



CALCULATION COVER SHEET

CALC NO. TXUT-001-FSAR-2.4.12-
CALC-039

REV. 2

PAGE NO. 1 of 39

Title:	Calculation of Horizontal and Vertical Pathways	Client: MNES
		Project: MITS187

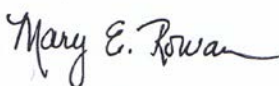


Item	Cover Sheet Items	Yes	No
1	Does this calculation contain any open assumptions that require confirmation? (If YES, identify the assumptions) See Section 4.0 for a description of the open assumptions surface grading contours.	<input type="checkbox"/>	<input checked="" type="checkbox"/>
2	Does this calculation serve as an "Alternate Calculation"? (If YES, identify the design verified calculation.) Design Verified Calculation No. _____	<input type="checkbox"/>	<input checked="" type="checkbox"/>
3	Does this calculation Supersede an existing Calculation? (If YES, identify the superseded calculation.) Superseded Calculation No. _____	<input type="checkbox"/>	<input checked="" type="checkbox"/>

Scope of Revision: Revised references and reference numbers in text, corrected typographical errors.

Revision Impact on Results: None

Study Calculation Final Calculation
Safety-Related Non Safety-Related

(Print Name and Sign)

Originator:  M. Elizabeth Rowan	Date: 3/15/13
Design Verifier:  Caitlin Current	Date: 3/15/13
Project Management Approver:  Joe Mancinelli	Date: 3/15/13



**CALCULATION
REVISION STATUS SHEET**

**CALC NO. TXUT-001-FSAR-2.4.12-
CALC-039**

REV. 2

PAGE NO. 2 of 39

CALCULATION REVISION STATUS

<u>REVISION</u>	<u>DATE</u>	<u>DESCRIPTION</u>
0	2/21/2013	Original Calculation
1	2/22/2013	Revised Appendix D to include Figure 1
2	3/15/2013	Updated references, revised reference numbers throughout text, corrected typos.

PAGE REVISION STATUS

<u>PAGE NO.</u>	<u>REVISION</u>	<u>PAGE NO.</u>	<u>REVISION</u>
1-39	2		

APPENDIX REVISION STATUS

<u>APPENDIX NO.</u>	<u>PAGE NO.</u>	<u>REVISION NO.</u>	<u>APPENDIX NO.</u>	<u>PAGE NO.</u>	<u>REVISION NO.</u>
Appendix A	electronic files	0			
Appendix B	electronic files	0			
Appendix C	electronic files	0			
Appendix D	1-1	2			



**CALCULATION
DESIGN VERIFICATION
PLAN AND SUMMARY SHEET**

**CALC NO. TXUT-001-FSAR-2.4.12-
CALC-039**

REV. 2

PAGE NO. 3 of 39

Calculation Design Verification Plan:

Apply CSP Number 3.01, Revision 6, Section 4.5, Design Review Method.

The calculation Design Inputs, Assumptions and Methodology will be verified to ensure that:

- They were appropriate and correctly applied, and
- They are reasonable for the purpose of completing an analysis of groundwater pathways using numerical modeling software (MODFLOW and MODPATH).

The set-up and results of model files will be reviewed to make sure that:

- the horizontal pathway model was correctly set-up;
- the vertical pathway model was correctly set-up;
- each pathway model produced the same results as those delivered for review; and
- the steady-state flow model for each pathway model converged properly with acceptable mass balance.

The calculation methodology, results, and conclusions will be verified to ensure that:

- the calculation satisfied the objective;
- the calculation conclusions are valid; and
- the conclusions are supported by the calculation.

(Print Name and Sign for Approval – Mark “N/A” if not required)

Approver:

Date: 3/15/13

Calculation Design Verification Summary:

Model results and calculations were verified by:

- Comparing reference materials against model setup, inputs and listed assumptions, both in the model itself and this CALC write-up;
- Independent calculation of values derived from inputs;
- Completion of model simulations on an independent computer to verify the results; and
- Independent creation of model output figures/graphs to verify the results.

Comments were provided pertaining to model results read from output information and transcribed to the calc; inconsistencies were corrected. The model results were found to be reproducible, reasonable, and accurate. Calculations were independently verified to be correct. Calculation logic, methodology, and presentation are considered acceptable.

Based On The Above Summary, The Calculation Is Determined To Be Acceptable.

(Print Name and Sign)

Design Verifier:

Caitlin Current

Date: 3/15/13

Others:

Date:



**CALCULATION
DESIGN VERIFICATION
CHECKLIST**

**CALC NO. TXUT-001-FSAR-2.4.12-
CALC-039**


REV. 2

PAGE NO. 4 of 39

ITEM	CHECKLIST ITEMS	Yes	No	N/A
1	Design Inputs – Were the design inputs correctly selected, referenced (latest revision), consistent with the design basis and incorporated in the calculation?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	Assumptions – Were the assumptions reasonably and adequately described, justified and/or verified, and documented?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	Quality Assurance – Were the appropriate QA classification and requirements assigned to the calculation?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	Codes, Standards and Regulatory Requirements – Were the applicable codes, standards and regulatory requirements, including issue and addenda, properly identified and their requirements satisfied?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
5	Construction and Operating Experience – Have applicable construction and operating experience been considered?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
6	Interfaces – Have the design interface requirements been satisfied, including interactions with other calculations?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
7	Methods – Was the calculation methodology appropriate and properly applied to satisfy the calculation objective?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	Design Outputs – Was the conclusion of the calculation clearly stated, did it correspond directly with the objectives and are the results reasonable compared to the inputs?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	Radiation Exposure – Has the calculation properly considered radiation exposure to the public and plant personnel?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
10	Acceptance Criteria – Are the acceptance criteria incorporated in the calculation sufficient to allow verification that the design requirements have been satisfactorily accomplished?	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
11	Computer Software – Is a computer program or software used, and if so, are the requirements of CSP 3.02 met?	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

COMMENTS:

(Print Name and Sign)

<p>Design Verifier: Caitlin Current</p> 	<p>Date: 3/15/13</p>
<p>Others:</p>	<p>Date:</p>



	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12- CALC-039
		REV. 2
		PAGE NO. 5 of 39

Table of Contents

1.0	PURPOSE AND SCOPE.....	6
2.0	SUMMARY OF RESULTS AND CONCLUSIONS.....	6
3.0	REFERENCES.....	8
4.0	ASSUMPTIONS.....	9
5.0	DESIGN INPUTS.....	10
5.1.	Flow Model Domain.....	10
5.2.	Site Topography.....	14
5.3.	Model Layers.....	15
5.4.	Aquifer Parameters.....	18
5.5.	Model Boundaries.....	22
5.6.	Particle Release Locations.....	24
6.0	METHODOLOGY.....	26
6.1.	Groundwater Flow Simulation.....	27
6.2.	Particle Tracking Calculations.....	27
7.0	CALCULATION RESULTS.....	28
7.1.	Horizontal Pathway Base Run.....	29
7.2.	Vertical Pathway Base Run.....	33
7.3.	Sensitivity Analysis for Horizontal Pathway.....	35
7.4.	Sensitivity Analysis for Vertical Pathway.....	38
8.0	CALCULATION RESULTS.....	39
9.0	APPENDICES.....	39

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 6 of 39

1.0 PURPOSE AND SCOPE

This calculation documents the structure and results of particle-tracking modeling completed for the Comanche Peak Nuclear Power Plant (CPNPP) Units 3 and 4. Particle-tracking is used to characterize the movement of groundwater in the subsurface at each unit following a postulated release from the Boric Acid Tanks (BAT). The horizontal pathway of groundwater movement is evaluated using a single-layer numerical model, which limits groundwater movement to occurring only in the horizontal direction. A multi-layer numerical model is used to evaluate the vertical pathway of groundwater movement. Particle-tracking results are used to provide pathway characteristics for input to the RESRAD model.

2.0 SUMMARY OF RESULTS AND CONCLUSIONS

The pathway characteristics of groundwater movement in the horizontal and vertical directions from the BATs located at Units 3 and 4 are identified. The horizontal pathways with the shortest travel distance and fastest travel times from each unit are illustrated in Figure 2.1. The vertical pathway is illustrated in Figure 2.2; the vertical pathway from each unit is identical, as conditions beneath each unit for evaluating vertical migration (hydrogeologic properties and distance to underlying formations) are identical.

Multiple pathways for the horizontal movement of groundwater particles are identified in the model. However, Pathway 3-1 is identified as the key pathway of interest (Figure 2.1), as it has the fastest travel time at Unit 3 and only a slightly greater pathway distance than the next shorter pathway. This pathway extends west from the BATs, moving through Engineered Fill on the west and then north side of the unit, between the Ultimate Heat Sink (UHS) basins, and then exiting to Squaw Creek Reservoir (SCR) in the model northeast of the unit. This pathway has been simplified in the model using conservative assumptions for the pathway analysis which include extending the Engineered Fill to SCR. The pathway is calculated to be 1,194 feet in length with a particle travel time of 62 days.

The vertical pathway is calculated to be 186 feet long with a travel time of 8,115 days. The pathway begins at the base of the excavation adjacent to the BATs and extends through the bedrock of the Glen Rose Formation to the top of the underlying Twin Mountains Formation.

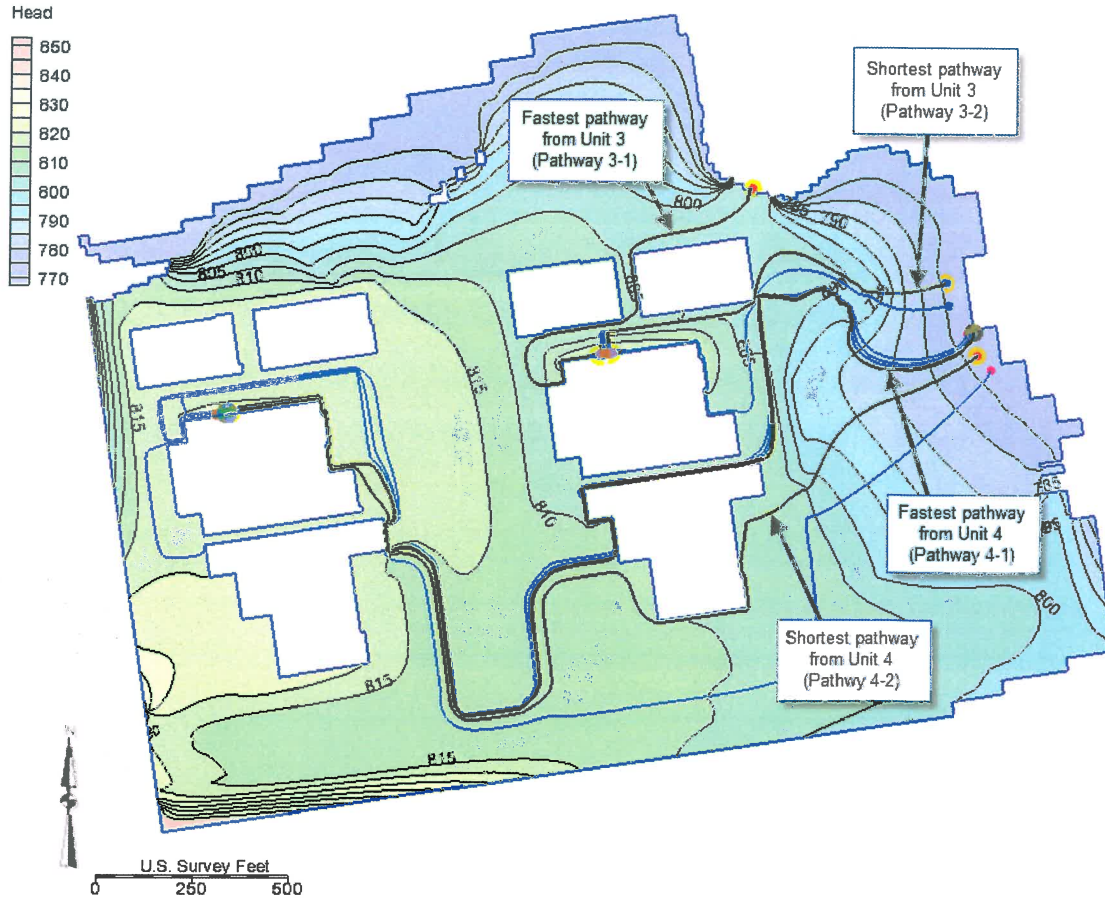


Figure 2.1 Calculated paths of horizontal groundwater movement away from BATs at Units 3 and 4 with calculated heads in horizontal flow model.

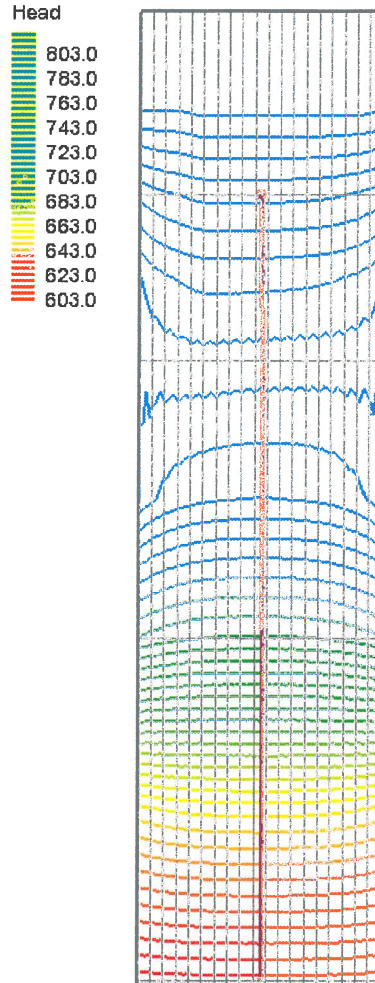



Figure 2.2 Calculated path of vertical groundwater movement away from BATs at Units 3 and 4.

3.0 REFERENCES


1. ENERCON, "Estimation of Conservative Bounding Fill and Infiltration Cap Properties and Determination of Above Grade Fill Extents," Project Report Number TXUT-001-PR-020, Rev 0, March 15, 2013.
2. ENERCON, "Groundwater Monitoring Well Gauging and Squaw Creek Reservoir Elevation Assessment Report For the COL Application," Project Report Number TXUT-001-PR-019, Rev 0, February 8, 2013.
3. MHI, Grading and Drainage Plan, Document No. 4CS-CP34_20080060, Rev. 4, Final, issued December 19, 2012.
4. MHI, Nuclear and Turbine Island Excavation Plan and Sections, Document No. 4CS-CP34_20110023, Rev. 1, Final, issued December 12, 2012.

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 9 of 39

5. Groundwater Modeling System (GMS), developed by Aquaveo, Version 8.2, 2012.
6. Harbaugh, A.W. 2005. MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model – the Ground-Water Flow Process. Chapter 16 of Book 6, Modeling techniques, Section A. Ground Water. U.S. Geological Survey. Reston, Virginia.
7. Pollock, David W. 1994. User’s Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW, the U.S. Geological Survey finite-difference ground-water flow model. U. S. Geological Survey Open-File Report 94-464.
8. USGS Ground-Water Software, MODPATH Version 5.0. A particle-tracking post-processing model for MODFLOW-2000 and MODFLOW-2005. Website, <http://water.usgs.gov/nrp/gwsoftware/modpath5/modpath5.html> , accessed November 29, 2011.
9. USGS, Ground Water Atlas of the United States, Oklahoma, Texas, HA 730-E, Website <http://pubs.usgs.gov/ha/ha730/ch e/E-text8.html> , Accessed July 19, 2011, Table 7.
10. Wolock, David M., Estimated Mean Annual Natural Ground-Water Recharge in The Conterminous United States, USGS NSDI, USGS Open File Report 03-311, 2003 digital data set accessed at <http://water.usgs.gov/lookup/getspatial?rech48.grd>.
11. Luminant, Comanche Peak Nuclear Power Plant (CPNPP) Combined License Application – Part 2: Final Safety Analysis Report (FSAR). Revision 3. July 2012.
12. Anderson, M.P. and W.W. Woessner. 1992. Applied Groundwater Modeling, Academic Press, Inc., San Diego, CA.
13. ArcGIS, Version 10.0, ESRI, Redlands, CA.
14. Texas Water Development Board (TWDB), 1982, Report 269, Occurrence, Availability and Chemical Quality of Ground Water in the Cretaceous Aquifers of North-Central Texas, Volume 1, Website, <http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWReports/R269v1/Figures/Figure19.pdf> , Accessed 4/21/11
15. Texas Water Development Board, 2011a, Hood County Water Level Publication Report, Website, <http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/Database%20Reports/Hood/Water%20Levels.pdf> , Accessed 4/19/11
16. Texas Water Development Board, 2011b, Somervell County Water Level Publication Report, Website, <http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/Database%20Reports/Somervell/Water%20Levels.pdf> , Accessed 4/19/11

4.0 ASSUMPTIONS

- 4.1 To simplify modeling efforts, sloped excavation walls are depicted as vertical walls for the horizontal pathway model.

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 10 of 39

- 4.2 The model domain for the horizontal pathway is spatially limited in area to focus on the evaluation of groundwater flow in and around the excavated portions of the CPNPP site adjacent to Squaw Creek Reservoir. The horizontal pathway flow model was defined to be a single-layer model to constrain groundwater flow to occur only in the horizontal direction; no vertical flow is allowed, providing a conservative influence on the horizontal movement of groundwater particles. The dimensions of the horizontal model domain were set to cover an area of approximately 2,520 ft by 1,910 ft (parallel to grid orientation) considered to be broad enough to allow adequate and unencumbered flow within the approximate area of interest around each unit.
- 4.3 The engineered granular fill to be placed around the nuclear reactor building and in site excavations/buildups is unknown at this time. The specifications used in this model are presented in the white paper “Estimation of Conservative Bounding Fill and Infiltration Cap Properties and Determination of Above Grade Fill Extents” (Reference 1). The highest hydraulic conductivity (K) value of the possible fill materials is used for the granular fill in the flow model, allowing for the fastest groundwater movement in the horizontal pathway.
- 4.4 The head at the theoretical release points adjacent to the BATs in both the horizontal and vertical pathway models are assigned a value of 821 ft msl, a theoretical maximum relative to the DCD. This creates a maximum hydraulic gradient for the movement of groundwater particles. This also creates a situation where modeled water levels are above the ground surface in some areas of the plant (indicated by flooded cells in MODFLOW). The pathway model is not, however, intended to simulate water levels specifically associated with a theoretical release, but instead is intended to create a head distribution that generates a maximum rate of groundwater flow along the calculated flowpaths. Thus the calculated water levels are not considered indicative of water levels which may theoretically occur at the site, and the flooded cells do not impact the model results.
- 4.5 All elevations (groundwater and otherwise) are referenced to mean sea level (ft msl).


5.0 DESIGN INPUTS

Two models have been developed for the pathway analysis, one to simulate the horizontal pathway and one to simulate the vertical pathway. The models were developed to allow conservative properties specific to the horizontal and vertical pathways to be assigned in each respective model. For each of the model inputs, a discussion is provided in this section describing the setup of the horizontal pathway model and describing the setup of the vertical pathway model. The MODFLOW and MODPATH model files (electronic files) are provided in Appendix A as an electronic attachment (DVD).

5.1. Flow Model Domain

The domain of the flow model used to simulate the horizontal pathway differs from the domain used for the vertical pathway model in that: 1) the horizontal pathway model utilizes a single layer and spatially covers the area around the power block; and 2) the vertical pathway model utilizes five layers and has a limited spatial extent.

- a. Domain of Horizontal Pathway Model

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 11 of 39

The flow model covers an area extending approximately 2,520 ft west to east and 1,910 ft south to north with the model domain centered on the power block area as shown in Figure 5-1, below. The model domain is subdivided into rows and columns (Figure 5-1) using a variably-spaced rectangular grid necessary for the finite-difference flow equation. The grid spacing ranges in size from less than 5 ft in the immediate vicinity of the power block to a maximum of 150 ft around the perimeter of the model domain. The grid is refined in the power block area to allow more detailed representation of model features and better lateral resolution of the calculated groundwater surface elevation.

A grid is defined across the entire model domain as outlined in Figure 5-1. Within the MODFLOW model cells are identified as either active or inactive, depending on whether or not groundwater flow occurs within the area of the model cell. Groundwater flow does not occur through buildings present in subsurface excavations (such as the Reactor Building, the Auxiliary Building, and the Turbine Building); thus these areas are inactive in the model. Also, cells situated on Squaw Creek Reservoir beyond the contact between the reservoir and the saturated subsurface are inactive. Areas of inactive cells are blank in the figure, while areas having active cells (used in the finite-difference calculations) are illustrated with outlines of individual cells.

The flow model for evaluating the horizontal pathway is defined to have one layer; this constrains groundwater flow to occur only in the horizontal direction providing the maximum rate of horizontal movement of groundwater.



Figure 5-1. Plan View of MODFLOW Horizontal Pathway Model Grid Superimposed on Planned Site Topography.

b. Domain of Vertical Pathway Model

The flow model for evaluating the vertical pathway covers a spatial area approximately 285 ft by 147 ft, with the model area subdivided into five layers. Within the power block area, model cells falling within the reactor buildings for Units 3 and 4 are specified as inactive in Layer 1, since no groundwater flow will occur through these structures. However, the underlying cells in Layers 2 through 5 are active in the model since groundwater movement can occur underneath the building areas. The vertical pathway model has been set up at a location situated at Unit 4; however, since subsurface conditions are the same at Unit 3, this model is considered representative for vertical groundwater movement from both units.

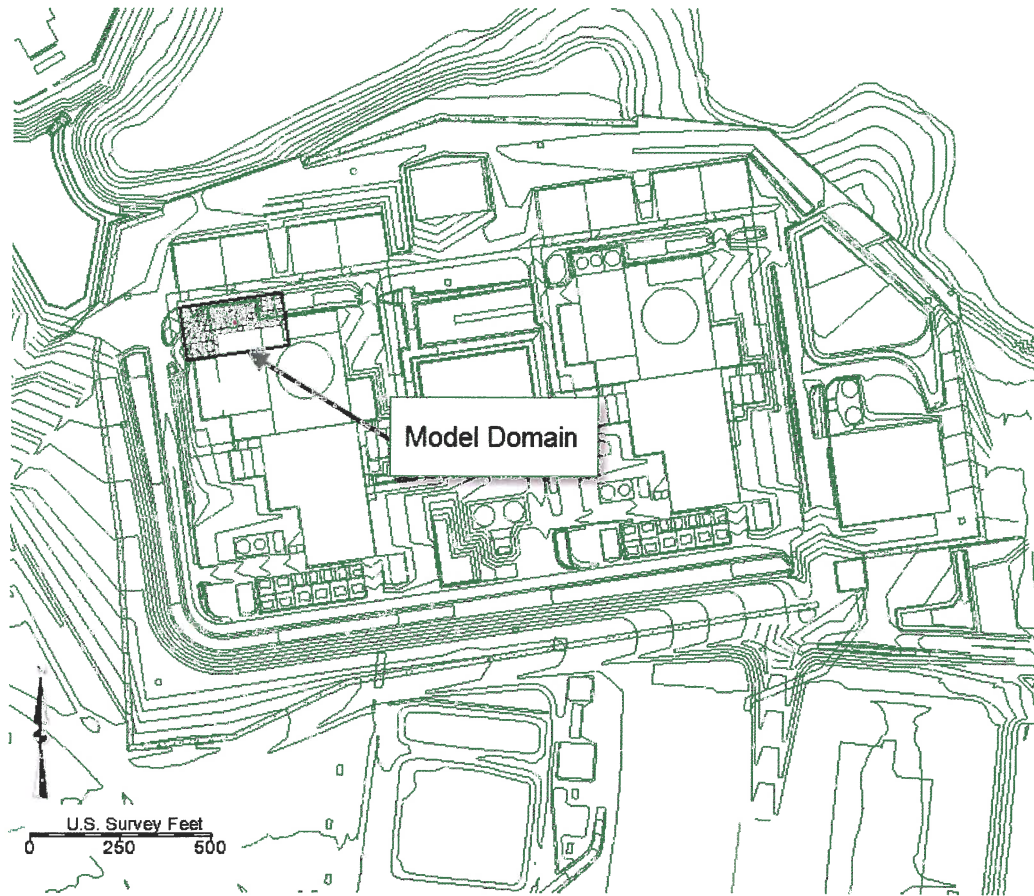


Figure 5-2. Plan View of MODFLOW Vertical Pathway Model Grid Superimposed on Planned Site Topography.

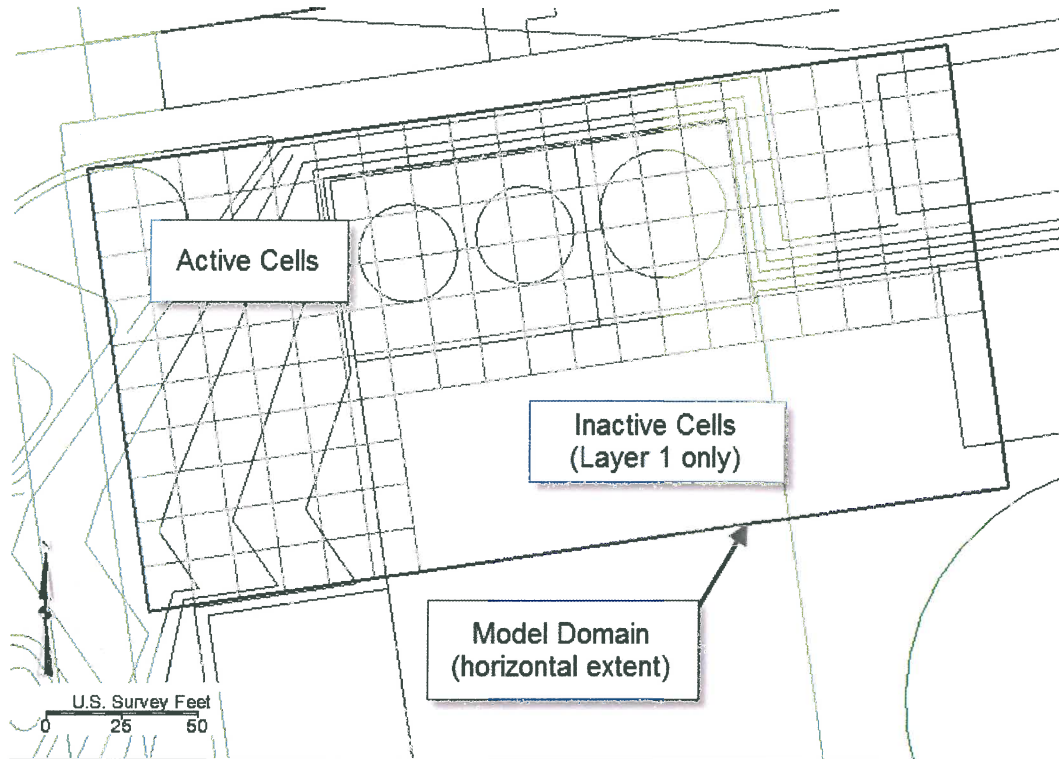


Figure 5-3. Plan View of Showing Detail of MODFLOW Vertical Pathway Model Grid.

5.2. Site Topography

The post-construction surface topography of the site is assigned as the top of the horizontal pathway model, since the model covers a broad spatial area. Since the vertical pathway model covers a limited spatial area, only a single value is needed for the top of each model layer.

a. Top of Horizontal Pathway Model

The modeled site topography represents the post-construction surface grade as shown in URS drawings (References 3 and 4). This surface is defined as the top of the horizontal pathway model; since there is only one layer in the model, this surface is the top of Layer 1. The three-dimensional surface was digitized in the GMS software from a shape file of the land surface contours. The electronic data files (ArcGIS shape file and GMS scatter point file) are on DVD and described in Appendix B. The contoured surface is shown below (Figure 5-4).

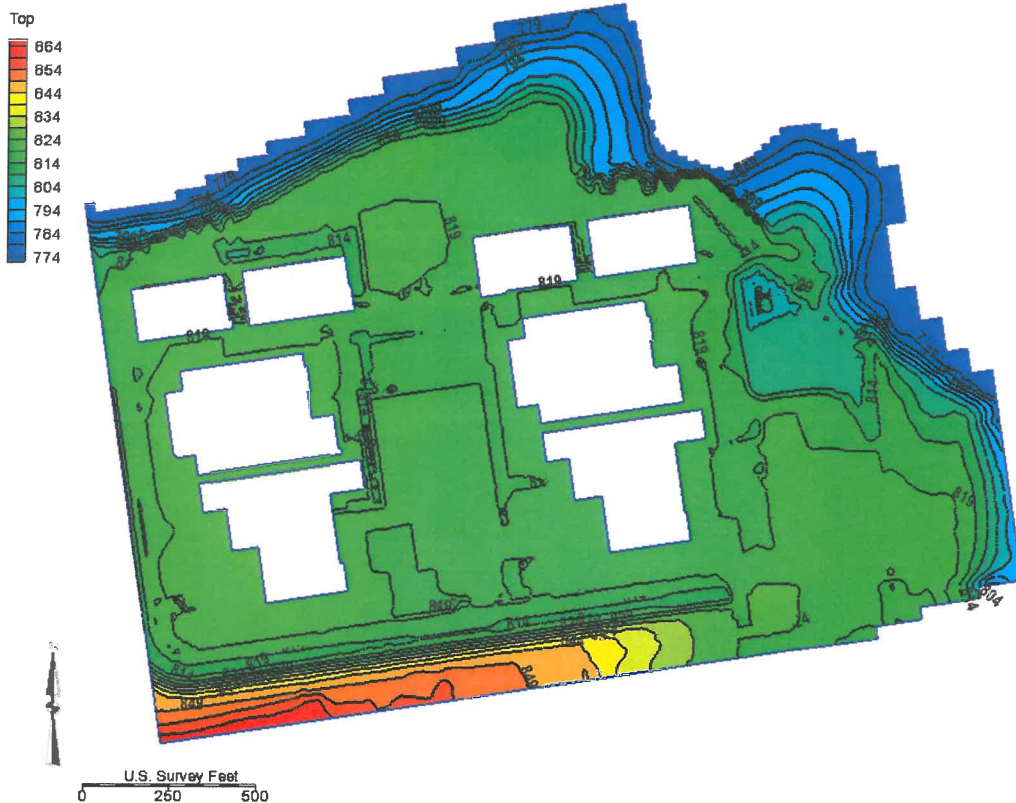


Figure 5-4. Plan View of Post-Construction Surface Topography in the Horizontal Pathway Model.

b. Top of Vertical Pathway Model

The top of the vertical pathway model is assigned an elevation of 822, the planned surface grade elevation for the main plant area.

5.3. Model Layers

The horizontal pathway model is comprised of a single layer, while the vertical pathway model incorporates five layers.

a. Bottom of Horizontal Pathway Model

The bottom of the single layer of the horizontal pathway model was defined to take into account the configuration of the excavations into which Engineered Fill is to be placed, as well as the base of the Existing Fill in two areas located on the northern and eastern edges of the site. Excavations into bedrock are planned to range from 779 ft at the Reactor Building and Auxiliary Building, rising to 782 ft msl around the Turbine Building and in the pipe tunnels around the power block area of each unit. Combining the excavation elevations with the top of rock elevations in the existing fill areas results in a combined surface as illustrated in Figure 5-5.



Figure 5-5. Elevations of Composite Top of Bedrock Surface Across the Model Domain.

To simplify this surface for use in the numerical model, the bedrock surface outside the excavation area was smoothed to an elevation of 782 over most of the area for representation in the numerical model. Elevations of excavations surrounding the power block areas were assigned at 779 or 782, representing the excavation elevation for plant construction. The resulting surface representing the bottom of the single layer in the horizontal pathway model is shown in Figure 5-6.



Figure 5-6. Bottom Elevation of Horizontal Pathway Model.

b. Bottom Elevations of Layers in Vertical Pathway Model

The vertical pathway model is set up to simulate the movement of groundwater from the base of the excavation at the BAT through the Glen Rose Formation to the top of the Twin Mountain Formation. Therefore, Layer 1 of the vertical pathway model represents bedrock and engineered fill materials (where the fill is emplaced in excavations into the bedrock), while Layers 2 through 4 represent bedrock of the Glen Rose Formation, and Layer 5 represents bedrock of the Twin Mountain Formation. The bottom elevation of each layer of the vertical pathway model is illustrated in Figure 5-7. The bottom elevation of Layer 1 is set at 779 ft msl, the lowest excavation elevation planned at the nuclear island. The bottom elevation of Layer 2 is set at 740 ft msl, just below the elevations of most of the deep bedrock wells at the site. The bottom elevation of Layer 3 is set at 675 ft msl, approximately halfway between the bottom elevations of Layers 2 and 4. The bottom elevation of Layer 4 is set at 595 ft msl to represent the top of the Twin Mountain Formation. The bottom of Layer 5 is set at 594 ft msl, to provide a model layer within which the head in the Twin Mountain can be specified.

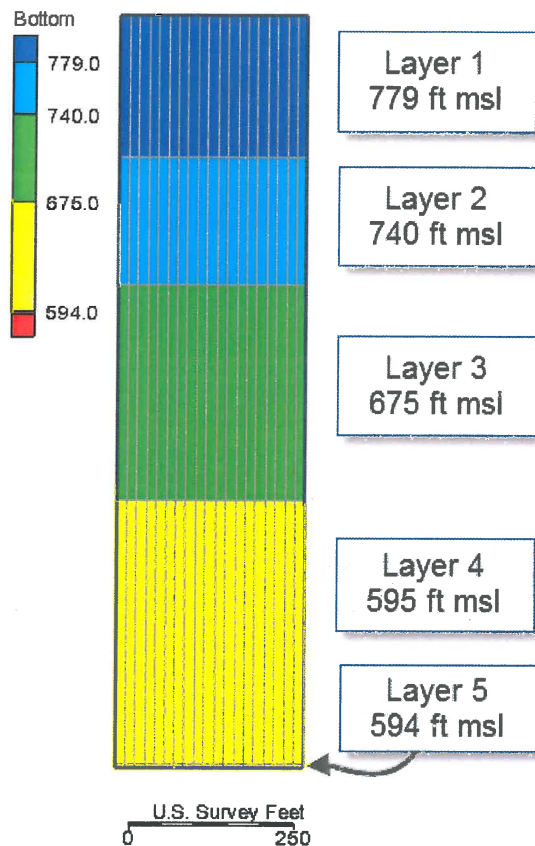



Figure 5-7. Bottom Elevations of Layers in Vertical Pathway Model.

5.4. Aquifer Parameters

The key hydraulic parameters for each of the subsurface materials represented in the pathway models include hydraulic conductivity (K) and specific yield (S_y). For purposes of the unconfined conditions evaluated in these models, S_y is considered equivalent to porosity (n_e). Four materials present in the subsurface at the site are represented in either the horizontal pathway and/or the vertical pathway model: Engineered Fill, Existing Fill, bedrock of the Glen Rose Formation, and bedrock of the Twin Mountains Formation.

A range of values for K and S_y is provided for the Engineered Fill materials (granular materials) in Estimation of Conservative Bounding Fill and Infiltration Cap Properties & Determination of Above Grade Fill Extents (Reference 1). K values presented range from a low of 6.31×10^{-4} cm/sec (1.79 ft/d) to a high of 1.65×10^{-1} cm/sec (468 ft/d). n_e is estimated to range from 0.17 to 0.2.

K values for the Existing Fill and for the bedrock are provided in Section 2.4.12.4.6.2 of the FSAR. Two areas of Existing Fill are present, one on the northern side of the construction area and one on the eastern

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 19 of 39

side of the construction area. The K value for the northern area of the Existing Fill is reported to be 5.0×10^{-4} cm/sec (1.42 ft/d); only one value is available for this area, so no range is considered. K values for the eastern area of Existing Fill are reported to range from 1.7×10^{-3} cm/sec (4.82 ft/d) to 3.5×10^{-3} cm/sec (9.9 ft/d). S_y (n_e) values for the Existing Fill are considered to be equivalent to that of the Engineered Fill, since both are granular materials.

K values for the Glen Rose bedrock have been derived from packer tests as well as from a limited number of slug tests at the site. K values developed from the packer tests are very low, on the order of 1×10^{-8} to 1×10^{-9} cm/s (2.8×10^{-5} ft/d to 2.8×10^{-6} ft/d); some packer tests reported values of zero, indicating no water movement through the tested zone. K values reported for the bedrock based on slug tests ranged from 1.37×10^{-5} cm/s (0.039 ft/d) to 6.29×10^{-6} cm/s (0.0178 ft/d). The packer test results are considered more representative of the K of the Glen Rose bedrock; however, a higher K value was used in the pathway models to provide conservatism in the calculated pathway of groundwater movement.

The porosity of the Glen Rose is reported to range from an average total porosity of 25.6 percent for the shallow bedrock (consisting of limestone and shale), to an average total porosity of 11.9 for deeper limestone (FSAR Section 2.4.12.2.5.1, page 2.4-80).

An average K for the Twin Mountains Formation is reported to be 9 ft/d (USGS 2011). Porosity of the sandstone samples retrieved during the 2007 CPNPP pre-COL investigation was reported as ranging from 0.19 to 0.37, with an average value of 0.27 (FSAR 2.45.4.2.3.1.3).

a. Aquifer Parameters for Horizontal Pathway Model

Three subsurface materials are represented in the horizontal pathway model: Engineered Fill, Existing Fill, and bedrock of the Glen Rose Formation. To provide a conservative estimate of the rate of groundwater movement along the horizontal pathway, maximum K values for the Engineered Fill and Existing Fill were used in the horizontal pathway model; this maximizes the groundwater flow rate calculated in the model. For the Glen Rose bedrock, the lower of the K results reported from slug tests (6.29×10^{-6} cm/sec) was used in the model. The spatial distribution of K values in the horizontal pathway model is illustrated in Figure 5-8.

The lowest of the reported n_e values was used for each subsurface material in the horizontal pathway model: 0.17 for the Engineered Fill and Existing Fill, and 0.119 for the Glen Rose bedrock.

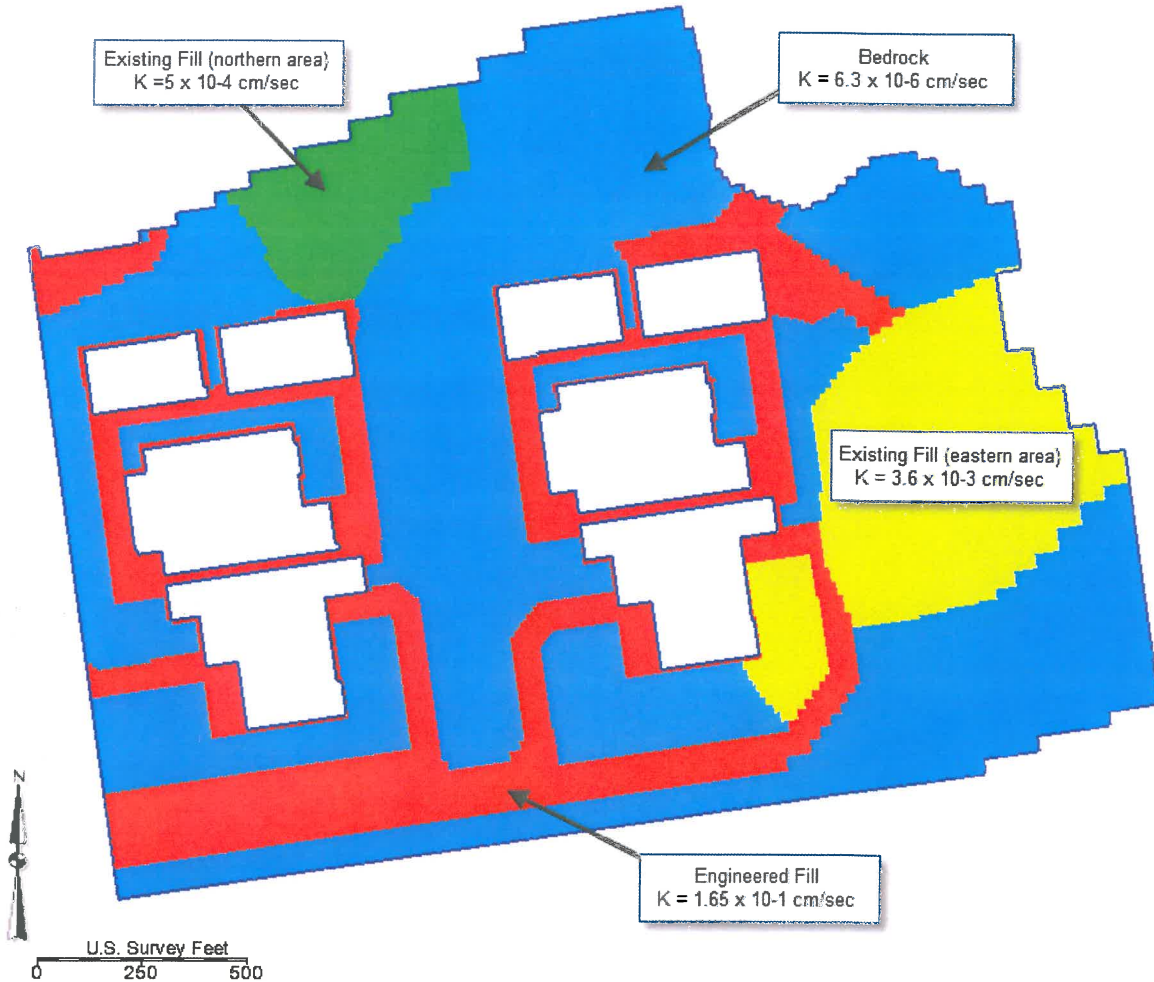



Figure 5-8. K Spatial Distribution in Horizontal Pathway Model

b. Aquifer Parameters for Vertical Pathway Model

Three subsurface materials are represented in the vertical pathway model: Engineered Fill, bedrock of the Glen Rose Formation, and bedrock of the Twin Mountains Formation. K and S_y values for the Engineered Fill were assigned the same values in the vertical pathway model as in the horizontal pathway model; however, because of the particle release locations (at the base of Layer 1, described in a later section), the hydraulic properties of the Engineered Fill do not exert substantial influence on the vertical pathway calculations.

For the Glen Rose bedrock, the lower of the K results reported from slug tests ($6.29 \times 10^{-6} \text{ cm/sec}$ or 0.0178 ft/d) was used for the horizontal K in the model. The value for n_e of the Glen Rose is assigned to be 11.9 %, the same as in the horizontal pathway model.

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 21 of 39

The numerical MODFLOW model also incorporates a vertical K, incorporated as a vertical anisotropy in the MODFLOW setup. The vertical anisotropy is the ratio of horizontal (K_H) to vertical K (K_V), or K_H/K_V , and can be related to bedding planes and laminae of the subsurface geologic materials. K_V is generally less than K_H , and values of 1 to 1000 are common in model application (Reference 12, p. 70). Given the vertical head differences observed in monitoring wells at the site (Reference 2), the vertical anisotropy at the site is expected to be high. Thus, a vertical anisotropy of 10.0 was used in the vertical pathway model to be conservative yet still account for some anisotropy.

The K and n_e values for the Twin Mountains Formation are assigned at 9 ft/d and 0.19, respectively (Reference 9).

The distribution of subsurface materials represented in the vertical pathway model is illustrated in Figure 5-9.

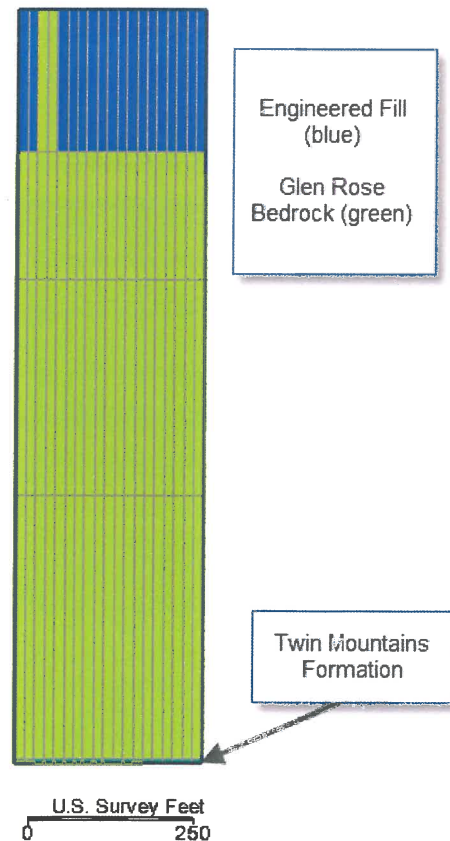


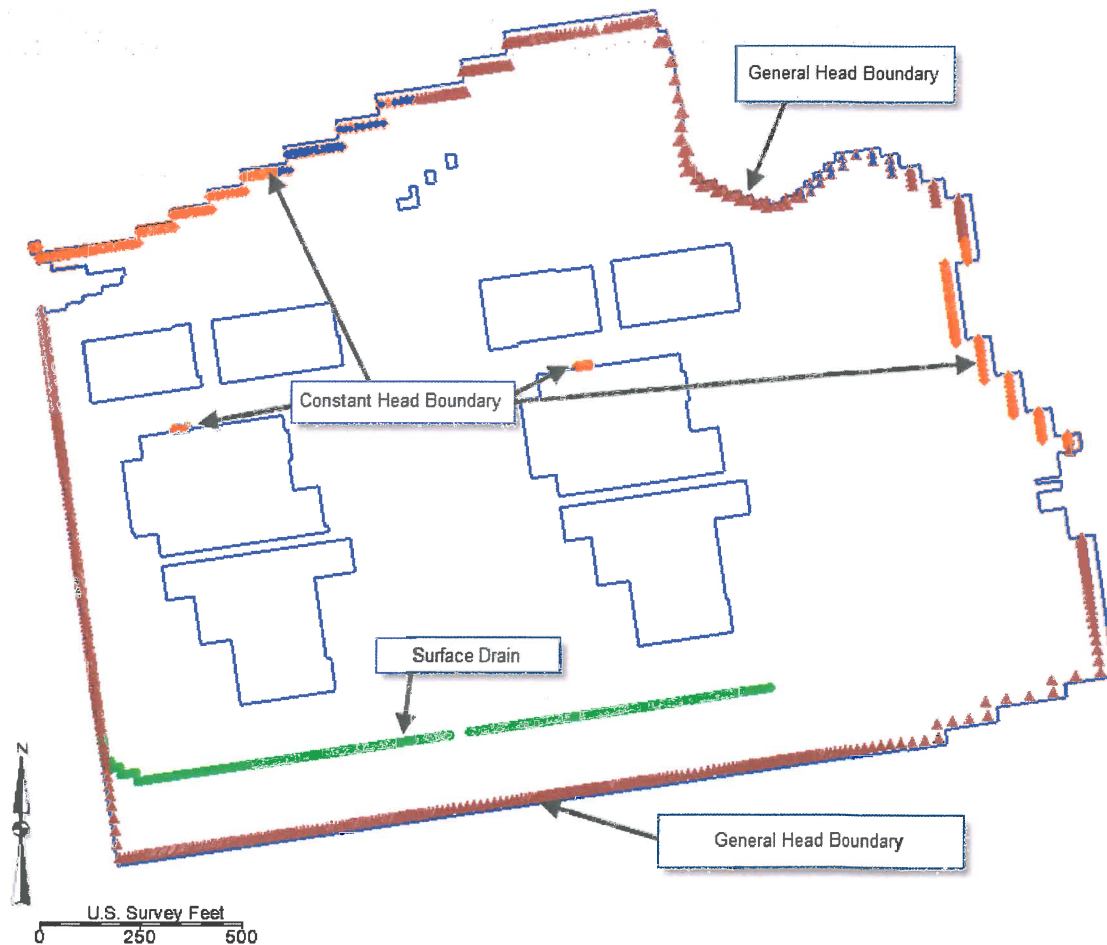
Figure 5-9. Subsurface Materials Distribution in Vertical Pathway Model

5.5. Model Boundaries

Model boundaries for the horizontal and vertical pathway models were assigned specifically for each pathway model.

a. Boundaries for Horizontal Pathway Model

Squaw Creek Reservoir (SCR), a large man-made surface water body created to provide cooling water for CPNPP Units 1 and 2, serves as a major hydraulic boundary for the site. The boundary of the numerical model domain coincident with SCR was defined as either a constant head boundary or a GHB having an elevation of 772 ft msl; the water level in SCR has never dropped below this elevation (Reference 2). General head boundaries (GHB) were assigned along the remaining model edges in horizontal pathway model. Additionally, the water level at model cells adjacent to the BATs at each unit was assigned a constant head of 821, one foot below the DCD. This provides a theoretical maximum head at the theoretical release locations, maximizing the head at the origin of the calculated pathway. Boundary conditions are illustrated in Figure 5-10.




	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 23 of 39

Figure 5-10. Boundary Conditions in Horizontal Pathway Model

b. Boundaries for Vertical Pathway Model

Boundary conditions in the vertical pathway model were established to create a downward hydraulic gradient through the Glen Rose and into the Twin Mountains Formation to facilitate groundwater movement via the vertical pathway. The boundary conditions also provide stability to the numerical model (leaving no-flow boundaries in layers 2 through 4 of the model results in a model that oscillates and does not converge).

Constant head values were assigned at an elevation of 820 along the model edges in Layer 1, under the assumption there would be some limited change in head horizontally across the model domain. Additional constant head cells were assigned at an elevation of 821 at cells adjacent to the BATs in the layer. Constant head boundaries at a value of 779.5 were assigned along the model edges in Layer 2, to represent a groundwater elevation slightly above the base of the deepest excavation. Constant head boundaries at a value of 770 were assigned along the model edges in Layer 3 to create a downward vertical gradient. General Head boundary conditions were assigned along the model edges in Layer 4. Constant head boundaries were assigned at a value of 600 ft msl along the edges of Layer 5 to represent the head in the Twin Mountains Formation. Water levels were assigned at this assumed elevation to represent saturation at the base of the Glen Rose Formation; water levels in the Twin Mountains Formation are lower than this elevation (Appendix D). Boundary conditions assigned in the vertical pathway model are illustrated in Figure 5-11.

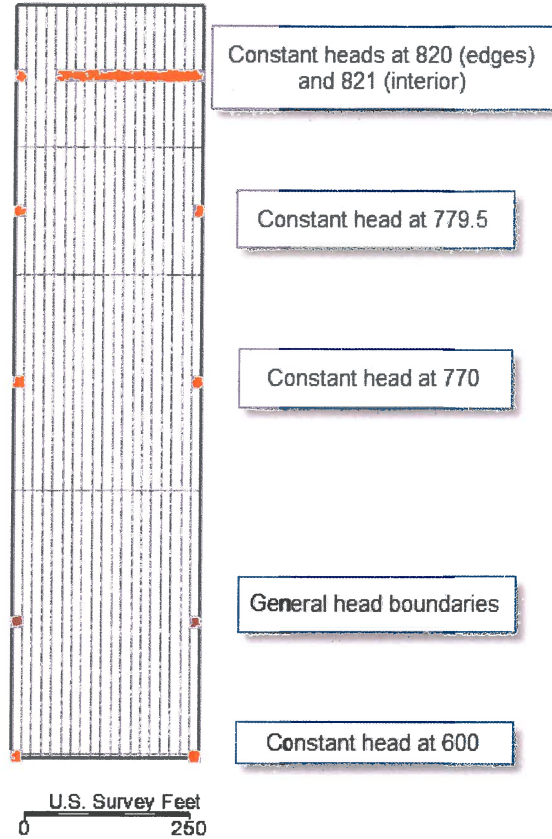


Figure 5-11. Boundary Conditions in Vertical Pathway Model

5.6. Particle Release Locations

Particle-tracking was completed for each pathway direction (horizontal and vertical) by releasing particles at specific locations depending on the model being completed. Locations of particle releases are described below.

a. Horizontal Pathway Particle Release Locations

Particles are released in the model at the water table in cells adjacent to the BATs at each unit. One particle is released at the water table per cell, as illustrated in Figure 5-12.

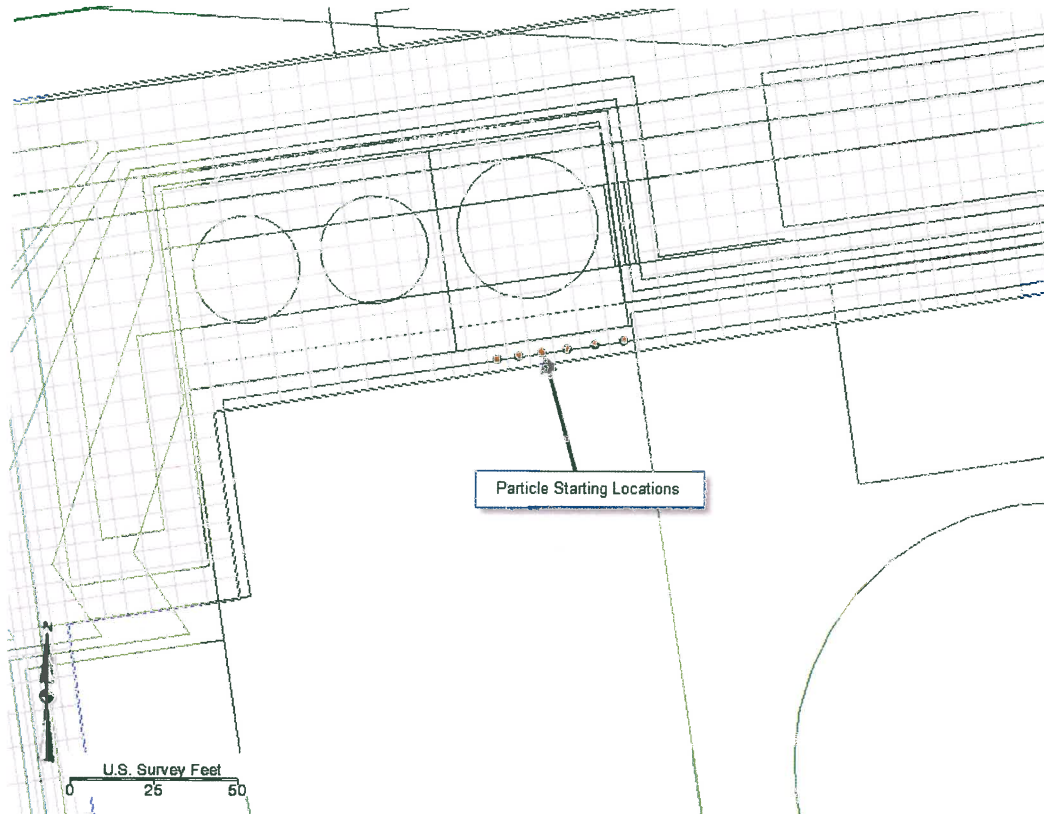


Figure 5-12. Starting Locations for Particles in Horizontal Pathway Model

b. Vertical Pathway Particle Release Locations

For the vertical pathway model, one particle is released on the bottom face of a cell (bottom of Layer 1) situated at a location adjacent to the BATs, as illustrated in Figure 5-13.

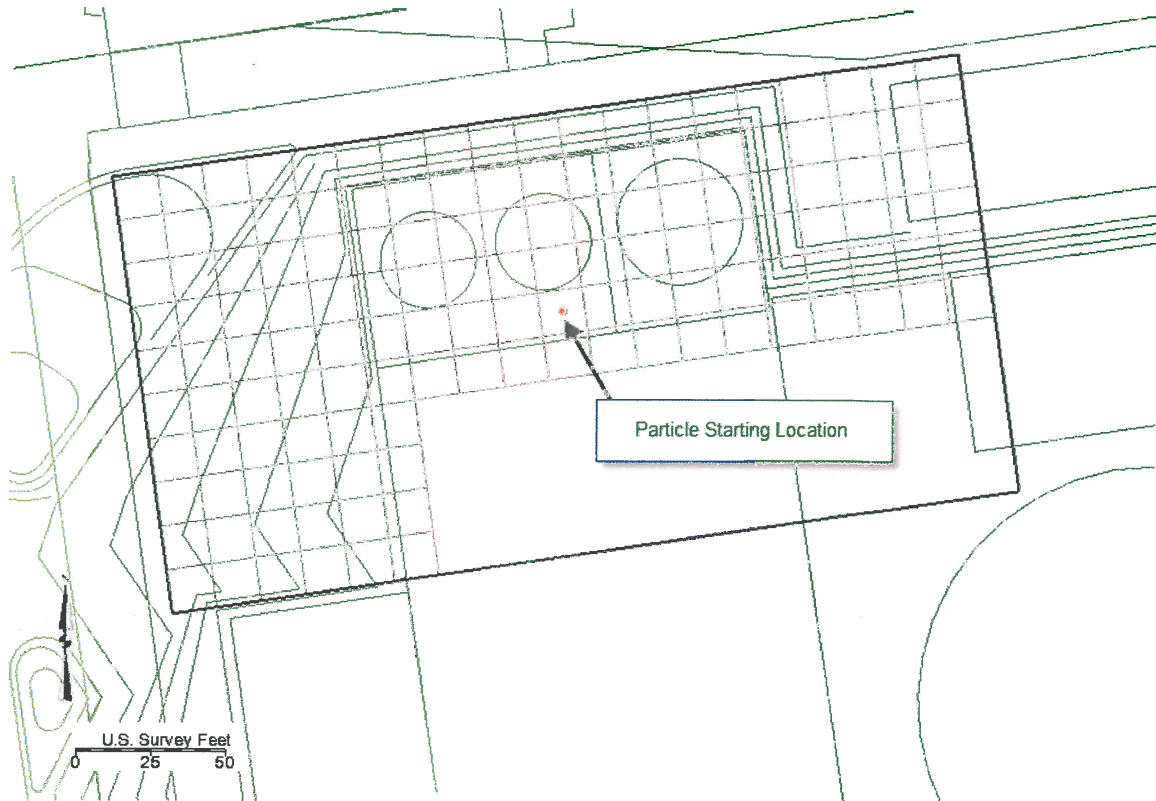



Figure 5-13. Starting Locations for Particles in Vertical Pathway Model

6.0 METHODOLOGY

Determination of groundwater flow paths involves first simulating the groundwater flow field for each pathway (horizontal and vertical) using the MODFLOW model, then introducing particles at selected locations and tracking the movement of the particles through the flow field using the MODPATH computer program. Two separate model setups are utilized in conducting the groundwater pathway analysis: one to simulate the horizontal pathway and one to simulate the vertical pathway. Parameters selected for each pathway model are selected to be conservative (i.e., to maximize the rate of groundwater flow through the pathway).

The horizontal pathway analysis model consists of a single-layer MODFLOW model. Groundwater particles for MODPATH are introduced in the Engineered Fill material adjacent to the location of the BAT at each Unit. MODPATH will simulate the horizontal movement of groundwater particles through the Engineered Fill and surrounding subsurface materials under the steady-state flow field generated by MODFLOW. The vertical pathway analysis model consists of a multi-layer MODFLOW model. Groundwater particles for MODPATH will be introduced in the model at the bottom of the NI excavations. MODPATH will simulate the vertical movement of the groundwater particles from the bottom of the

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 27 of 39

excavation through the Glen Rose Formation, to the top of the Twin Mountains Formation. MODFLOW runs are completed under steady-state model conditions.

Parameter values for K, porosity (n), and SCR water elevation are selected to maximize the flow velocity along the subject pathway (horizontal or vertical). A constant head boundary is assigned at the particle release locations to maximize the hydraulic gradient along the subject pathway (horizontal or vertical). Sensitivity analyses are completed to assess the model sensitivity to changes in parameters to more conservative values, and involved evaluating changes K and n to the pathway characteristics.

The function of each program is described below.

6.1. Groundwater Flow Simulation

MODFLOW-2005 is a computer program developed by the US Geological Survey that simulates three-dimensional groundwater flow through a porous medium using a finite-difference method. The groundwater flow equation and explanation are shown in Figure 6-1, from the MODFLOW-2005 reference manual (Harbaugh, 2005; Reference 6). An electronic copy of the MODFLOW-2005 manual is provided in electronic format in Appendix C.

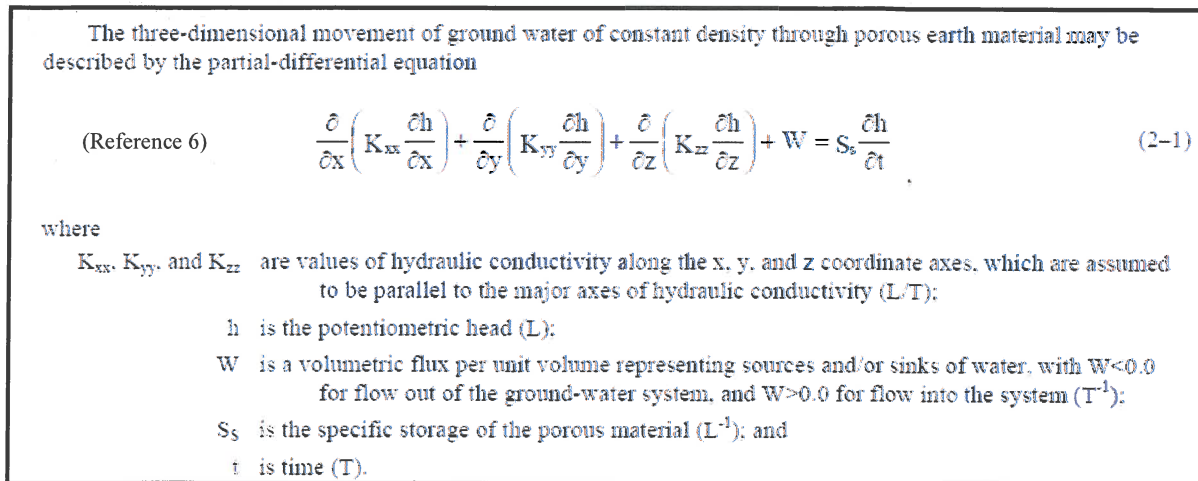
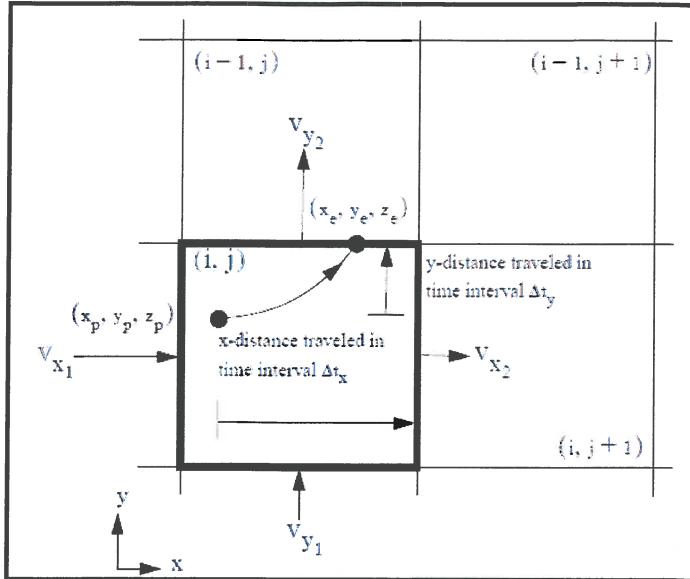


Figure 6-1. Explanation of Groundwater Flow Equation

6.2. Particle Tracking Calculations

MODPATH is a computer program that tracks the movement of particles of water through a flow field defined from a MODFLOW model. MODFLOW simulates three-dimensional groundwater flow through a porous medium using a finite-difference method. MODPATH calculates values of the principal components of the velocity vector at every point in the flow field based on the inter-cell flow rates from the finite difference model, using the information generated by MODFLOW. A schematic explaining the basic process for the calculation is shown in Figure 6-2, from the MODPATH reference manual (Reference 7).



**Figure 6-2. Schematic of computation of exit point and travel time
(two-dimensional flow in x-y plane)**

An electronic copy of the MODPATH Version 3.0 manual is provided on DVD in Appendix C. The MODPATH user's guide was written for version 3.0, and has not been updated for version 5.0. The major difference between version 5.0 and version 3.0 is the file location used for reading model information. This difference does not negate application of the User's Manual for version 5.0, and lack of a current user's guide does not affect use of the program for the pathways calculation since the core operation of the program has not changed.

GMS (Reference 5) is the pre-and post-processing software used to construct, run, and process MODFLOW files for the CPNPP project. MODFLOW is one of several modeling program modules available within GMS. GMS facilitates the input and modification of the model structure and aquifer parameters for the creation of MODFLOW packages which MODFLOW uses to solve the groundwater flow equations. GMS then reads the MODFLOW output files and displays the results.

7.0 CALCULATION RESULTS

For each of the directional pathways being evaluated (horizontal groundwater movement and vertical groundwater movement), a groundwater flow model was created in MODFLOW using parameter values for the basic pathway model setups as previously described. After each model was constructed and the resulting pathway details were identified, sensitivity analyses were completed to evaluate the impacts on the pathway travel time and distances associated with changes to MODFLOW model parameters.

Results presented for each simulation include a plan view of the full flow model domain with the groundwater surface contoured via color-fill with calculated groundwater flowpaths shown on the figure. A tabular summary of the key flowpath for each run (from Unit 3 for the horizontal pathway) is provided in Table 7-1.

Table 7-1 – Summary of MODPATH Runs and Results

MODPATH Horizontal Pathway Analysis - Runs, Parameter Values, Filenames, and Results for Key Pathway										
Filename	Run ID	K (ft/d)				Porosity (percent)			Key Pathway (Unit 3, Pathway 3-1) Distance (ft)	Key Pathway (Unit 3, Pathway 3-1) Time of Travel (d)
		Engineered Fill	Glen Rose bedrock	Northern Existing Fill	Eastern Existing Fill	Engineered Fill	Glen Rose bedrock	Existing Fill (N and E Areas)	Unit 3	Unit 3
FinalV2_MODPATH.gpr	Base Run	468	0.01783	1.4	9.9	17	11.9	17	1194	62
FinalV2_Horiz_KBr.gpr	Sensitivity 1	468	0.039	1.4	9.9	17	11.9	17	1200	62
FinalV2_Horiz_KBrLow.gpr	Sensitivity 2	468	0.00181	1.4	9.9	17	11.9	17	1196	62
FinalV2_Horiz_nBr.gpr	Sensitivity 3	468	0.01783	1.4	9.9	15	5	15	1194	55
SCR elevation set at 772 for all runs										
Head at BAT was assigned a constant value of 821 ft msl										
MODPATH Vertical Pathway Analysis - Runs, Parameter Values, Filenames, and Results										
Filename	Run ID	K (ft/d)				Porosity (percent)			Vertical Anisotropy	Pathway Time of Travel
		Engineered Fill	Glen Rose bedrock	Northern Existing Fill	Eastern Existing Fill	Engineered Fill	Glen Rose bedrock	Existing Fill	Kh/Kv	Time of Travel (d)
FinalV1_B_MODPATH_vert2.gpr	Base Run	468	0.0178	na	na	17	11.9	na	10	8115
FinalV1_B_vert2_nBR.gpr	Sensitivity 4	468	0.0178	na	na	17	5	na	10	3410
FinalV1_B_vert2_KvKhBR.gpr	Sensitivity 5	468	0.0178	na	na	17	11.9	na	5	1932
Head at BAT was assigned a constant value of 821 ft msl										
na - not applicable										


7.1. Horizontal Pathway Base Run

The water table calculated for the horizontal pathway is illustrated in Figure 7-1. Calculated heads range from a maximum of 849 feet msl at the southwest corner of the model to a minimum of 772 ft msl along the edge of SCR. The hydraulic gradient flattens in areas of existing fill present to the north and east of the two units.

Flowpaths calculated for the horizontal pathway are illustrated in Figure 7-2. The flowpaths move in multiple directions, generally through the Engineered Fill into the Existing Fill before moving into SCR. The calculated flowpaths have travel times that range from 62 to 1,576 days for Unit 3 (with an average of 1,139 days) and that range from 531 to 8,855 days at Unit 4 (with an average of 2,081 days). The majority of the pathways exit to the eastern area of Existing Fill. The shortest and fastest flowpaths from each unit are illustrated in Figure 7-3, and a summary of these pathways is provided in Table 7-2. The shortest and fastest horizontal pathways are calculated to move from Unit 3.

The Base Run for the horizontal pathway incorporates parameters in an approach to create a conservative evaluation of the groundwater movement in the horizontal direction, based on the following:

- The MODFLOW model simulating groundwater flow is a single-layer model, constraining groundwater flow to only the horizontal direction. This prevents vertical flow of groundwater in the ‘z’ direction, maximizing groundwater movement in the ‘x’ and ‘y’ directions.
- K is set at maximum values for the Engineered Fill and Existing Fill, maximizing groundwater flow rate and the resulting groundwater travel times (Reference 1 and Reference 11).
- The elevation of SCR is assigned the lowest value reported for the reservoir, and the head at the BATs is set at a theoretical maximum value; the combined influence of these parameters creates maximum hydraulic gradients along the calculated flowpaths (Reference 1).

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 30 of 39

- The porosity for the Engineered Fill and Existing Fill materials has been assigned the lowest value of the potential range of values reported for these materials (Reference 1 and Reference 11).
- The area of Engineered Fill northeast of Unit 3 has been extended to SCR to be conservative. This area of Engineered Fill will be emplaced behind a retaining wall to be constructed between the unit and SCR. It is anticipated that this wall will have drains along the base of the wall to prevent fluid buildup behind the wall. Thus, fluid from a theoretical release flowing into the Engineered Fill would move not only behind the wall (and then via the subsurface to the area of existing fill to the south), but would also flow through the drains and out to SCR. In terms of fluid volume, the amount flowing out to SCR would be only a small portion of the fluid associated with the release; however, the exact volume cannot be calculated at this time. Therefore, the area of Engineered Fill was extended to SCR in the model to create a complete pathway to SCR through the Engineered Fill northeast of Unit 3.

Pathway 3-1 originating in Unit 3 is identified as the key pathway of concern for evaluating potential radionuclide movement. This pathway has the fastest travel time of any pathway (62 days), moving directly to SCR through Engineered Fill, with a pathway distance of 1,194 feet. Pathway 3-2 at Unit 3 has a slightly shorter length (1,074 feet); however, the travel time for particles to reach SCR is 1,556 days, significantly greater than the 62-day travel time for Pathway 3-1. The fastest and shortest pathways at Unit 4 have greater travel times and distances to SCR than the pathways calculated from Unit 3. Thus, Pathway 3-1 is considered to be the most conservative pathway of interest for evaluating potential groundwater migration from a theoretical release.


	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 33 of 39

Table 7-2 – Summary of Horizontal Pathways from Units 3 and 4

Pathway Characteristic	Pathway 3-1 Unit 3 Fastest	Pathway 3-2 Unit 3 Shortest	Pathway 4-1 Unit 4 Fastest	Pathway 4-1 Unit 4 Shortest	Units
Calculated Distance from Particle Origination to SCR	1,194	1,074	3,966	3,392	ft
Hydraulic gradient (821 ft to 772 ft over path distance)	0.041	0.046	0.012	0.014	dimensionless
Hydraulic conductivity for path (calculated based on velocity and distance for entire path)	468 1.55×10^{-1}	15 5.29×10^{-3}	622 2.19×10^{-1}	316 1.11×10^{-1}	ft/d cm/sec
Total porosity	20	20	20	20	percent
Effective porosity	17	17	17	17	percent
Calculated particle travel time	62	1,556	531	767	days

7.2. Vertical Pathway Base Run

The subsurface head distribution calculated for the vertical pathway is illustrated in Figure 7-4. Calculated heads are constrained by the constant head values assigned in the upper and lower layers, ranging from a maximum of 821 feet in Layer 1 to 600 feet in Layer 5.

The flowpath calculated for the vertical pathway is illustrated in Figure 7-5. The flowpath moves from the top of the Glen Rose Formation beneath the BATs through the bedrock, exiting into the Twin Mountains Formation. The pathway is 186 feet long with a travel time of 8,115 days. A single flowpath is calculated for the vertical direction of groundwater flow since subsurface characteristics of the Glen Rose beneath Unit 3 and Unit 4 are identical for purposes of this analysis.

The Base Run for the vertical pathway incorporates parameters in an approach to create a conservative evaluation of the groundwater movement in the downward direction, based on the following:

- The head assigned at the BATs is a theoretical maximum of 821, creating a maximum vertical gradient downward toward the Twin Mountains Formation.
- The value assigned for porosity of the Glen Rose is the minimum value reported for site data, maximizing the rate of groundwater movement.
- The value assigned for K of the Glen Rose limestone is the minimum value derived from slug tests, resulting in a vertical movement greater than if values from the packer test results were used to define the parameter value.
- The head in the Twin Mountains Formation is based on water levels reported from USGS wells (Appendix D).

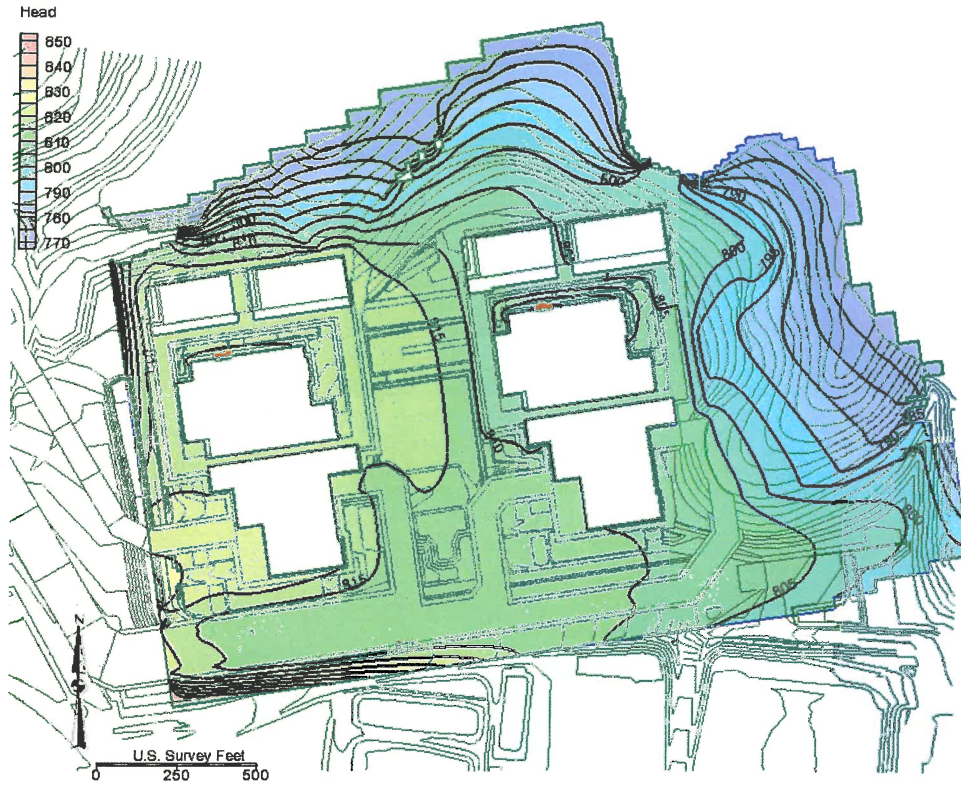


Figure 7-1. Plan View of Calculated Water Table, Horizontal Pathway Model.

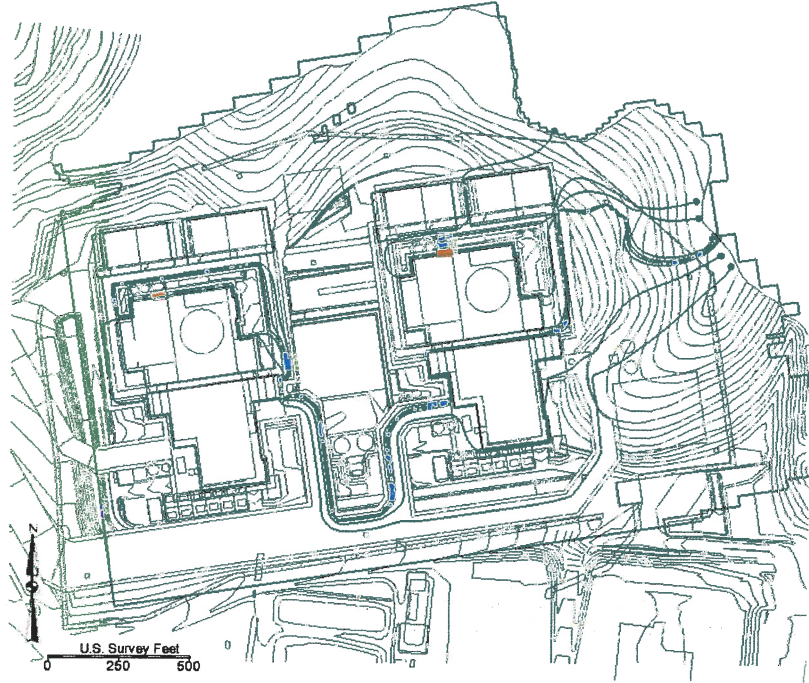


Figure 7-2. Calculated Flowpaths, Horizontal Pathway Model.

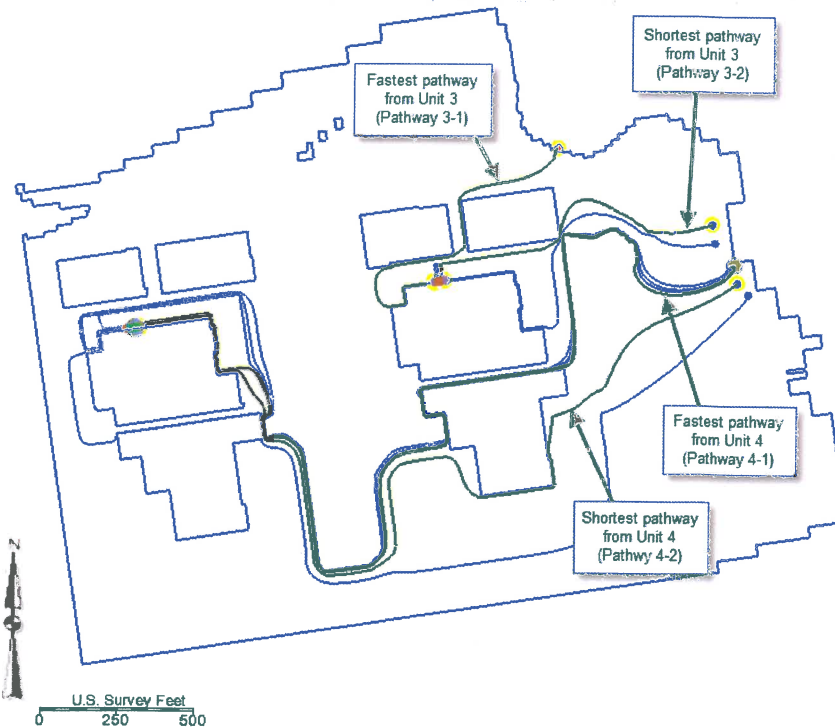


Figure 7-3. Key Calculated Flowpaths from Each Unit, Horizontal Pathway Model.

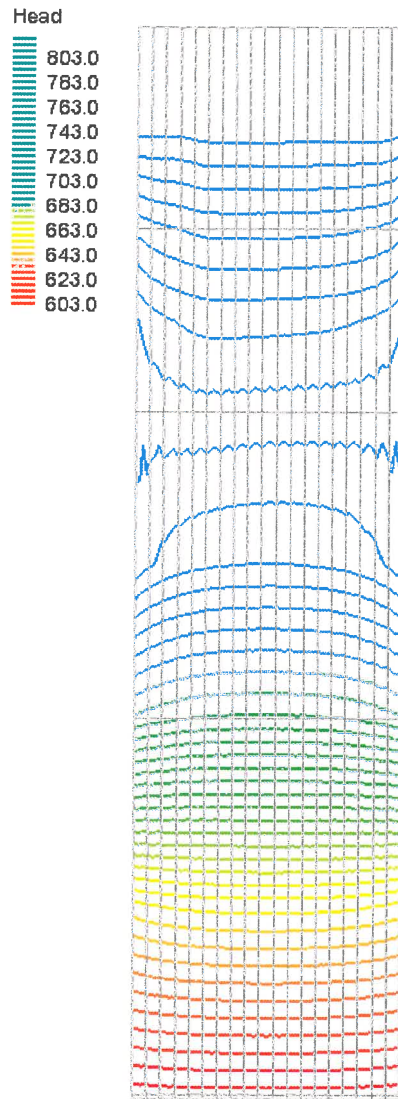



Figure 7-4. Cross-sectional View (from south) of Calculated Head, Vertical Pathway Model.

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 35 of 39

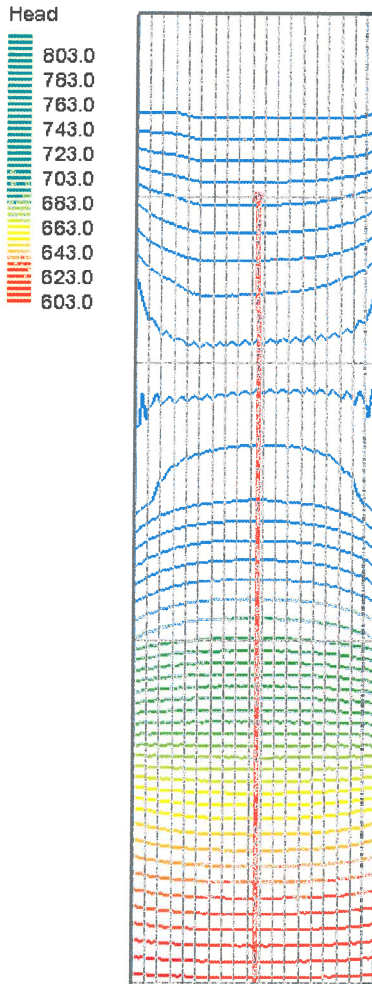


Figure 7-5. Calculated Flowpath in Cross-sectional View From South, Vertical Pathway Model.

7.3. Sensitivity Analysis for Horizontal Pathway

Three sensitivity runs were completed for the horizontal pathway, modifying parameters as listed in Table 7-1. Since the K values assigned for the Engineered Fill and Existing Fill in the horizontal pathway Base Run were selected to maximize the rate of groundwater movement calculated along each pathway, K values for these materials were not modified during the sensitivity analysis.

a. Sensitivity Run 1

The K value for the Glen Rose is assigned a value equal to the highest value reported from slug tests; other parameters in the pathway model remain the same (the K for the Engineered Fill is not changed since the highest value is already assigned in the model). The results are illustrated in Figure 7-6, with pathway distances and travel times for the key pathway reported in Table 7-1. There is no change to the key pathway identified at Unit 3 with the increase in

the K value for the Glen Rose bedrock. A shorter pathway is calculated from Unit 4, going to the west directly to a model boundary; however, the travel time for this path is significantly longer (31,271 days) as compared to the Base Run because this path moves primarily through bedrock.

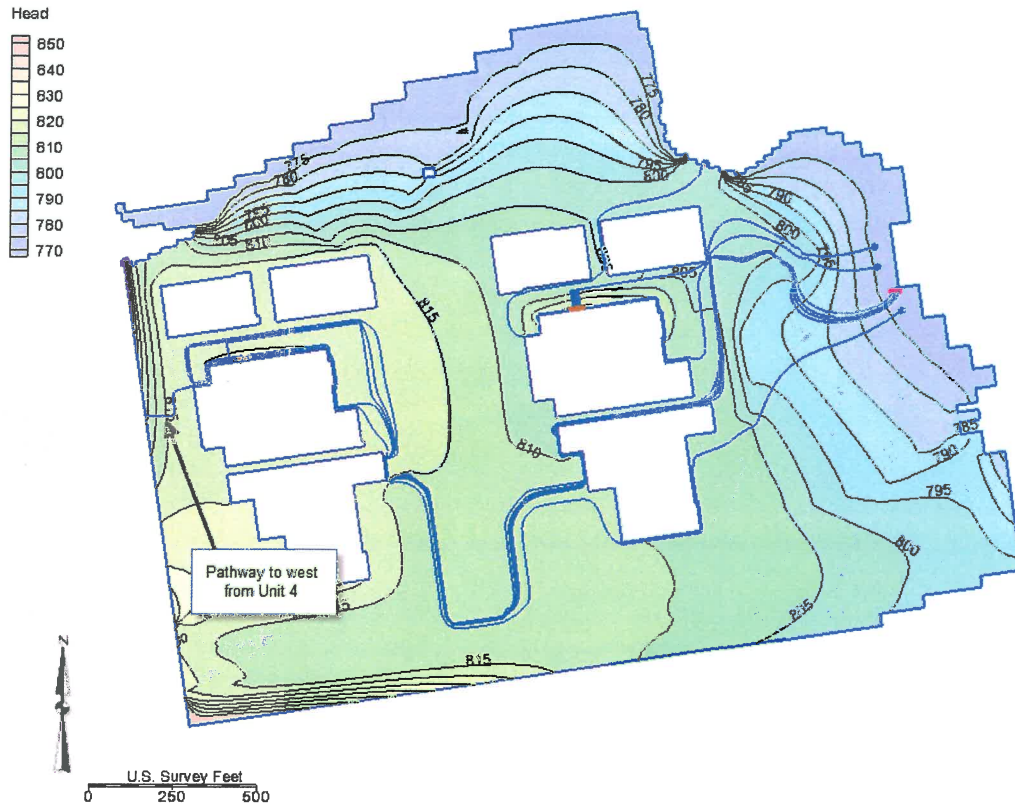


Figure 7-6. Calculated Flowpaths for Sensitivity Run 1, Horizontal Pathway Model.

b. Sensitivity Run 2

The K value for the Glen Rose is assigned a value representing the highest K value reported from packer tests. This parameter change results in calculated heads in the bedrock that are unrealistic for the physical setting of the site, with the maximum calculated head for the area between the two units approaching 845 ft msl. Additionally, there are a greater number of dry cells created in the model as a result of the lower groundwater movement through the bedrock.

Calculated pathways for this sensitivity run are illustrated in Figure 7-7.

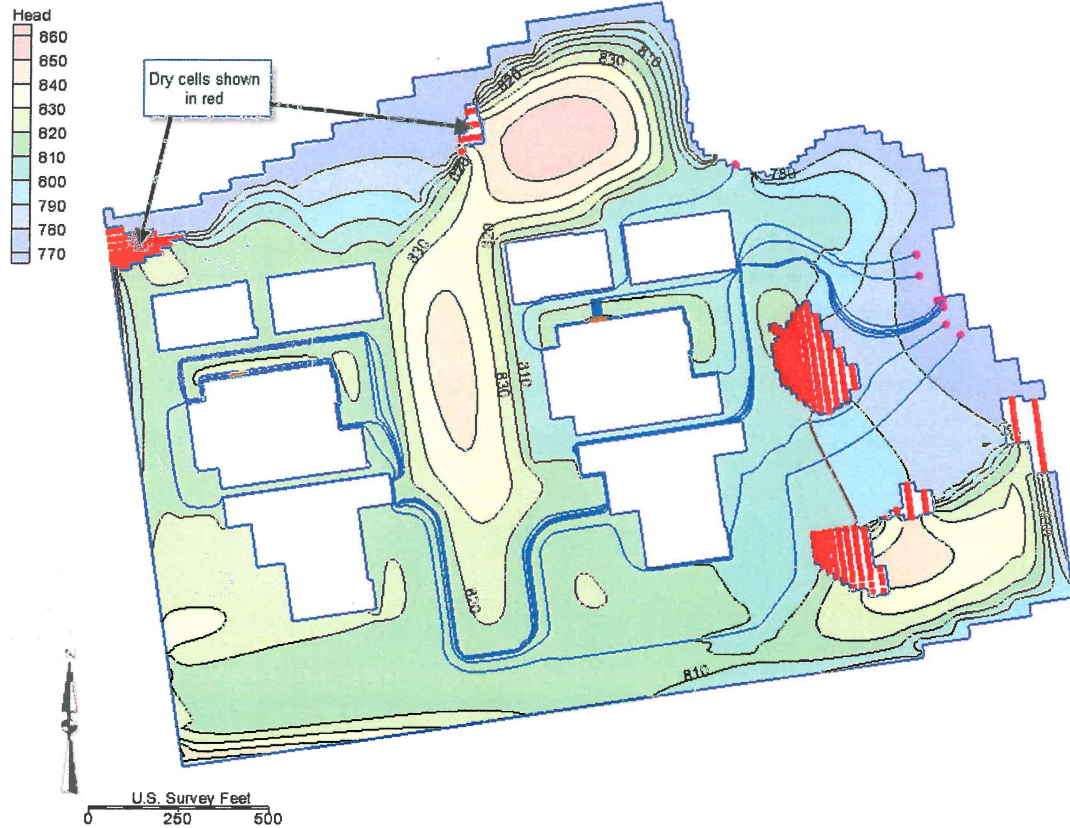


Figure 7-7. Calculated Flowpaths for Sensitivity Run 2, Horizontal Pathway Model.

c. Sensitivity Run 3

The porosity values for all subsurface materials (Engineered Fill, Existing Fill, and Glen Rose bedrock) are reduced for Sensitivity Run 3. The porosity for bedrock is changed to 5 percent (from 11.9 percent), while the porosity for fill (both Engineered Fill and Existing Fill) is changed to 15 percent (from 17 percent).

As expected, there is a decrease in the time of travel for each pathway, with little to no impact on the pathway lengths; calculated pathways are illustrated in Figure 7-8.

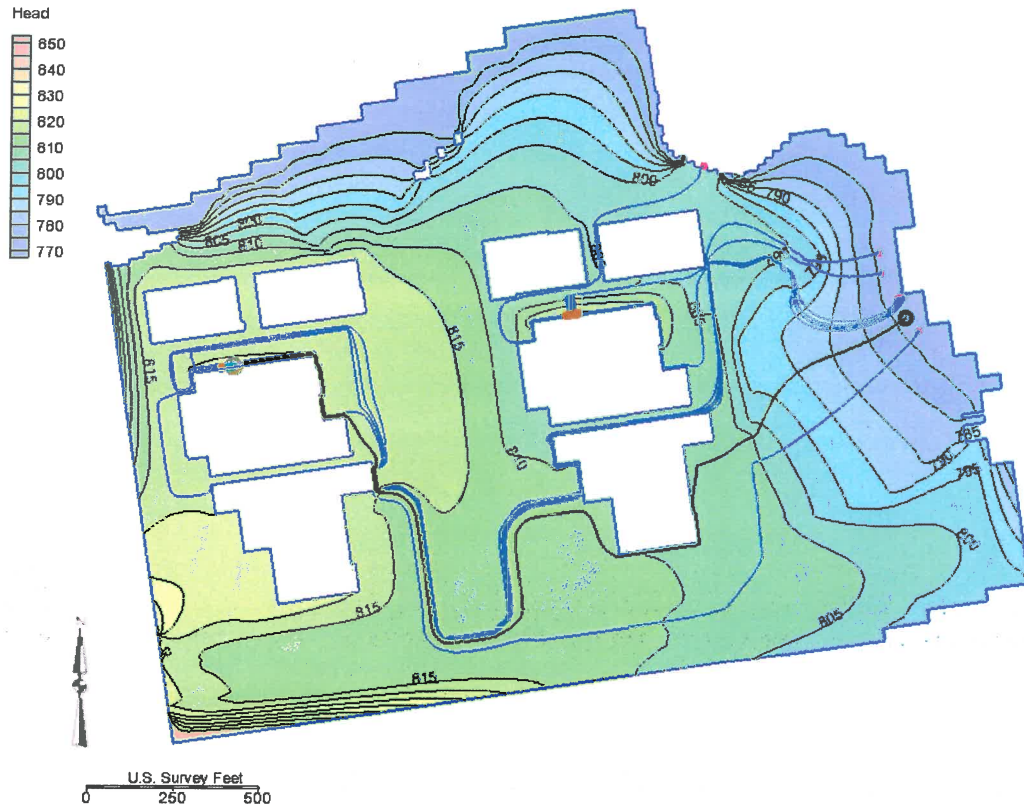


Figure 7-8. Calculated Flowpaths for Sensitivity Run 3, Horizontal Pathway Model.

7.4. Sensitivity Analysis for Vertical Pathway


The parameters that were varied are listed in Table 7- 1. The length and appearance of the vertical pathway does not change for any of the sensitivity runs, since the groundwater movement is consistently in a downward vertical path. Parameters for the Twin Mountains Formation were not varied since movement through that unit is not tracked in the pathway length or travel time measurements.

a. Sensitivity Run 4

For this sensitivity run, the porosity for the Glen Rose bedrock is changed from 11.9 percent to 5 percent. With this change, the time of travel for the pathway is reduced to approximately 3,410 days.

b. Sensitivity Run 5

For this sensitivity run, the vertical anisotropy for the Glen Rose bedrock is changed to 5 from 10. This increases the vertical time of travel to approximately 1,932 days for the vertical pathway, as would be expected.

	CALCULATION	CALC NO. TXUT-001-FSAR-2.4.12-CALC-039
		REV. 2
		PAGE NO. 39 of 39

8.0 CALCULATION RESULTS

The Horizontal and Vertical Base Run models simulate groundwater flow paths and groundwater travel times using extremely conservative assumptions. Flow paths and travel times in both the horizontal and vertical models are calculated using the combined influence of conservative groundwater flow parameters and boundary conditions. These conservative assumptions in combination create maximum groundwater flow rates for the subject pathways.

The Horizontal Base Run is a single-layer model that limits groundwater flow to only the horizontal direction with no downward component of flow. The pathways calculated in the Horizontal Base Run are influenced by the physical positions of the Engineered Fill, Existing Fill, and Bedrock at the site; parameter values, especially the values for K and n_e ; and the elevations assigned to SCR and hydraulic head at the BATs. Calculated horizontal pathway lengths are slightly longer for Unit 4 than for Unit 3, primarily because groundwater particles from both units migrate through Engineered Fill and into the eastern area of existing fill before exiting to SCR. One horizontal pathway from Unit 3, Pathway 3-1, is identified as the key conservative pathway for evaluating the horizontal migration of groundwater. This pathway is approximately 120 feet longer than the next shortest pathway (Pathway 3-2), but has a substantially shorter travel time of 62 days (versus the travel time of 1,556 days for Pathway 3-2).

A single downward pathway is calculated in the Vertical Base Run, with the calculated travel time influenced by the assigned parameters (especially k , n_e , and vertical anisotropy) as well as the assigned head values. The vertical pathway is calculated to be 186 feet long with a travel time of 8,115 days. The pathway begins at the base of the excavation adjacent to the BATs and extends through the bedrock of the Glen Rose Formation to the top of the underlying Twin Mountains Formation.

Sensitivity runs were completed to evaluate model results with a more conservative selection of model parameter values. Porosity values were reduced, K values were changed, and (for the vertical pathway), the vertical anisotropy was reduced. Pathway length change very little in the sensitivity analyses, for either the horizontal or the vertical models. For the horizontal pathway, a reduction in porosity of all subsurface materials has the greatest influence, decreasing the travel time of the Key Pathway from 62 to 55 days. For the vertical pathway, reducing the porosity of the Glen Rose bedrock and reducing the vertical anisotropy both serve to decrease the travel time of the pathway; of these two parameters, the vertical anisotropy has the most influence on the calculated time of travel.

9.0 APPENDICES

Appendix A – GMS model files, including MODFLOW model files for Horizontal and Vertical Pathways (electronic files on DVD)

Appendix B – ArcGIS files (electronic files on DVD)

Appendix C - The MODFLOW 2005 manual and MODPATH manual (electronic files on DVD)

Appendix D – Information on the Twin Mountains Formation Water Levels

Appendix A
Files on DVD

Appendix B
Files on DVD

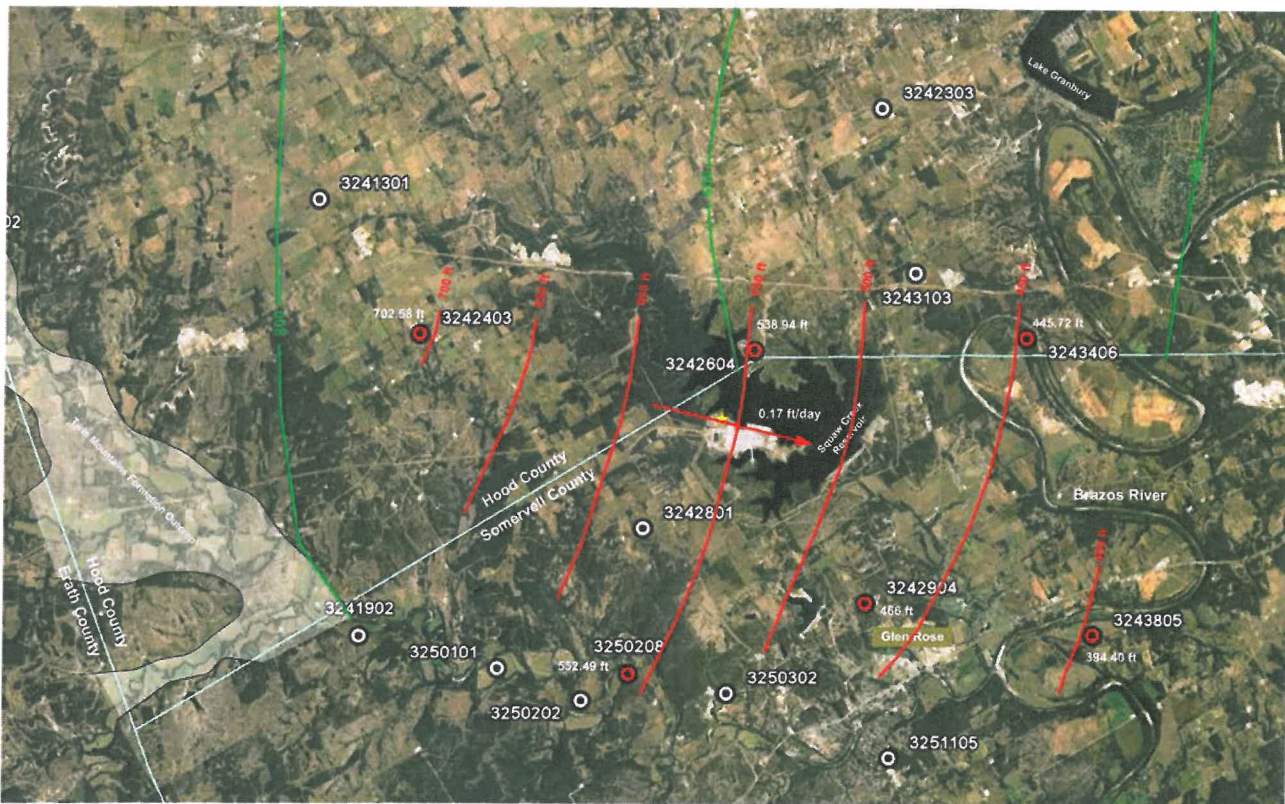
Appendix C
Files on DVD

Groundwater elevation data was obtained from six nearby USGS wells completed in the TMF aquifer (Reference 14) with recorded water levels in 2010 (Figure 1), including the CPNPP water supply well (USGS Well 3240604). Reported groundwater elevations for the five (5) identified wells and the CPNPP water supply well are shown in Table 1 (Reference 15 and Reference 16).

Table 1
Twin Mountain Formation Groundwater Elevations
(2010 Gauging Events)

Well (USGS No.)	Groundwater Elevation (ft msl)
3242403	702.58
3250208	552.49
3242604	538.94
3242904	466.00
3243406	445.72
3243805	394.40

Figure 1
Twin Mountain Formation Aquifer Potentiometric Surface Map (2010)



★ Location of CPNPP Units 3 and 4
 Top of Twin Mountains Formation
 at 595 ft msl (B1012)

● Groundwater well with 2010 TWDB data available

— Top of Twin Mountains Formation
 (Approximate elevation, feet msl)

FEET
 0 5000 10,000 15,000

Figure 1
Twin Mountain Formation Aquifer Potentiometric Surface Map (2010)

Water Wells completed in the Twin Mountains Formation
 Hood and Somervell Counties, Texas near CPNPP

(Reference 14) Twin Mountains Formation outcrop and top of formation elevations