Exelon Generation

NP-11-0038
August 17, 2011

10 CFR 52, Subpart A

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: Exelon Nuclear Texas Holdings, LLC
Victoria County Station Early Site Permit Application
Response to Request for Additional Information Letter No. 08
NRC Docket No. 52-042

Attached are responses to NRC staff questions included in Request for Additional Information (RAI) Letter No. 08, dated April 19, 2011, related to Early Site Permit Application (ESPA), Part 2, Sections 02.03.02, 02.04.03, 02.04.12, and 02.04.13. NRC RAI Letter No. 08 contained fourteen (14) Questions. This submittal comprises the final partial response to RAI Letter No. 08, and includes responses to the following two (2) Questions:

02.04.12-2
02.04.13-1

When a change to the ESPA is indicated by a Question response, the change will be incorporated into the next routine revision of the ESPA, planned for no later than March 31, 2012.

Of the remaining twelve (12) RAIs associated with RAI Letter No. 08, responses to nine (9) Questions were submitted to the NRC in Exelon Letter NP-11-0017, dated May 18, 2011, responses to two (2) Questions were submitted to the NRC in Exelon Letter No. NP-11-0021, dated June 2, 2011, and response to one (1) Question was submitted to the NRC in Exelon Letter No. NP-11-0030, dated July 13, 2011. This submittal completes the Exelon response to NRC RAI Letter No. 08, dated April 19, 2011.

Regulatory commitments established in this submittal are identified in Attachment 3.

If any additional information is needed, please contact David J. Distel at (610) 765-5517.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 17th day of August, 2011.

Respectfully,

Marilyn C. Kray

Marilyn C. Kray
Vice President, Nuclear Project Development

Attachments:
1. Question 02.04.12-2A
2. Question 02.04.12-2B
3. Question 02.04.12-2C
4. Question 02.04.12-2D
5. Question 02.04.12-2E
6. Question 02.04.12-2F
7. Question 02.04.13-1
8. Summary of Regulatory Commitments

cc: USNRC, Director, Office of New Reactors/NRLPO (w/Attachments)
USNRC, Project Manager, VCS, Division of New Reactor Licensing w/Attachments)
USNRC Region IV, Regional Administrator (w/Attachments)

RAI 02.04.12-2A:

Question:

In accordance with the requirements of 10 CFR 100.20(c) "Factors to be considered when evaluating sites" relating to hydrology and, 10 CFR 52.79(a) "Contents of applications; technical information in final safety analysis report" relating to hydrologic characteristics of the proposed site, and as recommended by Standard Review Plan 2.4.12 "Groundwater" acceptance criteria, additional information concerning the groundwater flow modeling is required for the NRC Staff's evaluation of the Application.
Please:

(A) Provide the technical basis for the conservative assumptions used for flow modeling extending to the hydraulic conductivity (Section 2.4.12-C-3.5) and the assumption of a maximum K for clay layers with respect to basin seepage and ground water mounding.

Response:

This response provides the technical basis for the conservative assumptions used for the groundwater flow modeling and for the use of a maximum hydraulic conductivity for clay layers for basin seepage and groundwater mounding.

The value selected for the vertical hydraulic conductivity of the uppermost model layer (layer 1, Clay 1), 0.068 feet/day, is the maximum value measured by Guelph Permeameter testing of this layer. This value provides a conservative analysis with respect to groundwater mounding at the power block because it allows the highest plausible rate of seepage from the cooling basin and prediction of correspondingly high groundwater levels in the power block.

The base of the cooling basin will be exposed to both the surface clay layer (model layer 1) and Sand 1 (model layer 2). Seepage through Sand 1 will be confined by a shallow clay layer (model layer 3). This shallow confining clay layer has been assigned a vertical hydraulic conductivity of 7×10^{-5} feet/day, as have the deeper confining layers. Selecting a value of vertical hydraulic conductivity greater than that used in the VCS model for the shallow and deeper confining clay layers would result in lowering of the groundwater head at the power block. This would result because more seepage would occur through the shallow confining clay layer into the underlying Upper Shallow aquifer (Sand 2), where the regional hydraulic gradient would induce groundwater flow toward the east. The 7×10^{-5} feet/day value of vertical hydraulic conductivity is the geometric mean of five values determined by laboratory testing of undisturbed soil samples from the Shallow and Deep Confining Layers (Table 2.4.12-13) and is considered representative for these clay layers.

The value (0.068 feet/day) for the vertical hydraulic conductivity of layer 1 (surface clay layer) in the VCS model is greater than the highest value reported in Reference 2.4.12-C-17 for the vertical hydraulic conductivity of the clay units in the Chicot aquifer [4.63×10^{-4} meter/day (1.52×10^{-3} feet/day) to 0.73×10^{-5} meter/day (2.4×10^{-5} feet/day)]. The value 7×10^{-5} feet/day is at the low end of the range reported in Reference 2.4.12-C-17 for the vertical hydraulic conductivity of the clay units in the Chicot Aquifer. On this basis, use of a higher value for layer 1 or a lower value for the deeper clay layers in the VCS model is not justified.

It can be noted that during the pumping test completed in the Deep aquifer, groundwater levels were monitored in an observation well completed in the Lower Shallow aquifer. The results of that testing indicate that there was no water-level response in the Lower Shallow aquifer resulting from pumping of the Deep aquifer. Therefore, it can be concluded that the Lower Shallow and Deep aquifers are hydraulically isolated in the area of the test. This finding supports the use of a relatively low value (i.e., 7×10^{-5} feet/day) for the vertical hydraulic conductivity of the confining clay layers in the VCS groundwater model.

Following submission of the ESPA, a re-evaluation of the aquifer saturated thicknesses was performed due to questions on the original results. This re-evaluation led to revisions to SSAR Subsection 2.4.12.2.4.1 and Table 2.4.12-9 to reflect the results of re-interpretation of the saturated thicknesses of the Upper Shallow and Deep aquifers and a corresponding revision of the transmissivities and hydraulic conductivities of the two aquifers.

The saturated thicknesses of the Upper Shallow and Deep aquifers were based upon groundwater level measurements in the observation wells and logs of geotechnical soil borings in the vicinity of the test wells monitored during the pumping tests conducted in these aquifers. Groundwater levels are provided in SSAR Table 2.4.12-6. The geotechnical soil boring data are summarized in SSAR Section 2.5.4 and the soil boring logs are provided in Part 5 of the ESPA.

The revised hydraulic conductivity values that resulted from re-evaluation of the aquifer pumping tests (SSAR Table 2.4.12-9) are lower for both the Upper Shallow aquifer and the Deep aquifer, when compared to the values used in the VCS groundwater model (SSAR Table 2.4.12-C-4). The lower revised hydraulic conductivity values are expected to cause a longer travel time due to decrease in groundwater velocity.

SSAR Subsections 2.4.12.2.4.1, 2.4.12.2.4.3, 2.4.12-C-3.5 and Tables 2.4.12-9 and 2.4.12-C-4 are revised as follows.

Associated ESPA Revisions:

SSAR Subsection 2.4.12.2.4.1 will be revised in a future revision of the ESPA as indicated:

2.4.12.2.4.1 Hydrogeological Parameters

Hydrogeologic field tests conducted at the VCS site included well slug tests and aquifer pumping tests. Slug tests were conducted in each of the site observation wells with the exception of OW-10U which had insufficient water in the well for testing.

Aquifer pumping tests were conducted at the VCS site in February 2008 at test well clusters TW-2320 (Upper Shallow aquifer) and TW-2359 (Deep aquifer). Each test consisted of a test pumping well and four adjacent observation wells. Nearby observation well pairs installed to monitor site groundwater levels were also monitored during the tests. The information obtained during the testing was used to evaluate the transmissivity and storativity of the aquifers.

Transmissivity is defined as the rate at which a fluid of a specified density and viscosity is transmitted through a unit width of an aquifer or confining bed under a unit hydraulic gradient. Transmissivity is a function of the properties of the fluid, the porous medium, and the thickness of the porous medium (Reference 2.4.12-15).

Storativity (storage coefficient) is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head (Reference 2.4.12-15). Hydraulic conductivity is defined as the coefficient of proportionality that describes flow per unit time under a unit hydraulic gradient through a unit area of a porous medium and is a function of the properties of the fluid and the porous medium. Hydraulic conductivity can be calculated by dividing the transmissivity by the saturated aquifer thickness (Reference 2.4.12-15).

Slug Test Analysis

Hydraulic conductivity can be determined from the slug test method, which evaluates the aquifer response to an instantaneous change in water level in the test well. A disadvantage of the slug test method is that it measures hydraulic conductivity only in the immediate vicinity of the test well. However, because the slug test requires minimal equipment and can be performed rapidly, slug tests can be performed in many wells, allowing a determination of spatial variability in hydraulic conductivity.

Slug tests were conducted in 53 of the 54 observation wells at the VCS site. (Observation well OW-10U had ~~has~~ insufficient water in the well for testing.) Slug test results are summarized in Table 2.4.12-8. (Test ~~Data~~ results and analysis are presented in Reference 2.5.4-2). The minimum, maximum and geometric mean hydraulic conductivity values from the slug test~~s~~ analyses presented in Table 2.4.12-8 for the Upper Shallow, Lower Shallow, and Deep aquifer zones at the VCS site are as follows:

Aquifer Zone	Minimum (feet/day)	Maximum (feet/day)	Geometric Mean (feet/day)
Upper Shallow	0.06	56.79	12.29
Lower Shallow	0.02	163.5	24.76
Deep	0.67	142.7	9.80

Notes:
1 Minimum value = lowest value of the mean test results.
2 Maximum value = highest value of the mean test results.
3 Geometric mean = geometric mean of the average value for the analytical method results per well.

The data presented in Table 2.4.12-8 suggest variations in the materials tested, indicative of heterogeneous conditions. The slug test results for the Upper Shallow, Lower Shallow, and Deep aquifer zones were contoured to evaluate spatial trends (~~see~~ Figure 2.4.12-18). For consistency, the hydraulic conductivities calculated from the rising head slug tests, Bouwer-Rice analytical method (~~see~~ Table 2.4.12-8) were used.

The Upper Shallow aquifer contour map indicates a discontinuous zone of increased hydraulic conductivity trending north to south from OW-07U to OW-2304U. The Lower Shallow aquifer contour map indicates an area of increased hydraulic conductivity trending northwest to southeast parallel to Linn Lake between OW-2307L and OW-2348U. An isolated area of increased hydraulic conductivity is also present in the Lower Shallow aquifer zone in the vicinity of OW-2320U. The Deep aquifer zone exhibits a general increase in hydraulic conductivity from west to east across the VCS site and does not appear to have any particular zones of increased hydraulic conductivity. The hydraulic conductivity trends in the Lower Shallow and Deep aquifers are generally consistent with coarsening and thickening of alluvial deposits in the direction of the Guadalupe River Valley. The contour maps also show the locations of the aquifer pumping tests in the Upper Shallow and Deep aquifers, although the hydraulic conductivity values from the aquifer pumping tests were not used in the contouring.

Pumping Test Analysis

Aquifer pumping tests were conducted at the VCS site in February 2008 at test well clusters TW2320 (Upper Shallow aquifer) and TW-2359 (Deep aquifer) as shown in Figure 2.4.12-10. Each test consisted of a test well and four adjacent observation wells. Nearby observation well pairs installed to monitor site groundwater levels were also monitored during the tests. The information obtained during the testing was used to evaluate the transmissivity and storativity of the aquifers. Test ~~Data~~ results and analysis are presented in Part 5 of this ESPA. The results of the February 2008 pumping tests, including additional analysis performed since 2008 are summarized in Table 2.4.12-9.

The Upper Shallow aquifer pumping test was conducted in the vicinity of observation test well cluster OW-2320, which is located in the approximate center of the cooling basin area. The test well cluster consisted of test well TW-2320U (pumping well) and four observation wells (OW-2320U1 through OW-2320U4), located at distances of approximately 15 to 50 feet from the test well as shown in Figure 2.4.12-19. Pressure transducers equipped with data loggers were used to measure water level drawdown and recovery in the test well and the observation wells. ~~and during recovery (completion of pumping).~~ The pressure transducer in observation well OW-2320U4 apparently malfunctioned during the test and did not provide usable data.

TW-2320U was pumped at a rate of approximately 3.2 gpm for 48 hours. Based on the results presented in Table 2.4.12-9, a transmissivity of approximately 312.2 ~~420~~ square feet per day, a storage coefficient of approximately 3.3×10^{-3} ~~1.6×10^{-6}~~, and a hydraulic conductivity of approximately 8.2 ~~60~~ feet per day (using a saturated thickness of 38 ~~7~~ feet) are estimated for the

Upper Shallow aquifer ~~zone~~ at this location.

A distance drawdown analysis of the data was performed to ~~evaluate~~ compare with the single well test data analysis at times of 300 and 3000 seconds after pumping began. At 300 seconds, transmissivity of approximately 1474 square feet per day, hydraulic conductivity of 39 feet per day, and a storage coefficient of approximately 5 x 10^{-4} were estimated for the Upper Shallow aquifer. At 3000 seconds, transmissivity of approximately 738.7 square feet per day, hydraulic conductivity of 19 feet per day, and a storage coefficient of 4 x 10^{-4} were estimated for the aquifer zone at this location. ~~A transmissivity of approximately 700 square feet per day, a hydraulic conductivity of approximately 100 feet per day, and a storage coefficient of approximately 6.1 x 10^{-3} to 5.2 x 10^{-4} were estimated for the aquifer zone at this location.~~ The distance drawdown analysis suggests a higher hydraulic conductivity than ~~then~~ that of the single well test analysis ~~analyses~~.

The Deep aquifer pumping test was located near the northeastern corner of the cooling basin between observation well clusters OW-06, OW-07, and OW-10. The test well cluster consisted of ~~the~~ test well TW-2359L and four observation wells (OW-2359L1 through OW-2359L3 ~~OW-2320L3~~ screened in the Deep aquifer and OW-2359U1 screened in Lower Shallow aquifer) as shown in Figure 2.4.12-20. TW-2359L was pumped at a rate of approximately 21 gpm for 24 hours. The transducer at OW-2359L1 failed during the test resulting in no useable data for this observation point. Based on the results presented in Table 2.4.12-9, a transmissivity of approximately 2507.3 ~~2060~~ square feet per day, a storage coefficient of approximately 4.1 ~~3.8~~ x 10^{-4}, and a hydraulic conductivity of approximately 47.3 ~~103~~ feet per day (using a saturated thickness of 53 ~~20~~ feet) were ~~are~~ estimated for the aquifer zone at this location.

A distance drawdown analysis of the Deep aquifer test data was also performed to ~~evaluate~~ compare with the single well test data analysis. This analysis yields an estimated transmissivity of 3157.7 square feet per day after 300 seconds and 2508.2 square feet per day after 3000 seconds of pumping. The corresponding hydraulic conductivity varies between 60 feet per day and 47 feet per day, respectively (assuming a saturated thickness of 53 ft). The distance drawdown analysis after 3000 seconds of pumping yielded virtually the same estimates of transmissivity and hydraulic conductivity in the Deep aquifer as the single well test analysis. ~~A transmissivity of approximately 2810 square feet per day, a hydraulic conductivity of approximately 140 feet per day, and a storage coefficient of approximately 4.2 x 10^{-5} were estimated for the aquifer zone at this location. The distance drawdown analysis also suggests a higher hydraulic conductivity then that of the single test analyses.~~

The site-specific hydraulic conductivity and transmissivity values obtained from the pumping tests are, in general, consistent with regional values for the Chicot Aquifer (Reference 2.4.12-16). The Upper Shallow aquifer ~~pumping test (~~hydraulic conductivity values of approximately 8

~~60 to 100~~ feet per day~~)~~ from the single well test analysis and 39 feet per day from the distance drawdown test analysis plot ~~plots~~ approximately on the 20 feet per day slug test contour in Figure 2.4.12-18, indicating ~~a 3 to 5 times difference~~ reasonable agreement between the test methods. The Deep aquifer ~~pumping test (~~hydraulic conductivity values of approximately 47 ~~103 to 140~~ feet per day~~)~~ from the single well test analysis and 60 feet per day from the distance drawdown test analysis plot between the 10 and 20 feet per day slug test contours, indicating approximately a 3 ~~7~~ to 4 ~~10~~ times difference between the test methods. It should be noted that the aquifer pumping test wells were open to a thicker sequence of sands than the slug test wells. ~~and are on the upper end of the slug test results.~~

The first paragraph of SSAR Subsection 2.4.12.2.4.3 will be revised in a future revision to the ESPA, as indicated:

2.4.12.2.4.3 Summary of Aquifer Properties

Based on the results of the geotechnical and hydrogeological testing the hydraulic conductivity values derived from grain size, aquifer pumping tests, and slug tests at the VCS site (included in Part 5 of the ESPA) are considered to be in agreement within the range of regional hydraulic conductivity values (Reference 2.4.12-16). Results of the statistical analysis ~~also~~ indicate that the slug tests have the greatest range of hydraulic conductivity. Following is a summary of hydraulic conductivity ranges determined by different methods:

- Chicot Aquifer regional values (from the technical literature): 11 to 98 feet per day
- VCS pumping test results: 8 ~~60~~ to 60 ~~140~~ feet per day
- VCS slug test results: 0.02 to 164 feet per day
- VCS grain size analysis (sand): 11 to 30 feet per day
- VCS Guelph permeameter test results: less than 3 feet per day

Section 2.4.12-C-3.5 of Appendix C to the SSAR will be revised in a future revision to the ESPA, as indicated:

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~~ determined from a 48-hour aquifer pumping test performed in test well TW-2320U in this unit as shown in Subsection 2.4.12, Table 2.4.12-9.

- Horizontal hydraulic conductivity of the remaining saturated sand layers, including the Lower Shallow aquifer (Sand 4) and Deep aquifer (Sand 5 and Sand 6), represents the ~~mean~~ hydraulic conductivity derived from a 24-hour aquifer pumping test performed in test well TW-2359L in Sand 5 ~~Deep aquifer pumping tests~~ as shown in Subsection 2.4.12, Table 2.4.12-9. The horizontal hydraulic conductivities of Sand 4, Sand 5, and Sand 6 are assumed to be equal, based upon grain size analysis, as shown in Figure 2.4.12-22.

- Vertical hydraulic conductivity of the sand layers was ~~were~~ calculated using the typical ratio of Kh/Kv = 3 (Reference 2.4.12-C-9).

- Vertical hydraulic conductivity of layer 1 ~~Clay 1~~ of the model (Clay 1) was assigned a Kv 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 Kv based on laboratory permeability testing of undisturbed soil samples from Subsection 2.4.12, Table 2.4.12-13.

  The values of vertical hydraulic conductivity selected for the modeled clay layers are conservative with respect to both cooling basin seepage and groundwater mounding at the power block. The value selected for the vertical hydraulic conductivity of the uppermost model layer (layer 1, Clay 1), 0.068 feet/day, is the maximum value measured by the Guelph Permeameter testing of this layer. This value provides a conservative analysis with respect to groundwater mounding at the power block because it allows the highest plausible rate of seepage from the cooling basin and prediction of correspondingly high groundwater levels in the power block.

  The base of the cooling basin will be exposed to both the surface clay layer (model layer 1) and Sand 1 (model layer 2). Seepage through Sand 1 will be confined by an underlying shallow clay layer (model layer 3). This shallow confining clay layer has been assigned a vertical hydraulic conductivity of 7×10^{-5} feet/day, as have the deeper confining layers in the model. Selecting a value of vertical hydraulic conductivity greater than that used in the VCS model for the shallow and deeper confining clay layers would result in lowering of the groundwater head at the power block. This would result because more seepage would occur through the shallow confining clay layer into the underlying Upper Shallow aquifer (Sand 2), where the regional hydraulic gradient would induce groundwater flow toward the east. The 7 x 10^{-5} feet/day value of vertical hydraulic conductivity is the geometric mean of five values determined by laboratory testing of undisturbed soil samples from the Shallow and Deep Confining Layers (Table 2.4.12-13) and is considered representative for these clay layers.

The value (0.068 feet/day) for the vertical hydraulic conductivity of layer 1 (surface clay layer) in the VCS model is greater than the highest value reported in Reference 2.4.12-C-17 for the vertical hydraulic conductivity of the clay units in the Chicot aquifer [4.63 x 10^{-4} meter/day (1.52 x 10^{-3} feet/day) to 0.73 x 10^{-5} meter/day (2.4 x 10^{-5} feet/day)]. The value 7 x 10^{-5} feet/day is at the low end of the range reported in Reference 2.4.12-C-17 for the vertical hydraulic conductivity of the deeper clay units in the Chicot Aquifer. On this basis, use of a higher value for layer 1 or a lower value for the deeper clay layers in the VCS model is not justified.

It can be noted that during the pumping test completed in the Deep aquifer, groundwater levels were monitored in an observation well completed in the Lower Shallow aquifer. The results of that test indicate that there was no water-level response in the Lower Shallow aquifer resulting from pumping of the Deep aquifer. Therefore, it can be concluded that the Lower Shallow and Deep aquifers are hydraulically isolated in the area of the test. This finding supports the use of a relatively low value (i.e., 7 x 10^{-5} feet/day) for the vertical hydraulic conductivity of the confining clay layers in the VCS groundwater model.

- Horizontal hydraulic conductivity of clayey layers – used the relationship Kh/Kv = 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 is ~~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 Kh/Kv = 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.

SSAR Table 2.4.12-9 will be revised in a revision to the ESPA, as indicated:

Table 2.4.12-9
Summary of Aquifer Pumping Test Results

TW-2320U Aquifer Pumping Test **48 hour test**

Observation Well	Saturated Thickness (ft)	Theis Method		Cooper-Jacob Method		Neumann Method		Vertical/Horizontal Hydraulic Conductivity (unitless)
		Transmissivity (ft^2/d)	Storage Coefficient (unitless)	Transmissivity (ft^2/d)	Storage Coefficient (unitless)	Transmissivity (ft^2/d)	Storage Coefficient (unitless)	
OW-2320U1	38 ~~7~~	295 ~~325.3~~	1.89 x 10^{-3} ~~2.61 x 10^{-6}~~	371 ~~471.6~~	1.40 x 10^{-3} ~~1.65 x 10^{-6}~~	295	1.98 x 10^{-3}	0.16
OW-2320U2	38 ~~7~~	248 ~~284.0~~	6.10 x 10^{-3} ~~1.68 x 10^{-6}~~	310 ~~370.4~~	4.42 x 10^{-3} ~~1.18 x 10^{-6}~~	248	6.07 x 10^{-3}	0.14
OW-2320U3	38 ~~7~~	276 ~~365.8~~	2.94 x 10^{-3} ~~1.98 x 10^{-6}~~	361 ~~422.3~~	2.23 x 10^{-3} ~~1.46 x 10^{-6}~~	276	2.94 x 10^{-3}	0.17
Combination/ Drawdown	38 ~~7~~	370 ~~374.0~~	2.85 x 10^{-3} ~~1.80 x 10^{-6}~~	378 ~~423.1~~	2.36 x 10^{-3} ~~---~~	283	5.75 x 10^{-3}	0.15
Combination/ Recovery	38 ~~7~~	340 ~~727.9~~	---	---	---	---	---	---
mean		306 ~~415.4~~	3.45 x 10^{-3} ~~1.84 x 10^{-6}~~	355 ~~421.8~~	2.59 x 10^{-3} ~~1.43 x 10^{-6}~~	275.5	4.19 x 10^{-3}	0.16
Hydraulic Conductivity (ft/d)		8.0 ~~59.3~~	---	9.3 ~~60.3~~	---	7.2	---	---

Mean of Transmissivity (Theis, Cooper-Jacobs, and Neumann Methods): 312.2 ft^2/d
Mean of Hydraulic Conductivity (Theis, Cooper-Jacobs, and Neumann Methods): 8.2 ft/d
Mean of Storage Coefficient (Theis, Cooper-Jacobs, and Neumann Methods): 3.3 x 10^{-3}

Table 2.4.12-9
Summary of Aquifer Pumping Test Results (con't)

TW-2359L Aquifer Pumping Test **24 hour test**

Observation Well	Saturated Thickness (ft)	Theis Method		Cooper-Jacob Method		Hantush-Jacob Method		Vertical/Horizontal Hydraulic Conductivity (unitless)
		Transmissivity (ft^2/d)	Storage Coefficient (unitless)	Transmissivity (ft^2/d)	Storage Coefficient (unitless)	Transmissivity (ft^2/d)	Storage Coefficient (unitless)	
OW-2359L2	53 ~~20~~	2526 ~~2228.4~~	7.33×10^{-5} ~~3.67×10^{-4}~~	2546 ~~1402.8~~	6.43×10^{-5} ~~7.50×10^{-4}~~	2455	1.59×10^{-3}	0.0073
OW-2359L3	53 ~~20~~	2502 ~~2452.5~~	7.64×10^{-5} ~~1.92×10^{-4}~~	2509 ~~1986.2~~	7.48×10^{-5} ~~2.73×10^{-4}~~	2527	7.33×10^{-4}	0.0055
Combination/ Drawdown	53 ~~20~~	2508 ~~2311.6~~	7.35×10^{-5} ~~2.63×10^{-4}~~	2495 ~~2032.2~~	7.36×10^{-5} ~~4.21×10^{-4}~~	2551	1.04×10^{-3}	0.0014
Combination/ Recovery	53 ~~20~~	2440 ~~2294.9~~	---	---	---	---	---	---
mean		2494 ~~2321.8~~	7.44×10^{-5} ~~2.74×10^{-4}~~	2517 ~~1807.1~~	7.09×10^{-5} ~~4.81×10^{-4}~~	2511	1.12×10^{-3}	0.0047
Hydraulic Conductivity (ft/d)		47.0 ~~116~~	---	47.5 ~~90.4~~	---	47.4	---	---

Mean of Transmissivity (Theis, Cooper-Jacobs, and Hantush-Jacob Methods): 2507.3 ft^2/d
Mean of Hydraulic Conductivity (Theis, Cooper-Jacobs, and Hantush-Jacob Methods): 47.3 ft/d
Mean of Storage Coefficient (Theis, Cooper-Jacobs, and Hantush-Jacob Methods): 4.1×10^{-4}

Notes:
ft^2/d = square feet per day
ft/d = feet per day

Table 2.4.12-C-4 of Appendix C to the SSAR will be revised in a future revision to the ESPA, as indicated:

Table 2.4.12-C-4
Hydraulic Conductivity Values

Model Layer[a]	Geotechnical Layer	Model Horizontal Hydraulic Conductivity K_h (ft/day)	Source	Model 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[c]	Reference 2.4.12-C-9	2.75[c]	Table 2.4.12-14
3	Clay 1 Bottom	7 x 10^{-4}	Reference 2.4.12-C-9	7 x 10^{-5}	Table 2.4.12-13
4	Sand 2	60[c]	Table 2.4.12-9[e]	20[c]	Reference 2.4.12-C-9
5	Clay 3	7 x 10^{-4}	Reference 2.4.12-C-9	7 x 10^{-5}	Table 2.4.12-13
6	Sand 4	103[d]	Table 2.4.12-9[e]	34	Reference 2.4.12-C-9
7	Clay 5 Top	7 x 10^{-4}	Reference 2.4.12-C-9	7 x 10^{-5}	Table 2.4.12-13
8	Sand 5	103[d]	Table 2.4.12-9[e]	34	Reference 2.4.12-C-20
9	Clay 5 Bottom	7 x 10^{-4}	Reference 2.4.12-C-9	7 x 10^{-5}	Table 2.4.12-13
10	Sand 6	103[d]	Table 2.4.12-9[e]	34	Reference 2.4.12-C-9
11	Clay 7 and 9 Sand 8 and 10	1.4 x 10^{-3}	Reference 2.4.12-C-9	1.4 x 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
(d) Adjusted during calibration – model layers 6, 8, and 10 to K_h = 103 feet/day and K_v = 34 feet/day
(e) Table 2.4.12-9 was revised to include the updated hydraulic conductivity after re-interpretation of the saturated thickness for Upper Shallow and Deep aquifers. The groundwater modeling values for hydraulic conductivity of the sand layers are higher but matched favorably with the hydraulic conductivity values in Reference 2.5.4-2 and meet the model calibration criteria as discussed in Subsection 2.4.12-C-5.

Note: K_h of Sand 2 determined from 48-hour pumping test of TW-2320U in Sand 2. K_h of Sand 4, Sand 5 and Sand 6 determined from 24-hour pumping test of TW-2359L in Sand 5. K_h of Sand 4, Sand 5 and Sand 6 assumed to be equal based on grain size analysis.

The following reference will added to Section 2.4.12-C-8 of Appendix C to the SSAR, in a future revision of the ESPA:

Reference 2.4.12-C-17 Cleveland, Theodore G., Bravo, Rolando., and Rogers, Jerry R., Storage Coefficients and Vertical Hydraulic Conductivities in Aquitards Using Extensometer and Hydrograph Data, Ground Water, Vol. 30, No.5, pages 701-708, 1992.

Revisions to the corresponding sections of the environmental report (ER subsections 2.3.1.2.2.4.1 and 2.3.1.2.2.4.3) and ER Table 2.3.1.2-6, consistent with the SSAR revisions, will be made a future revision of the ESPA.

RAI 02.04.12-2B:

Question:

In accordance with the requirements of 10 CFR 100.20(c) "Factors to be considered when evaluating sites" relating to hydrology and, 10 CFR 52.79(a) "Contents of applications; technical information in final safety analysis report" relating to hydrologic characteristics of the proposed site, and as recommended by Standard Review Plan 2.4.12 "Groundwater" acceptance criteria, additional information concerning the groundwater flow modeling is required for the NRC Staff's evaluation of the Application.
Please:

(B) Discuss the model calibration and apparent spatial correlation of residuals and specifically the tendency for the model to under estimate higher observed heads and over estimate lower observed heads and the impact on simulated gradients, flow paths and transport.

Response:

This response provides the technical basis for calibration of the VCS numerical model. The apparent spatial correlation of residuals, the tendency for the model to under estimate higher observed heads and over estimate lower observed heads and the impact of these tendencies on simulated hydraulic gradients, groundwater flow paths and effluent transport are evaluated.

The VCS steady-state groundwater model was calibrated against the arithmetic mean for each observation well of the groundwater levels measured between October 2007 and August 2009. Calibration of the model was accomplished by adjusting recharge and hydraulic conductivity to obtain the best match between observed groundwater heads and simulated heads. Two stages of calibration were performed:

1) Trial-and-Error Calibration

This method consisted of manually adjusting recharge and hydraulic conductivity until a good agreement between the simulated and observed groundwater heads was obtained. The recharge rate was varied by creating the two zones shown in SSAR Figure 2.4.12-C-4. Zone 1 in the figure represents the less permeable surface material comprised of Clay 1-Top, which was adjusted to a recharge rate of 0.0 inch/year. Zone 2 represents the more permeable zone comprised of Sand 1, which was adjusted to a recharge rate of 0.4 inch/year. The horizontal and vertical hydraulic conductivity was varied for the Lower Shallow (layer 6) and Deep (layers 8 and 10) aquifers, with final calibrated values of 103 feet/day and 34 feet/day, respectively (SSAR Table 2.4.12-C-4). The trial-and-error method produced results that satisfy the model calibration criteria in model layers 6, 8, and 10. However, the simulated heads in model layer 4 did not satisfy the calibration criteria. The calibration criteria are discussed in SSAR subsection 2.4.12-C-5.1.

2) Inverse Automated Calibration

This method uses the PEST (Parameter ESTimation) algorithm (SSAR Reference 2.4.12-C-16) to adjust model parameters until the fit between model output (simulated groundwater head) and field observations of head is optimized. In the VCS groundwater model, the PEST algorithm was used to determine the horizontal hydraulic conductivity for model layer 4 and the vertical hydraulic conductivity for model layer 1. The PEST algorithm produced an estimated horizontal hydraulic conductivity of 68 feet/day for model layer 4 and an estimated vertical hydraulic conductivity of 0.06 feet/day for model layer 1. Because model layers 2 and 4 are of similar lithology, a horizontal hydraulic conductivity of 68 feet/day was also assigned to model layer 2 (SSAR Table 2.4.12-C-4).

The updated hydraulic conductivities and recharge rates from the trial-and-error method and the inverse automated method provide the final calibration. SSAR Table 2.4.12-C-7 presents the observed and simulated heads for those wells used as calibration targets. Based on the calibration statistics and mass balance discrepancy, the model satisfies the calibration criteria (SSAR Subsection 2.4.12-C-5.2).

Apparent Spatial Correlation of Residuals

SSAR Table 2.4.12-C-7 shows the head residuals, which are the difference between simulated groundwater heads and observed heads. SSAR Figure 2.4.12-C-5 shows a scatter plot of simulated versus observed heads in layers 4, 6, 8, and 10 of the groundwater model as well as model calibration statistics. A positive residual means that the simulated head is greater than the observed head and a negative residual means that the simulated head is less than the observed head. SSAR Figures 2.4.12-C-11, 2.4.12-C-12, 2.4.12-C-13 and 2.4.12-C-14 show "bubble plots" of the calibration residuals in model layers 4, 6, 8, and 10, respectively, where the size of the bubble corresponds to the magnitude of the residual. The red bubbles indicate that the simulated heads over estimate the observed heads, whereas the blue bubbles indicate that the simulated heads under estimate the observed heads. Based on these plots, the residuals tend to be spatially biased in that the model under-predicts the heads in the power block and cooling basin areas, whereas the model over-predicts the heads at the northeastern corner of the cooling basin and near Linn Lake.

The residuals are larger (both positively and negatively) in Sand 2 (model layer 4), compared to Sand 4 (model layer 6), Sand 5 (model layer 8), and Sand 6 (model layer 10). These differences in residuals are likely due to the effect of spatial heterogeneity in hydraulic conductivity within the sand layers and also may be due to the physics of flow that is not captured by the conceptual or the numerical models. In the calibrated model the hydraulic conductivity of each of the layers is assumed to be uniform. As a result, the model does not simulate the spatial heterogeneity in the hydraulic conductivity of the sands that affects the groundwater head.

The potentiometric head in and around the power block area and most of the cooling basin is under-predicted by the groundwater model in Sand 2, Sand 4, Sand 5, and Sand 6. This under-prediction of simulated groundwater values is likely due to higher hydraulic conductivity values in the groundwater model at the power block area than the actual hydraulic conductivity values. Lower values of hydraulic conductivity compared to those in the existing model may lower (improve) residuals in some areas, but could also create or exacerbate them in others. The simulated heads tend to be over-predicted in the same sand layers to the east of the cooling basin and near Linn Lake. These residuals are also likely due to local variations in hydraulic conductivity in this area, which are not simulated by the model. The apparent natural heterogeneity in the aquifer makes it unlikely that the simulated and observed heads can be closely matched in all areas of the site.

The numerical groundwater model closely mimics the conceptual model; however, it is postulated that it is the spatial heterogeneity in the subsurface that results in over-prediction and under-prediction of the simulated heads compared to the observed heads. The model correctly simulates the direction of vertical groundwater flow between the sand layers and the magnitude of the modeled vertical gradients reasonably agrees with the observed values in the power block area, cooling basin and east of the cooling basin. Comparison of the observed and simulated gradients is shown in detail in Table 1 and Figure 3 in the response to RAI 02.04.12-8.

Because the simulated vertical flow directions and gradients of the calibrated pre-construction groundwater model reasonably agree with the observed vertical flow directions and gradients in the power block area, cooling basin and near Linn Lake the under- or over-prediction of simulated heads with respect to observed heads is not expected to affect the gradients, flow paths, or effluent transport in the post-construction groundwater model. Incorporation of heterogeneity in the hydraulic conductivity of the sand layers may reduce the magnitude of the residuals and their apparent spatial correlation. However, incorporation of such heterogeneity is unlikely to significantly change the flow paths or effluent transport from the post-construction simulation shown in SSAR Section 2.4.13, which is based on a uniform distribution of hydraulic conductivity in the sand layers.

Associated ESPA Revisions:

No ESPA revision is required as a result of this response.

RAI 02.04.12-2C:

Question:

In accordance with the requirements of 10 CFR 100.20(c) "Factors to be considered when evaluating sites" relating to hydrology and, 10 CFR 52.79(a) "Contents of applications; technical information in final safety analysis report" relating to hydrologic characteristics of the proposed site, and as recommended by Standard Review Plan 2.4.12 "Groundwater" acceptance criteria, additional information concerning the groundwater flow modeling is required for the NRC Staff's evaluation of the Application.
Please:

(C) Provide the technical basis and background for the vertical conductivity values from Reference 2.4.12-C-9 that were used for site specific groundwater flow modeling.

Response:

SSAR Reference 2.4.12-C-9 provides estimates for the anisotropy ratio of horizontal to vertical hydraulic conductivity of 3:1 in sand layers and 10:1 in clay layers. This response describes the test methods used and the resulting estimates of site-specific values of horizontal and vertical hydraulic conductivity assigned in the VCS numerical groundwater model. These site-specific values are compared to hydraulic conductivity values for the Chicot aquifer published by other investigators and are shown to agree with the published scientific literature.

The value for vertical hydraulic conductivity of the clay in model layer 1 (0.06 feet/day) is based on the results of borehole permeameter tests in layer 1 (the uppermost clay layer) from SSAR Table 2.4.12-14. The vertical hydraulic conductivity of the remaining clay layers in the model (7×10^{-5} feet/day) is based on laboratory permeability testing of undisturbed soil samples from the shallow (layers 3 and 5) and deep (layer 9) confining clay layers (SSAR Table 2.4.12-13). The horizontal hydraulic conductivity of each clay layer in the model is assumed to be ten times the vertical hydraulic conductivity (SSAR Reference 2.4.12-C-9).

The value of horizontal hydraulic conductivity of the sand in model layer 4 (68 feet/day) is based on the results of a 48-hour pumping test of this layer. Similarly, the horizontal hydraulic conductivity of the sand in model layer 8 (103 feet/day) is based on the results of a 24-hour pumping test of this layer. The horizontal hydraulic conductivity of the sands in model layers 6 and 10 is assumed to be the same as that determined by the pumping test of layer 8 because the grain size distribution of samples from layers 6, 8 and 10 are similar (SSAR Figure 2.4.12-22). The vertical hydraulic conductivity of each sand layer in the model is assumed to be one-third of the corresponding horizontal hydraulic conductivity (SSAR Reference 2.4.12-C-9).

As noted in the response to RAI 02.04.12-2A, a re-evaluation of the aquifer saturated thicknesses was performed following submission of the ESPA due to questions regarding the original thicknesses. This re-evaluation led to revision of the horizontal hydraulic conductivities of the Upper Shallow and Deep aquifers. The revised horizontal hydraulic conductivity value for the Upper Shallow aquifer ranged between approximately 8 and 39 feet per day. The revised horizontal hydraulic conductivity value for the Deep aquifer ranged between approximately 47 and 60 feet per day.

These revised values are reasonably comparable to but generally lower than those previously reported and used in the groundwater model. Both the original and revised values are within the range reported by other investigators of the Chicot aquifer (SSAR References 2.4.12-16, 2.4.12-28 and 2.4.12-29). The values presently used in the groundwater model meet the calibration criteria established for development of the groundwater model, as described in SSAR Appendix 2.4.12-C, Subsection 2.4.12-C-5. Replacing the current hydraulic conductivity values used in the model with the revised, lower values for the Upper Shallow and Deep aquifers would be expected to cause a longer travel time, due to a decrease in groundwater flow velocity. Accordingly, the original hydraulic conductivity values have been retained in the VCS model, reiterating that they are reasonably comparable to the revised values and in the range reported by other investigators. As described above, the original values are expected to be conservative relative to the revised values with respect to the modeled travel time in the Upper Shallow and Deep Aquifers. Table 1 lists the values of hydraulic conductivity used in the VCS numerical model, values of hydraulic conductivity for the Chicot aquifer from the scientific literature and the revised values of hydraulic conductivity based on re-evaluation of the saturated thicknesses of the Upper Shallow and Deep aquifers at the VCS site.

Values of Hydraulic Conductivity for the Chicot Aquifer From the Scientific Literature

Literature Citation	Clay			Sand		
	K_h (feet/day)	K_v (feet/day)	K_h/K_v	K_h (feet/day)	K_v (feet/day)	K_h/K_v
Reference 2.4.12-C-9 (Walton)	--	--	10	--	--	3
Reference 2.4.12-16 (Young et al.)	--	--	--	13 to 154	--	--
Reference 2.4.12-28 (Haug et al.)	2.8E-4 (Clay 1)	2.8E-5 (Clay 1)	10	8.5 to 11.3 (Sand 1)	0.85 to 1.13 (Sand 1)	10
	5.7 (Clay 2)	0.57 (Clay 2)	10	28.3 (Sand 2)	2.8 (Sand 2)	10
Reference 2.4.12-29 (Bravo el al.)	--	--	--	170	0.01	1[(a)]
Reference 2.4.12-30 (Cleveland et al.)	--	1.52E-3 to 2.4E-5	--	--	--	--

Values of Hydraulic Conductivity Used in the VCS Numerical Groundwater Model

Clay			Sand		
K_h (feet/day)	K_v (feet/day)	K_h/K_v	K_h (feet/day)	K_v (feet/day)	K_h/K_v
0.6 (layer 1)	0.06 (layer 1)	10	68 (layers 2 & 4)	23 (layers 2 & 4)	3
7 E-4 (layers 3,5,7&9)	7 E-5 (layers 3,5,7&9)		103 (layers 6, 8 & 10)	34 (layers 6, 8 & 10)	

Revised Values of Hydraulic Conductivity

Sand		
K_h (feet/day)	K_v (feet/day)	K_h/K_v
8 to 39 (layer 4)	--	(b)
47 to 60 (layer 8)	--	

Notes:

K_h = horizontal hydraulic conductivity

K_v = vertical hydraulic conductivity

(a) $K_h = K_v$ = 170 feet/day (in the groundwater model)

(b) K_h/K_v (layer 4) = 6.5 (Neumann Method)

K_h/K_v (layer 8) = 696 (Hantush-Jacob Method)

Table 1 Values of Hydraulic Conductivity

Associated ESPA Revisions:

Subsection 2.4.12.2.4.3 of the SSAR is revised as follows. Note that the first paragraph of the subsection was revised in response to RAI 02.04.12-2A and RAI 02.04.12-4.

2.4.12.2.4.3 Summary of Aquifer Properties

Based on the results of ~~the~~ geotechnical and hydrogeological testing the hydraulic conductivity values derived from grain size analysis, aquifer pumping tests, and slug tests at the VCS site (included in Part 5 of the ESPA) are considered to be in agreement and within the range of ~~regional~~ hydraulic conductivity values reported for the region (Reference 2.4.12-16). Results of ~~the~~ statistical analysis ~~also~~ indicate that the slug tests produce ~~have~~ the greatest range of hydraulic conductivity. Following is a summary of hydraulic conductivity ranges determined by different methods:

- Chicot Aquifer regional horizontal hydraulic conductivity values (from the technical literature): ~~11~~ 8.5 to 170 ~~98~~ feet per day
- VCS horizontal hydraulic conductivity pumping test results: 8 ~~60~~ to 60 ~~140~~ feet per day
- VCS slug test horizontal hydraulic conductivity results: 0.02 to 164 feet per day
- VCS grain size analysis horizontal hydraulic conductivity (sand): 11 to 30 feet per day
- VCS Guelph permeameter test vertical hydraulic conductivity results: less than 3 feet per day

The lower range in the slug test, grain size analysis, and the Guelph permeameter values are up to three orders of magnitude lower than the regional and VCS pumping test values. This may be due to the fact that the regional values are based on the probability of water wells being located in the most permeable sands, while the wells at VCS have ~~were of~~ short screen lengths, and are located in the more permeable material within the borehole drilled, regardless of whether or not ~~if~~ the material is suitable for water production.

As discussed in SSAR Section 2.4.12.1.4, the VCS site is underlain by unconsolidated and discontinuous interbedded layers of sand and clay of the Chicot aquifer that dip toward the Gulf of Mexico. The Chicot aquifer at the site is divided informally into the Upper Shallow, Lower Shallow, and Deep aquifers.

(End of Subsection 2.4.12.2.4.3)

SSAR Subsection 2.4.12.3.1.2 was revised in response to RAI 02.04.12-5. Note that this subsection was formerly numbered 2.4.12.3.1.1 (Groundwater Model Development), but was renumbered by the response to RAI 02.04.12-1, which inserted a new Subsection 2.4.12.3.1.1. The response to RAI 02.04.12-5 added two new subsections to SSAR Subsection 2.4.12.3.1.2. The response to RAI 02.04.12-2C adds a new subsection to SSAR Subsection 2.4.12.3.1.2. This new subsection is 2.4.12.3.1.2.3.

2.4.12.3.1.2.3 Comparison of Site Specific Hydraulic Conductivities to Published Scientific Literature

The value of vertical hydraulic conductivity of the clay in model layer 1 is based on the results of borehole permeameter tests in layer 1 (the uppermost clay layer) from Table 2.4.12-14. The vertical hydraulic conductivity of the remaining clay layers in the model is based on laboratory permeability testing of undisturbed soil samples from the shallow (layers 3 and 5) and deep (layer 9) confining layers (Table 2.4.12-13). The horizontal hydraulic conductivity of each clay layer in the model is assumed to be ten times the corresponding vertical hydraulic conductivity (Reference 2.4.12-C-9).

The value of horizontal hydraulic conductivity of the sand in model layer 4 is based on the results of a 48-hour pumping test of this layer and optimized through model calibrations. Similarly, the horizontal hydraulic conductivity of the sand in model layer 8 is based on the results of a 24-hour pumping test of this layer and adjusted during model calibration. The horizontal hydraulic conductivity of the sands in model layers 6 and 10 is assumed to be the same as that determined by the pumping test of layer 8 because the grain size distribution of samples from layers 6, 8 and 10 are similar (SSAR Figure 2.4.12-22). The vertical hydraulic conductivity of each sand layer in the model is assumed to be one-third of the corresponding horizontal hydraulic conductivity (Reference 2.4.12-C-9).

Values for the hydraulic conductivity of sand and clay layers in the VCS groundwater model were compared to values published in the scientific literature for the Chicot aquifer. Reference 2.4.12-16 provides a range of hydraulic conductivity values determined from qualifying pumping tests in the Chicot aquifer. The range of horizontal hydraulic conductivity values reported in Reference 2.4.12-16 for the Chicot aquifer varies between 13 feet/day and 154 feet/day. The values of horizontal hydraulic conductivity assigned to the "sand units" of the Chicot aquifer in the VCS groundwater model range from 68 feet/day to 103 feet/day and are within the range reported in Reference 2.4.12-16.

Reference 2.4.12-29 describes a groundwater model that simulates the hydrological conditions of the Chicot and Evangeline aquifers that underlie the Houston area. The Chicot and Evangeline are the same aquifers that extend to the VCS site. The horizontal hydraulic conductivity of the highly permeable zones of the Chicot aquifer in the Houston area is reported to be 170 feet/day (Table 2 of Reference 2.4.12-29). The vertical hydraulic conductivity of the permeable unit of the Chicot aquifer reported in Table 2 of Reference 2.4.12-29 is 0.01 feet/day. However, in the groundwater model described in Reference 2.4.12-29, both the Chicot and Evangeline aquifers are modeled as isotropic, with the horizontal and vertical hydraulic conductivities equal to 170 feet/day.

Reference 2.4.12-30 reports that the vertical hydraulic conductivity of the clay units of the Chicot aquifer in the Houston area ranges between 4.63×10^{-4} meters/day (1.52×10^{-3} feet/day) and 0.73×10^{-5} meters/day (2.4×10^{-5} feet/day). Except for Clay 1-Top (6×10^{-2} feet/day), the vertical hydraulic conductivity assigned to the clay layers in the VCS groundwater model is 7×10^{-5} feet/day. This value is within the range reported in Reference 2.4.12-30.

Reference 2.4.12-28 provides estimates of the horizontal and vertical hydraulic conductivities of the various sand and clay units of the Upper Chicot aquifer used in a groundwater model of the Port Arthur, Texas area. The vertical extent of that model is the "Sand 2" hydrostratigraphic unit of the Upper Chicot aquifer, which seems to correspond to Sand 2 in the VCS groundwater model.

Table 1 of Reference 2.4.12-28 lists a horizontal hydraulic conductivity for the surficial clay unit at the Port Arthur site of 1×10^{-9} meters/second (2.8×10^{-4} feet/day). For the "Sand 1" unit at the Port Arthur site (which seems to correspond to Sand 1 at the VCS site) the values for horizontal hydraulic conductivity range between 3×10^{-5} meters/second (8.5 feet/day) and 4×10^{-5} meters/second (11.3 feet/day). For the Middle clay unit at the Port Arthur site (which seems to correspond to Clay 2 at the VCS site) the horizontal hydraulic conductivity is listed as 2×10^{-5} meters/second (5.7 feet/day) and for the "Sand 2" unit (which seems to correspond to Sand 2 at the VCS site) the value is 1×10^{-4} meters/second (28.3 feet/day). The anisotropy ratio of horizontal to vertical hydraulic conductivity for both the sand units and the clay units at the Port Arthur site is modeled as 10:1 (Reference 2.4.12-28).

The horizontal hydraulic conductivity values reported in Reference 2.4.12-16 for the sand layers in the Chicot aquifer bound the values used in the VCS site groundwater model. The anisotropy ratio of horizontal to vertical hydraulic conductivity of 3:1 assigned to the sand layers in the VCS groundwater model falls within the reported range for the Chicot aquifer of 10:1 at the Port Arthur site (Reference 2.4.12-28) and 1:1 in the Houston area (Reference 2.4.12-29).

The anisotropy ratio of horizontal to vertical hydraulic conductivity of 10:1 used in the VCS groundwater model for the clay layers of the Chicot aquifer agrees with that reported in Reference 2.4.12-28 for the clay layers of the Chicot aquifer at the Port Arthur site. The vertical hydraulic conductivity values for the clay layers in the VCS groundwater model are nominally within the range reported in Reference 2.4.12-30 for the Chicot aquifer in the Houston area.

The values of hydraulic conductivity for the sand and clay units of the Chicot aquifer represented in the VCS groundwater model are based on the results of site-specific pumping tests, grain size analysis and laboratory permeameter tests. These values and the anisotropy ratio of horizontal to vertical hydraulic conductivity assigned in the VCS groundwater model are within the range of the values published in the scientific literature.

(End of Subsection 2.4.12.3.1.2)

The following references are being added to SSAR Subsection 2.4.12.6:

2.4.12-28 Haug, A; Petrini, R.H.; Grisak, G.E.; and Klahsen, K.. *Geostatistical Assessment of Numerically Simulated Groundwater Flow in the Upper Chicot Aquifer Near Port Arthur, Texas. ModelCARE 90: Calibration and Reliability in Groundwater Modeling* (Proceedings of the conference held in The Hague, September 1990). IAHS Publ. no. 195, 427-437, 1990

2.4.12-29 Bravo, Rolando., Rogers, Jerry R., and Cleveland, Theodore G., Modeling *Ground Water Flow Using Flux Boundary Conditions. Water Resources Bulletin.* Vol. 32, No. 1, 39-46, 1996.

2.4.12-30 Cleveland, Theodore G., Bravo, Rolando., and Rogers, Jerry R., *Storage Coefficients and Vertical Hydraulic Conductivities in Aquitards Using Extensometer and Hydrograph Data, Ground Water,* Vol. 30, No.5, 701-708, 1992.

Text similar to that added to SSAR Subsection 2.4.12.2.4.3 will be inserted into Environmental Report (ER) Subsection 2.3.1.2.2.4.3, Summary of Aquifer Properties.

Revisions to the corresponding section of the ER (Section 2.3.1.2.3.1.2) that are consistent with the SSAR revisions will be made in the next revision of the ESPA. Note that this subsection was formerly numbered 2.3.1.2.3.1.1, but was renumbered by the response to RAI 02.04.12-1, which inserted a new Subsection 2.3.1.2.3.1.1.

ER Subsection 2.3.1.2.4 will be updated to include the applicable references. The ER revisions will be made in the next update of the ESPA.

RAI 02.04.12-2D:

Question:

In accordance with the requirements of 10 CFR 100.20(c) "Factors to be considered when evaluating sites" relating to hydrology and, 10 CFR 52.79(a) "Contents of applications; technical information in final safety analysis report" relating to hydrologic characteristics of the proposed site, and as recommended by Standard Review Plan 2.4.12 "Groundwater" acceptance criteria, additional information concerning the groundwater flow modeling is required for the NRC Staff's evaluation of the Application.
Please:

(D) Provide the basis for determining elevations of drains, constant head, and river cells representing canal, river, creeks and seeps and the impact of elevation estimate errors on calibration and postulated pathways.

Response:

This response provides the technical basis for determining the elevations of drains, constant head and river cells representing the Victoria Barge Canal, rivers, creeks and seeps in the groundwater model for Victoria County Station (VCS). A qualitative analysis of the uncertainty in estimates of the elevation of the canal, rivers, creeks and seeps and its impact on postulated groundwater pathways is also provided.

Methods for determining the elevations of drains, constant head and river cells representing the Victoria Barge Canal, rivers, creeks and seeps in the calibrated groundwater model are discussed in the revisions of SSAR Subsection 2.4.12.3.1.4 beginning on page 3 of this response. A qualitative analysis of the uncertainty in estimates of the elevation of drains, constant head and river cells, and the impact on postulated pathways follows:

- Drain cells in the VCS model represent Kuy Creek, Dry Kuy Creek, other unnamed creeks and potential seepage areas that may occur on the slope at the western edge of the Guadalupe River valley when the cooling basin is full. The "DRAIN" package in the "MODFLOW" groundwater numerical model code is designed to simulate the effects of features such as agricultural drains, springs, seeps and diffuse flow such as seepage to wetlands, which remove groundwater from the aquifer at a rate proportional to the difference between the head in the aquifer and the fixed head or elevation of the drain. The drainage continues as long as the head in the aquifer is above the drain elevation, but ceases if the head falls below that level. The groundwater velocity toward the drain cells is increased when the difference between the head in the aquifer and drain elevation is greater, which results in higher hydraulic gradient and faster groundwater travel time.

  Therefore, if drain elevations in the VCS model were raised higher than the elevations in the calibrated model, less groundwater would be removed from the model domain and a lower hydraulic gradient and a longer travel time would result for groundwater flowing toward the drains. Similarly, if drain elevations were decreased lower than those in the calibrated model, more groundwater would be removed from the model domain and would result in a higher hydraulic gradient and a shorter travel time for groundwater flowing toward the drains. The elevations of the drains were determined by estimating the elevations of channel bottoms for Kuy Creek, Dry Kuy Creek, other unnamed creeks and potential seepage areas from the Bloomington, Bloomington SW, McFadden and Raisin, Texas USGS topographic maps (References 2.4.12-32, 2.4.9-14, 2.4.12-36 and 2.4.12-37, respectively). Because the contour interval of these maps is 5 feet, the error in estimating the elevations of channel bottoms of the surface water features is expected to be no greater than 5 feet.

A release of radionuclides is postulated to occur from the basement of the radwaste building within the power block area into model layer 4 (Sand 2) and flow vertically downward through relatively permeable backfill into model layer 6 (Sand 4), as shown in SSAR Figure 2.4.12-C-35. The concentration of radionuclides in the postulated release to which an off-site receptor potentially could be exposed is related to the groundwater travel time during which radioactive decay can occur. The flow path of the postulated release is toward the east and the drain cells representing unnamed creeks and seepage areas on the slope at the western edge of the Guadalupe River valley. The drain cells in this area are assigned in model layers 1 and 2, whose elevations are above the flow path of the postulated release in layer 6. While the drain cells may capture some small percentage of the postulated release in the upper part of the flow path, most of the radionuclides would flow beneath the drain cells toward the Guadalupe River. Raising or lowering the elevation of the drain cells by 5 feet (the probable error in the estimate of the drain elevation) would not likely affect the travel time or flow path of the majority of the release, which would flow beneath the drains toward the river at the same rate, irrespective of the drain elevations.

- The Victoria Barge Canal is simulated in the VCS model as river cells. It is a sea-level canal and is dredged periodically to maintain a minimum depth for commercial navigation. Accordingly, the stage and bottom elevation (0 feet NAVD88 and -12 to -15 feet NAVD88, respectively) of the canal are relatively constant and well known (SSAR Reference 2.4.12-31). The canal is east of the Guadalupe River and its stage (0 feet NAVD88) is at a lower elevation than that of the river (10 to 12 feet NAVD88 near the VCS site). The bottom elevation of most of the canal is assigned as -12 feet NAVD88, whereas the bottom elevation of the river channel near the VCS site is assigned as approximately -6 to -7 feet NAVD88. It is unlikely that raising or lowering the stage or bottom elevation of the canal (within the narrow limits prescribed by maintenance of a sea-level canal) would significantly impact the travel time or flow path of the hypothetical release.

- Elevations of the Guadalupe River channel bottom were derived from channel profiles developed from bathymetric survey data. The bottom elevation averages about 4 feet NAVD88 approximately 5 miles northeast of the power block, in the area of the proposed discharge for the cooling basin blow-down to the river. The average bottom elevation immediately downstream of the confluence of the Guadalupe and San Antonio Rivers, near the Guadalupe-Blanco River Authority salt water barrier and the proposed raw water make-up intake structure for the cooling basin is about -10 feet NAVD88. These elevations were interpolated linearly to estimate a bottom elevation of about -6 to -7 feet NAVD88 in the area of the VCS site. Because of the relatively good control provided by the bathymetric survey data, it is not likely that the uncertainty in estimating the bottom elevation of the river is more than approximately 3 feet. This amount of uncertainty is not likely to have a large impact on model calibration or postulated groundwater pathways.

USGS gage 08177520 measures the stage in the Guadalupe River near Bloomington, Texas (Reference 1). The gage is located approximately 5 miles northeast of the VCS power block. Flood stage at USGS gage 08177520 is 20 feet NGVD29 (19.59 feet NAVD88, Reference 2) and the average annual stage during the period of record (1999 through 2008) varied about 8 feet from approximately 9.5 feet to 17.5 feet NAVD88 (Reference 1). At a second gage down river near Tivoli, Texas (USGS 08188800) the average annual stage varied about 3 feet from approximately 3 to 6 feet NAVD88 during the period 2000 to 2011 (Reference 1). Interpolation of the stage between these gages provided an estimate of the average steady-state stage in the groundwater model near the VCS site of 13.5 to 5.0 feet NAVD88.

Higher river stage elevations in the model river cells (such as in the Guadalupe River) compared to the elevations used in the calibrated model would lower the hydraulic gradient between the power block area and the river. The lower gradient would result in a decrease in groundwater velocity and a longer travel time to the site boundary for a postulated release of radionuclides from the power block area. Conversely, lowering of the stage of the Guadalupe River (compared to the stage in the calibrated model) would result in a higher hydraulic gradient, faster groundwater velocity and shorter travel time to the site boundary for a postulated release from the power block area.

The variation in the average annual stage during the period of record at the two USGS gages provides a measure of the uncertainty in the average steady-state stage near the VCS site. That uncertainty is estimated to be one-half of the range in average annual stage at USGS gage 08177520, or approximately 4 feet. It is difficult to predict whether or not variation of the steady-state river stage by approximately 4 feet would significantly affect calibration of the VCS model. Groundwater travel time predicted by the calibrated VCS model along the approximately 11,000-foot flow path from the power block area to the eastern site boundary is approximately 41,000 days (110 years) (SSAR Appendix C, Subsection 2.4.12-C-6.3). The Guadalupe River is approximately 12,000 feet farther to the east, resulting in a much longer travel time from the power block area to the river. Because of the relatively long travel time from the power block area to the Guadalupe River annual variations in the average river stage on the order of 4 feet may not significantly affect postulated groundwater pathways.

- Linn Lake is represented in the groundwater model as constant head cells. No data are available to establish the average stage and depth of the lake. However, observations by on-site investigators have established that the profile of the lake is relatively flat and much of the lake bed is exposed during periods of drought, such as in 2008. As discussed in the response to RAI 02.04.12-8, because of its geomorphology, location within the floodplain and proximity to the Guadalupe River, the lake and river are assumed to be hydraulically connected and the stage of the lake is likely to trend with the stage of the river. Within the vicinity of the lake, the Guadalupe River stage is estimated to range between an elevation of approximately 5 and 15 feet NAVD88. Based on observations of Linn Lake during dry periods, the lake is relatively shallow, with an estimated lake bottom elevation of approximately 10 feet NAVD88. Therefore, a constant head of 10 feet NAVD88 was chosen to approximate the long-term, steady-state stage of the lake.

An increase of stage in Linn Lake compared to the stage in the calibrated model would decrease the groundwater gradient between the lake and the aquifer beneath the VCS site west of the lake. The higher stage in the lake would reduce the groundwater velocity and increase the modeled travel time for a postulated release of radionuclides from the power block area. Conversely, a lower stage in Linn Lake would result in an increased groundwater velocity and shorter travel time compared to the travel time in the calibrated model. However, as discussed above, the stage of Linn Lake in the model approximates the lowest stage that is physically observed at the site. Thus, the model would be expected to provide a conservative travel time. The travel time from the power block area to Linn Lake predicted by the calibrated VCS model is more than 41,000 days. Because of the relatively long travel time, variations in the average annual stage of the lake on the order of a few feet may not significantly affect postulated groundwater pathways.

Response References:

1 U.S. Department of the Interior, U.S. Geological Survey, Surface Water Data for Texas, USGS Surface-Water Annual Statistics. Available at: http://waterdata.usgs.gov/tx/nwis/annual?, accessed May 23, 2011.

2 National Vertical Datum Conversion Utility available online at: http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html, accessed July 2, 2011.

Associated ESPA Revisions:

SSAR Subsection 2.4.12.3.1.4 will be updated in a future revision to the ESPA as indicated. Note that this subsection was formerly numbered 2.4.12.3.1.3, but was renumbered by the response to RAI 02.04.12-1, which inserted a new Subsection 2.4.12.3.1.1.

2.4.12.3.1.~~3~~4 Boundary Conditions

The pre-construction model boundary conditions are discussed in Appendix 2.4.12-C and are summarized as follows.

The ~~R~~recharge boundary condition~~s~~ was assigned to the uppermost active model cells. Two zones of recharge were used for pre-construction conditions to represent areas overlain by clay or sandy deposits. ~~These values~~ The values of recharge in each zone were adjusted during calibration.

The evapotranspiration (ET) boundary condition was assigned as a single zone. 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, as further explained in Appendix 2.4.12-C.

A constant head boundary was assigned to represent Linn Lake in the model. The lake is represented by an elevation head of 10 feet.

A general head boundary was assigned along the west central and northwestern edge of the model to represent regional inflow of groundwater in the Upper Shallow aquifer (layer 4), the Lower Shallow aquifer (layer 6), and ~~in~~ the Deep aquifer (layer 8 and layer 10).

Drain boundaries were assigned in layer 1 and layer 2 along Kuy and Dry Kuy Creeks, other unnamed creeks and streams adjacent to the VCS site, and on the Guadalupe River Valley slope to the east of the proposed cooling basin to simulate seepage areas. Drain boundaries were assigned in layer 3 along Kuy Creek from its confluence with Dry Kuy Creek to its confluence with the Guadalupe River to simulate seepage ~~from layer 3~~ in this area.

River boundaries were assigned as discussed in Appendix 2.4.12-C for the Guadalupe River, San Antonio River, Coleto Creek, Black Bayou, and the Victoria Barge Canal.

The surface water elevations in the canal, rivers, creeks and seeps were determined from published literature values, U.S. Geological Survey (USGS) topographic maps, and from site observations. Three types of model boundary conditions (river, drain and constant head) were assigned to the surface water features, as shown in Table 2.4.12-C-6 in Appendix 2.4.12-C.

The elevations of the drains simulating Kuy Creek, Dry Kuy Creek, the primary unnamed creeks and the Guadalupe River Valley seeps were estimated from USGS topographic maps (Reference 2.4.12-32 and References 2.4.12-35 through 2.4.12-37) and interpretation of site stratigraphy in the area of the drainage features. The drain elevations were assigned using a Visual MODFLOW formula ($BOT + 1.0), which places the drain elevation 1 foot above the bottom of the cell that represents the creek or seep.

A river boundary condition was assigned to the Victoria Barge Canal, Guadalupe River, Coleto Creek, San Antonio River, and Black Bayou to represent the groundwater and surface water interactions. The Victoria Barge Canal was assigned a stage of 0 ft NAVD88 and a channel bottom of approximately -12 ft NAVD88 based on Reference 2.4.12-31.

The mean stage in the Guadalupe River was estimated using data from USGS stream gages 08176500, 08177520 and 08188800 at Victoria, Bloomington and Tivoli, Texas, respectively (Reference 2.4.12-34). The elevation of the Guadalupe River channel bottom was derived from channel profiles developed from bathymetric survey data. A linear gradient was assumed in order to assign river stage and bottom elevations in the numerical model. At the north end of the model domain a stage elevation of 20 ft NAVD88 and bottom elevation of 10 ft NAVD88 were estimated. At the southeast corner of the model domain a stage elevation of 5 ft NAVD88 and a bottom elevation of -10 ft NAVD88 were estimated. These bottom elevation estimates were extrapolated from bathymetric survey data for a reach of the river located between the upstream and downstream model boundaries, in conjunction with the topography at the river in these areas.

The stage of the Coleto Creek was estimated using the mean stage at the Coleto Creek Reservoir (USGS gage 08177400) and USGS gage 08177500 located on the Coleto Creek near Victoria, Texas (Reference 2.4.12-34). The stage was linearly interpolated from an estimated 72 ft NAVD88 downstream of the Coleto Creek Reservoir at the western boundary of the VCS model domain to a stage elevation of 19 ft NAVD88 at the confluence of the Coleto Creek with the Guadalupe River. The bottom elevation of the river at the western boundary of the model domain (67 ft NAVD88) was estimated based on a regional cross section developed for the model. A bottom elevation of 14 ft NAVD88 at the confluence of the creek with the Guadalupe River was estimated based on extrapolated bathymetric survey data for the Guadalupe River.

The stage of the San Antonio River was based on linear interpolation of the mean stage at USGS gage 08188570 near McFadden, Texas (Reference 2.4.12-34). A stage elevation of 62 ft NAVD88 was estimated for the San Antonio River at the western boundary of the VCS model domain. The stage elevation was estimated to be approximately 5 feet below the average ground surface elevation within the local river valley, as determined from the National Elevation Dataset and the Lott Lake USGS topographic quadrangle map (References 2.4.12-38 and 2.4.12-35, respectively). The bottom elevation at this location was estimated assuming a river depth of approximately 20 feet. These values were then linearly interpolated to a stage elevation of 5 ft NAVD88 and a bottom elevation of -10 ft NAVD88 at the confluence with the Guadalupe River.

Linn Lake was assigned a constant head of 10 ft NAVD88, based on the estimated stage of the Guadalupe River to the east of Linn Lake.

Table 2.4.12-C-6 will be revised as indicated:

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[a]	Cauchy (Type 3) – River	0 ft (sea level canal) Eastern side of model domain
Guadalupe River[b]	Cauchy (Type 3) – River	20 to 5 ft Eastern side of model domain
San Antonio River[b]	Cauchy (Type 3) – River	62 to 5 ft Western and southern side of the model domain
Coleto Creek[b]	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)

(a) Reference 2.4.12-31
(b) Reference 2.4.12-34

The following references are added to Section 2.4.12.6 of the SSAR:

2.4.12-31 Victoria Economic Development Corporation (2009) Victoria Barge Canal, available online at http://www.victoriaedc.com/content/view/46/91/ accessed November 11, 2009.

2.4.12-32 U.S. Geological Survey (1995) 7.5-Minute Topographic Quadrangle Map, Bloomington, Texas.

2.4.12-33 (added in response to RAI 02.04.12-8)

2.4.12-34 U.S. Geological Survey (2009) *USGS Surface-Water Daily Statistics for Texas*, available online at http://waterdata.usgs.gov/tx/nwis/dvstat?referred_module=sw&county_cd=48469&site_tp_cd=OC &site_tp_cd=OC-CO&site_tp_cd=ES&site_tp_cd=LK&site_tp_cd=ST&site_tp_cd=STCA&site_tp_cd=ST-DCH&site_tp_cd=STTS&format=station_list&sort_key=site_no&group_key=NONE&list_of_search_criteria=county_cd%2Csite_tp_cd%2Crealtime_parameter_selection accessed September 27, 2009.

2.4.12-35 U.S. Geological Survey (1962) 7.5-Minute Topographic Quadrangle Map, Lott Lake, Texas, photorevised 1987.

2.4.12-36 U.S. Geological Survey (1962) 7.5-Minute Topographic Quadrangle Map, McFadden, Texas, photorevised 1987.

2.4.12-37 U.S. Geological Survey (1962) 7.5-Minute Topographic Quadrangle Map, Raisin, Texas, photorevised 1987.

2.4.12-38 U.S. Geological Survey (1999) National Elevation Dataset, available on-line at http://gisdata.usgs.net/ned/ accessed October 26, 2009.

Text identical to that added to SSAR Subsection 2.4.12.3.1.4 will be inserted into re-numbered Environmental Report (ER) Subsection 2.3.1.2.3.1.4, with the following exceptions:

- References will be in the format used throughout the ER;
- The reference to Table 2.4.12-C-6 in the first paragraph of the added text will read "SSAR Appendix 2.4.12-C (Table 2.4.12-C-6)";

Re-numbered ER Subsection 2.3.1.2.3.1.4 will be updated to include the applicable references. The ER revisions will be made in the next update of the ESPA.

RAI 02.04.12-2E:

Question:

In accordance with the requirements of 10 CFR 100.20(c) “Factors to be considered when evaluating sites” relating to hydrology and, 10 CFR 52.79(a) “Contents of applications; technical information in final safety analysis report” relating to hydrologic characteristics of the proposed site, and as recommended by Standard Review Plan 2.4.12 “Groundwater” acceptance criteria, additional information concerning the groundwater flow modeling is required for the NRC Staff’s evaluation of the Application.
Please:

(E) Discuss areas where the predicted water levels are above land surface for pre-construction and post-construction particularly around the proposed cooling basin, and the impacts to calibration and simulations. Of particular concern are areas around the toe of the cooling basin where steep gradients are created by seepage and subsequent drainage by Dry Kuy Creek.

Response:

The response to RAI 02.04.12-2E includes the technical basis and background to describe those areas, particularly around the proposed cooling basin, where predicted groundwater potentiometric levels are above land surface for pre-construction and post-construction conditions and the resulting impacts to model calibration and simulations. Of particular concern are areas around the toe of the cooling basin embankment where steep gradients in the potentiometric head are created by seepage and subsequent drainage by Dry Kuy Creek.

To determine the areas of the VCS site where the predicted groundwater potentiometric levels are above the land surface, the model land surface elevations (the elevation of the top of model layer 1) were subtracted from the simulated elevations of the groundwater potentiometric heads in model layer 1. Figure 1 shows the pre-construction conditions, where the model land surface elevations were subtracted from the simulated pre-construction elevations of the groundwater potentiometric heads in model layer 1. Model cells with groundwater potentiometric head elevations above the land surface elevation are denoted as “flooded” cells. No “flooded” cells are observed near the proposed cooling basin in the pre-construction model simulation. However, as would be expected, “flooded” cells are located at the Guadalupe River in areas where the hydraulic head in the river is higher than the land surface elevation. Because no “flooded” cells occur under pre-construction conditions throughout most of the model domain, and flooding of no more than three feet occurs in cells in the Guadalupe River, there is little potential for significant impact to model calibration.

Figure 2 shows areas with the potential for “flooded” cells after filling the cooling basin to its design pool elevation of 90.5 feet NAVD88 (SSAR Subsection 2.4.1.1). The “flooded” cells were calculated in the same way as for pre-construction conditions, except that the model land surface elevation was subtracted from simulated post-construction groundwater potentiometric head elevations in model layer 1. Figure 2 shows “flooded” cells around the perimeter of the cooling basin and along the Guadalupe River. The potential depth of flooding around the perimeter of the cooling basin varies from approximately 0.07 to 18.25 feet. The model cells within the footprint of the cooling basin are flooded to a depth of 21.5 feet (the design pool elevation of 90.5 feet NAVD88 minus the elevation of the bottom of the basin, which is 69 feet NAVD88). The most pervasive flooding potential outside of the cooling basin footprint is indicated along the south-central toe of the cooling basin embankment near Dry Kuy Creek.

"Flooded" cells represent cells where the simulated hydrostatic pressure within model layer 1 causes the elevation of the groundwater potentiometric head to be above the land surface elevation. The groundwater model does not simulate an engineered design of the cooling basin embankment, including its height, width, the hydraulic conductivity of the embankment soil or design features to reduce the gradient of the potentiometric head through or beneath the embankment. As such, the simulated groundwater potentiometric levels in the vicinity of the embankment do not reflect the levels that will be achieved when the embankment is designed and constructed. The cooling basin is simulated using the MODFLOW "River Package", which simulates a design pool elevation of 90.5 feet NAVD88 in the model cells within the footprint of the basin. The effect of the water level in the cooling basin is to increase the hydrostatic pressure and potentiometric head in the model cells surrounding the embankment, creating an artesian condition in the local aquifer (Sand 1).

SSAR Subsection 2.5.5.1.6 notes that initial seepage analyses made with respect to flow through and below the embankment indicate that exit gradients in the potentiometric head at the outboard toe of the embankment approach or exceed critical values and it would be necessary to excavate a 10-foot-deep trench at the toe of the embankment and backfill it with drainage sand to reduce exit gradients to acceptable values. As indicated in the response to RAI 02.05.05-5 and the revision proposed to SSAR Subsection 2.5.5.2.3 therein, subsurface and groundwater conditions at locations beyond the outboard toe of the embankment would be defined by supplemental investigations conducted at the COL stage. These supplemental investigations would provide the means to analyze this potential occurrence in more detail.

As noted in SSAR Subsection 2.4.1.1, the natural grade surrounding the cooling basin ranges from an elevation of approximately 80 feet NAVD88 in the north near the power block to about 62 feet NAVD88 along the southern end. As shown in Figure 2, the potential for flooding appears to be greatest at the southern end of the cooling basin, particularly in the area where the embankment crosses over the channel of Dry Kuy Creek. The creek is incised into the local topography and the bottom of its channel is at an elevation of approximately 54 feet NAVD88, whereas the land surface elevation adjacent to the creek is approximately 62 feet NAVD88. Therefore, the difference in elevation between the design water surface in the cooling basin (90.5 feet NAVD88) and the land surface surrounding the basin embankment (and the potential for flooding) is greatest within the channel of Dry Kuy Creek.

The cells in model layer 1 in the Dry Kuy Creek channel are assigned as drains using the MODFLOW "Drain Package". Drain cells remove groundwater from the aquifer at a rate proportional to the difference between the head in the aquifer and the fixed head or elevation of the drain. Removal of excess groundwater at the drain cells of Dry Kuy Creek results in relatively steep gradients of the potentiometric head along the toe of the cooling basin embankment near the creek. These steep gradients cause the potential for flooding adjacent to the drain cells.

The dimensions of the model cells in the area where the most pervasive flooding potential occurs are 500 by 500 feet. Because the size of the cells is relatively large, some cell boundaries extend beyond the creek channel and artificially increase the extent of the deepest predicted flooding potential. Similarly, in other parts of the basin embankment the model cell boundaries extend beyond the embankment and the extent of flooding potential shown on Figure 2 is amplified. Flooding potential is shown along the eastern, western, and northern perimeters of the cooling basin; however, the difference between the design water surface elevation in the cooling basin and the land surface elevation in these areas is generally less than it is on the southern perimeter and the resulting potentiometric head and flooding potential is generally less. Figure 2 shows that no flooding potential occurs in the power block area and most of the flooding potential occurs within one cell of the cooling basin embankment. Because the impact is mostly restricted to the periphery of the cooling basin and the vicinity of Dry Kuy Creek, based on engineering judgment it is likely that there is no impact to the simulations in other parts of the model domain.

Associated ESPA Revisions:

No ESPA revision is required as a result of this response.

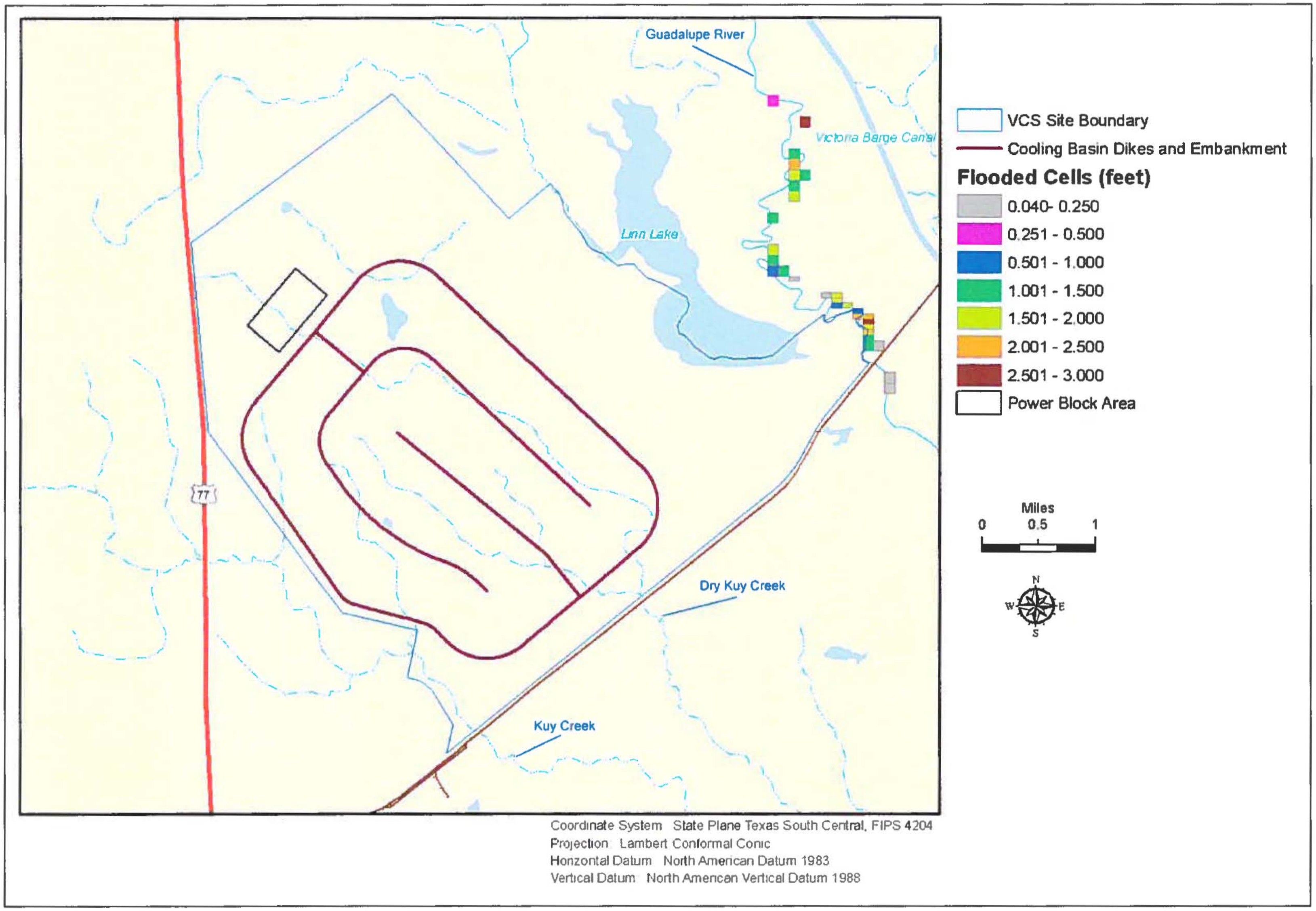


Figure 1: Location of Cells With the Potential for Flooding Under Pre-construction Conditions

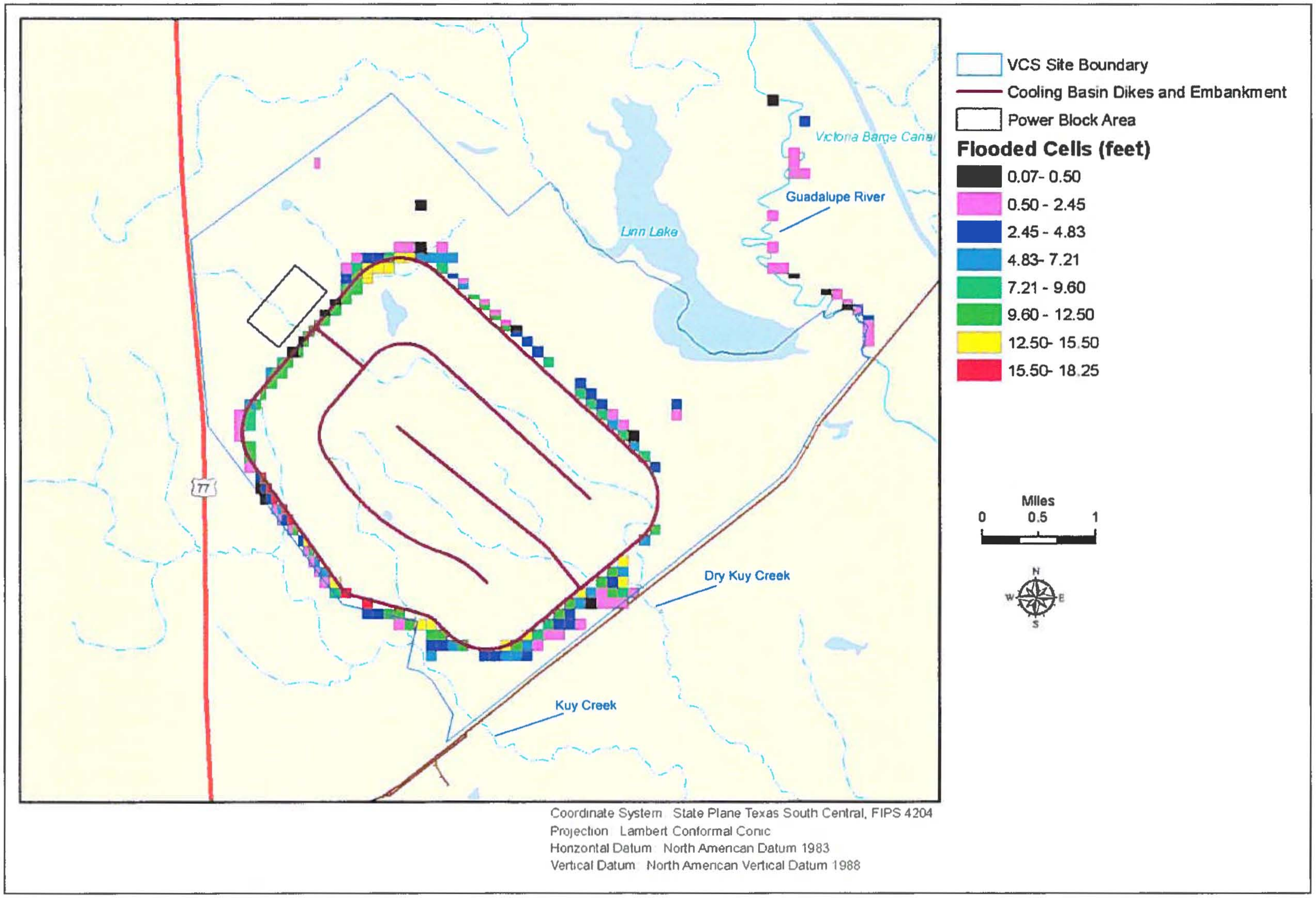


Figure 2: Location of Cells With the Potential for Flooding After Filling the Cooling Basin to its Design Pool Elevation of 90.5 feet NAVD88

RAI 02.04.12-2F:

Question:

In accordance with the requirements of 10 CFR 100.20(c) "Factors to be considered when evaluating sites" relating to hydrology and, 10 CFR 52.79(a) "Contents of applications; technical information in final safety analysis report" relating to hydrologic characteristics of the proposed site, and as recommended by Standard Review Plan 2.4.12 "Groundwater" acceptance criteria, additional information concerning the groundwater flow modeling is required for the NRC Staff's evaluation of the Application.
Please:

(F) Discuss the hydraulic conductivity zones used for model layer 1, cooling basin leakage, the bottom of the cooling basin with respect to differences in the hydraulic properties of various hydrogeologic units, and the basin sensitivity simulations.

Response:

Model layer 1 (Clay 1-Top) is comprised predominantly of clay of high to low plasticity and some sandy clay (SSAR Subsection 2.5.4). Layer 1 was assigned a vertical hydraulic conductivity of 0.06 feet/day in the VCS numerical groundwater model (SSAR Table 2.4.12-C-4). This value was derived from the maximum value measured by borehole permeameter tests in clayey soil (0.068 feet/day), which was adjusted during calibration of the model (SSAR Table 2.4.12-14). Model layer 2 (Sand 1) is comprised predominantly of clayey sand (SSAR Subsection 2.5.4). Layer 2 was initially assigned a vertical hydraulic conductivity of 2.75 feet/day in the VCS groundwater model (SSAR Table 2.4.12-C-4), which was based on the maximum value measured by borehole permeameter tests in sandy soil. During model calibration this value was adjusted to 23 feet/day (SSAR Table 2.4.12-14).

Both Clay 1-Top and Sand 1 are exposed at ground surface in different areas of the cooling basin under pre-construction conditions. Figure 2.4.12-C-4 shows the pre-construction model domain to be divided into two recharge zones assigned to the uppermost active model layer. The two recharge zones were assigned to reflect the different hydraulic conductivities of Clay 1-Top and Sand 1, both of which outcrop within the footprint of the basin. Clay 1-Top comprises the surface layer over most of the basin footprint. A recharge rate of 0.0 inches/year (SSAR Figure 2.4.12-C-4) and a vertical hydraulic conductivity of 0.06 feet/day were assigned in this area. In the remaining area of the cooling basin, where the model cells are shaded blue, Sand 1 comprises the surface layer. A recharge rate of 0.4 inches/year (SSAR Figure 2.4.12-C-4) and a vertical hydraulic conductivity of 23 feet/day were assigned in this area.

The natural ground surface elevation within the footprint of the cooling basin ranges from 80 feet NAVD88 in the northwest corner to approximately 63 feet NAVD88 in the southeast corner (SSAR Reference 2.5.4-2). When construction is complete, the bottom of the basin will be graded to an elevation of 69 feet NAVD88 in the northern portion and the remaining basin area toward the south will follow the natural grade (SSAR Subsection 2.4.8.1). Grading of the cooling basin footprint will remove the entire thickness of Clay 1-Top in some areas in the north and expose more of Sand 1 relative to pre-construction conditions. Figure 2.5.5-1 shows the subsurface stratigraphy at elevation 69 feet NAVD88 (the bottom of the cooling basin) and the approximate area where Sand 1 will be exposed when excavation of the cooling basin is complete.

Seepage through the bottom of the cooling basin was simulated in the VCS groundwater model by assigning a "river boundary" condition in each cell within the footprint of the basin. Recharge within the entire footprint was reduced to 0.0 inches/year. Definition of the river boundary in each cell requires specification of the river stage and the riverbed conductance. The conductance is the product of the surface area of the cell and the vertical hydraulic conductivity of the riverbed, divided by the riverbed thickness (SSAR Reference 2.4.12-C-1). The river stage within each boundary cell was assigned an elevation of 90.5 feet NAVD88, which is the design pool elevation under normal operating conditions (SSAR subsection 2.4.8.1). The riverbed in each cell was assigned a bottom elevation of 69 feet NAVD88, with an overlying 2-foot thick layer of sediment whose vertical hydraulic conductivity was estimated to be 34 feet/day. Under these conditions ("base case") the model predicts a seepage rate from the cooling basin of approximately 3,930 gallons per minute (gpm).

A sensitivity analysis of the cooling basin seepage simulation was conducted to evaluate the effects of uncertainty in two input parameters: the conductance of the river boundary and the vertical hydraulic conductivity of Clay 1-Top, which forms the bottom of the majority of the cooling basin. Because the surface area of the model cells is fixed by the model design, the uncertainties associated with the river boundary are the thickness and vertical hydraulic conductivity of the sediment forming the riverbed. Two feet is the probable upper bound of the sediment thickness because its source is limited primarily to re-deposited sediment mobilized from within the cooling basin and make-up water to the basin. The assumed vertical hydraulic conductivity of 34 feet/day in the base case corresponds to sediment consisting of well-sorted sand (SSAR Reference 2.4.12-15). However, the riverbed sediment may be comprised of silty sand whose vertical hydraulic conductivity would be in the range of 3.4 feet/day. Using this lower value of vertical hydraulic conductivity the model predicts a seepage rate from the cooling basin of approximately 3,360 gpm, or approximately 14.5 percent (570 gpm) less than the rate when a vertical hydraulic conductivity one order of magnitude higher is assumed. This finding indicates that seepage through the cooling basin is sensitive to lowering of the vertical hydraulic conductivity of the riverbed sediment. By lowering the vertical hydraulic conductivity of the sediment by one order of magnitude the resultant seepage is approximately 14.5% lower than that of the base-case scenario.

As described in the response to RAI 02.04.12-2A, the value selected for the vertical hydraulic conductivity of Clay 1-Top (0.06 feet/day) is based on the maximum value measured by borehole permeameter testing of this layer at the VCS site (0.068 feet/day), adjusted during model calibration. This value provides a higher rate of seepage from the cooling basin than any other permeameter test result and is higher than the values reported in SSAR Reference 2.4.12-C-17 for the vertical hydraulic conductivity of the clay units in the Chicot aquifer. A simulation was performed to evaluate the effect of uncertainty in the value of this parameter using a vertical hydraulic conductivity for Clay 1-Top of 0.6 feet/day. The resulting seepage rate using this higher value of vertical hydraulic conductivity is 4,010 gpm, or approximately 2 percent (80 gpm) more than the rate when the vertical hydraulic conductivity of Clay 1-Top is assumed to be one order of magnitude lower. This finding indicates that the simulated seepage rate is relatively insensitive to an increase in the vertical hydraulic conductivity of Clay 1-Top to a value greater than that used in the calibrated model.

Associated ESPA Revisions:

The last paragraph in SSAR Subsection 2.4.12.3.2.1 is revised as follows.

Appendix 2.4.12-C presents the results of the sensitivity analysis by comparing the base case seepage rate described above with two sensitivity cases. Sensitivity case 1 appears to be sensitive to a change in the vertical hydraulic conductivity of sediment on the bottom of the cooling basin. An order of magnitude reduction in the vertical hydraulic conductivity of the sediment results in an approximately 14.5 percent reduction in the seepage rate from the cooling basin. Sensitivity case 2 appears to be insensitive to a change in the vertical hydraulic conductivity of the surficial clay layer. An order of magnitude increase in the vertical hydraulic conductivity of the clay results in only an approximately 2 percent increase in seepage from the cooling base. ~~Both cases appear to be relatively insensitive, 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 an upper bound for the hydraulic conductivity in the clay.

The last paragraph of Subsection 2.4.12-C-6.1 of SSAR Appendix C is revised as follows.

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. Sensitivity case 1 appears to be sensitive to a change in the vertical hydraulic conductivity of sediment on the bottom of the cooling basin. An order of magnitude reduction in the vertical hydraulic conductivity of the sediment results in an approximately 14.5 percent reduction in the seepage rate from the cooling basin. Sensitivity case 2 appears to be insensitive to a change in the vertical hydraulic conductivity of the surficial clay layer. An order of magnitude increase in the vertical hydraulic conductivity of the clay results in only an approximately 2 percent increase in seepage from the cooling basin. ~~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.

(End of SSAR Subsection 2.4.12-C-6.1)

Text similar to that added to SSAR Subsections 2.4.12.3.2.1 and 2.4.12-C-6.1 will be inserted into Environmental Report (ER) Subsection 2.3.1.2.3.2.1, Cooling Basin Seepage. Revisions to ER Subsection 2.3.1.2.3.2.1 that are consistent with the SSAR revisions will be made in the next revision of the ESPA.

RAI 02.04.13-1:

Question:

In accordance with 10 CFR 100.20(c), 10 CFR 20 Appendix B, Table 2, Column 2, 10 CFR 52.79(a) requirements and criteria of SRP 2.4.12 and SRP 2.4.13, the NRC staff request that the applicant discuss the development of the groundwater transport model, parameters and the associated conservatism incorporated into the parameters and simulations.

Response:

The analysis of radionuclide transport in groundwater at the Victoria County Station (VCS) site relies on simulations of groundwater flow provided by the numerical groundwater model developed for the site. The following subsections and appendices of the SSAR and RAIs dated April 19, 2011 discuss the groundwater model.

- SSAR Subsection 2.4.12.3
- SSAR Appendix 2.4.12-C
- SSAR Subsection 2.4.13
- RAI 02.04.12-1
- RAI 02.04.12-2A
- RAI 02.04.12-2B
- RAI 02.04.12-2C
- RAI 02.04.12-2D
- RAI 02.04.12-2E
- RAI 02.04.12-2F
- RAI 02.04.12-6
- RAI 02.04.12-8
- RAI 02.04.13-2

The numerical model is based upon a conceptual model of the site and surrounding area. The conceptual model is the overall qualitative understanding of how the local and regional topography, climate, geomorphology, stratigraphy, groundwater use patterns, hydrology and boundary conditions affect groundwater flow in the aquifer.

The topography of the VCS site was established using the U.S. Geological Survey 1999 National Elevation Dataset. This dataset references surface elevations to the NAVD88 vertical datum. Climatic parameters of average rainfall and evapotranspiration were determined from records of the Victoria County Groundwater Conservation District (SSAR Reference 2.4.12-2) and the Texas A & M University System Texas ET Network. The regional stratigraphy and geomorphology were established from publications of the Texas Water Development Board, TWDB, (SSAR References 2.4.12-4, 2.4.12-8, 2.4.12-14 and 2.4.12-16); the Texas Department of Water Resources (SSAR Reference 2.4.12-5); and the U.S. Geological Survey (SSAR Reference 2.4.12-3).

The stratigraphy at the VCS site was determined by drilling and testing more than 200 geotechnical soil borings, geologic/geophysical soil borings, monitoring wells and cone penetrometer tests in the Chicot aquifer. The results of these tests are included in Part 5 of the ESP application. The hydraulic conductivity of the sand and clay units beneath the site were estimated based on the results of on-site pumping tests, slug tests, in-situ permeameter tests, laboratory permeameter tests of undisturbed soil samples, soil grain-size analyses and review of the literature related to the Chicot aquifer (SSAR Subsections 2.4.12.1.4 and 2.4.12.2.4). Groundwater use patterns were established with information available from the U.S. Environmental Protection Agency (SSAR Reference 2.4.12-9) and TWDB (SSAR References 2.4.12-10, 2.4.12-11 and 2.4.12-12). Hydrology and boundary conditions were determined from publications of the Texas Department of Water Resources (SSAR Reference 2.4.12-5) and the TWDB (SSAR References 2.4.12-8, 2.4.12-14 and 2.4.12-16).

The conceptual model of the VCS site subdivides the upper Chicot aquifer into a total of 11 interbedded sand and clay layers (SSAR Appendix C, Subsection 2.4.12-C-3.3) based on the results of the VCS subsurface investigation, included in Part 5 of the ESP application. Similar subdivision of the upper Chicot aquifer into a series of interbedded sand and clay layers was done for a site-specific groundwater model in Port Arthur, Texas (SSAR Reference 2.4.12-28, RAI 02.04.12-1). The geotechnical boring logs and groundwater levels (measured in a total of 64 observation and test wells at the VCS site during 2008 and 2009) suggest that the upper Chicot aquifer can be subdivided into the Upper Shallow, Lower Shallow, and Deep aquifer zones. The groundwater level data were used to develop potentiometric surface maps (SSAR Figure 2.4.12-15, Sheets 1 through 21) that indicate the groundwater flow direction in each of the three aquifer zones is generally to the east toward the Guadalupe River.

Groundwater flow paths associated with an accidental release of liquid effluent from a liquid waste management system (LWMS) tank were evaluated by conducting particle tracking analyses using the VCS numerical groundwater model with post-construction conditions (SSAR Subsection 2.4.13). These conditions include raising the grade in the area of the power block by approximately 15 feet and constructing an approximately 4,900-acre cooling basin south of the power block area (SSAR Subsection 2.4.12). Impoundment of surface water in the cooling basin induces seepage that will alter shallow groundwater flow patterns in the site area.

Alternative groundwater pathways were simulated for a variety of scenarios by assuming release of particles to the engineered fill surrounding the building in the power block where the LWMS tank from which the release is postulated is located. As presented in SSAR Appendix C, Subsection 2.4.12-C-6.3, all of the scenarios considered indicate an accidental release of radioactive liquid effluent would result in vertically-downward transport through the engineered backfill until it enters the Lower Shallow aquifer. From there transport along an approximately 14,000-foot flow path would occur horizontally through the Lower Shallow aquifer to the eastern boundary of the VCS site, with a groundwater travel time of approximately 41,000 days. Groundwater travel time is determined by dividing the flow-path distance by the groundwater seepage velocity (SSAR Reference 2.4.12-15).

$t = D/v_s$

where: t = groundwater travel time (days)
D = groundwater flow path distance (feet)
v_s = groundwater seepage velocity (feet/day)

Calculation of the seepage velocity is also provided in SSAR Reference 2.4.12-15:

$v_s = Ki/\eta_e$

where: v_s = groundwater seepage velocity (feet/day)
K = hydraulic conductivity (feet/day)
i = hydraulic gradient (dimensionless)
η_e = effective porosity (dimensionless)

Therefore: $t = D\eta_e/Ki$ (Equation 1)

One postulated transport scenario includes a water well located at the boundary of the VCS site, east of the power block area. As shown in SSAR Figure 2.4.13-1, the particle tracking analysis for this scenario indicates the released particles would not be captured by the pumping water well. However, to account for uncertainty regarding the flow path and the radius of influence of the pumping water well and to provide an added measure of conservatism, it is assumed that the water well at this location would capture an accidental release of liquid effluent. With this assumption, the flow path distance would be decreased to approximately 10,500 feet and the associated travel time would be decreased to approximately 32,000 days (SSAR Subsection 2.4.13.2).

Based upon the postulated transport scenario, an analysis was conducted (SSAR Subsection 2.4.13) to predict radionuclide concentrations that might be encountered in the nearest source of potable water, located in an unrestricted area (i.e., the hypothetical water well noted above). The analysis accounts for the parent radionuclides postulated to be released from the LWMS tank, plus progeny radionuclides that would be generated subsequently during transport. The resulting radionuclide concentrations were compared to their effluent concentration limits (ECLs) identified in 10 CFR 20, Appendix B, Table 2, Column 2, to determine their acceptability.

The transport analysis was conducted in three stages. First, a screening analysis was completed considering only advection and radioactive decay to eliminate radionuclides that would decay to concentrations less than one percent of their ECLs during an approximately 32,000-day travel time along the approximately 10,500-foot flow path from the source of the release to the receptor. All but eight of the radionuclides in the source term (parent and progeny) were eliminated in this screening. The remaining radionuclides are listed in SSAR Table 2.4.13-3.

Next a screening analysis that included the effects of retardation by adsorption of radionuclides to the aquifer matrix, in addition to advection and radioactive decay, was completed to estimate the concentrations at the receptor of the remaining eight radionuclides. The receptor is assumed to be located at the closest down-gradient boundary of the VCS site within the groundwater flow path. The distribution coefficients (K_d) for these radionuclides were obtained by laboratory testing of 20 soil samples from the VCS site to determine site-specific K_d values (SSAR Table 2.4.13-4).

For each radionuclide, the lowest K_d value measured in the soil samples from the Lower Shallow aquifer was used in the transport analysis. No data are available for yittrium-90. The K_d value for strontium-90 was assigned to yittrium-90 because as a daughter product of strontium-90 the chemical characteristics of the two radionuclides are expected to be similar. K_d values of zero were assigned to tritium and iodine-129 because these radionuclides are not expected to adsorb significantly to the aquifer matrix.

When including the effect of retardation in the transport analysis, only tritium and iodine-129 concentrations exceed one percent of their ECLs (as indicated in SSAR Table 2.4.13-3). The tritium concentration exceeds its ECL by a factor of 7.3, and its impact is evaluated in a third stage of the transport analysis. Iodine-129 is not evaluated further because its concentration is only approximately 4 percent of its ECL.

The third stage of the transport analysis accounts for longitudinal and transverse dispersion in groundwater, in addition to advection, radioactive decay and retardation. This analysis results in an estimated tritium concentration at the receptor that is two percent of its ECL. Therefore, the "sum of fractions" (comprised of the sum of the ratios of each radionuclide concentration to its ECL) for tritium (0.02) and iodine-129 (0.04) is approximately 0.06. All other radionuclides in the source term and their progeny do not significantly contribute to the dose at the receptor. Because the sum of fractions is less than one, compliance with the requirements of 10 CFR 20 at the nearest potential potable water supply in an unrestricted area is achieved, with a wide margin for uncertainty.

The following summarizes sources of conservatism in the groundwater transport analysis:

- The bounding concentration of each radionuclide in the liquid radioactive effluent postulated to be released to groundwater is the maximum concentration produced by any of five reactor types being considered for use at the VCS site (SSAR Subsection 2.4.13).

- The LWMS tank with the largest total inventory of radionuclides (concentration times volume) is assumed to be the source of liquid radioactive effluent postulated to be released to groundwater. The largest LWMS tank is that used by the "mPower" reactor technology (500,000 gallons). This tank is larger than the largest LWMS tank for any of the other 5 reactor types by a factor of about 4 (120,000 gallons for the APWR reactor technology). However, because the concentrations of radionuclides produced by the mPower reactor technology are less than the bounding concentrations by a factor of at least 20 (SSAR Tables 2.4.13-1 and 2.4.13-2) the total inventory of radionuclides in the mPower tank is approximately one-fifth of the total inventory in the largest LWMS tank of the other five reactor types filled with the bounding radionuclide concentrations.

  A transport analysis that assumes the mPower LWMS tank would be filled with the bounding concentrations of radionuclides would not be plausible because these concentrations would not be produced by the mPower reactor technology. Therefore, use of the volume of the LWMS tank for the APWR reactor technology provides the most plausible and conservative transport analysis that would result in the most adverse contamination of groundwater or surface water via the groundwater pathway.

- Eighty percent (96,000 gallons) of the volume of the largest LWMS tank for the five reactor types considered is assumed to be released instantaneously and directly to groundwater (SSAR Reference 2.4.13-8). The postulated mechanism of release, the volume of liquid released and the associated radionuclide concentrations were selected to produce an accident scenario that would result in the most adverse contamination of groundwater, or surface water via the groundwater pathway (SSAR Subsection 2.4.13.3.2).

- The transport analysis neglects the ability of secondary containment features associated with the postulated failed LWMS tank to delay, disperse or dilute the flow of released liquid radioactive effluent (SSAR Subsection 2.4.13.1).

- Exposure to the postulated release of liquid radioactive effluent is assumed to occur at the "receptor", which is located at the closest down-gradient boundary of the VCS site within the groundwater flow path. This location was determined by the particle tracking analysis to be approximately 14,000 feet along the groundwater flow path from the LWMS tank that is postulated to fail (SSAR Appendix C, Table 2.4.12-C-11). As shown in SSAR Figure 2.4.13-1, the particle tracking analysis for the scenario that includes a pumping water well near this location indicates the released particles would not be captured by the pumping water well.

  Nevertheless, to allow for uncertainty in the groundwater flow path and the radius of influence of a hypothetical pumping water well near the receptor, the distance to the receptor was shortened from approximately 14,000 feet to approximately 10,500 feet and the corresponding travel time was shortened from approximately 41,000 days to approximately 32,000 days (SSAR Subsection 2.4.13.2). This shortened distance and travel time results in less radioactive decay within the flow path and provides a measure of conservatism in the transport analysis.

- Aquifer thickness is an input parameter in the analysis used to estimate the effect of dispersion during groundwater transport (SSAR Subsection 2.4.13.3.2). The solution of the advection-dispersion equation used in the analysis (SSAR Reference 2.4.13-7) assumes that the postulated release instantaneously and uniformly fills the entire saturated thickness of the aquifer over a specified width. As shown in SSAR Equations 2.4.13-7 and 2.4.13-10, there is an inverse relationship between aquifer thickness and effluent concentration. Therefore, a smaller aquifer thickness would result in a higher effluent concentration. A thickness of 10 feet was assumed for the Lower Shallow aquifer in the area of the flow path of the postulated effluent release. The average thickness of this aquifer in the area of the flow path is approximately 24 feet and 10 feet is approximately the minimum thickness in this area. Therefore, use of an aquifer thickness of 10 feet provides a measure of conservatism in the transport analysis.

- Distribution coefficients (K_d) were used to calculate a retardation factor (R) to estimate the effect of retardation within the flow path by adsorption of radionuclides to the aquifer matrix. The retardation factor is calculated using SSAR equation 2.4.13-6:

  $$R = 1 + (\rho_b K_d)/\eta_e$$

  where:
  R = retardation factor (dimensionless)
  ρ_b = dry bulk density (g/cm^3)
  K_d = distribution coefficient (cm^3/g)
  η_e = effective porosity (dimensionless)

Distribution coefficients for radionuclides of interest were determined by laboratory analysis of soil samples from the Lower Shallow aquifer at the VCS site. The Lower Shallow aquifer is the unit through which virtually all of the transport of the postulated release of radioactive effluents occurs (SSAR Subsection 2.4.13.2). The minimum K_d for each radionuclide was used in the transport analysis (SSAR Subsection 2.4.13.3.1). Because there is a direct relationship between the distribution coefficient and retardation factor, use of the minimum K_d produces a relatively low retardation factor and provides a measure of conservatism in the transport analysis.

- A dry bulk density (unit weight) of 96.9 pounds per cubic foot (1.55 g/cm^3) was specified to calculate the retardation factor for the transport analysis. This value is the minimum measured by laboratory analysis of 14 soil samples from the Lower Shallow aquifer at the VCS site (SSAR Table 2.4.12-10). The measured values range from 96.9 pcf to 125.6 pcf, with a geometric mean of 107.2 pcf. Use of the minimum value in the range provides a measure of conservatism in the transport analysis.

- The effective porosity of the soil in the Lower Shallow aquifer was also used to calculate the retardation factor for the transport analysis. The effective porosity of rocks and sediment is assumed to be equal to their specific yield based on SSAR Reference 2.4.12-C-9. Accordingly, based on SSAR Figure 2.4.12-21 and a median grain size of 0.1 millimeters for its fine-grained sand, the effective porosity of the Lower Shallow aquifer is estimated to be approximately 29 percent. This value is approximately 80 percent of the average of the total porosity (36.5 percent) determined by laboratory analysis of soil samples from the Lower Shallow aquifer at the VCS site (SSAR Table 2.4.12-10).

  Different values for the effective porosity of fine-grained sediments have been estimated by other investigators. SSAR Reference 2.4.12-15 describes a study that found that the "effective pore fraction" (the ratio of effective porosity to total porosity – $\eta_{effective}/\eta_{total}$) is a function of the size of the fluid molecules flowing through a sediment relative to the size of the openings between pores of the sediment. The study found that when water tagged with tritium flowed through lacustrine clay in a permeameter, the effective pore fraction was essentially 1.0. Results of the study suggest that for sediments the effective pore fraction for water molecules should be 1.0. These results are relevant to the transport analysis at the VCS site, where the materials of the aquifer units are fine sand to clayey sand and where tritium was shown to be transported most readily of all the radionuclides in the postulated release of liquid radioactive effluent (SSAR Table 2.4.13-3, column 15). Based on the study findings, the effective porosity of the Lower Shallow aquifer at the VCS site may be closer to 36.5 percent than the 29 percent assumed.

  Another study by the U.S. Geological Survey is provided in Reference 1. This study was conducted to estimate the rate of groundwater recharge to the Chicot and Evangeline aquifers in the Houston, Texas area. The study used measurements of environmental tritium concentrations below the water table and an estimate of the effective porosity of the aquifer soil to estimate the average rate of groundwater recharge. Following is an excerpt from Reference 1 that describes the authors' estimate of effective porosity:

"Determining effective porosity, the amount of interconnected pore space available for fluid transmission (Lohman and others, 1972, p. 10), is problematic. In coarse homogeneous sediments, effective porosity can equal total porosity. However, in heterogeneous sediments of gravel, sand, silt, and clay (as in outcrops of the Chicot and Evangeline aquifers), effective porosity is less than total porosity because not all of the total porosity is available for fluid transmission. These sediments typically contain void spaces isolated from the interconnected void spaces that transmit fluid; and fluid passageways blocked by adhesive films around materials of small particle size (Daly, 1982, p. 24). Methods for determining effective porosity from laboratory core analysis are available (American Petroleum Institute, 1960, in Wolff, 1982, p. 4; Daniels and others, 1989, in Daniels and others, 1991, p. 27); core sampling and analysis, however, were beyond the scope of work in this study. Accordingly, an appropriate effective porosity to use in the computation of recharge rate in the Chicot and Evangeline outcrop area was determined from hydrogeologic literature and judgment based on knowledge of the lithologic characteristics of the outcrops.

Knott and Olimpio (1986), in a somewhat similar application of equation 7 to compute recharge rates at two sites in a "relatively homogeneous" sand and gravel aquifer using environmental tritium, assumed that effective porosity is the same as total porosity. Total porosities of 36 and 34 percent were determined from laboratory analyses and used in their recharge-rate computations.

Based on numerous laboratory analyses, Morris and Johnson (1967, tables 5, 6) report mean total porosities for gravel, sand, silt, and clay of 31, 34, 46, and 48 percent, respectively. Other compilers of large numbers of total porosities of unconsolidated sedimentary deposits (Manger, 1963, table 4; Wolff, 1982, table 4.2.1) report values of generally similar magnitudes. Thus a reasonable assumption is that total porosity in the outcrops of the Chicot and Evangeline aquifers probably is in the 30- to 50-percent range. Although materials of small particle size typically have larger total porosities than materials of large particle size, materials of small particle size have proportionately less interconnected pore space and, consequently, smaller effective porosities than materials of large particle size (Daly, 1982, p. 25). The degree to which effective porosity differs from total porosity in the Chicot and Evangeline aquifers is controlled primarily by the fraction of aquifer sediments consisting of fine-grained sand, silt, and clay particles. In turn, the spatial distribution of these sediments controls the direction and rate of recharge to the aquifers. These lithologic characteristics, and the particle size and distribution of sediments in the Chicot and Evangeline aquifers, are direct results of the depositional episodes noted previously.

The authors infer from the information available and from consultation with other scientists familiar with the hydrogeology of the study area (E.T. Baker, U.S. Geological Survey, oral commun., 1995; D.J. Nyman, U.S. Geological Survey (retired), oral commun., 1995; J.M. Sharp, Jr., Department of Geology, University of Texas, oral commun., 1995; L.E. Garner, Bureau of Economic Geology, University of Texas, oral commun., 1995) that effective porosity in the outcrop area of the Chicot and Evangeline aquifers likely *ranges from about 20 to 25 percent. Accordingly, an effective porosity in the middle of that range (23 percent) is used in the recharge-rate computation."*

The value for effective porosity estimated by the authors of Reference 1 (23 percent) appears to be based primarily on engineering judgment. The value for effective porosity estimated in the study cited in SSAR Reference 2.4.12-15 (equal to total porosity based on an effective pore fraction of 1.0 for fine-grained soil when water is the transmitted fluid) is based on empirical data. The estimated value for effective porosity used in the VCS transport analysis (29 percent) is based on the empirical data provided in SSAR Figure 2.4.12-21, measured site-specific values of total porosity and an estimate of 0.8 for the effective pore fraction of the fine-grained sand in the Lower Shallow aquifer, as discussed in SSAR Subsection 2.4.12.2.4.2. On this basis, the effective porosity value used in the VCS transport analysis is reasonable and conservative.

An effective porosity of 29 percent was used for the particle tracking simulation and effluent transport analysis. Although an estimate of effective porosity lower than 29 percent would result in a faster travel time (Equation 1) and correspondingly less radioactive decay, it would also result in more retardation (SSAR Equation 2.4.13-6). Considering that these mechanisms tend to counteract, the cumulative conservatism described herein for the radionuclide transport analysis and the wide margin with which compliance with the requirements of 10 CFR 20 is achieved when assuming an effective porosity of 29 percent, it is likely that compliance would also be achieved with a lower estimate of effective porosity in the range of 20 to 25 percent, as suggested in Reference 1.

- As discussed in the response to RAI 02.04.12-2A and the proposed revision to Table 2.4.12-9 therein, the hydraulic conductivity of Sand 2 (Upper Shallow aquifer) has been revised from 60 to 8 feet/day and that of Sand 5 (Deep aquifer) from 103 to 47 feet/day. Based on similar grain size analyses (SSAR Figure 2.4.12-22) the hydraulic conductivities of Sand 4, Sand 5 and Sand 6 are assumed to be equal. Virtually all transport of the postulated release of liquid radioactive effluent occurs through Sand 4 (SSAR Figure 2.4.12-C-35). The hydraulic conductivity of Sand 4 assumed in the transport analysis is the original value of 103 feet/day. Because the revised value of hydraulic conductivity (47 feet/day) is lower, it would result in slower seepage velocity, longer travel time and more opportunity for radioactive decay relative to the original value. Therefore, the value of hydraulic conductivity used in the transport analysis provides a conservative analysis.

Response References:

1. Noble, J.E., P.W. Bush, M.C. Kasmarek, and D.L. Barbie, Estimated Depth to the Water Table and Estimated Rate of Recharge in Outcrops of the Chicot and Evangeline Aquifers Near Houston, Texas, U.S. Geological Survey Water-Resources Investigations Report 96-4018, 1996.

Associated ESPA Revisions:

The last sentence of SSAR Subsection 2.4.13.2 is revised as follows:

In this case, the travel time and pathline distance would be approximately 32,000 days and 10,500 feet, respectively~~, both of which are more conservative than predicted~~. This travel time and flow path distance are shorter and more conservative than the 41,000 days and 14,000 feet, respectively, predicted in the absence of a hypothetical pumping water well that intercepts the postulated liquid effluent at the property boundary east of the power block area.

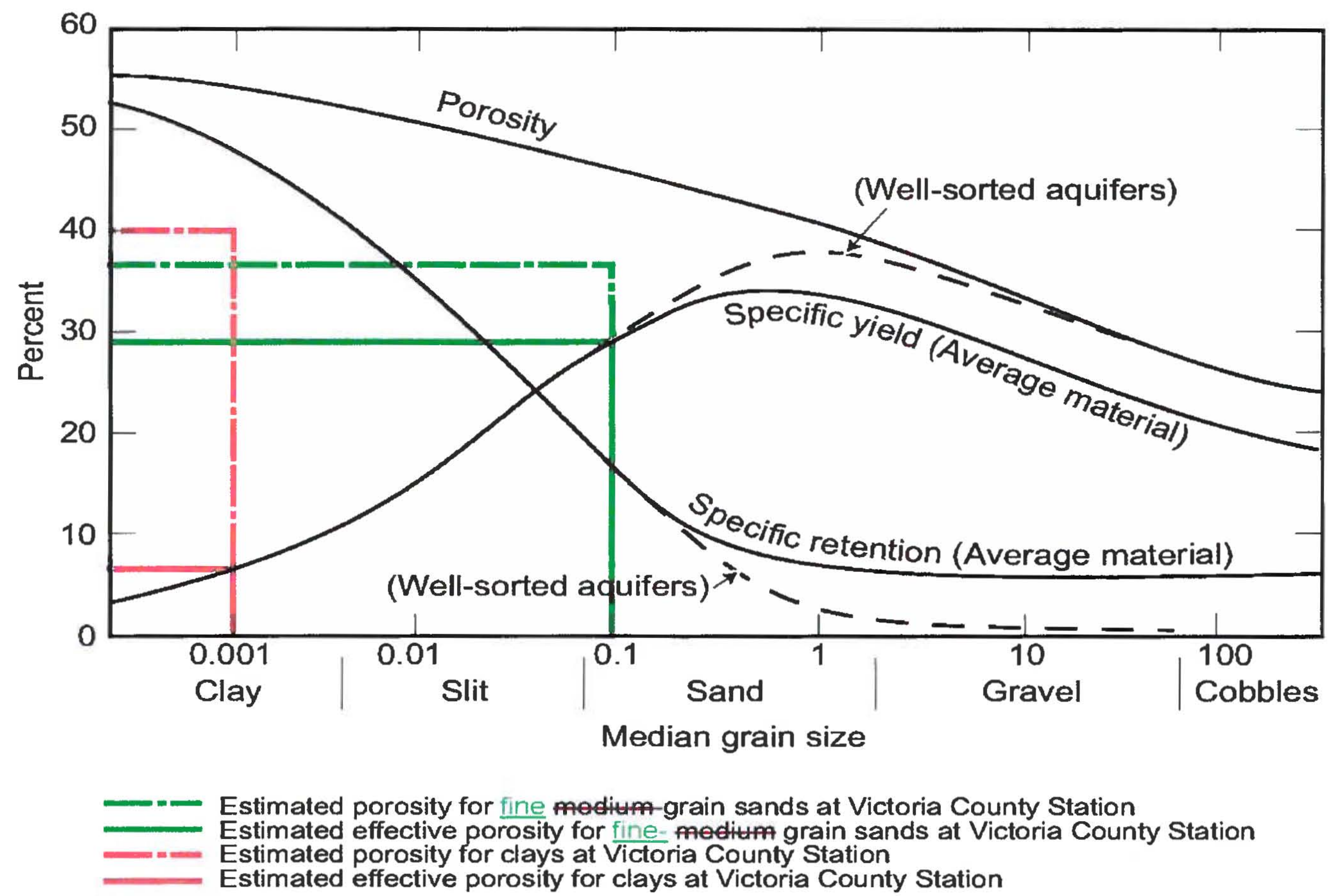
The second paragraph in SSAR Appendix C, Subsection 2.4.12-C-6.3 is revised as follows:

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 water wells located on the site boundary to north and west of the power block area represent the closest locations of a receptor ~~locations~~ to the accidental release. The well located on the east ~~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 NAVD88, for the western well, the screened interval was from -4 to -31 feet NAVD88, and for the eastern well, the screened interval was from 8 to -31 feet NAVD88. The wells were pumped at 50 gpm, which is considered the maximum practical pumping rate for the Lower Shallow aquifer based on site observations.

(End of SSAR Appendix C, Subsection 2.4.12-C-6.3)

No modification of the environmental report is required to make it consistent with the SSAR revisions in this RAI response.

SSAR Figure 2.4.12-21 is revised as follows:



Source: Table 2.4.12-10
Modified from Reference 2.4.12-18

ATTACHMENT 8

SUMMARY OF REGULATORY COMMITMENTS
(Exelon Letter to USNRC, NP-11-0038, dated August 17, 2011)

The following table identifies commitments made in this document. (Any other actions discussed in the submittal represent intended or planned actions. They are described to the NRC for the NRC's information and are not regulatory commitments.)

COMMITMENT	COMMITTED DATE	COMMITMENT TYPE	
		ONE-TIME ACTION (Yes/No)	Programmatic (Yes/No)
Exelon will revise the VCS ESPA SSAR Section 2.4.12 and ER Section 2.3.1 to incorporate the change shown in the enclosed response to the following NRC RAI: 02.04.12-2A (Attachment 1)	Revision 1 of the ESPA SSAR and ER planned for no later than March 31, 2012	Yes	No
Exelon will revise the VCS ESPA SSAR Section 2.4.12 and ER Section 2.3.1 to incorporate the change shown in the enclosed response to the following NRC RAI: 02.04.12-2C (Attachment 3)	Revision 1 of the ESPA SSAR and ER planned for no later than March 31, 2012	Yes	No
Exelon will revise the VCS ESPA SSAR Section 2.4.12 and ER Section 2.3.1 to incorporate the change shown in the enclosed response to the following NRC RAI: 02.04.12-2D (Attachment 4)	Revision 1 of the ESPA SSAR and ER planned for no later than March 31, 2012	Yes	No
Exelon will revise the VCS ESPA SSAR Section 2.4.12 and ER Section 2.3.1 to incorporate the change shown in the enclosed response to the following NRC RAI: 02.04.12-2F (Attachment 6)	Revision 1 of the ESPA SSAR and ER planned for no later than March 31, 2012	Yes	No
Exelon will revise the VCS ESPA SSAR Sections 2.4.12C and 2.4.13 to incorporate the change shown in the enclosed response to the following NRC RAI: 02.04.13-1 (Attachment 7)	Revision 1 of the ESPA SSAR and ER planned for no later than March 31, 2012	Yes	No