02.04.12-33, Supplement 4

QUESTION:

In the review of the document "Groundwater Model Development and Analysis for STP Units 3&4" provided as part of applicant's response to RAI 02.04.12.20, the staff noted that while the purpose of a groundwater flow model for a site goes beyond just calibration, one of the primary bases for determining a model's reliability to predict post-construction conditions is documenting its ability to reproduce existing field observation. The staff conclude from the review (of the FSAR Rev 2 Sections 2.4S.12 and 2.4S.13, and RAI responses including 2008 data and interpretations) that among the critical observed field conditions not reproduced by the existing model one must include (1) a groundwater divide in the Upper Shallow Aquifer in the immediate vicinity of the proposed location for STP Units 3&4, (2) a groundwater divide (that cannot be excluded) in the Lower Shallow Aquifer in the immediate vicinity of the proposed location for STP Units 3&4, and (3) an exposure pathway in the vicinity of Kelly Lake where there is an upward gradient from the Lower to the Upper Shallow Aquifer and the Upper Shallow Aquifer is hydraulically connected to Kelly Lake. Provide either 1) a revised conceptual model to better represent the current observed field conditions, a revised numerical model, its revised results and conclusions, and proposed changes to the FSAR Sections 2.4.12 and 2.4.13, or 2) a justification of why these inconsistencies between observations and model predictions do not make the model unreliable for these assessments.

Reference: "Groundwater Model Development and Analysis for STP Units 3&4", South Texas Project, U7-C-STP-NRC-080070, Attachment 2, by Bechtel Power, December 2008.

RESPONSE:

STPNOC Letter U7-C-STP-NRC-090146 (ML092710096), dated September 21, 2009, provided the initial response to RAI 02.04.12-33. STPNOC Letter U7-C-STP-NRC-090206 (ML093360350), dated November 30, 2009, provided a supplement to the response to RAI 02.04.12-33, which included the updated STP 3 & 4 numerical groundwater model summary report, "Groundwater Model Development and Analysis for STP Units 3 & 4," Bechtel Power Corporation, December 2008, Revised November 2009." STPNOC Letter U7-C-STP-NRC-100010 (ML100140408), dated January 11, 2010, provided the "Input and Output Files" used for the November 2009 update of the groundwater model. STPNOC Letter U7-C-STP-NRC-100031 (ML100560122), dated February 10, 2010, provided groundwater numerical model calculation files.

In response to NRC Request for Additional Information Letter No. 333, dated April 16, 2010 (ML101060021), a number of sensitivity analyses were performed on the numerical groundwater model. Although the resulting maximum water table in the STP 3 & 4 power block area and the radionuclide transport pathways for the STP 3 & 4 site predicted by the model were confirmed by the sensitivity analyses, some refinements of the model were made. These refinements were discussed in the response to RAI 02.04.12-40, which was provided by STPNOC Letter U7-C-STP-NRC-100195 (ML102450252), dated August 30, 2010.

Subsequent sensitivity analyses were conducted to address: 1) the effects of the spatially-biased residuals in the calibrated numerical model results and to assess the impact of spatial bias on predicted pathways (RAI 02.04.12-46); and 2) the effects that varying the proposed structural backfill hydraulic conductivity may have on groundwater levels beneath the power block (RAI 02.04.12-48). The results of the subsequent sensitivity analyses did not indicate a need to produce further model refinements.

A summary report of the updated STP 3 & 4 groundwater numerical model, "Groundwater Model Development and Analysis for STP Units 3 and 4," Bechtel Power Corporation, revised January 2011, is being provided in conjunction with this supplemental response. In addition, the Input and Output Files used in the January 2011 update of the groundwater numerical model are being provided in the enclosed digital versatile disk (DVD).

The following revisions to the STP 3 & 4 COLA will be made.

The first, third and fourth paragraphs from FSAR subsection 2.4S.12.3.4 will be revised as follows:

2.4S.12.3.4 Three-Dimensional Numerical Groundwater Flow Model

A three-dimensional, steady-state, numerical groundwater flow model was developed to better understand groundwater flow conditions at the north end of the site during pre-construction and post-construction of Units 3 & 4. This model is described in detail in Reference 2.4S.12-23. To assist in the modeling effort, 26 new observation wells were installed in pairs at 13 well clusters during July and August 2008, with one set within the Upper Shallow Aquifer and the other set within the Lower Shallow Aquifer. Each well was constructed and hydraulically tested similarly to the 28 observation wells that were installed during the 2006-2007 subsurface investigation. These new observation wells were installed along the north and northeast embankment of the MCR and toward the north and northeast property boundaries to obtain additional hydrogeologic information and reduce uncertainty associated with groundwater flow paths near the MCR, the proposed power block, and the east site boundary. Locations of the 26 new wells (OW-50U/L through OW-62U/L) are illustrated by Figure 9~~10~~ presented in Reference 2.4S.12-23. Water levels were measured in the new and existing observation wells in September and December 2008. The numerical model was calibrated to the data collected in September 2008.

As described in Reference 2.4S.12-23, the groundwater model uses seven layers to explicitly simulate three-dimensional flow in the Upper Shallow Aquifer (Stratum C), Lower Shallow Aquifer (Strata E and H), and intervening confining clay units (Strata A/B, D and F). The Stratum A/B constitutes two model layers (one and two) to reproduce the various building foundation depths at STP Units 1 & 2 using inactive (no-flow) cells. The numerical code MODFLOW 2000 developed by the U.S. Geological Survey was used to build, execute, and calibrate the model as implemented in the user-interface software Visual MODFLOW developed by Waterloo Hydrogeologic, Inc. (now owned by Schlumberger Water Services). The model was developed using available historic data and data collected during the 2006 to 2008 subsurface investigations, and by using various boundary conditions to simulate local streams, surface water bodies, and recharge. The calibrated model was used to simulate post-construction conditions that account for the presence of backfill material and slurry walls in the area of the new STP 3 & 4 structures. Within Visual MODFLOW, three-dimensional particle tracking flow paths were generated from the model output using MODPATH to simulate particle travel and groundwater pathways of potential liquid effluent releases from the power block area.

~~Results of the pre-construction particle tracking simulations shown in Figures 76 through 81 in Reference 2.4S.12-23 indicate that the postulated effluent release to groundwater of the Lower Shallow Aquifer (Strata E and H) within the power block area of STP 3 & 4 would move eastward through the Lower Shallow Aquifer and discharge to the Colorado River (Stratum E) or move southeastward through the Lower Shallow Aquifer towards the Colorado River (Stratum H). These results also indicate that a release to the Upper Shallow Aquifer (Stratum C) within the Power Block of STP 3 & 4, in pre-construction conditions, would flow to Units 1 & 2 and then down through the backfill at Units 1 & 2 to the Lower Shallow Aquifer (Stratum E) and discharge to the Colorado River.~~ To simulate pre-construction groundwater flow conditions, particles were placed around the proposed locations for Unit 3 and Unit 4 within model layers 3, 5 and 7, which represent Strata C, E and H, respectively, of the Shallow Aquifer. The results of the pre-construction particle tracking simulations are shown in Figures 56 through 61 in Reference 2.4S.12-23. These results indicate that groundwater flow from Unit 3 in Stratum C of the Upper Shallow Aquifer flows eastward within Stratum C until Units 1 & 2 are encountered. At this location, flow is then down through the backfill at Units 1 and 2 to Stratum E of the Lower Shallow Aquifer where the groundwater discharges to the Colorado River. Additionally, the pre-construction results show that groundwater flow within the Upper Shallow Aquifer from Unit 4 is to the west and remains within Stratum C. The results for the Lower Shallow Aquifer indicate that groundwater flow from each release point within Stratum E is eastward through Stratum E until it discharges to the Colorado River, and that groundwater flow from each release point within Stratum H is southeastward toward the Colorado River.

Figures 62~~84~~ through 67~~89 and 93 through 98~~ in Reference 2.4S.12-23 illustrate a ~~two~~ post-construction scenario~~s, one without and one~~ with proposed building foundations and excavation backfill, slurry walls around the main construction excavation, a shallower slurry wall around the main circulating water lines, ~~respectively~~ and two crane foundation retention walls, one adjacent to each proposed unit. To accommodate the varied keyed depths of these structures, the model layering was increased from seven to 10 layers by adding a layer to three of the intervening confining clay units. As in the pre-construction scenario, particles were placed around Units 3 & 4 within model layers 4, 7 and 10 now representing Stratum C, E and H, respectively, of the Shallow Aquifer. These particles represent locations for a postulated accidental release of liquid effluent to each of the three Shallow Aquifer layers. The post-construction p~~P~~article tracking results ~~for both scenarios~~ indicate that the particle ~~a~~ released within model layer 4 (Stratum C of ~~to~~ the Upper Shallow Aquifer) would migrate downward from the release points through the backfill at Units 3 & 4 to Stratum E of the Lower Shallow Aquifer and flow eastward past the site boundary until groundwater flow discharges to the Colorado River from Stratum E. The Both post-construction scenario results are similar for the Lower Shallow Aquifer to the pre-construction results for Strata E and H of the Lower Shallow Aquifer.

Reference 2.4S.12-23 in FSAR Subsection 2.4S.12.6 will be revised as follows:

2.4S.12-23 "Groundwater Model Development and Analysis for STP Units 3 & 4," Bechtel Power Corporation, December 2008, Revised November 2009 and January 2011.

A copy of "Groundwater Model Development and Analysis for STP Units 3 & 4," Bechtel Power Corporation, January 2011, is being submitted in conjunction with this response.

GROUNDWATER MODEL DEVELOPMENT AND ANALYSIS FOR STP UNITS 3 & 4

Bechtel Power Corporation
December 2008 (Rev. 0)
November 2009 (Rev. 1)
January 2011 (Rev. 2)

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Abbreviations

cm/s	centimeters per second
ft	feet
ft/day	ft per day
ft^3/s	cubic ft per second
gpm	gallons per minute
gpd/ft^2	gallons per day per square foot
bgs	below ground surface
btoc	below top of casing
dd mm ss	degrees-minutes-seconds (latitude and longitude)
%	percent

Acronyms

BCLOSE	Budget Closure Criterion
DAMP	Damping Factor
CFRW	Crane Foundation Retention Wall
COLA	Combined License Application
ECP	Essential Cooling Pond
FSAR	Final Safety Analysis Report
GAM	Groundwater Availability Model
GHB	General Head Boundary
HFB	Horizontal Flow Barrier
LAYCON	MODFLOW Layer Type
MCR	Main Cooling Reservoir
MSL	Mean sea level
MXCYC	Maximum Cycles
MXITER	Maximum Iterations
NED	National Elevation Database
NRC	Nuclear Regulatory Commission
NRMS	Normalized Residual Mean Squared
RAI	Request for Additional Information
RMS	Residual Mean Squared
RLRS	Relocated Little Robbins Slough
SAMG	Algebraic Multigrid Methods for Systems
SEE	Standard Error of the Estimate
STP	South Texas Project
STPEGS	South Texas Project Electrical Generating Station
STPNOC	South Texas Project Nuclear Operating Company
TWDB	Texas Water Development Board
UFSAR	Updated Final Safety Analysis Report
USGS	United States Geological Survey

EXECUTIVE SUMMARY

A groundwater flow model of the South Texas Project (STP) site was originally developed to support Commitments No. 6 and No. 8 for the Units 3 & 4 Combined License Application (COLA). The model is a three-dimensional representation of the Shallow Aquifer, using multiple layers to simulate flow in the Upper Shallow Aquifer (sand Stratum C) and Lower Shallow Aquifer (sand Strata E and H), and includes intervening confining clay layers. The model is 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, Inc.

Hydrostratigraphic layer elevations were developed from geotechnical borings drilled for Units 1 & 2 and Units 3 & 4 site explorations, from additional on-site borings and well logs, and from off-site wells logs downloaded from the Texas Water Development Board (TWDB) Groundwater Database (TWDB, 2008).

Hydraulic conductivity values are based on results from four historical on-site pumping tests in the Shallow Aquifer, from slug tests in the STP Units 3 & 4 observation wells, and from laboratory tests of clay and compacted structural backfill.

The interaction between surface water and groundwater is simulated by including in the model the Main Cooling Reservoir (MCR), the Essential Cooling Pond (ECP), the Colorado River, Kelly Lake, Little Robbins Slough, unnamed tributaries, drainage ditches, and levee-bound irrigation channels.

Spatially-variable groundwater recharge based on land use, vegetation, and surficial soil permeability is not considered due to the widespread and persistent surficial clay strata across the model domain. Consequently, direct recharge by precipitation within the model domain is not a significant factor affecting groundwater levels or flow paths.

The groundwater model is a steady-state flow model calibrated to site groundwater level data obtained September 22, 2008. The model was developed and refined in four stages. Revision 0 was the 2008 development of the model using site data collected prior to 2008. Revision 1 (Run 101) incorporated additional 2008 site hydrogeologic data. Revision 2 (model Run 201) was a 2009 model refinement to support the NRC's Request for Additional Information (RAI) question 02.04.12-33. The primary focus of Revision 2 was to examine the potential for hydraulic connection among surface water features located to the North and West of the MCR to refine the simulated groundwater potentiometric surface in the Upper Shallow Aquifer. Revision 3 (model Run 301) was developed to update the groundwater model based on a series of sensitivity analyses and model simulations completed in 2010 to address a set of NRC RAI questions (NRC RAI Letter No. 333) concerning the Revision 2 groundwater flow model.

For the response to Commitment No. 6, installation of new monitoring wells has demonstrated that water levels measured in Stratum C at Kelly Lake have water levels close to that of Kelly Lake, suggesting a potential hydraulic connection between surface water and groundwater.

For the response to Commitment No. 8, simulated groundwater level contours were included for post-construction conditions, accounting for the installation of slurry walls and for excavations through clay and sand strata in the Shallow Aquifer at the power block area, including the placement of structural backfill at Units 3 & 4. Particle tracking was included to identify the groundwater pathways for postulated accidental liquid effluent releases from STP Units 3 & 4.

Run 301 presents both pre- and post-construction Units 3 & 4 groundwater simulations. The post-construction model incorporates subsurface slurry walls and Crane Foundation Retaining Walls (CFRWs) that will be used to support excavation and construction of Units 3 & 4 facilities. The post-construction simulations also incorporate an upper bounding MCR stage level of 49.5 ft MSL, which is the elevation of the top of the MCR spillway slide gates when closed.

To determine pre-construction groundwater flow prior to the construction of Units 3 & 4, model simulations of groundwater flow and particle tracking were performed to predict pathlines for

particles released within each of the sand strata (Strata C, E, and H) at the site location were the units would be constructed. Pathlines for particles released at the proposed location of Unit 3 in Stratum C travel towards the southeast until entering the fill at Units 1 & 2 where they travel downward through the fill and around the building foundations to Stratum E before continuing eastwards past the site boundary to the Colorado River. The particles released in Stratum C at Unit 4 travel to the west through Stratum C to the STP western site boundary. Particles released in Stratum E of the Lower Shallow Aquifer for both units travel towards the east and southeast until intersecting the Colorado River. Particles released in Stratum H travel towards the southeast, following the direction of regional groundwater flow.

A post-construction scenario with slurry and CFRWs shows simulated water levels to be lower in the Upper Shallow Aquifer at Units 3 & 4 relative to simulated levels in the pre-construction model. Conversely, post-construction simulated water levels in the Lower Shallow Aquifer are higher at Units 3 & 4 relative to levels simulated in the pre-construction model. This is due to the removal and replacement of a portion of the confining layer that separates the Upper and Lower Shallow Aquifers with structural fill to represent the Units 3 & 4 construction excavation. The structural fill, which is of higher hydraulic conductivity than the confining layer it replaces, creates a greater degree of hydraulic connection between the Upper and Lower Shallow Aquifers. This enables the Upper Shallow Aquifer to contribute water to the Lower Shallow Aquifer. The maximum elevation of simulated groundwater head at STP Units 3 & 4 at steady state conditions remained below the previously defined site characteristic maximum groundwater elevation of 28 feet MSL.

The post-construction particle tracking (representing groundwater flow) indicates movement to the east and southeast from STP Units 3 & 4 based on simulated groundwater flow in the model. Particles released adjacent to the Units 3 & 4 proposed radwaste and reactor building locations travel downward through the power block excavation backfill to Stratum E of the Lower Shallow Aquifer. The particles then travel in an east to southeast direction within the Lower Shallow Aquifer to the eastern site boundary

Sensitivity analyses were performed to evaluate the sensitivity of groundwater head and particle tracking pathways to: 1) general head boundaries and drain boundaries; 2) backfill hydraulic conductivity; 3) infiltration rates at the proposed STP Units 3 & 4; 4) MCR relief well failures; and 5) effect of groundwater head spatial bias residuals. Further, the plausibility that the bias may result in the elimination of a southwesterly particle pathway from the STP Units 3 & 4 was evaluated. The sensitivity analyses showed that the maximum groundwater head at STP Units 3 & 4 for steady state conditions remained below the previously identified maximum groundwater elevation of 28 ft MSL. Similarly, particle tracking for these post-construction sensitivity model runs did not show evidence of a southwesterly pathway from the STP Units 3 & 4; groundwater pathways were east to southeast to the STP site boundary.

1. OBJECTIVE & SCOPE

The objective of this report is to document the development, calibration, and simulation results of a groundwater flow model for the Shallow Aquifer at the South Texas Project (STP) site.

The model was originally developed to support STP commitments for U.S. Nuclear Regulatory Commission (NRC) docketing and acceptance review of the COL Application for STP Units 3 & 4 (STPNOC, 2007 and 2008). Subsequently, the model was revised to support responses to the NRC's Request for Additional Information (RAI) Letter No. 202, dated August 5, 2009, including the response to RAI 02.04.12-33 (STPNOC, 2009), and responses to RAI Letter No. 333, dated April 16, 2010 (STPNOC, 2010).

The model was initially developed in July through September 2008. Additional development occurred during October through November 2008, October through November 2009, and October through December 2010. The purpose of the most recent period of development was to provide support for the responses to RAI Letter No. 333, primarily RAI 02.04.12-38, through -40, RAI 02.04.12-43 through -46, and RAI 02.04.12-48 through -50 (STPNOC, 2010) by revising the model based on a series of analyses and model simulations completed in December 2010. The analyses evaluated model bias and potential boundary constrictions, and demonstrates that the model simulation does not result in a post-construction southwest transport pathway from Units 3 & 4 and does not constrain the predicted water level beneath Units 3 & 4.

Based on the model analyses and simulations, model bias was found, particularly water levels above layer 1 ("flooded cells"), and remedied in this revision (model Run 301). The resulting simulation for the new base model, Run 301, reflects the necessary changes implemented to adequately resolve the issue of water levels above layer 1 and the implementation of recharge directly to layers representing the Upper Shallow Aquifer. Other model changes include a revision to the representation of the MCR to be restricted to layer 1 to prevent potential overestimation of seepage from "stacked" river and constant head boundaries. In addition, changes to the proposed power block construction, such as inclusion of CFRWs and depths of penetration of the slurry wall that will surround the Units 3 & 4 power block area were implemented in the post-construction run, Run 301PC. The changes made to Run 301 confirm the post-construction simulation results for maximum groundwater table elevations and pathways produced by the previous model revision (model Run 201). During all periods of model development, a three-dimensional multiple-layer groundwater model was used to simulate groundwater flow in the Shallow Aquifer.

2. AQUIFER DESCRIPTION & AVAILABLE DATA

2.1 Site Overview

The 12,220-acre STP site is located in the coastal plain of southeastern Texas in Matagorda County (Figure 1). The power station lies approximately 10 miles north of Matagorda Bay. The 7,000-acre MCR is the predominant feature at the STP site. The reservoir is fully enclosed with a compacted earth embankment, and it encompasses the majority of the southern and central portion of the site. The existing facilities for STP 1 & 2 are located outside of the MCR northern embankment. Planned STP 3 & 4 are to be located further north of the embankment and northwest of STP 1 & 2.

The STP site, in general, has less than 15 ft of natural relief in the 4.5-mile distance from the northern to southern boundary (Figure 1). The Colorado River flows along the southeastern site boundary. There are also several unnamed drainages within the site boundaries, one of which feeds Kelly Lake (Figure 2). Figure 2 shows the topography and hydrologic features within about 3 miles of the site based on digital data from the U.S. Geological Survey (USGS, 2009). Figure 3 shows the existing (pre-development) topography of the site in more detail based on aerial survey data (P2 Energy Solutions/Tobin, 2007).

The elevation planned for STP 3 & 4 is 34 ft mean sea level (MSL). Existing ground surface elevations at STP 3 & 4 range from about 32 ft to 34 ft MSL. The excavation for the reactor building will extend to an elevation of approximately -60 ft MSL, which is approximately 94 ft below proposed rough grade (STEPGS, 2010). Foundations in general for STP 3 & 4 safety-related structures will be placed on in-situ soil or concrete fill, with the exception of the Diesel Fuel Oil Storage Tank Vaults and the Reactor Service Water Tunnels, which will be placed on structural fill. Nonsafety-related structure foundations will be placed on structural fill.

2.2 Regional Hydrostratigraphy

As discussed in the STP 3 & 4 FSAR Subsection 2.4S.12 (STPEGS, 2010), the STP site is located within the Gulf Coastal Plains physiographic province and overlies the Coastal Lowland Aquifer System (also called the Gulf Coast Aquifer in Texas). This aquifer system is composed of sand, silt, and clay deposited in several depositional environments: continental (alluvial plain), transitional (delta, lagoon, and beach), and marine (continental shelf). The deposits thicken towards the Gulf of Mexico, resulting in wedge-shaped hydrogeologic units. The major units comprising this system include the Chicot Aquifer, Evangeline Aquifer, Burkeville Confining Unit, Jasper Aquifer, Catahoula Confining Unit, and Vicksburg-Jackson Confining Unit. The Chicot Aquifer extends to a depth of greater than 1,000 ft in the vicinity of the STP site. The Chicot Aquifer is comprised of Holocene alluvium in river valleys and Pleistocene age Beaumont, Montgomery, and Bentley Formations, and the Willis Sand.

The Beaumont Formation consists of fine-grained mixtures of sand, silt, and clay deposited in alluvial and deltaic environments. In the upper portion of the Beaumont Formation, sands occur as sinuous bodies, representing laterally discontinuous channel deposits, while the clays and silts tend to be more laterally continuous, representing their deposition as natural levees and flood deposits. The deeper portion of the Beaumont Formation is more than 250 ft below ground surface (bgs) at the STP site and includes thicker and more continuous sands. The Holocene alluvium of the Colorado River occurs in a relatively narrow band along the river. Because the alluvial materials are deposited in a channel incised into the Beaumont Formation, it is expected that the Holocene alluvium is in contact with the shallow aquifer units of the Beaumont Formation.

At the STP site, the Chicot Aquifer is divided into two aquifer units, the Shallow Aquifer and the Deep Aquifer, with the Shallow Aquifer overlain by a confining layer, and with the Shallow and Deep Aquifers separated by another confining layer. Figure 4 provides a hydrostratigraphic column for the STP site.

The base of the Shallow Aquifer is approximately 90 ft to 150 ft bgs in the site area. The Shallow Aquifer has limited production capability and is used for livestock watering and occasional domestic use (STPEGS, 2010). The Deep Aquifer is the primary groundwater production zone and lies below depths of approximately 250 ft to 300 ft. A zone of predominantly clay, usually greater than 150 ft thick, separates the Shallow and Deep Aquifers.

The Shallow Aquifer is divided into upper and lower zones over the STP site. Both zones respond to pumping as confined or semi-confined aquifers with different potentiometric heads. The Upper Shallow Aquifer is comprised of sand layers to depths of approximately 50 ft bgs. The Lower Shallow Aquifer consists of sand layers between depths of approximately 50 ft to 150 ft bgs.

Groundwater flow is, in general, southeasterly from recharge areas where the sand layers outcrop at the surface, to discharge areas that are primarily either the Colorado River or the Gulf of Mexico. The outcrop areas for the Beaumont Formation sands are in northern Matagorda County (Shallow Aquifer) and Wharton County (Deep Aquifer) to the north of Matagorda County.

2.3 Confined Shallow Aquifer

The Shallow Aquifer at the STP site consists of interbedded sand, clay, and silt, as shown in these cross sections:

- Figure 5: Hydrogeologic Cross Section at STP 3 & 4
- Figure 6: Stratigraphic Cross Section at STP 3 & 4
- Figure 7: Stratigraphic Cross Section at STP 1 & 2
- Figure 8: Stratigraphic Cross Section at North Embankment of MCR

The hydrogeologic units correspond to the geotechnical soil units shown in Figure 5 through Figure 8 as follows:

- Confining layer – Stratum A of silty clay and Stratum B of clayey silt.
- Upper Shallow Aquifer – Stratum C of silty sand.
- Confining layer – Stratum D of silty clay.
- Lower Shallow Aquifer – Stratum E of sand and Stratum H of silty sand, interbedded with discontinuous intervening Stratum F of silty clay. Beneath a portion of Unit 1, the Lower Shallow Aquifer includes Stratum G of silty sand interbedded with Strata F1 and F2 of silty clay.

The base of the Shallow Aquifer coincides with the top of Stratum J, which is the confining layer for the Deep Aquifer. STPEGS, 2010 identifies Strata F, H, and J as comprising the confining layer between the Shallow Aquifer and the Deep Aquifer, but for the purpose of this modeling calculation, Strata F and H are considered part of the Shallow Aquifer. This is based in part on similar water levels measured in Strata E and H, and in part on localized absence of Stratum F, for example as shown in Figure 6.

Elevation contours for the top of Strata A through H in the power block area are presented in STPEGS 2010; Section 2.5S.1.

2.4 Site Groundwater Levels

Regional potentiometric surface maps are not available for the Shallow Aquifer primarily because of the limited concern for the aquifer due to its sparse regional use for water supply.

Water level data for the STP site are available for the following wells and piezometers in the Shallow Aquifer (Bechtel, 2010):

- Quarterly measurements for March, June, September, and December 2008 for observation wells at STP 3 & 4, for several MCR piezometers, and for several STP 1 & 2 piezometers
- Monthly measurements between December 2006 and December 2007 for observation wells at STP 3 & 4
- STP 1 & 2 piezometers, with water level measurements between January 1980 and December 1995

- MCR piezometers, with water level measurements between January 1985 and August 2004

Figure 9 shows locations of observations wells and piezometers with measurements between December 2006 and September 2008.

The Upper Shallow Aquifer groundwater flow direction in the vicinity of STP 3 & 4 is generally toward the southeast (STPEGS, 2010). There is also an apparent southerly flow direction along the west side of the MCR. This southerly flow direction may be influenced by the leakage from the MCR or by operation of the MCR relief wells. In the Lower Shallow Aquifer, the flow direction is generally easterly in the vicinity of STP 3 & 4, and then turns southeasterly near the eastern edge of the site. Both the Upper and Lower Shallow Aquifer flow directions are consistent with flow toward the Holocene alluvium in the Colorado River floodplain.

Well pairs screened in the Upper and Lower Shallow Aquifer indicate a consistent downward gradient for water level measurements in STP 3 & 4 observation wells, with a head difference between the two aquifers ranging from approximately 3 ft to 11 ft (STPEGS, 2010). Installation of new STP 3 & 4 groundwater observation wells in 2008 demonstrated that water levels measured in the Upper Shallow Aquifer at Kelly Lake have water levels close to that of Kelly Lake, suggesting a potential hydraulic connection between surface water and groundwater. It is also possible that Kelly Lake is fed by groundwater due to the observed upward gradient between the Upper and Lower Shallow Aquifer in the vicinity of Kelly Lake. This upward gradient is only observed at Kelly Lake; across the remainder of the STP site a consistent downward gradient is observed between the two aquifers.

2.5 Surface Water

Surface water within the STP site includes the following:

- Essential Cooling Pond (ECP) – The STP 1 & 2 ECP is located east of the STP 1 & 2 power block area (Figure 3). The water level in this pond is 26 ft MSL (STPEGS UFSAR; Subsection 2.4.13.2.3). Seepage from the ECP is estimated to be 0.11 cubic ft/second (49 gallons/minute) based on a 3-month water balance study in 1986, when the pond was filled to normal operating level of between 25.6 ft to 26 ft MSL, and using median estimate for evaporation of 0.51 cubic ft/second (Bechtel, 1987).
- Kelly Lake – The lake is located southeast of the power block areas outside the northeastern corner of the MCR (Figure 2), with a water surface elevation of about 11 ft MSL (USGS, 1972).
- MCR – The 7,000-acre MCR is located south of the power block area with a normal maximum operating level of 49 ft MSL (STPEGS, 2010). Discharge from the MCR to the Shallow Aquifer occurs primarily through the reservoir floor. Seepage from the reservoir is estimated to be 3,530 gallons/minute (STPEGS UFSAR; Subsection 2.4.13.3.2.3). This seepage includes (a) flow collected by relief wells (and presumably vertical sand drains) that is discharged to the MCR toe drainage ditch, and (b) flow that is not captured by relief wells or vertical sand drains and continues down gradient.
- The Texas Prairie Wetlands Project Area or "duck pond" – This area is located northeast of the Units 2 & 2 power block area (Figure 3), and is periodically flooded to enhance wildlife habitation.
- Little Robbins Slough, unnamed tributaries, and drainage ditches – Storm water run-off within the STP site flows into drainage ditches, Little Robbins Slough (Figures 2 and 3), and unnamed tributaries, and is not regularly contained by any basins within the STP site. Where Little Robbins Slough has been relocated around the west side of the MCR, it is referred to as the Relocated Little Robbins Slough (RLRS).

- Colorado River – The eastern boundary of the STP site coincides with the Colorado River (Figure 2).
- Levee-bound irrigation ditches – these features are noted on USGS quadrangles to operate on the siphon irrigation design. They are assumed to contain diverted surface water maintained at or above adjacent land surface to operate the siphon system. This could act as a source of water to the Upper Shallow Aquifer considering the levees are likely constructed from material excavated from Stratum A/B, thus exposing the top of the aquifer along the channel bed.

2.6 Net Infiltration

The net infiltration, or groundwater recharge, accounts for the rate of net gain of the groundwater system resulting from surface infiltration. Recharge of aquifers along the Gulf Coast occurs mainly in outcrop areas of sand units in upland areas. Recharge is low through the Beaumont Formation clay (Chowdhury et al., 2004). Several investigators have estimated recharge rates for the Gulf Coast Aquifer, as summarized in Table 1. The Groundwater Availability Model (GAM) for the Central Gulf Coast (Chowdhury et al., 2004) indicates recharge rates ranging from 0.06 to 0.09 inch/year. The Climate Division Texas-08 (Upper Coast), which includes the STP site, receives an average annual precipitation of 50.31 inches for the period from 1971 through 2000 (STPEGS, 2010). The recharge rates in the Central Gulf Coast GAM are equivalent to 0.12% to 0.17% of annual precipitation (Waterstone Environmental Hydrology and Engineering, Inc., 2003).

Figure 10 indicates the major recharge sand zones in orange for the Coastal Plain Aquifer in Matagorda County and beyond. The presence of an extensive clay confining layer (Stratum A) in the vicinity of the STP site suggests minor or negligible groundwater recharge in that vicinity, and is expected to be less than the regional recharge rate estimated by the Central Gulf Coast GAM. The value of groundwater recharge over the model domain used in this model report is 0.001 inches per year and is applied directly to the model layer representing the Upper Shallow Aquifer to reflect the distant secondary sand recharge zones (shown in olive-brown) that may lie between the major recharge areas and the model domain.

2.7 Hydraulic Conductivity

The following sections describe the results from pumping tests, slug tests, and laboratory tests to evaluate hydraulic conductivity for the Shallow Aquifer.

2.7.1 Pumping Tests

Aquifer pumping tests in the Shallow Aquifer have been performed in four test wells located on the STP site as indicated on Figure 11 (Woodward-Clyde Consultants, 1975). Table 2 provides additional details of the pumping tests. Additionally, five short duration (6 to 8 hour pumping period) aquifer pumping tests were conducted in the Upper Shallow Aquifer in five MCR relief wells during the construction and filling of the MCR. These tests, due to their short duration and the boundary influences of MCR filling, were not presented or used in the groundwater evaluations because they do not provide representative properties of the Upper Shallow Aquifer.

Pumping test results are summarized as follows:

- Test well WW1 (Strata E and H) – Two pumping tests performed at this well located near the southeast corner of the MCR indicate a hydraulic conductivity of 0.019 cm/s for the Lower Shallow Aquifer. The radius of influence was about 1.1 miles after 4,000 minutes. The 80-ft test interval appears to include Strata E and H with Stratum F absent. Piezometers in the Upper Shallow Aquifer and in the confining clay (Stratum D) indicate no hydraulic connection between the Upper and Lower Shallow Aquifers.
- Test well WW2 (Stratum E) – Two pumping tests performed at this well located near the southeast corner of the STP 1 & 2 power block area indicate an average hydraulic conductivity of 0.03 cm/s for the Lower Shallow Aquifer. The radius of influence was

about 1 mile after 17,000 minutes in the second pumping test. Strata E and H are possibly hydraulically connected at 2,000 to 3,000 ft south of the test well. Piezometers monitored in the Upper Shallow Aquifer indicated no response.

- Test well WW3 (Stratum C) – This pumping test is located adjacent to test well WW2 near the southeast corner of the STP 1 & 2 power block and indicates a hydraulic conductivity of 0.0031 cm/s for the Upper Shallow Aquifer. The radius of influence was about 500 ft after 1,300 minutes.
- Test well WW4 (Stratum C) – This pumping test is located near the southwest corner of the MCR and indicates a hydraulic conductivity of 0.02 cm/s for the Upper Shallow Aquifer, depending on how the data is analyzed (early time versus late time because of non-uniform thickness). The radius of influence was about 600 ft after 2,750 minutes. An overlying sand layer joins the tested interval sand at about 250 ft north of the test well, but test data show thinning of the tested interval near the radius of influence. A piezometer in the Lower Shallow Aquifer (Stratum E) indicates it is not in hydraulic communication with the tested interval. STPEGS, 2010, Subsection 2.4S.12.2.5, indicates a localized hydraulic connection between the Upper and Lower Shallow Aquifers. However, based on the elevation corresponding to Stratum E in Figure 3.4-6 of the pumping test report (Woodward-Clyde Consultants, 1975), the Lower Shallow Aquifer showed no response and no connection with the Upper Shallow Aquifer test zone and therefore, the degree of communication between the tests zones is considered unknown.

2.7.2 Slug Tests

During the 2006, 2007, and 2008 subsurface investigations for STP 3 & 4, slug tests were performed in 28 observation wells in the Upper Shallow Aquifer and 26 observation wells in the Lower Shallow Aquifer. As summarized in Table 3, the test results indicate a range of hydraulic conductivity from 0.0004 cm/s to 0.06 cm/s. The geometric mean hydraulic conductivity for the Upper Shallow Aquifer (Stratum C) is 0.005 cm/s. The geometric mean hydraulic conductivity for Stratum E in the Lower Shallow Aquifer is 0.009 cm/s (including OW-308L and OW-332L, which are screened in both Strata E and H because clay Stratum F is absent at those locations). The geometric mean hydraulic conductivity for Stratum H in the Lower Shallow Aquifer is 0.005 cm/s. The geometric mean hydraulic conductivity of 0.005 cm/s for slug tests in the Upper Shallow Aquifer is greater than the pumping test result of 0.003 cm/s at test well WW3 near STP 1 & 2. The geometric mean hydraulic conductivities of 0.009 and 0.005 cm/s for slug tests in Strata E and H, respectively, of the Lower Shallow Aquifer are less than the pumping test result of 0.03 cm/s at test well WW2 near STP 1 & 2.

2.7.3 Laboratory Tests

Table 4 summarizes laboratory test results for six samples of clay from Strata A, B, and D, collected at depths between 3 ft and 39 ft during the investigation for STP 1 & 2. The hydraulic conductivity for samples from Strata A and B range from 2×10^{-8} cm/s to 2×10^{-6} cm/s, with a geometric mean of 2×10^{-7} cm/s. The hydraulic conductivity for one sample from Stratum D is 4×10^{-8} cm/s.

Table 4 also includes laboratory test results for two samples of compacted clay from the ECP. The average hydraulic conductivity is 5×10^{-5} cm/s. Also included in Table 4 are laboratory results for two compacted samples of structural backfill for STP 1 & 2. The hydraulic conductivities range from 0.002 to 0.003 cm/s.

2.8 Water Wells

No water supply wells are screened in the Shallow Aquifer within the STP site. Livestock wells and occasional domestic supply wells are located in Matagorda County beyond the STP site. The nearest water well in the Shallow Aquifer is #2004120846, which is an 80-ft deep livestock well. This well is estimated to yield about 200,000 gallons per year (STPEGS, 2010; Subsection 2.4S.12.3.1), or about 0.4 gallons per minute (gpm).

3. MODEL DEVELOPMENT

3.1 Conceptual Hydrogeologic Model

Based on the aquifer description in Section 2.3, the Shallow Aquifer is conceptualized as consisting of three sand strata (Strata C, E, and H) and three confining strata (Strata A/B, D, and F). The top of clay Stratum J forms the bottom of the Shallow Aquifer. The significant thickness of Stratum J, which separates and confines the Lower Shallow Aquifer and the Deep Aquifer, is expected to allow negligible vertical flow between the aquifers. This negligible vertical flow would not have a significant effect on flow paths in either aquifer.

Primary recharge to the Shallow Aquifer occurs in upland outcrop areas of the aquifer layers and along rivers in their upper reaches. Surface water recharge within the STP site is expected mainly from leakage out of the MCR. Minor recharge may occur from infiltration of precipitation and irrigation water (after evapotranspiration losses), and from storm water run-off and irrigation return water collected in drainage ditches, unnamed tributaries, and Little Robbins Slough. However, the majority of the model area is covered by a surficial clay layer. Recharge through this clay is expected to be insignificant across most of the model domain.

Localized areas where this clay cover is absent, and where localized recharge to the Shallow Aquifer may occur, include structural backfill at the STP 1 & 2 power block, sand borrow pits within the MCR (where the confining clay has been excavated), a portion of RLRS, and within the Colorado River channel. Portions of the levee-bound irrigation channels to the north and west of the MCR may be hydraulically connected with the Upper Shallow Aquifer. The degree of connection among various irrigation channel segments and the Upper Shallow Aquifer is examined as part of model calibration. The ECP is clay-lined and leakage from this pond to the Upper Shallow Aquifer is expected to be minor.

Discharge from the Shallow Aquifer occurs to the Colorado River, to relief wells and vertical sand drains around the perimeter of the MCR, and at a few shallow water wells outside the STP site used for livestock. Minor upward discharge may occur to wetlands, but because the surficial confining clay layer is commonly present, this discharge is expected to be negligible. Drainage ditches and unnamed tributaries are generally not sufficiently deep to have direct hydraulic connection with the Upper Shallow Aquifer. However, a portion of the RLRS is hydraulically connected with the Upper Shallow Aquifer along the southwest side of the MCR. Portions of Little Robbins Slough and plant area drainage ditches to the north and west of the MCR may also be hydraulically connected with the Upper Shallow Aquifer. The degree of connection for several slough and ditch segments is assessed as part of model calibration. The Colorado River channel has been incised into the Shallow Aquifer. This incised river channel and the possible presence of Holocene alluvium in the incised river channel are expected to create a direct hydraulic connection between the river and the Shallow Aquifer.

The model domain was selected to minimize the impact of assumptions regarding boundary conditions at model sides on prediction of flow paths originating within the STP 3 & 4 power block area. The boundaries of the model domain were placed where reasonable assumptions regarding local conditions could be made. Figure 12 shows the model domain. The model area extends several miles beyond the STP site. From STP 3 & 4, the model extends about 2 miles to the north, 3 miles to the east (to the Colorado River), 7 miles to the south, and 3 miles to the west. The model covers a total area of 44,000 ft by 44,000 ft (about 69 square miles).

The northern model boundary coincides with an upland area at a ground surface elevation of about 30 to 35 ft MSL between the Colorado River and the Tres Palacios River. The eastern model boundary extends to the Colorado River, which has a stage at elevation of about 0 to 5 ft MSL. The southern model boundary is about 2.5 miles south of the MCR and coincides with a lowland area at a ground surface elevation of about 0 ft to 10 ft MSL approaching Matagorda Bay. The western model boundary extends to the Tres Palacios Bay and River which is about 5 miles beyond available water level data for the Shallow Aquifer.

3.2 Numerical Model

The conceptual hydrogeologic model is developed into a three-dimensional multiple-layer numerical groundwater model using the code MODFLOW-2000 (Harbaugh et al., 2000).

3.2.1 Numerical Code

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 (McDonald and Harbaugh, 1984 and 1988).

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 a major revision of the code that expands upon the modularization approach that was originally included in MODFLOW.

The modeling pre-processor Visual MODFLOW (Schlumberger Water Services, 2009) is used to facilitate the development of the STP groundwater flow model. Visual MODFLOW was developed by Waterloo Hydrogeologic Inc., which is now owned by Schlumberger Water Services.

3.2.2 Numerical Solver

The Algebraic Multigrid Methods for Systems (SAMG) solver in Visual MODFLOW was used to solve the equations for the STP model. This solver uses various settings to achieve convergence that include Maximum Iterations (MXITER), Maximum Cycles (MXCYC), Budget Closure Criterion (BCLOSE) and Damping Factor (DAMP). For highly nonlinear conditions such as models that use non-confined layer settings (LAYCON 1 or 3) with a large amount of river and drain boundaries, reducing the default values for the MXCYC and DAMP settings usually provides convergence (Schlumberger Water Services, 2009). Model Run 301 uses the default values for this solver.

3.2.3 Model Grid

Figure 12 and Figure 13 show the model grid for the model domain and for the power block vicinity, respectively. The model grid spacing is 20 ft within the plant area for planned STP 3 & 4. The grid spacing is 50 ft around the MCR perimeter and across the remainder of the STP site. The grid spacing increases beyond the STP site boundary to a maximum spacing of 2,000 ft. The relatively fine grid of 20 ft to 50 ft is selected to accurately model: (a) the thickness and extent of structural fill for STP 1 & 2 and for STP 3 & 4; and (b) the locations and spacing of MCR relief wells and vertical sand drains around the embankment perimeter, particularly where wells and drains are not closely-spaced and MCR seepage might not be fully captured.

3.2.4 Model Layers

The model is bounded by the ground surface on top and the top of Stratum J at the model bottom. The ground surface used in the model is based on aerial topographic data for the STP site (P2 Energy Solutions/Tobin, 2007) and USGS National Elevation Database (NED) data for the area outside the STP site (USGS, 2009). The ground surface elevations inside the MCR are based on digitized elevation contours from preconstruction USGS topographic sheets, with adjustments for estimated depths of clay borrow pits and sand pits (see further discussion in Subsection 3.3.2.2). Figure 14 shows the areas of the model with different sources of elevation information.

Seven model layers are included in the pre-construction Run 301 scenario as follows:

- Model Layer 1 – Strata A and B, predominantly clay and silt
- Model Layer 2 – Strata A and B, predominantly clay and silt
- Model Layer 3 – Stratum C, predominantly sand; referred to as the Upper Shallow Aquifer
- Model Layer 4 – Stratum D, predominantly clay
- Model Layer 5 – Stratum E, predominantly sand, referred to as the Lower Shallow Aquifer
- Model Layer 6 – Stratum F, predominantly clay
- Model Layer 7 – Stratum H, predominantly sand, also referred to as the Lower Shallow Aquifer

Two layers are used in the pre-construction model to represent the combined Strata A and B in order to permit the assignment of different foundation depths for Units 1 & 2 structures. All other strata are represented in the pre-construction model with a single layer.

For the post-construction scenario (Run 301PC), model layer 2 (Stratum A/B), model layer 4 (Stratum D), and model layer 6 (Stratum F) were split to facilitate the definition of various proposed slurry wall, CFRW, building foundation and structural fill depths in the Units 3 & 4 area of the model. The resulting 10 model layers included in the post-construction model are:

- Model Layer 1 – Strata A and B, predominantly clay and silt
- Model Layer 2 – Strata A and B, predominantly clay and silt
- Model Layer 3 – Strata A and B, predominantly clay and silt
- Model Layer 4 – Stratum C, predominantly sand; the Upper Shallow Aquifer
- Model Layer 5 – Stratum D, predominantly clay
- Model Layer 6 – Stratum D, predominantly clay
- Model Layer 7 – Stratum E, predominantly sand, the Lower Shallow Aquifer
- Model Layer 8 – Stratum F, predominantly clay and silt
- Model Layer 9 – Stratum F, predominantly clay and silt
- Model Layer 10 – Stratum H, predominantly sand, the Lower Shallow Aquifer

Figure 15 through Figure 21 show shaded elevation contour maps for the top of the various model layers, and for the model bottom elevation. Elevations are assigned to each model cell based on the results of the SURFER (Golden Software, Inc., 2002) gridding of stratigraphic picks. Figure 22 through Figure 24 show cross sections of the model layers.

3.2.5 Boundary Conditions

The STP model incorporates several types of boundary conditions including constant head, river, recharge, drain, general-head, and no-flow. Figure 25 and Figure 26 show boundary conditions for each model layer with assigned boundary conditions. A brief description of boundary conditions as they are used in the STP model is provided below:

- <u>River Boundary – (1) Main Cooling Reservoir, (2) Essential Cooling Pond, (3) Kelly Lake and (4) levee-bound irrigation ditches:</u> The river boundary condition allows leakage into the model or leakage out of the model based on: (1) specified surface water elevation; (2) simulated groundwater elevations in adjoining grid cells; and (3) soil conductance at the bottom of the reservoir, pond, or lake. River cells are utilized inside the MCR at model cells that are not already assigned as constant head boundaries. River cells are employed in lieu of constant head cells to allow flexibility to adjust the conductance between the reservoir, pond, or lake, and the subsurface during calibration. Figure 25 shows locations of river cells in the model that represent these four surface water features in Stratum A/B (model layers 1 and 2), and Figure 26 shows these four surface water features in Stratum C (Run 301 model layer 3). Figure 25 and Figure 26 show the levee-bound irrigation ditches that are identified as potential sources of water to the Upper Shallow Aquifer.

- <u>Constant Head Boundary – (1) Colorado River, and (2) Sand Borrow Pits in MCR:</u> The constant head boundary condition fixes the groundwater level in grid cells coinciding with locations where alluvial sand beneath the Colorado River channel is expected to be in direct hydraulic connection with the Upper Shallow Aquifer or Stratum C (Run 301, model layer 3), and at locations of two sand borrow pits within the MCR where material excavation for MCR construction extends into Stratum C. The constant head condition at the Colorado River allows groundwater discharge from the Shallow Aquifer to the river. The constant head condition within the MCR allows leakage from the reservoir into the Shallow Aquifer. The specified head is based on river surface elevation and MCR operating elevation. Figure 26 shows the locations of constant head cells in model layer 3 representing the Colorado River.

- <u>Recharge Boundary – Model Layer 1:</u> The recharge boundary condition is applied to the model layer corresponding to Stratum C (Run 301, model layer 3) to simulate the effect of recharge from distant updip outcrop locations. A plausible range of recharge rates was estimated prior to modeling.

- Drain Boundary – (1) Drainage Ditches and all of Little Robbins Slough, and (2) MCR Perimeter Relief Wells and Vertical Drains: The drain boundary condition represents locations where groundwater discharges to the ground surface. When the simulated groundwater level reaches the ground surface elevation (drain elevation), water is removed by the drain boundary. The drain has no effect on model flow when the simulated head is below the drain elevation. The rate of discharge from the model is equal to the drain conductance multiplied by the head difference between the drain elevation and the simulated groundwater level in the drain cell. Drain conductances are estimated during model calibration.

  Figure 25 shows locations of drain boundaries in Run 301, model layers 1 and 2 to represent drainage ditches and Little Robbins Slough. Figure 26 shows lines of drain cells representing the re-located portion of Little Robbins Slough, ditches to the west and north of the MCR, and the MCR relief wells, and sand drains in Run 301, model layer 3. MCR relief wells and the sand drains are grouped into individual drain lines according to spatial location and well top elevations. This simplifies the use of drain conductance as a calibration parameter for the relief well drains and to aggregate individual relief wells into groups while still maintaining the non-contiguous perimeter coverage of the relief wells.

- General-Head Boundary – Model Sides: General-head boundary conditions are assigned for the sand layers along the four sides of the model, to represent the influence of groundwater flow conditions beyond the model area. Flow through the north model side is influenced by aquifer recharge in the outcrop area beyond the model area. Flow through the south model side is influenced by Matagorda Bay and the Gulf of Mexico. Flow through the west model side is possibly influenced by Tres Palacios Bay, but this is uncertain. Flow through the east model side is influenced by the Colorado River. General-head conditions are estimated using the distance and head at the hydrologic feature beyond the model area, although the boundary cell conductance may be adjusted during model calibration. Figure 26 shows locations of the general-head boundaries for layers corresponding to Strata C, E, and H (e.g. Run 301, model layers 3, 5, and 7).

- No-Flow Boundary – (1) Clay Layers at Model Sides, (2) Bottom of Model, and (3) Area East of Colorado River: (1) The clay layers at the model sides are designated no-flow boundaries because horizontal flow through these clay layers will be insignificant compared to flow through the sand layers (also, this boundary condition will not constrain the calculation of vertical leakage across the clay layers). (2) The bottom of the model (top of Stratum J) is designated a no-flow boundary because water levels in the Shallow Aquifer are expected to be negligibly affected by small downward leakage (relative to much larger horizontal flow in sand layers) because of the significant cumulative thickness of clay between the Shallow Aquifer and the Deep Aquifer. (3) An area of inactive cells in the model on the east side of the Colorado River creates a default no-flow boundary, which is appropriate to simulate a hydraulic divide for the Shallow Aquifer, where groundwater flow toward the river discharges into the river. However, this area of inactive cells is only assigned to layers corresponding to Strata A, B, and C (i.e., Run 301, model layers 1 through 3) because it is believed the Colorado River is incised at least to Stratum D based on a comparison of surface and subsurface elevation interpretations (see Subsection 3.3.2.2). Additionally, inactive cells are used to represent the building footprints and foundations of Units 1 & 2.

- Water Well Boundary – Domestic or agricultural extraction wells located within the model domain are designated as pumped wells in the model and groundwater is extracted from the model from the corresponding cell(s). An 80-ft deep livestock well

(Well 2004120846) is located east of STP site (STPEGS, 2008) and is the only domestic/agricultural well represented in the model.

3.3 Assumptions

The model development includes the assumptions described below.

3.3.1 Hydrostratigraphic Units

The hydrostratigraphic units in the vicinity of the STP 3 & 4 power block area are assumed to be represented as continuous, relatively flat layers. The rationale for this assumption is shown in Figure 5 and Figure 6, which illustrate the interpreted hydrogeology and stratigraphy, respectively, at the Units 3 & 4 site. A laterally continuous relationship among sands observed in on-site boreholes is reasonable as shown in these two figures. The hydrostratigraphic representation with relatively flat, continuous layers provides a geometrically, simple relationship among observed sands. The thickness of the sands in the model varies as observed in on-site boreholes.

Geotechnical Strata A and B are assumed to be combined into one hydrogeologic confining unit in the model (Stratum A/B). (The Stratum A/B unit is represented with two model layers to facilitate definition of STP 1 & 2 building foundations.) The rationale for combining Strata A and B is justified due to the varying thicknesses and low water-bearing nature of both units. The thickness of Stratum A varies from 8 ft to 29 ft within the STP 3 & 4 power block area with an average thickness of 18 ft. Stratum A is generalized as a silty clay layer, which typically consists of yellowish red, brown, gray, and black clay, with varying amounts of silt, sand, and gravel (STPEGS, 2010; Subsection 2.5S.1.2.3). Stratum B thickness varies from 0 ft to 16 ft within the STP 3 & 4 power block area, with an average thickness of 7 ft. Stratum B is generalized as a clayey silt layer, and typically consists of yellowish red, reddish brown, and brown silt, silty sand, and clay (STPEGS, 2010; Subsection 2.5S.1.2.3). Although Stratum B has less clay than Stratum A, the predominance of fine-grained soils comprising Stratum B suggests it would behave hydraulically as a leaky confining layer compared to the underlying Upper Shallow Aquifer zone comprised of Stratum C sand layer. This simplification is assumed to have negligible effect on flow paths within the Shallow Aquifer because of the low-permeable nature of Strata A and B.

Stratum G (sand) is not included in the model and is assumed to have negligible effect on flow paths within the Shallow Aquifer. The rationale for this omission is that Stratum G is generally absent. Stratum G is a lenticular layer that generally exists only in the portion of the site below STP 1 and occurs between Strata F1 and F2 (both clays).

3.3.2 Boundary Conditions

Assumptions are associated with formulating of the no-flow, constant head, river, drain, and recharge boundary conditions used in the model. These assumptions are derived from site investigations or from State and Federal geologic and hydrologic records.

3.3.2.1 No-Flow Boundary

Downward leakage from the Shallow Aquifer to the Deep Aquifer is assumed to be sufficiently small and to have a negligible effect on flow paths within either aquifer, so the confining layer (Stratum J) for the Deep Aquifer is assumed to be a no-flow boundary for this model. This assumption is based on the head difference between the Shallow Aquifer and the Deep aquifer, and the dimensions and lithology of Stratum J that are based on stratigraphy identified in deep geotechnical borings within the STP site and stratigraphy identified in off-site well logs. These sources indicate that Stratum J is a 100-ft to 150-ft thick clay and silt layer with some discontinuous internal sand layers that separates the Shallow Aquifer from the Deep Aquifer (STPEGS, 2010; Subsection 2.4S.12.3.1), and is continuous across the model area.

3.3.2.2 Constant Head Boundary

The Colorado River average annual stage levels from 2003 to 2007 is estimated to be 4.5 ft MSL where it enters the model at the northern model boundary and 3.4 ft MSL where it exits the model at the eastern model boundary based on linear interpolation between USGS gage stations located north and south of the model domain. The elevation contours of the top of Stratum C are between about 20 ft to -5 ft MSL near the eastern portion of the model area, indicating that the stage of the Colorado River and the river bottom is incised into the Upper Shallow Aquifer. Holocene alluvium in the Colorado River channel is assumed to hydraulically connect the Upper Shallow Aquifer to the Colorado River. Whether the Lower Shallow Aquifer is hydraulically connected to the river is uncertain (Stratum D of clay would have to be absent beneath the river).

Two MCR sand pits are located as shown in Figure 27 and Figure 28. The sand pits are assumed to be excavated 20 ft below the original ground surface prior to construction of the MCR and thus provide a permanent and direct connection between the MCR and the Upper Shallow Aquifer. This is based on the MCR embankment construction that includes on-site sand excavated below the surficial clay layer (Stratum A/B). The sand is from borrow pits at sources A and B (Figure 28). Sand source A was originally overlain by Stratum A/B to depths of approximately 8 to 12 ft, and sand source B was originally overlain by Stratum A/B to depths of approximately 8 to 15 ft (STPEGS UFSAR; Subsection 2.5.6.4.1.1). The sands at source A extend to at least 25 ft below the original ground surface and the sands at source B extend to a depth of 25 to 35 ft below the original ground surface, although the upper 5 to 8 ft consists of intermixed clayey silts, silts, clayey sands, and silty sands (STPEGS UFSAR; Subsection 2.5.6.4.1.1). This information suggests that the excavated depth in the sand source area could be 20 ft or perhaps slightly more creating a constant source of water to the Upper Shallow Aquifer.

3.3.2.3 River Boundary

The MCR stage is assumed to be 42 ft MSL based on visual estimation of the MCR staff gage located near the outfall. This stage coincides with measurements for groundwater level calibration targets. (For post-construction simulations, a value of 49.5 ft MSL is used.)

The clay borrow pits within the MCR are assumed to be excavated 10 ft below the original ground surface prior to providing construction material for the MCR embankment and internal dikes, and likely do not penetrate to the Upper Shallow Aquifer. This assumption is based on a rough order-of-magnitude volume estimate that indicates a required depth of perhaps 10 ft to provide adequate material. Like the sand borrow pits, the clay borrow pits are located within the MCR as shown in Figure 27 and Figure 28. The embankment volume includes a core of approximately 45-ft height and 12-ft width, side slopes of about 250-ft width, and embankment length of about 65,000 ft:

- Embankment volume = [(45 ft x 12 ft) + 2 x (½ x 45 ft x 250 ft)] x 65,000 ft = 766,350,000 cubic ft.

Including the internal dikes and rounding upward to order-of-magnitude gives result of 1 billion cubic ft of soil. Assuming about 1/3 of the bottom of the MCR is excavated for clay borrow pits, the typical excavation depth is:

- Borrow depth = 1,000,000,000 cubic ft / (0.33 x 7,000 acres x 43,560 sq ft/acre) = 10 ft.

Unlike the MCR sand borrow pits, this estimate indicates that a thin semi-confining unit between the MCR and the Upper Shallow Aquifer exists outside of the sand borrow pits. In the model, this area uses river boundary cells to adjust the conductance to the existing clay separating the MCR and the Upper Shallow Aquifer.

The ECP is assumed to have a constant surface water elevation of 26 ft MSL based on the normal maximum operating water elevation for the ECP (STPEGS UFSAR; Subsection 2.4.13.2.3). This is nearly the same as the groundwater level in the Upper Shallow Aquifer.

Kelly Lake is assumed to have a constant surface water elevation of 11 ft MSL. This is based on the USGS Blessing SE Quadrangle (USGS, 1972), which indicates an elevation of 11 ft MSL for the water surface in Kelly Lake.

Kelly Lake is assumed to be hydraulically connected to the Upper Shallow Aquifer based on water level measurements from observation wells OW-959U and OW-961U (in Stratum C adjacent to Kelly Lake), which were measured to be 11.14 and 10.34 ft MSL during September 2008, respectively. These values approximate the documented 11 ft MSL stage of Kelly Lake, suggesting a potential hydraulic connection. Additionally, a reversal of the hydraulic gradient between the Upper and Lower Shallow Aquifer supports that groundwater discharge may be occurring in this area. This contrasts with the evaluation of water level data across the STP site, which indicates that the hydraulic head of the Upper Shallow Aquifer is on average approximately 6.5 ft greater than the Lower Shallow Aquifer.

3.3.2.4 Drain Boundary

MCR relief wells are assumed to be best represented in the model with lines of drain cells, rather than discrete drain cells. The rationale is that the lines of relief wells physically operate as a drainage curtain that can be adequately represented in the model with a drain line. Also, lines of drain cells were employed to simplify the use of drain conductance as a calibration parameter and to aggregate individual relief wells into groups while still maintaining the non-contiguous perimeter coverage of the relief wells. Each line, or group, of drain cells represents relief wells that have similar top of well elevations. The drain lines in the model are shown along with relief well locations on Figure 29. Figure 30 shows the MCR embankment stations.

The drain elevations for drain lines are assumed to vary linearly with MCR station across MCR perimeter segments. The drain cell elevations are assumed to be the top of the well because the relief wells are free-flowing. The locations and elevations of MCR relief wells are estimated using data from Bechtel (1986) and Bechtel (1989). Figure 31 shows the estimated drain elevations, which range from 8 ft to 26 ft MSL.

MCR relief wells are assumed to be best simulated as drain cells rather than pumped wells with fixed discharge rates. The rationale for this assumption is based on the fact that the relief wells are not pumped, but rather free flow when the groundwater level in Stratum C exceeds the drain pipe elevation at the relief well. Drain cells provide a more appropriate simulation option to describe how these relief wells actually function. Also, discharge rates measured at relief wells show a large range from well to well, and well spacing also varies around the perimeter (from 50 ft to 200 ft). High relief well discharge rates measured at some wells could result in those wells "going dry" during the simulation if an applied pumping rate exceeds the well yield based on the aquifer transmissivity in the model. This can make the process of modeling development difficult, considering that there are about 770 relief wells. In lieu of fixing the discharge rates in the model at individual relief wells (and vertical sand drains), the measured discharge rates can be used during calibration to compare simulated discharge to measured discharge. Drain cell elevations are first specified for relief wells with similar drain pipe elevations, and then drain cell conductances are adjusted within groups of relief wells, represented by drain lines, during model calibration to match measured discharge rates around the MCR. Seventeen intervals are employed in the discharge analysis with each interval corresponding to a drain line shown on Figure 29.

Vertical sand drains located at the bottom of the MCR toe drainage ditch between MCR Embankment Stations 32+00 to 108+00 and 268+60 to 276+00 are assumed to extend 5 ft into Stratum C. Additional vertical sand drains are assumed to extend to 10 ft total depth between MCR Stationing 108+00 to 120+00, 267+50 to 268+60, and 276+00 to 282+17. Figure 29 shows the portions of the MCR perimeter that have vertical sand drains. The elevation of drain boundary cells representing vertical sand drains can be estimated as 1 ft below the measured top of relief well elevations between MCR Embankment Stations 32+00 to 120+00 and between Stations 276+00 to 282+17. Vertical sand drains can be combined into lines of drain boundary cells that represent both relief wells and sand drains in regions where the two are collocated.

These assumptions are based on the embankment stations for vertical sand drains around the MCR (Bechtel, 2010). The embankment drawings provide information to determine the embankment stations for vertical sand drains around the MCR and gives the spacing between vertical sand drains of 5 ft (Bechtel, 2010). The elevations of drain cells corresponding to vertical sand drains are also estimated using the relationship between relief wells and collector ditches. The top of a relief well is typically about 1 ft above the adjacent collector ditch (Brown & Root Inc., 1983). Vertical sand drains have a top elevation equal to the invert of the collector ditch (Bechtel, 2010); the corresponding drain boundary cell elevation should be the ditch invert elevation when drain boundary cells represent vertical sand drains. Relief wells and vertical sand drains both provide pressure relief for Stratum C. Drainage from these two relief mechanisms will be controlled by the mechanism that provides drainage at the lowest potentiometric surface elevation. Sand drains provide drainage at a lower potentiometric surface elevation because the collector ditch invert is below the top of well elevations. Vertical sand drains will then control pressure relief when collocated with relief wells.

MCR internal dikes, shown in Figure 28, are not included in the model. The MCR internal dikes occupy a small portion of the reservoir area, so are expected to have an insignificant effect on leakage.

The MCR embankment internal sand drains are not included in the model. The MCR embankment internal sand drains provide internal drainage to reduce water pressures within the clay fill on the down-gradient side slope. The model-simulated water table within the clay fill of the embankment will be inaccurate. However, excluding these drains is expected to have an insignificant effect on the groundwater contours and flow paths in the underlying sand strata of the Shallow Aquifer, primarily because of the relatively small seepage that would occur laterally through the embankment in comparison to the seepage through the bottom of the reservoir.

Unnamed tributaries, drainage ditches, and the entire length of the Little Robbins Slough are assumed to be adequately simulated as drain cells in Stratum A/B (model layers 1 and 2). Figure 25 shows drain cells in Stratum A/B in the model that represent these surface water features. This assumption is based on the excavation depth of the RLRS along the west side of the MCR being about 10 to 12 ft below ground surface. This drainage channel and others are assumed to collect lateral groundwater seepage from Strata A and B (model layers 1 and 2) and upward seepage from Stratum C (model layer 3) and convey the seepage by surface flow out of the model domain. A relatively low drain cell conductance of 80 square ft/day is assigned to model cells along drainages. For a model cell with dimensions of 20 ft by 20 ft, this drain conductance corresponds to a hydraulic conductivity of 7×10^{-5} cm/s (assuming "drain" material with a unit thickness).

Portions of the RLRS, plant area drainage ditches, and levee-bound irrigation channels located to the west and north of the MCR are assumed to be in direct hydraulic communication with Stratum C (Run 301, model layer 3), and boundary conditions were therefore applied to the layer 3 of the model as shown in Figure 26. This assumption is based on the regional groundwater flow in the Shallow Aquifer, which is generally southeasterly from recharge areas where the sand layers outcrop to discharge areas – primarily the Colorado River or the Gulf of Mexico. The MCR acts as a source of water to the Shallow Aquifer. The combination of the regional flow pattern and the MCR is conceptually similar to the analytical solution for a lake superimposed on a uniform flow field. In this conceptual scenario, the lake or MCR would be expected to create a divide on the up-gradient side at the stagnation point created by counterbalancing radial flow outwards from the lake/MCR and regional groundwater flow from the northwest towards the southeast. However, the observed groundwater flow divide in the Upper Shallow Aquifer is due north of the MCR, rather than to the northwest as would be expected from purely the MCR and regional groundwater flow. Consequently, additional sources and/or sinks apparently affect groundwater flow patterns in the Upper Shallow Aquifer to the north and northwest of the MCR. Levee-bound irrigation channels that operate by siphons were identified on the Blessing SE, TX quadrangle (USGS, 1972) as significant surface water features that may impact Stratum C. The identified features, labeled as segments of the irrigation channels in the groundwater model for calibration, are displayed in Figure 32. Construction of the levees likely required clay from Stratum A/B to be removed from the excavated irrigation channel to a depth where communication with the Upper Shallow Aquifer is feasible. The degree of connection between these surface water features and the Upper Shallow Aquifer is examined as part of model calibration. Similarly, plant area drainage ditches and Little Robbins Slough were identified from the aerial data set (P2 Energy Solutions/Tobin, 2007) as surface water features whose incision into the local topographic surface may be sufficient to generate connection with the Upper Shallow Aquifer (Stratum C). Figure 3 displays the area surrounding the proposed Units 3 & 4 along with topographical elevations. Plant area drainage ditches and Little Robbins

Slough appear in this figure as green lines, where the color green represents a surface elevation in the range of 12 ft to 25 ft MSL. Elevations of the top of Stratum C in the model are shown on Figure 16; in the regions to the north and west of the MCR, the top of Stratum C surface elevations range from 15 ft to -10 ft MSL. Comparison of the surface elevations for Little Robbins Slough and plant area drainage ditches in Figure 3 with top of Stratum C surface elevations on Figure 16 suggests that hydraulic connection among these surface water features and Stratum C is possible. The degree of connection is examined as part of model calibration. Labeled drain boundary line segments, representing Little Robbins Slough and plant area drainage ditches that were employed in the groundwater model as part of model calibration are shown on Figure 33.

3.3.2.5 Recharge Boundary

Groundwater recharge is assumed to originate from distant outcrop areas north of Matagorda County (Figure 10), and precipitation is assumed to have no significant impact on groundwater levels, flow, and recharge on the local aquifer system due to the prevalence of low-permeable surficial Stratum A/B clays. Hence, recharge is applied directly to the Shallow Aquifer at low rates in the groundwater model. This assumption is based on information that indicates the ground surface across most of the model area is comprised of clay soil with a slope of less than 1%. This clay soil is sufficiently thick (about 30 ft average) with a low vertical hydraulic conductivity (Section 2.7.3) that prevents significant direct recharge from local precipitation. Paved areas and areas covered with slabs or occupied by buildings will have zero recharge. Within the power block area, compacted clay soil with minimal vegetation (barren land) is expected to have high run-off and low infiltration, whereas areas of exposed structural backfill (clean sand) are expected to have low run-off and high infiltration. However, for the proposed Unit 3 & 4 power block area, the structural backfill will have a clay cap to prevent expected high infiltration. Figure 34 shows the existing ground cover with respect to potential aerial recharge within the power block areas, and Figure 35 shows the existing extent of vegetation and buildings.

3.3.3 Steady-State Condition

The groundwater levels measured from the STP 3 & 4 observation wells and site piezometers in September 2008 are assumed to approximate steady-state conditions for the STP site. This assumption is based on observations that MCR level changes rapidly affect (on the order of hours) groundwater levels in the Upper Shallow Aquifer adjacent to the MCR at the STP site. Groundwater levels in the Upper Shallow Aquifer increased significantly during initial reservoir filling in the late 1980s. The MCR and groundwater levels were relatively low in late 1995/early 1996 and late 1999/early 2000, and relatively high in 1997 and late 2002/early 2003, coinciding with approximately 9-ft fluctuations in the MCR level between 36 and 45 ft MSL. Groundwater levels in the Upper Shallow Aquifer had fluctuations of up to 10 ft in the 1990s with fluctuations up to approximately 3 ft between 2000 and 2006 (STPEGS, 2010; Figure 2.4S.12-23). The Shallow Aquifer piezometers at STP 1 & 2 in the vicinity of the power block were affected by excavation dewatering in the early 1980s, and then were affected by reservoir filling in the late 1980s as shown in Table 5. Slight seasonal and annual fluctuations of 1 to 2 ft in groundwater levels appear typical for most of the STP 3 & 4 groundwater observation wells in sand strata. The September 2008 measurements do not appear anomalous and are expected to be representative for conditions with an MCR level near 42 ft MSL and assuming near-average monthly precipitation.

3.3.4 Hydraulic Conductivities

Each model layer is assumed to be homogeneous and a single value of horizontal hydraulic conductivity and a single value of vertical hydraulic conductivity can be used to describe each stratum. The rationale of this assumption considers that a unique distribution of hydraulic conductivities across the model area cannot be determined based on the limited available data. It is commonly accepted that hydraulic conductivity values vary within an aquifer, and the variability of hydraulic conductivity within an aquifer is typically described with a log-normal distribution (Freeze and Cherry, 1979). However, a single vertical and horizontal value of hydraulic conductivity for each stratum provides a simple conceptual model that is preferred due to the lack of data.

The vertical hydraulic conductivity values for clay strata (Strata A/B, D, and F) are assumed to be within the range 2 x 10^{-8} cm/s to 2 x 10^{-6} cm/s, and the horizontal hydraulic conductivity values within sand strata are assumed to be 0.03 cm/s. The clay values are based on laboratory testing of vertical hydraulic conductivity for clay samples range from 2 x 10^{-8} cm/s to 2 x 10^{-6} cm/s (Table 4), and the horizontal hydraulic conductivity for the sand strata is within the typical range for sand-sized materials (Freeze and Cherry, 1979) and agrees with values obtained from pump tests summarized in Section 2.7.1.

The hydraulic conductivity of the clay liner for the ECP is assumed to be 5 x 10^{-5} cm/s based on results of laboratory tests conducted on two samples of compacted clay from the ECP. The clay line is also assumed to be homogeneous and isotropic.

The hydraulic conductivity of the structural fill for STP 3 & 4 is assumed to be 2.5 x 10^{-3} cm/s, similar to the structural fill for STP 1 & 2 (Table 4), and the structural fill is assumed to be homogeneous and isotropic. This is based on the possibility that the structural fill for STP 3 & 4 may use similar material as in STP 1 & 2. However, the source is not yet identified. STP 1 & 2 used well-graded sand from the Eagle Lake/Gifford Hill source, approximately 55 miles north of the site (STPEGS, 2010; Subsection 2.5S.4.5.1).

3.3.5 Water Well

The 80-ft deep livestock well located east of STP site (Figures 25 and 26) is assumed to be screened in both Strata C and E. This well has been selected because it is down gradient of the power block area. This assumption is based on the average depth to the base of Stratum E to be approximately 87 ft (STPEGS; 2010; Table 2.5S.4-2), which places the base of the well within Stratum E. It has been assumed that the length of well screen is approximately 50 ft, which places the top of the screen at a depth of approximately 30 ft, which is close to a depth of approximately 27 ft, the average depth to the top of Stratum C.

3.3.6 Plant Area Excavations

Foundations of Units 1 & 2 structures are represented in the model with inactive cells within the identified building footprints and above the estimated excavated depth. Figure 36 shows the location of STP 1 & 2 buildings, and Figure 37 shows elevation contours for STP 1 & 2 main excavation and corresponding extent of structural backfill. These areas and depths are based on data digitized from the STP 1 & 2 UFSAR (Bechtel, 2010), which provide building footprint locations and the extent and depth of excavation.

The proposed excavation limits for STP Units 3 & 4 correspond to the extent of structural backfill. Figure 38 shows the location within the model of STP 3 & 4 buildings, as well as existing buildings for STP 1 & 2. Based on this representation of the Units 3 & 4 footprint, the model incorporates the extent of the structural backfill and buildings by revising material properties for model cells within the structural backfill extent and by assigning inactive model cells at building locations.

The construction excavation slurry walls and the CFRWs are assumed to be 3 ft in thickness, with a hydraulic conductivity of 1 x 10^{-6} cm/s (see further discussion in Section 5). Figure 38 shows the representation within the model of Units 3 & 4 slurry walls and CFRWs for STP 3 & 4. The model incorporates the walls by assigning "horizontal flow barrier" boundary condition along sides of cells corresponding to wall locations and model layers penetrated by the walls. The horizontal flow barrier condition is used by MODFLOW to simulate thin, vertical, low-permeability features.

4. MODEL CALIBRATION

The model is calibrated to existing conditions by comparing the simulated groundwater levels with measured groundwater levels and by comparing simulated discharge rates from the MCR relief wells to measured discharge rates.

4.1 Calibration Targets

Groundwater levels were measured at the STP site in September 2008. As discussed in Section 3.3.3, these September 2008 measurements are assumed to represent steady-state conditions. Consequently, the September 2008 values are used for model calibration targets, and Table 6 summarizes these values.

MCR relief well discharge rates were most recently measured in 2004, but data are also available between 1984 and 1995. Table 7 summarizes the relief well discharge rate calibration targets. In Table 7, relief well discharge values are aggregated to groups that correspond to the drain lines shown in Figure 29.

Total seepage from the MCR is previously estimated to be 3,530 gpm (STPEGS UFSAR; Subsection 2.4.13.3.2.3). This seepage rate is equivalent to about 10 inches per year infiltration over the 7,000-acre MCR. Approximately 68% of the total seepage from the MCR is expected to be captured by relief wells.

The Colorado River streamflow gain during a low-flow period in 1918 is estimated to have been about 20 gpm per mile. This result suggests that discharge from the Shallow Aquifer along the 7.98-mile long model boundary to the Colorado River would have been on the order of 100 to 200 gpm prior to filling of the MCR. After filling of the MCR, some of the seepage into the Shallow Aquifer that is not captured by the relief wells and vertical sand drains should cause an increased discharge to the Colorado River. Modeling of existing conditions should indicate a groundwater discharge to the Colorado River that exceeds the historical estimate of 100 to 200 gpm.

4.2 Calibration Criteria

Model calibration criteria include groundwater levels and groundwater flow as explained below.

4.2.1 Groundwater Level Criteria

The following groundwater level criteria, based on engineering judgment are used for model calibration:

a. Maximum absolute residual (R_{max}) <6 ft.

b. Root mean squared error (RMS), Equation (5) <3 ft.

c. Normalized root mean squared ($NRMS$), Equation (6) <10%.

d. Absence of areal bias in the largest residuals, i.e., highest residuals, are not clustered in particular regions of the model.

A summary of the definitions of the calibration criteria listed above and of the various calibration statistics employed to assess the goodness-of-fit of the model is provided in the following. All of these definitions were obtained from the Visual MODFLOW v.4.3 User's Manual (Schlumberger Water Services, 2009).

The calibration residual (R_i) at an observation point i is defined as:

$$R_i = {}^{model}X_i - {}^{obs}X_i \qquad (1)$$

where,

${}^{model}X_i$ is the calculated groundwater level at point i and

${}^{obs}X_i$ is the observed groundwater level at point *i*.

The Residual Mean ($\overline{R}$) is the average difference between the calculated and observed results:

$$\overline{R} = \frac{1}{n}\sum_{i=1}^{n} R_i \quad (2)$$

where

n is the number of observed groundwater level measurements.

The Absolute Residual Mean ($|\overline{R}|$) provides a measure of the average magnitude of residuals, R_i:

$$|\overline{R}| = \frac{1}{n}\sum_{i=1}^{n} |R_i| \quad (3)$$

The Standard Error of the Estimate (SEE) is a measure of the variability of the residual around the expected residual value:

$$SEE = \sqrt{\frac{\frac{1}{n-1}\sum_{i=1}^{n}\left(R_i - \overline{R}\right)^2}{n}} \quad (4)$$

The Root Mean Squared error (*RMS*) residual is defined as:

$$RMS = \left[\frac{1}{n}\sum_{i=1}^{n} R_i^2\right]^{1/2} \quad (5)$$

The *NRMS* residual is the *RMS* residual divided by the maximum difference in observed groundwater levels:

$$NRMS = \frac{RMS}{{}^{obs}X_{\max} - {}^{obs}X_{\min}} \quad (6)$$

In addition, a map showing the calibration residual at each observation point is examined for possible clustering of the larger residuals, which may suggest an areal bias in the calibration.

4.2.2 Groundwater Flow Criteria

The following groundwater flow criteria are used for model calibration:

a. Mass balance discrepancy (M_d), Equation (7) < 0.1%
b. Calculated groundwater discharge rate to Colorado River exceeding the historical estimate by USGS for streamflow gain in 1918.
c. Calculated discharge from MCR to groundwater approximately equal to the calculated, or estimated, total MCR seepage value of 3,530 gpm.
d. Calculated MCR seepage captured by the relief well system should be within the bounds of relief well discharge data and of the estimate of 68 percent of the total MCR seepage (2400 gpm) captured by the relief well system.

The mass balance discrepancy (M_d) is defined as:

$$M_d = \frac{V_{in} - V_{out}}{\frac{1}{2}\left(V_{in} + V_{out}\right)} \quad (7)$$

(McDonald and Harbaugh, 1988, 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.

4.3 Model Calibration

Calibration of the model following incorporation of the Run 301 refinements was not necessary considering the resulting head residuals from Run 301 were comparable to model Run 201. The calibration effort for Run 201 addresses only one conceptual model, which is that of a uniform hydraulic conductivity for each hydrogeologic unit or stratum. As discussed in Section 1, model development has occurred in several phases. Analysis and model runs employed in earlier phases of development were used to set hydraulic conductivity and recharge values in the model (Bechtel, 2010) including sensitivity evaluations (Bechtel, 2010a).

Preliminary runs used various values for hydraulic conductivity and recharge for calibration parameters. These aquifer parameters were derived during the preliminary runs as the values that provided the best calibration according to the calibration criteria in Section 4.2. However, the calibration results of these preliminary runs were not acceptable, and following the establishment of the hydraulic conductivity, recharge and boundary head values, they were no longer varied during subsequent calibration. Values of hydraulic conductivity for each of the model layers and zones are presented in Table 8. For this model, the sand layers each had a constant value of 0.03 cm/s, while the clay layers each had a horizontal hydraulic conductivity value of 3.0×10^{-7} cm/s and a vertical value of 3.0×10^{-8} cm/s. The value for the sands is at the upper end of those observed during aquifer testing, while the value for the clays is close to the geometric mean of test results for samples from this material. Figure 39 through Figure 41 illustrate the hydraulic conductivity zones for each of the seven model layers.

The final calibration was achieved through a series of simulations using different values of drain cell conductance for the relief wells and vertical sand drains. For the final calibration, the primary calibration parameter was the drain cell conductance for drain lines representing the relief wells and vertical sand drains, drain cell conductance for the drain lines representing Little Robbins Slough and plant area drainage ditches, and riverbed hydraulic conductivity for river cells representing levee-bound irrigation channels. The calibration of the previous model revisions indicated that the largest stress to the groundwater model was from the MCR sand pits. In this revision, the MCR representation in the model was altered for Run 301 by eliminating the "stacked" river and constant head boundaries from the model layers beneath layer 1. In Run 301, the MCR sand pits are represented by constant head cells only in layer 1 and by a zone of hydraulic conductivity in layer 2 (and layer 3 in the post-construction scenario, Run 301PC) beneath the constant head cells that have been set equal to the hydraulic conductivity of the Upper Shallow Aquifer sand. This representation is considered to be less dependent upon model calibration and have less unintended influence on the model results.

4.3.1 Calibration Procedure

Calibration of Run 201 involved manual adjustment of riverbed hydraulic conductivity of river boundary cells that represent levee-bound irrigation channels, shown on Figure 32, manual adjustment of drain conductance of drain boundary cells which represent the ditches shown on Figure 33, and manual adjustment of drain conductance of drain lines representing MCR relief wells which are shown on Figure 29.

4.3.1.1 Manual Calibration of Riverbed Conductivity and Drain Line Conductance

Hydraulic connection between surface water features located to the west and north of the MCR provided the primary calibration focus. Plant area drainage ditches, Little Robbins Slough, and the levee-bound irrigation channels were the surface water features identified as possibly being connected to the Upper Shallow Aquifer. Drainage ditches and Little Robbins Slough were represented with drain boundary cells in the model; levee-bound irrigation channels were represented with river boundary cells.

In the calibration process, water surface elevations and physical dimensions of drainage ditches and levee-bound irrigation channels were fixed. Water surface elevations and physical dimensions of the levee-bound irrigation channels were estimated from a topographic map of the vicinity (USGS, 1972). Water surface elevations in drainage ditches and Little Robbins Slough were estimated from aerial data (P2 Energy Solutions/Tobin, 2007).

Drain conductance and the hydraulic conductivity of riverbed material in Stratum C (Run 301 model layer 3) were used as calibration parameters. Conductance and hydraulic conductivity were varied as part of calibration to represent the degree of connection between the particular surface water feature and the Upper Shallow Aquifer. Larger values of conductance and hydraulic conductivity represent a greater degree of connection while lower values represent a lesser degree of connection. The greater degree of hydraulic connection between the surface water feature and Stratum C can be created by assigning the bottom of the surface water feature to be below the top of the Stratum C, or by assigning relatively high hydraulic conductivity zones immediately adjacent to or beneath the surface water feature.

In calibration, manual adjustment of riverbed hydraulic conductivity and drain line conductance encompassed the following ranges:

- River cell hydraulic conductivity: 3.0×10^{-10} cm/s to 3.0×10^{-2} cm/s
  - Note that the low hydraulic conductivity value of 3.0×10^{-10} cm/s was used to effectively "turn off" river boundary segments by reducing the hydraulic conductivity value to the point where the hydraulic connection was effectively non-existent.
- Drain line conductance for drains representing ditches: 1.8×10^{-4} cm/s per 30.48 cm (1 ft) to 1.8×10^{-1} cm/s per 30.48 cm (1 ft)
- Drain line conductance for drains representing MCR relief wells: 3.5E $\times 10^{-4}$ cm/s per 30.48 cm (1 ft) to 3.5 cm/s per 30.48 cm (1 ft)

Riverbed hydraulic conductivity and drain line conductance values were manually varied within the ranges given above to obtain the best-fit to measured water levels in the Upper Shallow Aquifer (Stratum C, Run 301 model layer 3). The RMS, Equation (5), and the NRMS, Equation (6), were the two statistics employed to determine the best representation of measured water levels. The location of the groundwater flow divide in the Upper Shallow Aquifer was also examined as part of the determination of the model parameters providing the best fit to measured water levels. The manual calibration run with the lowest RMS and NRMS is used as the calibrated model. Table 9 provides the values of riverbed hydraulic conductivity for the river boundaries representing levee-bound irrigation channels, of drain line conductance for drain lines representing irrigation ditches and Little Robbins Slough, and of drain line conductance for drain lines representing MCR relief wells and vertical sand drains as used in the calibrated model.

Figure 29, Figure 32, and Figure 33 display the locations of the boundaries whose hydraulic conductivity or drain line conductance are provided in Table 9. In Table 9, the highest drain line conductance values are for ditches located to the north and northwest of the MCR, and the largest riverbed conductivity values are for two levee-bound irrigation ditch segments located to the north of the MCR. The other eight levee-bound irrigation ditch segments have the low hydraulic conductivity value of 3.0×10^{-10} cm/s, which suggests that these segments are not hydraulically connected to Stratum C. The highest conductance values and largest riverbed hydraulic conductivity values denote areas where it is likely that surface water features are hydraulically connected to the Upper Shallow Aquifer. These manual calibration results suggest that hydraulic connection among a few surface water features to the north of the MCR and the Upper Shallow Aquifer is responsible for generating the groundwater flow divide in the model similar to the observed groundwater flow divide in the Upper Shallow Aquifer just to the north of the MCR.

4.3.2 Calibration Results

Table 10 presents a comparison of the match of water levels estimated with the three latest model revisions with measured water levels in September 2008. All three model revisions listed in Table 10 meet the general criteria given in Section 4.2 of:

- A maximum residual (R_{max}) < 6 ft
- A RMS value < 3 ft
- A NRMS value < 10%; and,
- A mass balance discrepancy (M_d) < 0.1%.

Although Run 201 provides a slightly better match to data than Run 301 when the criteria of lowest overall RMS and NRMS are applied (Table 10), the slight difference does not merit recalibration for Run 301. This is largely due to the use of Run 201 to formulate Run 301. Detailed results from Run 301 are presented below. Consequently, Run 301 was used as the base model to formulate the post-construction scenario Run 301PC, which is described in Section 5.

Figure 42 displays the simulated potentiometric surface contours for Stratum C of Run 301. A dominant feature in this figure are the closely-spaced (steep) contours that emanate away from each borrow pit within the MCR. These steep contours illustrate the effects of the direct connection between both sand borrow pits, modeled as constant head cells with a specified head of 42 ft MSL, and the Upper Shallow Aquifer (Stratum C). Also notable in this figure is how the model reproduces the groundwater divide located to the north of the MCR. Model sensitivity observed during the manual calibration to the various surface water features listed in Table 9 suggests that connectivity between the levee-bound irrigation ditch segments Spur 1 and Spur 2 (see Figure 32) and the Upper Shallow Aquifer (Stratum C) creates the divide north of the MCR in the model.

Figure 43 and Figure 44 show the simulated potentiometric surface contours for Strata E and H of Run 301, respectively. Groundwater flow in these two strata is from the northwest to southeast. Contours in Stratum E at the east side of the domain suggest some interaction/influence of the Colorado River with Stratum E.

Plots of observed head and model calculated head for all data points and for Strata C, E, and H are provided on Figure 45, Figure 46, Figure 47, and Figure 48, respectively. Consequently, the model calculated values are acceptable for each of the observed values with 95% confidence (Schlumberger Water Services, 2009). However, the plot of observed head and model calculated head for Stratum H, Figure 48, suggests a systematic bias in the calculated values in this layer. The comparison of model result to data provided by these four figures is summarized in Table 10.

Figure 49, Figure 50, and Figure 51 provide the value and the location in space of each residual for Stratum C. The maximum residual in Stratum C is located along the northeast perimeter of the MCR and is shown on Figure 50 (right panel). Residuals in the proposed Units 3 & 4 power block region display a positive bias (see Figure 51), indicating Run 301 is over-predicting water levels in this area. The location and value of residuals in Stratum E are provided on Figure 52, Figure 53, and Figure 54. Figure 55 displays location and values of residuals in Stratum H. Run 301 under-predicts water levels in general as suggested by the negative overall residual mean of -0.147 ft and the negative residual means of -0.783 ft for Stratum E and -0.265 ft for Stratum H. However, Run 301 tends to slightly over-predict water levels in Stratum C as evidenced by the relatively small positive residual mean of 0.119 ft for this layer.

4.3.2.1 Groundwater Pathlines from Proposed Units 3 & 4 Site

Run 301 was also used to predict groundwater pathlines for particles released from each of the sand strata (Strata C, E, and H) at proposed Units 3 & 4 during pre-construction conditions. A total of eight particles were released in this scenario: four from each corner of the reactor building at Unit 4 and four from each corner of the reactor building of Unit 3. This scenario was run to evaluate what effects the proposed construction of STP 3 & 4 may have on groundwater flow by comparing them with the resulting pathlines of particles released at the same locations in the post-construction simulation. Pathlines for particles released at the location of proposed Unit 3 in Stratum C travel towards the southeast until entering the fill at Units 1 & 2 (Figure 56), where they travel downward through the fill and around the building foundations to Stratum E before continuing towards the east past the STP site boundary to the Colorado River (Figure 57). Pathlines that travel to layers below the release point are shown as red in plan view as depicted on Figure 56 for the particles released at Unit 3. The particles released in Stratum C at Unit 4 travel to the western site boundary and are depicted as light blue in Figure 56 because, unlike the particles released at Unit 3, these particles travel only within Stratum C.

The fastest travel time simulated for the Upper Shallow Aquifer to the site boundary is about 160 years from the release point at the northwest corner of proposed Unit 4 to the west site boundary (Figure 56). Each of the particles released at Unit 3 in the Upper Shallow Aquifer during pre-construction Run 301 travel in the Upper Shallow Aquifer for about 36 years (shown in light blue in Figure 56) before traveling down to the Lower Shallow Aquifer through the backfill at Units 1 & 2 (Figure 57). The fastest travel time for these particles to reach the site boundary is about 138 years after traveling southeast through Stratum E (shown in red in Figure 56).

Particles released in Stratum E of the Lower Shallow Aquifer travel towards the east and southeast until intersecting the Colorado River as shown in Figure 58 and Figure 59. The fastest travel time to the STP eastern site boundary within Stratum E is about 137 years for the particle released at the northeast corner of Unit 3. Particles released in Stratum H travel towards the southeast, following the direction of regional groundwater flow, and leave the model domain near the southeastern corner as shown in Figure 60 and Figure 61. The fastest travel time for these particles to reach the southeast site boundary is about 808 years.

4.3.2.2 Water Budgets

A summary of the water budget for Run 301 is provided in Table 11. This table shows the contribution of domain boundaries and of sources and sinks within the model domain. The total discharge from the MCR estimated by model is 3,700 gpm which is similar to the 3,530 gpm previously estimated for MCR discharge to groundwater (STPEGS UFSAR, Section 2.4.13.3.2.3). Groundwater discharge to the Colorado River is estimated at about 670 gpm which exceeds the 100 to 200 gpm lower boundary discussed in Section 4.1. Of note, the simulated ECP seepage is 0.8 gpm, which is significantly underestimated relative to the water budget analysis (Bechtel, 1987) that indicated this to be 49 gpm.

During construction of STP 1 & 2, the MCR seepage analysis indicated that 68% of the MCR discharge to groundwater (2,400 gpm) would be captured by the MCR relief well system (STPEGS UFSAR, Section 2.4.13.3.2.3, p. 2.4-68). Instantaneous relief well discharge measurements were collected 41 times between 1985 and 2004. The maximum measured relief well discharge was measured on February 15, 1991 to be 1665 gpm, which is 69% of the estimated amount of MCR discharge captured by the relief well system. The relief well discharge data do not include discharge captured by the vertical sand drains, and the amount of discharge captured by the sand drains at the site is unknown.

Table 7 provides a comparison among the MCR seepage captured by the relief wells and sand drains in Run 201 and Run 301, and the average relief well discharge as derived from data collected between 1985 and 2004. The modeled relief well system, which includes the sand drains, captures more MCR discharge than the average discharge from data. Given the uncertainty in the amount of discharge collected by the vertical sand drains, the MCR discharge collected by the relief well system in the model is expected to be between the average relief well discharge from data (1,034 gpm) and the total estimated discharge from the MCR captured by the relief wells and vertical sand drains (2,400 gpm). Run 301 provides an estimate of the MCR discharge captured by the relief well system (1,821 gpm) that is between the hypothesized 1,034 gpm lower and 2,400 gpm upper bounds for MCR discharge captured by the relief wells.

At the most abstract and conceptually simple level of analysis the impact of the MCR on regional groundwater flow is analogous to a circular, constant head source super-imposed on a regional flow field. The regional flow field at the site is from northwest to southeast and the MCR provides a source of water with head levels above the regional potentiometric surface. Conceptually, discharge from the MCR to the regional groundwater flow regime is expected to occur mainly across the eastern and southern sides of the MCR because a stagnation point is expected on the upstream side of the MCR which will limit discharge to regional groundwater across the northern and western portions of the MCR perimeter.

Table 12 provides a comparison of MCR discharge to groundwater captured by relief wells according to perimeter segments representing cardinal directions. The relative amounts of discharge captured as simulated by Revisions 1 and 2 and the current model (Revision 3) along with the relative amounts obtained from the average discharge from data are provided in Table 12. From this table, the major portion of MCR discharge to groundwater occurs across the eastern and southern sides of the MCR in each model revision. The relief well discharge data also suggest the major portion of MCR discharge occurs across the eastern and southern sides. However, the data also suggest a significant portion of discharge occurs across the western boundary. The relative amount of discharge across the eastern and southern boundaries is likely underestimated in the data because the data do not include discharge captured by the vertical sand drains that are located along the eastern (northeast and southeast) sides of MCR.

4.3.3 Model Limitations

A groundwater model was developed for the STP site for the Shallow Aquifer and calibrated to groundwater level data collected during September 2008 and groundwater discharge data collected from September 1985 to December 2004. The pre-construction model represents the hydrogeology at the site with seven continuous layers. These layers represent three clay strata (Strata A/B, D, and F) and three sand strata (Strata C, E, and H). Note that Stratum A/B is divided into two layers in the model. Each model layer is homogenous. Layers representing clay strata (Strata A/B, D, and F) are vertically anisotropic, with a vertical hydraulic conductivity 1/10th the value of the horizontal hydraulic conductivity. The calibrated model meets the accuracy requirements set forth in Sections 4.1 and 4.2 and captures model-wide water budgets and flow patterns.

The ability of the model to reproduce water levels observed during September 2008 is shown on Figure 45 through Figure 55 and is summarized in Table 10. A simplistic summary of the model's ability to match observations from September 2008 is that the model is expected to produce water levels that differ from observed levels by about 1.5 ft, based on the overall RMS, and the model-produced water levels will typically be higher than the observed water levels, based on the positive overall mean residual. The overall NRMS for the model of 7.983% suggests the expected magnitude of error in model predicted water levels is about 8% of the observed range of water levels at the site.

In terms of general applicability, the steady-state model was calibrated to one set of instantaneous water level measurements using an instantaneous observation of the water surface in the MCR. These values are believed to be representative of steady-state conditions as noted in Section 3.3.3.

5. POST-CONSTRUCTION SIMULATIONS

The elevation planned for STP 3 & 4 is 34 ft MSL (STPEGS, 2010). Existing ground surface elevations at STP 3 & 4 range from about 32 ft to 34 ft MSL. The excavation for the reactor building will extend to an elevation of approximately -60 ft MSL, which is approximately 94 ft below proposed rough grade (STPEGS, 2010).

The excavation, construction, and backfill of Units 3 & 4 is represented in the model, Run 301PC. A slurry cutoff wall for construction groundwater dewatering control is to be constructed around the main excavation for STP 3 & 4 and will be keyed a minimum of 3 ft into Stratum J clay, which corresponds with the base of the groundwater model. The slurry wall around the south circulating water lines excavation will be keyed a minimum of 3 ft in Stratum D clay (model layer 5). Two CFRWs are also keyed into the top of Stratum D. The slurry wall and CFRWs are 3 ft to 5 ft wide and are designed to have a minimum permeability of 1 x 10^{-6} cm/s (Bechtel, 2010). The slurry wall will be located at least 30 ft beyond the excavations and is continuous around the perimeter. A clay cap will be placed over the fill material where the fill material would be exposed to grade. Figure 38 shows a representation of the location of the slurry wall and the CFRWs.

5.1 Post-Construction Groundwater Simulations

Modifications to represent the post-construction scenarios were made to Run 301 to include model representation of structural backfill for STP 3 & 4 excavation, inactive cells representing building foundations and footprints, the bentonite or bentonite-cement slurry wall around the excavation area, two CFRWs, and a clay cap.

As mentioned in Section 3.3.2.3, the water level in the MCR is assumed to be 49.5 ft MSL for post-construction conditions; a water level of 42 ft MSL was used for model calibration.

The hydraulic conductivity of the structural backfill material for the construction of STP Units 3 & 4 is assumed to be similar to that of the fill material used for STP Units 1 & 2, which is approximately 2.5 x 10^{-3} cm/s. The hydraulic conductivity of the layers and other parameters used in the model were not changed with the exception that a clay cap will be placed over the fill material (Bechtel, 2010). Drain lines that represent plant area drainage ditches that cross the proposed site have been removed in the vicinity of the proposed structures under the assumption that the ditches will be reconfigured as part of construction.

5.1.1 Release of Particles from Corners of STP 3 & 4 Reactor Buildings

Three separate model runs were conducted for the post-construction scenario to determine groundwater flow direction and travel time from Units 3 & 4. Particle tracking was performed using MODPATH where a particle was released at the four corners of the two reactor buildings for a total of 8 particles per layer. One run was executed for each of the three sand layers – Strata C, E, and H.

Particles released from the four corners of the reactor buildings are used to provide a representation of the groundwater flowpath from the Units 3 & 4 power block area. A larger array of particles was released as part of the sensitivity analysis summarized in Section 6. Particles released within the footprint of the slurry wall surrounding Units 3 & 4 migrated to the east and southeast similar to the particle represented by those released at the four corners of the reactor building (Bechtel, 2010a).

5.1.1.1 Structural Backfill for STP 3 & 4 with Slurry and Crane Foundation Retaining Walls

Figure 38 provides a representation of the proposed locations for slurry walls, CFRWs, and building footprints for Units 3 & 4. Slurry walls and CFRWs were represented in the model with the Horizontal Flow Barrier package (Hsieh et al., 1993). Flow barriers, or walls, were assumed to be 3 ft thick and to have a hydraulic conductivity of 1 x 10^{-6} cm/s (Bechtel 2010 and STPEGS, 2010 FSAR Subsection 2.5S.4.5.2.5). The slurry cutoff wall for construction groundwater dewatering control extends across all 10 layers in the post-construction Run 301PC model. Model layers 2, 4, and 6 (representing Clay Stratum A/B, Stratum D, and Stratum F) were divided into two layers each to facilitate the representation of the minimum key depth for the slurry wall around the south circulating water lines excavation in the model and the CFRWs. As a result, Stratum A/B is represented by model layers 1 through 3, Stratum C is model layer 4, Stratum D is model layers 5 and 6, Stratum E is model layer 7, Stratum F is model layers 8 and 9, and Stratum H is now model layer 10. The slurry cutoff wall around the south circulating water lines excavation extends across the top five model layers, whereas the slurry wall around the main construction excavation extends throughout the depth of the model. The CFRWs extend into the top of model layer 8 (Stratum F).

Following incorporation of the structural backfill, slurry walls, and CFRWs the model was run to steady state. Figure 62 to Figure 64 show simulated post-construction model groundwater heads and particle pathlines for Strata C, E, and H respectively. These three figures show that contours are refracted across the Units 3 & 4 slurry walls. Additionally, Figure 63 shows that the contours in the vicinity of Units 1 & 2 are refracted due to the difference in hydraulic conductivity between the structural backfill and Stratum E.

Particle tracking results for particles released within Stratum C (model layer 4) are shown in Figure 62 in plan view and in Figure 65 in cross-section. These two figures show the results of a simulated release at the proposed reactor buildings for Units 3 & 4 would first travel down through the structural fill to the Lower Shallow Aquifer, then travel in a southeasterly or easterly direction (Stratum E) to the STP site boundary, ultimately discharging into the Colorado River. Figure 62 shows that some of the particles released at Unit 3 in Stratum C travel in an immediate southerly direction prior to migrating eastward. The minimum travel time for these particles is about 112 years. However, because no particle remains in the Upper Shallow Aquifer, this travel time is mostly in Stratum E (model layer 7) of the Lower Shallow Aquifer.

Figure 63 and Figure 66 show that particles released at Units 3 & 4 in Stratum E (model layer 7) follow a similar path in Stratum C as they travel in a southeasterly or easterly direction to the site boundary. Some of the particles released at Unit 4 migrate down to Stratum H, as shown by the red pathlines. Particles that travel within the layer they are released are shown as light blue pathlines. The fastest simulated particle travel time to reach the site boundary is about 118 years, which is similar to the Stratum C release scenario.

Particles released from Stratum H (model layer 10) travel in a southeasterly direction. However, these particles do not discharge to the Colorado River within the model domain. Stratum H particles leave the model domain across the eastern boundary in the southeastern portion of the model as illustrated in Figure 64 and Figure 67. The fastest travel time to the east site boundary is about 855 years.

The post-construction model Run 301PC was run with the water level in the MCR set to 49.5 ft MSL to simulate the upper bounding stage of the MCR. Contour plots of groundwater level change were created from this post-construction run for Strata C, E and H.

Figure 68 displays drawdown in Stratum C. This figure suggests that water levels in Stratum C (Upper Shallow Aquifer) decreased in the vicinity of Units 3 & 4 under post-construction conditions (Run 301PC), with groundwater elevations not exceeding 21 ft MSL at the power block. Figure 69 shows drawdown in Stratum E. Groundwater head in Stratum E increased approximately 2.5 ft to 3 ft under post-construction conditions (Run 301PC) when compared to pre-construction (Run 301) groundwater heads. The maximum groundwater head in Stratum E under post-construction condition at the Units 3 & 4 was not more than 20 ft MSL. The decrease in Upper Shallow Aquifer water levels and corresponding increase in Lower Shallow Aquifer water levels is due to the removal of portions of the confining layers, Strata A/B and D, and replacement with relatively higher hydraulic conductivity fill material. Consequently, the Units 3 & 4 excavation area acts as a source of recharge to Stratum E under post-construction conditions because Strata C and E are in direct communication in this area via the structural fill and because water levels in Stratum C are higher than those in Stratum E. North and west outside of the slurry wall, the groundwater also appears to increase slightly. This is likely due to the effect of the low-permeable slurry wall that acts as a barrier to the regional flow from the northwest.

An increase in water levels within the slurry wall is also predicted for Stratum H as illustrated by Figure 70; however, the maximum groundwater head at the Units 3 & 4 in Stratum H is at an elevation of approximately 17 ft MSL. Although the excavation and structural fill do not penetrate Stratum H, the main excavation slurry wall does. The slurry wall may act to trap water that percolates down to Stratum H from overlying strata.

This simulation (model Run 301PC) was also run with the MCR stage set at 42 ft MSL to compare directly to the pre-construction scenario of model Run 301. The results of the post-construction simulated water levels with the MCR stage set at 42 ft MSL were generally consistent with the results with the MCR stage at 49.5 ft MSL, especially for Strata E and H. For Stratum C, the potentiometric surface configurations were similar between the two except at the MCR, where the heads were 1 to 2 ft lower for the 42 ft MSL simulation. Additionally for Stratum C, the heads at Units 3 & 4 were about 1 ft less when the MCR stage was set at 42 ft MSL compared to when the MCR stage was set at 49.5 ft MSL. This comparison suggests that when the maximum MCR operational stage is in effect, a head increase of one foot can be expected at Units 3 & 4 and virtually no difference was noticed at Units 1 & 2. This may be due to the far greater density of relief wells in the model between Units 1 & 2 and the MCR compared to those between Units 3 & 4 and the MCR.

6. SENSITIVITY ANALYSIS

To support responses to NRC 2010 groundwater modeling RAIs concerning Model Run 201 (STPNOC, 2010), a series of systematic sensitivity analyses were undertaken (Bechtel, 2010a). This was designed to evaluate model sensitivity to certain stresses and presents a model verification using groundwater and MCR levels from February and March 2003 to validate the model for post-construction runs.

To perform the sensitivity analyses the causes of dry and flooded cells within the model domain were investigated by evaluating the model surface topography, the simulated depth to water from Revision 2, and the effects of drain boundaries and general head boundaries (GHB). Based on the findings of the sensitivity analyses, the model was refined to perform a model validation run and to develop post-construction scenarios that include the effects of the CFRWs and relief well failure.

The findings of the sensitivity analyses suggest that the perceived irregularities of the dry cells and flooded cells do not affect the results and conclusions made in Revision 2. However, the model topography, recharge, GHBs, and drain boundaries were refined based on the findings of these evaluations and incorporated in to model Run 301.

The validation run required a different set of calibration targets and MCR stage to evaluate how well the model can predict a known condition and to simulate post-construction scenarios when the MCR stage is elevated to include the future operation of Units 3 & 4. (The September 2008 site conditions used in the Run 201 pre-construction model included a MCR stage of 42 ft.) March 2003 site conditions were selected for the validation analysis. The MCR stage for this evaluation was elevation 47 ft MSL. A total of 169 piezometers, including installations within the MCR embankment, served as the calibration targets for the validation run. With the exception of a few piezometers installed along the crest and middle of the embankment slope, results indicate a high degree of correlation between the predicted heads and the calibration targets. The steep hydraulic gradient and relatively low-resolution model grid within the embankment prevent accurate model prediction of the actual heads in comparison with the observed heads within the embankment. Recalibration was not necessary.

Post-construction sensitivity simulation scenarios included particle tracking, a refined power block design (foundation depths, excavation depths, slurry wall designs), and the use of CFRWs and an MCR stage level of 49.5 ft MSL. This MCR stage was based on the spillway elevation and represents an upper bounding condition considering an increased stage would merely cause water within the MCR to be diverted over the spillway and be returned to the Colorado River. The post-construction scenario indicates particles released within the vicinity of Unit 3 & 4 (simulating groundwater flow paths) travel in an east to southeast direction to the site boundary similar to that documented in Revision 2 (Run 201). The particle moves downward through the Units 3 & 4 fill material to the Lower Shallow Aquifer before continuing eastward or southeastward to the site boundary. The base case scenario predicts post-construction water levels to be more than 10 ft below the finished grade of Units 3 & 4.

Two MCR relief well failure scenarios were also run as part of the sensitivity analysis. The first scenario was run with inactivated drain boundaries representing relief wells along the north perimeter of the MCR to simulate relief well failure. The second scenario evaluated the unlikely failure of all MCR relief wells. Post-construction groundwater levels beneath Units 3 & 4 were predicted to be slightly higher than those identified when the relief wells are operated under steady state conditions but remained well below the defined site characteristic maximum groundwater elevation of 28 ft MSL.

Additional sensitivity analyses were conducted to address NRC's questions about whether the spatial bias of groundwater residuals in Run 201 diminished the possibility of predicting a southwest pathway in either the Upper or Lower Shallow Aquifer. For the pre-construction model, PEST with pilot points and regularization using the SVD-Assist technique was used to estimate the spatial variation of the horizontal hydraulic conductivity field (Watermark Numerical Computing, 2010; Doherty, 2003 and 2010). PEST with the pilot points and regularization technique was used to reduce the groundwater head residuals. A total of 430 pilot points were used to determine the zones of horizontal hydraulic conductivity distribution in Strata C, E, and H. The simulated to observed groundwater head fit was much better than that in model Run 201 and in Run 301, and the groundwater head residuals were much lower than compared to Run 201 and Run 301. Hydraulic conductivity values in wells where slug tests were conducted were compared with the PEST pilot points with regularization-derived hydraulic conductivity values. The values fall within the range of the alluvium fill deposits and compare satisfactorily to the slug test values. Particle tracking on the post-construction scenario with the PEST pilot points with regularization-derived hydraulic conductivity in Strata C, E, and H did not show a southwesterly pathway but confirmed the east to southeast flow direction shown in the post-construction simulations for Run 201 and Run 301PC for the particles released from the radwaste and the reactor buildings. The shortest travel time to the site boundary to the east was approximately 336 years.

Another sensitivity run was conducted by determining the optimized uniform hydraulic conductivity value for Strata C, E, and H using PEST (Doherty, 2003 and 2010). The uniform hydraulic conductivity for Strata C, E, and H were 82.3 ft/day (0.03 cm/sec), 65.4 ft/day (0.023 cm/sec), and 324.7 ft/day (0.115 cm/sec), respectively. Particle tracking on the post-construction model showed no evidence of a southwesterly pathway and the shortest travel time to the site boundary to the east was 118 years.

Lastly, the following sensitivity analyses were conducted to determine the sensitivity to groundwater heads at the proposed STP Units 3 & 4 power block area by:

1) Varying the excavation backfill hydraulic conductivity (Run 301 PC base case of 2.5×10^{-3} cm/sec) from 5×10^{-4} cm/sec to 2×10^{-2} cm/sec;
2) Varying the base case post-construction recharge rate at the power block of 0.001 inch/year (Run 301PC) by increasing the rate by 100% (0.002 inch/year), 200% (0.003 inch/year), and by three orders of magnitude (1.0 inch/year); and
3) Combining the recharge rate increased by three orders of magnitude (1.0 inch/year) along with an excavation backfill hydraulic conductivity of 5×10^{-4} cm/sec.

Decreasing the backfill hydraulic conductivity from 2.5×10^{-3} cm/sec to 5×10^{-4} cm/sec results in a 0.85 ft groundwater head increase in Stratum C; whereas using a backfill hydraulic conductivity of 2×10^{-2} cm/sec results in 0.6 ft decrease in groundwater head in Stratum C. With a backfill hydraulic conductivity value of 5.0×10^{-4} cm/sec, the model results show a groundwater head decrease that ranges from 0.7 ft to 1.4 ft in Stratum E and 0.17 ft in Stratum H. A backfill hydraulic conductivity value of 2.0×10^{-2} cm/sec results in a groundwater head increase that ranges from 0.5 ft to 0.75 ft in Stratum E and 0.15 ft in Stratum H. MODPATH particle tracking runs show that the minimum time for the particles to reach the site boundary to the east varied between 96 years and 127 years, with longer time for lower hydraulic conductivity backfill material.

Increasing the recharge rate in the Units 3 & 4 power block area by three orders of magnitude (1 inch/year) resulted in a 0.5 ft groundwater head increase at Stratum C. The groundwater head increase in Stratum C was minimal when increasing the recharge rate by 100% and by 200%. In Stratum E, the maximum groundwater head increase in the power block area was about 0.0011 ft, 0.0014 ft, and 0.34 ft with 100%, 200%, and three order of magnitude increase of recharge rates, respectively. In Stratum H, the maximum groundwater head increase in the power block area was negligible with 100% and 200% recharge rate increases, respectfully. The maximum groundwater head increase in the power block area was 0.03 ft for the three orders of magnitude increase in the recharge rate.

A model run was conducted with a combination of the three-orders of magnitude recharge rate (1 inch/year) and an excavation backfill hydraulic conductivity value of 5×10^{-4} cm/sec. The purpose of this run was to determine the probable maximum groundwater head increase at the power block area. The result of the model run showed the maximum groundwater head increase in Stratum C at the power block area was about 1.24 ft. However, groundwater heads decreased in Strata E and H at the power block area by 1.2 ft and 0.15 ft, respectively. Particle tracking analysis indicates that particles released in the vicinity of the Units 3 & 4 radwaste and reactor buildings will travel through the backfill material to Stratum E, to the eastern site boundary. The minimum travel time was approximately 125 years. Sensitivity analyses performed indicate that the maximum groundwater head at STP Units 3 & 4 for steady state conditions remain below the defined site characteristic maximum groundwater elevation of 28 ft MSL.

7. CONCLUSIONS

A three-dimensional multiple-layer model was developed to simulate groundwater flow under present and post-construction conditions at the STP site. The model was developed using available historic data and data collected in support of the COLA. The model was calibrated to water level data collected in September 2008 (Run 301).

The calibrated model was used to simulate post-construction conditions, accounting for the presence of backfill material, slurry walls and CFRWs, building foundations, and clay cap in the area of the proposed Units 3 & 4 structures. Particle tracking was performed to identify the groundwater pathways for postulated accidental liquid effluent releases points from Units 3 & 4.

The post-construction simulation results (Run 301PC) indicate that hypothetical effluent releases to the groundwater from within the power block area of Units 3 & 4 will move downward through the fill material within the power block area and then eastward through the Lower Shallow Aquifer (Stratum E) and to the eastern site boundary or will move in a southeasterly direction (Stratum H) towards the Colorado River. The simulation results indicate that an accidental release would not impact the Upper Shallow Aquifer within the vicinity of the power block but migrate downward to the Lower Shallow Aquifer through the fill material at Units 3 & 4.

Simulated groundwater levels were also examined under post-construction conditions (Run 301PC). In the post-construction scenario, simulated groundwater levels are lower in the Upper Shallow Aquifer at the Units 3 & 4 site relative to levels simulated in the calibrated model of existing pre-construction conditions (Run 301). Simulated water levels in the Lower Shallow Aquifer are higher at Units 3 & 4 relative to levels simulated in the pre-construction scenario. These water level changes occur because the simulation of the Unit 3 & 4 excavation requires the portion of the confining layer that separates the Upper and Lower Shallow Aquifers to be removed and replaced with structural fill that is relatively permeable. The fill material creates a greater degree of hydraulic connection between the Upper and Lower Shallow Aquifers. This allows the Upper Shallow Aquifer to contribute water to the Lower Shallow Aquifer and generates the water level changes noted above. Sensitivity analyses performed indicate that the maximum groundwater head at STP Units 3 & 4 for steady state post-construction conditions is below the identified site characteristic maximum groundwater elevation of 28 ft MSL, simulated elevation of approximately 21 ft MSL.

Run 301PC post-construction simulations are similar to the Run 201 simulations. A hypothetical effluent releases to the groundwater from within the power block area of Units 3 & 4 will move downward through the fill material within the power block area and then eastward through the Lower Shallow Aquifer and to the eastern site boundary. The maximum groundwater head at STP Units 3 & 4 for steady state post-construction conditions is below the identified site characteristic maximum groundwater elevation of 28 ft MSL.

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Table 1: Estimated Recharge Values for Gulf Coast Aquifer

Source	Recharge Rate (in/yr)	Study Area
Chowdhury et al., 2004	0.06	San Patricio to Jim Hogg counties
Chowdhury et al., 2004	0 to 6	Texas Gulf Coast
Chowdhury et al., 2004	6	Harris, Montgomery, and Walker counties
Chowdhury et al., 2004	0.12 to 0.25	Texas Gulf Coast
Chowdhury et al., 2004	0.32 to 0.43	Northern Gulf Coast GAM
Chowdhury et al., 2007	0.09 to 0.15	Southern Gulf Coast GAM
Chowdhury et al., 2004	0.06 (pre-development from 1910 to 1940) 0.09 (calibrated transient model (1989) 0.06 (calibrated transient model 1999)	Central Gulf Coast Groundwater Availability Model

Notes:

Recharge rates for Central Gulf Coast model from Chowdhury et al., 2004 (Tables 2, 4, and 5 and active cells covering 43,560 sq. mi)

Recharge rates for other studies cited in Chowdhury et al., 2004 (Table 1) and in Chowdhury et al., 2007 (Table 1)

Table 2: Pumping Test Results for Shallow Aquifer

Test Well	Stratum	MCR Embankment Station	Coordinates (feet NAD 27) Easting (X)	Coordinates (feet NAD 27) Northing (Y)	Test Well Screen Interval (feet MSL)	Number of Piezometers Monitored	Pumping Rate (gal/min)	Radius of Influence Distance (feet)	Radius of Influence Time (min)	Transmissivity (gal/day/feet)	Aquifer Thickness (feet)	Hydraulic Conductivity (gal/day/ sq feet)	Hydraulic Conductivity (feet/day)	Hydraulic Conductivity (cm/s)
Upper Shallow Aquifer														
WW3	C	–	2,945,065	361,275	2 to -16	7	10	500	1,300	1,100	17	65	8.6	0.0031
WW4	C	–	2,935,502	344,437	-10 to -26	18	50	600	2,750	12,500	30	420	56	0.020
											Minimum	65	8.6	0.0031
											Maximum	420	56	0.020
											Geometric Mean	165	22	0.0078
Lower Shallow Aquifer														
WW2[a]	E	–	2,945,056	361,270	-35 to -53	11	140	5,000	500	13,000	21.5	600	80	0.028
								5,200	17,000	14,000		651	87	0.031
WW1	E and H	–	2,955,734	347,930	-45 to -125	10	200	5,800	4,000	33,150	80	410	55	0.019
							300	3,350	1,000					
											Minimum	410	55	0.019
											Maximum	651	87	0.031
											Geometric Mean	506	68	0.024

Notes:

(a) Where multiple values are reported for one test well, the arithmetic mean is first calculated for that well before determining the geometric mean for all wells in each aquifer zone.

Sources:

Woodward-Clyde Consultants, 1975
Bechtel, 2010

Table 3: Slug Test Results for Shallow Aquifer (Sheet 1 of 2)

Observation Well	Sand Stratum	Coordinates (feet NAD 27) Easting (X)	Northing (Y)	Filter Pack (feet MSL)	Hydraulic Conductivity: Rising Head Test Analyses (feet/day) Butler	Kansas Geological Survey	Bouwer-Rice	McElwee-Zenner	Springer-Gelhar	Falling Head Test Analyses (feet/day) Butler	Kansas Geological Survey	Bouwer-Rice	McElwee-Zenner	Springer-Gelhar	Arithmetic Mean (feet/day)	(gal/day/ft)	(cm/s)
Upper Shallow Aquifer - Stratum C (sorted in descending order of hydraulic conductivity)																	
OW-348U	C	2,942,994	362,685	7 to -9	P	83	88	NA	NA	68	71	65	NA	NA	75	561	0.03
OW-308U	C	2,943,354	363,196	-2 to -17	70	64	63	NA	NA	64	62	68	NA	NA	65	487	0.02
OW-349U	C	2,943,582	362,902	-2 to -17	P	P	43	NA	NA	P	P	53	NA	NA	48	359	0.02
OW-958U	C	2,951,470	358,680	10 to -9.5	NA	47	NA	NA	P	No data	No data	No data	No data	No data	47	349	0.02
OW-420U	C	2,942,019	362,902	-2 to -17	P	33	45	NA	NA	No data	No data	No data	No data	No data	39	292	0.01
OW-934U	C	2,948,234	362,080	3 to -13	P	32	33	NA	NA	49	P	40	NA	NA	39	288	0.01
OW-930U	C	2,949,507	360,210	5 to -11	P	23	32	NA	NA	P	47	48	NA	NA	38	281	0.01
OW-438U	C	2,942,025	363,792	5 to -11	38	39	26	NA	NA	P	P	24	NA	NA	32	238	0.01
OW-931U	C	2,939,520	361,979	10 to -6	34	23	20	NA	NA	P	P	49	NA	NA	32	236	0.01
OW-953U	C	2,944,472	362,763	-4 to -18	P	29	NA	P	NA	No data	No data	No data	No data	No data	29	216	0.01
OW-910U	C	2,941,247	363,362	10 to -5	26	29	21	NA	NA	P	P	P	NA	NA	25	190	0.009
OW-332U	C	2,943,591	363,739	-1 to -16	37	36	27	NA	NA	19	18	11	NA	NA	25	185	0.009
OW-408U	C	2,942,456	363,194	4 to -12	17	11	11	NA	NA	22	32	28	NA	NA	20	151	0.007
OW-932U	C	2,942,097	361,899	7 to -8	21	13	14	NA	NA	P	16	22	NA	NA	17	129	0.006
OW-959U	C	2,953,294	358,472	2.9 to -11	NA	16	NA	NA	17	No data	No data	No data	No data	No data	16	123	0.006
OW-928U	C	2,940,356	364,934	6 to -10	19	P	8	NA	NA	19	16	16	NA	NA	16	117	0.006
OW-954U	C	2,943,894	366,226	3.3 to -12	12	15	NA	12	NA	No data	No data	No data	No data	No data	13	97	0.005
OW-962U	C	2,948,585	365,226	2.2 to -12	13	9	NA	13	NA	No data	No data	No data	No data	No data	12	86	0.004
OW-951U	C	2,941,337	361,186	13 to -0.9	8	16	NA	8	NA	No data	No data	No data	No data	No data	11	80	0.004
OW-956U	C	2,950,300	362,530	12 to -1.7	6	11	NA	6	NA	No data	No data	No data	No data	No data	8	57	0.003
OW-952U	C	2,942,756	361,195	-3 to -17	7	6	NA	7	NA	No data	No data	No data	No data	No data	7	52	0.002
OW-933U	C	2,943,495	361,898	6 to -8	P	10	3	NA	NA	8	5	3	NA	NA	6	43	0.002
OW-929U	C	2,945,478	364,672	-8 to -23	P	3	4	NA	NA	P	12	2	NA	NA	5	39	0.002
OW-955U	C	2,947,416	360,480	2.7 to -9.6	P	4	NA	P	NA	No data	No data	No data	No data	No data	4	29	0.001
OW-961U	C	2,955,406	356,192	1.9 to -12	3	6	NA	3	NA	No data	No data	No data	No data	No data	4	31	0.001
OW-950U	C	2,939,596	360,120	-1 to -16	P	3	NA	P	NA	No data	No data	No data	No data	No data	3	20	0.001
OW-957U	C	2,949,313	359,317	6.9 to -9	P	2	NA	NA	P	No data	No data	No data	No data	No data	2	14	0.0007
OW-960U	C	2,953,287	357,253	-4 to -20	NA	1	NA	NA	P	No data	No data	No data	No data	No data	1	8	0.0004
														Minimum	1	8	0.0004
														Maximum	75	561	0.03
														Geometric Mean	14	107	0.005

Table 3: Slug Test Results for Shallow Aquifer
(Sheet 2 of 2)

Observation Well	Sand Stratum	Coordinates (feet NAD 27) Easting (X)	Coordinates (feet NAD 27) Northing (Y)	Filter Pack (feet MSL)	Hydraulic Conductivity – Rising Head Test Analyses (feet/day) Butler	Rising Head Kansas Geological Survey	Rising Head Bouwer-Rice	Rising Head McElwee-Zenner	Rising Head Springer-Gelhar	Falling Head Test Analyses (feet/day) Butler	Falling Head Kansas Geological Survey	Falling Head Bouwer-Rice	Falling Head McElwee-Zenner	Falling Head Springer-Gelhar	Arithmetic Mean (feet/day)	Arithmetic Mean (gal/day/ft)	Arithmetic Mean (cm/s)
Lower Shallow Aquifer - Stratum E (sorted in descending order of hydraulic conductivity)																	
OW-956L	E	2,950,303	362,511	-68 to -82	P	P	NA	96	NA	No data	No data	No data	No data	No data	96	715	0.034
OW-308L	E & H	2,943,374	363,196	-52 to -67	64	67	65	NA	NA	72	73	56	NA	NA	66	495	0.02
OW-408L	E	2,943,603	362,902	-34 to -50	P	72	P	NA	NA	70	68	50	NA	NA	65	486	0.02
OW-933L	*E*	2,942,116	361,899	-43 to -58	P	51	63	NA	NA	P	P	64	NA	NA	59	444	0.02
OW-348L	E	2,943,609	363,729	-34 to -49	58	46	44	NA	NA	76	61	39	NA	NA	54	404	0.02
OW-332L	E & H	2,943,611	363,740	-57 to -73	53	54	P	NA	NA	49	49	55	NA	NA	52	389	0.02
OW-349L	E	2,943,014	362,686	-36 to -52	63	51	35	NA	NA	43	40	52	NA	NA	47	354	0.02
OW-953L	E	2,944,473	361,743	-39 to -54	P	39	NA	P	NA	No data	No data	No data	No data	No data	39	292	0.01
OW-934L	E	2,943,515	361,898	-56 to -71	P	P	35	NA	NA	P	P	32	NA	NA	34	251	0.01
OW-959L	E	2,953,295	358,451	-44 to -58	19	P	NA	19	NA	No data	No data	No data	No data	No data	19	139	0.007
OW-932L	E	2,949,526	360,214	-33 to -49	24	23	18	NA	NA	22	22	25	NA	NA	22	167	0.008
OW-955L	E	2,947,405	360,460	-37 to -51	24	23	NA	24	NA	No data	No data	No data	No data	No data	24	177	0.008
OW-952L	E	2,942,777	361,193	-37 to -52	14	23	NA	14	NA	No data	No data	No data	No data	No data	17	127	0.006
OW-950L	E	2,939,595	360,135	-91 to -105	2	3	NA	2	NA	No data	No data	No data	No data	No data	2	16	0.0008
OW-910L	*E*	2,942,045	363,791	-46 to -61	3	0.3	0.6	NA	NA	2	0.9	0.5	NA	NA	1	9	0.0004
OW-958L	E	2,951,490	358,670	-70 to -83	P	P	NA	P	NA	No data	No data	No data	No data	No data	NA	NA	NA
														Minimum	1	9	0.0004
														Maximum	96	715	0.03
														Geometric Mean	26	196	0.009
Lower Shallow Aquifer - Stratum H (sorted in descending order of hydraulic conductivity)																	
OW-961L	H	2,955,403	356,174	-77 to -92	179	P	NA	173	NA	No data	No data	No data	No data	No data	176	1,316	0.06
OW-929L	H	2,940,376	364,932	-46 to -61	56	54	29	NA	NA	59	P	59	NA	NA	51	384	0.02
OW-930L	H	2,945,498	364,672	-65 to -80	40	37	27	NA	NA	24	15	19	NA	NA	27	202	0.010
OW-438L	H	2,942,473	363,196	-59 to -74	17	27	10	NA	NA	15	28	14	NA	NA	19	138	0.007
OW-928L	H	2,941,266	363,363	-76 to -91	19	11	7	NA	NA	P	24	21	NA	NA	16	123	0.006
OW-962L	H	2,948,586	365,206	-71 to -85	9	11	NA	9	NA	No data	No data	No data	No data	No data	10	72	0.003
OW-951L	H	2,941,355	361,192	-83 to -99	4	11	NA	4	NA	No data	No data	No data	No data	No data	6	47	0.002
OW-954L	H	2,943,894	366,206	-50 to -65	3	3	NA	3	NA	No data	No data	No data	No data	No data	3	23	0.001
OW-957L	H	2,949,330	359,307	-73 to -89	P	1	NA	P	NA	No data	No data	No data	No data	No data	1	7	0.0003
OW-960L	H	2,953,302	357,243	-70 to -84	P	P	NA	P	NA	No data	No data	No data	No data	No data	NA	NA	NA
														Minimum	1	7	0.0003
														Maximum	176	1,316	0.06
														Geometric Mean	13	99	0.005

Sources:

Bechtel, 2010

Notes:

"P" indicates poor curve match or questionable data;
"NA" indicates no result was provided for this method;
Stratum identified in bold italic font is assigned to the identified strata based on hydrogeologic interpretation.

Table 4: Laboratory Hydraulic Conductivity Test Results

Boring/Sample	Depth (feet)	Soil Type	Hydraulic Conductivity (cm/s)	Hydraulic Conductivity (feet/day)
Stratum A/B				
B-601 S2	3	Silty clay	3.6×10^{-7}	0.0010
B-241 T3	9	Silty clay	2.4×10^{-6}	0.0068
B-242 T3	9	Silty clay	1.2×10^{-6}	0.0034
B-601 T5	9	Silty clay	2.4×10^{-8}	0.000068
B-601 T9	29	Silty clay	2.6×10^{-8}	0.000074
		Geometric mean	2.3×10^{-7}	0.00065
Stratum D				
B-400 T11	39	Silty clay	4.0×10^{-8}	0.00011
Essential Cooling Pond (ECP)				
Two samples (average)		Clay	5×10^{-5}	0.14
Structural Backfill				
Sample 1	--	Sand	2×10^{-3}	5.7
Sample 2	--	Sand	3×10^{-3}	8.5

Source:

STPEGS UFSAR; Section 2.5.4.2.6 and Table 2.5.4-33

Table 5: Comparison of Historic and Recent Water Level Data for MCR Piezometers

		Water Level Elevation, feet MSL (NGVD 29)									
		Historic Data (Jan. 1985 - Sep. 2004)				Historic Data after Reservoir Filling (Jan. 1990 - Sep. 2004)				Recent Data (September 22-23, 2008)	
Well	Location	Number of Readings	Mean	Minimum	Maximum	Number of Readings	Mean	Minimum	Maximum	Water Level	Deviation from
Upper Shallow Aquifer - Stratum C											
P131	MCR toe	164	25.0	21.13	26.8	87	25.8	24	26.8	21.4	-4.4
P235	MCR toe	159	16.4	14.8	19.65	88	16.6	14.8	17.3	13.22	-3.3
P240	MCR toe	149	19.6	15.32	22.3	79	20.6	17.4	22.3	16.23	-4.4
P246	MCR toe	150	24.4	19.19	27.7	85	25.3	21.1	27.7	21.55	-3.7
P272[(a)]	MCR toe	152	13.7	9.83	15.5	88	14.5	13.5	15.5	14.7	0.2
P279	Adjacent to Plant Drainage Ditch		21.0	18.9	22.1	86	21.5	20.4	22.1	19.75	-1.7
P331	MCR intermediate berm	148	12.2	7.37	15	86	12.1	8.7	15	10.4	-1.7
P336	Adjacent to Kelly Lake	147	13.0	10.4	14.8	86	13.0	10.4	14.8	10.3	-2.7
P337	Adjacent to Kelly Lake	145	13.9	11.61	16.09	86	13.9	11.61	15.5	13.3	-0.6
P396	Adjacent to Plant Drainage Ditch	141	18.5	17.13	19.4	88	18.7	17.3	19.4	17.21	-1.5
P426	Adjacent to Little Robbins Slough	132	13.4	11.07	14.6	88	13.8	13.1	14.6	14.3	0.5
P446[(a)]	MCR toe	132	25.4	24.08	27	88	25.6	24.3	27	25	-0.6
P453	Adjacent to MCR Spillway	120	9.0	6.55	12.05	85	9.3	7.1	10.9	6.3	-3.0

Source: Bechtel, 2010

Note: (a) Data from June 29, 2008

Table 6: Water Levels for Model Calibration – September 2008
(Sheet 1 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer - Stratum C													
225A[e]	Units 1 & 2 Administration Bldg.	C	–	2,946,803	361,227	14.00	–	–	25.04	28.04	6.50	9.52	18.52
601	Northeast of Plant Area	C	–	2,949,991	364,507	37.00	–	–	27.26	29.24	10.90	12.82	16.42
602A[e]	North of Plant Area	C	–	2,942,959	364,315	40.00	–	–	31.31	33.29	8.45	10.15	23.14
OW-308U	Unit 3 Power Block Area	C	–	2,943,354	363,196	47.10	46.00	-16.12	29.88	31.80	8.2	10.12	21.68
OW-332U	Unit 3 Power Block Area	C	–	2,943,591	363,739	46.10	45.00	-14.76	30.24	32.10	9.0	10.87	21.23
OW-348U	Unit 3 Power Block Area	C	–	2,942,994	362,685	39.10	38.00	-7.49	30.51	32.28	8.6	10.40	21.88
OW-349U	Unit 3 Power Block Area	C	–	2,943,582	362,902	46.10	45.00	-15.60	29.40	31.29	7.8	9.73	21.56
OW-408U	Unit 4 Power Block Area	C	–	2,942,456	363,194	43.10	42.00	-10.50	31.50	33.57	9.8	11.85	21.72
OW-420U	Unit 4 Power Block Area	C	–	2,942,019	362,902	49.10	48.00	-15.75	32.25	33.79	10.5	12.03	21.76
OW-438U	Unit 4 Power Block Area	C	–	2,942,025	363,792	41.00	40.00	-9.47	30.53	32.18	9.1	10.75	21.43
OW-910U	Units 3 & 4 Heat Sink Basin	C	–	2,941,247	363,362	36.10	35.00	-4.31	30.69	32.32	9.4	11.06	21.26

Table 6: Water Levels for Model Calibration – September 2008
(Sheet 2 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer - Stratum C (Continued)													
OW-928U	Outside Power Block	C	–	2,940,356	364,934	39.60	38.50	-8.48	30.02	31.69	8.8	10.48	21.21
OW-929U(d)	Outside Power Block	C	–	2,945,478	364,672	60.10	59.00	-22.09	36.91	38.71	15.8	17.63	21.08
OW-930U	Outside Power Block	C	–	2,949,507	360,210	36.10	35.00	-9.38	25.62	27.33	9.1	10.84	16.49
OW-931U	Outside Power Block	C	–	2,939,520	361,979	36.00	35.00	-4.47	30.53	32.10	10.1	11.65	20.45
OW-932U	Outside Power Block	C	–	2,942,097	361,899	39.60	38.50	-7.15	31.35	32.83	9.1	10.55	22.28
OW-933U	Outside Power Block	C	–	2,943,495	361,898	37.10	36.00	-7.13	28.87	30.62	6.5	8.29	22.33
OW-934U	Outside Power Block	C	–	2,948,234	362,080	41.10	40.00	-11.46	28.54	30.39	10.5	12.37	18.02
OW-950U	Southwest of Plant Area	C	–	2,939,584	360,120	42.00	41.00	-12.96	28.04	29.33	4.4	5.65	23.68
OW-951U	Outside Power Block	C	–	2,941,337	361,188	30.00	29.00	1.05	30.05	31.39	7.1	8.40	22.99
OW-952U	Outside Power Block	C	–	2,942,756	361,195	45.00	44.00	-14.61	29.39	30.38	5.7	6.64	23.74
OW-953U	Outside Power Block	C	–	2,944,472	362,763	46.00	45.00	-16.08	28.92	29.85	8.3	9.25	20.60
OW-954U	Outside Power Block	C	–	2,943,894	366,226	46.00	45.00	-10.07	34.93	35.76	10.2	11.00	24.76

Table 6: Water Levels for Model Calibration – September 2008 (Sheet 3 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer – Stratum C (Continued)													
OW-955U	Between Kelly Lake & ECP	C	–	2,947,416	360,480	40.00	39.00	-7.53	31.47	32.46	12.6	13.58	18.88
OW-956U	East of ECP	C	–	2,950,300	362,530	29.00	28.00	0.30	28.30	29.38	10.9	11.93	17.45
OW-957U	Between Kelly Lake & ECP	C	–	2,949,313	359,317	34.00	33.00	-6.96	26.04	27.15	7.6	8.72	18.43
OW-958U	Between Kelly Lake & ECP	C	–	2,951,470	358,680	34.00	33.00	-7.47	25.53	26.71	9.0	10.14	16.57
OW-959U	Adjacent to Kelly Lake	C	–	2,953,294	358,472	36.00	35.00	-9.15	25.85	26.56	14.7	15.42	11.14
OW-960U	Adjacent to Kelly Lake	C	–	2,953,287	357,253	39.00	38.00	-18.44	19.56	20.50	5.4	6.32	14.18
OW-961U	Adjacent to Kelly Lake	C	–	2,955,406	356,192	25.00	24.00	-10.10	13.90	15.14	3.6	4.80	10.34
OW-962U	Northeast of Plant Area	C	–	2,948,585	365,226	43.00	42.00	-9.80	32.20	33.14	10.6	11.57	21.57
P131 (a)(b)(c)	MCR toe	C	639+00	***2,950,165***	***358,693***		39	-14.0	***25***	31.0	3.60	7.75	21.40
P235 (a)(b)	MCR toe	C	125+50	***2,955,530***	***355,361***		27	-11.1	16.2	19.5	3.00	6.28	13.22
P240 (a)(b)	MCR toe	C	159+80	***2,955,880***	***351,840***		39	-22.8	16.2	20.9	0.00	4.67	16.23
P246 (a)(b)	MCR toe	C	536+50	***2,936,060***	***354,235***		40	-14.2	25.9	29.6	4.30	8.05	21.55

Table 6: Water Levels for Model Calibration – September 2008 (Sheet 4 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer - Stratum C (Continued)													
P272 (a)(b)(e)	MCR toe	C	446+90	***2,935,135***	***345,139***		46	-21.3	24.7	27.3	10.0	12.6	14.70
P279 (a)(b)	Adjacent to Plant Drainage Ditch	C	19+00	***2,946,230***	***360,866***		37	-10.9	25.8	29.1	6.0	9.4	19.75
P331 (a)(b)	Adjacent to Kelly Lake	C	97+50	***2,953,427***	***357,646***		20	-6.5	13.6	19.4	3.2	9.0	10.40
P336 (a)(b)	Adjacent to Kelly Lake	C	117+50	***2,954,700***	***356,470***		22	-9.2	12.6	16.5	2.3	6.2	10.27
P337 (a)(b)	Adjacent to Kelly Lake	C	102+50	***2,953,615***	***356,936***		22	-8.9	13.3	16.6	0.0	3.3	13.30
P396 (a)(b)	Adjacent to Plant Drainage Ditch	C?	49+80	***2,948,900***	***359,414***		15	7.2	22.5	26.2	5.3	9.0	17.21
P426 (a)(b)(e)	Adjacent to Little Robbins Slough	C	386+50	***2,940,010***	***342,176***		35	-12.7	22.1	25.1	7.8	10.8	14.30
P446 (a)(b)(c)(e)	MCR toe	C?	608+50	***2,939,975***	***360,078***		26	1.9	***28***	29.4	3.0	–	25.00
P453 (a)(b)	Adjacent to MCR Spillway	C?	226+40	***2,956,315***	***344,524***		17	1.6	18.1	22.1	11.8	15.8	6.30
Lower Shallow Aquifer - Stratum E													
225C (e)	Units 1 & 2 Administration Bldg.	*E?*	–	2,946,759	361,215	69	–	–	25.0	28.1	12.20	15.80	12.29
437	South of MCR	*E?*	–	2,948,389	341,979	73.5	–	–	20.6	22.5	4.40	6.90	15.55

Table 6: Water Levels for Model Calibration – September 2008 (Sheet 5 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer – Stratum E (Continued)													
OW-308L	Unit 3 Power Block Area	E & H	–	2,943,374	363,196	97.10	96.00	-66.13	29.87	31.78	14.5	16.4	15.39
OW-332L	Unit 3 Power Block Area	E & H	–	2,943,609	363,729	103.10	102.00	-71.99	30.01	32.08	14.7	16.8	15.32
OW-348L	Unit 3 Power Block Area	E	–	2,943,014	362,686	79.10	78.20	-48.12	30.08	31.86	14.8	16.5	15.32
OW-349L	Unit 3 Power Block Area	E	–	2,943,603	362,902	81.10	80.00	-50.59	29.41	31.03	14.0	15.6	15.45
OW-408L	Unit 4 Power Block Area	E	–	2,942,473	363,196	81.30	80.20	-48.47	31.73	33.76	16.4	18.4	15.38
OW-910L[d]	Units 3 & 4 Heat Sink Basin	*E*	–	2,941,266	363,363	92.10	91.00	-60.25	30.75	32.48	15.3	17.0	15.46
OW-932L	Outside Power Block	E	–	2,942,116	361,899	79.60	78.50	-47.41	31.09	32.79	16.0	17.7	15.06
OW-933L[d]	Outside Power Block	*E*	–	2,943,515	361,898	87.10	86.00	-57.26	28.74	30.45	13.4	15.1	15.33
OW-934L	Outside Power Block	E	–	2,948,254	362,082	100.00	99.00	-69.96	29.04	30.94	15.9	17.8	13.13
OW-950L	Southwest of Plant Area	E	–	2,939,595	360,135	132.00	131.00	-103.06	27.94	29.03	13.5	14.6	14.47
OW-953L	Units 1 & 2 Power Block Area	E	–	2,944,473	362,743	82.00	81.00	-51.85	29.15	30.07	13.7	14.6	15.50
OW-955L	Between Kelly Lake & ECP	E	–	2,947,405	360,460	81.00	80.00	-48.96	31.04	32.13	17.7	18.8	13.32

Table 6: Water Levels for Model Calibration – September 2008
(Sheet 6 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer - Stratum E (Continued)													
OW-956L	East of ECP	E	–	2,950,303	362,511	109.00	108.00	-79.56	28.44	29.46	15.9	16.9	12.56
OW-959L	Adjacent to Kelly Lake	E	–	2,953,295	358,451	83.00	82.00	-56.29	25.71	26.62	14.4	15.3	11.35
Lower Shallow Aquifer - Stratum H													
601A	Northeast of Plant Area	*H?*	–	2,950,036	364,505	95	–	–	27.2	29.2	15.40	16.90	12.25
OW-438L	Unit 4 Power Block Area	H	–	2,942,045	363,791	104.10	103.00	-72.89	30.11	31.57	14.6	16.1	15.50
OW-928L	Outside Power Block	H	–	2,940,376	364,932	121.10	120.00	-90.19	29.81	31.56	14.2	15.9	15.64
OW-929L	Outside Power Block	H	–	2,945,498	364,672	98.10	97.00	-60.07	36.93	38.63	22.1	23.8	14.80
OW-930L	Outside Power Block	H	–	2,949,526	360,214	106.50	105.00	-78.79	26.21	27.98	13.9	15.7	12.33
OW-951L	Outside Power Block	H	–	2,941,355	361,192	128.00	127.00	-97.13	29.87	30.96	15.0	16.1	14.85
OW-952L	Outside Power Block	H	–	2,942,777	361,193	80.00	79.00	-49.55	29.45	30.71	14.6	15.8	14.90
OW-954L	Outside Power Block	H	–	2,943,894	366,206	99.00	98.00	-62.96	35.04	36.00	19.6	20.5	15.46
OW-957L	Between Kelly Lake & ECP	H	–	2,949,330	359,307	114.00	113.00	-86.97	26.03	27.11	13.7	14.8	12.29

Table 6: Water Levels for Model Calibration – September 2008 (Sheet 7 of 7)

Well	Location	Stratum	MCR	Coordinates (feet NAD 27)		Depth (feet bgs)		Elevation (feet MSL)			Water Level (September 22, 2008)		
			Embankment Station	Easting (X)	Northing (Y)	Well Depth	Screen Bottom	Screen Bottom	Ground Surface / Well Pad	Reference Point	Depth (ft bgs)	Depth (ft btoc)	Elevation (ft MSL)
Upper Shallow Aquifer - Stratum H (Continued)													
OW-958L	Between Kelly Lake & ECP	H	–	2,951,490	358,670	107.90	106.90	-81.45	25.45	26.45	13.7	14.7	11.80
OW-960L	Adjacent to Kelly Lake	H	–	2,953,302	357,243	102.50	101.50	-81.93	19.57	20.62	8.3	9.4	11.27
OW-961L	Adjacent to Kelly Lake	H	–	2,955,403	356,174	105.00	104.00	-89.60	14.40	15.45	3.5	4.6	10.90
OW-962L	Northeast of Plant Area	H	–	2,948,586	365,206	116.00	115.00	-82.85	32.15	33.17	18.6	19.6	13.56

Sources:
Bechtel, 2010;
STPEGS UFSAR;

Notes:
(a) Bold italic font for strata indicates estimated based on screen elevation (geologic log not available).
(b) Bold italic font for coordinates indicates estimate initially based on MCR embankment stationing and approximate offset from embankment crest, and then adjusted based on field inspection during water level measurement.
(c) Bold italic font for ground surface elevation indicates estimated from aerial data (P2 Energy Solutions/ Tobin, 2007). Accuracy expected between 1 ft and 2 ft.
(d) Strata identified in bold italic font is assigned to the identified strata based on hydrogeologic interpretation.
(e) Data from June 29, 2008, STPEGS UFSAR; Table 2.5.4-20

Abbreviations:
bgs - below ground surface
btoc - below top of casing/reference point

Table 7: MCR Relief Well Discharge, Comparison between Data and Model

Drain Line Location	MCR Station (ft)[a]		MCR Discharge Captured by Relief Wells (gpm)			MCR Discharge Captured by Relief Wells (percentage of total captured)		
	Start	End	Average from Data[b] (gpm)	Revision 2 Run 201[c] (gpm)	Revision 3 Run 301[c] (gpm)	Average from Data[b] (%)	Revision 2 Run 201 (%)	Revision 3 Run 301 (%)
East1	162+00	180+50	11.3	74.3	63.7	1.1	4.3	3.5
East2	181+00	191+80	7.2	39.0	33.6	0.7	2.3	1.8
East3	191+86	202+00	5.3	2.6	1.4	0.5	0.2	0.1
East4	202+40	230+60	74.8	0.0	0.0	7.2	0.0	0.0
North1	643+00	653+00	0.8	0.0	0.0	0.1	0.0	0.0
North2	0+00	14+00	0.0	0.0	0.0	0.0	0.0	0.0
Northeast*	32+00	121+00	87.4	341.3	359.4	8.5	19.9	19.7
Northwest1	566+00	579+80	68.9	51.2	21.5	6.7	3.0	1.2
Northwest2	585+30	616+00	68.9	0.0	0.0	6.7	0.0	0.0
South1	282+60	316+60	120.5	45.5	32.2	11.7	2.7	1.8
South2	317+00	348+50	98.9	73.4	62.2	9.6	4.3	3.4
South3	349+50	367+30	30.3	89.1	86.6	2.9	5.2	4.8
South4	379+00	413+90	119.7	535.2	637.2	11.6	31.2	35.0
Southeast*	230+90	282+17	66.2	15.4	2.5	6.4	0.9	0.1
Southwest	415+67	457+15	160.8	288.5	370.7	15.6	16.8	20.3
West1	459+10	566+00	91.9	123.4	126.2	8.9	7.2	6.9
West2	543+50	585+30	20.9	36.9	24.6	2.0	2.2	1.4
Totals			1033.9	1715.8	1821.8	100.0	100.0	100.0

(a) Wells are not evenly spaced around the MCR perimeter; consequently, drain lines do not form a continuous perimeter.
(b) Discharge values compiled from 41 instantaneous measurements collected between 9/1/1985 and 12/4/2004.
(c) Captured MCR discharge is generally interpreted as the simulated flow from the model domain within a budget zone to the drain line boundary location representing the relief wells except when this value exceeds the simulated inflow to the budget zone from the MCR bottom. In this case, the simulated flow into the budget zone from the MCR bottom is used to represent flow to the relief wells because not all MCR seepage is captured by relief wells in reality.
* Groundwater models include sand drains in these areas in addition to relief wells. Data only include discharge from relief wells.

Table 8: Hydraulic Conductivity Values Employed in Models

Strata or Location	Revision 1 (Run 101)		Revision 2 (Run 201)		Revision 3 (Run 301)	
	Layer[a]	Conductivity (cm/s)	Layer[a]	Conductivity (cm/s)	Layer[a]	Conductivity (cm/s)
A/B Clays	1 - H	3.00E-07	1 and 2 - H	3.00E-07	1 and 2 - H	3.00E-07
	1 - V	3.00E-08	1 and 2 - V	3.00E-08	1 and 2 - V	3.00E-08
C Sand	2 - H	3.00E-02	3 - H	3.00E-02	3 - H	3.00E-02
	2 - V	3.00E-02	3 - V	3.00E-02	3 - V	3.00E-02
D Clay	3 - H	3.00E-07	4 - H	3.00E-07	4 - H	3.00E-07
	3 - V	3.00E-08	4 - V	3.00E-08	4 - V	3.00E-08
E Sand	4 - H	3.00E-02	5 - H	3.00E-02	5 - H	3.00E-02
	4 - V	3.00E-02	5 - V	3.00E-02	5 - V	3.00E-02
F Clay	5 - H	3.00E-07	6 - H	3.00E-07	6 - H	3.00E-07
	5 - V	3.00E-08	6 - V	3.00E-08	6 - V	3.00E-08
H Sand	6 - H	3.00E-02	7 - H	3.00E-02	7 - H	3.00E-02
	6 - V	3.00E-02	7 - V	3.00E-02	7 - V	3.00E-02
Colorado River Bottom Sediment	1 and 2	1.00E-03 (H = V)	1,2, and 3	1.00E-03 (H = V)	1,2, and 3	1.00E-03 (H = V)
Units 1 & 2 and 3 & 4 Fill Material	1 - 4	2.50E-03 (H = V)	1 - 5	2.50E-03 (H = V)	1 - 5	2.50E-03 (H = V)
Sediment Covering MCR Sand Pits	1	1.00E-05 (H = V)	1 and 2	1.00E-05 (H = V)	1 and 2	N/A[b]

Note: H and V denote horizontal and vertical respectively.

Table 9: Drain Conductance and Hydraulic Conductivity of Surface Water Features

Plant Area Drainage Ditches and Little Robbins Slough (Figure 33)			
Drain Line	Section	Conductance	
		ft/day per ft	cm/s per ft
Re-located Little Robbins Slough	1	200.0	7.06E-02
	2	80.0	2.82E-02
	3	0.5	1.76E-04
	4	0.5	1.76E-04
	5	5.0	1.76E-03
	6	2.5	8.82E-04
East-West Upper		200.0	7.06E-02
East-West Lower		0.1	3.53E-05
Ditch - D10		200.0	7.06E-02

Levee-Bound Irrigation Channels (Figure 32)	
Irrigation Ditch Segment	Riverbed Hydraulic Conductivity (cm/s)
East-West 1	3.00E-10
East-West 2	3.00E-10
North-South 1	3.00E-10
North-South 2	3.00E-10
North-South 3	3.00E-10
Spur 1	4.50E-06
Spur 2	4.50E-06
Spur 3	3.00E-10
Spur 4	3.00E-10
Spur 5	3.00E-10

Table 9: Drain Conductance and Hydraulic Conductivity of Surface Water Features - Continued

MCR Relief Wells and Sand Drains (Figure 31)			
Drain Line	Section	Conductance	
		ft/day per ft	cm/s per ft
North	1	15.0	5.29E-03
	2	15.0	5.29E-03
Northeast	1	15.0	5.29E-03
East	1	15.0	5.29E-03
	2	15.0	5.29E-03
	3	15.0	5.29E-03
	4	15.0	5.29E-03
Southeast	1	15.0	5.29E-03
	2	15.0	5.29E-03
South	1	15.0	5.29E-03
	2	15.0	5.29E-03
	3	15.0	5.29E-03
	4	7.5	2.65E-03
Southwest	1	15.0	5.29E-03
West	1	1.5	5.29E-04
	2	1.5	5.29E-04
Northwest	1	15.0	5.29E-03
	2	15.0	5.29E-03

Table 10: Model Calibration Statistics

Calibration		Revision 1	Revision 2	Revision 3
Run Label		**101**	**201**	**301**
Mass Balance Discrepancy, M_d (%)		0.01	-0.01	-0.015
Stratum	Model Layers	2,4,6	3,5,7	3,5,7
All Measurements Strata C, E, and H	Largest Residual (ft)	7.470	-6.590	-7.093
	Largest Residual Location	P453	437	437
	Smallest Residual (ft)	-0.003	0.032	-0.002
	Smallest Residual Location	OW-955L	OW-954U	OW-956U
	Residual Mean (ft)	0.096	0.216	-0.147
	Abs. Residual Mean (ft)	1.194	1.041	1.043
	Standard Error of Estimate	0.206	0.170	0.175
	Root Mean Squared (RMS) Error (ft)	1.752	1.458	1.493
	Normalized RMS (%)	9.370	7.796	7.983
	Correlation Coefficient	0.912	0.947	0.943
	Number of Data Points	73	73	73
Stratum C	Model Layer	2	3	3
	Largest Residual (ft)	7.470	-3.588	-3.586
	Largest Residual Location	P453	P131	P131
	Smallest Residual (ft)	-0.044	0.032	-0.002
	Smallest Residual Location	OW-348U	OW-954U	OW-956U
	Residual Mean (ft)	0.106	0.344	0.119
	Abs. Residual Mean (ft)	1.468	1.018	1.03
	Standard Error of Estimate	0.305	0.197	0.207
	Root Mean Squared (RMS) Error (ft)	2.004	1.338	1.361
	Normalized RMS (%)	10.714	7.154	7.278
	Correlation Coefficient	0.892	0.957	0.952
	Number of Data Points	44	44	44

Table 10: Model Calibration Statistics (continued)

Calibration		Revision 1	Revision 2	Revision 3
Run Label		**101**	**201**	**301**
Mass Balance Discrepancy, M_d (%)		0.01	-0.01	-0.015
Stratum	Model Layer	4	5	5
Stratum E	Largest Residual (ft)	-5.269	-6.590	-7.093
	Largest Residual Location	437	437	437
	Smallest Residual (ft)	-0.003	0.050	-0.023
	Smallest Residual Location	OW-955L	OW-933L	OW-332L
	Residual Mean (ft)	0.101	-0.147	-0.783
	Abs. Residual Mean (ft)	1.089	1.148	1.088
	Standard Error of Estimate	0.426	0.489	0.466
	Root Mean Squared (RMS) Error (ft)	1.652	1.901	1.967
	Normalized RMS (%)	39.327	45.273	46.825
	Correlation Coefficient	0.667	0.616	0.608
	Number of Data Points	16	16	16
Stratum H	Model Layer	6	7	7
	Largest Residual (ft)	1.502	2.790	2.336
	Largest Residual Location	OW-928L	OW-928L	OW-928L
	Smallest Residual (ft)	-0.025	0.180	0.099
	Smallest Residual Location	OW-957L	OW-951L	601
	Residual Mean (ft)	0.060	0.226	-0.265
	Abs. Residual Mean (ft)	0.394	0.987	1.033
	Standard Error of Estimate	0.156	0.339	0.343
	Root Mean Squared (RMS) Error (ft)	0.543	1.195	1.219
	Normalized RMS (%)	11.445	25.207	25.71
	Correlation Coefficient	0.974	0.967	0.962
	Number of Data Points	13	13	13

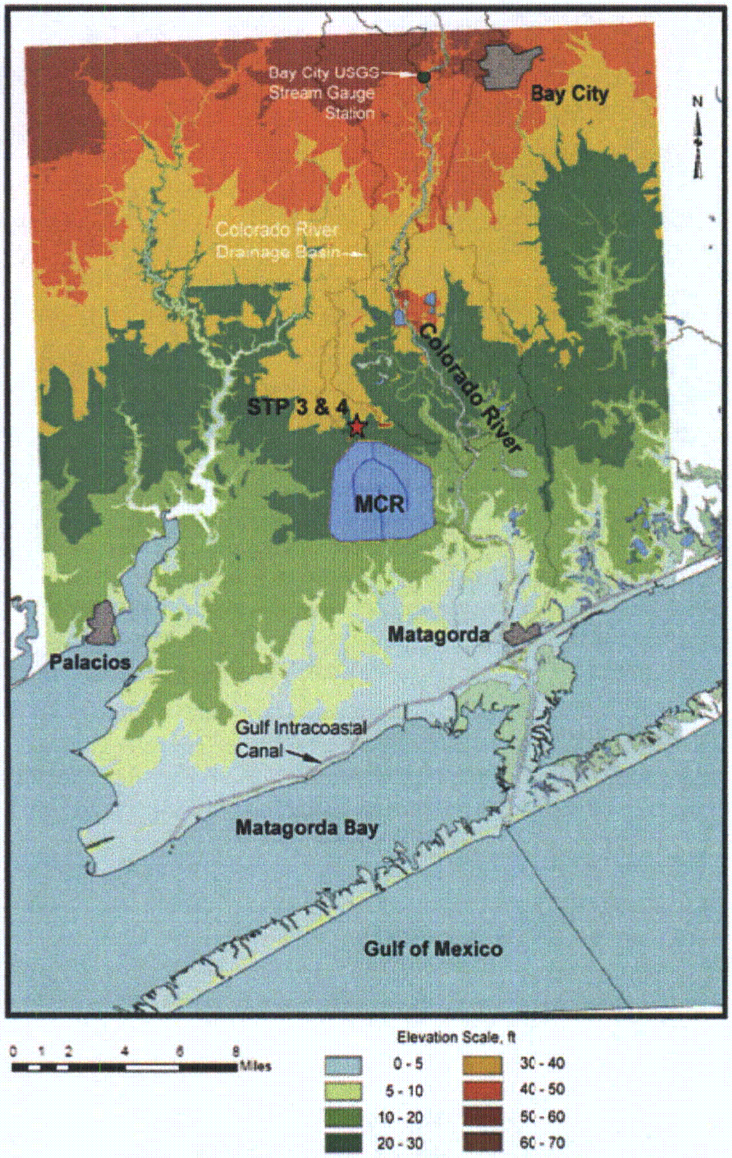
Table 11: Water Budget for Run 301

Model	Revision 3 (Run 301)	
Boundary	Water Budget (gpm)	
	Inflows	Outflows
MCR Discharge Total	3,700.6	0.0
Through Sand Pits	3,446.6	0.0
Through Remaining Portion of MCR	253.9	0.0
Precipitation/Recharge	2.0	0.0
ECP	0.8	0.0
Stratum C GHB	213.6	243.3
Stratum E GHB	217.1	99.6
Stratum H GHB	182.7	91.0
Levee-Bound Irrigation Canals	148.8	3.3
Livestock Well	0.0	0.4
Colorado River	0.3	669.6
Canals and Ditches in Stratum A/B	0.0	575.8
Little Robbins Slough and Plant Area Drainage Ditches in Stratum C	0.0	638.9
Kelly Lake	0.0	312.7
MCR Relief Wells and Sand Drains from MCR	0.0	1,821.1
MCR Relief Wells and Sand Drains from other Sources	0.0	10.8
Totals	**4,465.9**	**4,466.6**
Percent Discrepancy (M_d)	**-0.015**	

Table 12: MCR Relief Well Discharge Aggregated by Cardinal Direction

Direction	MCR Discharge Captured by Relief Wells (percentage of total captured)			
	Average from Data (%)	Revision 1 – Run 101 (%)	Revision 2 – Run 201 (%)	Revision 3 – Run 301 (%)
North	0.1	0.0	0.0	0.0
East*	18.0	19.7	26.6	25.1
South*	57.7	65.6	61.0	65.4
West	24.2	14.8	12.3	9.5

East includes Northeast, East1, East2, East3, and East 4 from Table 7.
South includes Southeast, South1, South2, South3, South4, and Southwest from Table 7.
West includes West1, West2, Northwest1, and Northwest 2 from Table 7.
North includes North1 and North2 from Table 7.



Source: STPEGS, 2010 ; Figure 2.4S.1-1

Figure 1: Site Location

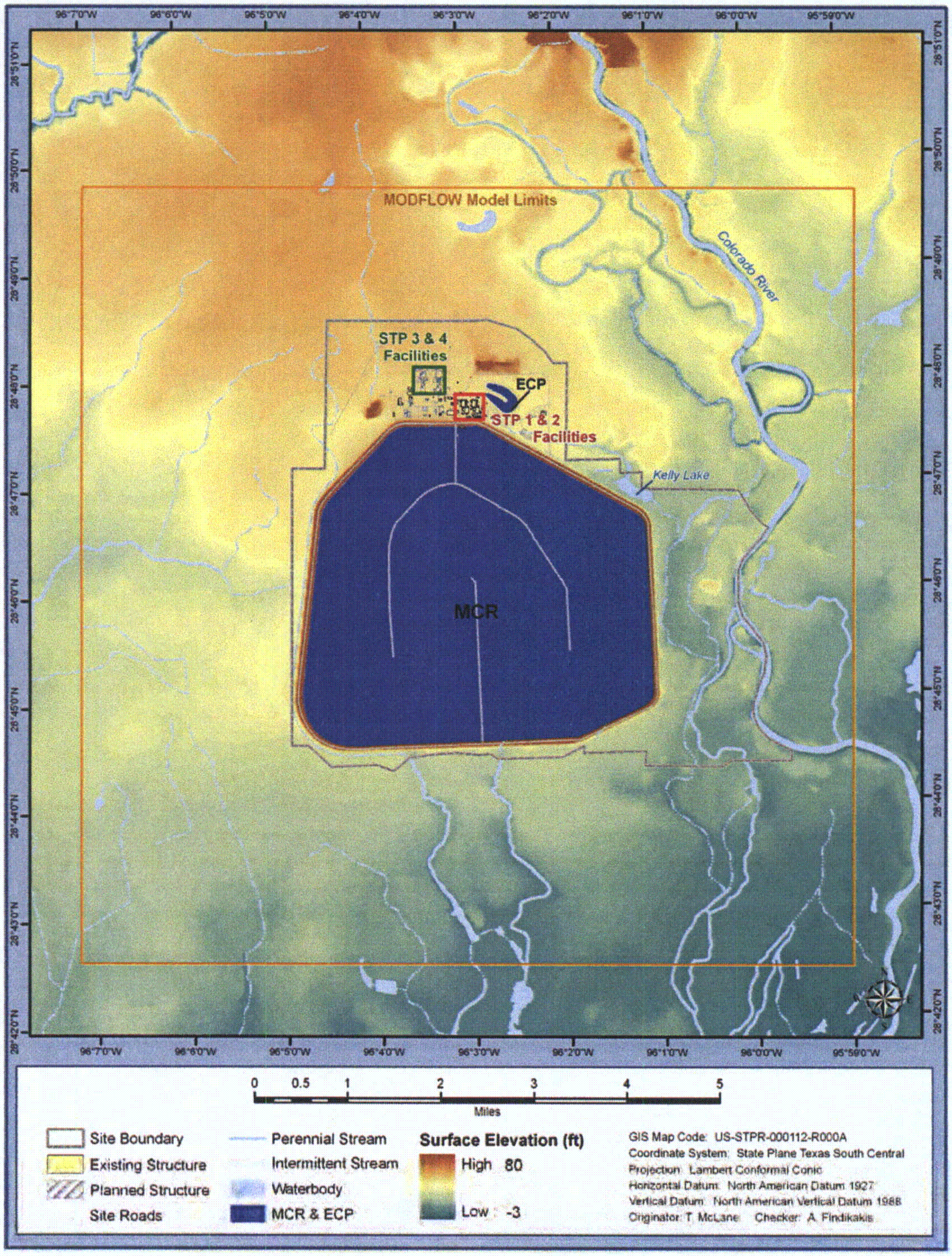


Figure 2: Site Topography

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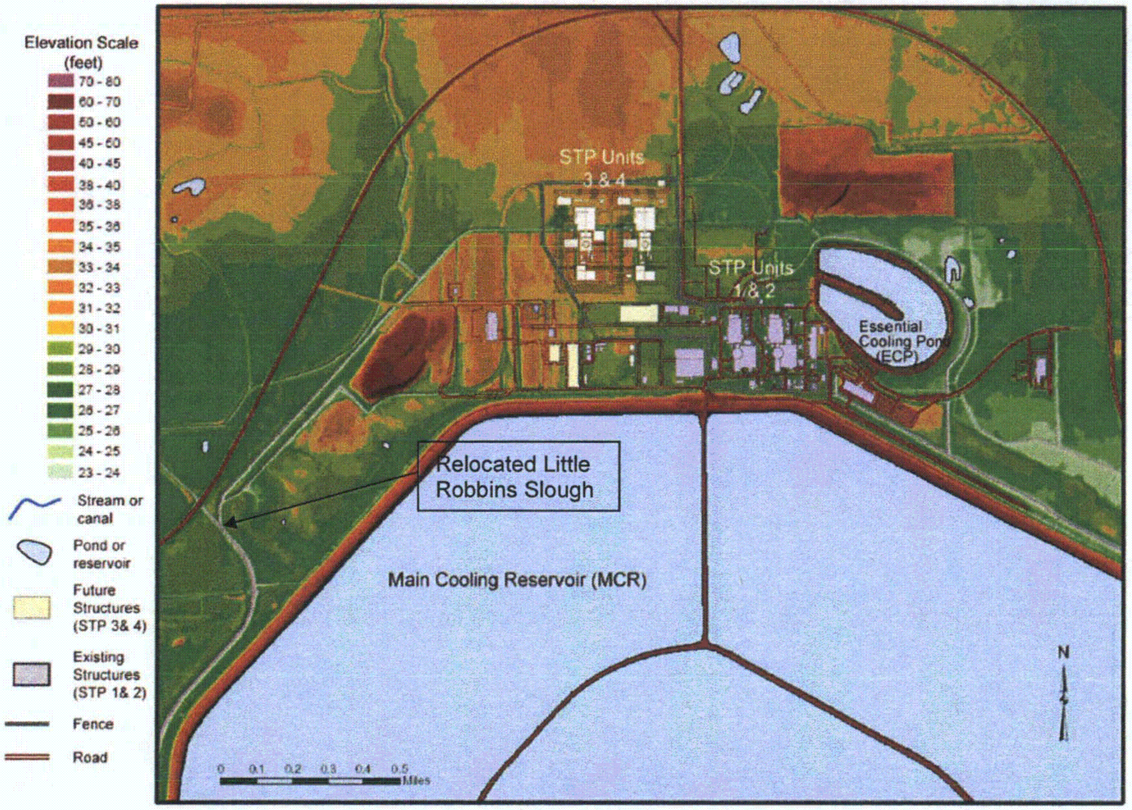

Source: STPEGS, 2010

Figure 3: Site Facilities

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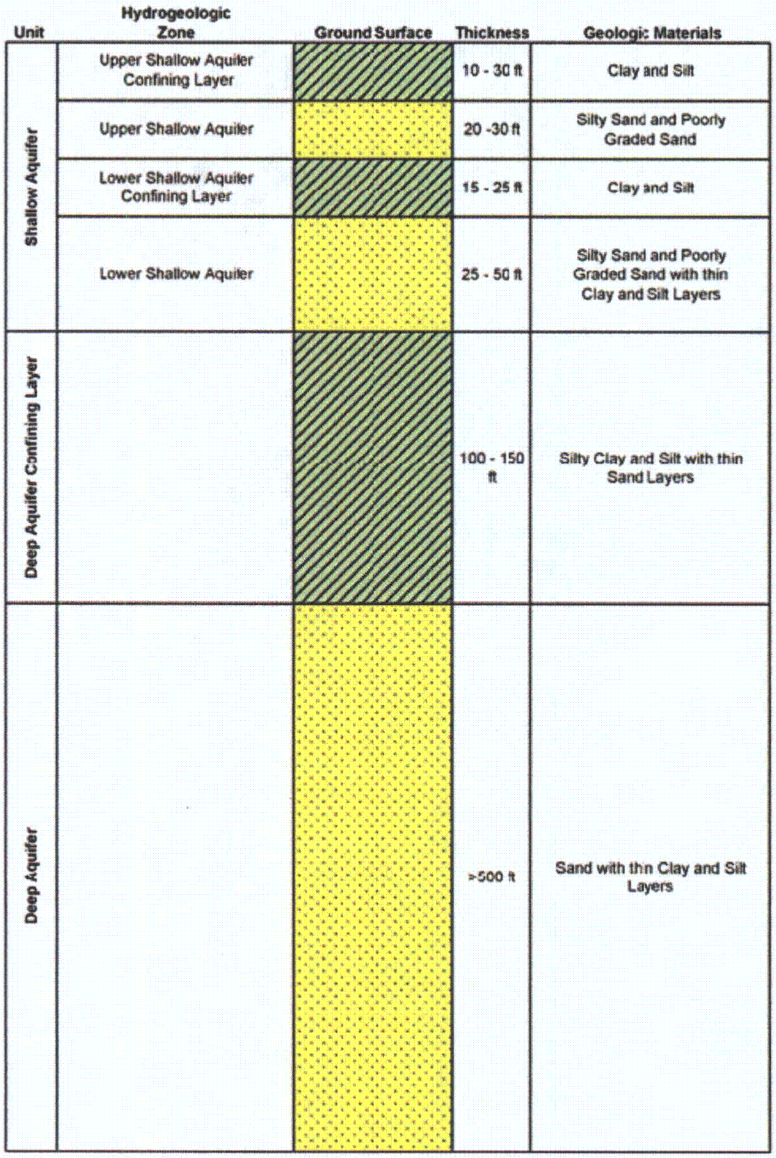
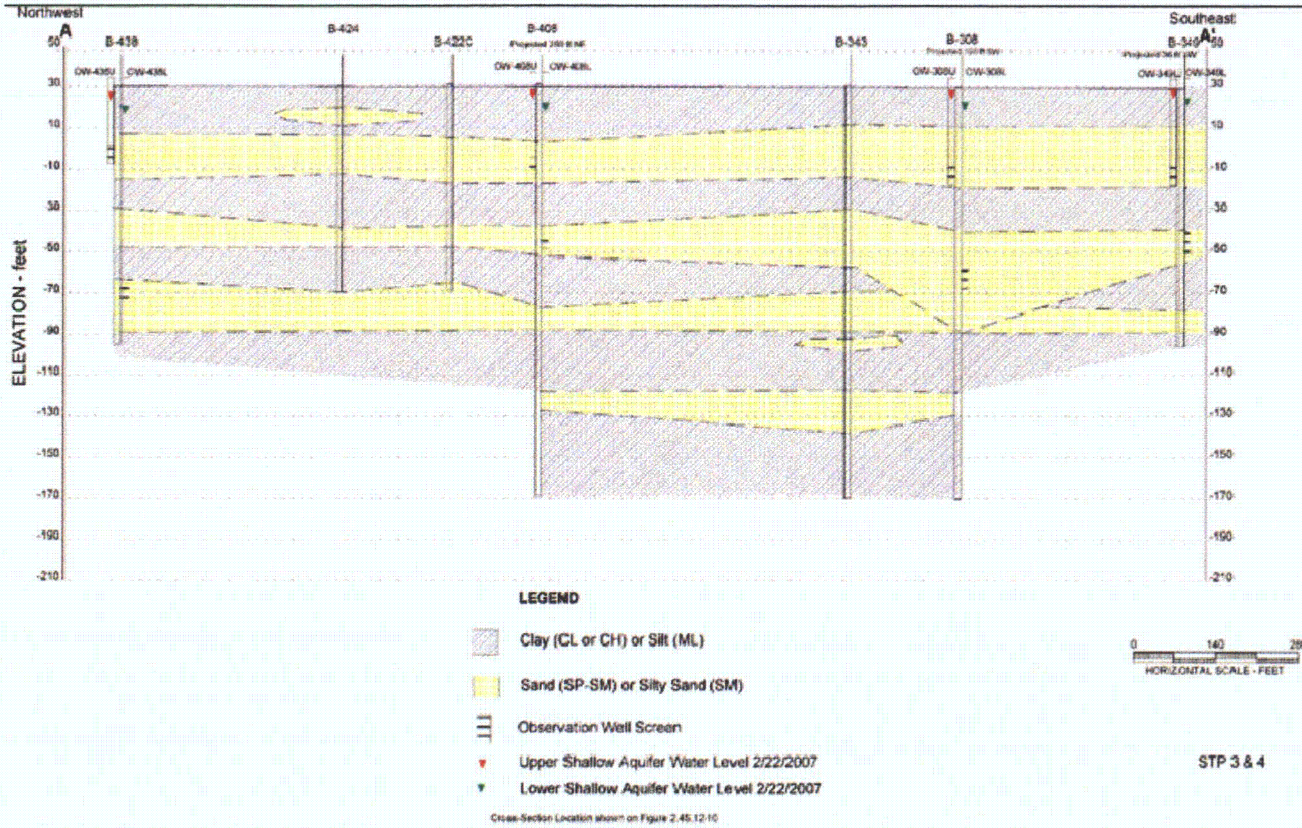


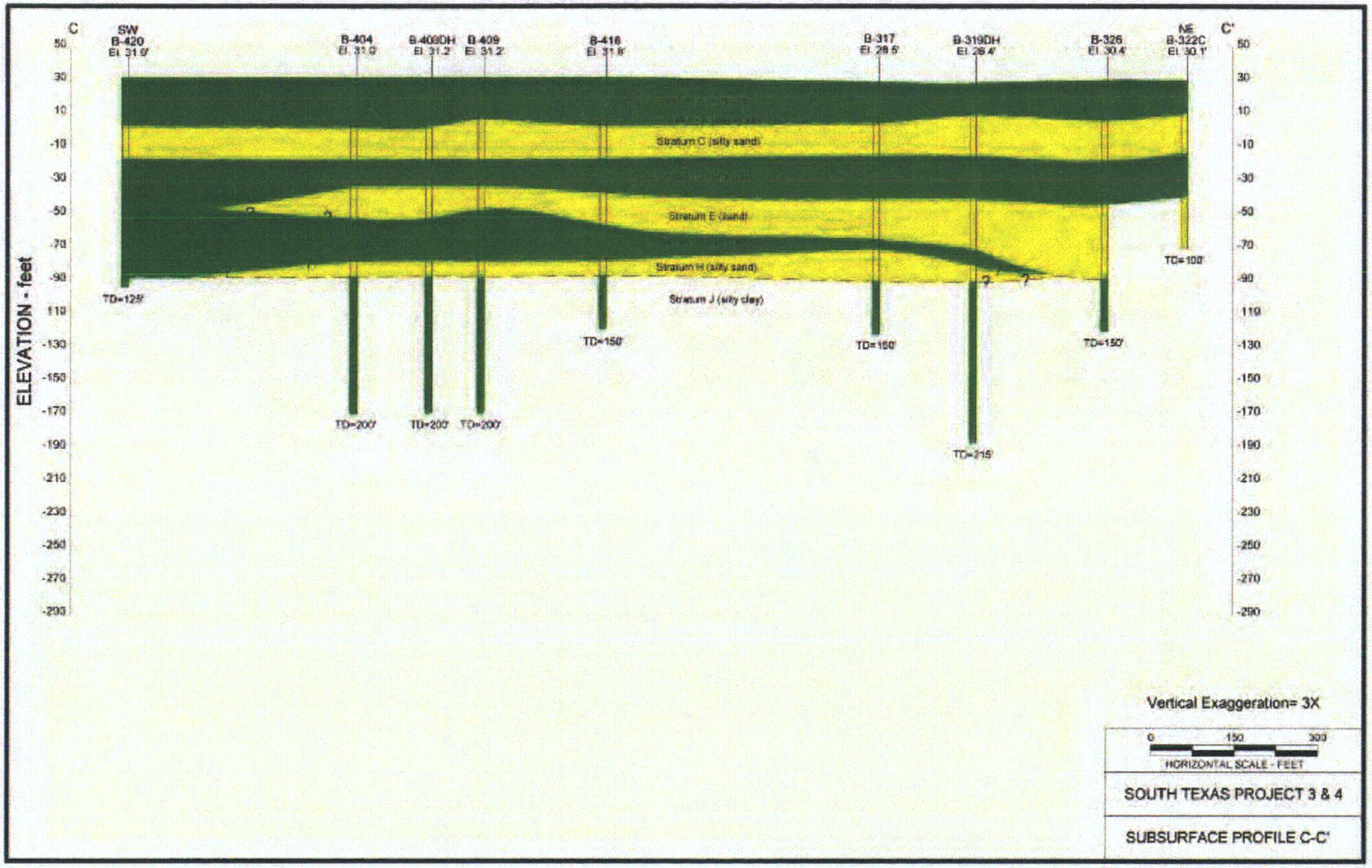
Source: STPEGS, 2010; Figure 2.4S.12-29

Figure 4: Hydrogeologic Column



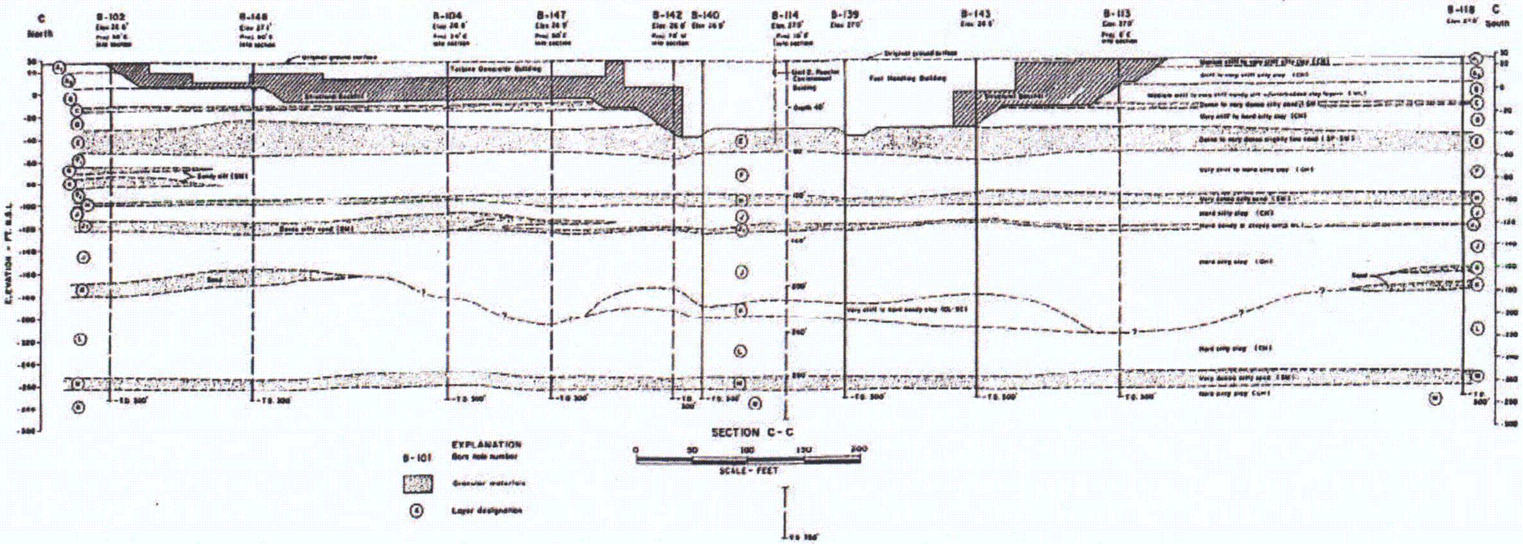
Source: STPEGS, 2010; Figure 2.4S.12-20. Location of cross section provided on STPEGS, 2010; Figure 2.4S.12-10.

Figure 5: Hydrogeologic Cross Section at STP 3 & 4



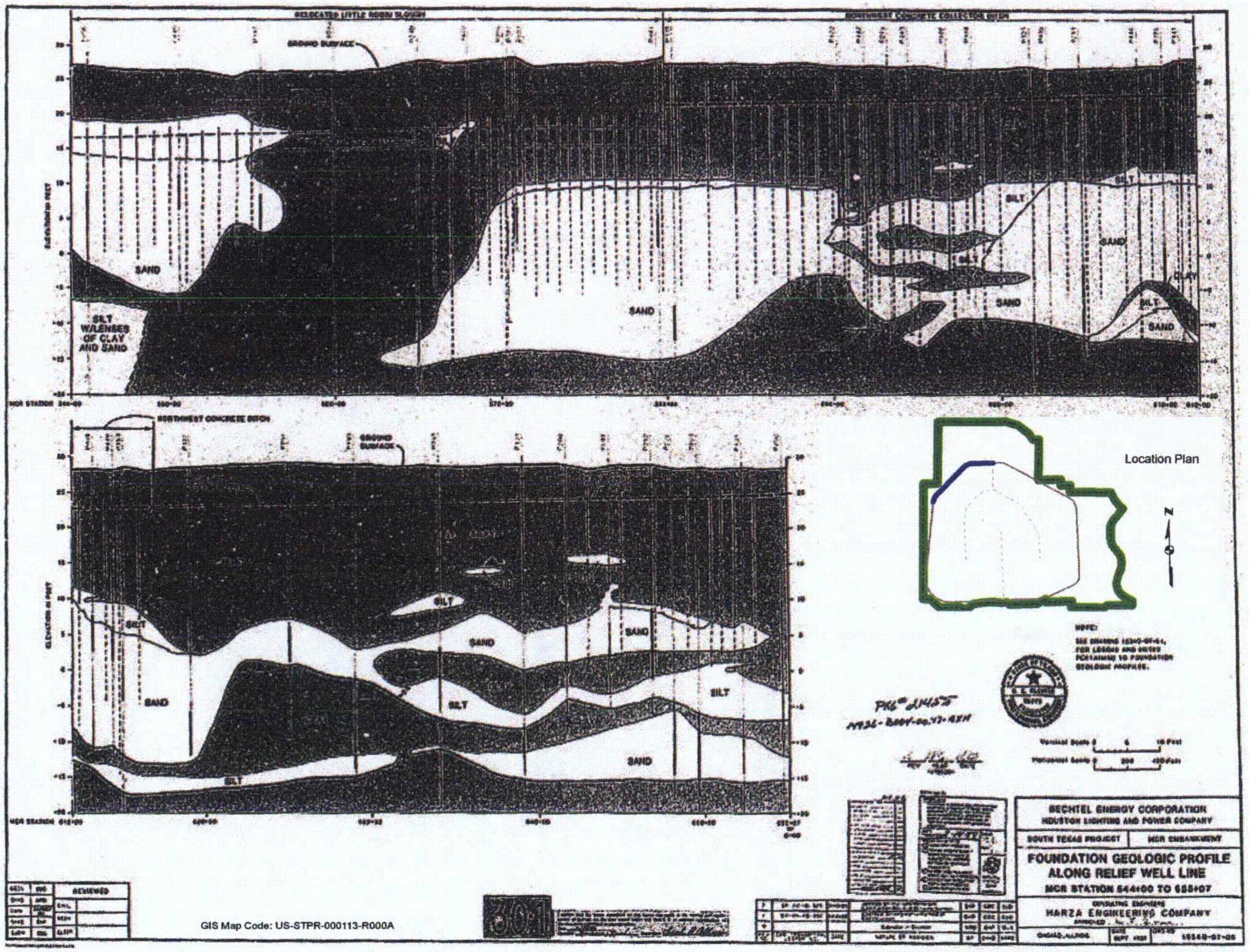
Source: STPEGS, 2010; Figure 2.5S.1-34. Location of cross section provided on STPEGS, 2010; Figure 2.5S.1-31.

Figure 6: Stratigraphic Cross Section at STP 3 & 4



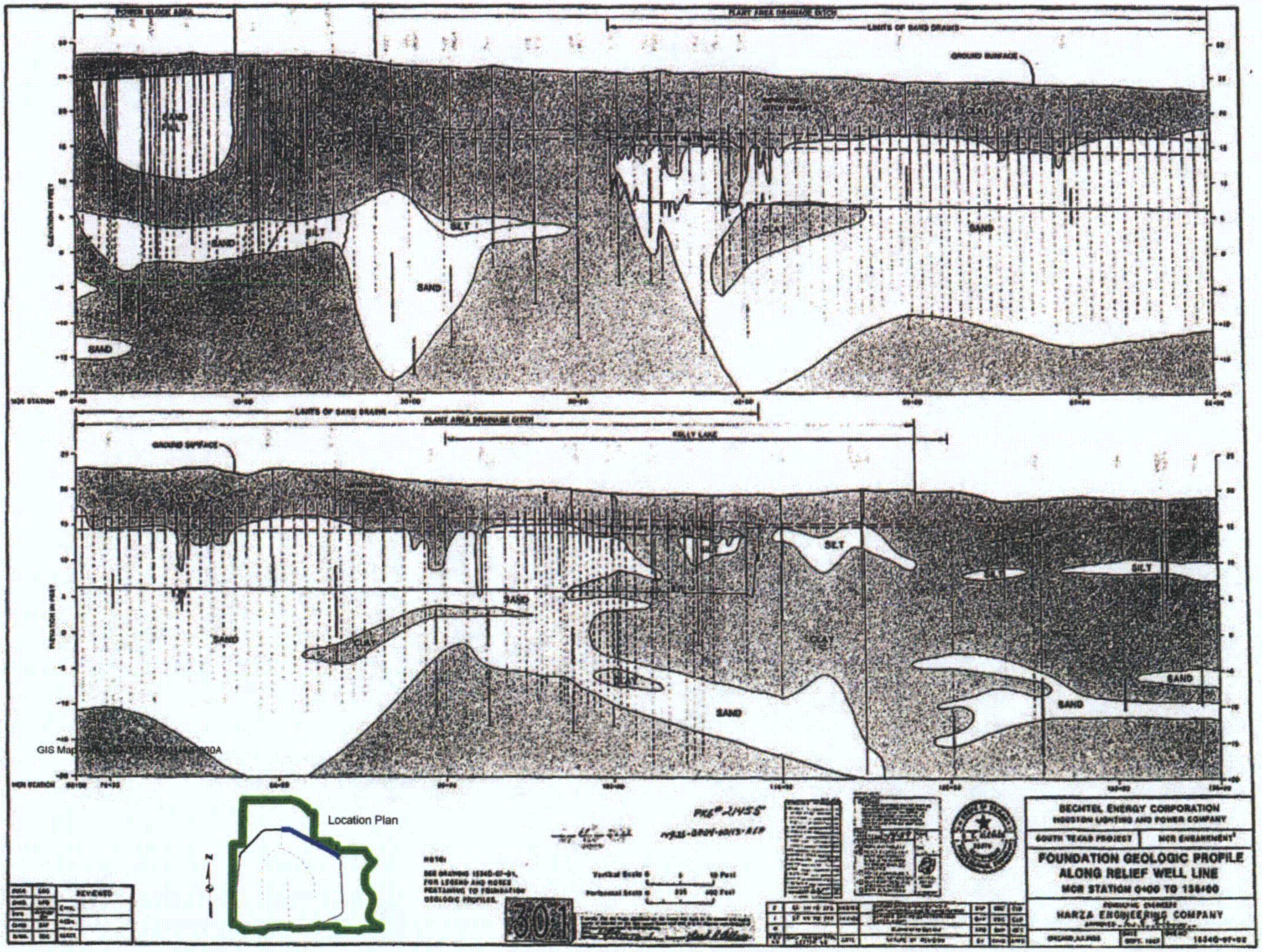
Source: STPEGS UFSAR; Figure 2.5.1-5. Location of cross section provided on STPEGS UFSAR; Figure 2.51-2.

Figure 7: Stratigraphic Cross Section at STP 1 & 2



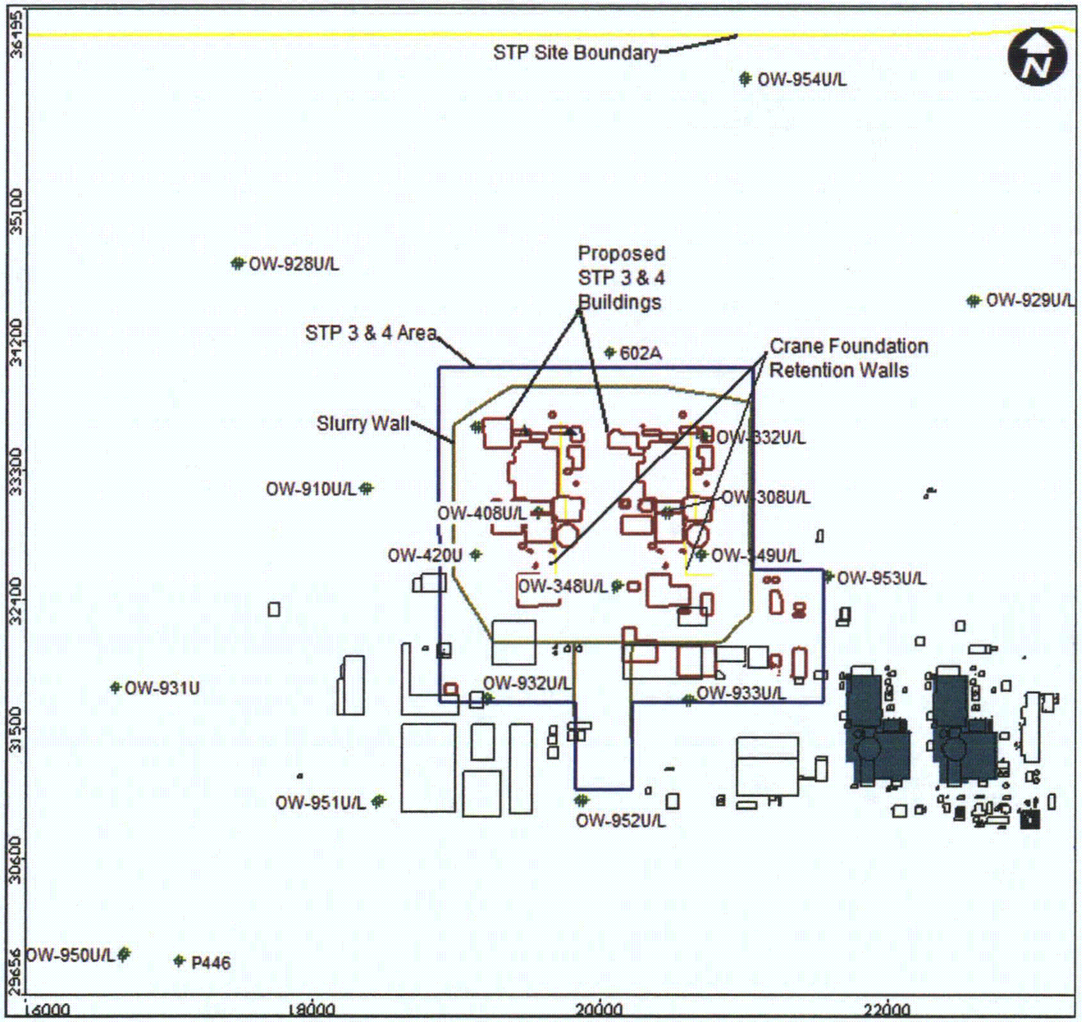
Note: "Sand" in cross section corresponds to Stratum C.
Source: Bechtel, 2010.

Figure 8: Stratigraphic Cross Section at North Embankment of MCR
(Sheet 1 of 2)



Note: "Sand" in cross section corresponds to Stratum C. Source: Bechtel, 2010.

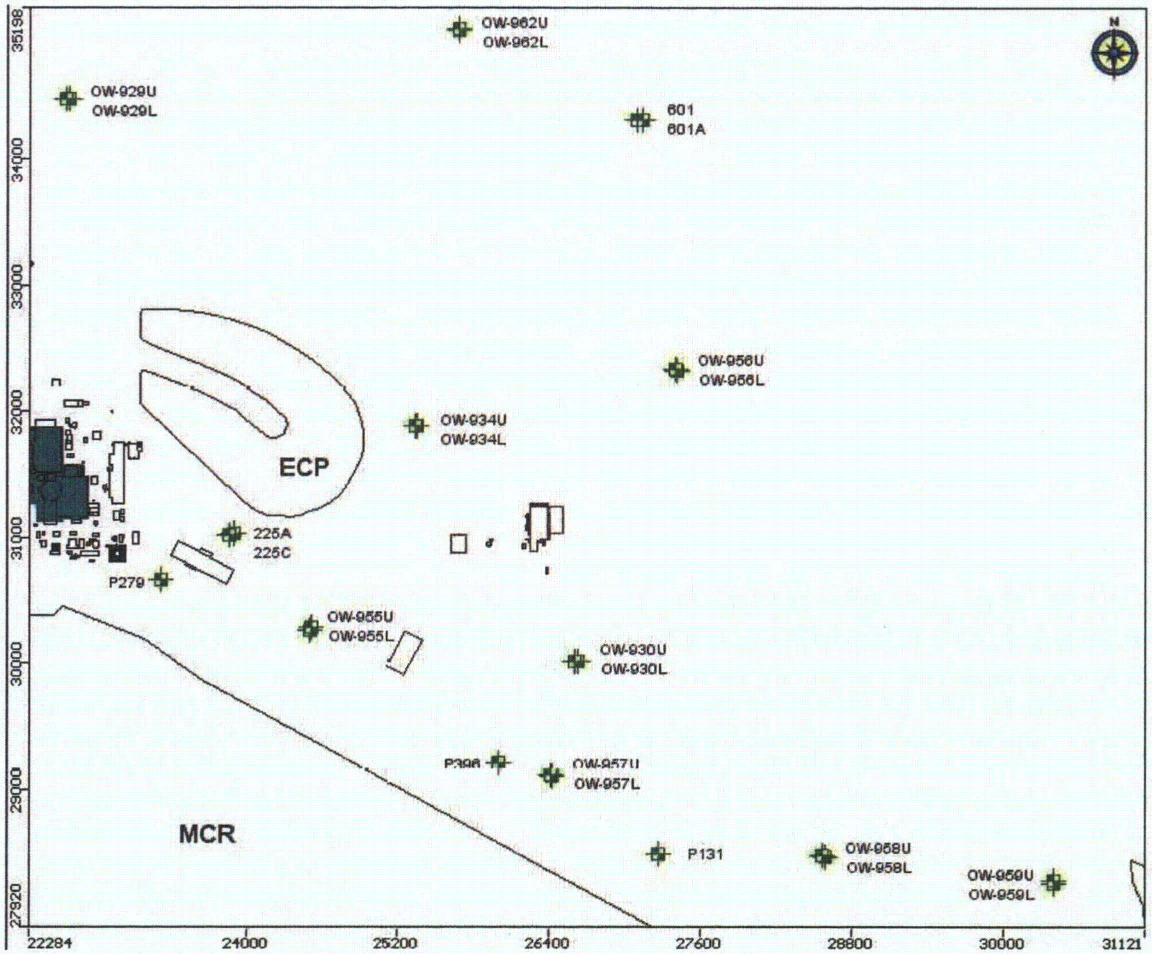
Figure 8: Stratigraphic Cross Section at North Embankment of MCR
(Sheet 2 of 2)



Note: Locations shown for wells and piezometers with measurements between December 2006 and September 2008.

Figure 9: Observation Wells and Piezometer Locations as Represented in the Groundwater Model

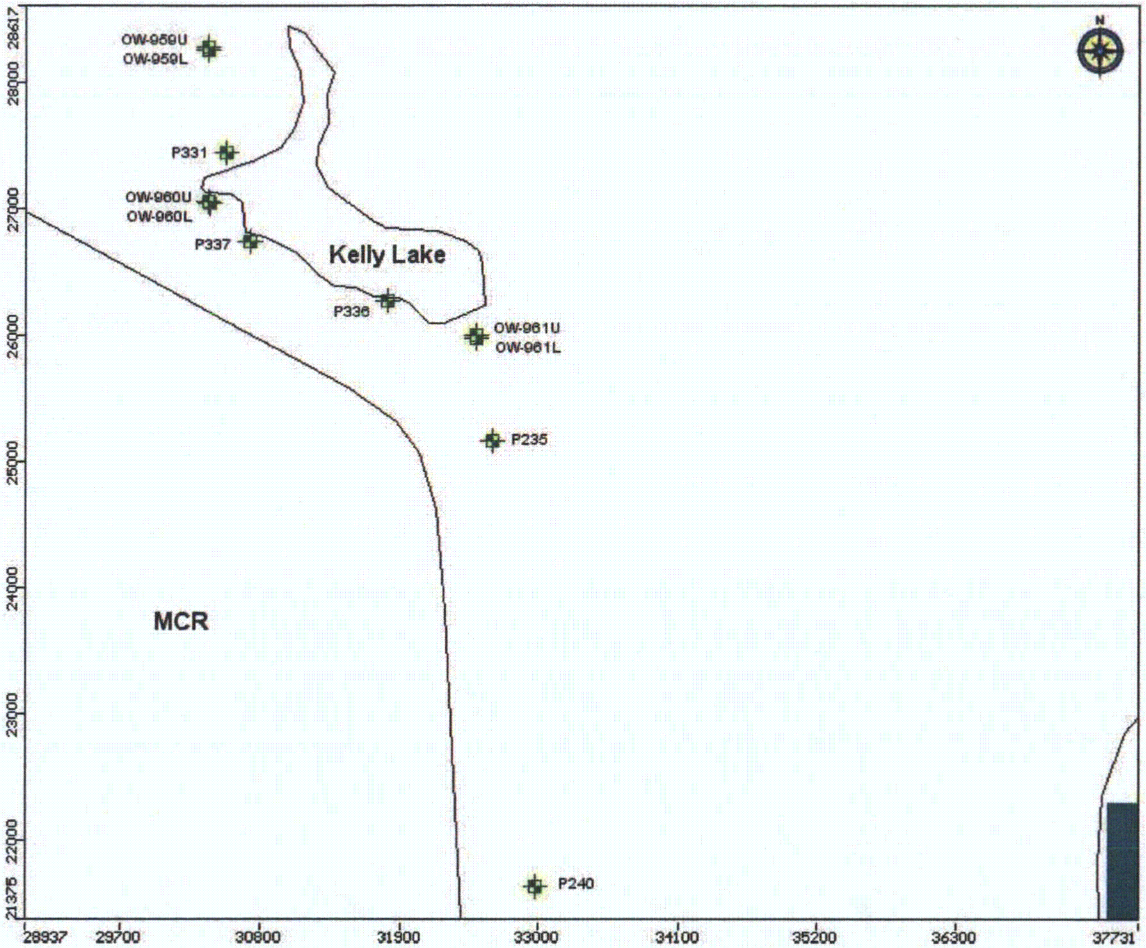
(Sheet 1 of 4)



Note: Locations shown for wells and piezometers with measurements between December 2006 and September 2008.

Figure 9: Observation Wells and Piezometer Locations as Represented in the Groundwater Model

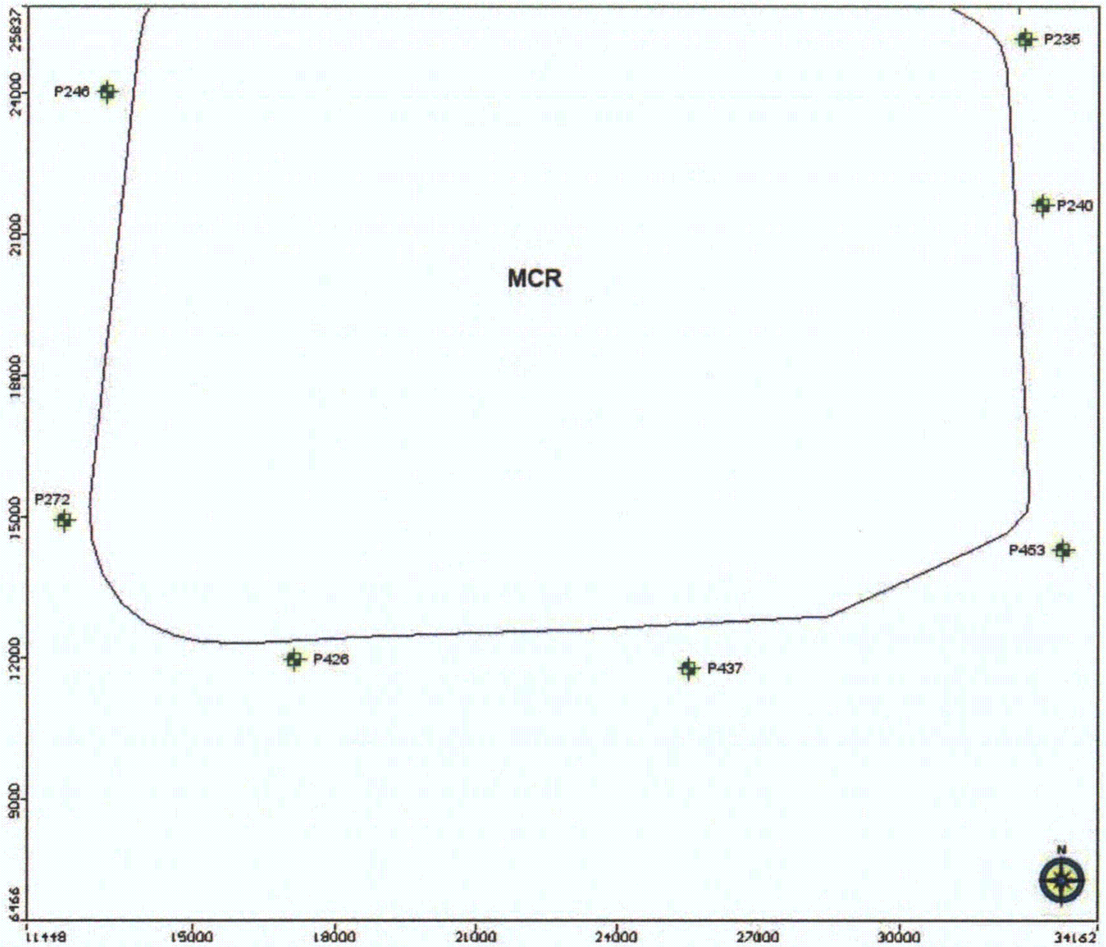
(Sheet 2 of 4)



Note: Locations shown for wells and piezometers with measurements between December 2006 and September 2008.

Figure 9: Observation Wells and Piezometer Locations as Represented in the Groundwater Model

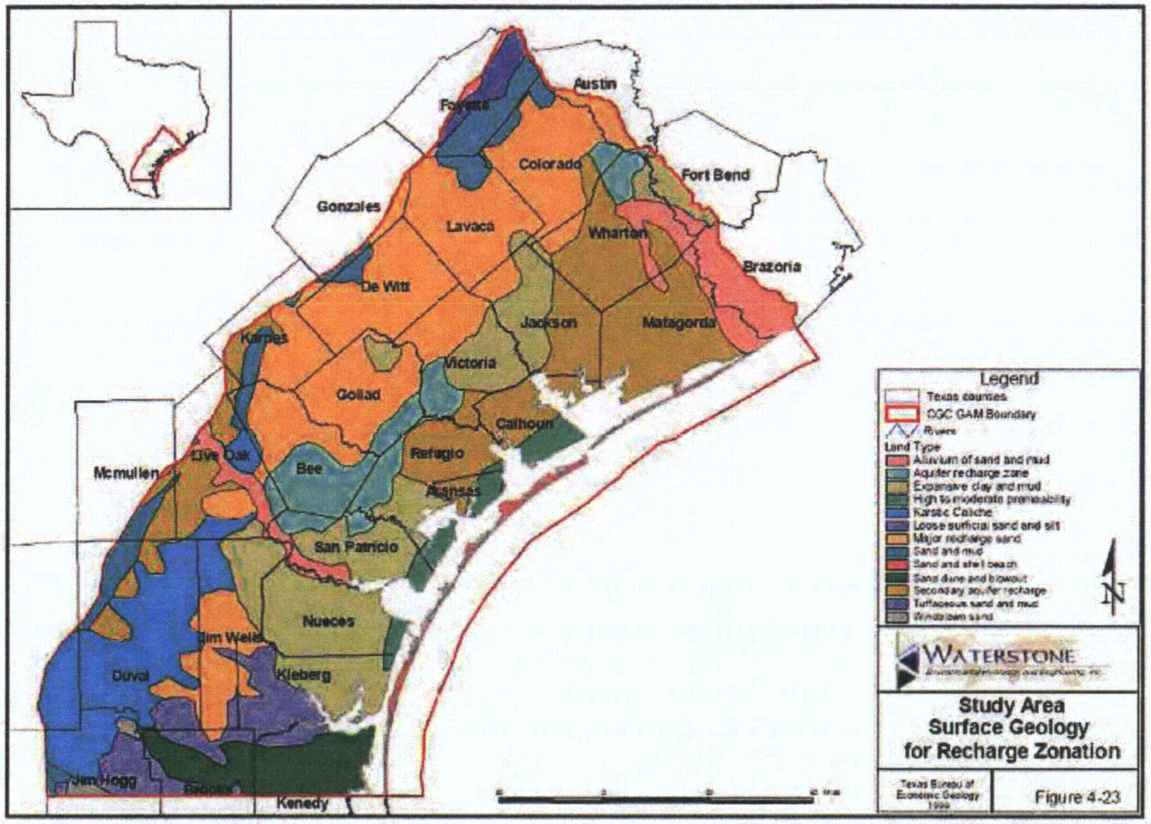
(Sheet 3 of 4)



Note: Locations shown for wells and piezometers with measurements between December 2006 and September 2008.

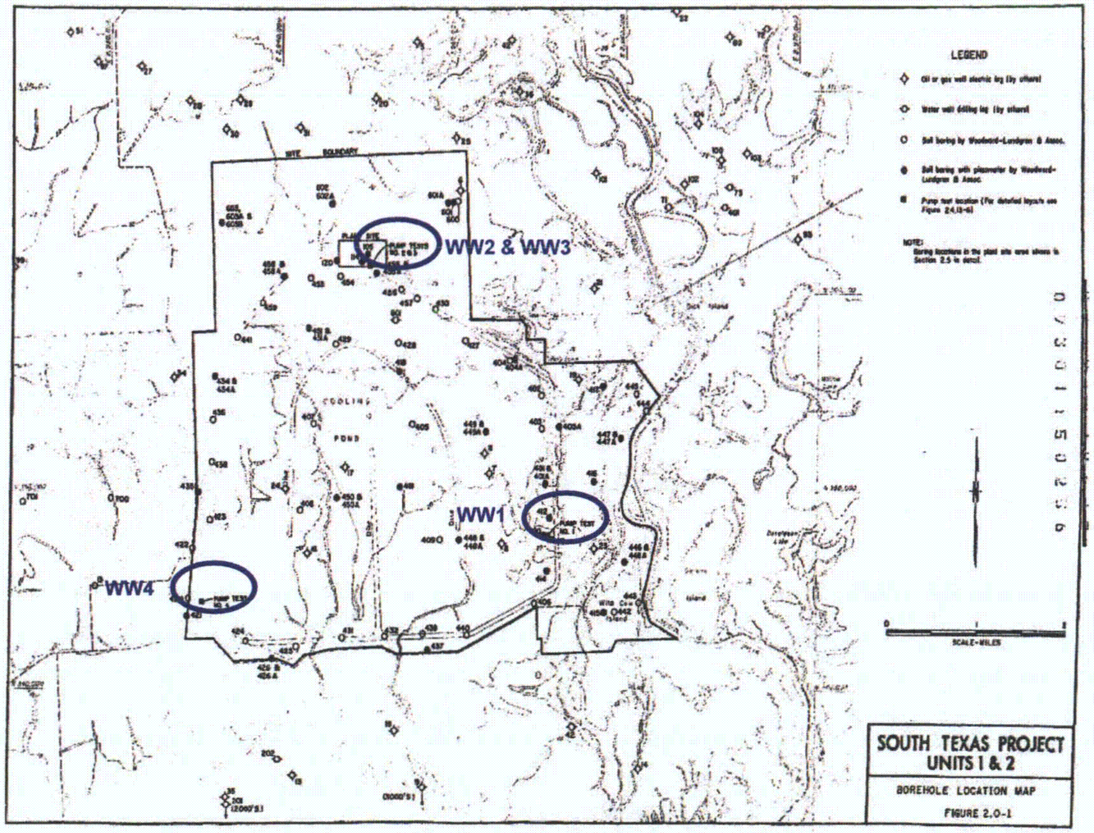
Figure 9: Observation Wells and Piezometer Locations as Represented in the Groundwater Model

(Sheet 4 of 4)



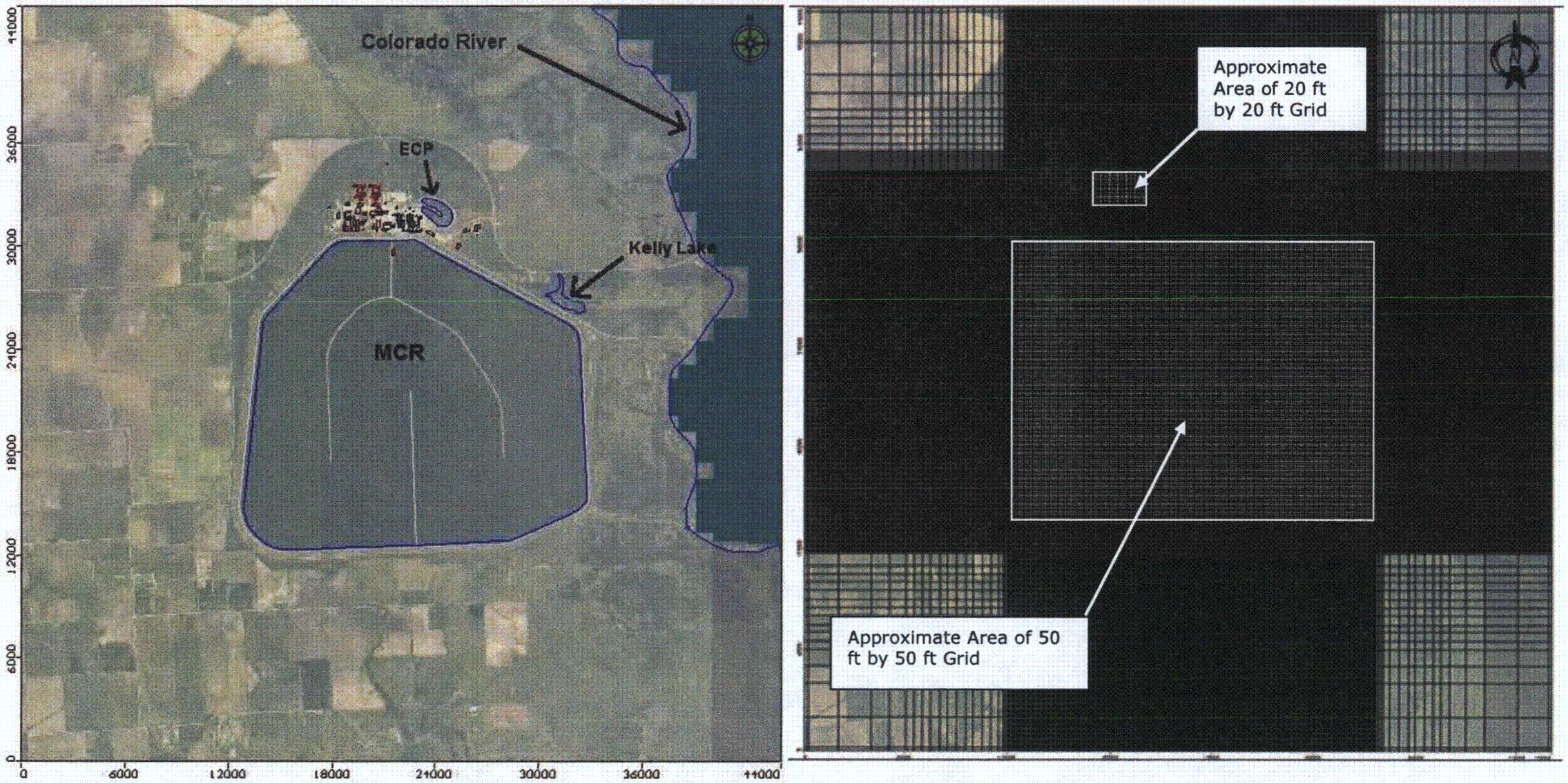
Source: Waterstone Environmental Hydrology and Engineering, Inc., 2003

Figure 10: Recharge Zones in Central Gulf Coast Groundwater Availability Model



Source: Woodward-Clyde Consultants, 1975

Figure 11: Pumping Test Well WW1 through WW4 Locations



Note: Red lines = footprints of proposed Units 3 & 4 structures; Black lines = footprints of existing structures; Blue-Green fill/hatch = inactive model cells; x- and y- axis labels are feet in the model coordinate system.

Note: Due to number of rows and columns in numerical grid, detail in area of MCR and Power Block not visible. The purpose of the figure is to display regions of the model domain where the model grid is refined. The refined grid regions correspond to the black areas in the center of the figure because the gaps between grid lines are small relative to the scale of the figure and individual grid lines in these regions are not discernable.

Figure 12: Numerical Model Domain and Numerical Model Grid

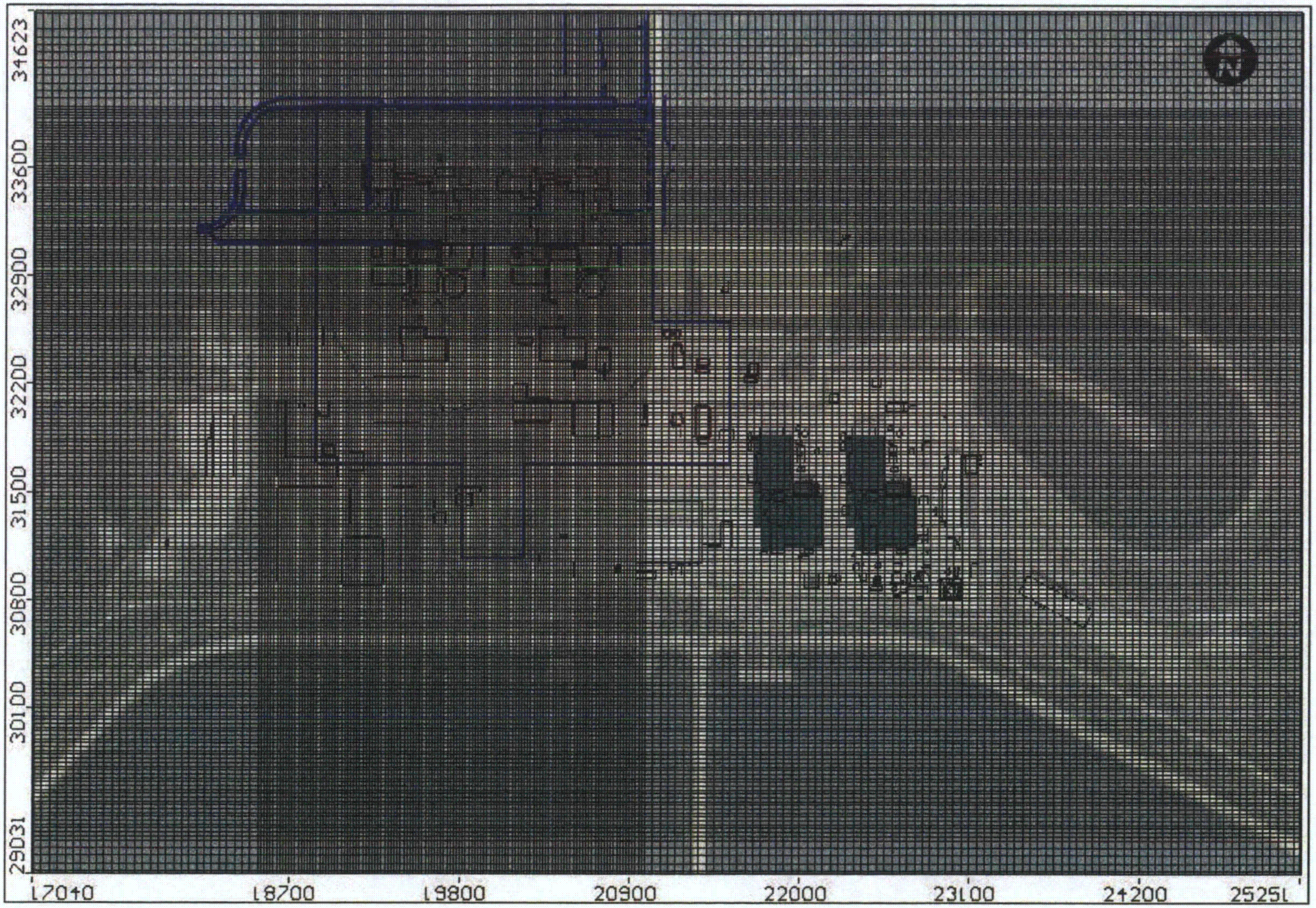
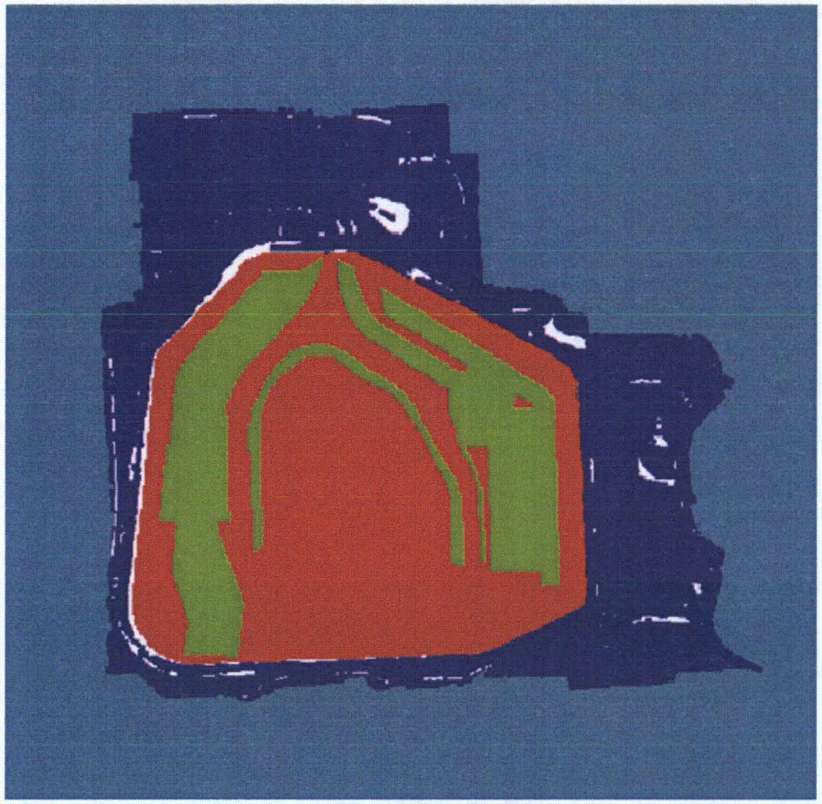
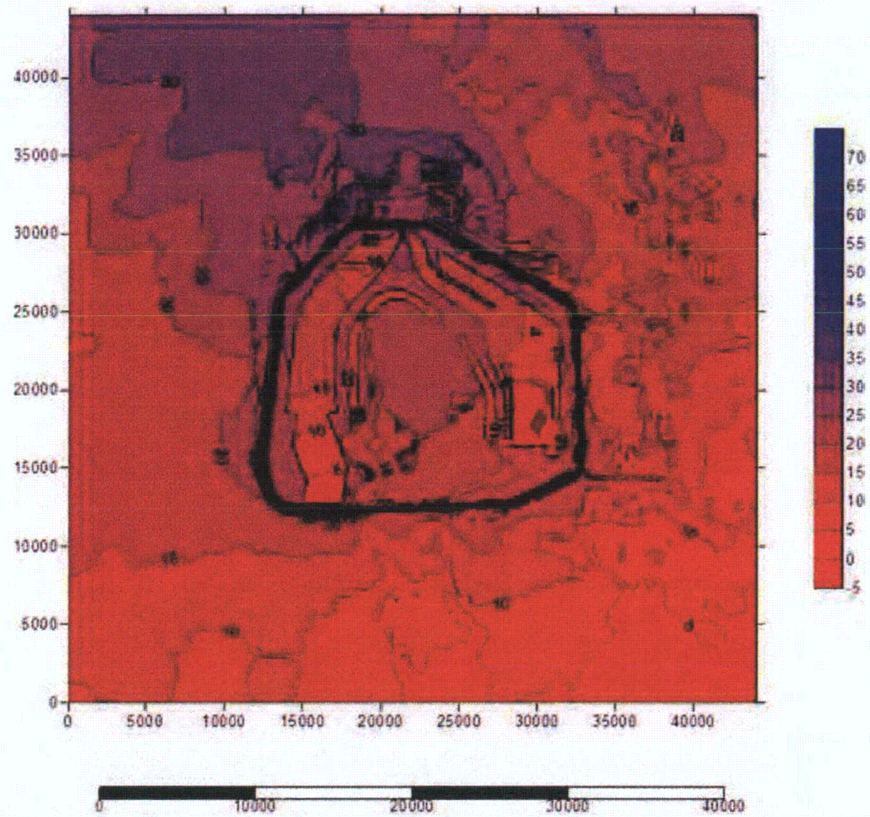


Figure 13: Numerical Model Grid in Power Block Area



Legend: Blue = USGS National Elevation Dataset (NED) outside STP site. Purple = Aerial data within STP site (P2 Energy Solutions/Tobin, 2007). Red = Digitized from USGS topographic maps. Olive green = Estimated for clay and sand borrow pits (estimated depths subtracted from digitized topography).

Figure 14: Ground Surface Elevation Data Sources



Notes: Contours generated using default kriging parameters in SURFER, with 20-ft grid. Elevation in feet MSL.

Figure 15: Shaded Contour Map of Top of Stratum A/B Elevation (Existing Ground Surface, model layer 1)