Appendix 2.4.12-C

Groundwater Flow Model for the Victoria County Station Site, Texas

(84 pages)

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2.4.12-C-1 **Purpose**

The VCS Groundwater Flow Model is prepared to evaluate potential impacts on the groundwater flow system from the construction and operation of the cooling basin. Four specific areas of impact were assessed:

- Seepage rate from the cooling basin into the site groundwater system.
- Post-construction groundwater level in the power block area.
- Plant construction dewatering.
- Postulated post-construction accidental release groundwater pathway, including the impact of cooling basin seepage.

The groundwater flow model is executed under the Visual MODFLOW version 4.3 environment developed by Schlumberger Water Services (Reference 2.4.12-C-1). The program consists of a series of pre- and post-processors that feed information to various numerical groundwater flow models developed by others. The groundwater flow model selected for the VCS utilizes a three-dimensional finite-difference groundwater flow model known as MODFLOW-2000 (Reference 2.4.12-C-2). This model consists of a main program that directs the execution of the simulation and a series of user selectable packages or modules that do the following:

1. Simulate groundwater flow using block-centered (BCF), hydrogeologic unit (HUF), or layer property (LPF) finite-difference approaches.

2. Control the solution of the finite-difference equations to represent the system (GMG, LMG [SAMG], PCG2, WHS, SIP1, or SOR1).

3. Simulate boundary conditions, including drains (DRN1), evapotranspiration (EVT1), general head boundaries (GHB1), horizontal flow barriers (HFB1), lakes (LAK3), recharge (RCH1), rivers (RIV1), specified head boundaries (CHD1), streams (STR1), and wells (WEL1).

Additionally, a subsidiary program known as MODPATH (Reference 2.4.12-C-3) is used to perform particle tracking to estimate travel time from postulated radwaste buildings within the power block to the nearest receptor for simulation of the accidental release groundwater pathways for radionuclides.

This work was accomplished by the following processes (Reference 2.4.12-C-4):

- Develop a conceptual hydrogeologic model
- Develop groundwater flow model design
- Calibrate numerical model using existing data

- Perform a sensitivity analysis to document the effects of parameter uncertainty
- Perform predictive simulations
- Perform a sensitivity analysis to document the effects of uncertainty in predictive simulations
- Document modeling results

Note that all references to elevations given in this appendix are to the North American Vertical Datum of 1988 (NAVD 88), unless otherwise indicated.

2.4.12-C-2 **Assumptions**

The general assumptions used in the model include:

- Homogeneous conditions are assumed for each material type (sand or clay).
- The flow regime represents a constant density system.
- The flow regime represents an equivalent porous medium based on the granular nature of the materials.
- A single value of hydraulic conductivity is selected for each of the sand units represented in the model.
- For the pre-construction conditions, two zones of recharge are assumed for the model area: Zone 1 represents the uplands, where clay is the dominant surficial material and Zone 2 represents the surface outcrop of sand units, where recharge is interpreted to be higher.
- Review of the Texas Water Development Board (TWDB) well logs and reports suggests that there are no major groundwater extraction areas within the model area. The majority of wells within the model area are domestic, stock watering, and oil and gas rig water supply wells. These types of wells are assumed to have average pumping rates of less than 10 gpm, which would have minimal impact on groundwater levels outside of the immediate area of the well. Therefore, with the exception of the accident analysis particle tracking, pumping from individual wells is not included in the model.
- Simulations are assumed to represent steady-state conditions, since there is little evidence to suggest that time-dependent (transient analysis) is necessary, nor is there sufficient onsite or offsite historical groundwater level data to support transient modeling.

Upon plant completion, the following cooling basin/power block area parameters are assumed:

- The hydraulic conductivity (K_h) of the fill material used in plant construction is assumed to be that of a clean sand and gravel at 500 feet/day (Reference 2.4.12-C-4). A K_h/K_v of 10 was used for the backfill to represent the vertical anisotropy created by compaction of lifts of the fill material.

- Post-construction recharge is represented by: no recharge in the cooling basin and power block building areas, twice the pre-construction Zone 2 recharge is assumed in power block backfill areas, and the pre-construction recharge distribution is assumed for all other model areas. The power block area backfill is assumed to be approximately five times more permeable than the natural sand units, however mitigating surface features such as finish grading to assure overland flow rather than ponding, storm drains to conduct surface drainage, and vegetation control are assumed to reduce the amount of infiltration through the backfill.
- The VCS cooling basin bottom is assumed to be elevation 69 feet.
- The cooling basin dikes are not considered in the seepage analysis due to their small size in relation to the cooling basin area.
- The power block is assumed to be excavated to elevation -15 feet.
- The level for the VCS cooling basin is assumed to be elevation 90.5 feet ± 1 foot.
- The finished plant grade in the power block area is assumed to be elevation 95 feet.

2.4.12-C-3 **Summary of Available Data**

2.4.12-C-3.1 **Regional Overview**

The VCS site is located in southern Victoria County and is approximately 13.3 miles south of the City of Victoria, Texas. The VCS site lies within the Coastal Prairies subprovince of the Gulf Coastal Plains physiographic province, which extends as a broad band along the coast of the Gulf of Mexico. The geologic materials underlying the Coastal Prairies subprovince is that of a deltaic depositional environment. This deltaic environment consists of a complex overlapping series of braided stream, levee, lagoon, and overbank flood sediments deposited in the Gulf of Mexico Basin during the Pleistocene. The deltaic depositional environment was influenced by a series of transgressive and regressive sea levels in the Gulf of Mexico (Reference 2.4.12-C-5). The deltaic depositional environment would be similar to that seen on the present-day Mississippi delta. In the subsurface, deltaic deposits appear as alternating and interfingering layers of clay, sand, gravel, and silt. Continental uplift and subsidence of underlying sediments within the Gulf of Mexico Basin have produced units that dip toward the Gulf of Mexico.

The primary aquifers in the site area are the Chicot and Evangeline aquifers. The Chicot aquifer is comprised of the Pleistocene-aged Beaumont Clay and the Lisse Formation. Defining a stratigraphic contact between these formations is problematic due to the considerable heterogeneity of the sediments, a general absence of index fossils and marker beds, and an absence of diagnostic electric log signatures. The Evangeline aquifer is comprised primarily of the

Pliocene-aged Goliad Sand, which consists of coarse-grained sediments. The Chicot and Evangeline aquifers are components of the encompassing Gulf Coast aquifer system, which is the primary aquifer system along the Gulf Coast of Texas (Reference 2.4.12-C-5).

2.4.12-C-3.2 **Site-Specific Information**

The VCS site is a greenfield site and little historical hydrogeologic data are available. The site consists of approximately 11,500 acres of land presently used for cattle ranching, oil and gas production, and recreational uses. The proposed site land utilization includes areas for the power block, the cooling basin, and support facilities. Figure 2.4.12-3 of Subsection 2.4.12 presents a plan view of the proposed VCS layout.

Plant-specific subsurface information for the VCS site was obtained primarily from the site investigation program conducted between September 2007 and February 2008 as described in Subsections 2.4.12.1.4 and 2.5.4. The subsurface investigation consisted of geotechnical borings logs, borehole geophysics, geotechnical field and laboratory testing, cone penetrometers, installation of groundwater observation wells, performance of slug tests and pumping tests, and other geotechnical and hydrogeologic data collection.

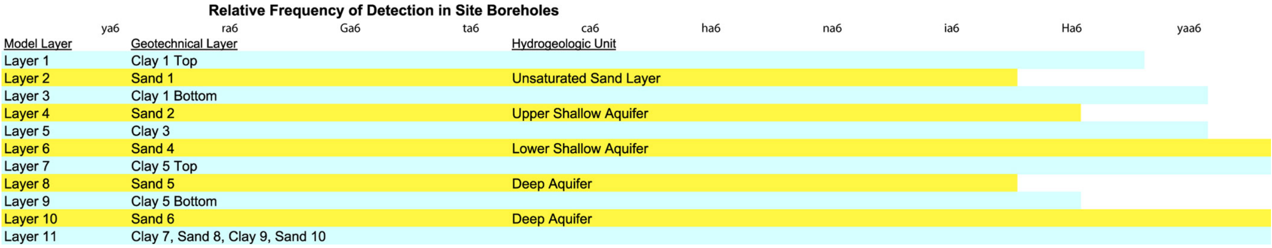
The power block area of the site is presently at an approximate elevation of 80 feet and the ground surface is generally flat within the power block area. Plant-specific boring information suggests that the bottom of the Chicot aquifer is approximately 300 feet below current ground surface in the power block area. To the east of the power block area, a steep decrease in surface elevation marks the edge of the Guadalupe River Valley. The surface elevation on the Guadalupe River floodplain is approximately 15 feet. It should be noted that site elevations are reported referencing the NAVD 88 elevation datum, while the elevations on some of the regional maps used as background are referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). The datum shift between NAVD 88 and NGVD 29 is approximately 0.44 feet in the VCS area (Reference 2.4.12-C-6).

The Chicot aquifer is subdivided into three saturated sandy zones at the VCS site: the “Upper Shallow” aquifer, the “Lower Shallow” aquifer, and the “Deep” aquifer. Additionally, a sand layer designated the “Sand 1” aquifer exists above the saturated zone beneath the cooling basin. These sand units are separated by less permeable layers of clayey materials. The primary zones of concern for VCS cooling basin seepage and excavation dewatering are the Sand 1 aquifer and the Upper Shallow aquifer.

2.4.12-C-3.3 **Stratigraphic Data**

Site investigation borehole log data and borehole geophysical logs were combined with offsite TWDB driller’s logs (Reference 2.4.12-C-7) to develop a stratigraphic model of the area. Geologic cross-sections were prepared to correlate the onsite geotechnical layering information to the TWDB driller's logs representing the regional stratigraphy. The stratigraphic interpretations were used to create kriged surfaces for each layer, which were imported into the model grid as the bottom elevation of each model layer. Where a layer was missing, a thickness of 1 foot was assigned to the layer, and the properties of the underlying layer were used.

Eleven model layers were chosen to represent the component of the Chicot Aquifer based on the borehole data. The model layers representing the sand layers at the VCS site are: Unsaturated Sand or Sand 1 (model layer 2), Upper Shallow aquifer or Sand 2 (model layer 4), Lower Shallow aquifer or Sand 4 (model layer 6), and the Deep aquifer representative of Sand 5 and Sand 6 (model layers 8 and 10). The interfingering clay layers (Clay 1 Top, Clay 1 Bottom, Clay 3, Clay 5 Top, and Clay 5 Bottom) are represented by model layers 1, 3, 5, 7, 9. Model layer 11 encompasses Clay 7, Sand 8, Clay 9, and Sand 10. The explicit method of representing a confining layer using a model layer was selected to represent the confining layers at the VCS site, resulting in the following eleven model layers:



Model Layer	Geotechnical Layer	Hydrogeologic Unit
Layer 1	Clay 1 Top	
Layer 2	Sand 1	Unsaturated Sand Layer
Layer 3	Clay 1 Bottom	
Layer 4	Sand 2	Upper Shallow Aquifer
Layer 5	Clay 3	
Layer 6	Sand 4	Lower Shallow Aquifer
Layer 7	Clay 5 Top	
Layer 8	Sand 5	Deep Aquifer
Layer 9	Clay 5 Bottom	
Layer 10	Sand 6	Deep Aquifer
Layer 11	Clay 7, Sand 8, Clay 9, Sand 10	

The relative frequencies of detection of the units indicate continuity or lack thereof for each geotechnical layer.

2.4.12-C-3.4 **Groundwater Level Measurements**

Because the VCS site is a greenfield site, little historical groundwater level data exist for the site proper, however the TWDB does maintain several observation wells close to the site to measure water levels in the Chicot and Evangeline aquifers. Regionally, groundwater flow is generally toward the southeast, or toward the Gulf of Mexico, as shown in Figure 2.4.12-13 in Subsection 2.4.12, which is a regional potentiometric surface map for the Chicot aquifer for 1999. The limited number of data points in the site area would obscure any localized impacts from rivers in the site area. Figure 2.4.12-14 in Subsection 2.4.12 presents the steady-state simulated groundwater level elevations in the Chicot aquifer using the calibrated Central Gulf Coast Groundwater Availability Model (GAM) (Reference 2.4.12-C-8). This map shows the influence of the Guadalupe and San Antonio rivers on localized flow conditions adjacent to the site, where an east-west component of flow is overlain on the regional flow pattern.

Monthly groundwater level measurements commenced at the site in October of 2007 through February 2009. Quarterly measurements commenced after February 2009. Table 2.4.12-C-1 presents the arithmetic mean value of the VCS site groundwater levels collected through August 2009. Potentiometric surface maps for VCS site groundwater level measurements are presented in Subsection 2.4.12, Figure 2.4.12-15. These values along with groundwater level measurements for three TWDB observation wells were used as calibration targets for the groundwater model. Water level measurements from the TWDB observation wells were averaged over the years 2007 through 2009 to provide a comparable dataset to site observations.

A regional potentiometric surface was developed using groundwater levels from selected TWDB well logs. The general regional flow pattern shown in Figure 2.4.12-14 in Subsection 2.4.12 and the site-specific measurements were used to identify anomalies in the well log water levels. These anomalies were removed along with densely clustered data. Considering the dense coverage of available driller's logs across the model domain and the fact that the data was collected over a period of 20 years, censoring a portion of the dataset is not believed to significantly skew the results. Table 2.4.12-C-2 presents the groundwater level data selected for use. The resulting potentiometric surface is shown in Figure 2.4.12-C-1. This figure was created using linear kriging with a 500 feet by 500 feet grid. Because this figure is based on measurements not synoptically collected, the resulting potentiometric surface is assumed to represent average conditions in the aquifers, which is appropriate for steady-state analysis. The wells used to prepare this map are primarily screened in the Deep aquifer although some wells are screened in the Upper and Lower Shallow aquifers. Therefore, the potentiometric surface shown in Figure 2.4.12-C-1 generally represents conditions in the Deep aquifer. Based on the VCS site groundwater level measurements, the vertical head differential between the different aquifer units within the Chicot Aquifer is small relative to the horizontal hydraulic gradient across the site and therefore, it is reasonable to project this relationship to that of the Upper Shallow and Lower Shallow aquifers and across the larger area covered by the map.

2.4.12-C-3.5 **Hydraulic Conductivity**

A variety of hydraulic conductivity values were needed to support defining the groundwater flow system. The following list summarizes the data needs and methodology for determining the values:

- Horizontal hydraulic conductivity of the Upper Shallow aquifer (Sand 2) represents the mean value for an aquifer pumping test performed in this unit from Subsection 2.4.12, Table 2.4.12-9.
- Horizontal hydraulic conductivity of the remaining saturated sand layers – Lower Shallow aquifer and Deep aquifer – represent the mean hydraulic conductivity derived from Deep aquifer pumping tests from Subsection 2.4.12, Table 2.4.12-9.

- Vertical hydraulic conductivity of the sand layers – used typical ratio of K_h/K_v = 3 (Reference 2.4.12-C-9).
- Vertical hydraulic conductivity of clayey layers – Clays in layer 1 of the model were assigned a K_v representing the maximum hydraulic conductivity determined from borehole permeameter tests (Subsection 2.4.12, Table 2.4.12-14) and the remaining clay layers were assigned a K_v based on laboratory permeability testing of undisturbed soil samples from Subsection 2.4.12, Table 2.4.12-13.
- Horizontal hydraulic conductivity of clayey layers – used the relationship K_h/K_v = 10 (Reference 2.4.12-C-9), a higher anisotropy ratio was used for the clays due to the presence of sand layers interbedded with the clay.
- Layer 11 was considered a special case because it includes both sand and clay layers. The vertical hydraulic conductivity of this layer was the weighted harmonic mean of the sand and clay layers as shown on Table 2.4.12-C-3, which includes the thickness and hydraulic conductivity for each unit. The relationship K_h/K_v = 10 was used to estimate the horizontal hydraulic conductivity.
- Vertical hydraulic conductivity of cooling basin bottom material (Sand 1) – maximum hydraulic conductivity from tests measuring saturated hydraulic conductivity of sand are discussed in Subsection 2.4.12.2.4.2 and Table 2.4.12-14.

The hydraulic conductivity values used in the model are summarized in Table 2.4.12-C-4. Some of the hydraulic conductivity values were adjusted as part of model calibration to match the observed heads.

2.4.12-C-3.6 **Other Properties**

Other properties used to support model development include recharge rate, evapotranspiration, specific storage, specific yield, and porosity. Values for these properties were established as described below.

The recharge rate was treated as a calibration parameter. The GAM (Reference 2.4.12-C-8) indicates a recharge rate range from 0.09 to 0.43 inches/year [2×10^{-5} to 9.8×10^{-5} feet/day] for the northern and southern Gulf Coast GAMs. The recharge rate was varied within this range during calibration to obtain the best match to observed groundwater levels at the site. Model calibration using recharge is discussed in more detail in Subsection 2.4.12-C-5.

The evapotranspiration (ET) rate in the upland areas (including the VCS site) is negligible because groundwater levels are greater than 30 feet below ground surface; however, in the Guadalupe and lower San Antonio River valleys groundwater levels are at or near the ground surface. ET data as potential evapotranspiration (PET) has been calculated for Victoria County (Reference 2.4.12-C-

10). The average PET rate is 57.02 inches/year with an average precipitation of 39.17 inches/year. In addition to the PET rate, an extinction depth is also needed to represent ET in the model. The extinction depth typically represents the maximum depth of the root zone. For the site area, an extinction depth of 5 feet is assumed.

The arithmetic mean total and effective porosity for each model layer are presented in Table 2.4.12-C-5. The specific yield of the different geotechnical layers is assumed to be the same as the effective porosity (Reference 2.4.12-C-9). The specific storage of the geotechnical layers was estimated using the mean storage coefficient from the TW-2320U aquifer pumping test (1.84 x 10^{-5}) and the saturated thickness of 7 feet (Subsection 2.4.12, Table 2.4.12-9). The resultant specific storage is 2.63 x 10^{-6} feet^{-1}. It should be noted that specific yield and specific storage are not needed for steady-state simulations, but are included in the Visual MODFLOW input for completeness.

2.4.12-C-4 **Numerical Model**

The model area was established to take advantage of natural boundary conditions in the site area. The Guadalupe and San Antonio Rivers, the Victoria Barge Canal, and Coleto Creek form physical boundaries along the north, east, west, and south perimeters of the model domain. Groundwater flow directions are interpreted as generally west to east across the VCS site, based on the regional potentiometric surface presented in Figure 2.4.12-C-1. Pre-construction groundwater discharge is interpreted to occur on the west side of the Guadalupe River valley into Linn Lake and a series of sloughs that run along the west side of the valley by discharge into these surface water features and by ET.

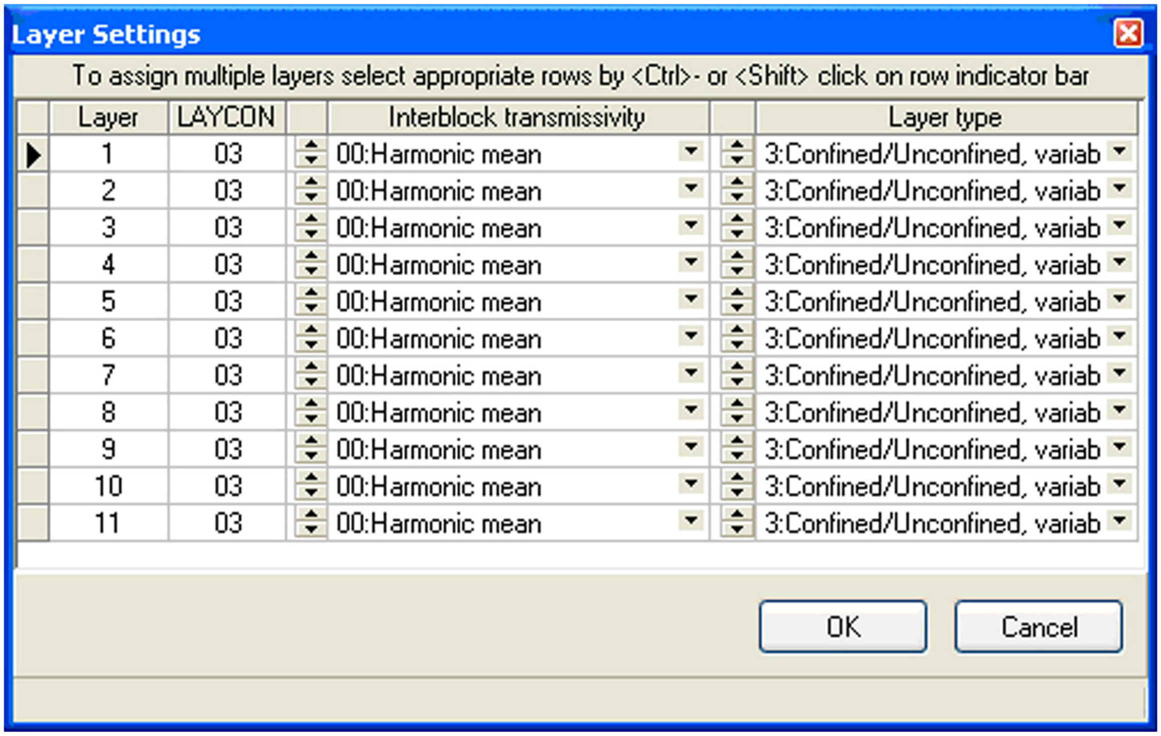
2.4.12-C-4.1 **Model Grid**

The model grid consists of 189 columns, 193 rows, and 11 layers. Grid spacing ranges from 500 feet at the edges to 250 feet in the power block area. Figure 2.4.12-C-2 is a plan view of the model domain showing the grid and calibration wells. Figure 2.4.12-C-3 shows a west to east cross-section through the model, passing through the proposed power block area.

The initial heads used in the model were determined in two steps. First, the heads were arbitrarily set to elevation 100 feet in each layer. A small value of ET (0.57 inch/year) was used in the initial simulation, and the resulting head distribution was saved at the end of the simulation. The ET rate was gradually increased to a realistic ET value of 57.02 inches/year.

Surface topography was incorporated into the model using the U.S. Geological Survey's National Elevation Dataset (NED) (Reference 2.4.12-C-11). This dataset has surface elevations referenced to the NAVD 88 vertical datum.

A layer type is defined for each layer in the model. The layer type represents the hydrogeologic conditions anticipated for each layer. For the VCS pre-construction model the layer type for all layers was Type 3 – Confined/Unconfined, with variable storage coefficient and transmissivity. The following layer definitions are used:



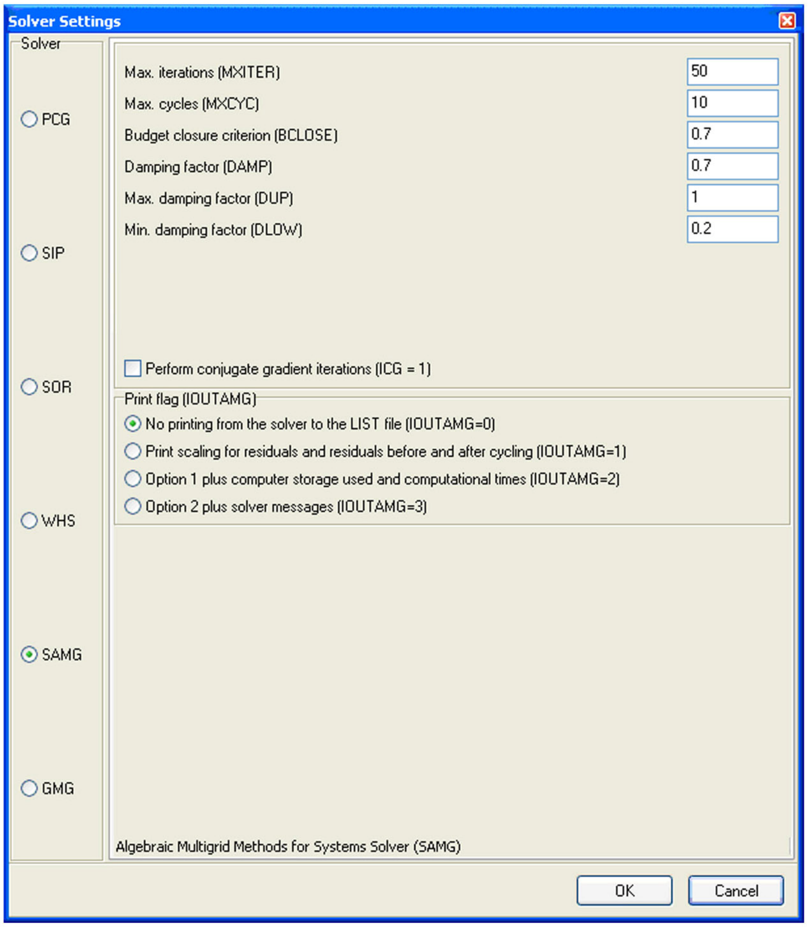
Layer Settings

To assign multiple layers select appropriate rows by <Ctrl>- or <Shift> click on row indicator bar

Layer	LAYCON	Interblock transmissivity	Layer type
1	03	00:Harmonic mean	3:Confined/Unconfined, variab
2	03	00:Harmonic mean	3:Confined/Unconfined, variab
3	03	00:Harmonic mean	3:Confined/Unconfined, variab
4	03	00:Harmonic mean	3:Confined/Unconfined, variab
5	03	00:Harmonic mean	3:Confined/Unconfined, variab
6	03	00:Harmonic mean	3:Confined/Unconfined, variab
7	03	00:Harmonic mean	3:Confined/Unconfined, variab
8	03	00:Harmonic mean	3:Confined/Unconfined, variab
9	03	00:Harmonic mean	3:Confined/Unconfined, variab
10	03	00:Harmonic mean	3:Confined/Unconfined, variab
11	03	00:Harmonic mean	3:Confined/Unconfined, variab

The MODFLOW default method for assigning inter-block transmissivity using the harmonic mean is used for all layers.

The solver used in the model is the algebraic multigrid (SAMG) solver (Reference 2.4.12-C-12). The following settings were used in the solver:



○ PCG
○ SIP
○ SOR
○ WHS
● SAMG
○ GMG

Max. iterations (MXITER)	50
Max. cycles (MXCYC)	10
Budget closure criterion (BCLOSE)	0.7
Damping factor (DAMP)	0.7
Max. damping factor (DUP)	1
Min. damping factor (DLOW)	0.2

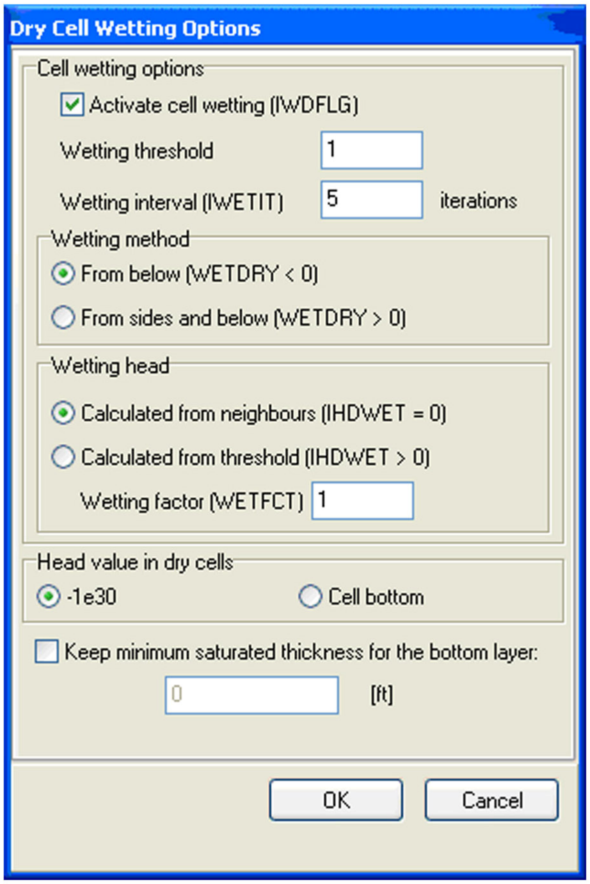
☐ Perform conjugate gradient iterations (ICG = 1)

Print flag (IOUTAMG)
● No printing from the solver to the LIST file (IOUTAMG=0)
○ Print scaling for residuals and residuals before and after cycling (IOUTAMG=1)
○ Option 1 plus computer storage used and computational times (IOUTAMG=2)
○ Option 2 plus solver messages (IOUTAMG=3)

Algebraic Multigrid Methods for Systems Solver (SAMG)

The SAMG solver has advantages over other solvers included with Visual MODFLOW for problems with large grids or a highly variable hydraulic conductivity field. The solver is also less sensitive to the initial head distribution (Reference 2.4.12-C-1).

The configuration of the model requires the use of the re-wetting function to saturate unsaturated cells in the model. The following settings were used:



Dry Cell Wetting Options

Cell wetting options

☑ Activate cell wetting (IWDFLG)

Wetting threshold 1

Wetting interval (IWETIT) 5 iterations

Wetting method

● From below (WETDRY < 0)

○ From sides and below (WETDRY > 0)

Wetting head

● Calculated from neighbours (IHDWET = 0)

○ Calculated from threshold (IHDWET > 0)

Wetting factor (WETFCT) 1

Head value in dry cells

● -1e30 ○ Cell bottom

☐ Keep minimum saturated thickness for the bottom layer:

0 [ft]

The discontinuity of the strata in the top four layers of model produces cyclic wetting and drying of cells in the areas where steep changes in layer elevations and stratigraphic layer pinch outs occur. This cyclic wetting and drying interferes with numerical convergence by the solver. By increasing the wetting interval, the solver can converge on a solution. A recommended range for the wetting interval is between three and five iterations (Reference 2.4.12-C-13)

2.4.12-C-4.2 Boundary Conditions

The pre-construction model boundary conditions are summarized in Table 2.4.12-C-6. The following boundaries were used in the groundwater flow model:

Recharge

The recharge boundary condition was assigned to the uppermost active model cell. Two zones of recharge were used for pre-construction conditions - Zone 1 represents areas overlain by clay and was initially assigned a value of 0.2 inch/year and Zone 2 represents areas overlain by sandy deposits and was initially assigned a value of 0.4 inch/year. These values were adjusted during calibration. The recharge zones used in the model are presented in Figure 2.4.12-C-4.

Evapotranspiration

The ET boundary condition was assigned as a single zone. The zone was assigned an ET of 57.02 inches/year throughout the model domain. An extinction depth of 5 feet was used to represent the maximum root penetration depth. It should be noted that Visual MODFLOW stops ET if the groundwater level is below the extinction depth or below the bottom of layer 1. Over most of the valley areas, layer 1 is 1 foot thick. To overcome this restriction, the thickness of layer 1 was increased to 5 feet in the valley areas. Although this represents a deviation from the conceptual model, the overall transmissivity relationship of the layers remains unchanged because layer 1 is assigned the hydraulic conductivity of the underlying unit.

General Head

The general head boundaries were assigned using a boundary distance of 10,000 feet, a hydraulic gradient for the west side of the model of 0.0012 feet/feet, a hydraulic gradient for the northeast and east sides of the model of 0.008 feet/feet (Figure 2.4.12-C-1), and the head distribution from Figure 2.4.12-C-1. The head at the boundary was computed by multiplying the boundary distance (10,000 feet) by the hydraulic gradient (0.0012 feet/feet or 0.008 feet/feet) to obtain a value of 12 feet or 8 feet. These values were added to the head measurements at the appropriate edge of Figure 2.4.12-C-1 to obtain the head at the boundary.

Layer 4 – Along the west edge of the model grid to represent regional inflow of groundwater in the Upper Shallow aquifer. The head elevations for the boundary were assigned using a linear gradient ranging from 92 to 72 feet (north to south). A hydraulic conductivity of 68 feet/day and an east-west face for applying the boundary were used. Along the northeast edge of the model to represent regional inflow from the north. The head elevation for the boundary was assigned as 38 feet, with a hydraulic conductivity of 68 feet/day and a north-south face for applying the boundary.

Layer 6 – Along the west side of the model grid to represent regional groundwater inflow in the Lower Shallow aquifer. The head elevations for the boundary were assigned using a linear gradient ranging from 92 to 72 feet (north to south). A hydraulic conductivity of 103 feet/day and an east-west face for applying the boundary were used. Along the northeast and east sides of the model to represent regional groundwater inflow. The head elevations were assigned using a uniform 38 feet in the northeast and a linear gradient ranging from 38 to 13 feet along the east side, a hydraulic conductivity of 103 feet/day, and either a north-south face for the northeast or an east-west face for the east sides of the model.

Layer 7 – Along the southern portion of the east side of the model grid to represent outflow in the sand portion of this layer. The head elevation was assigned as a linear gradient ranging from 23 to 16 feet, with a hydraulic conductivity of 103 feet/day and an east-west face for applying the boundary.

Layer 8 – Along the west side of the model grid to represent regional groundwater inflow in the Deep aquifer. The head elevations for the boundary were assigned using a gradient fill ranging from 92 to 72 feet (north to south). A hydraulic conductivity of 103 feet/day and an east-west face for applying the boundary were used. A second general head boundary was assigned along the northeast and east edges of the model domain to represent groundwater outflow in the Deep aquifer. The head elevations were assigned using a uniform 38 feet in the northeast and a linear gradient ranging from 38 to 13 feet along the east side, a hydraulic conductivity of 103 feet/day, and either a north-south face for the northeast or an east-west face for the east sides of the model.

Layer 9 – Along the southern portion of the east side of the model grid to represent outflow in the sand portion of this layer. The head elevation was assigned as a linear gradient ranging from 23 to 16 feet, with a hydraulic conductivity of 103 feet/day and an east-west face for applying the boundary.

Layer 10 – Along the west side of the model grid to represent regional groundwater inflow in the Deep aquifer. The head elevations for the boundary were assigned using a linear gradient ranging from 92 to 72 feet (north to south). A hydraulic conductivity of 103 feet/day and an east-west face for applying the boundary were used. A second general head boundary was assigned along the northeast and east edges of the model domain to represent groundwater outflow in the Deep aquifer. The head elevations were assigned using a uniform 38 feet in the northeast and a linear gradient ranging from 38 to 13 feet along the east side, a hydraulic conductivity of 103 feet/day, and either a north-south face for the northeast or an east-west face for the east sides of the model.

Drain

Layer 1 – Drain boundaries were assigned along Kuy and Dry Kuy Creeks, other unnamed creeks adjacent to the VCS site, and on the Guadalupe River Valley slope to the east of the proposed cooling basin to simulate seepage areas in the clay layer (Clay 1T). The unnamed creeks and the Guadalupe River Valley seeps are lumped together and referred to as “the downgradient drains.” The drain elevations were assigned using a Visual MODFLOW formula ($BOT + 1.0), which places the drain elevation at 1 foot above the bottom of the cell.

Layer 2 – Drain boundaries were assigned along Kuy and Dry Kuy Creeks, other unnamed creeks adjacent to the VCS site, and on the Guadalupe River Valley slope to the east of the proposed cooling basin to simulate seepage areas in the layer (Sand 1). The unnamed creeks and the Guadalupe River Valley seeps are lumped together and referred to as “the downgradient drains.” The drain elevations were assigned using a Visual MODFLOW formula ($BOT + 1.0), which places the drain elevation at 1 foot above the bottom of the cell.

Layer 3 – Drain boundaries were assigned along Kuy Creek from its confluence with Dry Kuy Creek to its confluence with the Guadalupe River to simulate seepage from Clay 1B, which is exposed in this area. The drain elevations were assigned using a Visual MODFLOW formula ($BOT + 1.0), which places the drain elevation at 1 foot above the bottom of the cell.

Two types of conductance values were used for the drains: drains present at the bottom of drainage channels and drains present in the sides of drainage channels. The definition of conductance for drains in the bottom of drainage channels is based on a 2 feet thick sediment layer (*M*) with a vertical hydraulic conductivity of 2.75 feet/day (*K*) (based on Sand 1 testing [Subsection 2.4.12, Table 2.4.12-14]). For Kuy Creek (west of the confluence with Dry Kuy Creek) and Dry Kuy Creek in model layer 2, a drain width of 20 feet (*W*) and a length of 500 feet (*L*) is assumed. The conductance (*C*) for an open drain is then (Reference 2.4.12-C-4):

$$C = \frac{KLW}{M} = \frac{2.75 \times 500 \times 20}{2} = 13750\ ft^2\ /\ day$$

The conductance (*C*) per unit length (*L*) would be:

$$C/L = \frac{13750}{500} = 27.5\ ft\ /\ day$$

For the downgradient drains east of the cooling basin in model layer 2, the same vertical hydraulic conductivity, drain length, and thickness are assumed with a drain width (*W*) of 500 feet:

$$C = \frac{2.75 \times 500 \times 500}{2} = 343750\ ft^2\ /\ day$$

And a conductance (*C*) per unit length (*L*) of:

$$C/L = \frac{343750}{500} = 688\ ft\ /\ day$$

For the downgradient drains north of the VCS (unnamed tributaries) the conductance values for Kuy Creek are used.

For drains in model layer 1 and in Kuy Creek east of the confluence with Dry Kuy Creek in model layer 2, the drains are present on the banks of the drainage channel and the conductance is based on a 1 foot thick sediment layer (*M*) with a vertical hydraulic conductivity of 2.75 feet/day (*K*) [based on Sand 1 testing (Subsection 2.4.12, Table 2.4.12-14)]. The drain width is the saturated thickness of the drain cell, which is defined by Visual MODFLOW as $ΔZ, the conductance per unit length (*L*) would be:

$$C/L = 2 \times \frac{2.75 \times \$\Delta Z}{1}$$

The conductance per unit length values are doubled because the drains would be present on both sides of the channel.

River

Where river boundaries are overlain by model layers, a hydraulic conductivity of 103 feet/day was assigned to the overlying model cells to allow vertical communication with the river boundary. The hydrogeologic properties (storage and porosity) of these overlying model cells were not changed as these cells are not involved in the particle tracking pathways from the site.

Victoria Barge Canal – A river boundary was assigned on the east side of the model grid to represent the barge canal. A channel bottom of approximately -12 feet and a stage of 0 feet were assigned to represent this sea level canal (Reference 2.4.12-C-14). The boundary was assigned in model layers 6 and 7 as appropriate based on the channel bottom elevation. A vertical hydraulic conductivity of 2.75 feet/day was used with a riverbed thickness of 1 foot. The channel width is 125 feet. A thinner riverbed thickness was assumed for this feature because it is a navigable water body and is regularly dredged.

Coleto Creek – A river boundary was assigned from the western edge of the model to the confluence with the Guadalupe River to represent Coleto Creek. The creek starts in model layer 1 on the west side of the model and ends in layer 5 at the confluence with the Guadalupe River. A linear gradient was used to assign stage and river bottom starting on the west side with a stage of 72 feet and a bottom of 67 feet and ending with a stage of 19 feet and a bottom of 14 feet. The layer assignment for the river boundary was based on the river bottom elevation. As the creek becomes more deeply incised, the boundary condition is assigned to the next lower model layer. The stage elevations were estimated using the mean stage from U.S. Geological Survey gage 8177500 (Reference 2.4.12-C-15). The river conductance was determined using a vertical hydraulic conductivity of 2.75 feet/day and a riverbed thickness of 2 feet. The width of the channel is assumed to be 20 feet.

Guadalupe River – A river boundary was assigned from the north side to the southeast corner of the model domain. A linear gradient was used to assign stage and bottom elevations starting at a stage of 22 feet and a bottom of 10 feet at the north end to a stage of 0 feet and a bottom of -10 feet at the southeast corner. The channel bottom information is derived from channel profiles and the stage is estimated using U.S. Geological Survey stream gage 8177520 data (Reference 2.4.12-C-15). The river boundary is located in model layers 6 and 7 based on the elevation of the channel bottom. A vertical hydraulic conductivity of 2.75 feet/day was used with a riverbed thickness of 2 feet. The width of the channel is 90 feet based on the aforementioned channel profiles.

San Antonio River – A river boundary was assigned from the west side of the model to the southeast side of the model to represent the San Antonio River. The river was represented by two reaches: (a) for the first reach, a linear gradient was used to assign stage and bottom elevations starting at a stage of 65 feet and a bottom of 40 feet on the west edge of the model domain to a stage of 20 feet and a bottom of 10 feet at U.S. Geological Survey gage 8188570 (Reference 2.4.12-C-15) near U.S. Highway 77, and (b) the second reach, a linear gradient was used to assign stage at bottom elevations starting at a stage of 20 feet and a bottom of 10 feet at U.S. Geological Survey gage 8188570 to a stage of 1 foot and a bottom of -10 feet at the confluence with the Guadalupe River. The San Antonio River starts in model layer 4 on the west side of the model and then is placed in model layer 5 as the channel becomes more deeply incised toward the east. A vertical hydraulic conductivity of 2.75 feet/day was used with a riverbed thickness of 2 feet. The width of the channel is estimated to be 70 feet.

Black Bayou – A river boundary was assigned along Black Bayou in model layers 4 or 5. This boundary corresponds to the eastern limit of the Upper Shallow aquifer in the site area. The stage ranged from 27 feet at the north end to 10 feet at the south end at Linn Lake. The river bottom varied between 26 feet in the north to 7 feet at Linn Lake. A vertical hydraulic conductivity of 2.75 feet/day was used with a riverbed thickness of 2 feet. The width of the Black Bayou channel was assumed to be 20 feet.

Constant Head

Linn Lake – A constant head boundary was used to represent the lake. A constant head of 10 feet was assigned in layers 4 or 5. The model cells overlying the constant head cells were assigned a hydraulic conductivity of 103 feet/day to allow communication with the underlying constant head cells. The hydrogeologic properties (storage and porosity) of these overlying model cells were not changed as these cells are not involved in the particle tracking pathways from the site.

2.4.12-C-5 **Model Calibration**

Model calibration involved adjustment of uncertain input parameters to obtain the best match between observed and simulated groundwater levels and the lowest water balance error. The input parameters with the most uncertainty are the recharge rate, because this value is based on regional observations rather than site-specific measurements and hydraulic conductivity. The model was calibrated by systematically varying these parameters over a plausible range to determine the values that yielded the best model fit to the observed potentiometric head data.

2.4.12-C-5.1 **Calibration Criteria**

The model was considered calibrated when the following criteria were met:

- Residual mean < 2 feet
- Absolute residual mean < 5 feet
- Root mean squared residual < 5 feet
- Normalized root mean squared residual < 10 percent
- Correlation coefficient > 0.8
- Mass balance discrepancy < 1 percent

The residual mean is a measure of the average residual head value defined by the equation:

$$\bar{R} = \frac{1}{n}\sum_{i=1}^{n} R_i$$ (Reference 2.4.12-C-1)

Where,

n = number of observations

R = residual (simulated head X_{sim} – observed head X_{obs})

The absolute residual mean is a measure of the average absolute residual value defined by the equation:

$$\left|\bar{R}\right| = \frac{1}{n}\sum_{i=1}^{n} \left|R_i\right|$$ (Reference 2.4.12-C-1)

Where variables are as defined previously.

The root mean squared residual (*RMS*) is defined by:

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n} R_i^2}$$ (Reference 2.4.12-C-1)

Where variables are as defined previously.

The normalized root mean squared (*NRMS*) residual in the RMS divided by the maximum difference in the observed head values and is determined from:

$$NRMS = \frac{RMS}{(X_{obs})_{\max} - (X_{obs})_{\min}}$$ (Reference 2.4.12-C-1)

Where variables are as defined previously.

The correlation coefficient (C) is calculated as the covariance (COV) between the simulated head (X_{sim}) and the observed head (X_{obs}) divided by the product of their standard deviations using the following formulae:

$$C = \frac{COV(X_{sim}, X_{obs})}{\sigma_{sim} \bullet \sigma_{obs}}$$ (Reference 2.4.12-C-1)

$$COV = \frac{1}{n}\sum_{i=1}^{n}(X_i - m_{sim})(X_i - m_{obs})$$ (Reference 2.4.12-C-1)

Where m_{sim} and m_{obs} are the mean values of simulated and observed heads and σ_{sim} and σ_{obs} are the standard deviations calculated from:

$$\sigma_{sim} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{sim} - m_{sim})^2}$$ (Reference 2.4.12-C-1)

$$\sigma_{obs} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_{obs} - m_{obs})^2}$$ (Reference 2.4.12-C-1)

The mass balance discrepancy is calculated by MODFLOW 2000 and represents the percent difference between water flow into the model and water flow out of the model.

The simulated and observed heads are typically plotted on a scatter graph, with the X-axis of the graph representing measured values and the Y-axis representing simulated values. A 45° line passing through graph origin (X = Y) represents perfect agreement between observed and simulated values. In addition to the quantitative criteria described above, Visual MODFLOW also includes two qualitative evaluation features. The program calculates the 95 percent confidence interval of the data set and plots this range on the scatter graph. The goal is to have this range bracket the 45° line (X = Y) on the graph. The program also calculates and displays the 95 percent interval of the data, where 95 percent of the total data points are expected to occur. The goal is to bracket the X = Y line and to minimize the width of this range.

2.4.12-C-5.2 **Summary of Calibrated Model Results**

The model calibration process was accomplished in two stages. The first stage involved adjusting the recharge and hydraulic conductivity to obtain the best match between simulated and observed heads. Two recharge zones were established in the model. One zone represented the more permeable surface materials, that is, where sand units outcrop at the surface and the other zone represented the less permeable surface materials. Figure 2.4.12-C-4 presents the location of these zones, with the blue shaded area representing the more permeable area (Zone 2) and the non-shaded area (Zone 1) representing the less permeable surface materials. After adjustment of these recharge zones, it was found that a recharge rate of 0.4 inch/year for the permeable zone and 0 inch/year for the less permeable zone produced the closest match to observed heads. The less permeable zone is lower than the regional range of recharge, however the regional recharge represents an average over a large area, whereas the VCS model is representative of a much smaller area. The potentiometric surface shown in Figure 2.4.12-C-1 indicates that the Deep aquifer may be influenced by the Guadalupe River and Victoria Barge Canal on the eastern side of the model domain. Initially the modeled heads did not reflect this influence. Review of the stratigraphic model within the Guadalupe River Valley suggests that the clay layers (model layers 7 and 9) have been eroded and replaced with more permeable valley fill deposits. Using the hydraulic conductivity of the underlying sand, the areas of layers 7 and 9 were revised from the original conceptual model within the Guadalupe River Valley, from south of the confluence with Coleto Creek to the southern edge of the model. This allowed the Deep aquifer to be hydraulically connected with the overlying river boundaries in layer 6 (Lower Shallow aquifer). This first stage of calibration produced very good agreement between simulated and observed heads in layers 6, 8, and 10 (or the Lower Shallow and Deep aquifers), however layer 4 heads (Upper Shallow aquifer) did not meet the calibration criteria.

The second stage of calibration focused on layer 4 using an automated calibration program called PEST (Parameter ESTimation) (Reference 2.4.12-C-16). This program is part of the Visual MODFLOW program package. The PEST program adjusts model parameters until the fit between model output (head) and field observations is optimized. PEST utilizes the weighted sum of squared differences between model-generated head values and those actually measured in the field. This sum of weighted, squared, model-to-measurement discrepancies is referred to as the "objective function." The program uses the Gauss-Marquardt-Levenberg algorithm to perform the parameter estimation process. For the VCS groundwater model, the program was constrained to vary the horizontal hydraulic conductivity values for the Upper Shallow aquifer sand in layer 4, which is hydraulic conductivity zone 5 in the model and the vertical hydraulic conductivity of model layer 1, which is hydraulic conductivity zone 7. The initial estimate for hydraulic conductivity was K_x,K_y = 60 feet/day in model layer 4 and K_z = 0.068 feet/day in model layer 1. The results suggest that a K_x of 68 feet/day in model layer 4 and K_z of 0.06 feet/day in model layer 1 would improve the model calibration for model layer 4 (Note that layer 1 is dry over virtually all of the model domain. The PEST-estimated K value for the layer 1 clay is therefore uncertain.) Because model layers 2 and 4 are similar materials, the K_x and K_z values used for model layer 4 are also used for model layer 2. These hydraulic conductivity values were used in the model to finalize the calibration. This stage of the calibration process was performed in lieu of a calibration sensitivity analysis.

Figure 2.4.12-C-5 presents the head scatter graph and calibration statistics for the model. Figure 2.4.12-C-6 presents the mass balance for the model. Table 2.4.12-C-7 presents the measured and simulated heads for the calibration targets. The total mass discrepancy for the calibrated model is 0.04 percent. Based on the calibration statistics and mass balance discrepancy, the

model meets the calibration criteria. Model layer 4 exhibits a systematic trend in residuals suggesting that factors other than hydraulic conductivity and recharge are influencing the head distribution in this layer. Figures 2.4.12-C-7 through 2.4.12-C-10 show the simulated potentiometric surface maps for the hydrogeologic units at the site based on current conditions. It should be noted that the jagged or closely spaced contours present on several of the maps represent areas within the layer where a hydraulic conductivity change is occurring, typically a change from sand to clay. Also, model layers 1, 2, and 3 are mostly unsaturated under pre-construction conditions. Figures 2.4.12-C-11 through 2.4.12-C-14 present the calibration residuals for model layers 4 (Upper Shallow aquifer), 6 (Lower Shallow aquifer), 8 (Deep aquifer), and 10 (Deep aquifer).

The Victoria Barge Canal is the primary groundwater sink in the Guadalupe River Valley as indicated by the flow budget presented in Table 2.4.12-C-8.

2.4.12-C-6 **Predictive Simulations**

The predictive simulations performed with the calibrated groundwater flow model include estimation of cooling basin seepage, the amount of water removed during power block area dewatering, and simulation of a post-construction accidental release of radioactive liquid effluent. The following adjustments were made to the pre-construction model for the post-construction conditions:

- Surface elevations within the power block area were set to between elevation 90 and 95 feet, and within the cooling basin the surface elevations were set to elevation 69 feet. Areas within the cooling basin where layer 1 was 1 foot in thickness (surficial clay absent as a result of excavation or erosion) were assigned the hydraulic conductivity of the underlying sand.
- Permeable backfill and inactive model cells were added to the power block area to represent backfill around buildings and the building foundations.
- The ET value of 57.02 inches/year was applied throughout the model domain, with the exception of the cooling basin and power block area building foundations (Figure 2.4.12-C-15).
- The layer type for layers 4 through 11 was changed from type 3 to type 0, because these layers are considered to be saturated in post-construction conditions.
- The Solver BCLOSE was reduced to between 0.04 and 0.009.
- The rewetting settings included a wetting threshold of 0.3.

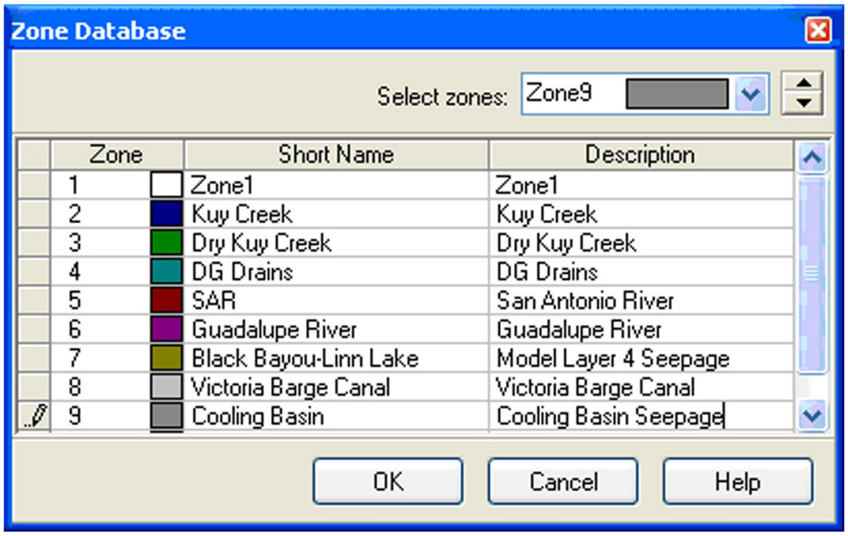
2.4.12-C-6.1 **Cooling Basin Seepage**

Cooling basin seepage was simulated using the river boundary condition to represent the cooling basin. The river stage for the boundary was set at 90.5 feet with the riverbed bottom at 69 feet.

The riverbed conductance is based on a 2 feet thick sediment layer with a K_v = 34 feet/day and a channel width of 500 feet or 250 feet (entire model cell). Figure 2.4.12-C-16 presents a plan view of the boundary conditions in model layer 1.

In addition to the cooling basin, the post-construction power block area conditions were also simulated. Postulated buildings similar to a generic ABWR technology were used to represent buildings within the power block area and were represented by inactive model cells, which were surrounded by cells with permeable backfill. A power block area recharge rate of 0.8 inch/year was assigned to cells not occupied by buildings and a recharge rate of 0 inch/year was assigned within the cooling basin. Figure 2.4.12-C-17 presents the recharge distribution at the cooling basin and power block area. The power block area backfill is assumed to be approximately five times more permeable than the natural sand units; however, mitigating surface features such as finish grading to assure overland flow rather than ponding, storm drains to conduct surface drainage, and vegetation control are assumed to reduce the amount of infiltration through the backfill. The recharge rate for the backfill exceeds the range for the GAM, however, the GAM only represents natural materials.

Cooling basin seepage was evaluated by looking at the flow budget in subareas of the model domain. Visual MODFLOW uses the program ZONEBUDGET to extract the subarea flow budget from the overall model flow budget. The program requires the user to define the subareas or zones within the model for which the flow budget is desired. The following zones were used in the VCS post-construction model:



Select zones: Zone9

Zone		Short Name	Description
1	⬜	Zone1	Zone1
2	🟦	Kuy Creek	Kuy Creek
3	🟩	Dry Kuy Creek	Dry Kuy Creek
4	🟦	DG Drains	DG Drains
5	🟥	SAR	San Antonio River
6	🟪	Guadalupe River	Guadalupe River
7	🟫	Black Bayou-Linn Lake	Model Layer 4 Seepage
8	⬜	Victoria Barge Canal	Victoria Barge Canal
9	⬛	Cooling Basin	Cooling Basin Seepage

Zone 1 is a default of the program and represents the area of the model not included in other zones. Zone 4 represents the downgradient drains (or seeps) in the Guadalupe River Valley to the north and east of the VCS site. The remaining zone descriptions are self-explanatory.

Figures 2.4.12-C-18 through 2.4.12-C-25 present the pre- and post-construction flow rates for the simulations. It should be noted that there is no pre-construction flow occurring from the cooling basin. These flow rates were converted to gallons per minute (gpm) from $feet^3$/day and are summarized in Table 2.4.12-C-8. The simulation results indicate an estimated 3930 gpm seepage rate from the cooling basin. Kuy Creek, Dry Kuy Creek, and the downgradient seeps show a 220 to 460 gpm increase in base flow (contribution from groundwater). The groundwater contribution to base flow in the Victoria Barge Canal increases by approximately 280 gpm and to the San Antonio River increases by approximately 170 gpm. The Guadalupe River and Black Bayou/Linn Lake flows remain essentially unchanged from the pre- to post-construction conditions.

Another impact of cooling basin seepage would be to raise groundwater levels beneath the power block area. Figure 2.4.12-C-26 presents a simulated potentiometric surface map in model layer 2 (geotechnical Sand 1) in the power block area. The map indicates that groundwater levels are predicted to rise after filling the cooling basin. However, the permeable backfill around the power block area buildings provides a pathway for vertical flow to bypass the underlying clay layers and enter the more permeable sands of the Lower Shallow aquifer. The maximum predicted groundwater elevation in the power block area is approximately elevation 85. Figure 2.4.12-C-27 presents a cross-section through the power block area showing groundwater elevations. Figure 2.4.12-C-28 presents the simulated potentiometric surface surrounding the cooling basin in layer 2.

Figure 2.4.12-C-28 indicates an anomalous condition on the Guadalupe River Valley side of the cooling basin. In this area, cells in layers 2 and 4 (geotechnical Sand 1 and Upper Shallow aquifer) are saturated, with a cell in layer 3 (clay) designated as dry. The heads in layers 2 and 4 are rapidly dissipated by boundary conditions (drains in layer 2 and constant heads in layer 4) in the Guadalupe River Valley. This results in insufficient head differential to produce horizontal or vertical flow into layer 3, and hence the layer is dry. Because groundwater flow is occurring primarily in the sands in layers 2 and 4, the presence of these dry cells in the clay (layer 3) should not represent a significant source of error in either flow or head computation.

A sensitivity analysis was performed on uncertain parameters associated with cooling basin seepage. The two primary uncertainties are the conductance of the cooling basin river boundary and the vertical hydraulic conductivity of the natural material underlying the cooling basin.

As discussed previously, the conductance is the product of the surface area and the hydraulic conductivity of the sediment layer divided by the thickness of the sediment (riverbed) layer. The surface area is fixed by the design of the basin, thus the uncertainties are the hydraulic conductivity and the thickness of the sediment or riverbed layer. Because the source of sediment for the cooling basin is limited to internal sources within the cooling basin and chemical precipitates from the cooling water and a thicker sediment layer would interfere with the proper operation of the cooling basin, a sediment thickness of 2 feet would likely be an upper bound condition. The vertical hydraulic conductivity of the sediment was assumed to be 34 feet/day for the base case, which represents a relatively clean sand. A more likely sediment composition would be that of a silty sand, with a hydraulic conductivity approximately an order of magnitude lower (3.4 feet/day). The first sensitivity case uses this lower hydraulic conductivity to estimate seepage from the cooling basin.

A second sensitivity case involves uncertainty regarding the hydraulic conductivity of the clay in model layer 1. Exposure to repeated wetting and drying cycles could result in a higher hydraulic conductivity of the surficial materials. An order of magnitude increase in vertical hydraulic conductivity (0.6 feet/day) of the clay in layer 1 is assumed for the second sensitivity case.

Table 2.4.12-C-9 presents the results of the sensitivity analysis by comparing the base case seepage rate described above with two sensitivity cases. Figure 2.4.12-C-29 presents the seepage rates for the two sensitivity cases. Case 1 and 2 appear to be relatively insensitive with less than 15 percent change in seepage for an order of magnitude change in parameter. The value selected for the hydraulic conductivity of the layer 1 clay in the base case represents the maximum value from the Guelph Permeameter testing and therefore would provide a reasonable estimate for the hydraulic conductivity in the clay.

2.4.12-C-6.2 **Power Block Area Construction Dewatering Effects**

Construction dewatering will be required when constructing the plant because the excavations for the deeper building foundations extend to elevation -15 feet, which is in the Lower Shallow aquifer (model layer 6). The Lower Shallow aquifer is assumed to be dewatered to the approximate bottom of the aquifer at elevation -20 feet. Two dewatering scenarios were considered:

1. Pre-construction groundwater conditions (cooling basin empty) with dewatering the entire power block area.
2. Post-construction groundwater conditions (cooling basin full) with dewatering the entire power block area.

These two scenarios were evaluated because the scheduling of the construction activities is still in the planning stage and these scenarios represent the two extreme conditions. These scenarios would represent the upper and lower bound of dewatering rates for the site. Both scenarios were simulated by assigning constant head cells in model layers 4 and 6 to represent the dewatering pumping. For the cooling basin full scenario constant head cells were also assigned to model layer 2. Model layer 2 is unsaturated under pre-construction conditions. The head in each constant head cell was set at 1 foot above the bottom of the cell. The interior of the excavation was assigned as inactive cells. Model layers 1, 3, and 5 were treated as no flow boundaries since the flow is primarily vertical within these clay layers.

Table 2.4.12-C-10 presents the results of the simulations. Dewatering pumping (flow) rates ranged from approximately 990 to 1840 gpm. Figures 2.12-C-30 through 2.12-C-33 present the simulated potentiometric surfaces and cross-sections in the power block area for the dewatering scenarios. The cooling basin full dewatering scenario resulted in further extension of the dry cells in the clay of layer 3 as discussed in Subsection 2.4.12-C-6.1.

2.4.12-C-6.3 **Accident Release Pathway**

The groundwater flow system downgradient of the power block area was evaluated to identify potential exposure points from an accidental release of radionuclides from postulated radwaste facilities. The release is postulated to occur below the basement of a radwaste building in the backfill present in model layer 4 (Upper Shallow aquifer). The release was simulated by placing six particles in the power block area backfill. The movement of these particles was calculated using MODPATH, which is a companion program to MODFLOW that uses its output to perform the particle tracking. Four particle release scenarios are considered:

1. No pumping.
2. With a hypothetical domestic well pumping on the north site boundary (approximately 4500 feet from the release).
3. With a hypothetical domestic well pumping on the west site boundary (approximately 3800 feet from the release).
4. With a hypothetical domestic well pumping on the east site boundary (approximately 11,000 feet from the release).

The hypothetical domestic wells are screened to fully penetrate model layer 6 (Lower Shallow aquifer), which is the uppermost aquifer used for water supply in the site area. Hypothetical wells located on the site boundary to north and west of the power block area represent the closest receptor locations to the accidental release. The well located on the west property boundary represents the most likely receptor based on simulated post-construction groundwater conditions. For the northern well, the screened interval was from -4 to -20 feet, for the western well, the screened interval was from -4 to -31 feet, and for the eastern well, the screened interval was from 8 to -31 feet. The wells were pumped at 50 gpm, which is considered the maximum practical pumping rate for the Lower Shallow aquifer based on site observations.

Table 2.4.12-C-11 presents a summary of the travel times from the release point to the exposure point at the property boundary as derived from the particle tracking. It should be noted that the MODFLOW simulation is a steady-state solution and is not time-dependent. The MODPATH

program uses the velocity components (V_x, V_y, and V_z) to compute the travel time of a particle through each cell. The Visual MODFLOW post-processor displays this travel time at user specified time intervals along each particle track pathway. For all simulations, a travel time interval of 1000 days was specified. Exposure is assumed to occur when a particle reaches the property boundary for the VCS site. The shortest travel time for a particle to reach the property boundary for each scenario is used. The results of the particle tracking indicate a travel time of approximately 41,000 days.

Figure 2.4.12-C-34 presents the particle track pathways for scenario 1. Figure 2.4.12-C-35 shows a cross-section through model row 95 with the particle track pathways. All pathways are projected onto the section. The cross-section indicates that when the particles are released into the fill they migrate down through the fill into model layer 6 (Lower Shallow aquifer) and then travel laterally toward the east-southeast. The particles eventually discharge into Linn Lake, the Guadalupe River, or into the Victoria Barge Canal.

Figures 2.4.12-C-36 and 2.4.12-C-37 present particle tracks for the northern and western pumping scenarios. Neither scenario results in capture of particles by the pumping wells. The primary influence of the offsite pumping is to locally divert the particle tracks toward the north prior to the particle continuing to the eastern site boundary. Figure 2.4.12-C-38 presents the particle tracks for the eastern pumping scenario. For this scenario, the pumping well causes a small deviation in the particle track, but does not capture the particles.

2.4.12-C-7 **Results**

A three-dimensional, eleven-layer groundwater flow model was developed and calibrated to evaluate groundwater level and flow changes associated with the operation of a cooling basin at the VCS site, with dewatering of site excavations, and to assess the impacts of post-construction conditions on the accidental release and transport of radionuclides. This included a reinterpreted conceptual model of the stratigraphy of the model area and incorporation of additional onsite and offsite data that was not available during the previous model development.

Specific findings of the modeling effort include:

- The groundwater levels in the power block area are predicted to be about elevation 85 feet or about 10 feet below the final plant grade of elevation 95 feet.
- The filling of the cooling basin to elevation 90.5 feet is predicted to raise groundwater levels beneath the site to a point where the currently unsaturated sand layer referred to as the Sand 1 geotechnical unit becomes saturated.

- Seepage from the cooling basin is predicted to increase groundwater contributions (base flow) to Kuy and Dry Kuy Creeks and seeps to the north and east of the VCS site. Seepage from the cooling basin is estimated to be approximately 3930 gpm.
- Seepage from the cooling basin is also predicted to alter the groundwater flow directions in the site area, particularly in the power block area.
- Construction dewatering scenarios were simulated with the cooling basin empty and full with an estimated range of pumping rates between 990 (empty) and 1840 gpm (full).
- Particle tracking suggests that the closest receptor for an accidental release at the power block area would be the eastern property boundary for the VCS site. Pumping of hypothetical domestic wells on the western, eastern, or northern property boundaries did not result in the capture of or significant changes in the flow path of any released particles. The shortest travel time to the property boundary was approximately 41,000 days (110 years) to the eastern site boundary.

2.4.12-C-8 **References**

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Table 2.4.12-C-1 (Sheet 1 of 2)
VCS Site Average Groundwater Level Elevations

Well	Easting (ft)	Northing (ft)	Unit[(a)]	Mean Groundwater Elevation (ft NAVD 88)	Screen Midpoint Elevation (ft NAVD 88)
OW-01L	2606687	13404252	Lower	30.00	-32.8
OW-01U	2606667	13404254	Upper	30.73	17.2
OW-02L	2607869	13411521	Lower	24.31	-27.9
OW-02U	2607862	13411502	Upper	24.55	17.3
OW-03L	2609287	13414919	Lower	19.03	-16.8
OW-3U[(b)]	2609295	13414934	Upper	Dry	27.6
OW-04L	2607440	13414269	Lower	22.62	-25.9
OW-04U	2607429	13414281	Upper	23.59	25[(c)]
OW-05L	2605813	13414774	Deep	25.61	-46.7
OW-05U	2605832	13414770	Upper	26.07	27.1
OW-06L	2604965	13415890	Lower	26.19	-10.5
OW-06U	2604967	13415876	Upper	26.35	21.5
OW-07L	2606531	13418421	Deep	19.62	-40.5
OW-07U	2606542	13418421	Upper	19.91	19.3
OW-08L	2598942	13415819	Deep	32.54	-49.4
OW-08U	2598935	13415801	Lower	36.02	-12.6
OW-09L	2604894	13414937	Deep	27.17	-32[(c)]
OW-09U	2604895	13414956	Upper	26.93	22.9
OW-10L	2604761	13418486	Deep	23.48	-53.9
OW-10U	2604768	13418474	Upper	22.27	25.1
OW-2150L	2599585	13412553	Deep	33.22	-56[(c)]
OW-2150U	2599583	13412568	Upper	44.85	20.9
OW-2169L	2599930	13412357	Lower	35.45	-15
OW-2169U	2599946	13412344	Upper	41.92	20.1
OW-2181L	2600072	13412138	Lower	35.64	-15.1
OW-2181U	2600053	13412147	Upper	41.62	35
OW-2185L	2600816	13412314	Lower	34.12	-15.2
OW-2185U	2600801	13412328	Upper	38.30	9.9
OW-2253L[(d)]	2600474	13413592	Deep	31.88	-58.8
OW-2253U[(d)]	2600495	13413585	Upper	45.40	21.2
OW-2269L	2600574	13413123	Deep	32.03	-54.1
OW-2269U	2600589	13413110	Lower	34.03	-12[(c)]
OW-2284L	2600939	13413064	Lower	33.63	-24
OW-2284U	2600957	13413055	Upper	42.75	11
OW-2301L	2596268	13414430	Deep	36.75	-53.1
OW-2301U	2596288	13414430	Upper	49.25	26.8

Table 2.4.12-C-1 (Sheet 2 of 2)
VCS Site Average Groundwater Level Elevations

Well	Easting (ft)	Northing (ft)	Unit[(a)]	Mean Groundwater Elevation (ft NAVD 88)	Screen Midpoint Elevation (ft NAVD 88)
OW-2302L	2598389	13407382	Deep	35.56	-60[(c)]
OW-2302U	2598388	13407362	Lower	37.30	-9.5
OW-2304L	2608678	13396528	Lower	26.19	-21.1
OW-2304U	2608679	13396542	Upper	34.12	23.8
OW-2307L	2603152	13420879	Lower	24.57	-28.1
OW-2307U	2603164	13420897	Upper	31.39	17.1
OW-2319L	2603052	13403611	Deep	32.87	-75.3
OW-2319U	2603046	13403590	Lower	33.95	-15.7
OW-2320L	2606834	13407581	Deep	28.73	-73.2
OW-2320U	2606850	13407570	Lower	27.75	-33.2
OW-2321L	2610028	13410955	Deep	20.23	-73
OW-2321U	2610041	13410944	Lower	20.40	-33.2
OW-2324L	2612217	13416301	Deep	12.28	-95.1
OW-2324U	2612203	13416317	Lower	12.74	-15.3
OW-2348L	2621644	13409618	Deep	11.14	-87.8
OW-2348U	2621661	13409636	Lower	10.91	-24.4
OW-2352L	2617519	13402468	Lower	18.86	-21.7
OW-2352U	2617539	13402471	Upper	18.83	13.2
OW-2359L1	2605471	13417264	Deep	22.94	-88.9
OW-2359U1	2605461	13417253	Lower	22.94	-12.3
7923601	2561712	13437903	Deep	68.91	4
7924102	2581676	13448023	Deep	48.90	3
7924702	2572205	13427869	Deep	58.44	-63.4

(a) Unit: Upper = Upper Shallow aquifer; Lower = Lower Shallow aquifer; Deep = Deep aquifer
(b) Not used for model calibration target
(c) Screen midpoint elevation adjusted to place observation well in the appropriate hydrogeologic unit
(d) Groundwater elevation data corrected for revised reference elevation

Table 2.4.12-C-2 (Sheet 1 of 4)
TWDB Groundwater Levels Used to Prepare Regional Potentiometric Surface Map

Well	Easting (ft)	Northing (ft)	Type	Date	Unit	Static Level (ft bgs)	Groundwater Elevation (NAVD 88)	Screen Midpoint Elevation (NAVD 88)
2975	2629306	13423478	Domestic	10/17/2001	Deep	13	-4	-118
2976	2630562	13422995	Domestic	10/18/2001	Deep	16	8	-116
3395	2593942	13444084	Domestic	11/16/2001	Deep	63	25	-57
12527	2591656	13442329	Domestic	9/18/2002	Lower	57	31	1
13049	2635570	13437024	Domestic	7/25/2001	Lower	45	19	-6
15387	2584676	13455143	Domestic	10/31/2002	Lower	44	33	-9
15388	2584676	13455143	Domestic	12/13/2002	Deep	42	35	-41
20512	2557613	13420970	Domestic	5/16/2003	Lower	47	67	-1
20516	2558217	13422192	Domestic	5/17/2003	Lower	43	70	-2
20754	2558534	13424722	Domestic	5/23/2003	Lower	51	60	-4
20756	2556606	13422672	Domestic	5/24/2003	Lower	51	63	-26
21203	2553283	13441508	Domestic	6/2/2003	Deep	45	76	-69
28288	2650367	13451230	Domestic	8/22/2003	Lower	31	29	-37
28700	2614329	13397964	Industrial	6/6/2003	Deep	55	9	-186
29459	2638583	13447886	Domestic	8/8/2003	Lower	40	24	-41
29661	2572086	13446352	Domestic	9/9/2003	Lower	40	66	-39
30482	2587888	13443983	Domestic	10/17/2003	Lower	50	40	6
30484	2580697	13431643	Stock	10/21/2003	Lower	49	46	-23
30487	2581098	13434377	Stock	10/23/2003	Lower	47	48	5
35570	2642383	13414821	Rig Supply	4/7/2004	Deep	50	-24	-84
37824	2595814	13390680	Domestic	8/29/2003	Deep	47	13	-70
38317	2623846	13450352	Domestic	3/16/2004	Lower	19	22	-28
39830	2620351	13441402	Public Supply	6/19/2004	Deep	13.5	22	-201
40870	2565386	13447659	Domestic	7/8/2004	Lower	48	60	3
40876	2557985	13425622	Domestic	7/15/2004	Lower	46	65	-9
41862	2630239	13456425	Domestic	7/26/2004	Lower	50	23	-32
44703	2564716	13433810	Domestic	9/10/2004	Upper	48	62	17
46887	2553498	13416259	Domestic	9/27/2004	Lower	49	52	-36
46888	2566591	13455860	Domestic	9/29/2004	Lower	35	58	-22
47169	2564716	13433810	Domestic	10/15/2004	Upper	48	62	30
47194	2610571	13383050	Domestic	10/21/2004	Deep	10	16	-109
47734	2586128	13448096	Domestic	10/27/2004	Upper	54	41	15
49428	2560160	13372424	Domestic	7/9/2003	Deep	23	62	-100
51472	2574592	13373866	Domestic	2/18/2004	Deep	40	42	-223
52185	2592889	13400328	Domestic	1/13/2004	Lower	42	36	-33
53341	2568845	13431855	Domestic	1/21/2005	Deep	55	51	-142

Table 2.4.12-C-2 (Sheet 2 of 4)
TWDB Groundwater Levels Used to Prepare Regional Potentiometric Surface Map

Well	Easting (ft)	Northing (ft)	Type	Date	Unit	Static Level (ft bgs)	Groundwater Elevation (NAVD 88)	Screen Midpoint Elevation (NAVD 88)
55969	2625500	13447452	Domestic	2/18/2005	Lower	35	24	-7
56174	2616736	13392854	Stock	1/27/2005	Deep	44	18	-54
58542	2563763	13448946	Domestic	3/17/2005	Deep	41	60	-117
62190	2625774	13447053	Domestic	12/17/2003	Lower	40	20	-32
62191	2625774	13447053	Domestic	12/29/2003	Lower	27	33	-20
63332	2566198	13435853	Domestic	6/2/2005	Upper	42	68	27
63333	2567877	13442244	Domestic	6/3/2005	Upper	42	68	40
66473	2552514	13445133	Domestic	9/3/2005	Deep	55	61	-171
70190	2650361	13461331	Rig Supply	10/26/2005	Deep	33	32	-65
72241	2649345	13453534	Domestic	10/14/2005	Lower	30	32	-16
74199	2650274	13461228	Irrigation	1/2/2006	Deep	33	32	-500
79458	2637407	13383923	Rig Supply	1/29/2006	Deep	32	-23	-177
80941	2582807	13449657	Rig Supply	2/28/2006	Deep	38	34	-113
83861	2597763	13428693	Domestic	3/28/2006	Deep	57	-8	-62
83923	2579059	13367979	Rig Supply	4/3/2006	Deep	50	27	-113
84813	2593692	13437716	Domestic	5/5/2006	Lower	52	20	-28
87073	2550192	13445501	Domestic	7/7/2006	Lower	45	76	-14
90311	2637916	13435348	Domestic	1/10/2003	Deep	47	13	-70
90980	2561827	13424976	Domestic	6/30/2006	Deep	43	65	-52
91796	2556196	13443170	Domestic	7/5/2006	Lower	32	87	-16
94678	2591928	13393747	Domestic	8/26/2003	Upper	47	38	5
96505	2577972	13429376	Domestic	8/30/2006	Deep	53	45	-82
96509	2577972	13429376	Domestic	8/30/2006	Deep	53	45	-82
97825	2633786	13422143	Domestic	9/16/2006	Deep	55	5	-48
105177	2594099	13434692	Domestic	2/26/2007	Lower	55	30	-20
109093	2646705	13456719	Domestic	2/17/2007	Deep	35	29	-41
109312	2584679	13427870	Stock	2/24/2007	Lower	60	33	-17
111653	2595760	13457852	Irrigation	4/30/2007	Deep	43	39	-108
114737	2567667	13394059	Domestic	6/15/2007	Deep	23	52	-55
114765	2577096	13373503	Rig Supply	5/31/2007	Deep	36	42	-62
116813	2554345	13441929	Domestic	6/18/2007	Lower	45	74	-22
123730	2567559	13400825	Domestic	9/4/2007	Lower	40	45	-6
123876	2579019	13375958	Rig Supply	9/26/2007	Deep	42	33	-60
125118	2577379	13449468	Domestic	9/30/2007	Lower	51	47	-16
125240	2553568	13451715	Domestic	1/11/2005	Lower	34	64	-2
126101	2597208	13413936	Industrial	10/31/2007	Deep	45	37	-78
126247	2589607	13399264	Domestic	10/21/2007	Deep	43	42	-110

Table 2.4.12-C-2 (Sheet 3 of 4)
TWDB Groundwater Levels Used to Prepare Regional Potentiometric Surface Map

Well	Easting (ft)	Northing (ft)	Type	Date	Unit	Static Level (ft bgs)	Groundwater Elevation (NAVD 88)	Screen Midpoint Elevation (NAVD 88)
126971	2561423	13416687	Rig Supply	10/29/2007	Deep	53	58	-53
128362	2639296	13422948	Domestic	11/23/2007	Deep	43	16	-254
129682	2593494	13396096	Rig Supply	11/1/2007	Deep	44	39	-57
129733	2585664	13395057	Rig Supply	11/13/2007	Deep	50	38	-132
129891	2596667	13393017	Rig Supply	11/29/2007	Deep	55	30	-55
131103	2621991	13459714	Domestic	11/29/2007	Lower	24	22	-26
131109	2647137	13427938	Domestic	11/3/2007	Deep	40	17	-114
133529	2595195	13390367	Rig Supply	12/28/2007	Deep	47	28	-95
134709	2594186	13386713	Rig Supply	2/8/2008	Deep	24	18	-83
134712	2578197	13382612	Rig Supply	2/4/2008	Deep	13	32	-70
136966	2571958	13371198	Rig Supply	2/27/2008	Lower	30	48	0
137968	2572442	13446358	Domestic	3/28/2008	Lower	50	55	-5
138301	2549695	13460341	Domestic	2/6/2007	Lower	38	73	-12
138492	2557861	13427843	Stock	4/1/2008	Lower	34	79	3
139366	2573143	13375156	Rig Supply	3/14/2008	Deep	25	52	-93
139380	2566733	13368690	Rig Supply	3/24/2008	Deep	29	49	-67
140059	2598215	13401730	Rig Supply	4/1/2008	Deep	38	37	-75
142684	2563200	13439543	Domestic	10/22/2004	Lower	44	67	-4
142764	2578594	13374638	Rig Supply	4/30/2008	Lower	42	36	-32
143295	2566186	13419793	Rig Supply	5/13/2008	Deep	42	63	-68
143694	2580145	13449109	Rig Supply	6/1/2008	Deep	44	48	-156
146005	2636438	13438352	Domestic	5/15/2008	Deep	35	27	-106
146330	2650857	13370326	Domestic	6/2/2008	Deep	-2	6	-146
147246	2599419	13441448	Domestic	7/9/2008	Lower	22	24	-34
148624	2642567	13429371	Stock	2/12/2006	Deep	44	15	-85
148628	2633111	13369604	Stock	2/17/2006	Deep	1	8	-57
148634	2572856	13431718	Domestic	3/9/2006	Lower	50	55	-39
150946	2630378	13367737	Industrial	8/22/2005	Deep	2	39	-179
151183	2643671	13367974	Domestic	7/18/2005	Deep	28	13	-119
152378	2550222	13443582	Domestic	8/6/2005	Deep	50	71	-61
153420	2592162	13390417	Rig Supply	8/8/2008	Deep	37	35	-118
155221	2553252	13392013	Stock	8/14/2008	Deep	30	68	-62
155301	2642071	13442089	Industrial	10/4/2008	Deep	37	23	-206
156209	2551353	13393701	Industrial	6/24/2005	Deep	40	58	-72
157382	2590715	13375443	Rig Supply	9/2/2008	Deep	38	39	-53
157386	2580339	13382546	Rig Supply	9/3/2008	Deep	10	39	-81
161253	2593997	13419438	Stock	10/8/2008	Deep	45	40	-67

Table 2.4.12-C-2 (Sheet 4 of 4)
TWDB Groundwater Levels Used to Prepare Regional Potentiometric Surface Map

Well	Easting (ft)	Northing (ft)	Type	Date	Unit	Static Level (ft bgs)	Groundwater Elevation (NAVD 88)	Screen Midpoint Elevation (NAVD 88)
161358	2609667	13368085	Rig Supply	10/16/2008	Deep	30	30	-70
161644	2623066	13449127	Domestic	12/5/2008	Deep	18	24	-63
161646	2592521	13433151	Stock	12/8/2008	Lower	47	38	-30
161688	2581900	13407117	Rig Supply	9/17/2008	Deep	39	46	-65
165912	2572413	13420498	Rig Supply	11/6/2008	Lower	43	57	-30
166025	2575389	13418324	Rig Supply	11/7/2008	Lower	44	51	-35
167501	2569737	13459546	Domestic	2/3/2009	Deep	72	26	-62
169413	2572955	13381315	Stock	2/19/2009	Deep	15	37	-128
169935	2560570	13431219	Domestic	6/20/2005	Upper	43	71	38
169956	2562731	13452263	Domestic	12/30/2004	Deep	40	58	-81
170172	2605749	13399130	Rig Supply	4/22/2005	Deep	50	20	-142
170186	2633755	13459012	Domestic	8/2/2004	Lower	41	34	-25
170597	2586817	13449521	Domestic	12/2/2004	Upper	24	40	34
170601	2588963	13443597	Domestic	7/16/2004	Deep	50	42	-108
170670	2628169	13447600	Domestic	1/3/2009	Lower	34	25	-23
170672	2581053	13437103	Domestic	3/10/2009	Lower	50	45	-5
171010	2610853	13366590	Domestic	2/2/2009	Deep	35	22	-123
183355	2576314	13372177	Rig Supply	5/14/2009	Deep	36	44	-110
185268	2572167	13446858	Domestic	5/25/2009	Lower	35	70	-5
187268	2563774	13408946	Stock	7/10/2009	Deep	50	55	-63
187653	2561835	13441340	Domestic	6/30/2009	Lower	42	68	-30
191003	2584205	13380690	Rig Supply	7/27/2009	Deep	9	36	-75

Unit: Upper = Upper Shallow aquifer; Lower = Lower Shallow aquifer; Deep = Deep aquifer
NAVD 88 = North American Vertical Datum of 1988
ftbgs = feet below ground surface

Table 2.4.12-C-3
Harmonic Mean Vertical Hydraulic Conductivity of Layer 11

Well	**Northing**	**Easting**	**Elevation (NAVD88)**	**Total Depth (ftbgs)**	**Sand 6**		**Clay 7**		**Sand 8**		**Clay 9**		**Sand 10**		
					Depth Bottom	Elev. Bottom	Depth Bottom	Thickness	Depth Bottom	Thickness	Depth Bottom	Thickness	Depth Bottom	Thickness	
129733	13395057	2585664.09	88	240	191.0	-102.9	206	15	▨	▨	▨	▨	▨	▨	
143580	13380355	2588403.74	39	275	120.0	-81.1	157	37	171	14	210	39	227	17	
143991	13386642	2636912.87	32	264	155.0	-122.6	180	25	233	53	248	15	▨	▨	
153420	13390417	2592161.86	72	250	214.0	-142.3	238	24	▨	▨	▨	▨	▨	▨	
39830	13441402	2620350.8	36	260	167.0	-131.3	196	29	207	11	▨	▨	▨	▨	
68027	13419465	2630892.05	14	180	140.0	-125.7	155	15	▨	▨	▨	▨	▨	▨	
68823	13415933	2619545.85	14	140	95.0	-80.7	105	10	▨	▨	▨	▨	▨	▨	
B-2301	13414430	2596278.37	80.79	300	194.0	-113.2	240	46	265	25	292	27	▨	▨	
B-2302	13407371	2598389.3	80	315	181.0	-101.0	227	46	273	46	▨	▨	▨	▨	
B-2303	13402308	2600478.63	75.56	310	192.0	-116.4	234	42	265	31	▨	▨	▨	▨	
B-2304	13396556	2608686.75	68.12	310	235.0	-166.9	236	🟨	288	52	▨	▨	▨	▨	
B-2305	13406653	2621646.04	65.58	305	185.2	-119.6	238.8	54	250	11	▨	▨	▨	▨	
B-2306	13411450	2615249.64	64.68	310	196.0	-131.3	220	24	231	11	▨	▨	▨	▨	
B-2307	13420888	2603157.79	76.38	310	189.0	-112.6	190	🟨	238.2	48	282	44	▨	▨	
B-11	13411479	2607866.27	74.5	310	205.0	-130.5	220	15	240	20	260	20	295	35	
B-2169	13412350	2599938.43	79.46	400	213.5	-134.0	253	40	284	31	326	42	334	8	
B-2170	13412414	2599989.73	79.72	300	197.0	-117.3	258.5	62	288.5	30	▨	▨	▨	▨	
B-2170R	13412396	2599989.34	79.17	300	203.0	-123.8	268.5	66	288.5	20	▨	▨	▨	▨	
B-2171R	13412480	2600074.23	79.97	300	219.2	-139.2	255	36	285	30	▨	▨	▨	▨	
B-2173	13412225	2599944.53	79.6	300	228.5	-148.9	257	29	287	30	▨	▨	▨	▨	
B-2174A	13412299	2600000.66	80.1	601	212.0	-131.9	243	31	284.6	42	321.8	37	335.5	14	
B-2182A	13412207	2600143.8	79.5	399.8	207.5	-127.8	230.5	23	284.6	54	348.6	64	373.2	25	
B-2269	13413117	2600582.5	80.45	403.3	201.7	-121.3	202.7	🟨	301.8	99	322.6	21	▨	▨	
B-2270	13413179	2600633.41	80.62	300	218.5	-137.9	219.5	🟨	258.5	39	▨	▨	▨	▨	
B-2271	13413253	2600735.25	80.46	301.2	209.0	-128.5	210	🟨	281	71	▨	▨	▨	▨	
B-2273	13412991	2600585.52	80.69	399.4	217.9	-137.2	218.9	🟨	291	72	334	43	367.9	34	
B-2274A	13413066	2600642.97	80.86	594.7	220.0	-139.1	221	🟨	290	69	327	37	368.2	41	
B-2282A	13412971	2600757.69	80.31	400	218.5	-138.2	219.5	🟨	285	66	331	46	373	42	Total
	🟨	Layer not present					Average Thickness (ft)	33		41		36.2		26.9	137
	▨	below bottom of the boring/well					Fraction of thickness (*w*)	0.24		0.30		0.26		0.20	1.00
							K_v (ft/d) [*x*]	7.00E-05		34		7.00E-05		34	

weighted harmonic mean 0.000138 ft/d

$$wHM = \frac{1}{\frac{w_1}{x_1} + \frac{w_2}{x_2} + \cdots \frac{w_n}{x_n}}$$

Table 2.4.12-C-4
Hydraulic Conductivity Values

Model Layer[a]	Geotechnical Layer	Horizontal Hydraulic Conductivity K_h (ft/day)	Source	Vertical Hydraulic Conductivity K_v (ft/day)	Source
1	Clay 1 Top	0.68[b]	Reference 2.4.12-C-9	0.068[b]	Table 2.4.12-14
2	Sand 1	8.2***	Reference 2.4.12-C-9	2.75***	Table 2.4.12-14
3	Clay 1 Bottom	7×10^{-4}	Reference 2.4.12-C-9	7×10^{-5}	Table 2.4.12-13
4	Sand 2	60[c]	Table 2.4.12-9	20[c]	Reference 2.4.12-C-9
5	Clay 3	7×10^{-4}	Reference 2.4.12-C-9	7×10^{-5}	Table 2.4.12-13
6	Sand 4	103	Table 2.4.12-9	34	Reference 2.4.12-C-9
7	Clay 5 Top	7×10^{-4}	Reference 2.4.12-C-9	7×10^{-5}	Table 2.4.12-13
8	Sand 5	103	Table 2.4.12-9	34	Reference 2.4.12-C-9
9	Clay 5 Bottom	7×10^{-4}	Reference 2.4.12-C-9	7×10^{-5}	Table 2.4.12-13
10	Sand 6	103	Table 2.4.12-9	34	Reference 2.4.12-C-9
11	Clay 7 and 9 Sand 8 and 10	1.4×10^{-3}	Reference 2.4.12-C-9	1.4×10^{-4}	Table 2.4.12-C-3

(a) Where geotechnical layers are absent in a given model layer, the underlying layer hydraulic conductivity is used.
(b) Adjusted during calibration – model layer 1 K_v = 0.06 feet/day and K_h = 0.6 feet/day
(c) Adjusted during calibration – model layers 2 and 4 K_h = 68 feet/day and K_v = 23 feet/day

Table 2.4.12-C-5
Porosity Values

Model Layer	Geotechnical Unit	Mean Total Porosity (%)	Mean Effective Porosity (%)
1	Clay 1 Top	35.8	7.2
2	Sand 1	31.0	24.7
3	Clay 1 Bottom	40.5	8.1
4	Sand 2	36.6	29.2
5	Clay 3	41.4	8.3
6	Sand 4	36.5	29.2
7	Clay 5 Top	38.1	7.8
8	Sand 5	35.0(a)	29.5(a)
9	Clay 5 Bottom	38.1	7.8
10	Sand 6	35.0	29.5
11	Clay 7 and 9 Sand 8 and 10	37.9	13.2

(a) Only one test performed – used mean value for Sand 6

Data Source: Subsection 2.4.12, Table 2.4.12-10

Table 2.4.12-C-6
Summary of Model Boundary Conditions

Feature	Boundary Type	Elevation and General Location of Boundary
Linn Lake	Dirichlet (Type 1) – Constant Head	10 ft – East of VCS site
Groundwater Flow Lines Model layers 2, 4, 6, 8, and 10	Neuman (Type 2)- No Flow Boundary	Portions of the north and south model boundary – parallel to groundwater flow direction
Clay layers Model layers 1,3,5,7,9, and 11	Neuman (Type 2)- No Flow Boundary	The no flow boundary condition was assigned to the perimeter of all clay layers, since the flow in these layers is primarily vertical
Recharge	Cauchy (Type 3) – Recharge	Uppermost active layer of the model
Evapotranspiration	Cauchy (Type 3) – ET	Layer 1 of the model
Victoria Barge Canal	Cauchy (Type 3) – River	0 ft (sea level canal) Eastern side of model domain
Guadalupe River	Cauchy (Type 3) – River	20 to 5 ft Eastern side of model domain
San Antonio River	Cauchy (Type 3) – River	62 to 5 ft Western and southern side of the model domain
Coleto Creek	Cauchy (Type 3) – River	72 to 19 ft North side of model domain
Black Bayou	Cauchy (Type 3) – River	27 to 10 ft East of VCS site
Downgradient Seeps	Cauchy (Type 3) – Drain	1 ft above bottom of drain cell East and north of VCS site
Kuy Creek	Cauchy (Type 3) – Drain	1 ft above bottom of drain cell West and south of VCS site
Dry Kuy Creek	Cauchy (Type 3) – Drain	1 ft above bottom of drain cell South of VCS site
Regional Groundwater Flow	Cauchy (Type 3) – General Head Boundary	Layers 4, 6, 7, 8, 9, and 10 (Refer to text for elevations)

Table 2.4.12-C-7 (Sheet 1 of 2)
Comparison of Simulated and Measured Heads

Well Name	Observed Head - h_{obs} (ft NAVD 88)	Simulated Head - h_{sim} (ft NAVD 88)	Residual Head (h_{obs}-h_{sim})	Absolute Residual Head $\|h_{obs}-h_{sim}\|$
0W-10U	22.27	29.93	-7.66	7.66
7923601	68.91	74.00	-5.09	5.09
7924102	48.90	47.77	1.13	1.13
7924702	58.44	59.11	-0.67	0.67
OW-01L	30.00	25.91	4.09	4.09
OW-01U	30.73	30.02	0.71	0.71
OW-02L	24.31	23.96	0.35	0.35
OW-02U	24.55	28.22	-3.67	3.67
OW-03L	19.03	22.46	-3.43	3.43
OW-04L	22.62	23.96	-1.34	1.34
OW-04U	23.59	27.82	-4.23	4.23
OW-05L	25.61	25.69	-0.09	0.09
OW-05U	26.07	29.58	-3.51	3.51
OW-06L	26.19	26.23	-0.04	0.04
OW-06U	26.35	30.06	-3.71	3.71
OW-07L	19.62	24.17	-4.54	4.54
OW-07U	19.91	28.45	-8.55	8.55
OW-08L	32.54	30.70	1.84	1.84
OW-08U	36.02	31.71	4.31	4.31
OW-09L	27.17	26.25	0.92	0.92
OW-09U	26.93	30.30	-3.37	3.37
OW-10L	23.48	26.20	-2.72	2.72
OW-2150L	33.22	31.10	2.12	2.12
OW-2150U	44.85	34.48	10.37	10.37
OW-2169L	35.45	31.08	4.37	4.37
OW-2169U	41.92	34.24	7.68	7.68
OW-2181L	35.64	30.97	4.67	4.67
OW-2181U	41.62	34.17	7.45	7.45
OW-2185L	34.12	30.07	4.05	4.05
OW-2185U	38.30	33.66	4.64	4.64
OW-2253L	31.88	30.31	1.57	1.57
OW-2253U	45.40	33.79	11.61	11.61
OW-2269L	32.03	30.29	1.74	1.74
OW-2269U	34.03	30.17	3.86	3.86
OW-2284L	33.63	29.84	3.79	3.79
OW-2284U	42.75	33.52	9.23	9.23
OW-2301L	36.75	33.49	3.27	3.27

Table 2.4.12-C-7 (Sheet 2 of 2)
Comparison of Simulated and Measured Heads

Well Name	Observed Head - h_{obs} (ft NAVD 88)	Simulated Head - h_{sim} (ft NAVD 88)	Residual Head (h_{obs}-h_{sim})	Absolute Residual Head $\|h_{obs}-h_{sim}\|$
OW-2301U	49.25	36.86	12.39	12.39
OW-2302L	35.56	32.10	3.45	3.45
OW-2302U	37.30	33.36	3.94	3.94
OW-2304L	26.19	25.00	1.19	1.19
OW-2304U	34.12	26.01	8.12	8.12
OW-2307L	24.57	27.17	-2.61	2.61
OW-2307U	31.39	31.22	0.17	0.17
OW-2319L	32.87	28.71	4.16	4.16
OW-2319U	33.95	28.76	5.19	5.19
OW-2320L	28.73	25.78	2.95	2.95
OW-2320U	27.75	25.36	2.39	2.39
OW-2321L	20.23	23.24	-3.01	3.01
OW-2321U	20.40	22.60	-2.20	2.20
OW-2324L	12.28	20.95	-8.67	8.67
OW-2324U	12.74	20.49	-7.75	7.75
OW-2348L	11.14	15.18	-4.04	4.04
OW-2348U	10.91	14.90	-3.99	3.99
OW-2352L	18.86	19.92	-1.06	1.06
OW-2352U	18.83	18.94	-0.11	0.11
OW-2359L1	22.94	25.83	-2.89	2.89
OW-2359U1	22.94	25.59	-2.65	2.65

Table 2.4.12-C-8
Estimated Cooling Basin Seepage

Flow Component	Pre-Construction (gpm)	Post-Construction (gpm)	Change[(a)] (gpm)
Cooling Basin	0	**3930**	+3930
Evapotranspiration	**(880)**	**(3770)**	+2890
Kuy Creek	0	**(220)**	+220
Dry Kuy Creek	0	**(460)**	+460
Downgradient Drains	0	**(310)**	+310
Black Bayou and Linn Lake	**(130)**	**(130)**	0
Victoria Barge Canal	**(16,240)**	**(16,520)**	+280
Guadalupe River	**7510**	**7510**	0
San Antonio River	**(940)**	**(1110)**	+170

(RED) numbers indicate flow out of the model or base flow to creeks and rivers.
BLUE numbers indicate flow into the model – surface water inflow to groundwater.
Rates rounded to the nearest 10 gpm.

(a) "+" indicates an increase in flow from pre- to post-construction conditions and a "–" indicates a decrease.

Flow Mass Balance	Pre-Construction (%)	Post-Construction (%)
Overall Flow Discrepancy	0.04	0.15

Table 2.4.12-C-9
Cooling Basin Seepage Sensitivity Analysis

Case	Cooling Basin Seepage Rate (gpm)	Change from Base Rate (gpm)
Base case Cooling Basin seepage	3930	0
River Boundary Conductance decreased 10x	3360	-570
Layer 1 Clay hydraulic conductivity increased 10x	4010	+80

Rates rounded to the nearest 10 gpm.

Table 2.4.12-C-10
Summary of Predictive Dewatering Simulations

Dewatering Scenario	Pumping Rate (gpm)
1. Cooling Basin Empty – Full Site Dewatering	990
2. Cooling Basin Full – Full Site Dewatering	1840

Simulated pumping rates rounded to the nearest 10 gpm.

Table 2.4.12-C-11
Summary of Particle Tracking Analysis

Scenario	Minimum Travel Time days (years)	Approximate Distance (ft)
1- No Pumping	41,000 (110)	14,000
2- Northern Domestic Well pumping 50 gpm	41,000 (110)	14,000
3 – Western Domestic Well pumping 50 gpm	41,000 (110)	14,000
4 – Eastern Domestic Well pumping 50 gpm	41,000 (110)	14,000

Travel time in days reported to the nearest 1000 days, travel time in years reported to the nearest 5 years, and distance reported to the nearest 500 feet.