayne aquifer. Subsequent work (Reference 17) supports an anisotropy ratio of 1.

Assumption: The horizontal hydraulic conductivities for all strata range between 4E-04 cm/s (Freshwater Limestone) and 4 cm/s (Key Largo Limestone).

Rationale: A unique distribution of hydraulic conductivities across the model area cannot be determined based on the available data; however, available results indicate the range of hydraulic conductivity to be expected.

Assumption: The hydraulic conductivity of material accumulated in the bottom of the cooling water canals is assumed to be 1E-04 cm/s.

Rationale: This represents a standard value for the hydraulic conductivity of silty sand (Reference 18).

3.3.5 Constant-Density

Assumption: The flow regime is simulated with a constant-density groundwater model.

Rationale: The primary purpose of this groundwater model is to estimate quantities and impacts for excavation dewatering and to evaluate the influence of the radial collector wells. For these two localized areas of interest the pressure influences of density variation are insignificant relative to the hydraulic gradient imposed by pumping.

Assumption: Seawater is used as the reference fluid.

Rationale: For a constant density model, water levels should be normalized to a reference fluid to satisfy the steady-state, constant-density equation.

Assumption: Water levels in canals are actual field measurements (not referenced to seawater density).

Rationale: Canals are relatively shallow such that any deviation from seawater density would provide little change in water level elevation.

3.3.6 Equivalent Porous Media

Assumption: The flow regime is simulated using an equivalent porous media (epm).

Rationale: Use of an epm for a flow regime of this scale is a reasonable assumption.

3.3.7 Groundwater Recharge

Assumption: Groundwater recharge zones are separated into three zones.

Rationale: Three groundwater recharge zones are used in the model. These zones represent 1) a recharge value of zero applied to the existing plant area that is paved and impermeable, and 2) wetlands, and 3) open water where the recharge value is equal to the average long-term precipitation. These recharge zones are based on the land use classifications of Langevin as shown in Figure 2CC-207 (Reference 9).

3.3.8 Construction Dewatering

Assumption: Figure 2.5.4-222 shows the location of the cut-off walls for Units 6 & 7 buildings. The elevation of the base of the excavation is –35 feet NAVD 88 and the cut-off wall depth has been revised to –65 feet NAVD 88. The thickness of the cut-off walls is 3 feet.

Rationale: Data digitized from Units 6 & 7 conceptual drawing.

Assumption: The walls are assumed to have a hydraulic conductivity of 1E-08 cm/s.

Rationale: The design value for the hydraulic conductivity of the cut-off walls is 8.3E-10 cm/s (Reference 19). A value of 1E-08 cm/s is a conservative estimate that will provide an upper bound on the dewatering rate.

Assumption: Units 6 & 7 are excavated and dewatered simultaneously.

Rationale: Simulation of concurrent dewatering will provide a conservative estimate of impacts to the groundwater regime.

3.3.9 Radial Collector Wells

Assumption: Figure 2.4.12-218 shows the planned area for the four radial collector wells, of which three are to be operational at any one time. Each of the radial collector wells is assumed to have eight lateral wells, each with 300 feet of screened casing at the end.

> Rationale: The extent of the lateral and screen length is a conservative estimate.

Assumption: A total of 28,800 gpm is pumped from each radial collector well.

> Rationale: Units 6 & 7 require a supply of 86,400 gpm.

Assumption: The three western-most radial collector wells and laterals will be modeled as operational for plant operations.

> Rationale: This simulation will provide a conservative estimate of the quantity of water originating from inland due to their proximity to land.

Assumption: Operation of the radial collector wells is simulated using the MODFLOW WEL package.

> Rationale: Use of the WEL package is a documented method of simulating horizontal wells (Reference 20). Other methods within MODFLOW of simulating the radial collector wells could include the drain package (DRN) and the multi-node well package (MNW).

Assumption: The laterals are assumed to be up to 700 feet in length with a maximum of 300 feet of screened casing at the end of the lateral.

> Rationale: The current layout of the radial collector wells is at a preliminary design. Initial estimates of blank and screened casing for the laterals are a conservative estimate based on drilling expectancy.

4.0 MODEL CALIBRATION

A multi-faceted approach to calibration was taken that included the following:

- Running the model to steady-state and comparing groundwater flow directions and levels with published data.
- Performing a qualitative comparison of calculated groundwater discharge/ recharge between cooling water canals and groundwater beneath Biscayne Bay to results from a site surface water modeling.

- Simulating the results of the pumping test at test well PW-7L and comparing modeled drawdowns to measured values in 14 observation wells.

4.1 Model Calibration

This calibration effort addresses only one conceptual model, which utilizes of a uniform and anisotropic hydraulic conductivity for each of the six model layers.

The primary calibration parameters were the river cell conductance and riverbed thickness for the cooling water canals and regional canals. These parameters were varied to achieve satisfactory agreement between simulated and observed flow directions, heads, and flow magnitudes. Other important parameters were the hydraulic conductivity and hydraulic conductivity anisotropy.

A target was set for each phase of the calibration, in which a mass balance discrepancy (M_d) of less than 0.01% would be achieved,

The mass balance discrepancy (M_d), given the constant density assumption, is defined as:

$$M_d = \frac{100 \times (V_{in} - V_{out})}{\frac{(V_{in} + V_{out})}{2}} \quad \text{(Reference 16, p. 3-18)}$$

Where,

V_{in} is the total flow into the model domain, and

V_{out} is the total flow out of the model domain.

4.2 Comparison to Model-Wide Flow Pattern

The initial phase of calibration involved adjusting the river cell vertical hydraulic conductivity and riverbed thickness in order to match the model-wide groundwater levels and flow. Hydraulic conductivities and the anisotropy ratio were also key parameters during the initial calibration phase.

One area that required revision during this phase of model calibration was the constant head cells in layers two through six on the northeast and southeast along the model perimeter. It was observed that simulated groundwater contours were indicating flow parallel to the coast in Biscayne Bay at these parts of the model rather than perpendicular. Those cells were replaced by general-head cells with the conductance represented by the hydraulic conductivity of each layer, and the external head as that of Biscayne Bay. The distance to the external head was systematically increased until it could be observed that it was not affecting the flow paths in Biscayne Bay. The constant-head cells in layers two through six on the eastern perimeter of the model were also updated to general-head cells following the same procedure as for the northeastern and southeastern boundaries. The purpose of this was to avoid the constraints observed in the constant-head cells on the northeast and southeast along the model perimeter

A total of two values for recharge were assigned to the three different zones throughout the model. For developed areas with building/pavement, a value of zero was used. For wetlands and open water a value of 45.77 inches/year was applied to the top layer of the model (mean precipitation from 1969 to 2008 water years). The different zones and respective recharge values are shown in Table 2CC-202.

For matching of flow direction and pattern, groundwater contours and levels were compared to two separate data sets as follows:

- Comparison of overall flow pattern to two potentiometric surface maps of the Biscayne Aquifer (Figures 2.4.12-219 and 2.4.12-220) from May and November 1993. The intention of this is to accurately capture the overall flow paths and direction.

- Comparison with average water levels for the period June to December 2008 at monitoring wells in the vicinity of Units 6 & 7, and two off-site wells. Given that this initial phase of calibration is more qualitative than quantitative, a criterion of matching heads within three feet was established. Groundwater targets are shown in Table 2CC-203.

After modifying the representation of Biscayne Bay in layers two through six, the initial phase of calibration of the model was achieved with a riverbed thickness of 0.1 feet and river cell vertical hydraulic conductivity of 1E-03 cm/s. The anisotropy ratio was also increased from 1:1 to 10:1.

Figures 2CC-214 through 2CC-219 show the simulated heads for layers one through six indicating a predominant flow direction from west to east, which is in agreement with Figures 2.4.12-219 and 2.4.12-220. Flows are more complex in the vicinity of the cooling canals due to the exchange of water between the canals and groundwater. These nuances are not captured in the larger flow picture shown in Figures 2.4.12-219 and 2.4.12-220.

Groundwater levels are reasonably well matched in the Miami Limestone, with the modeled head greater than measured by an average of 0.34 ft. For the deeper wells, the modeled head is less than measured by an average of 1.57 ft. This increase in the residuals with depth is a limitation of the constant-density assumption. The elevated saltwater concentrations at the base of the aquifer, which result in higher heads, are not represented using the constant density assumption. Table 2CC-204 provides a comparison of measured versus simulated water levels.

Values of hydraulic conductivity for each of the model layers are presented in Table 2CC-205.

4.3 Comparison with Surface-Water Modeling

Additional calibration parameters are the flow rates from the discharge side of the cooling water canals downward to the groundwater, and to the return canals coming from Biscayne Bay and groundwater beneath the canals. These values have been previously estimated by means of a surface water model the results displayed in Figure 2CC-213. This figure has been updated to include the flow rates from the groundwater model and is shown in Figure 2CC-220. The area outlined in blue shows that part of a previous surface water model that is replicated in the current groundwater model. The top figure for each parameter (precipitation, evaporation, net blowdown, and net makeup) represents that from the surface water model while the lower figure is the calculated value from the groundwater model. A comparison of the values indicates that the groundwater model shows a similar exchange pattern with the surface water model. The model values are presumed to be slightly lower because the plant was assumed to be operating at full capacity in the surface water model while operating conditions are unknown for the calibration period in the groundwater model.

4.4 Simulation of Pumping Test PW-7L

The final part of the calibration was performed by simulating the steady-state response to pumping from the Fort Thompson Formation within the footprint of the proposed reactor building for Unit 7. This test was one of four conducted in the first quarter of 2009 to assess the feasibility of construction dewatering. Two tests were conducted within the footprint of each of the reactor buildings for Units 6 & 7, one in the Key Largo Limestone (U or upper test zone), and one in the Fort Thompson Formation (L or lower test zone). The layout of the test (test well and monitoring wells) for the calibration is shown in Figure 2CC-221. The notation used for the observation well naming is as follows:

CX-#$

Where,

X	=	Reactor building (6 or 7)
#	=	Number indicating well position
1	=	approximately 10 feet east of upper zone test well
2	=	approximately 10 feet north of upper zone test well
3	=	approximately 25 feet north of upper zone test well
4	=	approximately 40 feet north of upper zone test well
5	=	approximately 10 feet east of lower zone test well
$	=	Alphabetic character designating the well monitoring zone
A	=	Miami Limestone
B	=	Freshwater Limestone
C	=	Tamiami Formation
D	=	Key Largo Limestone
E	=	Fort Thompson Formation

The constant rate test of well PW-7L was conducted in March 2009, with an average discharge rate of 3403 gpm for nine hours. The rational for selecting test well PW-7L is:

- The upper zone will be contained by a cut-off wall with the implication that the deeper zone tests are more relevant.
- Review of the PW-7L pumping test data was considered more complete than PW-6L.

4.4.1 Pumping Test Simulation

In the near vicinity of the reactor building, the grid of the model was refined from a cell size of 20 feet x 20 feet to 2 feet by 2 feet. This refinement was necessary due the close proximity of the observation wells to one another. The grid refinement is presented in Figure 2CC-222 along with a close-up showing the test and observation wells in Figure 2CC-221.

Because water levels in the Fort Thompson Formation stabilized within ten minutes of turning on the pump, the test was simulated by matching the water-levels (drawdown) at the end of the test only. The rationale for this is that the test had reached steady-state and hence a transient simulation was not necessary.

Results of this calibration run are tabulated in Table 2CC-206. This shows simulated and measured water levels in each of the monitoring wells that were instrumented. The water level response was reasonably well matched with the exception of the Freshwater Limestone and Fort Thompson Formation in wells C7-2 and C7-3, where it was under-predicted by approximately four feet. These two wells are the furthest out from the test well and it is possible that variations in the thickness/competence of the Freshwater Limestone are responsible for this deviation. A plot of observed versus simulated heads is presented for all monitored layers with the exception of the Freshwater Limestone. The Freshwater Limestone is omitted because flow through this layer is vertical and due to the vertical discretization of the model (single layer for Freshwater Limestone), heads cannot be accurately captured with this model. The normalized root mean square for all layers is 16%, which is considered acceptable for this model.

4.5 Conclusions

The model is considered to be calibrated based on the following observations:

- Matching of regional flow patterns and groundwater levels.
- Comparison with a previously developed surface water model shows similar flow exchanges between the cooling water canals and the groundwater beneath them.
- Replication of the pumping test at PW-7L indicates a good match between observed and modeled drawdowns.

5.0 CONSTRUCTION & POST-CONSTRUCTION SIMULATIONS

A concrete cut-off wall for construction groundwater dewatering control will be installed around the excavations for Units 6 & 7. It is estimated that the cut-off wall will extend to an elevation of –65 feet NAVD 88 with the base of the excavation at an elevation of –35 feet NAVD 88. The purpose of modeling the construction dewatering is to determine preliminary estimates of discharge rates in order to provide dry working conditions.

Radial collector wells will be installed on the Turkey Point peninsula in order to provide a backup cooling tower makeup water for Units 6 & 7. An estimate of the salinity of the pumped water is required to assess the water quality of the makeup water. These simulations are performed to determine the source of the makeup water (i.e., Biscayne Bay or landward portions of the aquifer). Simulations using the particle tracking code MODPATH (Reference 21) and water budget code ZoneBudget (Reference 22) are employed to determine the origin of water pumped from the radial collector wells.

5.1 Construction Dewatering Simulation

Groundwater flow simulations for dewatering of the power block excavations were performed with the calibrated base model. Several refinements were made to the base model to represent the excavations:

- The Key Largo Limestone was subdivided into two layers. Beneath the excavations, the new layer is horizontal with an elevation of –35 feet NAVD 88 to represent the base of the excavation.
- The Fort Thompson Formation was split into two layers. Beneath the excavations, the new layer is horizontal with an elevation of –65 feet NAVD 88 to represent the base of the cut-off walls.
- The Horizontal Flow Boundary (HFB) package (Reference 23) was used to simulate the cut-off walls from ground surface down to an elevation of –65 feet NAVD 88.
- The interior of the excavation was defined as inactive to flow.
- Pumping wells were added and represented as constant head cells. The pumping wells were installed around the interior perimeter of the excavation between the base of the excavation and the base of the cut-off wall in the lower portion of the Key Largo Limestone, Freshwater Limestone, and upper portion of the Fort Thompson Formation. The pumping level was set to –37 feet (NAVD 88).

Figure 2CC-223 shows the outline of the excavations while Figure 2CC-224 illustrates the implementation of the excavation in the model. This figure shows the model grid, excavation walls, and interior dewatering wells. A cross section through the model illustrating the depth of the excavation and cut-off walls is presented in Figure 2CC-225.

This model was run to steady-state along with a model budget simulation to determine the quantity of water being extracted from the interior dewatering wells. A total value of 18,010 gpm was extracted from the wells, or approximately 9,000 gpm per excavation. Figure 2CC-226 shows the results of this simulation in section, while Figures 2CC-227, 2CC-228, and 2CC-229 illustrate the groundwater contours for the three layers that contain dewatering wells (lower portion of Key Largo Limestone, Freshwater Limestone, and upper portion of Fort Thompson Formation).

To determine the origin of water into the excavations during dewatering, potentiometric contours were plotted to evaluate any divide around the cone of depression. Figure 2CC-230 shows the output of the dewatering model with potentiometric contours plotted. The solid blue line represents a divide splitting Units 6 & 7, indicating that when the excavations are dewatered simultaneously, Unit 6 draws water predominantly from Biscayne Bay while Unit 7 draws predominantly from the discharge side of the cooling water canals.

5.2 Radial Collector Well Simulation

Groundwater flow simulations for the radial collector wells were performed with the calibrated base model. Several refinements were made to the base model to represent the radial collector wells and laterals:

- The Key Largo Limestone was sub-divided into three layers. To represent the radial collector wells, new horizontal layers at –26.5 feet and –27.5 feet NAVD 88 were introduced. This new 1-foot thick layer was used to represent the lateral wells.

- Four pumping wells were placed on the last 300 feet of each lateral, each pumping at a rate of 900 gpm for a total of 3600 gpm per lateral or (8 laterals per radial collector well x 3600 gpm per lateral) 28,800 gpm per radial collector well.

- Three of the four radial collector wells are operational. To provide a conservative estimate of the source of the water to the radial collector wells, the three wells closest to the shore were modeled as operational.

- Zones were defined around the model to estimate the volume of water coming from land or Biscayne Bay. Zones were defined around the model to estimate the volume of water coming from land or Biscayne Bay. The zone defined to estimate the approach velocity through the muck was approximately 5,120 acres in size.

Figure 2CC-231 shows the modeled location of the radial collector wells on Turkey Point. Figure 2CC-232 shows the same image with the finite-difference grid overlaid and also the location of the pumping wells (light blue) representing the screened portion of the laterals. Figures showing the groundwater contours after model execution in the Key Largo Limestone are presented in Figures 2CC-233 and 2CC-234, respectively. Figure 2CC-235 is a cross section across the central radial collector well showing groundwater contours for all modeled layers.

To determine the origin of water drawn into the radial collector wells, an additional simulation was run with forward particle tracking. Concentric circles of particles were placed in increasing radius around the radial collector wells (in the top layer) and particle tracking then simulated by use of the program MODPATH.

After running this simulation, the volumetric flow rates were calculated for each of the boundaries identified above and compared to the total radial collector well discharge rate of 86,400 gpm. It was observed that 92 percent of the flow originated from Biscayne Bay (mainly through the muck, with a very small amount from the lateral boundaries) and only 8 percent originated from inland. Using the volume of water moving through the muck and the catchment area for Biscayne Bay an average approach velocity through the muck of 2.4E-05 cm/s was calculated.

5.2.1 Sensitivity Analysis

Because of uncertainty in the values of hydraulic conductivity of strata under Biscayne Bay, a sensitivity analysis was performed to evaluate how the hydraulic conductivity anisotropy ratio would affect the source of water to the radial collector wells. The sensitivity analysis focused on the overlying and underlying strata that confine the Key Largo Limestone. Two series of sensitivity analyses were run; the first involved modifying the vertical hydraulic conductivity of the layer beneath the pumped zone (Freshwater Limestone), and the second involved modifying the vertical hydraulic conductivity of the two layers above the pumped zone (Miami Limestone and muck). For both sets of cases the horizontal hydraulic conductivity was fixed and the vertical hydraulic conductivity varied to simulate the following anisotropy ratios (K_h:K_v): 0.01, 0.1, 1, 10, and 100 (The calibrated model has an anisotropy ratio of 10:1 for all layers as described in Section 4.3.1). During this exercise, attempts to model a K_h:K_v of 100:1 for either case resulted in excessive drawdown around the radial collector wells. Exclusion of the 100:1 bounding case is argued based on the resulting values of hydraulic conductivity. For the muck, the vertical hydraulic conductivity at this anisotropy ratio is 5E-05 cm/s which is outside the expected range for this material. For the Freshwater Limestone, a vertical hydraulic conductivity of 4E-06 cm/s is obtained, which is again outside the expected range for this material.

The approach outlined in Section 6.2 (particle tracking and ZoneBudget) for calculating the percentage of water originating from either Biscayne Bay or land to the radial collector wells was applied to this sensitivity analysis. A graphical representation of the results is shown in Figure 2CC-236, demonstrating that for all the sensitivity runs the percentage of water coming from Biscayne Bay is greater than 92 percent.

5.2.2 Revised Shoreline

The base model defines the shoreline as the eastern limit of the mangroves during mean tide level. In reality most of the mangroves are inundated, at a minimum, twice daily during high tide, and this is not captured by the base model. A more realistic representation for the Biscayne Bay shoreline includes the areas of mangroves that are inundated daily. Following modification to the limits of the constant-head boundary, the radial collector wells simulation was rerun along with two additional zones for calculating approach velocity. The first of these zones encompasses a single lateral, while the second covers the immediate area defined by the radial collector wells. These zones are illustrated in Figure 2CC-237. For the entire catchment area of the radial collector wells within Biscayne Bay the approach velocity is calculated as 2.3E-05 cm/s. When looking at the immediate vicinity of the wells, this value increases by an order of magnitude to 3.3E-04 cm/s, and becomes marginally larger for a single lateral at 3.5E-04 cm/s. Drawdown plots for the muck layer and pumped zone (Key Largo Limestone) are presented as Figures 2CC-238 and 2CC-239. With the revised shoreline, the percentage of flow originating from Biscayne Bay is 95 percent.

5.3 Units 6 & 7 Post Construction Simulation

Following construction of Units 6 & 7, plant grade will be much higher than it is at present. Currently the island is below 0 feet NAVD 88, and after construction it will be at its highest 25.5 feet NAVD 88. Post-construction ground contours are shown in Figure 2.5.4-222. To simulate post-construction groundwater conditions several changes were made to the base model:

- Cut-off walls installed during construction (and represented in dewatering simulations) are left in place.
- Concrete added within the cut-off walls between an elevation of –35 feet NAVD 88 (base of excavation) and -16 feet NAVD with a hydraulic conductivity of 1E-08 cm/s.
- Concrete mud mat for the reactor building was added within cut-off walls between –16 feet NAVD 88 and –14 feet NAVD 88 with a hydraulic conductivity of 1E-08 cm/s.
- Reactor building included as inactive to flow.
- Island defined as zero recharge zone to account for buildings and paved areas.
- Backfill added between reactor building and cut-off walls with a hydraulic conductivity of 0.01 cm/s.
- Muck removed from area in immediate vicinity of reactor buildings (shown in upper half of Figure 2.5.4-222) and replaced with backfill (hydraulic conductivity of 0.01 cm/s).

The results are presented in Figures 2CC-240 and 2CC-241, in plan and section respectively. The groundwater contours in plan are shown for the Key Largo Limestone. This is the first layer immediately beneath the reactor buildings where concrete is not present. Maximum potentiometric head underneath Units 6 & 7 are –0.59 feet NAVD 88 and –0.49 feet NAVD 88 respectively.

6.0 CONCLUSIONS

The objectives of the modeling effort were to simulate the localized effects of construction dewatering, construction of Units 6 & 7 (site grade increase and use of diaphragm walls for groundwater control), and operation of the radial collector wells. The model was developed using available historic data and data collected in support of the COL application.

The calibrated model was used to simulate construction dewatering for Units 6 & 7 reactor building excavation based on a conservative dewatering approach. Calculated flow rates to enable dry working conditions are about 9000 gpm per excavation, with expected extraction wells about every 20 feet around the inside perimeter of each excavation

The model was also used to determine the origin of water supplying the radial collector wells by a combination of particle tracking and evaluating flows through different parts of the model. These simulations indicate that approximately 95 percent of the pumped water will originate from Biscayne Bay while the remainder will originate from inland.

Post-construction simulations indicate that the maximum potentiometric head under Units 6 & 7 is –0.59 feet NAVD 88 and –0.49 feet NAVD 88, respectively.

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Table 2CC-201
Extinction Depth and Maximum Evapotranspiration Rate

Land-use category	Runoff coefficient	Extinction depth (meters)
Urban	0.5	0.30
Agriculture	.5	.43
Rangeland	.2	.61
Upland forests	.2	.70
Water	.0	.183
Wetlands	.0	.69
Barren land	.0	.15
Transportation	.5	.30

	January	February	March	April	May	June-October	November	December
Maximum evapo-transpiration rate (centimeters per day)	0.20	0.28	0.36	0.43	0.46	0.53	0.30	0.28

Source: Reference 9

Table 2CC-202
Model Calibration — Recharge

Run	Simulated Recharge (in/yr)		
	Wetlands	Building/ Pavement	Water
Base	45.77	0	45.77

Table 2CC-203
Model Calibration — Groundwater Level Calibration Targets

Observation Well	Formation	Water Level (NAVD88)
OW-606U	Miami Limestone	-1.18
OW-621U		-0.97
OW-636U		-0.43
OW-706U		-0.75
OW-735U		-0.95
OW-805U		-0.82
OW-809U		-0.98
OW-812U		-0.73
BBCW4	Key Largo Limestone	0.29
BBCW5		-0.71
OW-621L	Fort Thompson Formation	0.92
OW-636L		0.31
OW-721L		2.00
OW-735L		2.34
OW-802L		1.23
OW-805L		0.41
OW-809L		0.58
OW-812L		0.73

Note: Water levels are equivalent saltwater heads.

Table 2CC-204
Model Calibration — Measured Versus Simulated Water Levels

Observation Well	Formation	Measured Water Level (NAVD88)	Simulated Water Level (NAVD88)	Simulated - Measured Water Levels
OW-606U	Miami Limestone	-1.18	-0.61	0.57
OW-621U		-0.97	-0.60	0.37
OW-636U		-0.43	-0.51	-0.08
OW-706U		-0.75	-0.51	0.24
OW-735U		-0.95	-0.69	0.26
OW-805U		-0.82	-0.65	0.17
OW-809U		-0.98	-0.41	0.57
OW-812U		-0.73	-0.11	0.62
BBCW4	Key Largo Limestone	0.29	0.67	0.38
BBCW5		-0.71	0.88	1.59
OW-621L	Fort Thompson Formation	0.92	-0.59	-1.51
OW-636L		0.31	-0.77	-1.08
OW-721L		2.00	-0.48	-2.48
OW-735L		2.34	-0.62	-2.96
OW-802L		1.23	-0.37	-1.60
OW-805L		0.41	-0.63	-1.04
OW-809L		0.58	-0.34	-0.92
OW-812L		0.73	-0.04	-0.77

Note: Water levels are equivalent saltwater heads.

Table 2CC-205
Model Calibration — Hydraulic Conductivity

Run	Hydraulic Conductivity (cm/s)						
	Biscayne Aquifer						Other Materials
	Muck Layer 1	Miami Limestone Layer 2	Key Largo Limestone Layer 3	Freshwater Limestone Layer 4	Fort Thompson Fm Layer 5	Tamiami Fm Layer 6	Sandy Silt in Cooling Canal/Salinity Barriers
Base	0.005	0.01	4	4.00E-04	0.2	4.00E-02	1.00E-03

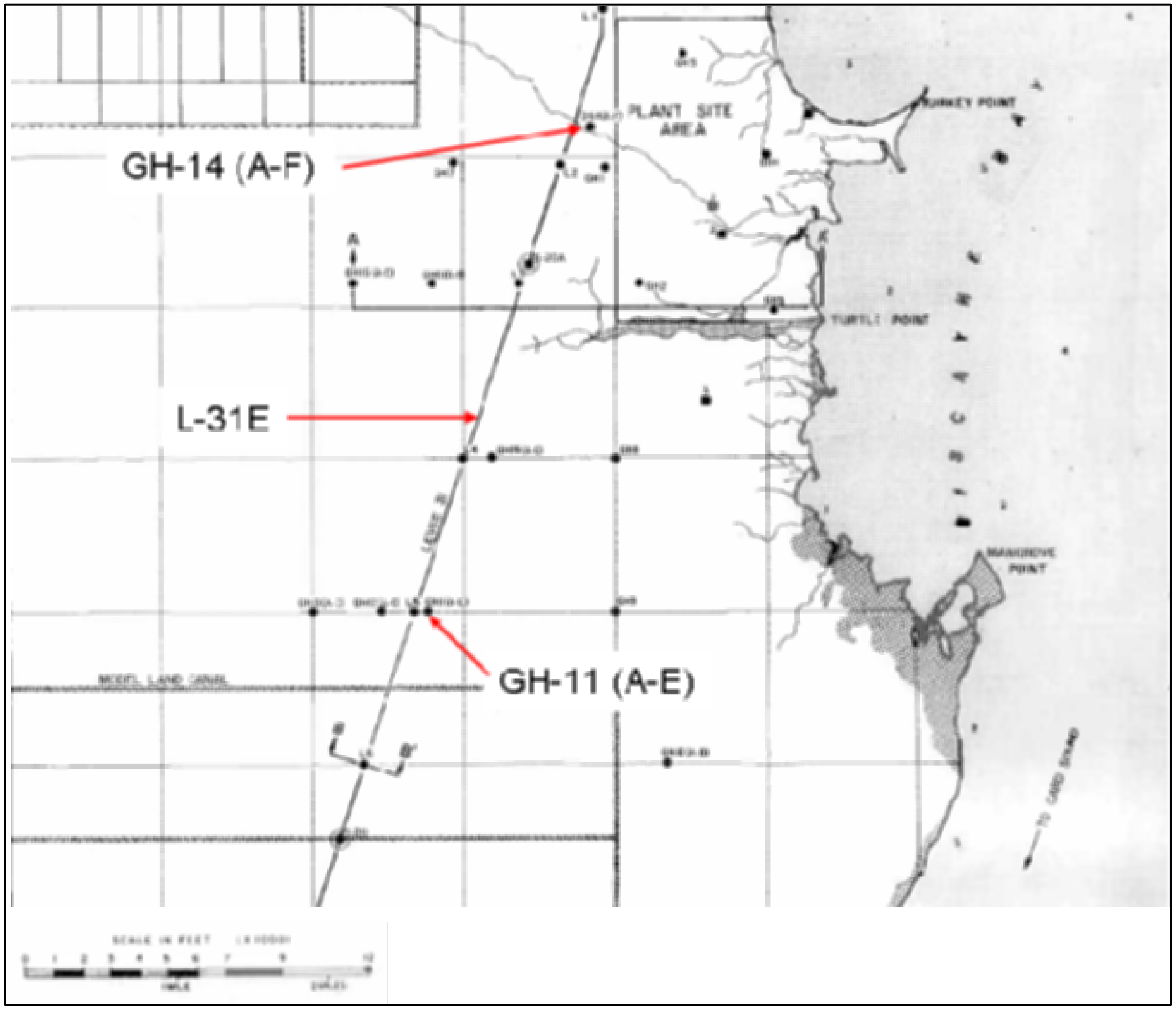
Notes:
Vertical hydraulic conductivity equal to 1/10 of horizontal value.

Table 2CC-206
Model Calibration — Pump Test PW-7L Simulation: Measured Versus Simulated Water Levels (at end of test)

Observation Well	Formation	Initial Water Level ft (NAVD88)[1]	Measured Water Level ft (NAVD88)	Simulated Water Level ft (NAVD88)	Measured Drawdown (ft)	Simulated Drawdown (ft)
C7-2A	Miami Limestone	-0.5	-0.81	-0.97	0.31	0.47
C7-3A		-0.5	-0.82	-0.97	0.32	0.47
C7-4A		-0.5	-0.81	-0.96	0.31	0.46
C7-5A		-0.5	-0.82	-0.96	0.32	0.46
C7-2D	Key Largo Limestone	-0.51	-0.85	-0.98	0.34	0.47
C7-3D		-0.51	-0.86	-0.98	0.35	0.47
C7-5D		-0.5	-0.88	-0.98	0.38	0.48
C7-2B	Freshwater Limestone	-0.49	-1.00	-4.82	0.51	4.33
C7-3B		-0.49	-0.55	-5.53	0.06	5.04
C7-5B		-0.49	-5.15	-6.57	4.66	6.08
C7-2E	Fort Thompson Formation	-0.48	-4.01	-8.85	3.53	8.37
C7-3E		-0.48	-5.43	-10.27	4.95	9.79
C7-4E		-0.47	-11.80	-12.76	11.33	12.29
C7-5E		-0.47	-12.99	-13.15	12.52	12.68
C7-2C	Tamiami Formation	-0.48	-2.09	-3.85	1.61	3.37
C7-3C		-0.47	-3.35	-3.88	2.88	3.41
C7-4C		-0.47	-2.48	-3.90	2.01	3.43

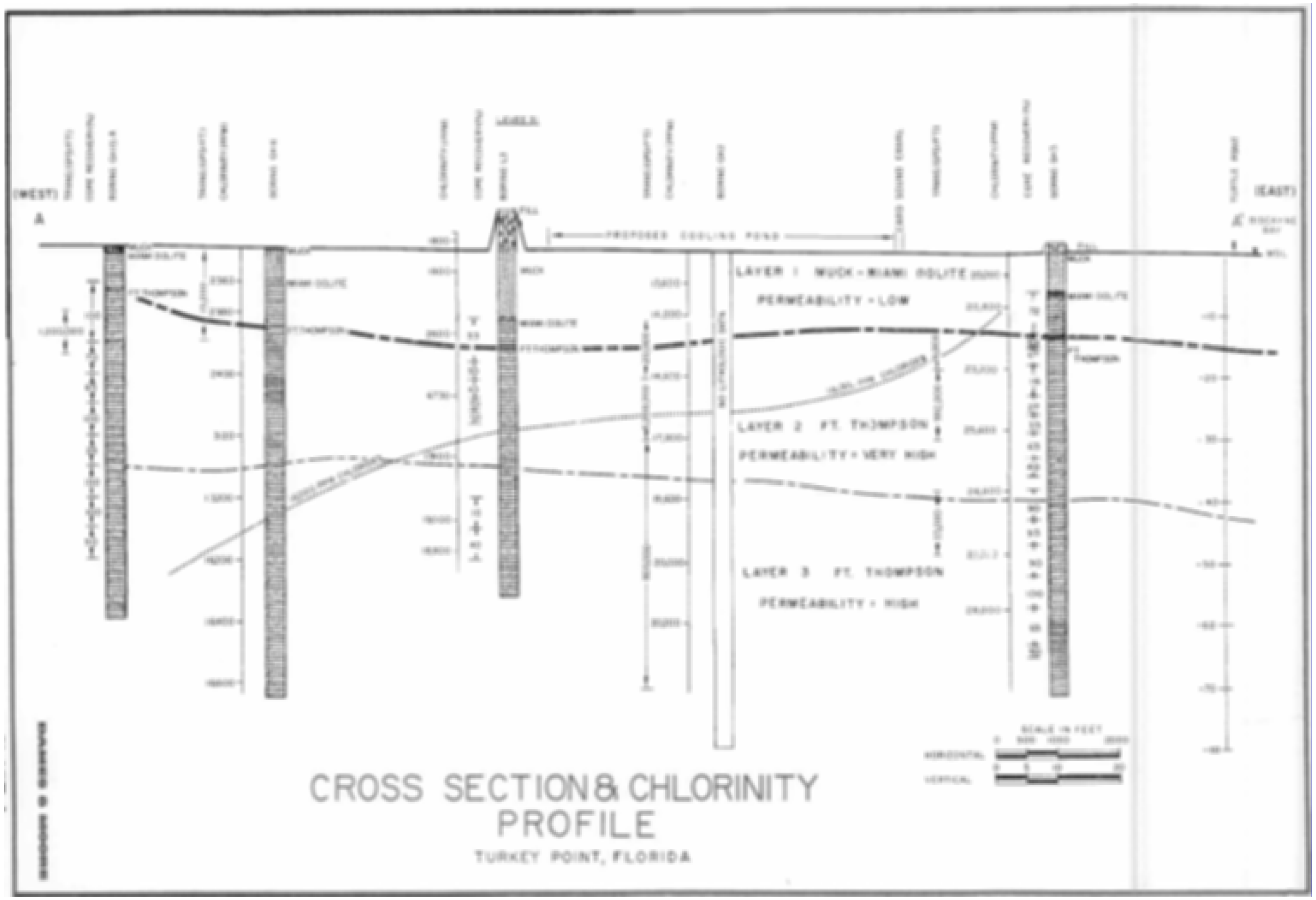
[1] Initial water levels obtained from steady-state model.

Figure 2CC-201 Cross Section Location



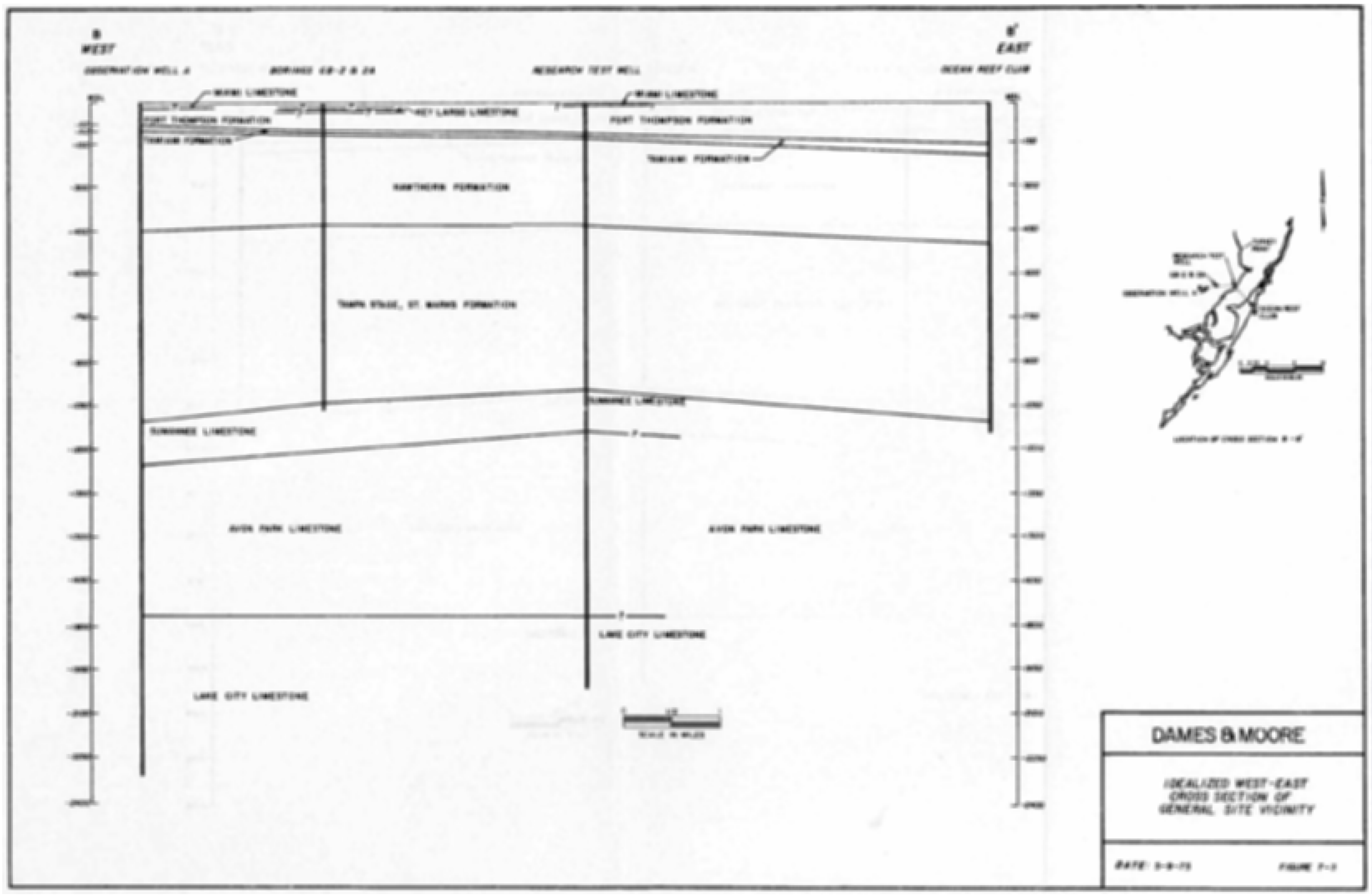
Source: Adapted from Reference 2
Note: Best available scan from original document

Figure 2CC-202 Hydrostratigraphic Cross Section A-A'



Source: Reference 2
Note: Best available scan from original document

Figure 2CC-203 West-East Cross Section of Site Vicinity



Source: Reference 5
Note: Best available scan from original document

Figure 2CC-204 Boring and Stratigraphic Cross Section Locations

Figure 2CC-205 Stratigraphic Cross Section A-A'

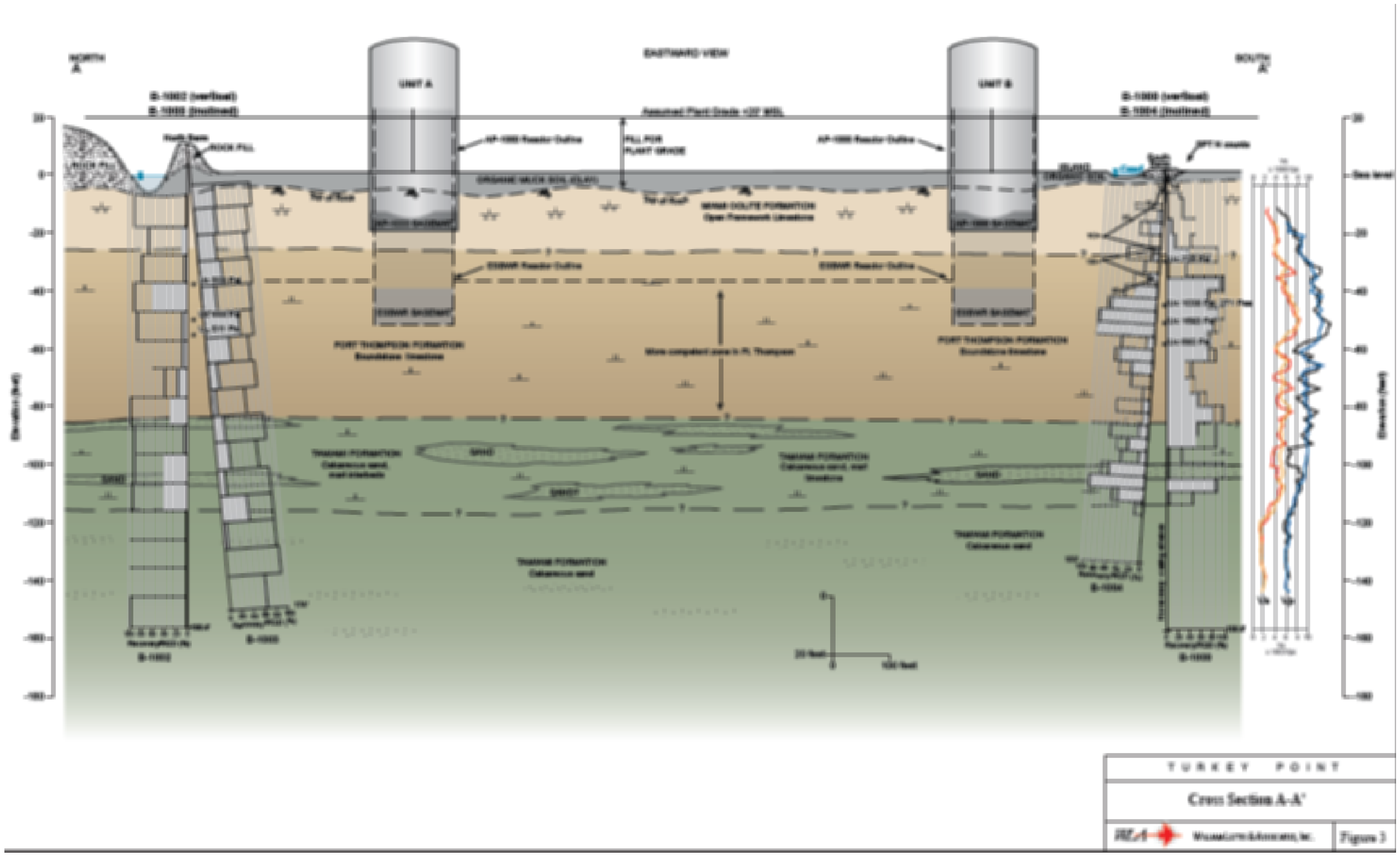


Figure 2CC-206 Stratigraphic Cross Section B-B'

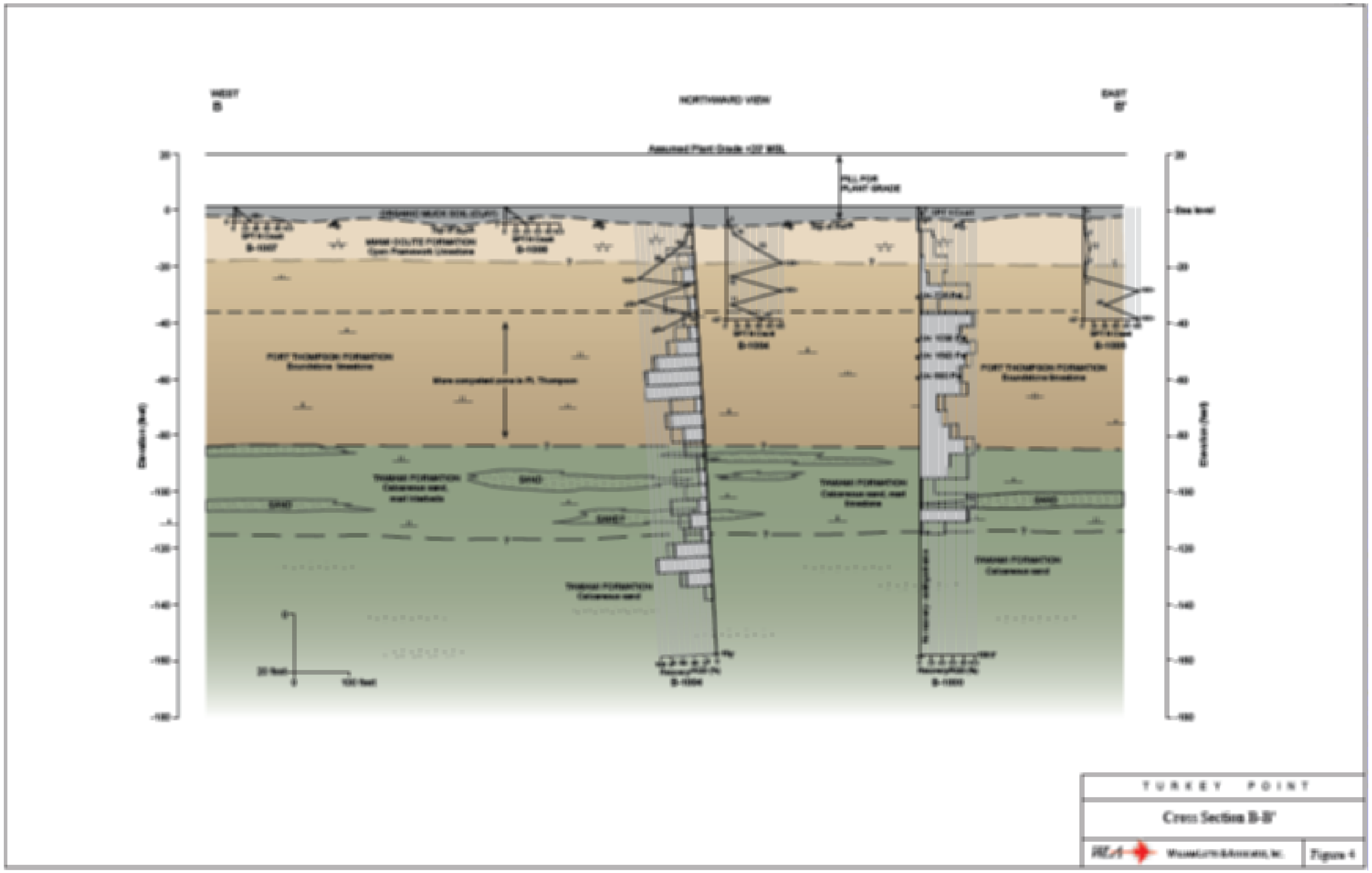
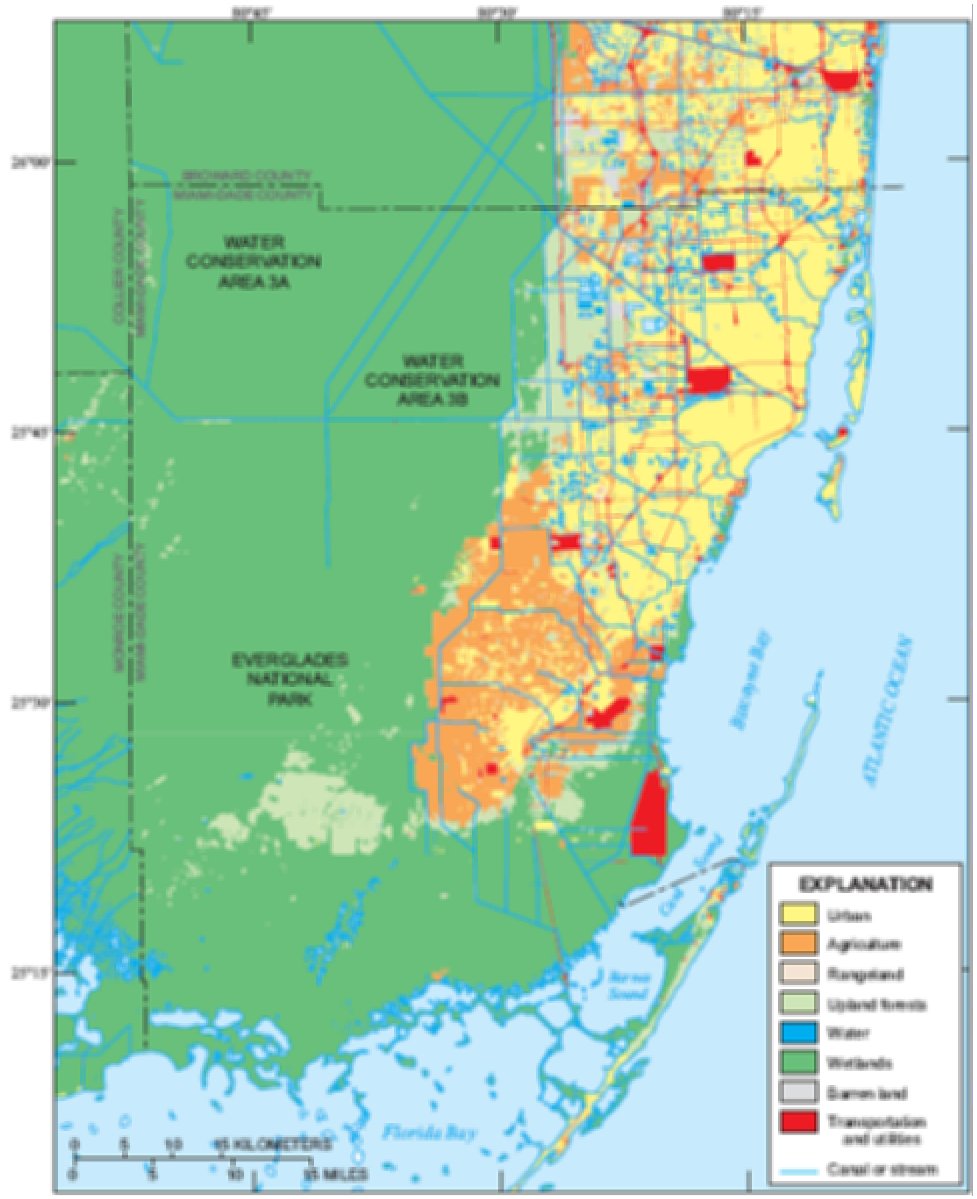


Figure 2CC-207 Land Use for Southern Florida



Source: Reference 9

Figure 2CC-208 Expanded Durov Plot of Units 6 & 7 Observation Wells

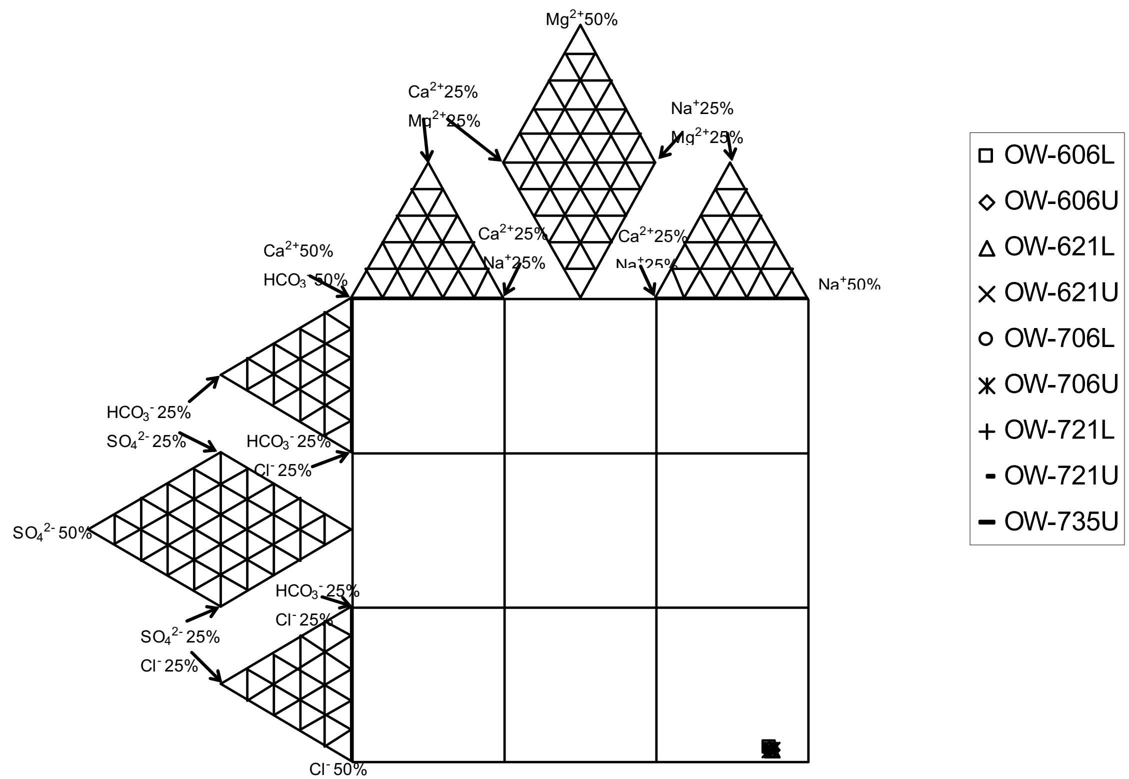
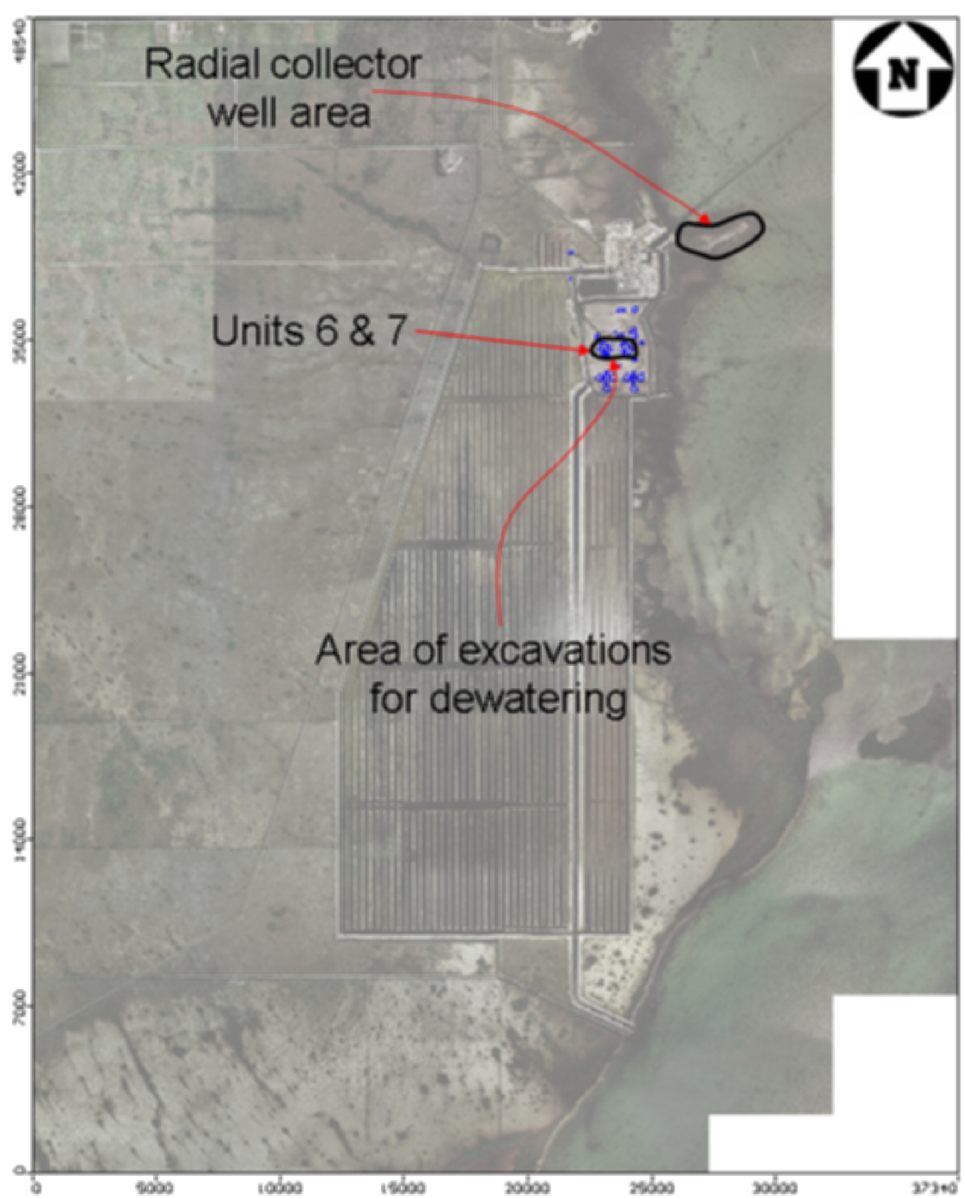


Figure 2CC-209 Numerical Model Areas of Interest



Note: Model domain identified by extents of axes, not extents of image

Figure 2CC-210 Detail Around Proposed Units 6 & 7

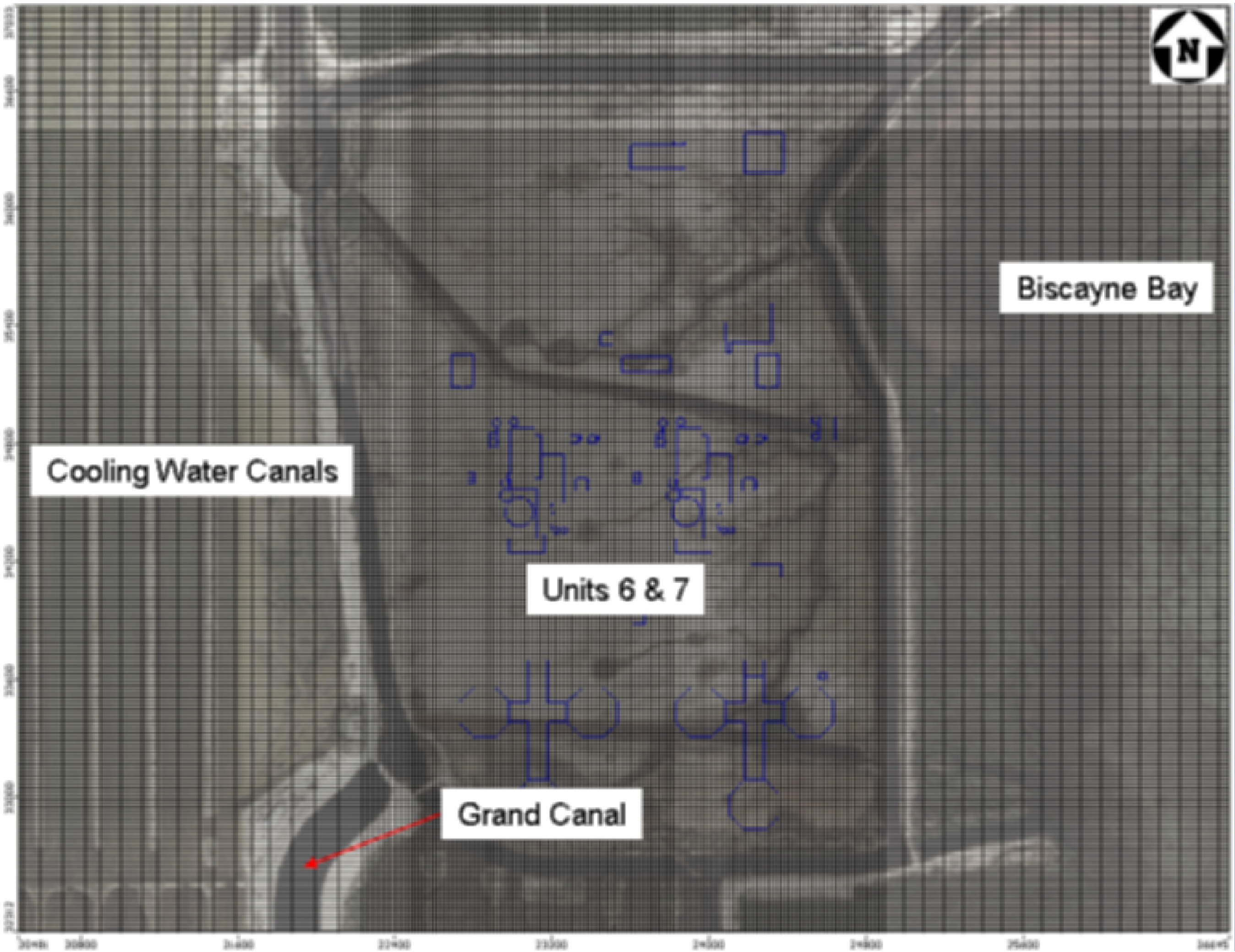
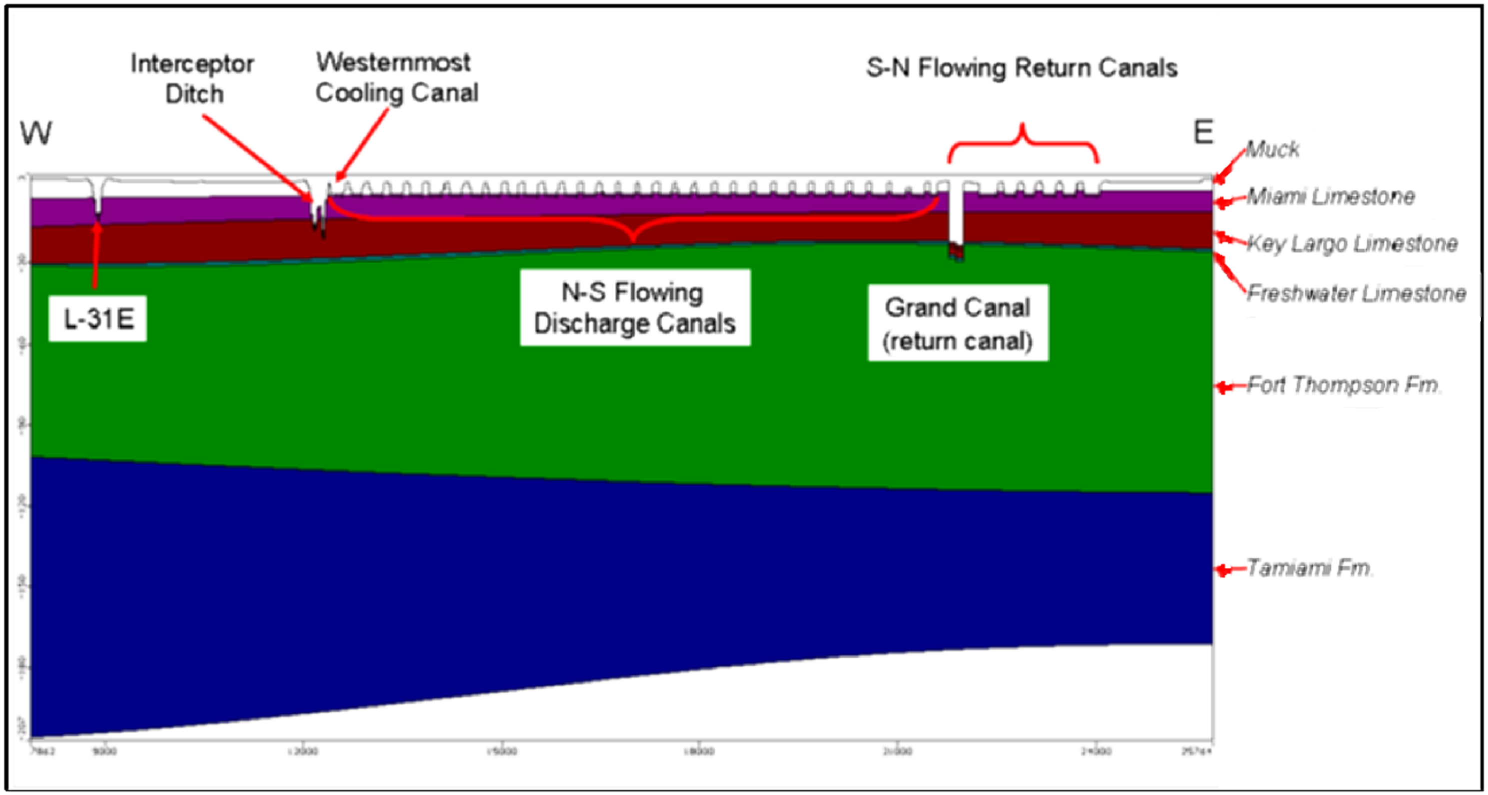
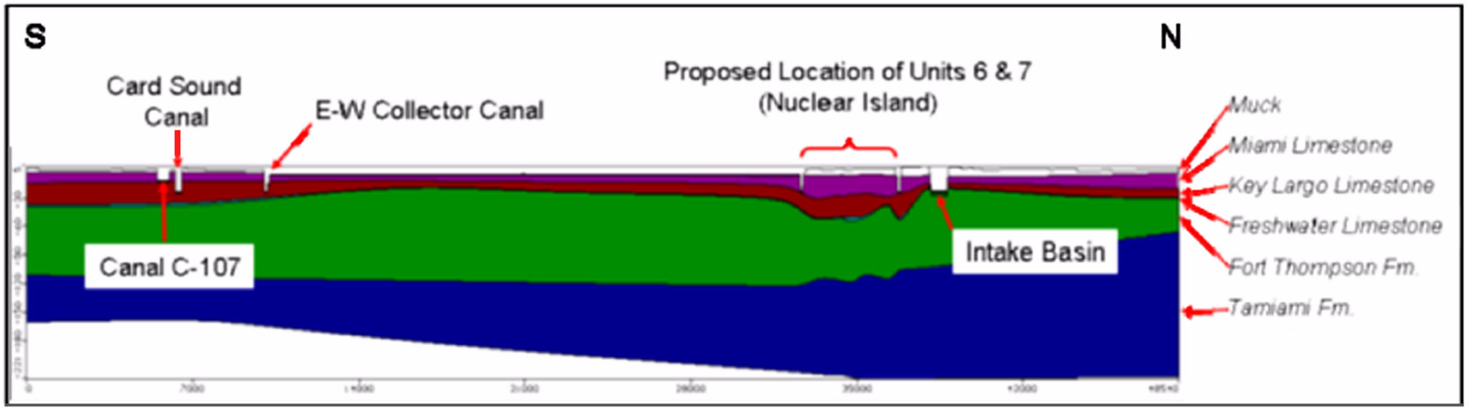


Figure 2CC-211 West-East Model Cross Section Towards Southern End of Cooling Water Canals



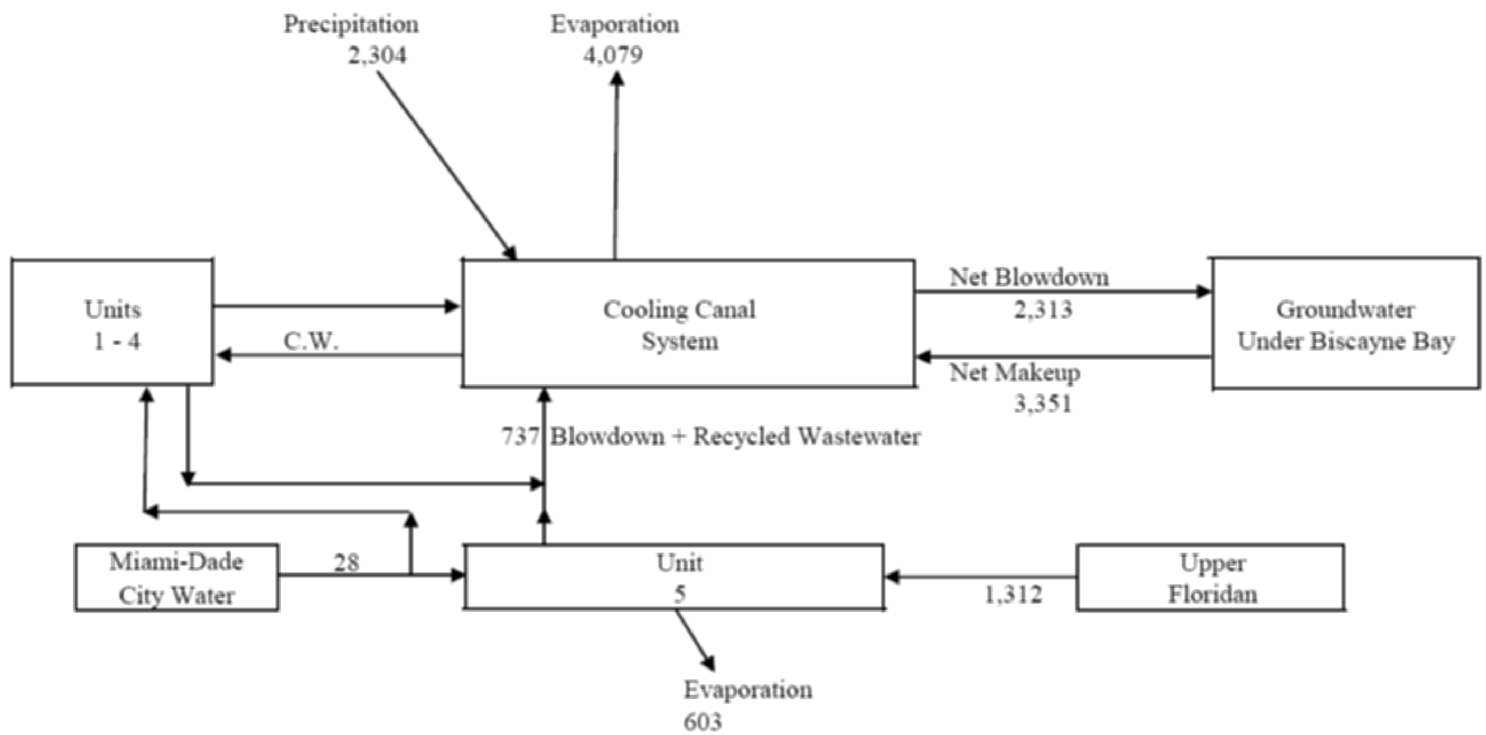
Note: Section along Row 1152, vertical exaggeration 40:1

Figure 2CC-212 South-North Model Cross Section Along Return Canal of Cooling Water Canals



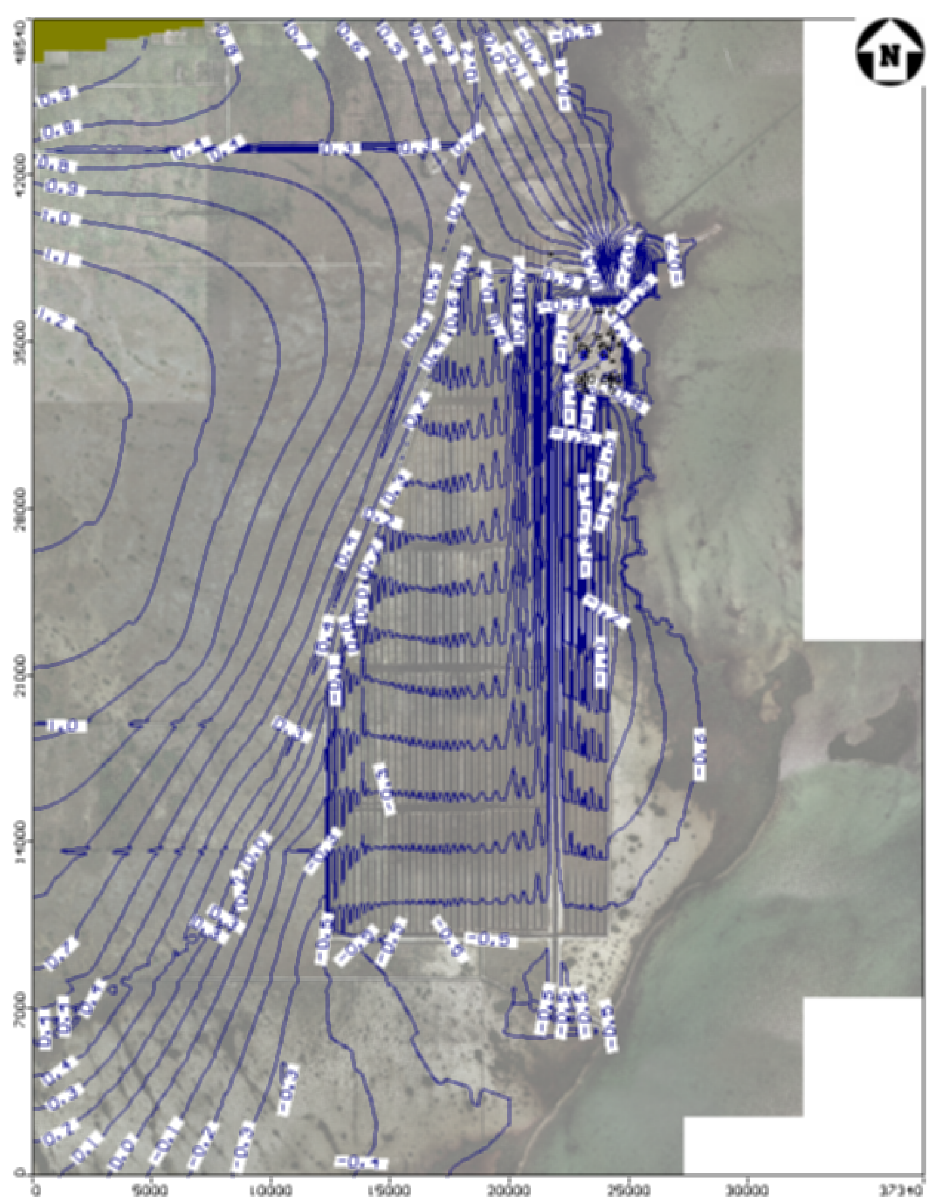
Note: Section along Column 602, vertical exaggeration 40:1.

Figure 2CC-213 Cooling Canals Water Balance



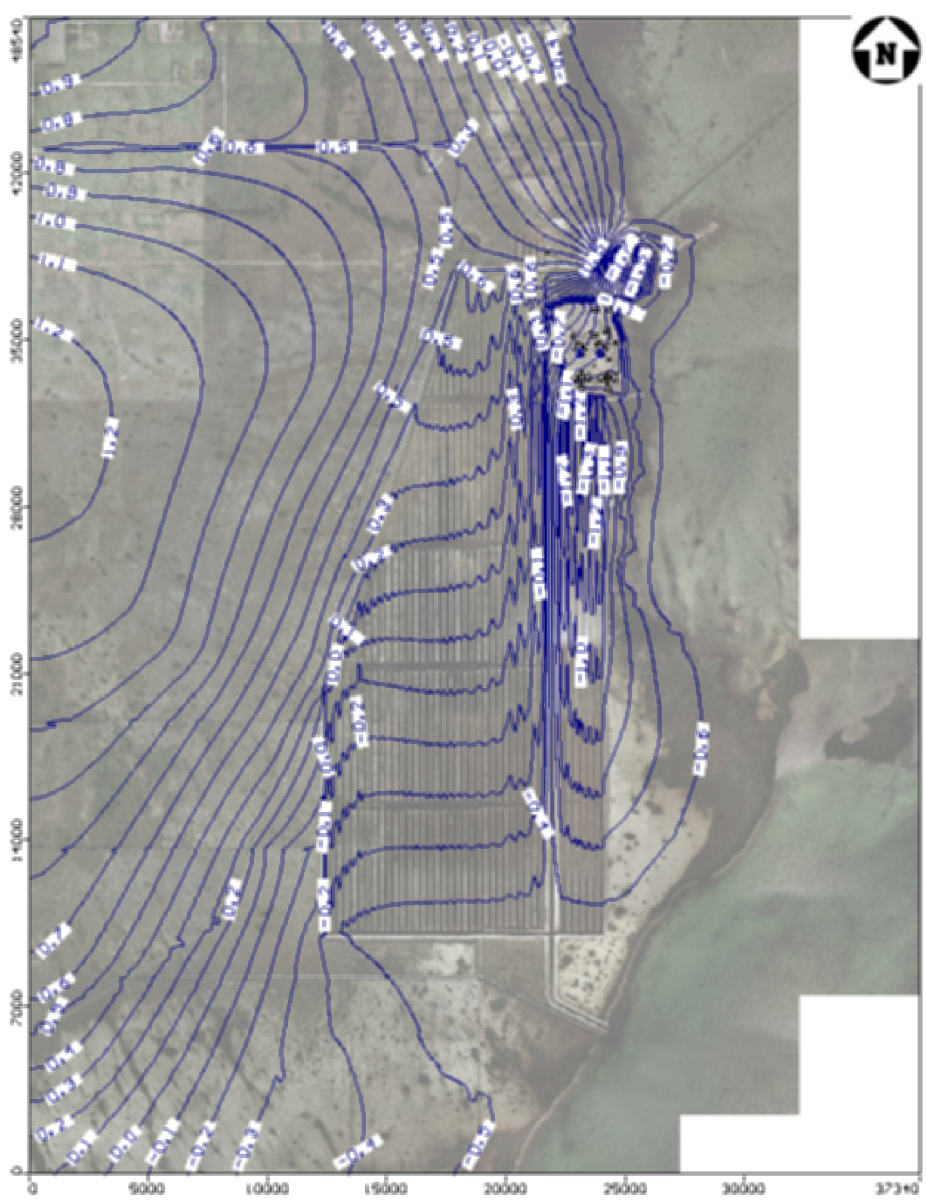
Note: Units in acre-ft/month.

Figure 2CC-214 Simulated Groundwater Contours — Model Layer 1 — Muck



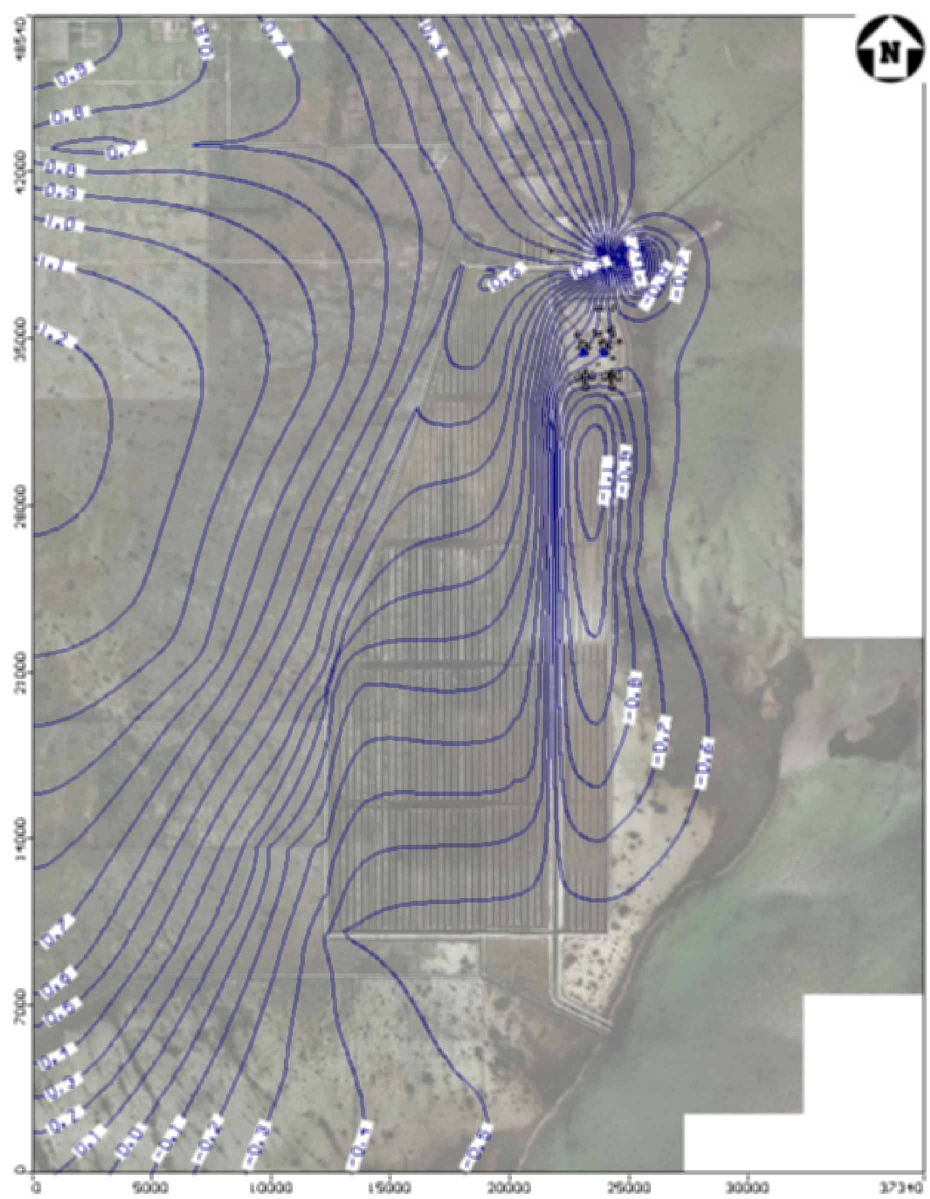
Legend: Contour interval is 0.1 feet (NAVD 88). Olive = Dry cells.
Run with the smallest residual and root mean square error

Figure 2CC-215 Simulated Groundwater Contours — Model Layer 2 — Miami Limestone



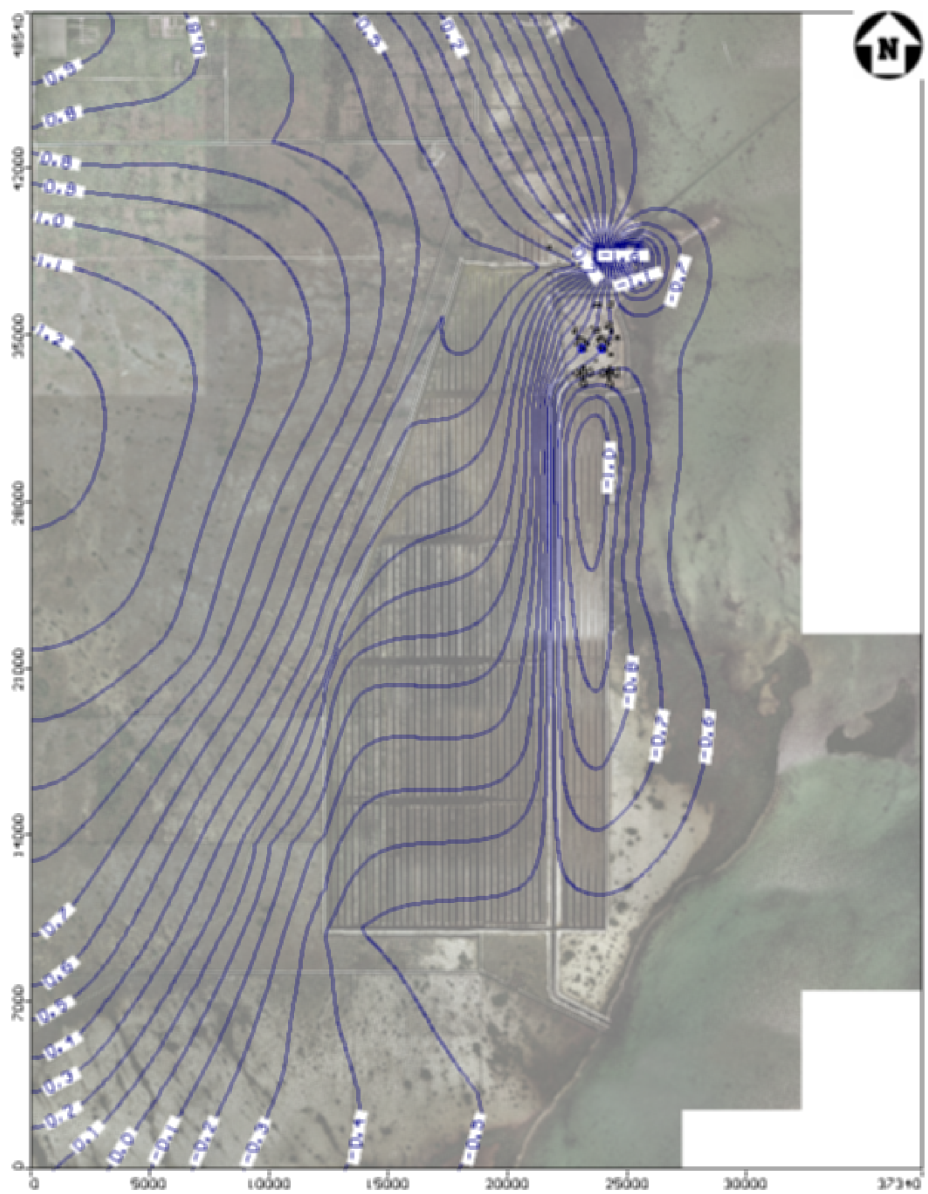
Legend: Contour interval is 0.1 feet (NAVD 88).
Run with the smallest residual and root mean square error.

Figure 2CC-216 Simulated Groundwater Contours — Model Layer 3 — Key Largo Limestone



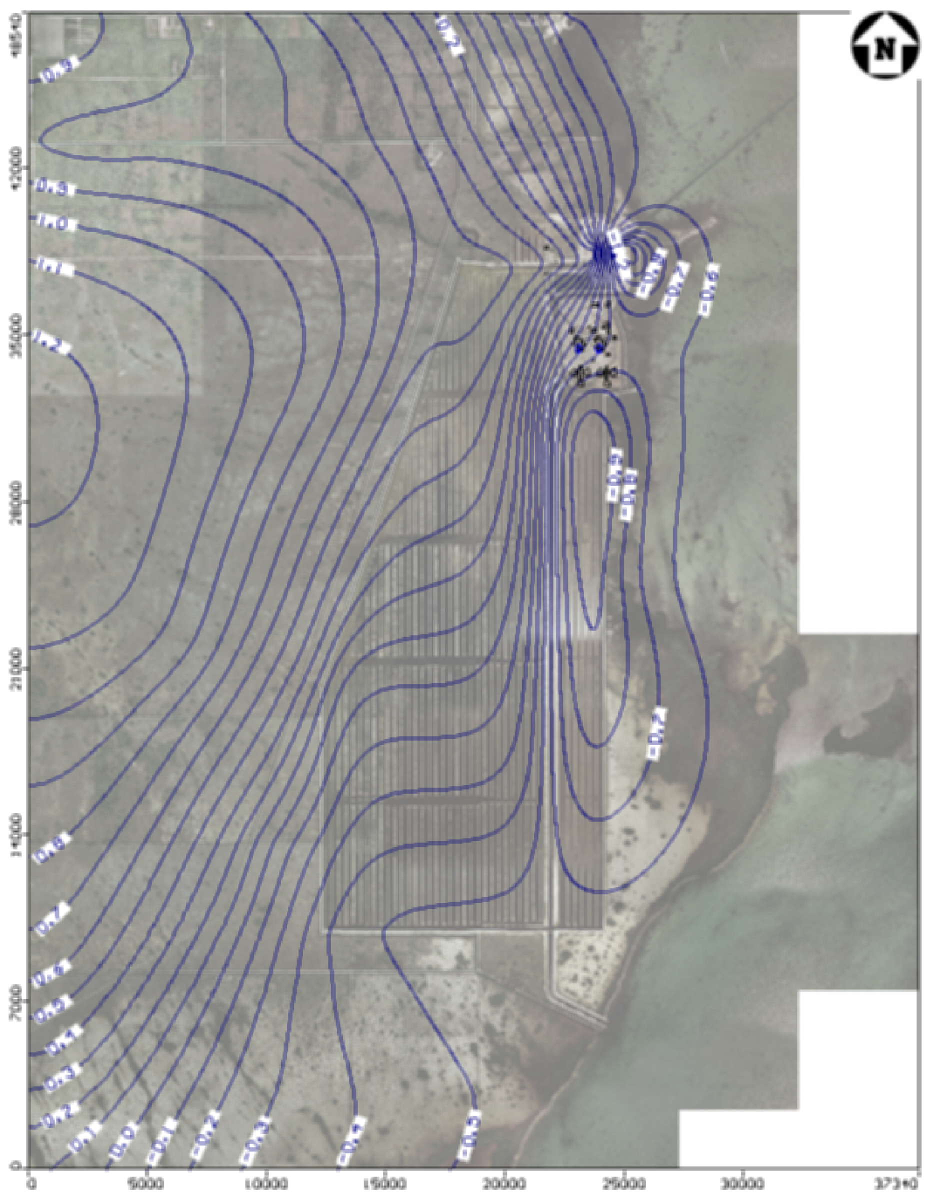
Legend: Contour interval is 0.1 feet (NAVD 88).
Run with the smallest residual and root mean square error.

Figure 2CC-217 Simulated Groundwater Contours — Model Layer 4 — Freshwater Limestone



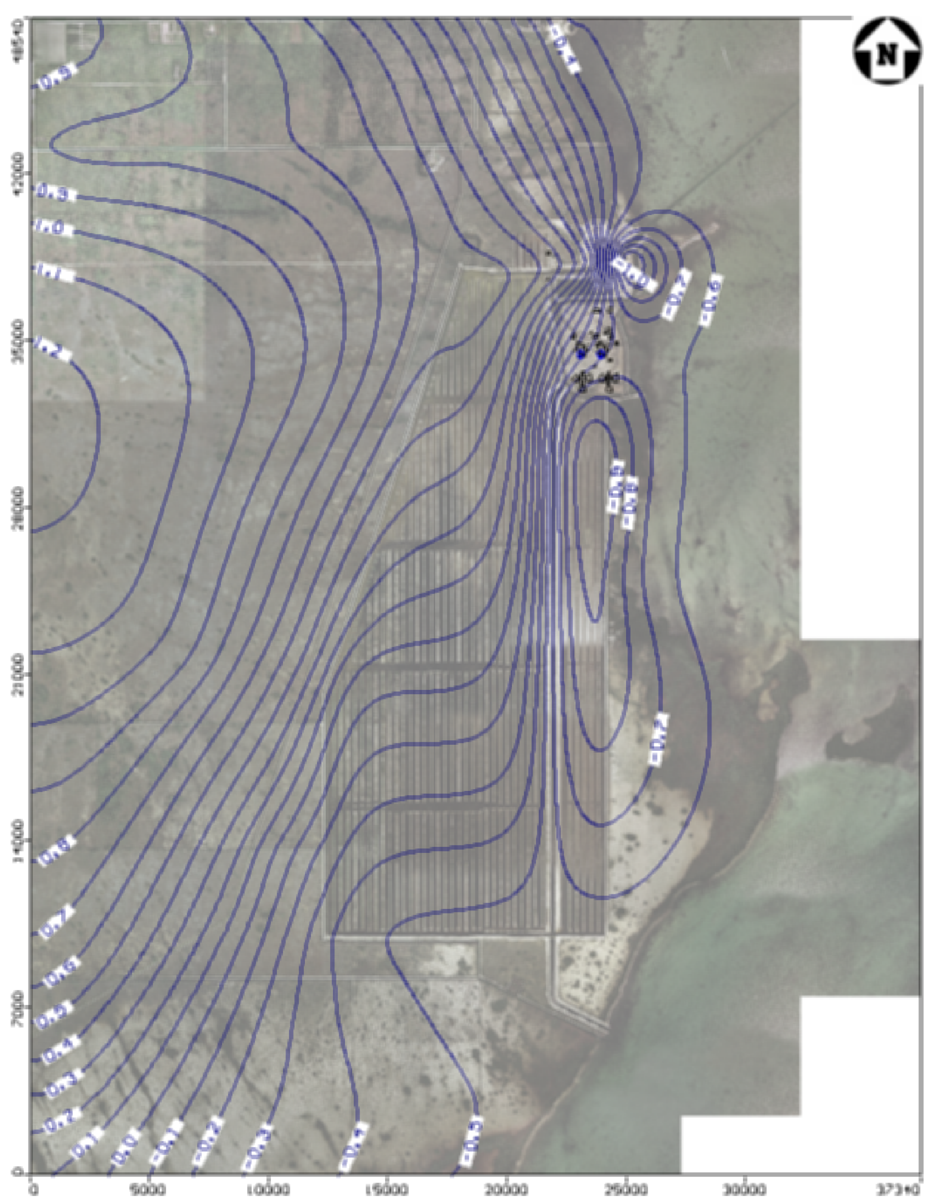
Legend: Contour interval is 0.1 feet (NAVD 88).
Run with the smallest residual and root mean square error.

Figure 2CC-218 Simulated Groundwater Contours — Model Layer 5 — Fort Thompson Formation



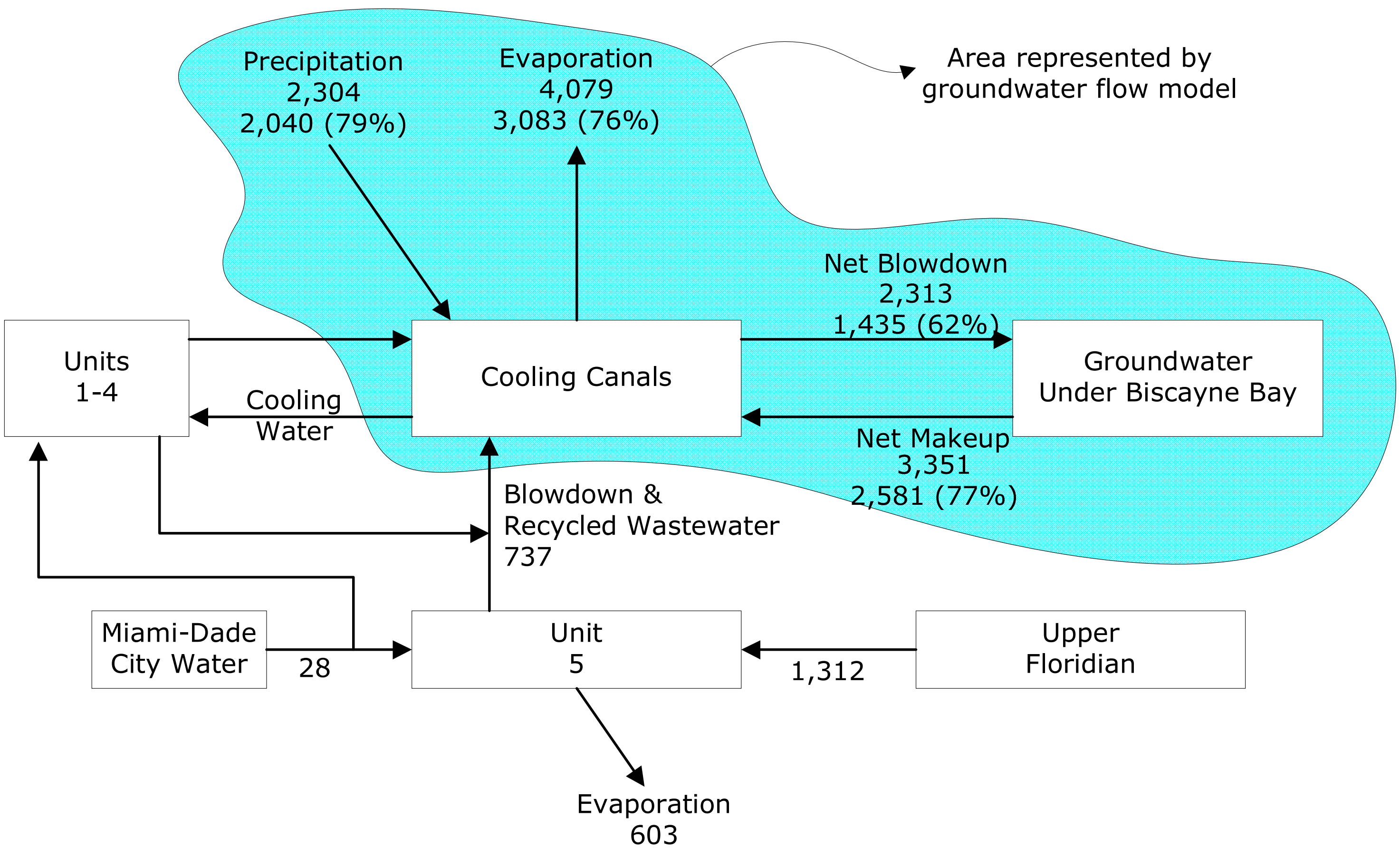
Legend: Contour interval is 0.1 feet (NAVD 88).
Run with the smallest residual and root mean square error

Figure 2CC-219 Simulated Groundwater Contours — Model Layer 6 — Tamiami Formation



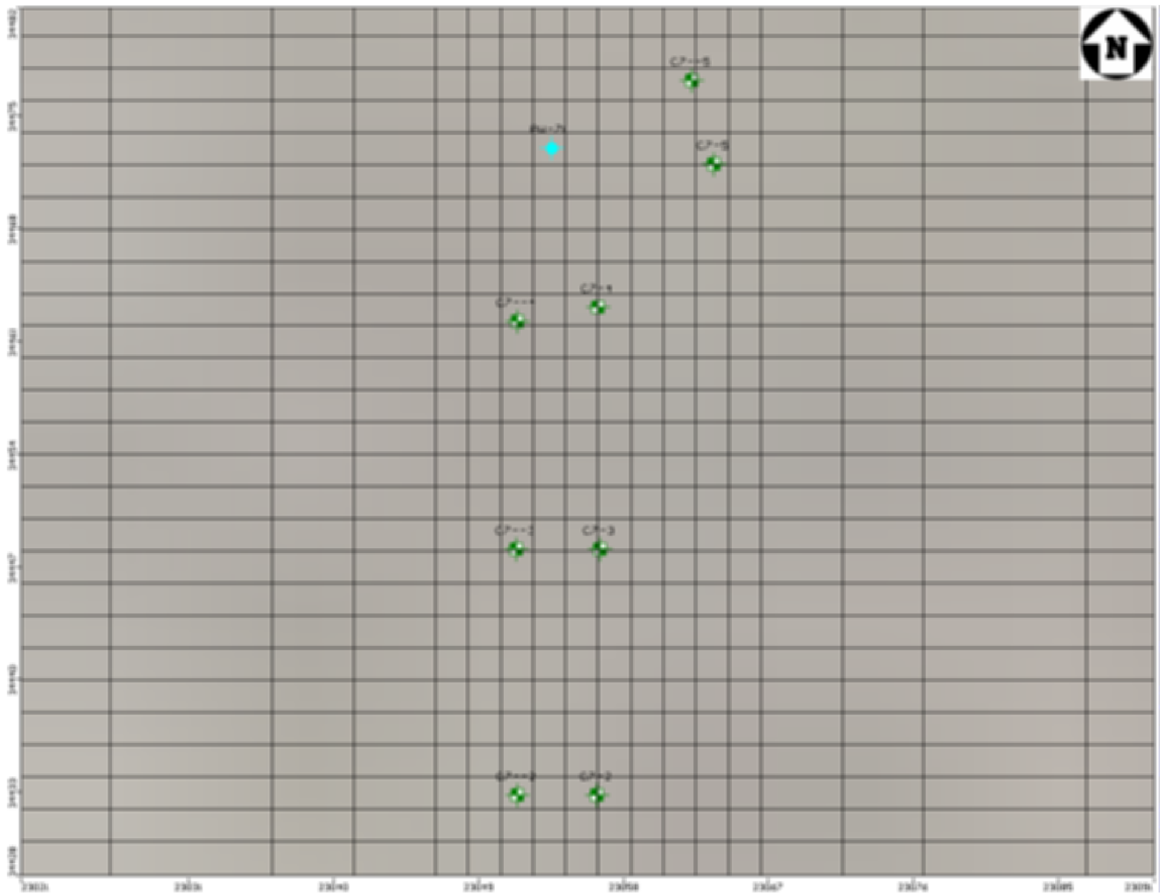
Legend: Contour interval is 0.1 feet (NAVD 88).
Run with the smallest residual and root mean square error.

Figure 2CC-220 Cooling Canals Water Balance — Comparison with Groundwater Model



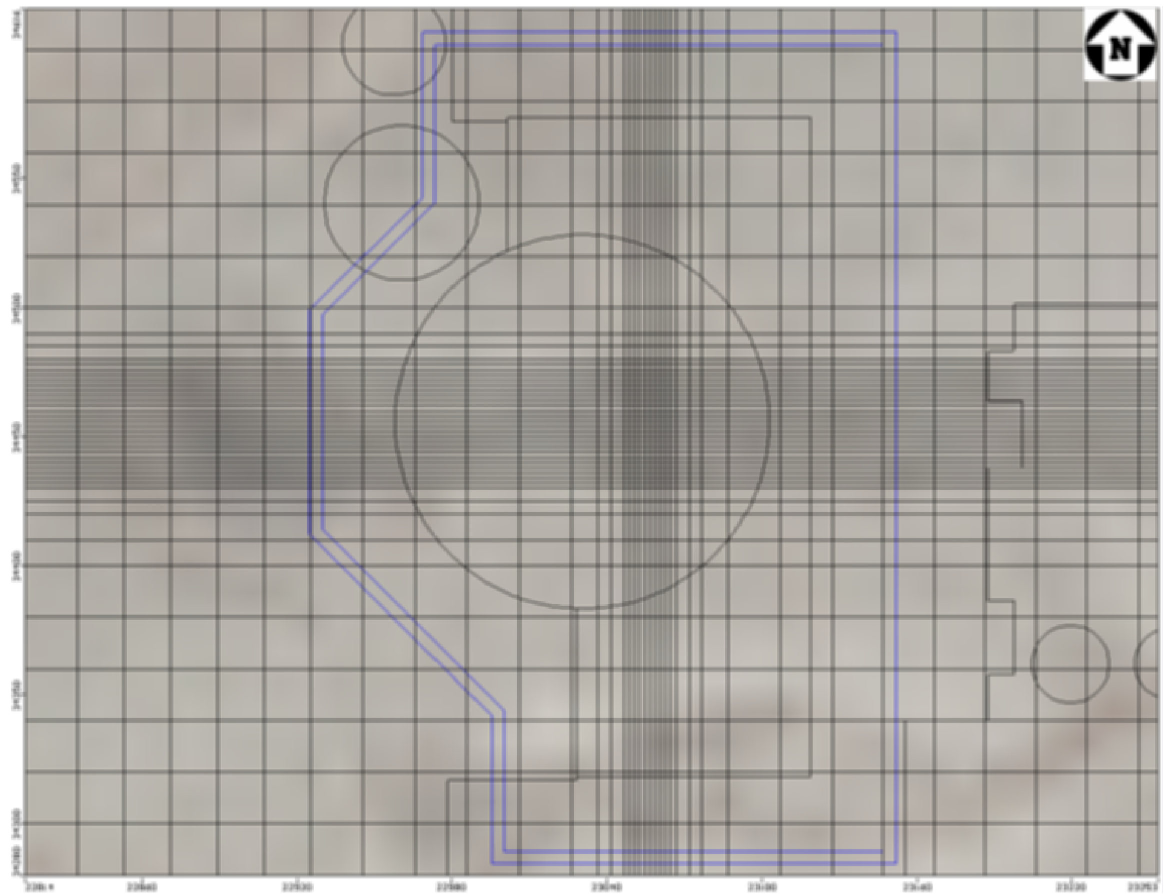
Notes:
Values in acre-ft/month.
Top value is plant at full capacity from a previous surface water model, lower value is from groundwater model at average plant conditions.

Figure 2CC-221 Test Well PW-7L and Related Observation Wells



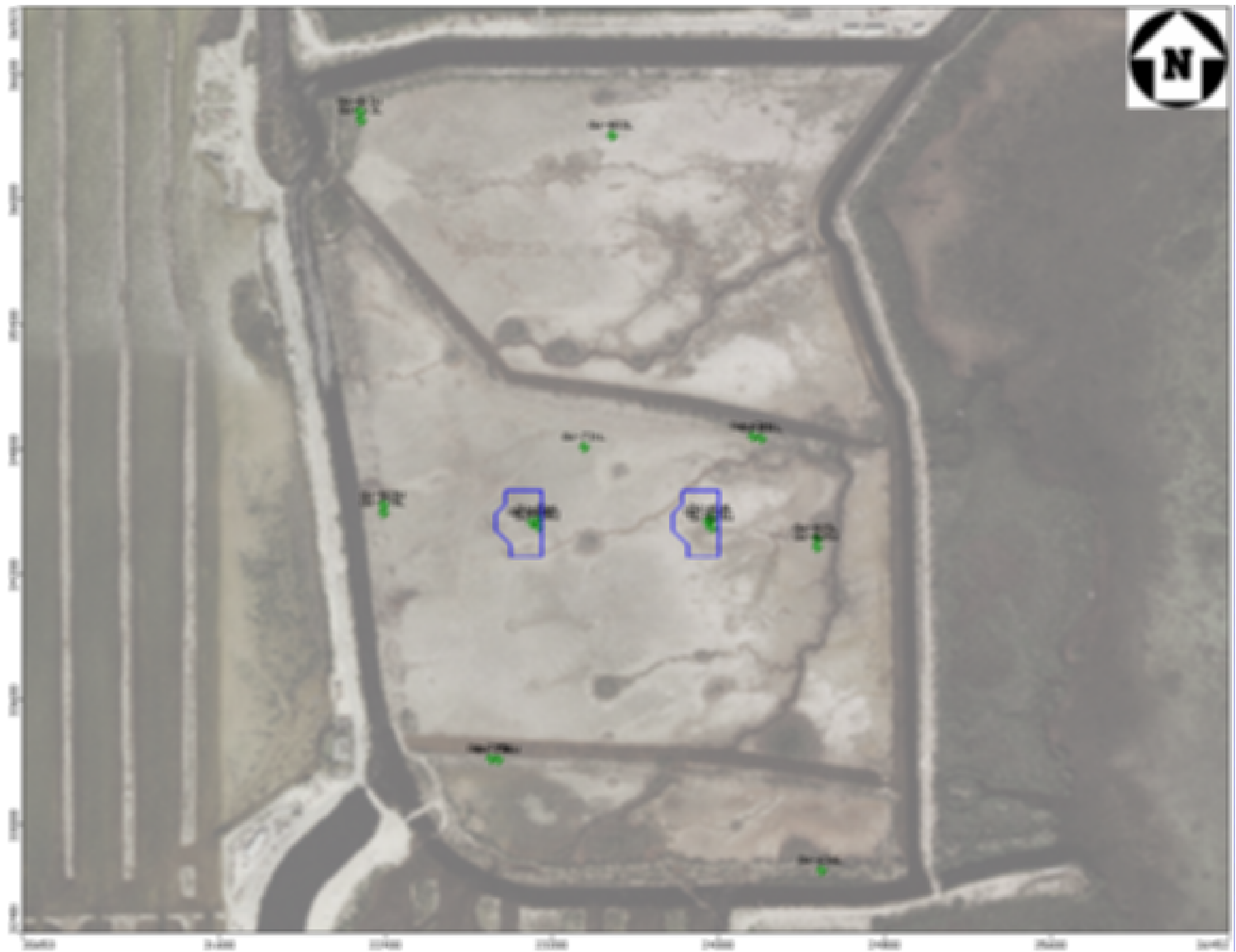
Legend: Blue = Pumping Well, Green = Observation Well.

Figure 2CC-222 Grid Refinement in Vicinity of Unit 7 Reactor Footprint



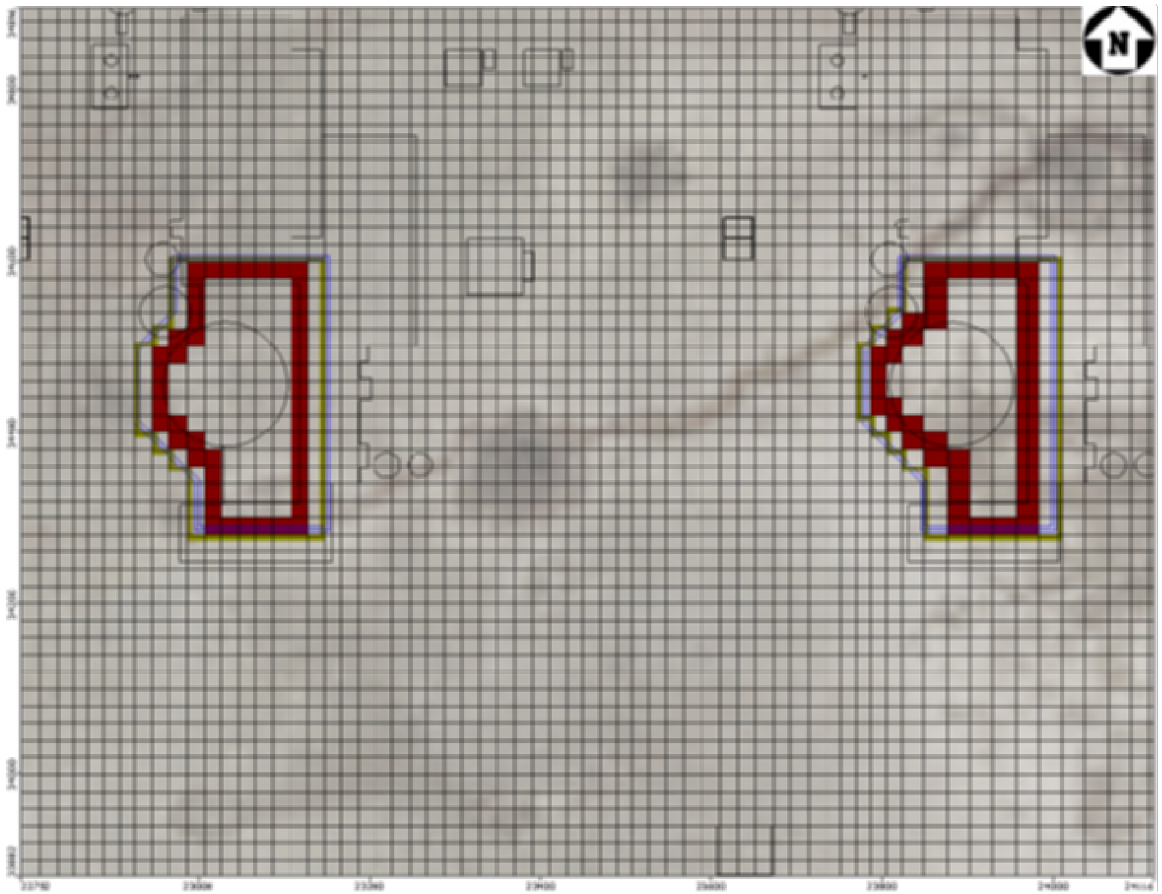
Legend: Blue=Cut-off wall.

Figure 2CC-223 Location of Units 6 & 7 Construction Dewatering Cut-Off Walls



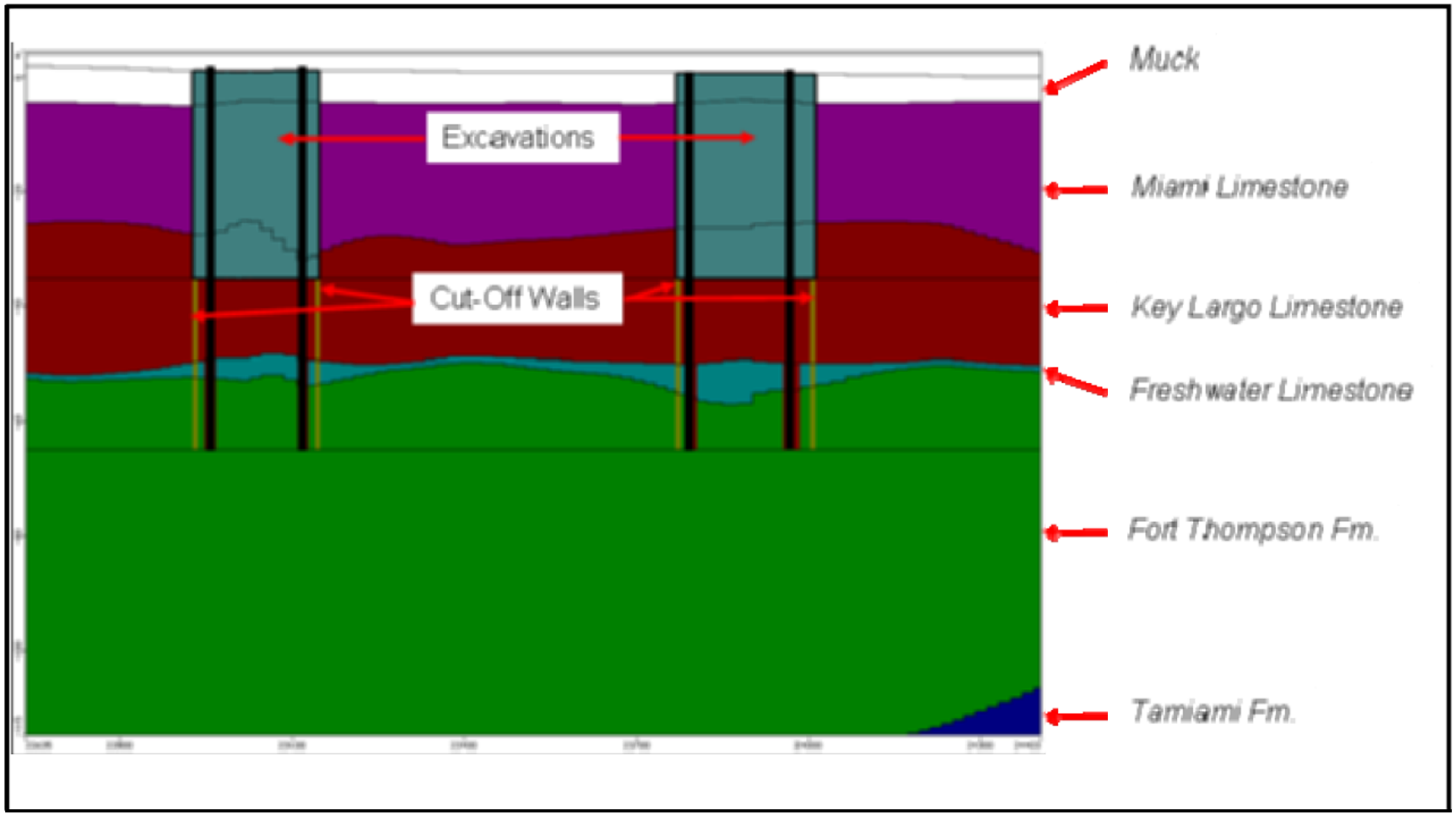
Legend: Blue=Cut-off wall.

Figure 2CC-224 Location of Units 6 & 7 Cut-Off Walls and Internal Dewatering Wells



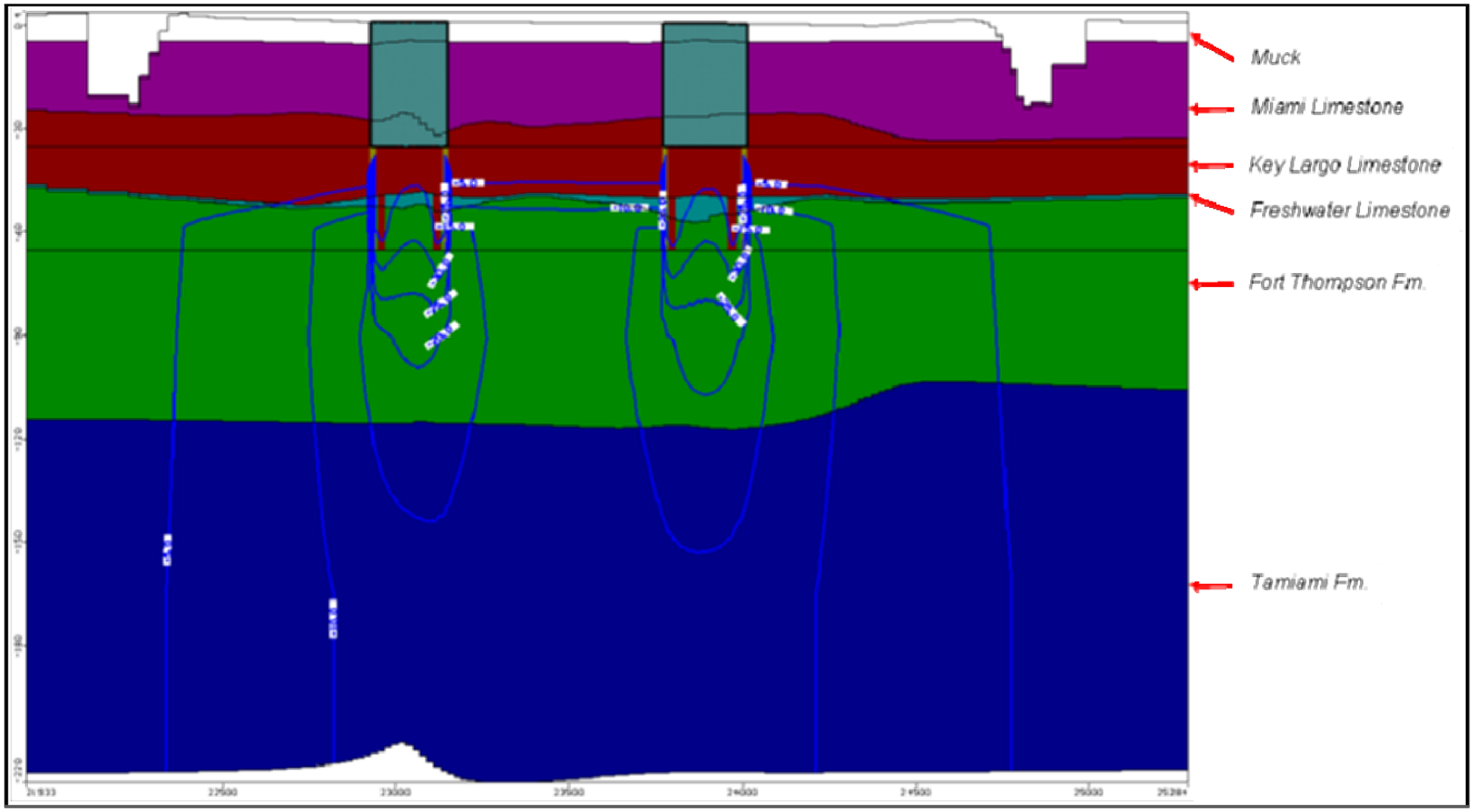
Legend: Red cells represent pumping wells (inside cut-off walls).

Figure 2CC-225 Cross Section of Units 6 & 7 Excavations in Numerical Model



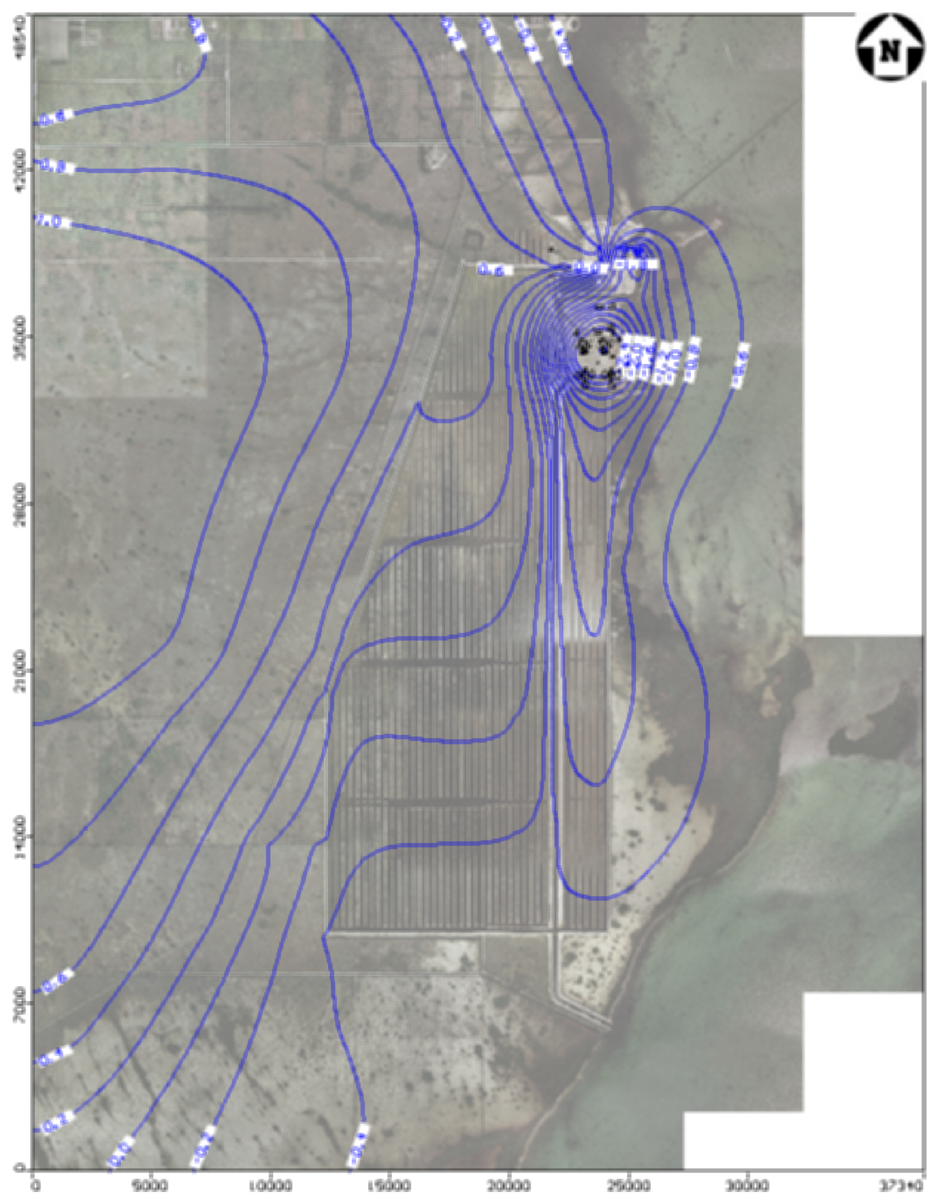
Legend: Black vertical lines on interior of excavations represent dewatering wells.
Section Across Row 264. Vertical Exaggeration 20:1. Vertical lines through excavations are observation wells in model.

Figure 2CC-226 Results of Dewatering Simulation for Units 6 & 7 Excavations



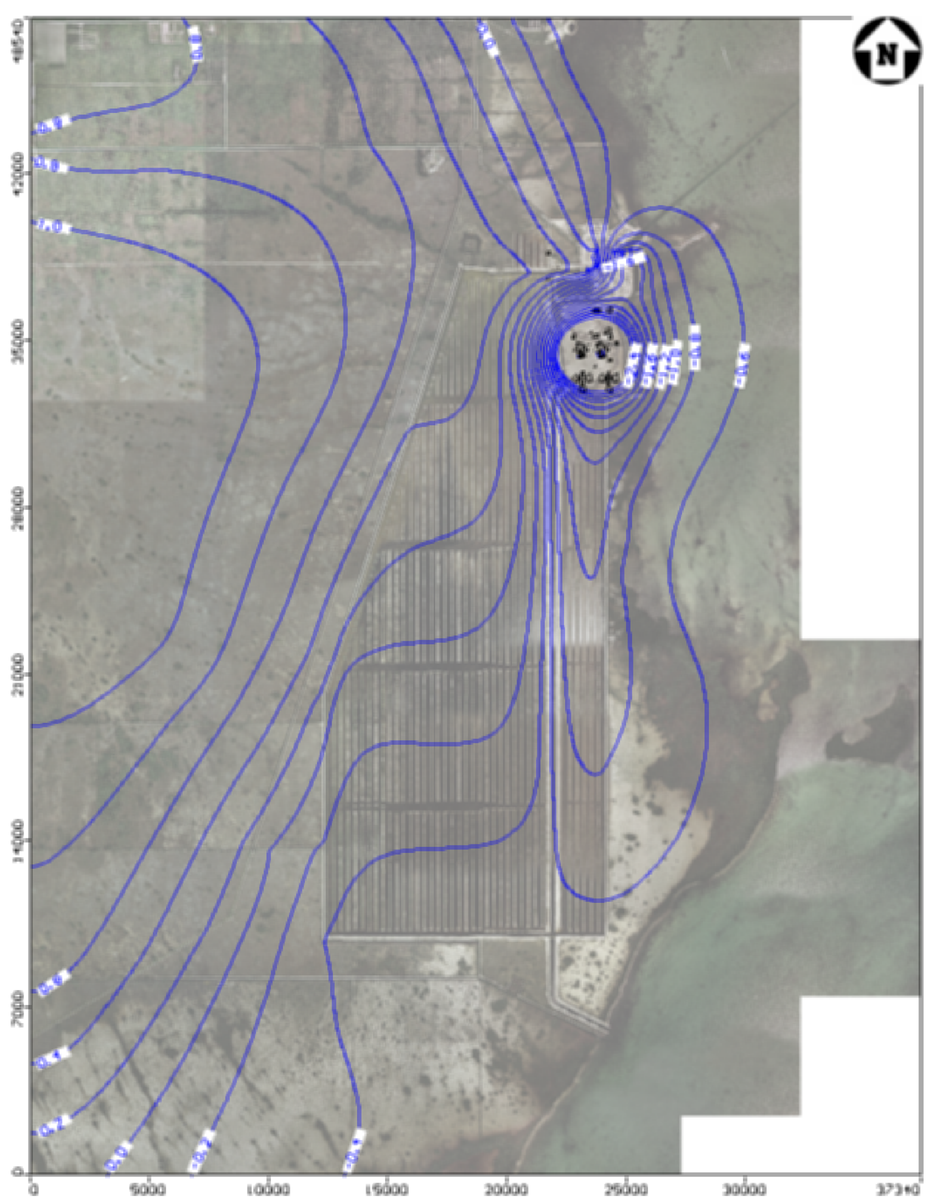
Legend: Blue lines are equipotentials in 5 feet increments.

Figure 2CC-227 Construction Dewatering: Simulated Groundwater Contours — Key Largo Limestone (Lower Portion)



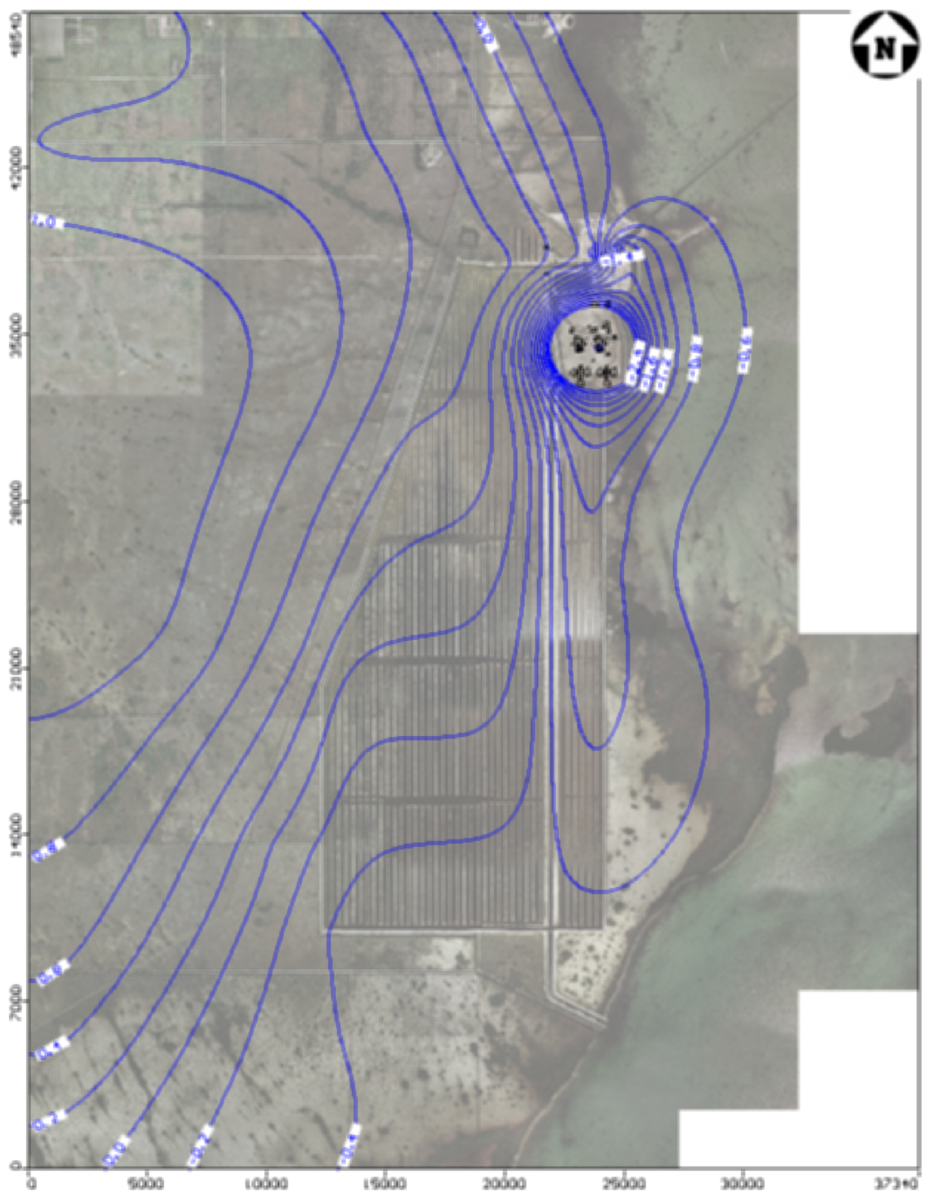
Legend: Contour interval is 0.2 feet (NAVD 88). Minimum contour shown is –2.4 feet.

Figure 2CC-228 Construction Dewatering: Simulated Groundwater Contours — Freshwater Limestone



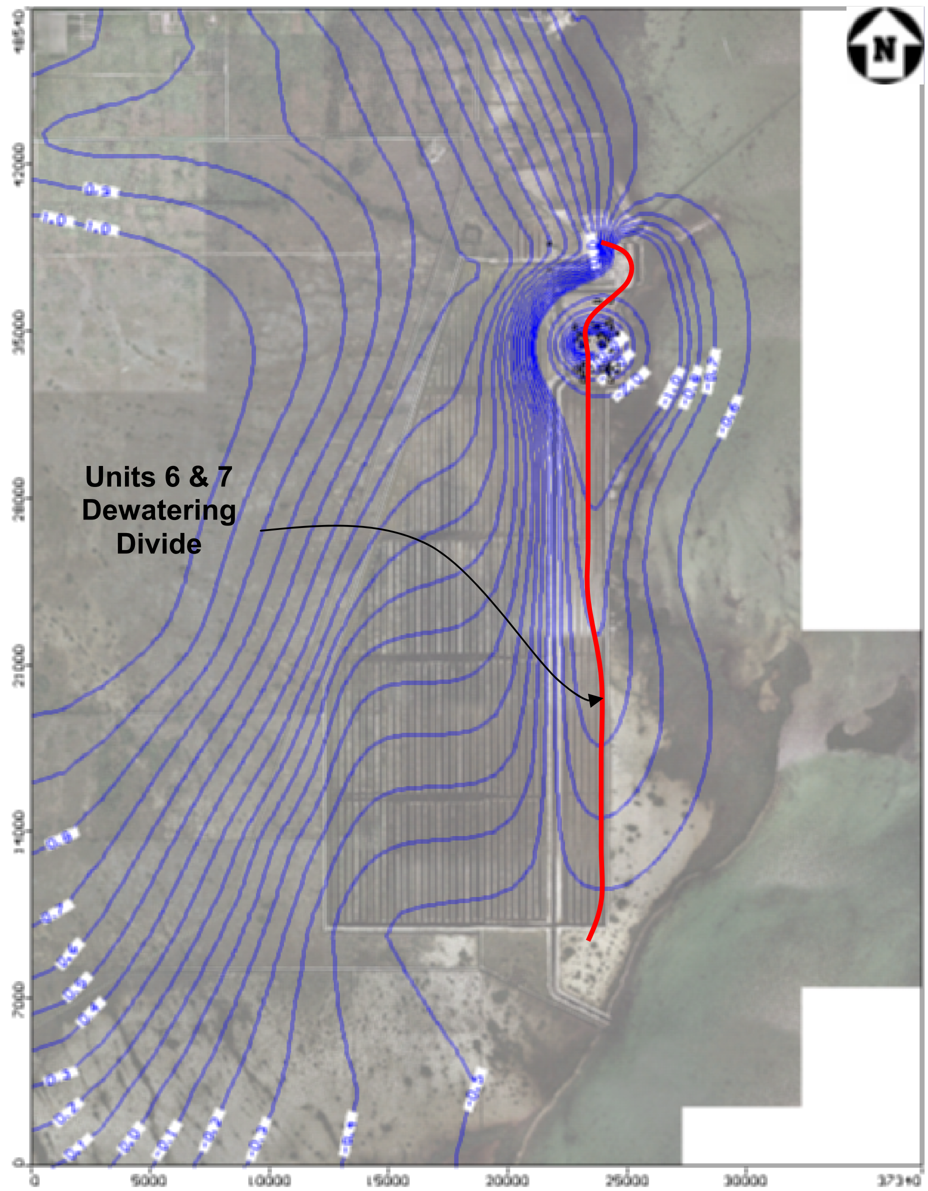
Legend: Contour interval is 0.2 feet (NAVD 88). Minimum contour shown is –2.4 feet.

Figure 2CC-229 Construction Dewatering: Simulated Groundwater Contours — Fort Thompson Formation (Upper Portion)



Legend: Contour interval is 0.2 feet (NAVD 88). Minimum contour shown is –2.4 feet.

Figure 2CC-230 Groundwater Contours in Fort Thompson Formation for Dewatering of Units 6 & 7 Excavations



Legend: Blue = Groundwater contours.
(0.1-foot interval from –1.0 to 1.0, and –1, –2, –3, –4, –5, and –10 feet).

Figure 2CC-231 Location of Radial Collector Wells and Laterals

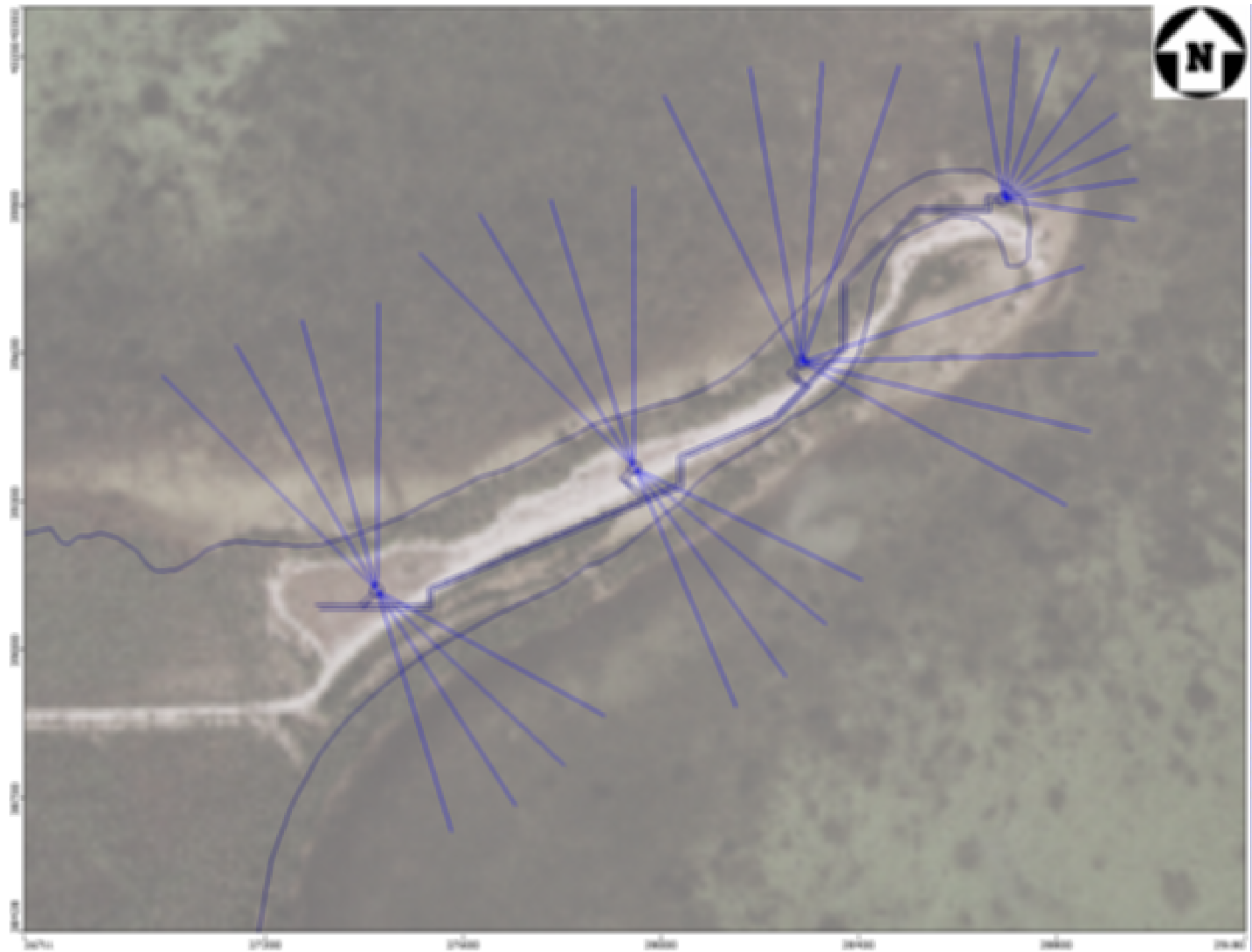


Figure 2CC-232 Location of Radial Collector Wells and Laterals, with Finite-Difference Grid and Pumping Well Locations Overlaid

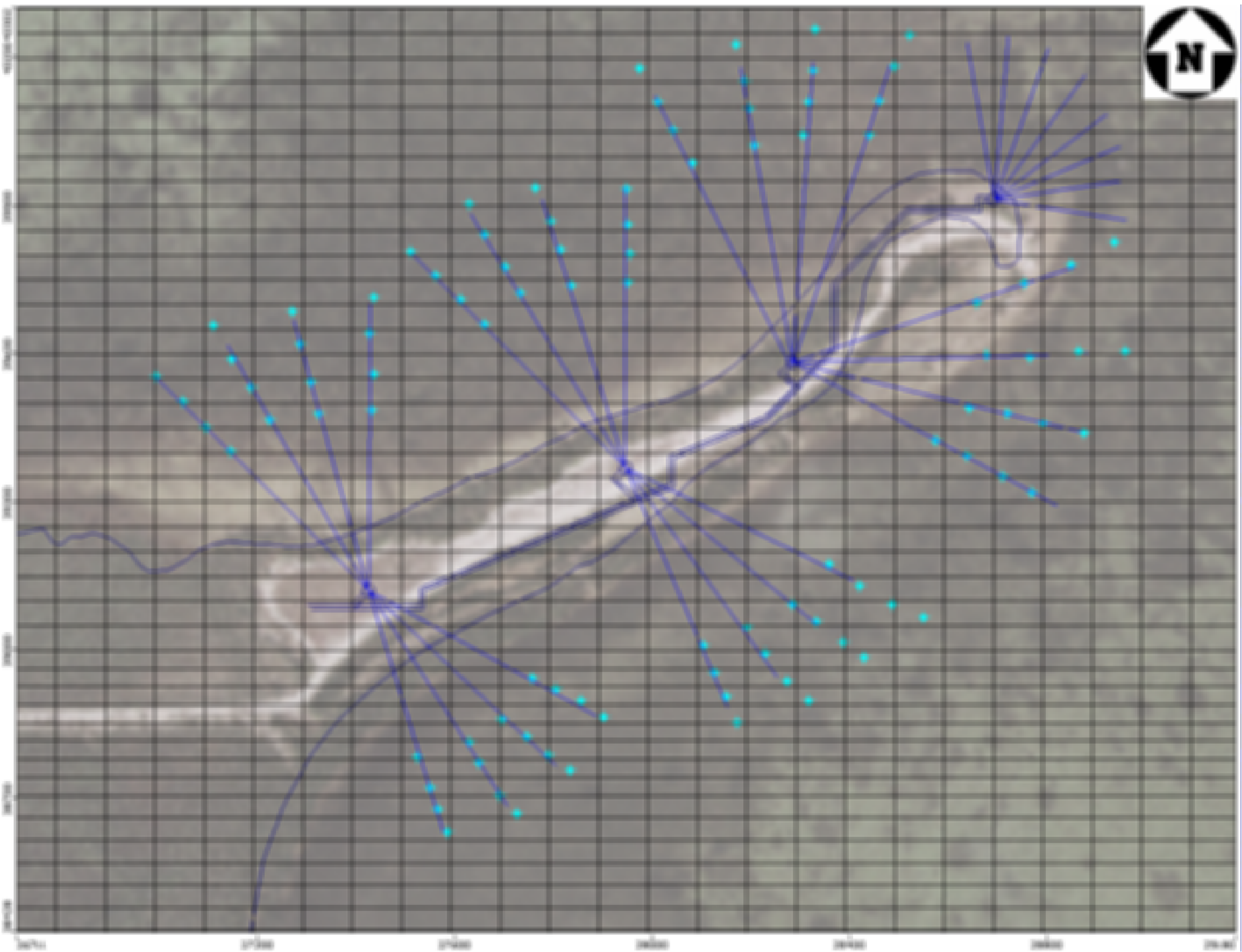


Figure 2CC-233 Groundwater Contours within Key Largo Limestone During Radial Collector Well Simulations

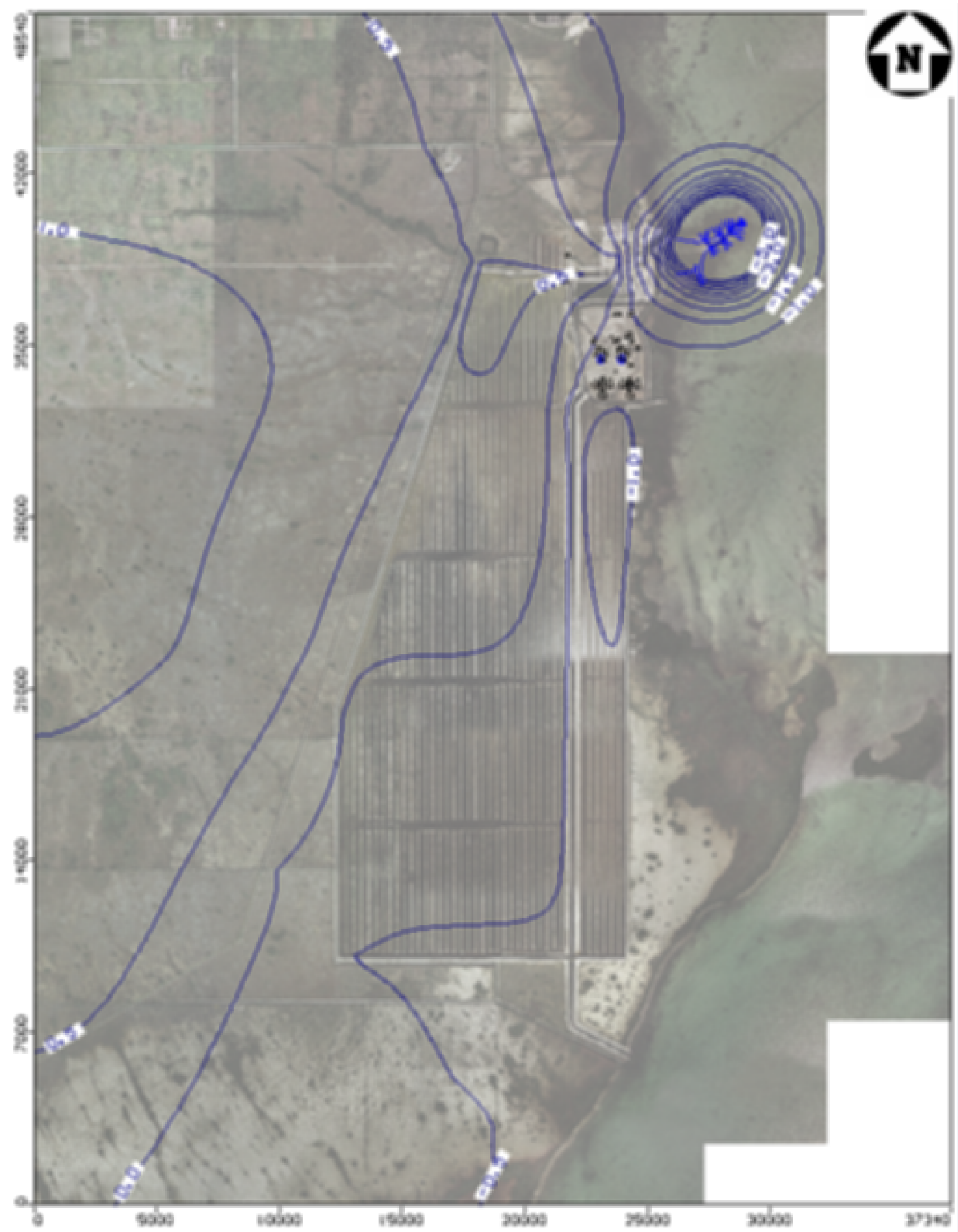


Figure 2CC-234 Groundwater Contours within Key Largo Limestone in Vicinity of Radial Collector Wells

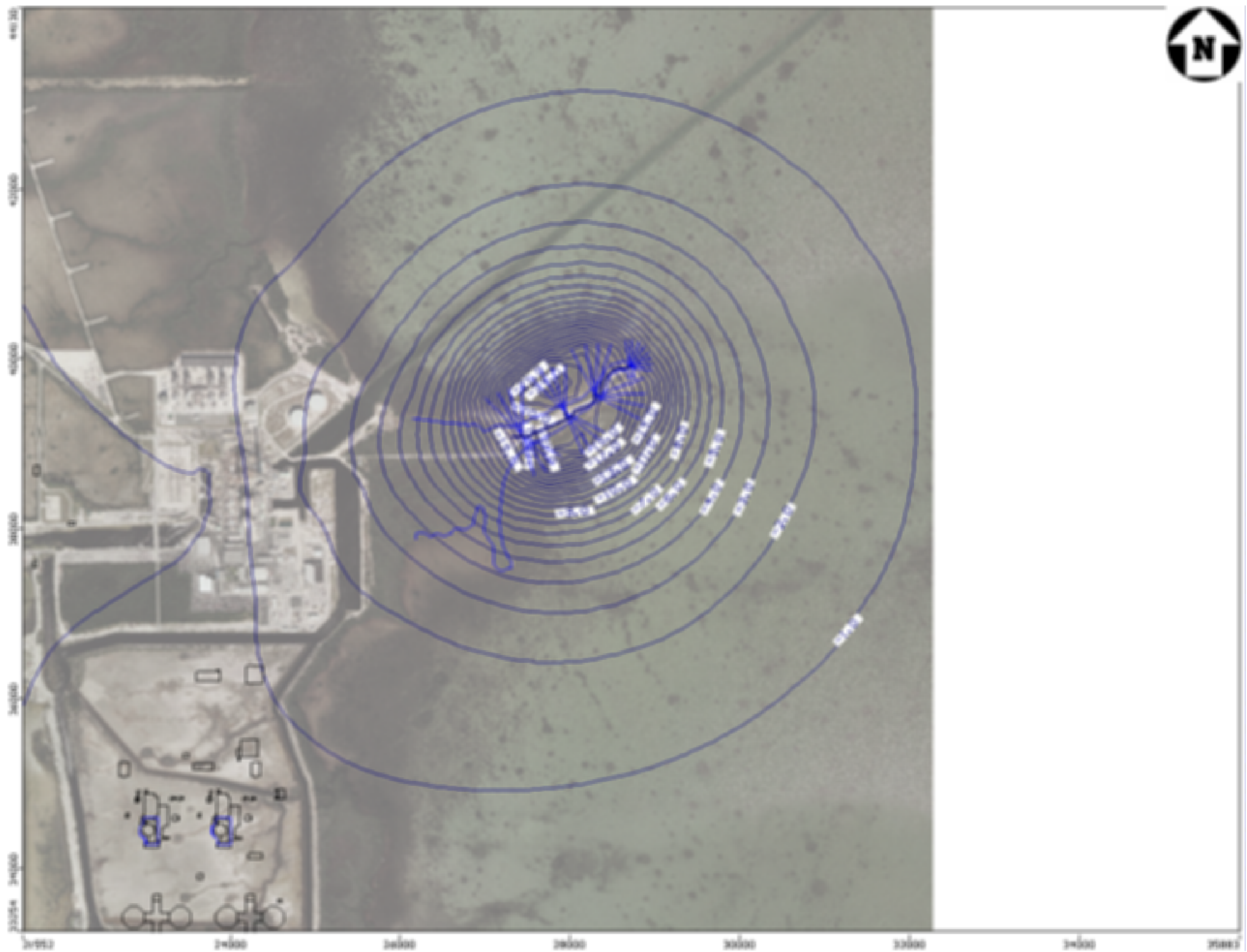
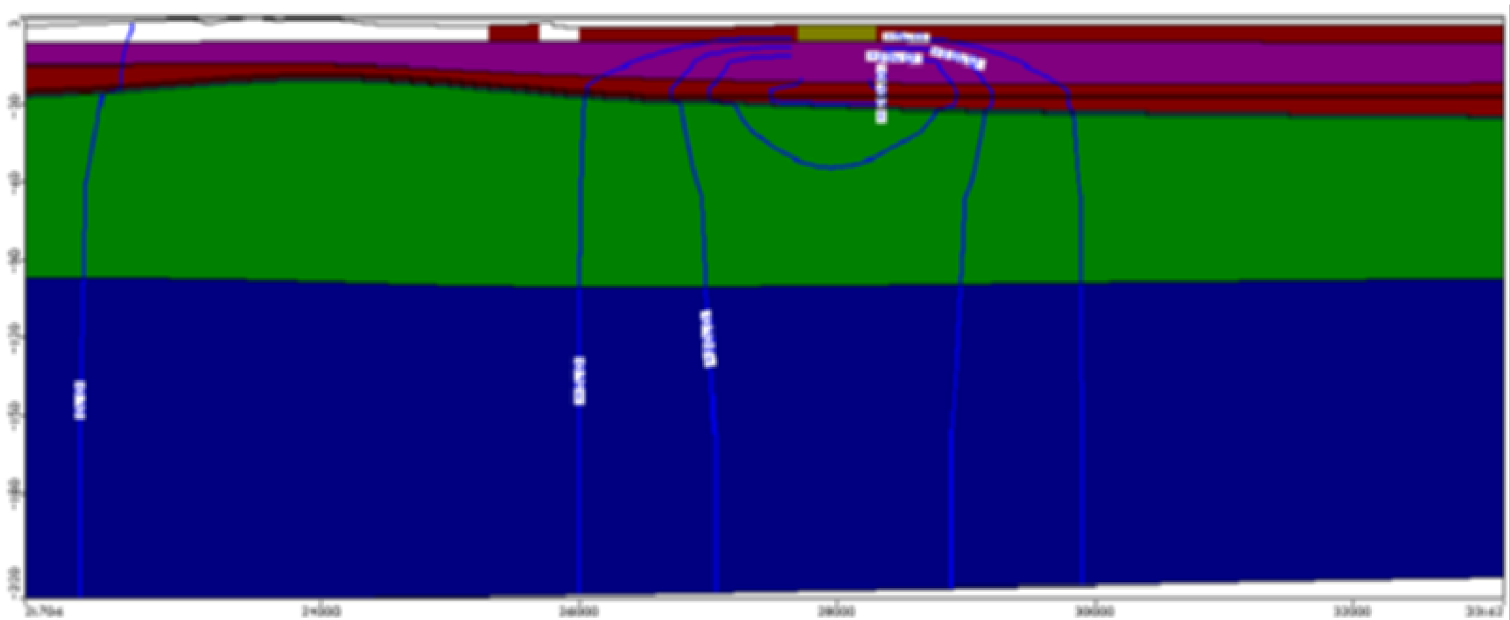


Figure 2CC-235 Results of Radial Collector Well Simulation



Note: Section Across Row 103, Vertical Exaggeration = 20. Equipotentials in 5 ft intervals.

Figure 2CC-236 Radial Collector Wells Sensitivity Analysis

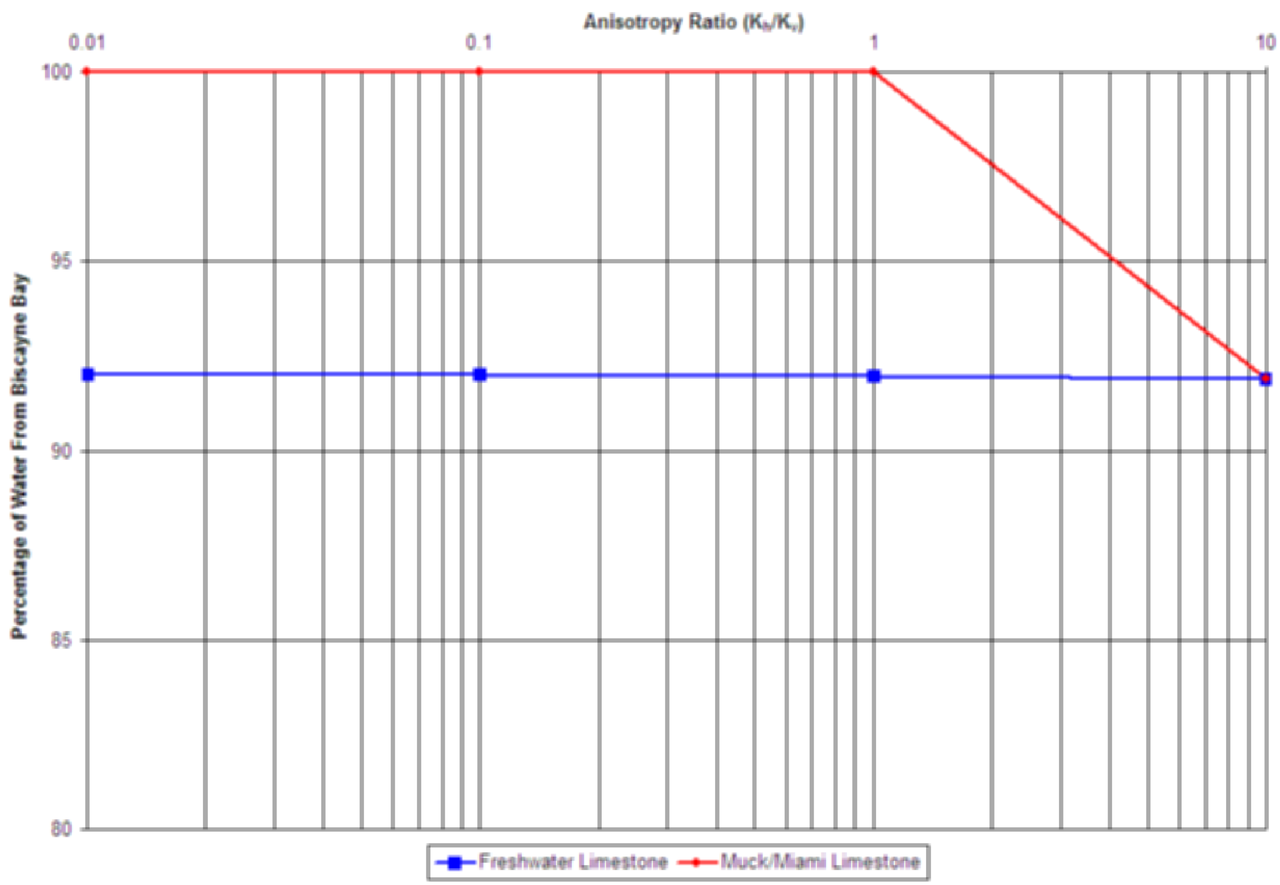


Figure 2CC-237 Additional Areas for Approach Velocity Calculation

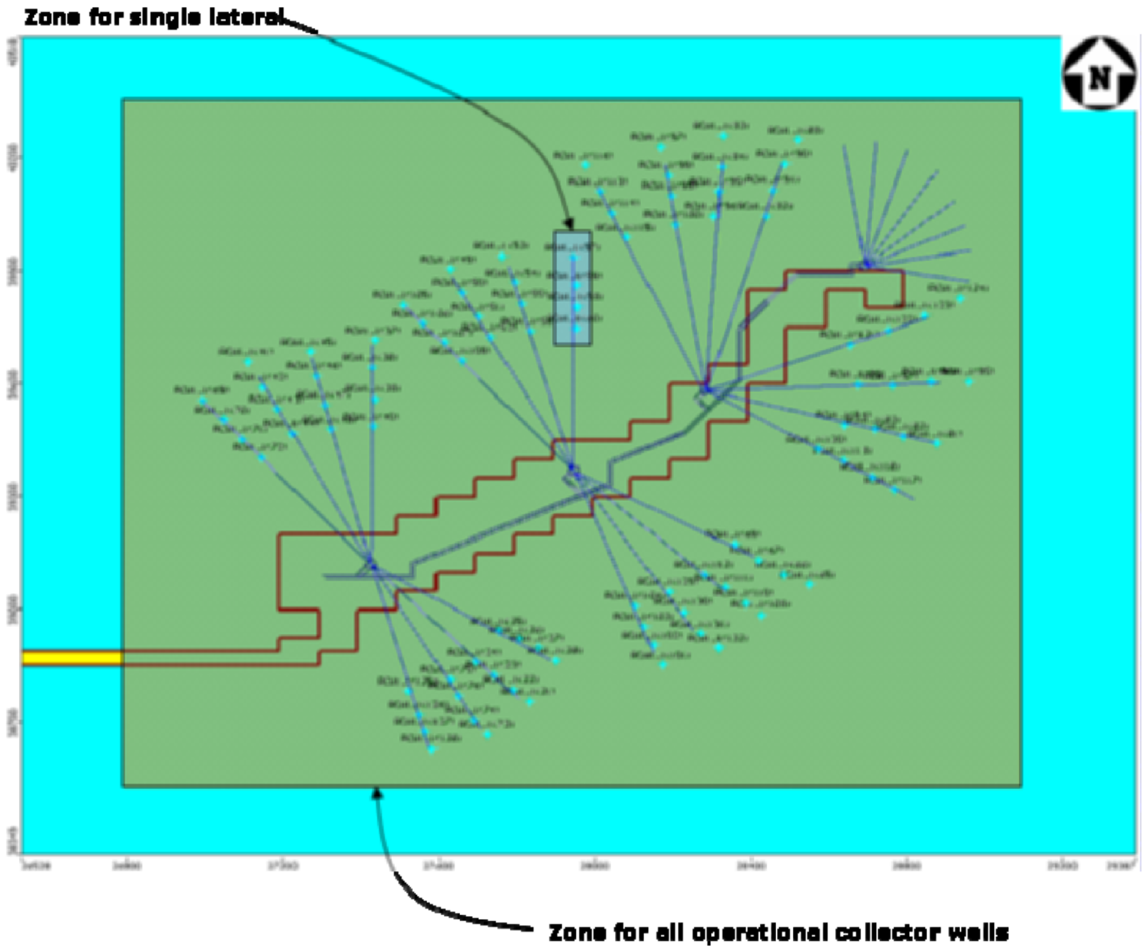
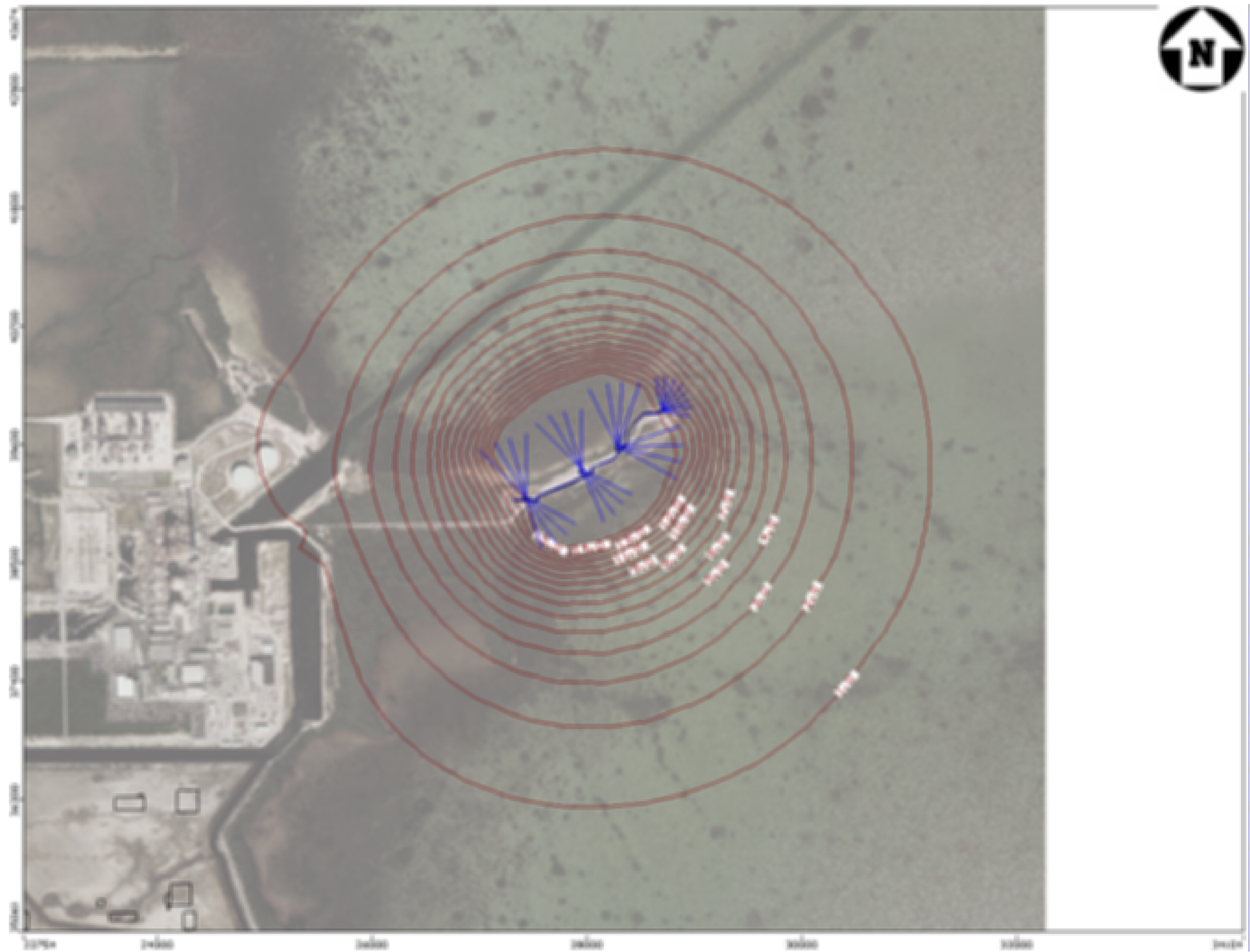


Figure 2CC-238 Drawdown within the Muck Layer

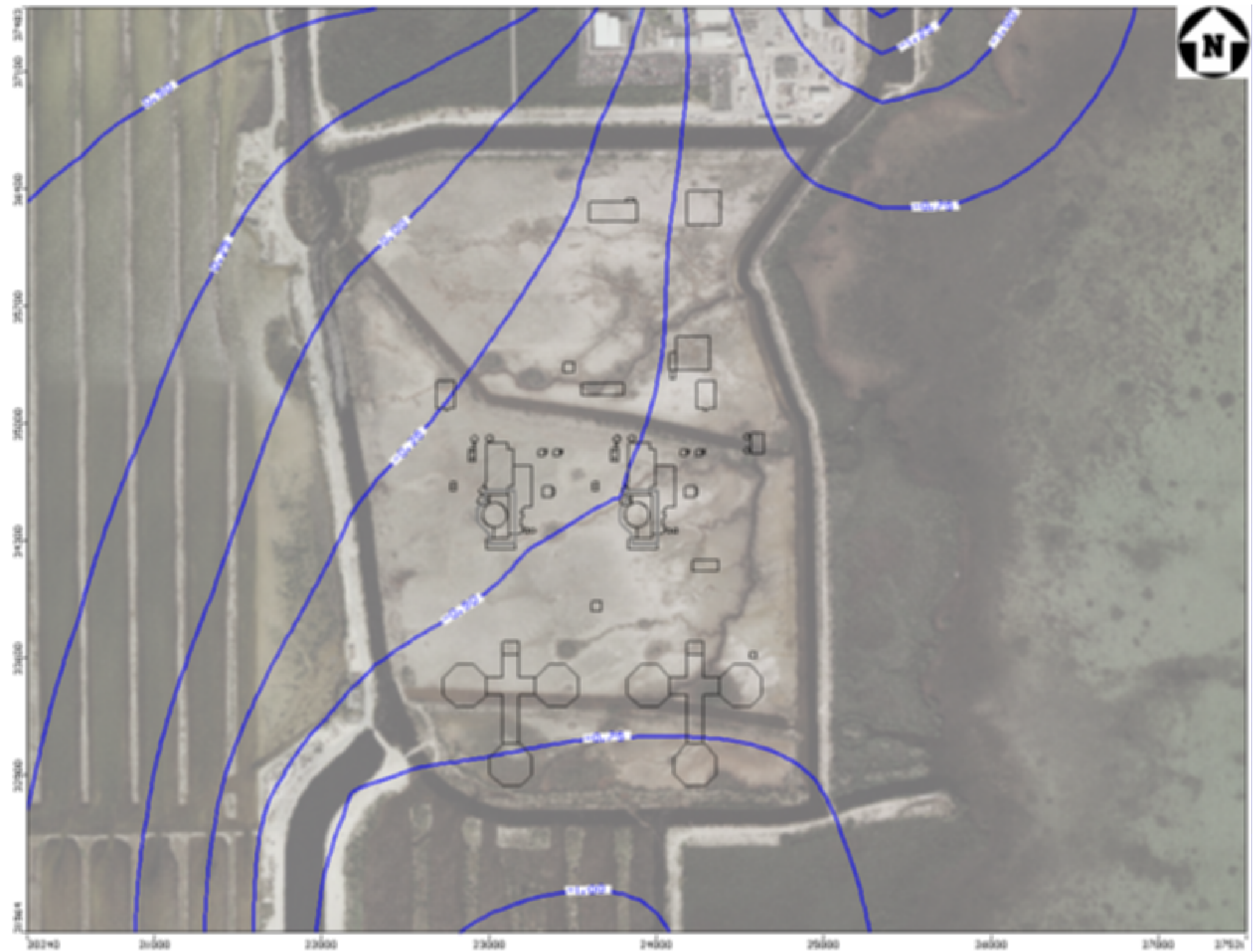
Note: Olive = Dry cells. Thick red line = revised shoreline.
Thin red line = 0.1, 0.5, 1.0, and 1.5 feet drawdown contours

Figure 2CC-239 Drawdown within the Pumped Layer (Key Largo Limestone)



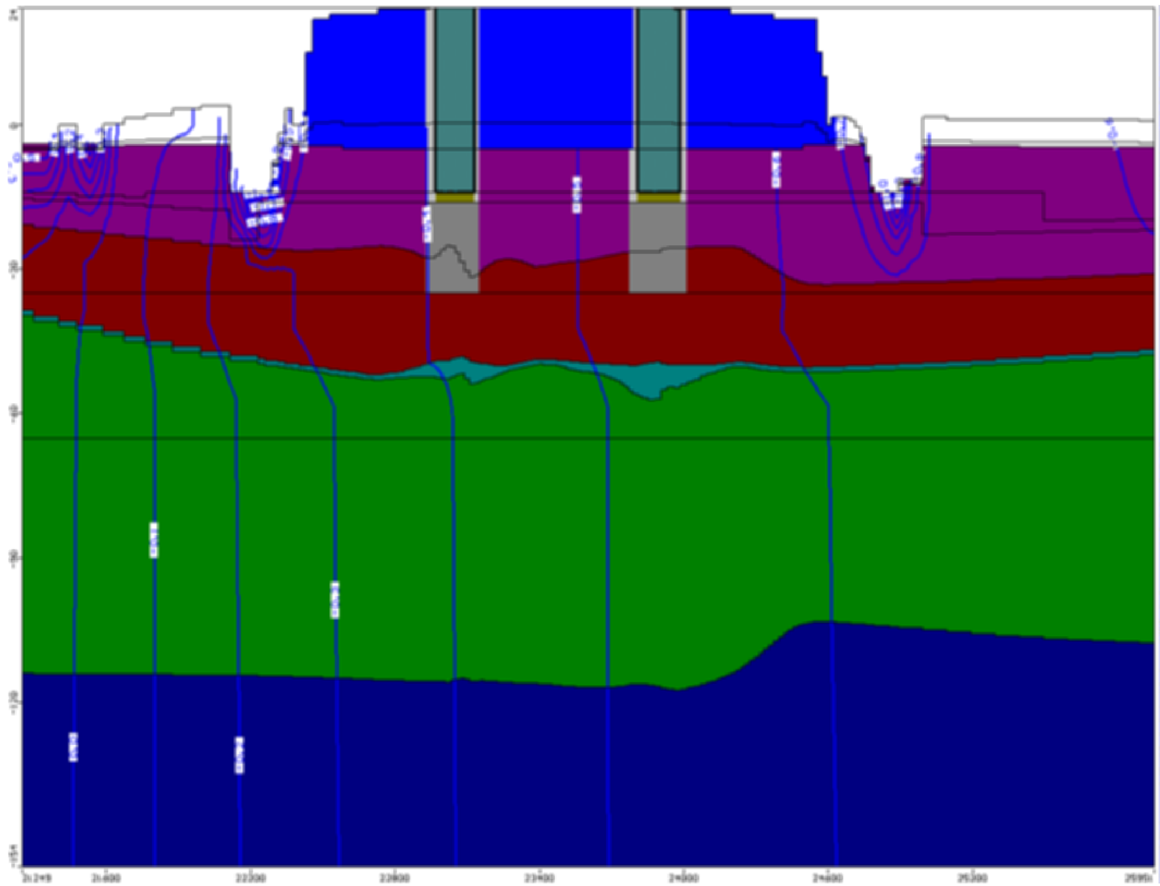
Note: Thin red line = Drawdown contours at 1-foot intervals.

Figure 2CC-240 Post-Construction Groundwater Contours in Key Largo Limestone — Plan



Legend: Blue=Groundwater contours in 0.25-foot increments.

Figure 2CC-241 Post-Construction Groundwater Contours — Section



Note: Section Across Row 263, Vertical Exaggeration = 20. Equipotentials in 0.1 ft intervals.