2.4 Hydrology

To ensure that a nuclear power plant(s) could be designed, constructed, and operated on an applicant's proposed ESP site in compliance with the Commission's regulations, the NRC staff evaluates hydrology information that may affect the design and siting of such a plant. The staff has prepared Sections 2.4.1 through 2.4.13 of this SER in accordance with the review procedures described in RS-002, using information presented in SSAR Section 2.4, the applicant's responses to RAIs, and generally available reference materials, as described in the applicable sections of RS-002.

The proposed site is adjacent to the currently operating NAPS Units 1 and 2. The water source for the proposed units on the ESP site is the impoundment of the North Anna River, referred to as Lake Anna. Lake Anna currently serves as the principal water source for the two existing units, both of which use once-through cooling systems to dissipate heat from the turbine condenser. The proposed units would also use Lake Anna as the source of cooling water. The applicant stated that the proposed Unit 3 would use a once-through cooling system, and the proposed Unit 4 would use a dry cooling tower system for heat rejection. Therefore, the water supply needs for Unit 4 would be minimal compared to those of the two existing units and the proposed Unit 3. Neither of the proposed units would rely directly on the lake for safety-related cooling needs. The ultimate heat sink (UHS) for each of the proposed units would consist of mechanical draft towers over a buried engineered water storage basin.

2.4.1 Hydrologic Description

2.4.1.1 Technical Information in the Application

SSAR Section 2.4.1 states that the ESP site is located near Lake Anna, which was created by a dam constructed across the North Anna River as part of the overall development of the NAPS site. The North Anna Dam is located about 6 km (4 mi) north of Bumpass, Virginia, and about 8 km (5 mi) downstream from the ESP site. Lake Anna is about 27 km (17 mi) long, with an irregular shoreline approximately 436 km (272 mi) in length.

Lake Anna is separated into two segments by a series of dikes and canals. The larger segment, approximately 3900 ha (9600 acres) in area, is named the North Anna Reservoir and serves as the storage impoundment. The smaller segment, approximately 1400 ha (3400 acres) in area, is named the Waste Heat Treatment Facility (WHTF) and functions to dissipate heat to the atmosphere from cooling water that has been discharged from the existing units.

The applicant stated that the North Anna Dam is the only significant water control structure on the North Anna River. The dam is an earth-filled structure, approximately 1500 m (5000 ft) long and 9 m (30 ft) wide at the crest at an elevation of 81 m (265 ft) mean sea level (MSL).[1] The dam has a 61-m (200-ft)-long concrete spillway founded on bedrock. The spillway has three

[1] Mean Sea Level (MSL): A datum, or "plane of zero elevation," established by averaging all stages of oceanic tides over a 19-yr tidal cycle or "epoch." This plane is corrected for the curvature of the earth and is the standard reference for elevations on the earth's surface. Another term for mean sea level is the National Geodetic Vertical Datum (NGVD).

radial crest gates, each of which is 12 m (40 ft) wide and 11 m (35 ft) high. Two skimmer gates, each 2.6 m by 2.6 m (8.5 ft by 8.5 ft), allow regulation of small discharges.

SSAR Section 2.4.1 states that the proposed ESP site will house two new reactor units. However, the applicant has not clearly demarcated the proposed locations of the units through survey coordinates, making it difficult to determine the feasibility of constructing intake tunnels and related structures. In RAI 2.4.1-1, the staff requested additional information on these survey coordinates, locations of any existing aquifers in the ESP site area, layout of intake tunnels and pipes from Lake Anna to the proposed new units, total service water flow rate for the two existing units, and the combined service water flow rate when all four units (two existing and two new) are operating. In response to RAI 2.4.1-1, the applicant provided a figure that lists coordinates of the ESP plant perimeter corners. Regarding aquifers, the applicant stated that the subsurface beneath the ESP site consists of a single aquifer that belongs to the Piedmont Physiographic Province aquifer system. Other aquifers nearest the ESP site belong to the Coastal Plain Physiographic Province, but occur about 24.1 km (15 mi) away. The applicant stated that, because the entire subsurface beneath the ESP site belongs to a single aquifer system, a drawing of the aquifer system is not required.

The applicant also stated in this RAI response that intake tunnels for Unit 3 will be routed from the ESP intake area about 61 m (200 ft) south to the ESP footprint, and the discharge tunnel for Unit 3 will be routed from the ESP footprint about 579 m (1900 ft) east to the ESP discharge. The applicant stated that there is adequate space available for these tunnels to ensure that they would not interfere with the underground piping and structures of the existing units.

The applicant also stated that the service water reservoir supplies service water for NAPS Units 1 and 2. The service water system for Units 1 and 2 is a single, two-loop system. Four 0.73 m^3/s (11,500 gpm) capacity pumps, two for each unit, service these two loops. Two of these pumps operate during normal operation, three during a unit shutdown, and all four during an accident condition. Two more identical pumps are located in the intake structure as backup to the normal service water supply. The applicant stated that the service water flowpath for any additional units on the ESP site is not defined, but that service water flows can be estimated to be approximately 5 percent of total circulating water flow.

The applicant stated that the nonsafety-related cooling water need for all four units, including the proposed additional units, is 3.4 m^3/s (121 cfs), which includes both natural and forced evaporation from the lake. The applicant estimated a margin of 5.9 m^3/s (209 cfs) in the water budget, assuming that the average net inflow of 10.5 m^3/s (370 cfs) is available, and a minimum release of 1.1 m^3/s (40 cfs) from Lake Anna is required.

The applicant revised the SSAR to be consistent with the above RAI responses.

SSAR Section 2.4.1.1 originally stated that during critical low-flow periods makeup water for cooling would be obtained from Lake Anna and supplemented by an external source that the COL applicant would identify. In RAI 2.4.1-2, the staff requested that the applicant identify the quantity of supplemental water. In response to RAI 2.4.1-2, the applicant stated that because of uncertainty concerning the adequacy of makeup water for the proposed Unit 4, its cooling system was changed from wet cooling towers to dry cooling towers. The applicant stated that dry cooling towers have no evaporative water losses, require no makeup water, and have no blowdown discharges. However, if the dry cooling tower system contains a secondary cooling water loop with a free water surface pump sump, a small amount of evaporation loss, on the order of $6.3x10^{-5}$ m^3/s (1 gpm), would occur. The applicant stated that with this change in the cooling system, the consumptive cooling water use for the proposed Unit 4 would decrease from 1.0 m^3/s (35 cfs) to $6.3x10^{-5}$ m^3/s (0.002 cfs) or less during normal plant operation. The applicant revised the SSAR to be consistent with these RAI responses.

Figure 2.4-10 in the SSAR shows the combined stage-storage relationship for Lake Anna and the WHTF. In RAI 2.4.1-3, the staff requested that the applicant provide the data for and a description of the method used to construct this stage-storage relationship. The stage-storage relationship should extend at least down to stage elevation 67 m (219 ft) MSL. In response to RAI 2.4.1-3, the applicant stated that it derived the stage-storage curve for Lake Anna from topographic contour maps. The applicant constructed contour maps from aerial photogrammetry of the proposed lake area before the North Anna Dam was built. It measured surface areas enclosed by the contours using a planimeter, and it determined incremental storage volume between two contours, assuming a truncated square pyramid shape between these contours. The applicant checked the stage-storage curve for accuracy on photo sheets and on U.S. Geological Survey (USGS) topographic maps. The applicant also provided a table showing the stage-storage curve and revised the SSAR to be consistent with the RAI response.

In SSAR Section 2.4.1.1, the applicant stated that the cooling water withdrawal rates for Unit 3 will be 71.9 m^3/s (2540 ft^3/s), and that for Unit 4 these rates will be 1.2 m^3/s (44 ft^3/s). In RAI 2.4.1-4, the staff requested that the applicant clarify whether these values were based upon annual averages or maximums. If these values are annual averages, the staff asked the applicant to provide estimates of maximums. In RAI 2.4.1-4, the staff also requested the applicant to provide the basis for the estimation of consumptive loss from the Unit 4 cooling tower. In response to RAI 2.4.1-4, the applicant stated that the cooling water withdrawal rate of 71.9 m^3/s (2450 cfs) for Unit 3 is a nominal design coolant flow. This is the nominal flow during periods of peak lake temperature. The applicant stated that the actual daily maximum circulating water flow would be within a few percent of the nominal value. The applicant also stated that a small amount of water, on the order of $6.3x10^{-5}$ m^3/s (1 gpm), may be consumed by the secondary cooling loop evaporative losses for the proposed Unit 4.

2.4.1.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as Appendix A to 10 CFR Part 50, General Design Criterion (GDC) 2, "Design Bases for Protection against Natural Phenomenon," 10 CFR 52.17(a), and 10 CFR 100.20(c), as well as the applicable regulatory guidance, RG 1.70 and RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance, with the exception that an ESP applicant need not demonstrate compliance with GDCs with respect to the hydrologic description of a proposed ESP site.

Section 2.4.1 of RS-002 provides the following review guidance used by the staff in evaluating this SSAR section.

The SSAR should address 10 CFR Part 52 and 10 CFR Part 100, as they relate to identifying and evaluating hydrologic features of the site. The regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that the physical characteristics of a site (including seismology, meteorology, geology, and hydrology) be taken into account to determine its acceptability for a nuclear power reactor. In addition, 10 CFR 100.20(c) addresses the hydrologic characteristics of a proposed site that may affect the consequences of an escape of radioactive material from the facility. Factors important to hydrologic radionuclide transport, described in 10 CFR 100.20(c)(3), should be obtained from onsite measurements. The staff evaluated SSAR Section 2.4.1 in light of these requirements.

To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the applicant's SSAR should contain a description of the surface and subsurface hydrologic characteristics of the site and region. This description should be sufficient to assess the acceptability of the site and the potential for those characteristics to influence the design of the SSCs of a nuclear power plant or plants (or a facility falling within a PPE) that might be constructed on the proposed site.

Meeting this guidance provides reasonable assurance that the hydrologic characteristics of the site and potential hydrologic phenomena would pose no undue risk to the type of facility (or facility falling within a PPE) proposed for the site. Further, it provides reasonable assurance that such a facility would pose no undue risk of radioactive contamination to surface or subsurface water from either normal operations or as the result of a reactor accident.

To meet the requirements of the hydrologic aspects of 10 CFR Part 52 and 10 CFR Part 100, SSAR Section 2.4.1 should form the basis for hydrologic engineering analysis with respect to subsequent sections of the application for an ESP. Therefore, completeness and clarity are of paramount importance. Maps should be legible and adequate in coverage to substantiate applicable data. Site topographic maps should be of good quality and of sufficient scale to allow independent analysis of preconstruction drainage patterns. Data on surface water users, location with respect to the site, type of use, and quantity of surface water used are necessary. Inventories of surface water users should be consistent with regional hydrologic inventories reported by applicable State and Federal agencies. The description of the hydrologic characteristics of streams, lakes, and shore regions should correspond to those of the USGS, the National Oceanic and Atmospheric Administration (NOAA), the Soil Conservation Service (SCS), the U.S. Army Corps of Engineers (USACE), or appropriate State and river basin agencies. Descriptions of all existing or proposed reservoirs and dams (both upstream and downstream) that could influence conditions at the site should be provided. Descriptions may be obtained from reports of the USGS, the U.S. Bureau of Reclamation (USBR), USACE, and others. Generally, reservoir descriptions of a quality similar to those contained in pertinent data sheets of a standard USACE hydrology design memorandum are adequate. Tabulations of drainage areas, types of structures, appurtenances, ownership, seismic and spillway design criteria, elevation-storage relationships, and short- and long-term storage allocations should be provided.

2.4.1.3 Technical Evaluation

The staff conducted a site visit in accordance with the guidance provided in Section 2.4.1 of RS-002. The staff used information from the site visit, digital maps, and streamflow data from the USGS to verify the hydrologic description provided in Section 2.4.1 of the SSAR. Because Virginia Electric and Power Company (which, like the applicant, is a subsidiary of Dominion Resources, Inc.) built the reservoir and continues to operate it, the company has a large volume of historical data pertaining to the reservoir. The applicant has supplemented that data with maps, charts, and data from State, Federal, and regulatory bodies describing hydrologic characteristics and water utilization in the site vicinity.

The staff verified the combined surface area of Lake Anna and the WHTF using the USACE major dams map layer. This map layer dataset lists the combined surface area of Lake Anna and the WHTF as 5,261 ha (13,000 acres), compared to 5,300 ha (13,096 acres) reported by the applicant.

The applicant stated in SSAR Section 2.4.1.2.1 that the catchment area of the North Anna River above the North Anna Dam is about 552 km^2 (343 mi^2). The staff verified this statement by comparing the catchment area reported by the applicant with the 554 km^2 (344 mi^2) drainage area of the USGS streamflow gauge 01670400, North Anna River near Partlow, Virginia. The applicant stated in SSAR Section 2.4.1.2.1 that the discharge measured at the Partlow streamflow gauge reflects the regulated outflow from Lake Anna for the entire period of record since the dam was completed in 1972. The staff determined that this statement is inaccurate because measurements of discharge from the dam are not available from the closure of the dam sometime in 1972 until October 1, 1978.

The staff independently searched for streamflow gauges in the site vicinity, and found that the USGS has maintained four streamflow gauges near the plant. Two gauges measured streamflows of tributaries draining into Lake Anna, and two measured streamflows downstream of the Lake Anna Dam. The longest streamflow record exists for the North Anna River near the Doswell, Virginia, gauge. This gauge reflects the release from Lake Anna and runoff from an additional 251 km^2 (97 mi^2) of watershed downstream of the Lake Anna Dam. Streamflow at this gauge was recorded from April 1929 through October 1988. Streamflow immediately downstream from the Lake Anna Dam (North Anna River near Partlow, Virginia) was recorded from October 1978 through October 1995. The gauge on Contrary Creek, which drains into Lake Anna, reflects only 14.3 km^2 (5.53 mi^2) of the watershed and has a record from October 1975 through January 1987. Another stream gauge upstream of Lake Anna (Pamunkey Creek at Lahore, Virginia) records runoff from 104.9 km^2 (40.5 mi^2) of the Pamunkey Creek drainage area for the period from August 1989 through July 1993. The two upstream gauges record flows representative of only 119 km^2 (46 mi^2), or approximately 13 percent of the total upstream area contributing flow to Lake Anna. The staff could not use the limited upstream tributary inflow data to independently estimate historical water level frequency at the ESP site. Consequently, the staff used a different empirical approach to estimate low water condition at the ESP site, as discussed in Section 2.4.11.3 of this SER.

In RAI 2.4.1-1, the staff requested additional information on coordinates of grid sectors for the individual NAPS units. The staff also requested a layout of the intake piping/tunnel from the lake to the units and locations of existing perched aquifers in the site area to demonstrate ESP site feasibility. In this RAI, the staff asked the applicant to provide the total service flow rate needed for the two existing units with once-through cooling systems, as well as the integrated cooling flow demand for all four units, to determine whether or not there is sufficient margin in the available waterflow from the North Anna Reservoir to account for any uncertainties associated with water and land-use changes in the vicinity of the plant.

The applicant’s response to RAI 2.4.1-1 included a figure that listed the coordinates of the corners of the ESP PPE (ESP site footprint). However, the applicant did not identify the coordinate system. The staff needs information regarding the coordinate reference system and the units of these coordinates to fully define the boundaries of the ESP site footprint. This is **Open Item 2.4-1**.

The applicant explained that ground water beneath the site is located in unconsolidated deposits and bedrocks in unconfined condition, and that it belongs to the Piedmont Physiographic Province aquifer system. The staff agrees with this explanation and concludes that there is a single aquifer beneath the site.

The applicant provided a figure that contains a layout of the ESP intake and discharge tunnels. Based on SSAR Figure 1.2-4, the staff determined that parts of the ESP intake and discharge tunnels will be located outside the PPE (ESP footprint). The applicant needs to specify minimum distances from the SSCs of the existing units to the ESP intake and discharge tunnels to ensure no interference will occur. This is **Open Item 2.4-2.** Once these distances are provided, and assuming the staff agrees with them, the staff plans to impose these distances as **Permit Condition 2.4-1** to ensure that no such interference will occur if a COL or CP is ultimately granted.

The applicant estimated a margin of 5.9 m^3/s (209 cfs) in the water budget, assuming that the average net inflow of 10.5 m^3/s (370 cfs) would always be available. Nonsafety-related cooling water needs for all units, including the proposed additional units, are 3.4 m^3/s (121 cfs), and a minimum release of 1.1 m^3/s (40 cfs) from Lake Anna is required by the State of Virginia. However, during periods of low flow, the expected inflow into Lake Anna can be substantially lower than the average inflow. These periods may be critical for nonsafety-related cooling needs. The applicant needs to describe the potential impacts of low-flow conditions on the operation of all units. This is **Open Item 2.4-3.**

SSAR Section 2.4.1.1 originally stated that during critical, low-flow periods, makeup water would be obtained from Lake Anna, supplemented by an external source which the COL applicant would identify. In RAI 2.4.1-2, the staff requested that the applicant identify the source and quantity of the makeup flow. The applicant stated that the change in the proposed Unit 4 cooling system from wet cooling towers to dry cooling towers will reduce its consumptive water use from 0.99 m^3/s (35 cfs) to on the order of 6.3×10^{-5} m^3/s (0.0022 cfs). The change of the proposed Unit 4 cooling system to a dry cooling system eliminates the need for any significant quantity of alternative cooling water. The applicant has revised its application to commit to a dry cooling system for the proposed Unit 4. This is a satisfactory response to RAI 2.4.1-2.

The staff independently obtained estimates of the stage-storage relationship for Lake Anna. The staff obtained USGS 1:24,000 digital raster graph maps for Lake Anna, and mosaicked them to create a georeferenced topographic map using the geographical information system (GIS) software, ArcMap, Version 9.0. The bathymetry contours on this topographic map have elevations from 54.9 m (180 ft) to 76.2 m (250 ft). The staff manually digitized the lake boundary and the bathymetry contour lines and corrected them for errors. The staff created a digital surface using these digitized contours. The staff created horizontal sections, or isosurfaces, of this digital surface from 54.9 m (180 ft) to 76.2 m (250 ft) at 3.05 m (10 ft) intervals. The staff digitally determined areas of these isosurfaces and then calculated the enclosed volume between two successive isosurfaces to independently estimate the stage-storage relationship for Lake Anna. The staff's independent estimates closely matched the applicant's stage-storage curve. Therefore, the staff considers the applicant's curve to be satisfactory.

SSAR Section 2.4.1.1 reports an estimated consumptive water use of 71.9 m^3/s (2540 cfs) for Unit 3, and 1.2 m^3/s (44 ft^3/s) for the proposed Unit 4. A subsequent letter from the applicant to the NRC dated March 31, 2004, stated that the proposed Unit 4 would use a dry cooling tower. In RAI 2.4.1-4, the staff requested the applicant to clarify whether or not the cooling water flow values are annual averages or maximums. If they are annual averages, estimates for daily maximums are needed. In its response, the applicant stated that the cooling water flow rate for the proposed Unit 3 of 71.9 m^3/s (2540 cfs) is a nominal value, and that the daily maximum flow rate would be within a few percent of this nominal value. In addition, a small amount of water, on the order of 6.3x10^{-5} m^3/s (1 gpm), will be consumed by the proposed Unit 4 secondary cooling loop evaporative losses.

Based on information provided in the SSAR and the applicant's response to the RAIs discussed in this section of this SER, the staff concludes that the additional water budget available for use by the new units is 71.9 m^3/s (2540 cfs). The staff intends to identify this maximum water use as **Permit Condition 2.4-2.** The PPE table (SSAR Table 1.3-1) states that the maximum inlet temperature is limited to 32.8 EC (91 EF); the staff intends to include this parameter value in any ESP that the NRC might issue for the site.

2.4.1.4 Conclusions

As set forth above, and with the exceptions noted, the applicant has provided sufficient information pertaining to the general hydrologic characteristics of the site, including descriptions of rivers, streams, and lakes; water-control structures; and users of waters. Therefore, the staff concludes that the applicant has met the requirements regarding general hydrologic descriptions with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c), except for those matters subject to the open items noted in Section 2.4.1.3 of this SER.

2.4.2 Floods

2.4.2.1 Technical Information in the Application

Lake Anna was created to provide a reliable supply of cooling water for the North Anna Nuclear Power Station. The watershed that drains into Lake Anna is approximately 837 km^2 (323 mi^2). The North Anna Dam is located about 6 km (4 mi) north of Bumpass, Virginia, and about 8 km (5 mi) downstream from the ESP site. Lake Anna is about 27 km (17 mi) long, with an irregular shoreline approximately 436 km (272 mi) in length.

The applicant presented peak flood discharges and peak reservoir levels for Lake Anna (since 1979) in SSAR Section 2.4.2.1. The largest flood recorded on the North Anna River at the Doswell, Virginia, gauge station occurred in 1969, with a peak discharge of 702 m^3/s (24,800 cfs). The applicant reported that the flood of 1972 that resulted from Hurricane Agnes was 680 m^3/s (24,000 cfs), and nearly matched the historical peak discharge. However, it was attenuated at the time by the recently completed, but only partially filled, Lake Anna.

In SSAR Section 2.4.2.2, the applicant considered several possibilities for determining its design-basis flood, including the probable maximum flood (PMF) on streams and rivers, potential dam failures, the probable maximum surge and seiche[2] flood, and ice effect flooding. The applicant selected the highest water level from among these flooding possibilities as the design-basis flooding level. The highest water level in Lake Anna resulted from the PMF produced by the probable maximum precipitation (PMP) over the lake's watershed. The applicant's analysis estimated a design-basis flood elevation of 81.5 m (267.39 ft) at the ESP site.

The staff requested, in RAI 2.4.2-1, that the applicant provide a description of likely upstream land-use changes and changes in downstream water demand that would alter both flood risk and the intensity and frequency of low-flow conditions. Factors affecting potential runoff (such as urbanization, forest fire, or change in agricultural use), erosion, and sediment deposition need to be considered for determining flood elevation at the ESP site. In addressing RAI 2.4.2-1, the applicant stated that its response to environmental RAI E4.2.2.-2 provided a description of likely upstream land-use changes and downstream water demand. The applicant identified three counties that may undergo growth located upstream of Lake Anna. New development could lead to an increase in impervious surface area and consequent increase in runoff to Lake Anna. The applicant stated that all three counties plan to implement storm water management measures to reduce downstream impacts. The projected development in these counties is low, and the applicant expects such development to result in only a small impact to Lake Anna. The applicant also described the potential effect of forest fires and consequent sediment deposition in Lake Anna, and concluded that these effects will not affect flood-level determination. The applicant stated that an increase in water demand resulting from the proposed Unit 3 would lead to longer periods when the lake level will be below 76.2 m (250 ft) MSL, as compared to existing conditions. The applicant proposed that the presence and operation of the proposed Unit 3 may increase the likelihood that the lake level will be below 76.2 (250 ft) MSL when a flood event occurred. Since more storage will be available under such circumstances, the applicant concluded that the flood-water level at the ESP site would be reduced. The applicant revised the SSAR to be consistent with its RAI response.

The staff requested, in RAI 2.4.2-2, that the applicant provide its methodology for documenting hillslope failures in the watershed of Lake Anna. Any documented hillslope failures should include both the failure mechanism and the hillslope properties (e.g., terrain grade, drainage, and soil type). In response to RAI 2.4.2-2, the applicant stated that it had investigated landslide hazards in the North Anna site area. The applicant used field reconnaissance, air photo interpretation, literature search, and discussions with researchers familiar with the region. The applicant determined that large, deep-seated landslides are not present in the North Anna site area or along the shores of Lake Anna. The topography in the Piedmont region is not susceptible to landslides and extensive debris flows. The applicant found no published maps of landslides in the Lake Anna area. The applicant concluded that no potential exists for large, deep-seated landslides or debris flows that may produce a seiche in Lake Anna.

[2] A standing wave oscillation of an enclosed water body that continues, pendulum fashion, after the cessation of the originating force, which may have been either seismic or atmospheric. (USACE 2003)

The staff requested, in RAI 2.4.2-3, that the applicant provide its methodology for documenting seismically induced seiches in Lake Anna. Any evidence of an historical seismically induced seiche in the area should include a description of the seismic event, land damage, date of occurrence, etc. In response to RAI 2.4.2-3, the applicant stated that it performed a literature search to determine if any seismically induced seiches had occurred in Lake Anna or other lakes in the area. In its response, the applicant referred to a paper published in the *Science of Tsunami Hazards*, the International Journal of the Tsunami Society. This paper lists all known reports of tsunamis and tsunami-like waves, including seiches, that have occurred in the eastern United States since 1600. The applicant found no listings of seiche activity in Virginia in the paper. The applicant also stated that the plant personnel at North Anna have not reported any seiches on Lake Anna.

The staff requested, in RAI 2.4.2-4, that the applicant demonstrate that drainage capacity at the existing grade is sufficient to accommodate local, intense precipitation. If this capacity is not sufficient, the staff asked the applicant to describe any active, safety-related drainage systems that will be installed for the proposed additional units. In addition, the staff requested the applicant to indicate whether drainage from the proposed site would use a drainage canal under the existing railroad spur. In its response, the applicant stated that the final grade at the ESP site would slope gently from south to north toward Lake Anna. The applicant stated that it would determine the final grade of the site after completing a detailed analysis for drainage of local intense precipitation (i.e., the local PMP defined in SSAR Section 2.4.2.3). The applicant proposed to drain local intense precipitation using surface ditches and swales. The applicant described two scenarios related to the existing railroad spur. If the spur is left in place, drainage culverts would be needed. Flood analysis for local intense precipitation would assume that all culverts are blocked, and grading near the railroad spur would be provided to allow flood water to flow over the railroad spur and the road located north of it. Grading north of the road would be provided to direct floodwater to a surface ditch that would discharge to Lake Anna. If the railroad spur is removed, the road north of it would be provided with a low-water crossing consisting of a wide drainage canal at an elevation lower than the existing elevation of the road. The applicant also proposed to provide a storm drain beneath this drainage canal to discharge flow generated by less severe storms. For either of these scenarios, the applicant stated that slab and entrance curb elevations for safety-related facilities would be placed above the flood elevations determined from a detailed analysis of flooding caused by local intense precipitation.

2.4.2.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to the NRC regulations and regulatory guidance. The applicant identified the applicable regulations as Appendix S to 10 CFR Part 50, 10 CFR 52.17(a), and 10 CFR 100.20(c), and the applicable regulatory guidance, RGs 1.29, 1.59, 1.70, and 1.102, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance. (Compliance with Appendix S is addressed in Section 2.4.5 of this SER.)

Section 2.4.2 of RS-002 provides the following review guidance the staff used in evaluating this SSAR section.

Acceptance criteria for this section address 10 CFR Part 52 and 10 CFR Part 100, as they relate to identifying and evaluating hydrologic features of the site. The regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability to host a nuclear reactor or reactors.

To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of the surface and subsurface hydrologic characteristics of the site and region and an analysis of the PMF. This description should be sufficient to assess the acceptability of the site and the potential for those characteristics to influence the design of plant SSCs important to safety. Meeting this guidance provides reasonable assurance that the hydrologic characteristics of the site and potential hydrologic phenomena would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting the relevant limiting parameters.

To meet the requirements of the hydrologic aspects of 10 CFR Part 52 and 10 CFR Part 100, the following specific criteria are used:

- For SSAR Section 2.4.2.1, “Flood History,” The potential flood sources and flood response characteristics of the region and site identified by the staff’s review (as described in the review procedures) are compared to those identified by the applicant. If similar, the applicant’s conclusions are accepted. If, in the staff’s opinion, significant discrepancies exist, the applicant will be requested to provide additional data, reestimate the effects on a nuclear power plant(s) or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site, or revise the applicable flood design bases, as appropriate.

- For the SSAR Section 2.4.2.2, “Flood Design Considerations,” the applicant’s estimate of controlling flood levels is acceptable if it is no more than 5 percent less conservative than the staff’s independently determined (or verified) estimate. If the applicant's SSAR estimate is more than 5 percent less conservative, the applicant should fully document and justify its estimate of the controlling level. Alternatively, the applicant may accept the staff's estimate.

- For SSAR Section 2.4.2.3, “Effects of Local Intense Precipitation,” the applicant's estimates of the local PMP and the capacity of site drainage facilities (including drainage from the roofs of buildings and site ponding) are acceptable, if the estimates are no more than 5 percent less conservative than the corresponding staff assessment. Similarly, conclusions relating to the potential for any adverse effects of blockage of site drainage facilities by debris, ice, or snow should be based upon conservative assumptions of the storm and vegetation conditions likely to exist during storm periods. If a potential hazard does exist (e.g., the elevation of ponding exceeds the elevation of plant access openings), the applicant should document and justify the local PMP basis.

The staff used the appropriate sections of the following documents to determine the acceptability of the applicant’s data and analyses in meeting the requirements of 10 CFR Part 52 and 10 CFR Part 100. RG 1.59 provides guidance for estimating the design-basis flooding considering the worst single phenomenon, as well as combinations of less severe phenomena. The staff used the publications of the USGS, NOAA, SCS, USACE, applicable State and river basin authorities, and other similar agencies to verify the applicant's data relating to the hydrologic characteristics and extreme events in the region.

2.4.2.3 Technical Evaluation

The staff obtained historical flows from USGS streamflow records for the Doswell and Partlow gauges. The peak discharge at Doswell ("Peak Streamflow for the Nation, USGS 01671000 North Anna River Near Doswell, Virginia") during the 1972 flood was 660 m^3/s (23,300 cfs), and the corresponding peak discharge at Partlow ("Peak Streamflow for the Nation, USGS 01670400 North Anna River near Partlow, Virginia") was 623 m^3/s (22,000 cfs).

Hydrometeorological Report (HMR) 52 ("Application of Probable Maximum Precipitation Estimates—United States East of the 105th Meridian," National Weather Service, August 1982) states that local intense precipitation at a given site should be based on the short-duration (1 hour), 1-mi^2 PMP. The staff used the HMR 52 guidelines to estimate the 1-hr, 1-mi^2 PMP depth for the ESP site. Column 2 of Table 2.4-1 lists the multiplication factors recommended in HMR 52 that are applied to 1-hr, 1-mi^2 PMP depth to estimate the PMP depths for other durations. Column 3 of Table 2.4.2-1 includes the staff's estimated PMP depths corresponding to these durations.

Table 2.4.2-1 Local Intense Precipitation (1-mi^2 Probable Maximum Precipitation) at the North Anna Early Site Permit Site

Duration	Multiplier to 1-hr PMP depth	PMP depth cm (in.)
5 min	0.331	15.42 (6.07)
15 min	0.522	24.33 (9.58)
30 min	0.748	34.87 (13.73)
1 hr	1.000	46.61 (18.35)
6 hr	1.527	71.17 (28.02)

The estimation of onsite drainage capacity and the availability of cooling water during critical low-flow periods calls for sufficient margins of safety to account for future urbanization of the watershed. These safety margins should be based upon available County and/or State growth management plans. A description of likely upstream land-use changes and changes in downstream water demand that could alter both flood risk and the intensity and frequency of low-flow conditions is needed. Factors affecting potential runoff (e.g., urbanization, forest fire, or change in agricultural use), erosion, and sediment deposition need to be considered in the determination of flood elevation at the site.

In response to RAI 2.4.2-1, the applicant described the effects of upstream land-use changes and an increase in downstream water demand. Using this information, and assuming very conservative infiltration loss terms (i.e., low water losses) during computation of flood-water elevations at the ESP site, the staff verified (as documented in Section 2.4.3 of this SER) that there is reasonable assurance that flooding caused by a PMF occurring in the Lake Anna watershed will not pose an undue risk to a facility falling within the PPE that might be located on the ESP site.

In response to RAI 2.4.2-2, the applicant performed field reconnaissance, literature searches, and consultations with researchers familiar with the region. The applicant found no evidence of large landslides or debris flows in the region that could produce a seiche in Lake Anna. The staff determined that the applicant has adequately addressed these concerns, and that it has provided sufficient information to conclude that hillslope failure leading to a seiche in Lake Anna is not credible.

In response to RAI 2.4.2-3, the applicant performed a literature survey and referred to a paper published in *Science of Tsunami Hazards* that lists all known tsunami and tsunami-like waves, including seiches, which have occurred in the eastern United States since 1600. The applicant did not find any listed event that occurred in Virginia. The applicant stated that plant personnel at North Anna have not reported any such event. The staff concluded that the applicant has adequately addressed the possibility that seismically induced seiches could occur in Lake Anna. The staff's independent estimate, discussed in Section 2.4.5 of this SER, also indicates that seismically induced seiches in Lake Anna are unlikely.

In response to RAI 2.4.2-4, the applicant stated that drainage facilities at the ESP site will be determined after detailed analysis of flooding resulting from local intense precipitation. The applicant described two possible scenarios, one for the case in which the existing railroad spur is left in place and the other for the case in which the railroad spur is removed. Both scenarios would possibly call for suitable grading at the site, near the railroad spur and near the road located north of the railroad spur, to direct any flood produced by local intense precipitation at the ESP site to Lake Anna.

Drainage systems, such as storm drains or culverts, may become blocked during a flooding event. To preclude the possibility of a safety concern for this reason, the staff intends to specify in **Permit Condition 2.4-3** that any COL or CP applicant would be required to design the ESP site grade in such a way as to ensure that any flooding caused by local intense precipitation on the ESP site will be discharged to Lake Anna without relying on such systems. In addition, the staff intends to specify in **Permit Condition 2.4-4** that the COL or CP applicant will also be required to locate any safety-related facility at an elevation above the maximum water surface elevation produced by local, intense precipitation (PMP) expected on the ESP site.

2.4.2.4 Conclusions

As set forth above, and with the conditions noted, the applicant has provided sufficient information pertaining to identifying and evaluating floods at the site. Therefore, the staff concludes that the applicant has met the requirements relating to floods with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c)(3). Further, the staff finds that the applicant appropriately considered the most severe flooding that has been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.3 PMF on Streams and Rivers

2.4.3.1 Technical Information in the Application

According to the applicant, the watershed draining into Lake Anna is approximately 837 km^2 (323 mi^2) in area. The area of Lake Anna, including the WHTF, is approximately 53 km^2 (20 mi^2). Flooding in the watershed would lead to increased water surface level in Lake Anna.

The applicant adhered to the six-subsection format outlined in RG 1.70. Accordingly, the staff's summary of the applicant's methods and findings, discussed below, will also follow this format.

Probable Maximum Precipitation

The applicant stated in SSAR Section 2.4.3.1 that the watershed drainage is 888 km^2 (343 mi^2), including the surface area of Lake Anna and the WHTF. The applicant estimated PMP according to procedures outlined in HMRs 51, 52, and 53. The applicant temporally distributed the 72-hr PMP storm according to guidelines in HMR 52 and ANS/ANSI-2.8-1992, "American National Standard for Determining Design Basis Flooding at Power Reactor Sites." To analyze the PMF runoff, the applicant used an antecedent 72-hr storm equivalent to 40 percent of the PMP, followed by 3 dry days, followed by the full 72-hr PMP storm.

Precipitation Losses

The applicant stated in SSAR Section 2.4.3.2 that it calibrated the precipitation loss parameters in the Hydrologic Engineering Center (HEC) watershed modeling code, HEC-1, using historical storms. The applicant adjusted these losses to minimize differences between observed and simulated rainfall runoff relationships for the basin. The applicant investigated the historical storms used in a 1976 study and three additional storms that occurred in February 1979, March 1994, and June 1995. The applicant selected these additional storms because they produced high water levels in Lake Anna.

Runoff and Stream Course Models

The applicant stated in SSAR Section 2.4.3.3 that it used HEC-1 to estimate runoff and to route the resulting flood through Lake Anna. The applicant then compared the HEC-1 computed discharge and reservoir stages to observed values. The applicant adjusted both base flow and precipitation losses to minimize differences between observed and simulated values, and it used HEC-1 to route the flood through the reservoir with a level pool routing procedure. The analysis treated Lake Anna, including the WHTF, as a single reservoir when the water surface was above 77.3 m (253.5 ft) MSL, corresponding to the top of the dikes separating the WHTF from Lake Anna. The analysis neglected any potential storage in the WHTF when the reservoir water surface was below 77.3 m (253.5 ft) MSL.

PMF Flow

The applicant estimated peak PMF inflow to Lake Anna in SSAR Section 2.4.3.4 as 8,555 m^3/s (302,100 cfs). The peak discharge over the North Anna Dam was estimated to be 3,993 m^3/s (141,000 cfs). The applicant also stated that no other dams exist upstream of the North Anna Dam, except two small reservoirs in the drainage area. The applicant did not include the effects of releases from these two small reservoirs in the PMF flow estimation.

Water Level Determinations

The applicant routed the PMF through the reservoir using an HEC-1 level pool routing procedure. The applicant stated in SSAR Section 2.4.3.5 that the maximum water level estimated at the dam was 80.49 m (264.07 ft) MSL. The applicant also stated that the resulting backwater profile at the ESP site would be approximately 0.06 m (0.2 ft) higher than the water level at the dam. Therefore, the applicant's maximum estimated PMF water surface elevation at the ESP site is 80.55 m (264.27 ft) MSL.

Coincident Wind Wave Activity

The applicant stated in SSAR Section 2.4.3.5 that it based the wave setup, added to the PMF-estimated water surface elevation at the ESP site, on a 2-yr wind, and that it used a wind speed over ground of 90 km/h (56.0 mi/h). The applicant estimated maximum and effective fetch lengths[3] to be 3,230 m (10,600 ft) and 1,433 m (4,700 ft), respectively. Based upon the values of these parameters, the applicant estimated a significant wave height[4] of 0.655 m (2.15 ft), a maximum wave height of 1.10 m (3.60 ft), a wind setup value of 0.027 m (0.09 ft), and a wave runup[5] value of 0.924 m (3.03 ft). The applicant reported the maximum PMF water surface elevation at the ESP site, including wind setup and wave runup, to be 81.5 m (267.39 ft) MSL.

The staff requested, in RAI 2.4.3-1, that the applicant provide a calibrated unit hydrograph, expressed in terms of input parameters for HEC-1, from an adjacent unregulated basin of a size similar to the Lake Anna watershed, or explain why such a hydrograph is not necessary. In its response, the applicant stated that the unit hydrograph it developed for Lake Anna was based on actual rainfall data and observed water level and discharge data measured at the North Anna Dam. The applicant stated that because this unit hydrograph is based on actual observed responses in the basin, it is more representative of the Lake Anna rainfall-runoff response than that of an adjacent unregulated basin. The applicant also provided definitions of the parameters of the Clark Synthetic Unit Hydrograph, and described how these parameters are affected by the presence of Lake Anna in the drainage area.

The staff requested, in RAI 2.4.3-2, that the applicant provide the supporting input files and the software version information that it used to generate the results discussed in this section. In its response, the applicant provided four HEC-1 input files that it used to determine the watershed runoff hydrograph, perform flood routing, and determine lake water levels. The applicant stated that it used Version 4.0.1E of the HEC-1 computer program for these analyses.

2.4.3.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC

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[3] Fetch length is the horizontal distance (in the direction of the wind) over which a wind generates seas or creates a wind setup. On reservoirs and smaller bodies of water, wind setup is the vertical rise in the still water level on the leeward side of a body of water caused by wind stresses on the surface of the water. Wind setdown is a similar effect, resulting in lowering of the water level. (USACE 2003).

[4] "Significant wave height" is a statistical term relating to the highest one-third of waves of a given wave group and defined by the average of their heights and periods. The composition of the highest waves depends upon the extent to which the lower waves are considered.

[5] "Wave runup" is the upper level reached by a wave on a beach or coastal structure, relative to the still water level.

regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.20(c), and the applicable regulatory guidance as RGs 1.29, 1.59, 1.70, and 1.102, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance.

Section 2.4.3 of RS-002 provides the following review guidance used by the staff in evaluating this SSAR section:

Acceptance criteria for this section address 10 CFR Part 52 and 10 CFR Part 100, as they relate to identifying and evaluating the hydrologic features of the site. The regulations in 10 CFR Part 52 and 10 CFR Part 100 require that a site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining the acceptability of a site for a nuclear reactor or reactors.

To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of the hydrologic characteristics of the site and region and an analysis of the PMF. This description should be sufficient to assess the acceptability of the site and the potential for those characteristics to influence the design of SSCs important to safety for a nuclear power plant(s) or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. Meeting this guidance provides reasonable assurance that any hydrologic phenomena of severity up to and including the PMF would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

To meet the requirements of the hydrologic aspects of 10 CFR Part 52 and 10 CFR Part 100, the following specific criteria are used:

The PMF, as defined in RG 1.59, has been adopted as one of the conditions to be evaluated in establishing the applicable stream and river flooding design basis referenced in Appendix A to 10 CFR Part 50, GDC 2. PMF estimates are needed for all adjacent streams or rivers and site drainage (including the consideration of PMP on the roofs of safety-related structures). The criteria for accepting the applicant’s PMF-related design basis depend on one of the following three conditions:

(1) The elevation attained by the PMF (with coincident wind waves) establishes a necessary protection level to be used in the design of the facility.

(2) The elevation attained by the PMF (with coincident wind waves) is not controlling; the design-basis flood protection level is established by another flood phenomenon (e.g., the probable maximum hurricane).

(3) The site is “dry”; that is, the site is well above the elevation attained by a PMF (with coincident wind waves).

When condition 1 is applicable, the staff will assess the flood level. The assessment may be made independently from basic data, by detailed review and checking of the applicant's analyses, or by comparison with estimates made by others that have been reviewed in detail. The applicant's estimates of the PMF level and the coincident wave action are acceptable if the estimates are no more than 5 percent less conservative than the staff estimates. If the applicant's estimates of discharge are more than 5 percent less conservative than the staff's, the applicant should fully document and justify its estimates or accept the staff estimates.

When condition 2 or 3 applies, the staff analyses may be less rigorous. For condition 2, acceptance is based on the protection level estimated for another flood-producing phenomenon exceeding the staff estimate of PMF water levels. For condition 3, the site grade should be well above the staff assessment of PMF water levels. The evaluation of the adequacy of the margin (difference in flood and site elevations) is generally a matter of engineering judgment. The judgment is based on the confidence in the flood-level estimate and the degree of conservatism in each parameter used in the estimate.

The staff used the appropriate sections of the following documents to determine the acceptability of the applicant's data and analyses. RG 1.59 provides guidance for estimating the PMF design basis. Publications of NOAA and USACE may be used to estimate PMF discharge and water level condition at the site, as well as coincident wind-generated wave activity.

2.4.3.3 Technical Evaluation

The staff's evaluation consisted of the following independent analysis to verify the applicant's PMF analysis. The staff completed this evaluation in accordance with RS-002.

<u>Probable Maximum Precipitation</u>

The staff determined the PMP using HMRs 51 and 52 and ANSI/ANS-2.8-1992. HMR 51 gives a set of charts of PMP depths for durations of 6, 12, 24, 48, and 72 hours, corresponding to drainage areas of 10, 200, 1,000, 5,000, 10,000, and 20,000 mi^2. Using these charts, the staff determined PMP depths (in inches) for drainage areas of 10, 200, 1000, and 5000 mi^2 for all of the above-stated durations (Table 2.4.3-1).

Using the values in Table 2.4.3-1, the staff prepared depth-area-duration curves following the guidelines of HMR 51 to bracket the drainage area of Lake Anna. Figure 2.4.3-1 illustrates these depth-area-duration curves. The staff determined PMP depth values corresponding to the North Anna Dam drainage area of 888 km^2 (343 mi^2) from Figure 2.4.3-1 to construct Table 2.4.3-2.

Table 2.4.3-1 Probable Maximum Precipitation Values for the North Anna Dam Drainage Area

	Duration (hr)				
Area (mi^2)	6	12	24	48	72
10	28.6	33.4	37.0	41.0	42.8
200	19.8	23.6	28.0	31.7	33.5
1000	14.6	18.5	23.8	26.0	27.0
5000	8.8	12.1	15.5	19.3	20.3

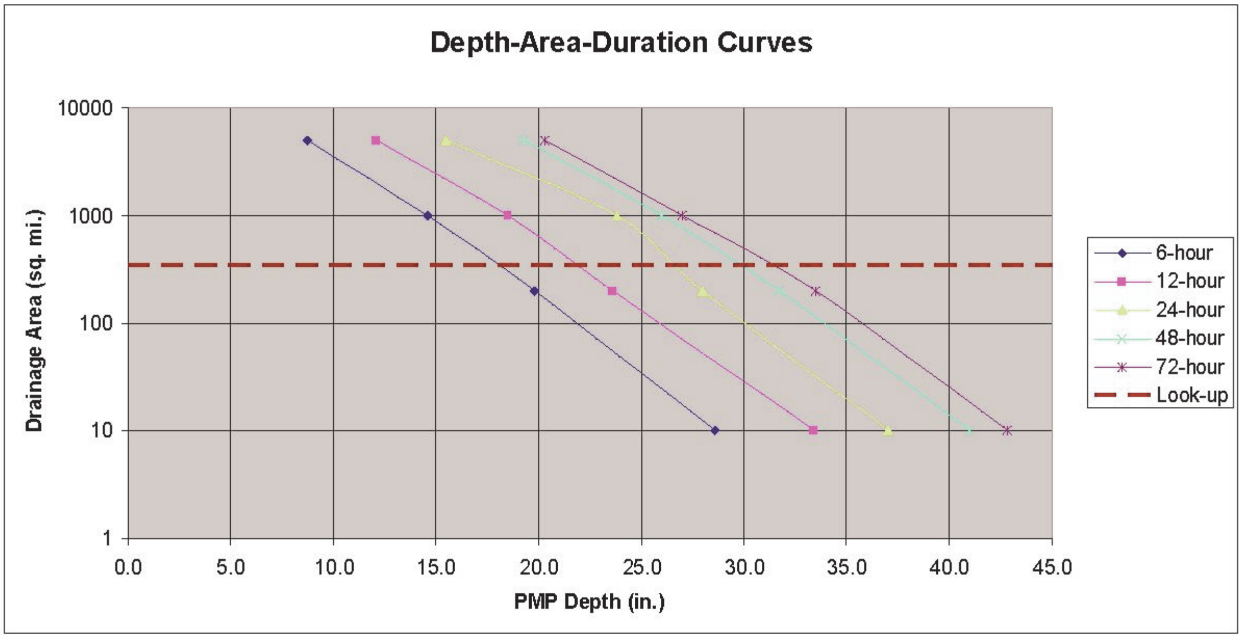

Figure 2.4.3-1 Depth-area-duration curves prepared for bracketing North Anna drainage area. The dotted horizontal line corresponds to a drainage area of 343 mi^2, equal to that of the North Anna Dam.

Table 2.4.3-2 PMP Depth-Duration Values for the North Anna Dam Drainage Area

	Duration (hr)				
	6	12	24	48	72
North Anna PMP (343 mi^2)	18.2	22.0	26.6	30.0	31.2

HMR 52 and ANSI/ANS-2.8-1992 provide guidelines for distributing the PMP depths in time to create a storm sequence during the PMP event. Following these guidelines, the staff computed incremental PMP depths corresponding to all 6-hr durations during the 72-hr PMP (column 2 of Table 2.4.3-3). The incremental depths were grouped into three 24-hr periods in descending order (column 3). The staff rearranged the PMP depths within each 24-hr group according to the guidelines of ANSI/ANS-2.8-1992 (column 4). Finally, the staff rearranged column 4 following the guidelines of ANSI/ANS-2.8-1992 to create the time distribution of the PMP storm over the North Anna Dam drainage area (column 5).

Table 2.4.3-3 Time Distribution of Probable Maximum Precipitation for the North Anna Dam Drainage Area

6-hr period	Depth (in.)	Group No.	ANSI/ANS-2.8-1992 Rearrange	Time Distribution for PMP (in.)	Time (hr)
1	18.20	1	2.30	0.85	6
2	3.80		3.80	0.85	12
3	2.30		18.20	0.85	18
4	2.30		2.30	0.85	24
5	0.85	2	0.85	2.30	30
6	0.85		0.85	3.80	36
7	0.85		0.85	18.20	42
8	0.85		0.85	2.30	48
9	0.30	3	0.30	0.30	54
10	0.30		0.30	0.30	60
11	0.30		0.30	0.30	66
12	0.30		0.30	0.30	72

Precipitation Losses

The staff assumed that no precipitation losses occurred in order to maximize the flood generated by the PMP storm over the North Anna Dam drainage area.

Runoff and Stream Course Models

The staff conservatively estimated runoff by assuming that the drainage instantaneously discharged to Lake Anna. Under this assumption, the staff estimated the runoff corresponding to all 6-hr durations by multiplying the PMP depth corresponding to that 6-hr duration by the area of the North Anna Dam drainage, and converting the volume of runoff into discharge. Table 2.4.3-4 depicts the PMF thus obtained for the North Anna Dam drainage.

Table 2.4.3-4 PMF into Lake Anna

Time (hr)	Runoff (in.)	Runoff (cfs)
6	0.85	31,358
12	0.85	31,358
18	0.85	31,358
24	0.85	31,358
30	2.3	84,851
36	3.8	140,188
42	18.2	671,426
48	2.3	84,851
54	0.3	11,067
60	0.3	11,067
66	0.3	11,067
72	0.3	11,067

PMF Flow

Table 2.4.3-4, above, presents the staff's estimates of the PMF for the North Anna Dam drainage.

Preliminary Water Level Determinations

The staff followed two approaches to independently and conservatively bracket water levels at the ESP site during the PMF. The first approach was to compute reservoir levels under a steady inflow equal to the applicant's peak PMF discharge (8,555 m^3/s (302,100 cfs)). The staff conservatively assumed a discharge capacity for each of three spillways of the North Anna Dam as 1,132 m^3/s (40,000 cfs). Under the steady inflow scenario, once the spillways reach their discharge capacity, the reservoir would fill and then overtop.

The staff estimated the overtopping flow that must pass over the crest of the dam to be 5,156 m^3/s (182,100 cfs). Under these conditions, the staff assumed the full width of the North Anna Dam to act like a weir, and estimated the height of flow passing over it using the following wide rectangular weir equation (Chow, *Open Channel Hydraulics*, 1959)—discharge per unit width is $q = CH^{3/2}$, where C is a coefficient ranging from 2.67 to 3.05, and H is the height of flow passing over the weir. The staff obtained values of H corresponding to the two extreme values of C, assuming the dam width is equal to 1,524 m (5,000 ft). Hence, the staff-estimated conservative value of H is 1.74 m (5.71 ft).

The staff estimated the corresponding water level to be 82.5 m (270.71 ft) MSL. This value is close to the plant grade. A further increase of water level caused by wind wave runup, surges, and seiche would result in flooding of the ESP site. However, the staff determined that the assumption of steady inflow equal to the applicant's peak PMF discharge was overly conservative, because the lake attenuates the time between the steady inflow and the peak PMF discharge.

The next approach the staff used was to route the staff-estimated PMF (column 3 of Table 2.4.3-4), assuming no precipitation loss and instantaneous translation, through Lake Anna using level pool routing (Linsley, et al., *Hydrology for Engineers*, 1982, p. 272). This second approach resulted in the reservoir inflow-outflow sequence shown in Figure 2.4.3-2. Figure 2.4.3-3 depicts the corresponding reservoir elevations. The staff used the following reservoir operation rules during the PMF event—(1) operate the spillway gates, if reservoir elevation is at 76.2 m (250 ft) MSL, to let all inflow pass through, and (2) raise reservoir gates gradually when reservoir elevation exceeds 76.2 m (250 ft) MSL to allow more discharge, depending on the reservoir elevation, until water is freely discharged over the spillways.

The staff estimated the maximum reservoir elevation during the PMF event to be 82.03 m (269.13 ft) MSL. A further increase of water elevation caused by wind wave runup, surges, and seiche would result in flooding of the ESP site. However, as previously stated, the staff determined that the level pool routing of the staff-estimated North Anna Dam drainage PMF was too conservative, because the lake attenuates the time between the steady inflow and the peak PMF discharge.

Because the preliminary analysis did not take into account the delaying effect of Lake Anna for the arrival of the peak PMF flow at the ESP site, the staff used the input data for the HEC-1 analysis from the applicant to independently estimate flood water level at the ESP site. This is discussed below.

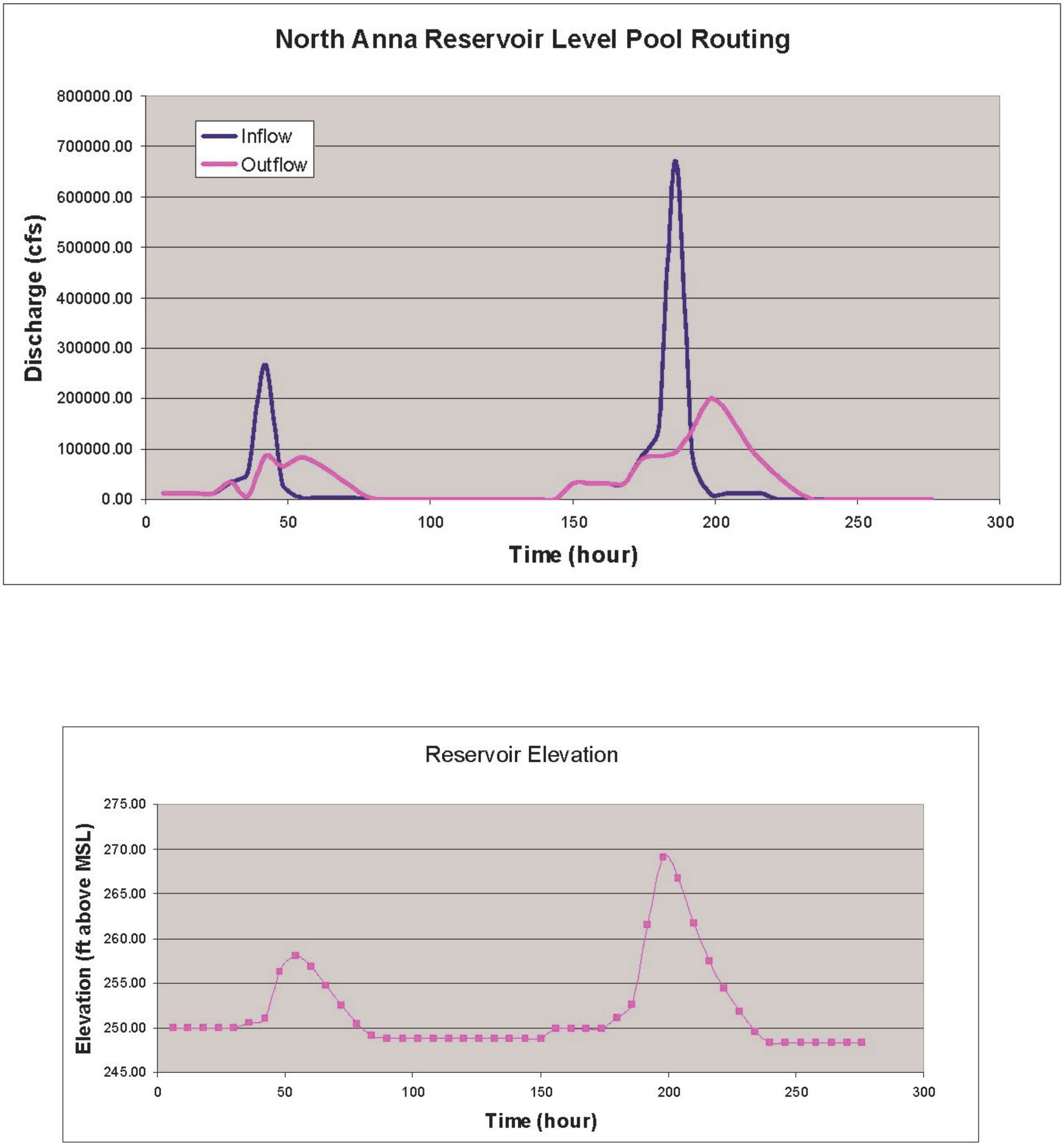

Figure 2.4.3-2 Inflow and outflow hydrographs for North Anna reservoir during the PMF event

Figure 2.4.3-3 Reservoir elevation during the PMF event

Coincident Wind Wave Activity

The staff estimated wave heights based upon wave height nomographs (see U.S. Army Corps of Engineers, "Coastal Engineering Manual," EM 1110-2-1100, Revision 1, 2003). These nomographs estimate wave height based upon fetch length and wind speed. Fetch length used by staff was 3,219 m (10,560 ft).

ANSI/ANS-2.8-1992 (p. 17) states, "A probable maximum hurricane (PMH) shall be considered for U.S. coastline areas and areas within 100 to 200 miles bordering...the Atlantic Ocean...." Guidance from ANSI/ANS-2.8-1992 suggests that, for the Great Lakes Region, the maximum over-water wind speed is 161 km/h (100 mph). The staff used this conservative value to estimate a wave height of 1.3 m (4.3 ft). This shallow-water wave height is based upon an average of the highest one-third of representative waves.

Section 2.4.5 of this SER discusses wind setup. Based upon a wind speed of 161 km/h (100 mph), the staff estimated the wind setup for the ESP site to be 0.14 m (0.46 ft).

The applicant did not specify in the SSAR the location of the lowest (and/or closest to Lake Anna) safety-related facility of the ESP site. The staff requested this information in RAI 2.4.1-1. The applicant responded by providing a revised site layout plan with coordinate grids. In order to meet the PPE constraints on ground water level and the site ground water level, the staff has proposed a permit condition in Section 2.4.12 of this SER regarding location of safety-related structures in the northeast corner of the ESP site.

In response to RAI 2.4.3-1, the applicant provided the details of its input for the HEC-1 analysis. The staff used the input and conducted its HEC-1 runs using the applicant's data for routing the PMF through Lake Anna, as described below. The staff determined that the maximum water surface elevation caused by PMF, wind setup, and wave runup is 0.46 m (1.5 ft) below the plant grade. The staff finds this to be satisfactory.

The staff's preliminary, highly simplified bounding estimate of water level exceeded the proposed ESP site grade. Therefore, the staff needed to review the applicant's HEC-1 calculations. The applicant provided the staff the HEC-1 input file it used in the calculations. The staff repeated the HEC-1 run using the applicant's input file and the newer Version 4.1 of the HEC-1 software, dated June 1998. The staff determined that the maximum inflow into the lake was 8,579 m^3/s (302,953 cfs). The peak outflow from the dam was 4,000 m^3/s (141,246 cfs), and the corresponding water surface elevation in the lake was 80.50 m (264.1 ft) MSL.

The staff also determined (Linsley, et al., *Hydrology for Engineers,* 3rd Edition, 1982; Pilgrim and Cordery, "Flood Runoff," Chapter 9 in *Handbook of Hydrology,* 1992) that for computing floods from PMP, unit hydrograph flood peaks should be increased from 5 to 20 percent, and the time to peak should be reduced to 33 percent. The staff adjusted the applicant's unit hydrograph according to these guidelines to provide a more conservative estimate. Figure 2.4.3-4 illustrates the staff's conservative and the applicant's original unit hydrographs.

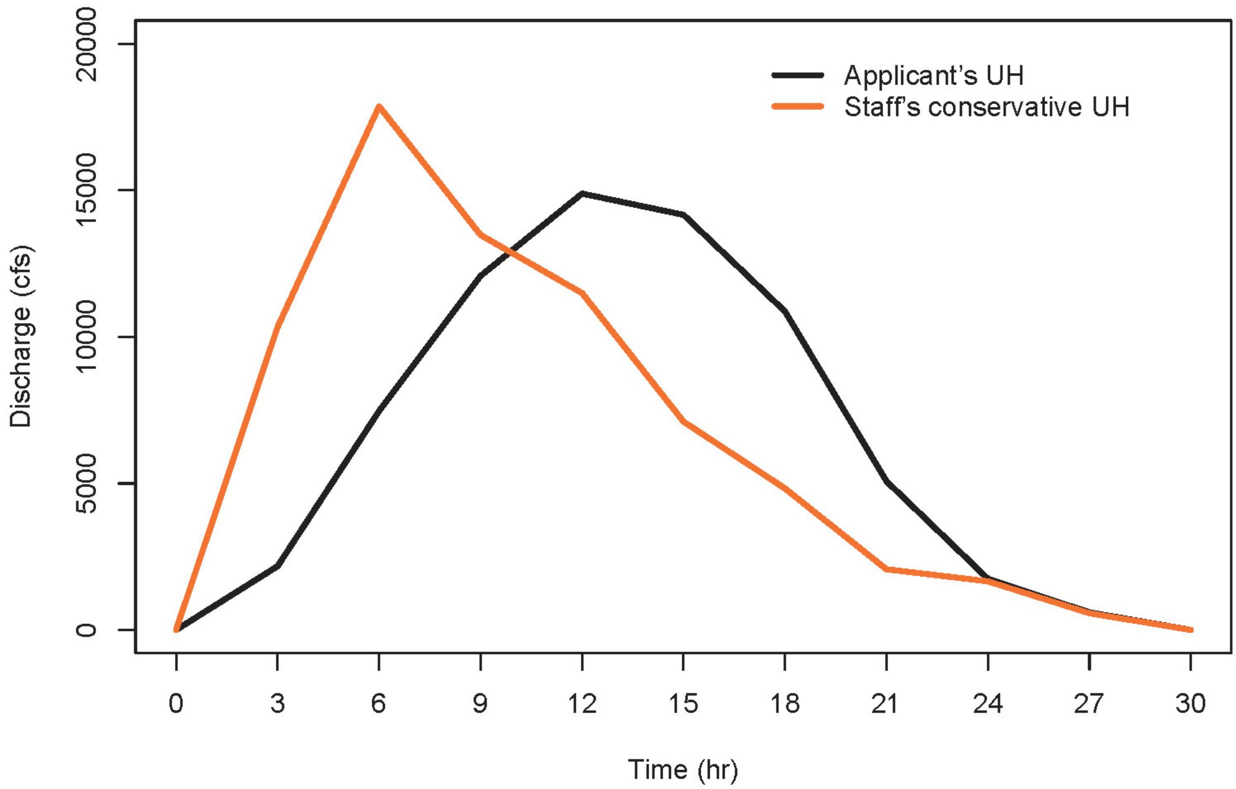

Figure 2.4.3-4 Applicant's original (black line) and staff's conservative (red line) unit hydrographs

The staff also conservatively assumed that no infiltration losses occurred during the PMP event. The staff modified the applicant's HEC-1 input file and carried out another HEC-1 run using the conservative unit hydrograph and no infiltration loss. This run resulted in a peak inflow of 9,697 m^3/s (342,502 cfs), and a corresponding peak discharge of 4,071 m^3/s (143,775 cfs). The maximum calculated water surface elevation at the dam was 80.7 m (264.6 ft) MSL.

The staff estimated the maximum water surface elevation at the ESP site by adding wave height [1.3 m (4.3 ft)) and wind setup (0.14 m (0.46 ft)] to the maximum water surface elevation at the dam [80.7 m (264.6 ft) MSL]. The staff estimated the maximum water surface elevation at the ESP site to be 82.14 m (269.5 ft) MSL. This conservatively estimated maximum water surface elevation at the ESP site is 0.46 m (1.5 ft) below the plant grade.

Two small lakes exist upstream from Lake Anna. Lake Louisa was formed by the construction of Louisa Dam on Hickory Creek in 1960, and Lake Orange was formed by the construction of Lake Orange Dam on Clear Creek in 1964. The combined capacity of these two lakes is 9.46 million m^3 (7,671 ac-ft), approximately equal to 3 percent of Lake Anna's storage capacity between normal pool and the top of the North Anna Dam. In Section 2.4.4 of this SER, the staff estimated that an increase in inflow volume of 9.46 million m^3 (7,671 ac-ft) to Lake Anna would result in an increase of 0.2 m (0.9 ft) in water surface elevation, if the starting elevation were

76.2 m (250 ft) MSL. The water surface elevation would increase 0.15 m (0.5 ft), if the starting water surface elevation were 80.8 m (265 ft) MSL. Therefore, the staff estimated the water surface elevation corresponding to the PMF, coincident wind wave action, and breach of Lakes Louisa and Orange to be 82.3 m (270 ft) MSL. The staff concluded from this information that the maximum water surface elevation caused by the PMF and the coincident wind effects will not result in flooding of the ESP site. The staff's estimate of the PMF level is slightly higher than the applicant's (270 ft MSL vs 267.39 ft MSL).

2.4.3.4 Conclusions

As set forth above, the applicant has provided sufficient information pertaining to identifying and evaluating the PMF on streams and rivers at the site. Therefore, the staff concludes that the applicant has met the requirements relating to the effects of PMF on streams and rivers at the site, with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c). Further, the staff finds that the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing the stream and river design basis flood, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.4 Potential Dam Failures

2.4.4.1 Technical Information in the Application

The ESP site is located adjacent to Lake Anna and is approximately 8 km (5 mi) upstream of the North Anna Dam. Lake Anna was created to supply water to the existing NAPS, and it would be the cooling water and primary service water source for the proposed North Anna Unit 3. The applicant intends to use a dry, closed-cycle cooling system for the proposed Unit 4 which would not withdraw significant amounts of water from the lake for cooling. The UHS for the proposed units would consist of a mechanical draft cooling tower over a buried water storage basin or other passive water storage facility, as called for by the reactor design. The UHS would also provide water for the service water system in the event that the primary source becomes unavailable.

The applicant stated that no other significant dams exist on the North Anna River, either upstream or downstream of the ESP site. The only impoundments in the area are small farm ponds and two small recreational lakes (Lake Louisa and Lake Orange). The applicant concluded that failure of either of these lakes would not produce any measurable effect on Lake Anna, the North Anna Dam, or any safety-related system.

The applicant concluded that the UHS design ensures adequate water, even if Lake Anna were to be drained as a result of a dam failure. The applicant also concluded that no safety-related structures or systems would be adversely affected by the loss of water caused by a dam failure.

The staff requested, in RAI 2.4.4-1, that the applicant document impounded volumes and the locations of Lake Louisa and Lake Orange relative to Lake Anna. The staff also requested that the applicant provide its methodology for documenting failure of dams on these lakes. In its response, the applicant stated that Lake Louisa is located on Hickory Creek, a tributary to the North Anna River, and Lake Orange is located on Clear Creek, a tributary to Pamunkey Creek, which is a tributary to Lake Anna. Lake Louisa is located approximately 5.5 km (3.4 mi) upstream of Lake Anna. It has a surface area of 113.3 ha (280 acres), and a storage volume of 5.81 million m^3 (4713 ac-ft). Lake Orange is located approximately 14.2 km (8.8 mi) upstream of Lake Anna. It has a surface area of 48.6 ha (120 acres), and a storage volume of 3.65 million m^3 (2958 ac-ft). The applicant stated that the storage capacity of Lake Anna between the normal water surface elevation of 76.2 m (250 ft) MSL and the top of the dam elevation of 80.8 m (265 ft) MSL is 302.2 million m^3 (245,000 ac-ft). This storage capacity of Lake Anna can sufficiently accommodate the combined storage capacity of the two recreational lakes, which is equal to 9.46 million m^3 (7,671 ac-ft). The applicant also considered the scenario in which dams on both Lake Louisa and Lake Orange fail during a PMP event, such that the discharge from these dam breaches arrived at Lake Anna at the same time as the peak discharge of the PMF generated by the PMP event on Lake Anna's watershed. The applicant estimated that the additional increase in PMF peak water surface elevation caused by these dam breaches would be 0.12 m (0.4 ft). The applicant concluded that the resulting water surface elevation would be 80.7 m (264.67 ft) MSL, which is below the proposed site grade of 271 ft MSL. (The staff considered such an effect in Section 2.4.3.3 of this SER.)

The staff requested, in RAI 2.4.4-2, that the applicant provide details regarding storage capacity and design parameters for this underground basin. In its response, the applicant stated that a mechanical draft cooling tower over an underground basin would be used as the UHS. A separate cooling tower and basin would be provided for each proposed unit. The storage volume for each basin would be 115,834 m^3 (4,090,625 ft^3), and each basin would be approximately 71.6 m (235 ft) wide, 106.7 m (350 ft) long, and 15.2 m (50 ft) deep. The applicant stated that additional basin depth will be provided for freeboard and to accommodate a possibly frozen surface layer.

2.4.4.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 52.17(a)(1)(vi), 10 CFR 100.20(c), and 10 CFR 100.23(c), and the applicable regulatory guidance as RGs 1.29, 1.59, 1.70, and 1.102, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance.

Section 2.4.4 of RS-002 provides the following review guidance used by the staff in evaluating this SSAR section:

Acceptance criteria for this section are based on meeting the requirements of the following regulations:

- 10 CFR Part 52 and 10 CFR Part 100, as they relate to evaluating hydrologic features of the site

- 10 CFR 100.23, as it relates to establishing the design-basis flood resulting from seismic dam failure

The regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability to host a nuclear reactor(s).

The regulations in 10 CFR Part 52 and 10 CFR Part 100 are applicable to SSAR Section 2.4.4 because it addresses the physical characteristics, including hydrology, considered by the Commission when determining the acceptability of a site for a power reactor. To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of the hydrologic characteristics of the region and an analysis of potential dam failures. The description should be sufficient to assess the acceptability of the site and the potential for those characteristics to influence the design of SSCs important to safety. Meeting this criterion provides reasonable assurance that the effects of high water levels resulting from failure of upstream dams, as well as those of low water levels resulting from failure of a downstream dam, would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of relevant parameters.

The regulation in 10 CFR 100.23 requires consideration of geologic and seismic factors in determining site suitability. Specifically, 10 CFR 100.23(c) requires an investigation of the geologic and seismic site characteristics to permit evaluation of seismic effects on the site. Such an evaluation will consider seismically induced floods, including failure of an upstream dam during an earthquake.

The regulation in 10 CFR 100.23 is applicable to SSAR Section 2.4.4 because it requires investigation of seismic effects on the site. Such effects include seismically induced floods or low water levels, which constitute one element in the Commission’s consideration of the suitability of proposed sites for nuclear power plants. RG 1.70 provides more detailed guidance on the investigation of seismically induced floods, including results for seismically induced dam failures and antecedent flood flows coincident with the flood peak. Meeting this guidance provides reasonable assurance that, given the geologic and seismic characteristics of the proposed site, a nuclear power plant or plants of a specified type (or falling within a PPE) could be constructed and operated on the proposed site without undue risk to the health and safety of the public, with respect to those characteristics.

The following criteria are used to meet the requirements of 10 CFR Part 52, 10 CFR Part 100, and 10 CFR 100.23, as they relate to dam failures:

- The staff will review the applicant’s analyses and independently assess the coincident river flows at the site and at the dams being analyzed. ANSI/ANS-2.8-1992 provides guidance on acceptable river flow conditions to be assumed coincident with the dam failure event. To be acceptable, the applicant’s estimates (which may include landslide-induced failures) of the flood discharge resulting from the coincident events should be no more than 5 percent less conservative than the staff estimates. If the applicant's estimates differ by more than 5 percent, the applicant should fully document and justify its estimates or accept the staff estimates.

- The applicant should identify the location of dams and potentially “likely” or severe modes of failure. Dams or embankments for the purpose of impounding water for a nuclear power plant(s) or plants that might be constructed on the proposed site should also be identified. The potential for multiple, seismically induced dam failures and the domino failure of a series of dams should be discussed. Approved models of the USACE and the Tennessee Valley Authority should be used to predict the downstream water levels resulting from a dam breach. First-time use of other models will necessitate complete model description and documentation. Acceptance of the model (and subsequent analyses) is based on staff review of model theory, available verification, and application. For cases which assume something other than instantaneous failure, the conservatism of the rate of failure and shape of the breach should be well documented. A determination of the peak flow rate and water level at the site for the worst possible combination of dam failures, as well as a summary analysis (that substantiates the condition as the critical permutation) should be presented, along with a description (and the bases) of all coefficients and methods used. In addition, the effects of other concurrent events on plant safety, such as blockage of the river and waterborne missiles, should be considered.

- The effects of coincident and antecedent flood flows (or low flows for downstream structures) on initial pool levels should be considered. Depending upon estimated failure modes and the elevation difference between plant grade and normal river levels, it may be acceptable to use conservative, simplified procedures to estimate flood levels at the site. Where calculated flood levels using simplified methods are at or above plant grade and use assumptions which cannot be demonstrated as conservative, it will be necessary to use unsteady flow methods to develop flood levels at the site. References 7, 13, and 14 of RS-002 are acceptable methods; however, other programs could be acceptable with proper documentation and justification. Computations, coefficients, and methods used to establish the water level at the site for the most critical dam failures should be summarized. Coincident wind-generated wave activity should be considered in a manner similar to that discussed in Section 2.4.3 of RS-002.

RG 1.59 provides guidance for estimating the design basis for flooding, considering the worst single phenomenon and a combination of less severe phenomena.

2.4.4.3 Technical Evaluation

The staff consulted USGS maps to independently verify the applicant's information, and concluded that no dams of significant storage, the failure of which could endanger the North Anna Dam, exist upstream.

Using the National Inventory of Dams, the staff independently found that Lake Louisa was formed by the construction of Louisa Dam on Hickory Creek in 1960, and Lake Orange was formed by the construction of Lake Orange Dam on Clear Creek in 1964. The storage capacity of Lake Louisa is 5.81 million m^3 (4,173 ac-ft) and Lake Orange is 3.65 million m^3 (2,958 ac-ft). The combined capacity of these two lakes is 9.46 million m^3 (7,671 ac-ft), approximately 3 percent of Lake Anna's storage capacity between normal pool and the top of the North Anna Dam. The staff estimated that an increase in inflow volume of 9.46 million m^3 (7,671 ac-ft) to Lake Anna would result in an increase of 0.2 m (0.9 ft) in water surface elevation, if the starting elevation were 76.2 m (250 ft) MSL. The water surface elevation would increase 0.15 m (0.5 ft), if the starting water surface elevation were 80.8 m (265 ft) MSL. The staff estimated the water surface elevation corresponding to the PMF, coincident wind wave action, and breach of Lakes Louisa and Orange to be 82.3 m (270 ft) MSL. The staff concludes that simultaneous arrival of all water stored in these two lakes coincident with the PMF would not result in flooding of the ESP site, which is at elevation 82.6 m(271 ft) MSL.

In the event of failure of the North Anna Dam, the proposed new nuclear power plants would rely on the UHS for essential cooling. The applicant intends to use underground reservoirs for the UHS, approximately 15.2 m (50 ft) deep. The maximum elevation of ground water at the proposed site is 82.3 m (270 ft) MSL. It is essential for ensuring the integrity of the UHS reservoirs that any uplift of the reservoirs caused by buoyancy, either during construction or during the life of the proposed plants, is precluded. Therefore, the free surface elevation of the UHS may not fall below 82.3 m (270 ft) MSL. This is **Permit Condition 2.4-5.**

In response to RAI 2.4.4-2, the applicant provided details of the UHS for the proposed units and storage capacity of the underground UHS basins. Based on the applicant's dimensions of the underground UHS basin, the staff estimated the storage capacity of the UHS basins to be 116,453 m^3 (4.1 million ft^3). Based on its review of site water availability, the staff concludes that the specified UHS storage capacity should be treated as a minimum acceptable capacity. This is **Permit Condition 2.4-6**.

2.4.4.4 Conclusions

As set forth above, the applicant has provided sufficient information pertaining to dam failures. Therefore, the staff concludes that the applicant has met the requirements relating to dam failures, with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c), and the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing the design basis dam failure, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.5 Probable Maximum Surge and Seiche Flooding

The ESP site is located on the shores of Lake Anna, approximately 80 km (50 mi) inland from the Chesapeake Bay at an elevation of 82.6 m (271 ft) MSL. Lake Anna is a 27-km (17-mi) long reservoir formed when the dam was constructed on the North Anna River. The ESP site is located at the approximate longitudinal midpoint of the reservoir, 8 km (5 mi) upstream of the North Anna Dam.

2.4.5.1 Technical Information in the Application

The applicant stated that the ESP site is not located on an estuary or an open coast, and concluded that both surge and seiche flooding would not produce critical water levels at the site. The applicant estimated a maximum fetch length of 3,230 m (10,600 ft). The applicant concluded that, given the relatively short fetch length, surges and waves produced from winds or oscillatory waves alone would not produce water heights greater than the still water level resulting from the PMF.

2.4.5.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as Appendix S to 10 CFR Part 50, 10 CFR 52.17(a), 10 CFR Part 100, and 10 CFR 100.20(c), and the applicable regulatory guidance as RGs 1.29, 1.59, 1.70, 1.102, and 1.125, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance, except that GDC 2 applies with respect to seismically induced floods and water waves. In addition, consideration of 10 CFR Part 50, Appendix S, is limited to the determination of seismically induced floods and water waves pursuant to Appendix S, Section IV(c).

Section 2.4.5 of RS-002 provides guidance for the staff's evaluation of this SSAR section. This section states that the staff's review is based on determining whether the requirements of 10 CFR Part 52 and 10 CFR Part 100 have been met, as they relate to evaluating the hydrologic characteristics of the site. Specific criteria necessary to meet the relevant hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100 are the regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c), which require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability for a nuclear reactor or reactors.

To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of the surface and subsurface hydrologic characteristics of the region and an analysis of the potential for flooding caused by surges or seiches. This description should be sufficient to assess the acceptability of the site and the potential for a surge or seiche to influence the design of SSCs important to safety for a nuclear power plant or plants of a specified type that might be constructed on the proposed site. Meeting this guidance provides reasonable assurance that the most severe flooding likely to occur as a result of storm surges[6] or seiches would not pose an undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

If it has been determined that surge and seiche flooding estimates are necessary to identify flood design bases, the applicant's analysis will be considered complete and acceptable if the following areas are addressed and can be independently evaluated from the applicant's submission:

- All reasonable combinations of probable maximum hurricane, moving squall line, or other cyclonic wind storm parameters are investigated, and the most critical combination is selected for use in estimating a water level.

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[6] A rise above normal water level on the open coast caused by the action of wind stress on the water surface. Storm surge resulting from a hurricane also includes that rise in level caused by atmospheric pressure reduction, as well as that resulting from wind stress (USACE 2003).

- Models used in the evaluation are verified or have been previously approved by the staff.

- Detailed descriptions of bottom profiles are provided (or are readily obtainable) to enable an independent staff estimate of surge levels.

- Detailed descriptions of shoreline protection and safety-related facilities are provided to enable an independent staff estimate of wind-generated waves, runup, and potential erosion and sedimentation.

- Ambient water levels, including tides and sea level anomalies, are estimated using NOAA and USACE publications as described below.

- Combinations of surge levels and waves that may be critical to the design of a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site are considered, and adequate information is supplied to allow a determination that no adverse combinations have been omitted.

This section of the SSAR may also state with justification that surge and seiche flooding estimates are not necessary to identify the flood design basis (e.g., the site is not near a large body of water).

The staff uses hydrometeorological estimates and criteria issued by USACE and NOAA for developing probable maximum hurricanes for east and Gulf Coast sites, squall lines for the Great Lakes, and severe cyclonic wind storms for all lake sites to evaluate the conservatism of the applicant's estimates of severe windstorm conditions, as discussed in RG 1.59. The USACE and NOAA criteria call for variation of the basic meteorological parameters within given limits to determine the most severe combination that could result. The applicant's hydrometeorological analysis should be based on the most critical combination of these parameters.

The staff uses data from the publications of NOAA, USACE, and other sources (such as tide tables, tide records, and historical lake level records) to substantiate antecedent water levels. These antecedent water levels should be as high as the "10% exceedance" monthly spring high tide, in addition to a sea level anomaly based on the maximum difference between recorded and predicted average water levels for durations of 2 weeks or longer for coastal locations, or the 100-yr recurrence interval high water for the Great Lakes. In a similar manner, the staff independently evaluates storm track, wind fields, effective fetch lengths, direction of approach, timing, and frictional surface and bottom effects to ensure that the most critical values have been selected. The staff verifies models used to estimate surge hydrographs that have not previously been reviewed and approved by the staff by modeling historical events, with any discrepancies in the model being on the conservative (i.e., high) side.

The staff uses criteria and methods of the USACE, as generally summarized in Reference 9 of RS-002, as a standard to evaluate the applicant's estimate of coincident wind-generated wave action and runup. In addition, the staff uses the criteria and methods of the USACE and other standard techniques to evaluate the potential for oscillation of waves at natural periodicity.

2.4.5.3 Technical Evaluation

The staff conducted its review in accordance with Section 2.4.5 of RS-002 and RG 1.59. The ESP site is located 80 km (50 mi) inland from the nearest body of open water (i.e., the Chesapeake Bay) subject to a storm surge. The ESP site is at an elevation of 82 m (270 ft) MSL. Therefore, the staff concluded that the ESP site is not subject to a storm surge.

The staff's independent evaluation to estimate seiche effects is described below. Fetch length is one of the key parameters for determining wind setup, and is generally based upon the longest straight-line distance to the opposing shore. Although the ESP site is 8 km (5 mi) from the North Anna Dam, and more than 16 km (10 mi) from the upstream end of the reservoir, the longest straight-line distance to the opposing shore is approximately 3 km (2 mi) (see Figure 2.4.5-1).

Wind setup near the ESP site is affected by irregular lake bathymetry and strong thermal stratification that exists during various parts of the year. An accurate estimate of the wind setup that considers all of these complicating factors would require use of a multidimensional hydrodynamic and water quality model.

A simplifying and conservative approach to estimating wind setup is to assume that the lake is not thermally stratified and is represented as a uniform rectangular basin with one side equal to the fetch length. The staff assumed a uniformly distributed wind stress along the water surface, so that the hydrodynamic equations of motion can be simplified, and an analytic solution for the surface setup can be obtained. The resulting solution is:

$$\varsigma = \frac{CU^2L}{h}$$

where, ζ is the wind setup in ft; U is the wind speed in mph; h is the average depth of the lake in ft; L is the fetch length in ft; and C is an empirical coefficient equal to 1.5×10^{-7} (Heaps, "Vertical Structure of Current in Homogeneous and Stratified Waters," in *Hydrodynamics of Lakes,* 1984, pp. 153–207). The staff used a value of 3,219 m (10,560 ft) for L. Bathymetry contours (see Figure 2.4.5-1) indicate the original river level was at an approximate elevation of 61 m (200 ft) MSL. Since the water depth, h, is in the denominator, a smaller depth would produce a larger (i.e., more conservative) wind setup. However, since wind setup is a relatively minor effect (no more than a few meters), a low initial lake surface elevation would indicate that the wind setup would be unlikely to reach the ESP site elevation and is not reasonable, so a deeper average water depth was chosen based upon the ESP site elevation. Accordingly, the staff used an average water depth of 11 m (35 ft).

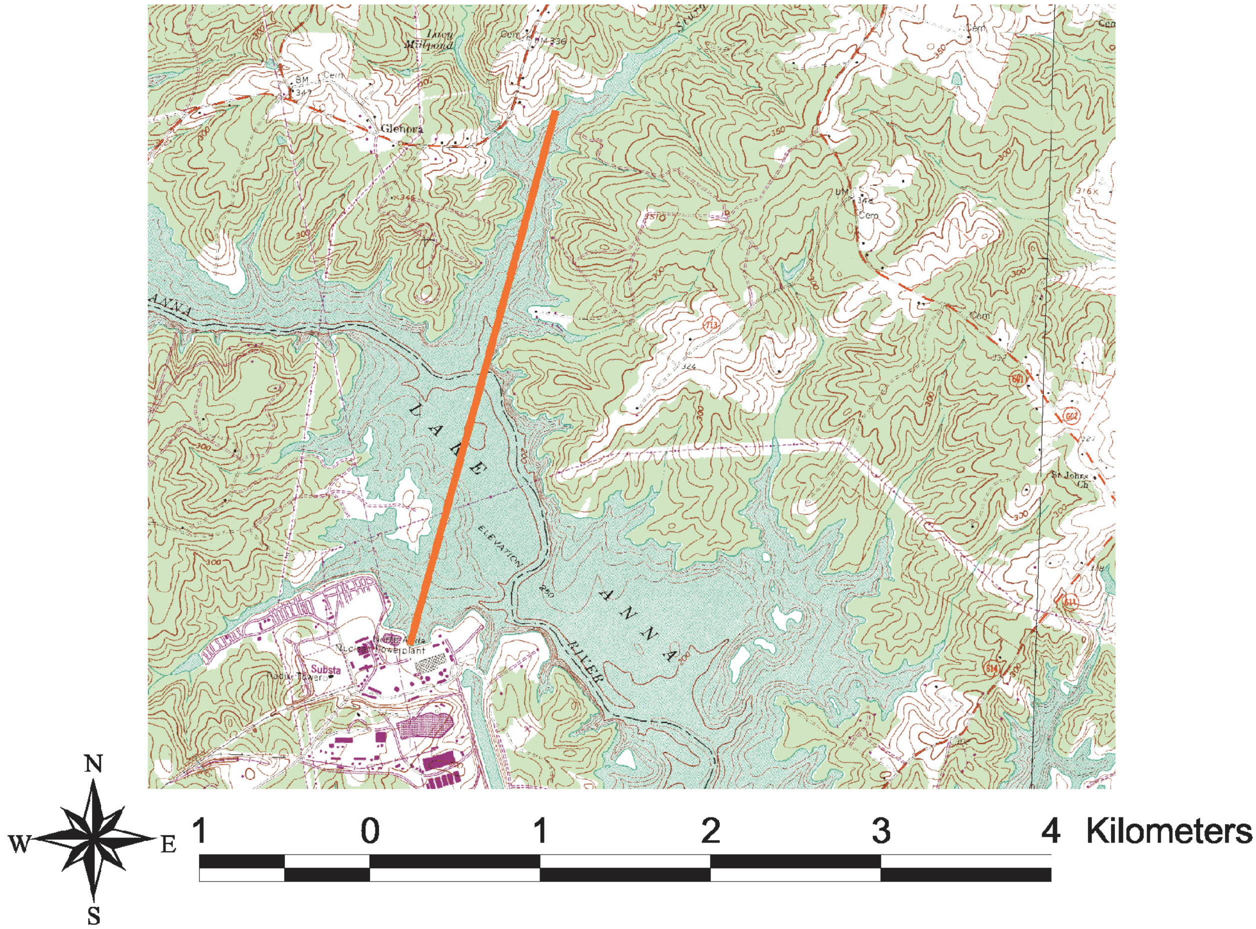

Figure 2.4.5-1 North Anna Power Station site and fetch length

Another parameter in the wind setup equation is wind speed over the water surface. One of the derivation assumptions for the wind setup equation is that the wind speed is steady and uniformly blowing in the direction of maximum fetch. ANSI/ANS-2.8-1992 suggests that, for the Great Lakes region, the maximum over-water wind speed is 169 km/h (100 mi/h). The staff used this conservative value as the steady over-water wind speed in the wind setup equation.

Using these parameters, the staff estimated the resulting wind setup as 0.14 m (0.46 ft). The staff combined this increase in water surface elevation at the ESP site with the estimated stage resulting from the PMF, as discussed in Section 2.4.3 of this SER.

The staff estimated the period of oscillation caused by seiche, along the fetch length line shown in Figure 2.4.5-1, based on the theory for free oscillation of water of uniform depth in a rectangular basin (Wilson, "Seiches," *Advances in Hydroscience,* Volume 8, 1972):

$$T = \frac{2L}{\sqrt{gh}}$$

where T is the period of seiche motion in seconds; g is the acceleration due to gravity (9.8 m/s^2 (32.2 ft/s^2)); and L and h are as defined in the equation for wind setup. The staff estimated the resulting seiche period to be approximately 10.5 minutes. This period is significantly shorter than the meteorologically induced wave periods (e.g., synoptic storm pattern frequency and dramatic reversals in steady wind direction required for wind setup). Therefore, the staff concludes that meteorologically forced resonance on Lake Anna is not likely.

Overall, the staff concludes that seismically induced seiche is not likely in Lake Anna because of the large difference between the period of oscillation caused by seiche and that of seismically induced vibration.

2.4.5.4 Conclusions

As set forth above, the applicant has provided sufficient information pertaining to identifying and evaluating surge and seiche at the site. Therefore, the staff concludes that the applicant has met the requirements relating to surge and seiche, with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c), and Section IV(c) of Appendix S to 10 CFR Part 50. In addition, the seismically induced flooding analysis reflects the most severe seismic event historically reported for the site and surrounding area (with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated), and the staff concludes that the applicant partially conforms to GDC 2, insofar as that analysis defines design bases for seismically induced surge and seiche.

2.4.6 Probable Maximum Tsunami Flooding

The ESP site is located approximately 80 km (50 mi) inland from the Chesapeake Bay (Potomac River), at an elevation of 82.6 m (271 ft) MSL, on the shores of Lake Anna, a 27-km (17-mi) long reservoir that was formed when the dam was constructed on the North Anna River. The ESP site is approximately 8 km (5 mi) upstream of the North Anna Dam.

2.4.6.1 Technical Information in the Application

The applicant stated in SSAR Section 2.4.6 that, because the site is at an inland location and not located on an estuary or open coast, tsunami flooding is not a design consideration. The applicant only considered tsunami flooding associated with seismically generated waves in open water that affect coastal areas.

2.4.6.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 52.17(a), 10 CFR Part 100, 10 CFR 100.20(c), and 10 CFR 100.23(c), and the applicable regulatory guidance as RGs 1.29, 1.59, 1.70, 1.102 and 1.125, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance, except that GDC 2 applies with respect to seismically induced floods and water waves.

Section 2.4.6 of RS-002 provides the guidance the staff used in evaluating this SSAR section, which is based on meeting the requirements of the following regulations:

- 10 CFR Part 52 and 10 CFR Part 100, as they relate to identifying and evaluating hydrologic features of the site

- 10 CFR 100.23, as it relates to investigating the tsunami potential at the site

The regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability to host a nuclear reactor or reactors. The regulations in 10 CFR Part 52 and 10 CFR Part 100 are applicable to SSAR Section 2.4.6 because they address the physical characteristics, including hydrology, considered by the Commission when determining the acceptability of the proposed site. To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of the hydrologic characteristics of the coastal region in which the proposed site is located and an analysis of severe seismically induced waves. The description should be sufficient to assess the acceptability of the site and the potential for a tsunami to influence the design of SSCs important to safety for a nuclear power plant or plants of a specified type that might be constructed on the proposed site. Meeting this guidance provides reasonable assurance that the most severe flooding likely to occur as a result of a tsunami would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

The regulation in 10 CFR 100.23(c) requires that geologic and seismic factors be considered when determining the suitability of the site. As required by 10 CFR 100.23(c), an investigation of the geologic and seismic site characteristics is conducted to permit adequate evalaution of seismic effects on the site. Such an evaluation will consider seismically induced floods and water waves. This regulation is applicable to SSAR Section 2.4.6 because it requires investigation of seismic effects on the site. Such effects include distantly and locally generated waves or tsunami that have affected or could affect a proposed site, including the runup or drawdown associated with historic tsunami in the same coastal region, as well as local features of coastal topography that might modify runup or drawdown. RG 1.70 provides more detailed guidance on the investigation of seismically induced flooding.

To meet the requirements of 10 CFR Part 52, 10 CFR Part 100, and 10 CFR 100.23, with respect to tsunami and the analysis thereof, the following specific criteria are used:

- If it has been determined that tsunami estimates are necessary to identify flood or low water design bases, the analysis will be considered complete if the following areas are addressed and can be independently evaluated from the applicant's submission:

    — All potential distant and local tsunami generators, including volcanoes and areas of potential landslides, are investigated and the most critical ones are selected.

    — Conservative values of seismic characteristics (source dimensions, fault orientation, and vertical displacement) for the tsunami generators selected are used in the analysis.

— All models used in the analysis are verified or have been previously approved by the staff. RG 1.125 provides guidance on the use of physical models of wave protection structures.

— Bathymetric data are provided (or are readily obtainable).

— Detailed descriptions of shoreline protection and safety-related facilities are provided for wave runup and drawdown estimates. RG 1.102 provides guidance on flood protection for nuclear power plants.

— Ambient water levels, including tides, sea level anomalies, and wind waves, are estimated using NOAA and USACE publications, as described below.

— If the applicant adopts RG 1.59, Regulatory Position 2, the design basis for tsunami protection of all safety-related facilities identified in RG 1.29 should be shown at the COL or CP stage to be adequate in terms of the time necessary for implementing any emergency procedures.

- The applicant's estimates of tsunami runup and drawdown levels are acceptable if the estimates are no more than 5 percent less conservative than the staff estimates. If the applicant's estimates are more than 5 percent less conservative (based on the difference between normal water levels and the maximum runup or drawdown levels) than the staff's, the applicant should fully document and justify its estimates or accept the staff estimates.

- This section of the SSAR will also be acceptable if it states the criteria the applicant used to determine that tsunami flooding estimates are not necessary to identify the flood design basis (e.g., the site is not near a large body of water).

2.4.6.3 Technical Evaluation

The staff found during its independent review that, according to NOAA (NOAA, 2004: What was the highest tsunami? Frequently asked questions, Tsunami Research Program website, http://www.pmel.noaa.gov/tsunami/Faq/x005_highest, accessed November 1, 2004), the 10 most destructive tsunamis in the Pacific Ocean since 1990 produced maximum wave heights of 3 to 15 m (9.8 to 49 ft). A wave height of 30.6 m (100 ft) was recorded on the coast of Japan during the 1993 Okushiri tsunami. The ESP site is located at an elevation of 82.6 m (271 ft) MSL. The staff therefore concluded that the effects of even the largest tsunamis in open water would not be high enough to exceed the elevation of the ESP site.

The staff also considered the potential of flooding on the shores of Lake Anna near the ESP site as a result of wave runup caused by a seismically induced hillslope failure. A hypothetical landslide was modeled to examine the potential for the ESP site to be exposed to a seismically induced water wave. The staff's calculation assumed a landslide created by the surrounding hillsides, which are at an approximate elevation of 91 m (300 ft) MSL. Assuming normal water surface level in Lake Anna, a landslide could therefore fall 15 m (50 ft) before hitting the water. If drag is neglected, an object falling from the hilltop could reach a vertical speed of approximately 17 m/s (55 ft/s). The staff conservatively assumed that such a hillslope failure might result in a horizontal water wave of the same speed. Also, the staff conservatively assumed that this landslide would displace water from the existing shoreline to the deepest portion of the river approximately 21 m (70 ft) offshore (see Figure 2.4.6-1).

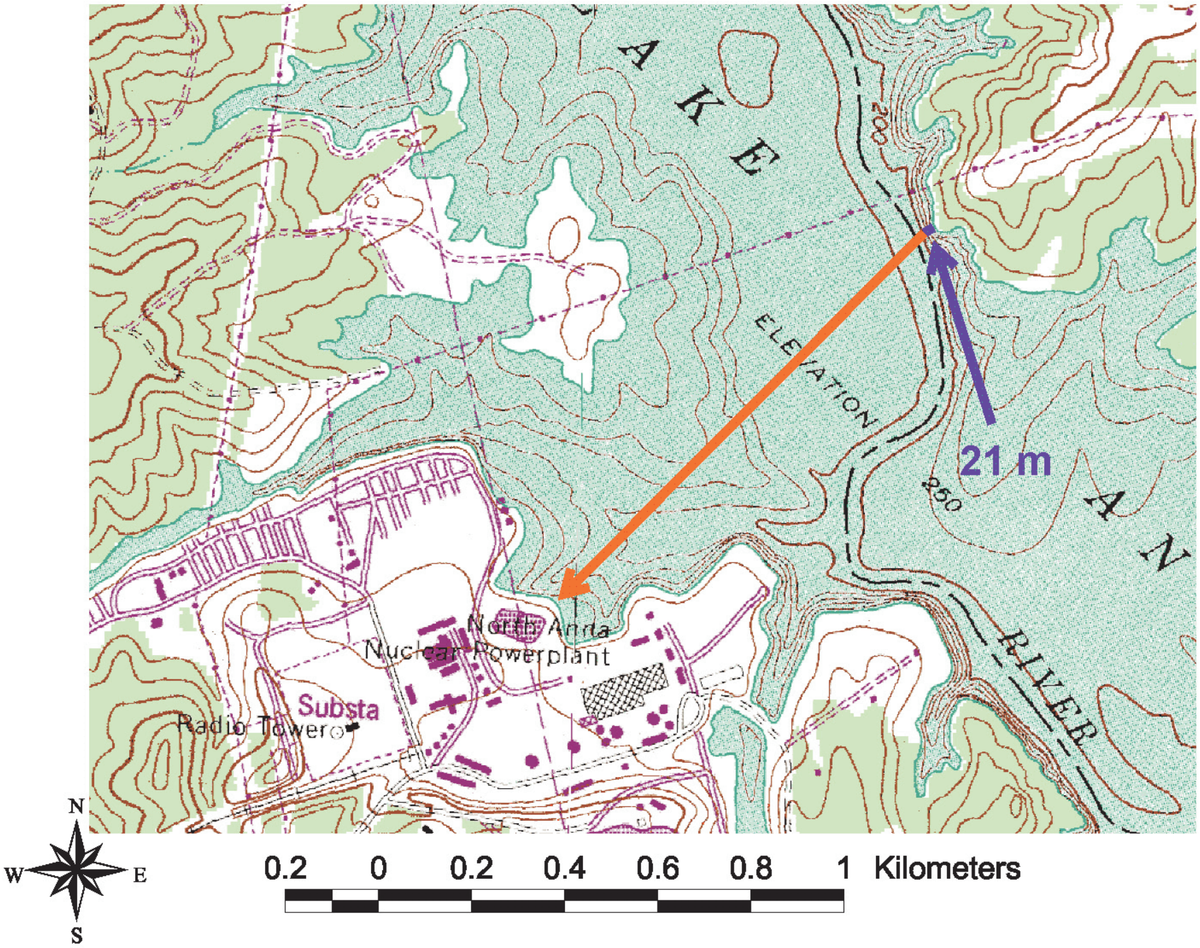

Figure 2.4.6-1 Landslide diagram resulting in wave traveling towards the ESP site. The 21 m (70 ft) segment indicated in blue is the distance from the shore to the thalweg, and represents that part of the water column displaced by the landslide.

The staff performed a numerical hydrodynamic modeling of Lake Anna using the three-dimensional transient-free surface model, Flow-3D. This model is a commercial software package that is supported though Flow Science, Inc. (Flow Science, Inc. "Flow-3D User's Manual," 2003). The model has a large user base and has been previously tested under a wide range of applications. Details of the model's theoretical background can be found in the "Flow-3D User's Manual" and in Hirt and Nichols, "Volume of Fluid (VOF) Method for the Dynamics of Free Boundaries," 1981. A recent and relevant application of the model for breaking waves, including free-surface breakup, can be found in Bradford,"Numerical Simulation of Surf Zone Dynamics," 2000.

Flow-3D uses the finite volume method to solve the three-dimensional Reynolds-averaged Navier-Stokes (RANS) equations. The physical domain simulated by the model can be divided into variable-sized hexahedral cells. The turbulence model used for this application was the Renormalized Group Model (Yakhot and Smith, “The Renormalization Group, the e-Expansion and Derivation of Turbulence Models,” 1972). The staff divided the domain into uniform cells 0.3 m (1 ft) in all directions. The staff simplified the model to two dimensions (model domain was one cell wide), and the domain totaled approximately 500,000 computational cells. Bathymetry near the ESP site was approximated using a preimpoundment contour map, which was further simplified into two sloping regions (Figure 2.4.6-2). The first region extended approximately 975 m (3200 ft) from the line following the lowest part of the lake bed (thalweg) towards the ESP site. Over this distance, the bottom rose 9 m (30 ft) from an elevation of 61 to 70 m (200 to 230 ft) MSL. The second region continued horizontally for approximately 274 m (900 ft), until intersecting the normal water surface level near the ESP site. Over this latter distance, the bottom rose 12 m (40 ft) from an elevation of 70 to 82 m (230 to 270 ft) MSL. The staff conservatively estimated bottom roughness to be equivalent to that of a smooth wall.

The staff initialized the numerical model with a 21-m (70-ft) horizontal zone with a horizontal velocity of 17 m/s (55 ft/s), while the remainder of the lake was quiescent (see Figure 2.4.6-2). The staff assumed the boundary condition at midlake to be a wall that caused outgoing waves to reflect back towards the ESP site. The boundary condition on top of the domain was gauge (atmospheric) pressure.

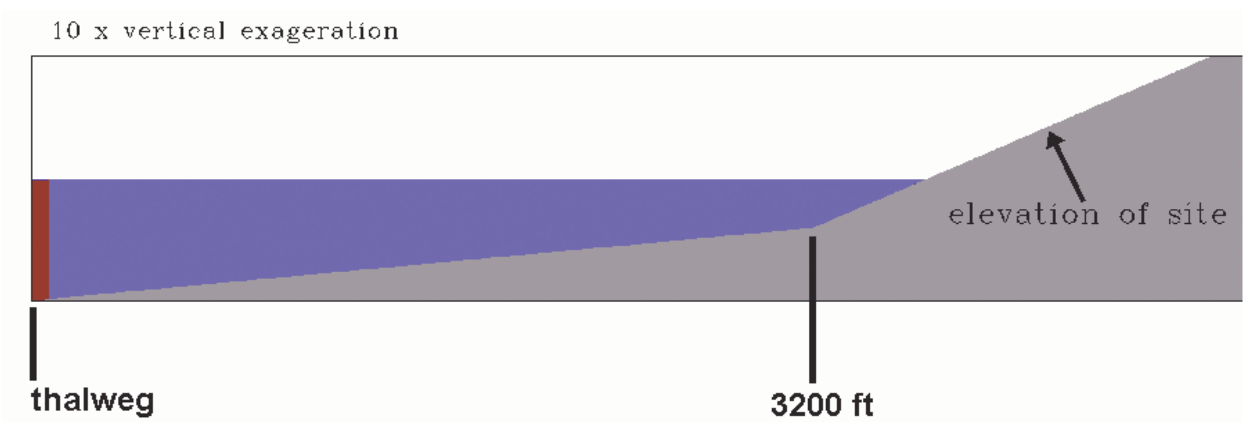

Figure 2.4.6-2 Initial conditions for the numerical model for wave runup. The red zone at the left of the figure is the 21-m (70-ft) wide zone initialized at 17 m/s (55 ft/s).

The highest extent of the wave runup was reached after approximately 118 seconds, and resembled a thin jet traveling up the smooth beach slope (see Figure 2.4.6-3). The highest extent of wave runup on the bank was just below an elevation of 83 m (270 ft) MSL, and the water did not reach the elevation of the ESP site. At an elevation of 83 m (270 ft) MSL, the wave was less than 0.3 m (1 ft) thick. The wave reached 0.6 m (2 ft) in thickness at an elevation of 79 m (260 ft) MSL, which was 3.35 m (11 ft) lower than the elevation of the ESP site.

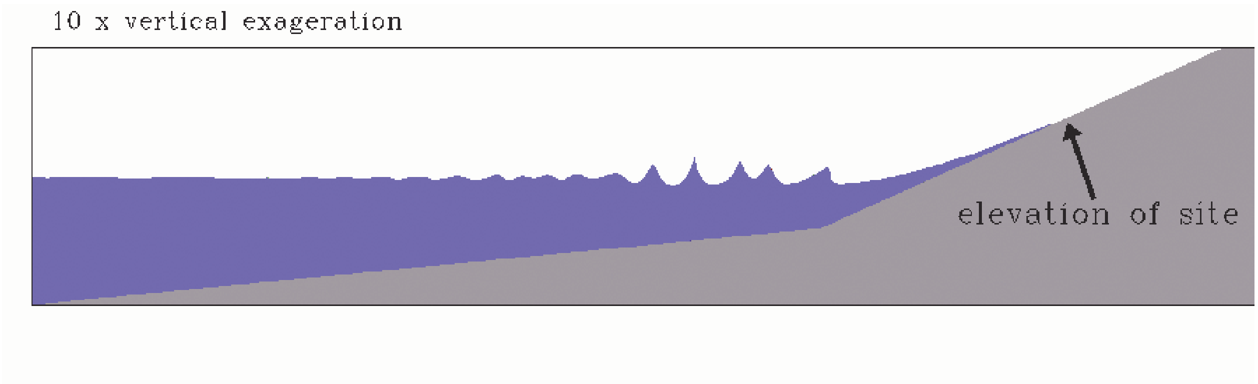

Figure 2.4.6-3 Highest extent of wave runup on shore

Therefore, the staff concluded that even under conservative conditions of flooding generated by severe landslide, the ESP site would remain dry.

2.4.6.4 Conclusions

As set forth above, the applicant has provided sufficient information pertaining to identifying and evaluating probable maximum tsunami flooding at the site. Therefore, the staff concludes that the applicant has met the requirements relating to probable maximum tsunami flooding, with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c)(3). Further, the staff finds that the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing design bases for tsunamis, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, and therefore the applicant partially conforms to GDC 2, insofar as that analysis defines design bases related to tsunamis.

2.4.7 Ice Effects

The ESP site is located approximately 80 km (50 mi) inland from the Chesapeake Bay (Potomac River) at an elevation of 82.6 m (271 ft) MSL. The climate at the site is influenced throughout the year by the Chesapeake Bay climate. The site is located on the shores of Lake Anna, a 27-km (17-mi) long reservoir that was formed when the North Anna Dam was constructed on the North Anna River. The site is located at the approximate longitudinal midpoint of the reservoir, 8 km (5 mi) upstream of the North Anna Dam.

2.4.7.1 Technical Information in the Application

In SSAR Section 2.4.7.3, the applicant discussed historical ice formation in the region. The applicant reported that, after the construction of the dam and before the start of the operation of the existing NAPS units, an ice sheet formed on the lake. However, since the beginning of operation of those units, ice sheets have formed only on the upper reaches of Lake Anna. The staff requested, in RAI 2.4.7-1, that the applicant provide details, including location, duration, and height, of the occurrence of ice dams, and subsequent downstream flood waves, in the region. In its response, the applicant stated that there are no historical records indicating the formation of ice dams in the North Anna River, and therefore no records of any subsequent downstream flooding resulting from breaking of ice dams.

SSAR Section 2.4.7.4 states that, during the design of the intake structures, any COL applicant should assess the formation of anchor ice on the trash racks and screens. The staff requested, in RAI 2.4.7-2, that the applicant provide site characteristics relevant to such an assessment, including constraints on intake design based on a propensity for anchor ice and potential ice depth. In its response, the applicant stated that site characteristics presented in SSAR Section 2.4.7.5 are not conducive to the formation of anchor ice on the trash racks and screens at the intake structure. The applicant indicated that there is no historical record of the formation of ice crystals or granules in turbulent water (resembling slush, and referred to as "frazil ice") in the existing intake structure. The applicant further stated that ice formation in the intake structure is an extremely rare event, such as when all units do not operate for prolonged periods during very severe wintry conditions. The applicant stated that when any unit is in operation, heat loads dissipated in Lake Anna would preclude the formation of any frazil ice, and thus the possibility of anchor ice. The applicant stated that an assessment would be made, at the COL stage, during the detailed design regarding whether anchor ice could form on intake structures, and that the design would address any such icing issues identified.

SSAR Section 2.4.7.5 states that, during the period the existing units have operated at the NAPS, surface ice has not formed in the area of the lake between the discharge and the intake of the plant. Ice sheets formed upstream of Route 208 during this period. The applicant stated that because the area where ice sheets formed is located far from the main circulation path of cooling water, ice sheet formation will not affect operation of the intake for the proposed additional units. The applicant also stated that ice sheet formation is possible in the lake when all units may be off line during a sustained cold period. Based on daily mean air temperature data for 1961 to 1995, the applicant stated that, during several years, the mean daily air temperature was below freezing for 1 to 3 weeks in January and February. The applicant estimated the maximum ice thickness that could have formed under historically observed low air temperature conditions, assuming no units were in operation. The applicant estimated 200 degree-days below freezing during January and February 1977. The applicant used Assur's method (described by Chow, "Handbook of Applied Hydrology," 1964) to estimate an ice thickness of 34.3 cm (13.5 in.). The applicant concluded that this surface ice thickness would not impact water flow to intakes during restart of the units because of a water depth of at least 7.3 m (24 ft) at the ESP intake.

SSAR Section 2.4.7.5 states that the emergency cooling and service water needed to maintain the proposed units in a safe mode would be supplied by a separate UHS. The staff requested, in RAI 2.4.7-3, that the applicant describe the source of cooling water needed for this purpose. In response to RAI 2.4.7-3, the applicant stated that initial filling and continued makeup water for UHS cooling tower basins would be obtained from Lake Anna.

The applicant stated that both emergency and service water would be provided by the UHS, and that safety-related facilities will not be affected by ice-flow accumulation. The staff requested, in RAI 2.4.7-4, that the applicant identify constraints on the design of the UHS with regard to ice formation, and that it indicate the maximum depth of ice formation in the water stored in the UHS to ensure the availability of sufficient water in the UHS during freezing. In its response, the applicant stated that the minimum water storage capacity of the UHS would be 115,834 m^3 (4,090,625 ft^3). The applicant stated that the UHS basins would be designed with sufficient depths to store the minimum water volume below the ice sheet, or measures would be taken to preclude the possibility of ice formation on the surface of the UHS basin.

SSAR Section 2.4.7.6 states that the PPE snow load is 50 lb/ft^2. The staff requested, in RAI 2.4.7-5, that the applicant confirm whether it calculated local snow load (a site characteristic) using the meteorological attributes discussed in SSAR Section 2.3.1.3.4. In its response, the applicant stated that the snow load for design of structures is determined using the equivalent depth of a 48-hr PMP on a 100-yr return period snowpack. The 100-yr snowpack is equivalent to 148.9 kg/m^2 (30.5 lb/ft^2), and the 48-hr PMP is equivalent to 526.8 kg/m^2 (107.9 lb/ft^2) or 0.53 m (20.75 in.) of water.

2.4.7.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 52.17(a), 10 CFR Part 100, 10 CFR 100.20(c), and 10 CFR 100.23(c), and the applicable regulatory guidance as RGs 1.27, 1.29, 1.59, 1.70, and 1.102, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance.

Section 2.4.7 of RS-002 provides review guidance used by the staff in evaluating this SSAR section. Acceptance criteria for this section are based on meeting the requirements of 10 CFR Part 52 and 10 CFR Part 100, as they relate to identifying and evaluating hydrologic features of the site.

The regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability for a nuclear power reactor. To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of any icing phenomena with the potential to result in adverse effects to the intake structure or other safety-related facilities for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. Ice-related characteristics historically associated with the site and region should be described, and an analysis should be performed to determine the potential for flooding, low water, or ice damage to safety-related SSCs. The analysis should be sufficient to evaluate the site's acceptability and to assess the potential for those characteristics to influence the design of SSCs important to safety for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. Meeting this guidance provides reasonable assurance that the effects of potentially severe icing conditions would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of relevant parameters.

RG 1.59 provides guidance for developing the hydrometeorologic design basis.

To meet the requirements of 10 CFR Part 52 and 10 CFR Part 100, as they relate to ice effects, the following specific criteria are used:

- Publications of NOAA, the USGS, USACE, and other sources are used to identify the history and potential for ice formation in the region. Historical maximum depths of icing should be noted, as well as mass and velocity of any large, floating ice bodies. The phrase, “historical low water ice affected,” or similar phrases in streamflow records (USGS and State publications) will alert the reviewer to the potential for ice effects. The following items should be considered and evaluated, if found necessary:

— The regional ice and ice jam formation history should be described to enable an independent determination of the need for including ice effects in the design basis.

— If the potential for icing is severe, based on regional icing history, it should be shown that water supplies capable of meeting safety-related needs are available from under the ice formations postulated, and that safety-related equipment could be protected from icing as in the second item above. If this cannot be shown, it should be demonstrated that alternate sources of water are available that could be protected from freezing, and that the alternate source would be capable of meeting safety-related requirements in such situations.

— If floating ice is prevalent, based on regional icing history, potential impact forces on safety-related intakes should be considered. The dynamic loading caused by floating ice should be included in the structural design basis. (This item is to be addressed at the COL or CP stage.)

— If ice blockage of the river or estuary is possible, it should be demonstrated that the resulting water level in the vicinity of the site has been considered. If this water level would adversely affect the intake structure, or other safety-related facilities of a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site, it should be demonstrated that an alternate safety-related water supply would not also be adversely affected.

- The applicant's estimates of potential ice flooding or low flows are acceptable if the estimates are no more than 5 percent less conservative than the staff estimates. If the applicant’s estimates are more than 5 percent less conservative than the staff’s, the applicant should fully document and justify its estimates or accept the staff estimates.

2.4.7.3 Technical Evaluation

In SSAR Section 2.4.7.3, the applicant discussed historical ice formation in the region. The applicant reported that, after the construction of the dam and before the start of the operation of the existing NAPS units, an ice sheet formed on the lake during the winter of 1977. Since NAPS began operating, ice sheets have formed only on the upper reaches of Lake Anna (upstream of the Route 208 bridge). The staff accessed the USACE historical database of ice jams on August 2, 2004. One ice jam was reported over the past 70 years for the North Anna River, on March 4, 1934, near the Doswell USGS gauge located approximately 25.7 km (16 mi) downstream of the ESP site. This observation suggests that ice jam formation upstream of the ESP site is possible. The breakup of an upstream ice dam may result in flood waves at the ESP site. SSAR Section 2.4.7 does not provide regional characteristics of the location, duration, height of ice dams, and ice-induced high flows.

Because there is an historical record of ice jams on the North Anna River, the staff determined that the applicant should address the possibility of an ice jam or an ice dam formation upstream of the ESP site, and should estimate the effect of a flood wave generated from the breakup of such an ice formation. This is **Open Item 2.4-4**.

Based on the information provided in the SSAR regarding the applicant's proposed UHS design, ice formation in the lake would not directly affect the UHS because its operation would be independent of the normal cooling water intake. However, ice formation in the lake could lead to increased reliance on the UHS. The staff's technical evaluation considered the safety implications of ice formation characteristics (i.e., sheet, anchor, and frazil ice) when all, some, or none of the four units (two existing and two future) would be in operation. The critical condition associated with freezing of the lake involves startup after all units have been shutdown. For this condition, it is necessary to quantify ice characteristics to be used by the COL or CP applicant for design of the intake structures.

The staff independently verified the following hydrological characteristics provided by the applicant:

- The lowest monthly minimum air temperature at the Richmond Airport for any month was !10 EC (15 EF) in January 1977. The long-term average minimum air temperature for station VA7201 is !2.5 EC (27.5 EF) in January, and !1.4 EC (29.5 EF) in February (NCDC, "Local Climatological Data Annual Summary and Comparative Data," temperature records through December 2001 for stations VA 7201, VA 6712, VA 6533, VA 5050, 2001).

- Three other NCDC weather stations surrounding the site recorded the following minimum temperatures. The lowest monthly minimum air temperature at Piedmont Research Station (station VA 6712, period of record August 1948 to December 2001) was !10 EC (13 EF) in January 1977. The long-term average minimum air temperature was !4 EC (24.0 EF) in the month of January, and !3.2 EC (26.2 EF) in February. The lowest monthly minimum air temperature at Partlow 3 WNW Station (station VA 6533, period of record June 1952 to December 1976) was !12 EC (11 EF) in January 1970. The long-term average minimum air temperature was !6.2 EC (20.8 EF) in the month of January, and !4.6 EC (23.8 EF) in February. The lowest monthly minimum air temperature at Louisa Station (station VA 5050, period of record August 1948 to December 2001) was !9.4 EC (15 EF) in January 1977. The long-term average minimum air temperature was !4 EC (24.8 EF) in January, and !3 EC (26.8 EF) in February.

The staff independently estimated the likely thickness of surface ice that may form near the intake structures. During this estimation, the staff used mean daily air temperatures recorded at the Piedmont Research Station (Station VA 6712 as discussed in the previous paragraph) located on the northwest ridge of the watershed draining into Lake Anna. The mean air temperatures at this station are available for water years 1949 to 2001. The staff estimated cumulative degree-days starting December 1 through March 31 for each water year. The most severe cumulative degree-days below freezing occurred in 1977 (Figure 2.4.7-1).

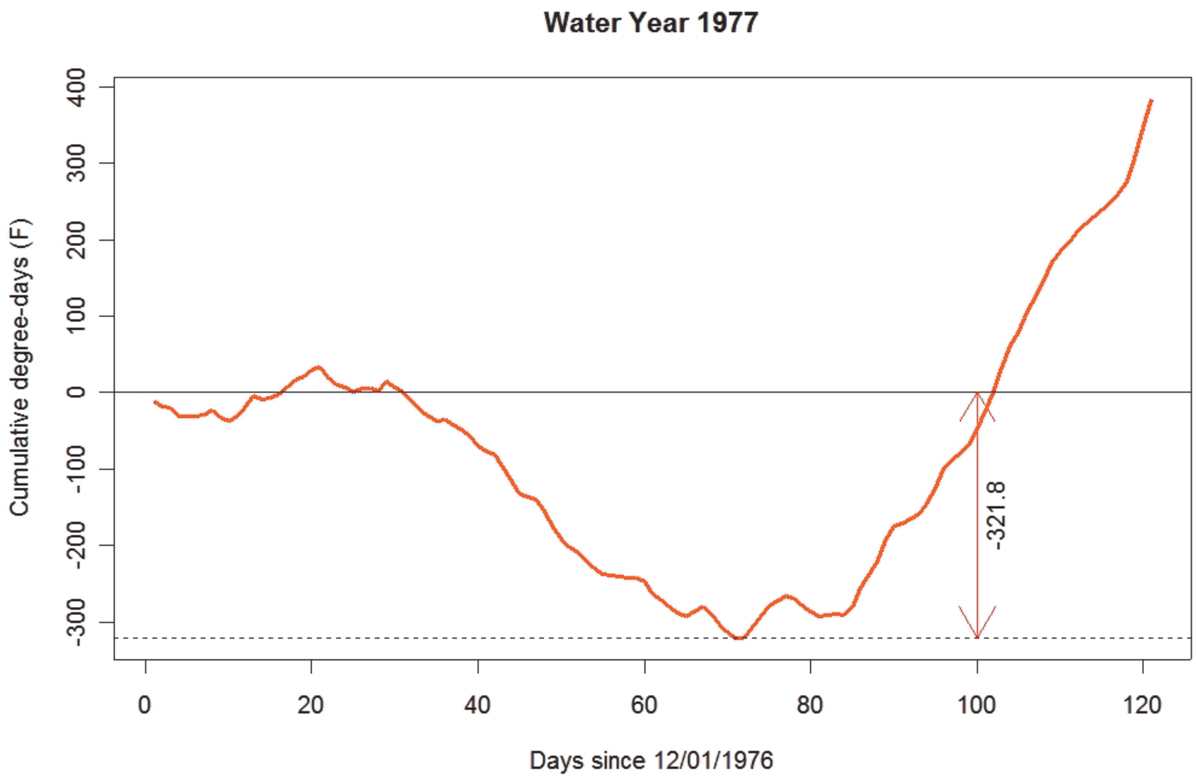

Figure 2.4.7-1 Accumulated degree-days since December 1, 1976, at the Piedmont Research Station meteorologic station

The maximum accumulated degree-days below freezing during the period of December 1, 1976, to March 31, 1977, were 178.8 EC (321.8 EF), as shown in Figure 2.4.7-1. The staff used Assur's method to estimate a maximum ice thickness of 43.4 cm (17.1 in.). The staff's estimate is higher than the applicant's estimate of 34.3 cm (13.5 in). However, this difference does not have any safety impact because, as explained below, the increase in ice thickness does not affect the intake for the proposed additional units. The staff intends to include a site characteristic value regarding intake water temperature as discussed in the following paragraph. The ice sheet could be in place for several weeks. The staff determined, based on Figure 3.4-4 of the applicant's Environmental Report and the applicant's commitment to a minimum water level of 73.8 m (242 ft) MSL, that the intake structure for the proposed additional units is at least 6.4 m (20 ft) below the minimum allowable low water level. The staff therefore concluded that the staff-calculated maximum estimated ice thickness of 43.1 cm (17.1 in) would not hamper operation of the proposed additional units. However, the staff also determined that extended periods of water temperatures at freezing are possible near the intake structure.

In response to RAI 2.4.7-2, the applicant stated that formation of frazil and anchor ice is an extremely rare condition that can only happen when all units are shut down and prolonged, wintry conditions prevail. The applicant stated that this issue would be addressed during design of the intake structures. However, the staff has determined that minimum lake temperature is a site characteristic important as a design basis for a nuclear power plant that might be constructed on the site, and therefore this is **Open Item 2.4-5.** The staff intends to include this as a site characteristic value in any ESP that the NRC may issue for this ESP application.

SSAR Section 2.4.7.5 states that a separate UHS would supply the emergency cooling and service water needed to maintain the proposed units in a safe mode. The SSAR did not identify the source of the cooling water needed for this purpose. In response to RAI 2.4.7-5, the applicant stated that the source of initial filling and continued makeup water for the UHS basins would be Lake Anna. The staff finds this to be acceptable based on the large quantity of water available for makeup and the relatively small demand represented by the UHS.

SSAR Section 2.4.7.5 states that the UHS will provide both emergency and service water, and that safety-related facilities will not be affected by ice-flow accumulation. The SSAR did not identify constraints on the design of the UHS with regard to ice formation, nor did it indicate the maximum depth of ice formation in the water stored in the UHS to ensure the availability of sufficient water in the UHS during freezing.

In response to RAI 2.4.7-4, the applicant stated that the minimum storage capacity of the UHS basins would be maintained by either providing sufficient depth, such that the minimum water volume would be available below the ice sheet, or by adopting measures that would preclude the formation of an ice sheet on the surface of the UHS basins. In order to obviate the need for any limits on the operation of the proposed units, the UHS storage capacity must be large enough to accommodate ice formation. This is **Permit Condition 2.4-7**. The applicant needs to identify an additional UHS design-basis site characteristic for use in evaluating the potential for water freezing in the UHS water storage facility. This information need is identified as an open item in Section 2.3 of this DSER.

SSAR Table 1.9-1 states that the PPE snow load is 30.5 lb/ft^2 based on the 100-year return period snow pack at the site. In response to RAI 2.4.7-3, the applicant stated that the weight of 100-year return period snow pack is 30.5 pounds per square ft and the 48-hour winter PMP is 20.75 in. In accordance with the criteria in RG 1.70, the snow load is obtained by the using a 48-hr PMP event on a 100-yr snowpack. The staff estimate of this combined load (using the applicant's 48-hour winter PMP value) is 675.7 kg/m^2 (138.4 lb/ft^2). The staff determined that this calculated site-specific snow load is overly conservative. See Section 2.3.1 of this DSER for additional information regarding this issue. Upon resolution of the open item related to snow load discussed in Section 2.3.1, the staff will establish the design snow load for the site and intends to include the value determined in any ESP that the NRC might issue for the proposed ESP site.

2.4.7.4 Conclusions

As set forth above, and with the exceptions noted, the applicant has provided sufficient information pertaining to ice effects. Therefore, the staff concludes that the applicant has met the requirements concerning ice effects, with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c), except for the matters described in the open items in Section 2.4.7.3 of this SER. Further, with the exceptions noted, the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing design basis information pertaining to ice effects, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.8 Cooling Water Canals and Reservoirs

Lake Anna was constructed to provide a reliable supply of cooling water for the NAPS. The North Anna Dam is located about 6 km (4 mi) north of Bumpass, Virginia, and about 8 km (5 mi) downriver from the ESP site. Lake Anna is about 27 km (17 mi) long, with an irregular shoreline approximately 436 km (272 mi) in length.

Lake Anna is separated into two segments by a series of dikes and canals. The larger segment, approximately 3900 ha (9600 acres), is named the North Anna Reservoir, and serves as the storage impoundment. The smaller segment, approximately 1400 ha (3400 acres), is named the Waste Heat Treatment Facility (WHTF), and functions to dissipate the heat of the cooling water discharged from the existing units to the atmosphere.

The North Anna Dam is the only significant water control structure on the North Anna River. The dam is an earth-filled structure, approximately 1500 m (5000 ft) long with a 9-m (30-ft) wide crest at elevation 81 m (265 ft) MSL. The dam has a 61-m (200-ft) long concrete spillway founded on bedrock. The spillway has three radial crest gates, each 12 m (40 ft) wide and 11 m (35 ft) high. Two skimmer gates, each 2.6 by 2.6 m (8.5 by 8.5 ft), allow regulation of small discharges.

2.4.8.1 Technical Information in the Application

The applicant stated in SSAR Section 2.4.8 that the proposed Unit 3 would use a once-through cooling system for normal plant cooling. This cooling system would withdraw cooling water at a rate of 71.9 m^3/s (2,540 cfs) from a new intake structure located west of the intake structures for the existing Units 1 and 2. The cooling water would be pumped through the proposed Unit 3 condensers and auxiliary heat exchangers, and then discharged into the WHTF for heat dissipation. A new outfall would be constructed adjacent to the existing units' outfall at the head of the discharge channel that leads into the WHTF.

The applicant informed the NRC of a revised approach to cooling the proposed Unit 4 in a letter dated March 31, 2004, and subsequently revised the SSAR to reflect this approach. The revised application states that the proposed Unit 4 would use a closed-cycle cooling system with dry cooling towers. This approach eliminates the use of Lake Anna as a source of makeup water for Unit 4, as well as the potential need for Unit 4 to rely on external water sources during drought conditions.

The applicant stated in SSAR Section 2.4.8 that the UHS for the proposed units would consist of a mechanical draft cooling tower over a buried water storage basin or other passive water storage facility. This facility would have its own source of water, independent of Lake Anna.

The applicant stated that a series of canals and dikes divide Lake Anna into two parts. The smaller part is the WHTF, and the larger part is the North Anna Reservoir. Circulating cooling water for the existing units is withdrawn from the North Anna Reservoir at the existing screen well, pumped through the condenser, and discharged through the circulating water discharge canal into the WHTF. The WHTF consists of three ponds that are interconnected by two canals. The discharge canal and the interconnecting canals are each designed to carry 226.5 m^3/s (8,000 cfs). The applicant estimated a maximum discharge capacity of 192.4 m^3/s (6,795 cfs) when all four units are operating, and concluded that the design water surface elevation of 76.7 m (251.5 ft) MSL in the WHTF would not be affected because the canals were designed for a discharge of 226 m^3/s (8,000 cfs). The canals are constructed through bedrock and are unpaved. Erosion protection is provided by vegetation on all banks, except near the discharge structure at Dike 3, where rip rap is provided.

The circulating water flows through these ponds and is discharged through six submerged skimmer gates located on Dike 3 into the North Anna Reservoir. The dikes are constructed of compacted earth material, except for a 213 m (700 ft) section of Dike 3, which is constructed of dumped rock fill. The submerged skimmer gates are constructed within the rock fill section, and the rock fill section itself acts as an emergency overflow spillway. The crest of the rock fill section is at an elevation of 77.3 m (253.5 ft) MSL, while the rest of the crest of the dike is at an elevation of 79.2 m (260 ft) MSL. When water surface elevation in the WHTF exceeds 77.3 m (253.5 ft) MSL, the rock fill section overtops, while ensuring the difference in water surface elevations between the WHTF and the North Anna Reservoir does not exceed 0.6 m (2 ft). The applicant estimated that the rock fill is likely to overtop once every 100 years.

2.4.8.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 50.55a, GDC 2 and 44, and 10 CFR Part 100, and the applicable regulatory guidance as RGs 1.27, 1.29, 1.59, 1.70, 1.102, and 1.125. The staff finds that the applicant correctly identified the applicable regulations and guidance, with the exception that an ESP applicant need not demonstrate compliance with the GDCs or 10 CFR 50.55a with respect to cooling water canals and reservoirs.

Acceptance criteria for this section are based on meeting the requirements of 10 CFR Part 52 and 10 CFR Part 100, as they relate to identifying and evaluating the hydrologic features of the site.

The regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that the site's physical characteristics (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability for a nuclear power reactor. To satisfy the hydrologic requirements of 10 CFR Part 52 and 10 CFR Part 100, the SSAR should contain a description of cooling water canals and reservoirs for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. The analysis related to cooling water canals and reservoirs should be sufficient to evaluate the site's acceptability, and to assess the potential for those characteristics to influence the design of SSCs important to safety for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. Meeting this guidance provides reasonable assurance that the capacities of cooling water canals and reservoirs are adequate.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

2.4.8.3 Technical Evaluation

The staff visually inspected the site on February 23 and 24, 2004. The staff determined that cooling canals, outfalls, and levees near the ESP site are accurately described in the application.

Section 2.4.3 of this SER presents the staff's evaluation of the ability of Lake Anna (including the WHTF) to survive a PMF. The staff did not consider Lake Anna a safety-related reservoir, since it is not a part of the proposed UHS for the proposed units.

The applicant stated that the UHS for the proposed additional units would consist of a mechanical draft cooling tower over a buried water storage basin. This UHS would have its own source of water that would be independent of the lake.

The applicant suggested that the proposed Unit 3 would use a once-through cooling system during normal plant operation. The applicant also suggested that the proposed Unit 4 would use a closed-cycle cooling system with dry towers during normal plant operation. The limitation on the quantity of cooling water and other attributes of the cooling system design for the proposed Units 3 and 4 are site constraints. Consequently, the staff intends to identify these items as site characteristics in any ESP the NRC might issue for the proposed ESP site.

The applicant did not provide details of the location and construction of the UHS buried water storage basin. These details are needed because they relate to the reliability and stability of the UHS under the pressure head of ground water, which is at the grade level at certain locations of the ESP site. Therefore, the staff could not review these details. These data are needed and are part of RAIs 2.4.1-1 and 2.4.4-2. The need for location and construction details to determine differential head between groundwater and the UHS is **Open Item 2.4-6.**

Lake Anna and the WHTF are not safety-related facilities, as described in the application. Consequently, any future design at the ESP site must not rely on the WHTF or on the North Anna Reservoir for any safety-related water use. This is **Permit Condition 2.4-8.**

The details provided in SSAR Section 2.4.8 associated with cooling water canals and reservoirs specific to the proposed Units 3 and 4 are design constraints for the COL or CP applicant.

2.4.8.4 Conclusions

As set forth above, and with the exception noted, the applicant has provided sufficient information pertaining to cooling water canals and reservoirs. Therefore, the staff concludes that the applicant has met the requirements related to cooling water canals and reservoirs, with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c)(3), except for the matters described in the open item noted in Section 2.4.8.3 of this SER. Further, with the exception noted, the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing design basis information related to cooling water canals and reservoirs, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.9 Channel Diversions

The watershed upstream of the North Anna Dam lies in the Piedmont Physiographic Province, a rolling to hilly area, underlain mostly by metamorphosed sedimentary and crystalline rocks. These rocks are relatively resistant to erosion.

2.4.9.1 Technical Information in the Application

The applicant stated in SSAR Section 2.4.9 that there has been no major channel diversion of the North Anna River. The applicant also stated that localized ice jams would not create a low-flow period of sufficient duration to affect the cooling water supply.

The staff requested, in RAI 2.4.9-1, that the applicant document historical or geological evidence of possible diversions and meandering of the North Anna River upstream of the ESP site. In its response, the applicant stated that the possibility of upstream diversion of the North Anna River is extremely remote. The applicant used interpretations of USGS topographic maps and pre-dam aerial photographs to conclude that historical channel diversions have been minor and have occurred only in ancient geologic periods. These diversions are confined to valley bottoms of the existing drainage pattern.

The applicant also stated, in response to RAI 2.4.9-1, that the underground storage basins for the UHS will be filled before plant startup and subsequently isolated from Lake Anna, thus eliminating Lake Anna as a backup water source for emergency cooling.

2.4.9.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as Appendix A to 10 CFR Part 50, GDC 44, 10 CFR 52.17(a), 10 CFR Part 100, and 10 CFR 100.20(c), and applicable regulatory guidance as RGs 1.27 and 1.70, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance, with the exception that an ESP applicant need not demonstrate compliance with the GDCs with respect to channel diversions.

Section 2.4.9 of RS-002 provides the review guidance used by the staff in evaluating this SSAR section. Acceptance criteria for this section relate to 10 CFR Part 52 and 10 CFR Part 100, insofar as they require that hydrological characteristics be considered in the evaluation of the site. The regulations in 10 CFR 52.17(a), 10 CFR 100.20(c), and 10 CFR 100.21(d) require that physical characteristics of the site (including seismology, meteorology, geology, and hydrology) be taken into account to determine the acceptability of a site for a nuclear reactor.

Channel diversion or realignment, which poses the potential for flooding or adversely affecting the supply of cooling water for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site, is one physical characteristic that must be evaluated pursuant to 10 CFR 100.21(d). Consideration of criteria under Section 100.21(d) in view of this evaluation provides reasonable assurance that the effects of flooding caused by channel diversion resulting from severe natural phenomena would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

To meet the requirements of 10 CFR Part 52 and 10 CFR Part 100, as they relate to channel diversion, the following specific criteria are used:

- A description of the applicability (potential adverse effects) of stream channel diversions is necessary.
- Historical diversions and realignments should be discussed.
- The topography and geology of the basin and its applicability to natural stream channel diversions should be addressed.
- If applicable, the safety consequences of diversion and the potential for high or low water levels, caused by upstream or downstream diversion, to adversely affect safety-related facilities, water supply, or the UHS should be addressed. RG 1.27 provides guidance on acceptable UHS criteria.

2.4.9.3 Technical Evaluation

The staff developed a basic understanding of the geomorphology of the region during its site visit. The staff's search did not produce any evidence of major channel diversion of the North Anna River. Channel diversions usually occur in relatively flat, deep alluvial plains where the river channel meanders greatly. The North Anna watershed upstream of the dam lies in the Piedmont Physiographic Province, a rolling to hilly area, underlain mostly by metamorphosed sedimentary and crystalline rocks. These rocks are relatively resistant to erosion. Because of these physiographic features, the staff concludes that channel diversion above Lake Anna is not likely.

Section 2.4.7 of this SER evaluates channel diversion caused by ice effects, and Section 2.4.11 of this SER evaluates the resulting low-water conditions.

In response to RAI 2.4.9-1, the applicant provided details of topographic and geomorphologic interpretations carried out using USGS topographic maps and pre-dam aerial photographs. The applicant concluded that the likelihood of diversion of North Anna River from its present drainage pattern is extremely remote. The staff concluded that the applicant has provided sufficient information to address this issue, and this information supports the above staff conclusion.

2.4.9.4 Conclusions

As set forth above, the applicant has provided information pertaining to channel diversions showing that channel diversion above Lake Anna is not likely. Therefore, the staff concludes that the applicant has met the requirements regarding channel diversions, with respect to 10 CFR 52.17(a), 10 CFR 100.20(c)(3), and 10 CFR 100.21(d). Further, the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing design basis information related to channel diversions, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.10 Flooding Protection Requirements

The proposed ESP site grade is at an elevation of 82.6 m (271.0 ft) MSL.

2.4.10.1 Technical Information in the Application

In SSAR Sections 2.4.2 and 2.4.3, the applicant estimated the design-basis flood elevation at the ESP site to be 81.5 m (267.4 ft) MSL. This elevation includes effects of flooding caused by a PMF resulting from a PMP over the North Anna Dam's drainage area, wind setup, and wave runup. The applicant stated that all safety-related SSCs for the proposed additional units would be placed at or above the existing site grade of 82.6 m (271.0 ft) MSL. The applicant therefore concluded that no safety-related flood-protection facilities are required for the ESP site.

In SSAR Sections 2.4.2 and 2.4.10, the applicant stated that the drainage design for the ESP site would consider the effects of intense, local precipitation. Safety-related facilities associated with the proposed additional units would be designed to withstand the peak discharge resulting from local, intense precipitation. In addition, the applicant stated that new facilities would incorporate measures to ensure that the existing units' safety-related facilities would not be compromised by flooding as a result of either construction or operation of the proposed additional units.

2.4.10.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 50.55a, GDC 2, 10 CFR 52.17(a), and 10 CFR 100.20(c), and the applicable regulatory guidance as RGs 1.29, 1.59, 1.70, 1.102, and 1.125. The staff finds that the applicant correctly identified the applicable regulations and guidance, with the exception that an ESP applicant need not demonstrate compliance with the GDCs or with 10 CFR 50.55a with respect to flooding protection. Acceptance criteria for this section relate to 10 CFR Part 52 and 10 CFR Part 100, insofar as they require that hydrological characteristics be considered in the evaluation of the site. Specifically, the regulations in 10 CFR 52.17(a) and 10 CFR 100.20(c) require that physical characteristics of the site (including seismology, meteorology, geology, and hydrology) be taken into account to determine the acceptability of a site for a nuclear reactor.

The regulation in 10 CFR 100.20(c) requires that the PMF be estimated using historical data. Meeting this requirement provides reasonable assurance that the effects of flooding or a loss of flooding protection resulting from severe natural phenomena would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

To meet the requirements of 10 CFR Part 52 and 10 CFR Part 100, as they relate to flooding protection, the following specific criteria are used:

- The applicability (potential adverse effects) of a loss of flooding protection should be described.
- Historical incidents of shore erosion and flooding damage should be discussed.
- The topography and geology of the basin and its applicability to damage as a result of flooding should be addressed.
- If applicable, the safety consequences of a loss of flooding protection, and the potential to adversely affect safety-related facilities, water supply, or the UHS should be addressed. RG 1.27 provides guidance on acceptable UHS criteria.

2.4.10.3 Technical Evaluation

During its review of SSAR Sections 2.4.2 and 2.4.3, the staff estimated the design-basis flood elevation to be 82.14 m (269.5 ft) MSL. The staff estimated local, intense precipitation for the ESP site to be 46.6 cm/hr (18.35 in./hr). Table 2.4.2-1 in Section 2.4.2 of this SER provides the complete hyetograph (a chart or graphic representation of the average distribution of rain over the site surface area) for the 6-hr local, intense precipitation.

Since the ESP site grade (at an elevation of 83 m (271.0 ft) above MSL) is higher than the design-basis flood elevation (82.3 m (270 ft) MSL), there are no applicable flood protection requirements. However, to ensure that safety-related SSCs that may be constructed on the proposed site are protected from flooding, they must be constructed with ingress and egress openings located above the elevation of 83 m (271 ft) MSL. This is **Permit Condition 2.4-9.** The staff plans to include the grade elevation as a PPE in any ESP that might be issued for the proposed site.

The need to protect the slope embankment at the intake location is based on the potential for degradation resulting from water and wave action. The requirement to provide erosion protection to protect the slope embankment is **Permit Condition 2.4-10**.

Any COL or CP applicant will be required to ensure that the flood control measures protecting the safety-related facilities of the existing units will not be compromised during construction or operation of the proposed units. This is **Permit Condition 2.4-11.**

2.4.10.4 Conclusions

As set forth above, the applicant has provided information pertaining to flooding protection requirements showing that the design-basis flood elevation is below the proposed grade of the ESP PPE (site footprint), and no flood protection measures are needed. Therefore, the staff concludes that the applicant has met the flood protection requirements with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c)(3). Further, the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing design basis information for flood protection, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.11 Low Water Considerations

The site is adjacent to Lake Anna, which provides the cooling water for the current and proposed units. Events that may potentially reduce or limit the availability of cooling water at this site include low lake elevation, seiches, wind-induced set down, and intake blockages from sediment or from ice.

The normal cooling water supply for nonsafety-related needs of the proposed units would be obtained from Lake Anna, created by the North Anna Dam. Thirty-day emergency cooling water would be provided by the UHS underground storage basins, which the applicant stated would be maintained full and are not dependent upon the water level in Lake Anna for their safety function.

Normal operation for the proposed Unit 3 would utilize a once-through cooling system, operated with water drawn from Lake Anna. The applicant's March 31, 2004, letter to NRC stated that the proposed Unit 4's normal operation cooling system would utilize dry cooling towers. The proposed UHS for both proposed units would be supplied from underground water storage basins. The applicant subsequently revised the SSAR to be consistent with the statements made in this letter.

2.4.11.1 Technical Information in the Application

The applicant considered constraints on water availability resulting from seiches in SSAR Section 2.4.11.2, from drought in Section 2.4.11.3, and from future controls in Section 2.4.11.4. In Section 2.4.11.4, the applicant cited its ESP Environmental Report (ER) (Part 3), Section 5.2.2, which describes a water budget calculation that estimates the lake elevation changes associated with the addition and operation of the proposed Unit 3. This water budget analysis considered the impact of induced evaporation associated with the proposed Unit 3 cooling system, and it provided information on the frequency and magnitude of low-water conditions in the lake.

In RAI 2.4.11-1, the staff requested information regarding critical ambient conditions, such as air temperature and relative humidity, which might limit operation of the UHS or constrain the safety-related cooling tower design. In its response, the applicant pointed out that the limiting conditions of plant operation from meteorological conditions related to the UHS cooling tower are discussed in its response to RAI 2.3.1-1. The applicant also stated that critical wet- and dry-bulb conditions would affect maximum evaporation and drift loss, along with minimum cooling from the UHS.

In Section 2.4.11.3 of the SSAR, the applicant stated that the minimum observed Lake Anna water surface elevation was 74.71 m (245.1 ft) MSL on October 10, 2002. This low water level followed the driest September to August period and the third driest October to September period in the 108-yr record for Virginia's statewide precipitation.

In SSAR Section 2.4.11.4, the applicant provided the results of a water budget analysis to estimate the lake levels, which is described in further detail in the applicant's ER (Part 3), Section 5.2.2. With all four units operating, the applicant estimated the minimum lake level to be 73.94 m (242.6 ft) MSL. In SSAR Section 2.4.11.1, the applicant stated that the shutdown threshold level for the existing units is an elevation of 74.37 m (244.0 ft) MSL. The shutdown threshold level for the new units would be an elevation of 73.76 m (242.0 ft) MSL. Section 2.4.11.3 of this SER further discusses these two different shutdown threshold levels, and the related minimum lake elevations.

In RAI 2.4.11-2, the staff requested the applicant to describe likely upstream land-use changes and changes in downstream water demand that could alter the frequency of low-flow conditions and related minimum water elevation in Lake Anna. This RAI also requested the applicant to calculate the availability of cooling water during critical low-flow periods, including sufficient margins to account for future urbanization of the watershed. In addressing this issue, the applicant stated that its response to the staff's environmental RAI E4.2.2-2 provided a description of the projected upstream development based on growth plans for the counties in the drainage area. All three upstream counties (Louisa, Orange, and Spotsylvania) anticipate future growth in areas near existing towns. Increased development would impact low-flow conditions because of increased ground water withdrawals and increased impervious areas. Decreased ground water levels may lead to reduced baseflow to Lake Anna. The applicant stated that the anticipated development is small compared to the size of the watershed, and concluded that its impact on low-flow conditions will be small. The applicant also concluded that the water balance model presented in ER (Part 3) Section 5.2.2 would be accurate, even after consideration of the impact resulting from upstream land-use changes. The applicant described the margins available in the cooling water supply in its response to RAI 2.4.1-1.

2.4.11.2 Regulatory Evaluation

Section 1.8 of the SAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as GDCs 2 and 44, as well as 10 CFR 100.23(c), and identified the applicable regulatory guidance as RGs 1.27 and 1.70, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance, with the exception that an ESP applicant need not demonstrate compliance with the GDCs with respect to low water considerations.

Acceptance criteria for this section relate to the following regulations and criteria:

- 10 CFR Part 52 and 10 CFR Part 100 require that hydrologic characteristics be considered in the evaluation of the site.

- 10 CFR 100.23 requires, in part, that siting factors to be evaluated must include cooling water supply.

The regulations in 10 CFR Part 52 and 10 CFR Part 100 require, in part, that hydrologic characteristics be considered in the evaluation of a nuclear power plant site. In order to satisfy 10 CFR Part 52 and 10 CFR Part 100, the applicant should describe in the SSAR the surface and subsurface hydrological characteristics of the site and region. In particular, the UHS for the cooling water system may consist of water sources affected by, among other things, site hydrological characteristics that may reduce or limit the available supply of cooling water for safety-related SSCs. Site hydrological characteristics that may reduce or limit the flow of cooling water include those resulting from river blockage or diversion, tsunami runup and drawdown, and dam failure.

Meeting the requirements of 10 CFR Part 52 and 10 CFR Part 100 provides assurance that severe hydrologic phenomena, including low-water conditions, would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

The regulation in 10 CFR 100.23 requires that siting factors, including cooling water supply, be evaluated. The evaluation of the emergency cooling water supply for a nuclear power plant(s) of a specified type (or falling within a PPE) that might be constructed on the proposed site should consider river blockages, diversion, or other failures that may block the flow of cooling water, tsunami runup and drawdown, and dam failures.

The regulation in 10 CFR 100.23 applies to this section because the UHS for the cooling water system consists of water sources that are subject to natural events that may reduce or limit the available supply of cooling water (i.e., the heat sink). Natural events, such as river blockages or diversion or other failures that may block the flow of cooling water, tsunami runup and drawdown, and dam failures, should be conservatively estimated to assess the potential for these characteristics to influence the design of SSCs important to safety for a nuclear power plant of a type specified by the applicant (or falling within a PPE) that might be constructed on the proposed site. The available water supply should be sufficient to meet the needs of the plant(s) to be located at the site; those needs may fall within a PPE (e.g., the stored water volume of the cooling water ponds), if an applicant uses that approach. Specifically, those needs include the maximum design essential cooling water flow, as well as the maximum design flow for normal plant needs at power and at shutdown.

To meet the requirements of the hydrologic aspects of the above regulations, the specific criteria discussed in the paragraphs below are used. Acceptance is based principally on the adequacy of the UHS to supply cooling water for normal operation, anticipated operational occurrences, safe shutdown, cooldown (first 30 days), and long-term cooling (periods in excess of 30 days) during adverse natural conditions.

<u>Low Flow in Rivers and Streams</u>

For essential water supplies, the low-flow/low-level design for the primary water supply source is based on the probable minimum low flow and level resulting from the most severe drought that can reasonably be considered for the region. The low flow and level site parameters for operation should be such that shutdowns caused by inadequate water supply will not trigger frequent use of emergency systems.

<u>Low Water Resulting from Surges, Seiches, or Tsunami</u>

For coastal sites, the appropriate probable maximum hurricane (PMH) wind fields should be postulated at the ESP stage to provide maximum winds blowing offshore, thus creating a probable minimum surge level. Low water levels on inland ponds, lakes, and rivers caused by surges should be estimated from probable maximum winds oriented away from the plant site. The same general analysis methods discussed in Sections 2.4.3, 2.4.5, and 2.4.6 of RS-002 are applicable to low-water estimates resulting from the various phenomena discussed. If the site is susceptible to such phenomena, minimum water levels resulting from setdown (sometimes called runout or rundown) from hurricane surges, seiches, and tsunami should be verified at the COL or CP stage to be higher than the intake design basis for essential water supplies.

Historical Low Water

If historical flows and levels are used to estimate design values by inference from frequency distribution plots, the data used should be presented so that an independent determination can be made. The data and methods of NOAA, USGS, SCS, USBR, and USACE are acceptable.

Future Controls

This section is acceptable if water use and discharge limitations (both physical and legal), already in effect or under discussion by responsible Federal, regional, State, or local authorities, that may affect water supply for a nuclear power plant of a type specified by the applicant that might be constructed on the proposed site, have been considered and are substantiated by reference to reports of the appropriate agencies. The design basis should identify and take into account the most adverse possible effects of these controls to ensure that essential water supplies are not likely to be negatively affected in the future.

2.4.11.3 Technical Evaluation

The applicant has stated that the proposed additional units will not rely on Lake Anna for safety-related water needs. Further, the applicant has proposed engineered subsurface water reservoirs and mechanical cooling towers to fulfill UHS requirements.

The staff has performed its review in accordance with the guidance in RS-002 regarding the frequency of shutdown of operating units. Low upstream tributary inflow and minimum lake elevations for operation of all four units should be such that shutdowns caused by inadequate water supply do not cause frequent use of emergency systems. Hydrologic conditions that could lead to low lake elevations can be characterized as follows:

- gradual, such as a sustained drought
- abrupt and prolonged, such as failure of the North Anna Dam
- abrupt, but temporary, such as hillslope failure

The technical evaluation in this section focuses on the gradual decrease in water elevation associated with drought; Section 2.4.4 of this SER discusses abrupt and prolonged low flow conditions resulting from a failure of the North Anna dam. Section 2.4.6 addresses the abrupt but temporary low flow condition caused by a hillslope failure. Wave runup results in high water level from a baseline pool level as the wave approaches the shore and a low water level as the wave recedes from the shore. Declines in the lake elevation will be sufficiently gradual to provide advance warning to properly respond to low-water conditions during which the UHS would be used, except in the case of failure of the North Anna Dam.

The staff performed an independent analysis of the Lake Anna water budget under critical conditions to estimate extreme low-water elevation. The staff constructed a coupled water budget and temperature model consistent with the limited available data. The water-budget component of the model was based on a lumped representation of the conservation of mass. The water temperature component of the model was a lumped, two-compartment representation of the lake based on conservation of energy. The water budget and temperature components are linked through the evaporation process.

In this water-budget model, changes in lake storage over time were equal to the differences between the inflows and the outflows. Inflows consisted of runoff from drainage upstream of the lake and precipitation occurring directly on the lake. Outflows consisted of the natural and induced evaporations and releases from the dam.

The staff estimated inflows from the drainage upstream of the lake using data from an adjacent drainage basin, the Little River drainage, adjusted for the difference in drainage areas. The Little River drainage area comprises 277 km^2 (107 mi^2) adjacent to the North Anna drainage. Based on a review of streamflow records from USGS gauge 01671100 (Little River near Doswell, Virginia), the staff selected the period from October 2001 to September 2002 as the critical water year. The staff used precipitation records from the meteorological station at the Richmond, Virginia, airport to estimate direct precipitation on the lake.

The staff estimated outflows from the lake based on the current operating rules for the Lake Anna Dam. This estimation did not reflect the fact that the current units are not allowed to operate below 74.4 m (244 ft) MSL, and that the applicant proposes not to operate the additional Unit 3 below 73.8 m (242 ft) MSL. Rather, for conservatism, the staff's analysis assumed all units continued to operate below these thresholds.

The staff estimated the evaporative loss from the ambient compartment of the lake from the Massachusetts Institute of Technology model (Ho, Edmond and E.E. Adams,"Final Calibration of the Cooling Lake Model for North Anna Power Station," Ralph M. Parsons Laboratory, Aquatic Science and Environmental Engineering, Department of Civil Engineering, Massachusetts Institute of Technology, Report No. 295, August, 1984). This model was empirically validated through onsite observation for the licensing of NAPS Units 1 and 2, and is acceptable. The staff derived the evaporative loss from the fixed temperature compartment using the applicant's PPE values. The staff performed sensitivity analyses to assess the impact of various evaporative loss assumptions.

The staff determined the minimum water surface elevation to be 74.4 m (244 ft) MSL when the existing units and the proposed Unit 3 are operating. The staff estimated that water surface elevation in the lake would fall to this minimum elevation only infrequently during low-water years. The applicant has proposed a minimum water surface elevation of 73.8 m (242 ft) MSL in SSAR Section 2.4.11.1.

Since the applicant's proposed minimum water surface elevation is lower than the staff's estimate, the applicant's value is acceptable. The staff intends to include this value as a site characteristic in any ESP the NRC might issue for the proposed site.

In RAI 2.4.11-1, the staff requested that the applicant estimate the frequency of low-water conditions that could result in use of the UHS. The staff further asked the applicant to describe in greater detail the critical ambient conditions, such as combinations of temperature and relative humidity, that might limit operations under low-water conditions. In its response, the applicant only discussed the issue related to evaporation loss from the UHS. Icing in the UHS storage basin may also result in limits on UHS operation. The staff determined, in Section 2.3.1.3 of this SER, that the 7-day average of low air temperature is !6.7 EC (19.9 EF). In order to obviate the need for limits on the operation of the proposed units, any COL or CP applicant should design the UHS storage capacity to accommodate ice formation at the sustained low-air temperature of !6.7 EC (19.9 EF). This is a permit condition, as discussed in Section 2.4.7 of this SER. The applicant's response to RAI 2.4.11-1 is satisfactory, based on the discussions above.

Future land-use development, such as urbanization of the upstream Lake Anna watershed, may lead to changes in consumptive water use. As an indicator of future development, the population of Louisa County, where the site is located, grew 25 percent from 1979 to 2000, and residential land use grew from 1.8 to 5.5 percent during the same period. Likely upstream land-use changes and changes in downstream water demand could alter the occurrence of low-flow conditions and related minimum lake levels.

In its response to RAI 2.4.11-2, the applicant indicated that upstream development is expected to be small compared to the size of the watershed and will have only a small effect on low-flow conditions. Based on this response, the staff determined that the applicant has adequately discussed the effects of upstream land-use change in the drainage area. The applicant identified cooling water needs that may lead to restrictions on the operation of future plants because of changes in the frequency of low-flow conditions and related minimum water elevation in Lake Anna. Any COL or CP applicant should identify the limiting conditions and propose the corresponding action. This is **COL Action Item 2.4-1.** The applicant's response to RAI 2.4.11-2 is satisfactory, based on the discussions above.

2.4.11.4 Conclusions

As set forth above, the applicant has provided information pertaining to low-water considerations, including hydrologic conditions that could lead to low lake elevations, conditions that could result in use of the UHS, and potential effects of upstream land-use change in the drainage area. Therefore, the staff concludes that the applicant has met the requirements related to low-water considerations with respect to 10 CFR 52.17(a) and 10 CFR 100.20(c). Further, the applicant has considered the most severe natural phenomena that have been historically reported for the site and surrounding area in establishing design basis information for low-water conditions, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.12 Ground Water

The North Anna Site is located in the Piedmont Physiographic Province in an area underlain by crystalline bedrock. The powerblock for the proposed additional units would be sited on soil that was disturbed during construction of the now-abandoned NAPS Units 3 and 4. Further disturbance of the subsurface environment is expected during construction of the proposed additional units.

2.4.12.1 Technical Information in the Application

In SSAR Section 2.4.12, the applicant provided a description of regional hydrogeology and ground water conditions based on reports prepared by the USGS, the Environmental Protection

Agency, and the Commonwealth of Virginia. In a generalization to the Piedmont Physiographic Province, Trapp and Horn (“Ground Water Atlas of the United States, Segment 11, Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia,” U.S. Geological Survey, Hydrologic Investigations Atlas 730-L, 1997) characterize the bedrock as “almost impermeable” and as yielding “water primarily from secondary porosity and permeability provided by fractures.” Water occurs primarily in a regolith (a layer of weathered, heterogeneous material overlying bedrock) of variable thickness. In discussing the hydrogeology of areas underlain by crystalline bedrock, Trapp and Horn state that the porosity of the regolith ranges between 20 and 30 percent, while the porosity of the bedrock is about 0.01 to 2 percent. Most fractures in the bedrock are steeply inclined, while “the size, number, and interconnection of the fractures decreases with depth.” Recharge to the aquifers in the Piedmont Physiographic Province occurs primarily from infiltration. Within the subsurface, water tends to follow the topography, moving from upland recharge areas to discharge areas at lower elevations.

The applicant based most of its description of local hydrogeology at the North Anna site on previous site investigations. In addition, the applicant conducted more recent site sampling and analysis as part of its subsurface investigation program. The applicant drilled seven boreholes (B01 to B07) and installed nine observation wells (OW-41 to OW-49) as part of this program. The applicant stated that the subsurface consists of five zones, the crystalline parent rock, weathered rock, two zones of saprolite (altered and weathered bedrock due to continual exposure to moisture still in place) distinguished by the amount of core stone in each zone, and residual soils. The borehole logs identify a sixth material, the fill, which occurs in the area near the abandoned Units 3 and 4. The applicant screened eight of the observation wells in the unconsolidated materials (residual soil, saprolite, or weathered rock) and one in the parent rock.

Previous studies (e.g., "Updated Final Safety Analysis Report, Revision 38, North Anna Power Station, Virginia Power") predicted that maximum ground water elevations beneath the site in the existing plant area could reach 80.0 to 82.3 m (265 to 270 ft) MSL based on a uniformly sloping water table from 82.6 m (271 ft) MSL at the toe of the slope south of abandoned Units 3 and 4 to the 76.2 m (250 ft) MSL elevation of Lake Anna. Figure 2.4-16 in the SSAR shows that water levels in new wells, OW-844 and OW-841, vary from about 81.4 m (267 ft) MSL (at OW-844) to 76.2 m (250 ft) MSL (at OW-841). The applicant used these measurements to support a design ground water level of 80.0 to 82.3 m (265 to 270 ft) MSL in the PPE (site footprint) of the ESP site.

The applicant conducted slug tests in the newly installed wells to provide estimates of saturated hydraulic conductivities. Saturated hydraulic conductivities for the wells drilled into the unconsolidated subsurface zone ranged from 0.06 to 1.0 m/d (0.2 to 3.4 ft/d). The slug test failed conditions set by the Bouwer-Rice method ("A Slug Test Method for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells, Water Resources Research, vol. 12, no. 3, pp. 423-428, 1976) for the well screened into the consolidated rock because of the short duration of stable data. This is frequently the case in consolidated rock. The applicant estimated the hydraulic conductivity using available slug test data and presented the results in SSAR Table 2.4-16. The saturated hydraulic conductivity values reported for this well were 0.54 to 0.94 m/d (1.8 to 3.1 ft/d).

SSAR Figure 2.4-15 depicts ground water levels between December 2002 and June 2003. The staff requested, in RAI 2.4.12-1, that the applicant update this figure with piezometer data from June 2003 to September 2003 and piezometer data before December 2002, if they exist, or explain how this span of data represents the seasonal variation in ground water levels. The staff also asked the applicant to explain how the ESP subsurface investigation program is consistent with previous ground water measurements. In its response, the applicant stated that it would update SSAR Table 2.4-15 and Figure 2.4-15 to include ground water level measurements taken at the North Anna site on September 29, 2003. The applicant also concluded that the quarterly measurements recorded for the ESP application appear to generally reflect the magnitude of ground water level fluctuation on a yearly basis. Further, the applicant noted that maximum ground water level fluctuations are likely to occur over much longer periods of time, and may be about 60 percent greater than those measured during the 1-yr ESP recording period.

2.4.12.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of the applicant's conformance to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as 10 CFR 52.17(a), 10 CFR 100.20(c), 10 CFR 100.23, and 10 CFR 100.23(c), and the applicable regulatory guidance as RGs 1.27, 1.29, and 1.70, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance.

Acceptance criteria for this section relate to the following regulations and criteria:

- 10 CFR Part 52 and 10 CFR Part 100 require that hydrologic characteristics be considered in the evaluation of the site.

- 10 CFR 100.23 sets forth the criteria to determine the suitability of design bases for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site with respect to seismic characteristics of the site. It also requires that siting factors, including the cooling water supply, be evaluated, taking into account information concerning the physical, including hydrological, properties of the materials underlying the site.

As specified in 10 CFR 100.20(c), the site's physical characteristics (including seismology, meteorology, geology, and hydrology) must be considered when determining its acceptability for a nuclear power reactor.

The regulation in 10 CFR 100.20(c)(3) requires that factors important to hydrological radionuclide transport be addressed using onsite characteristics. Pursuant to the hydrologic requirements of 10 CFR Part 100, the SSAR should describe ground water conditions at the proposed site and how those conditions will be affected by the construction and operation of a nuclear power plant or plants of a specified type that might be constructed on the site. Meeting this guidance provides reasonable assurance that ground water at or near a proposed site will not be significantly affected by the release of radioactive effluents from a plant(s) of a specified type that might be constructed on the proposed site.

The regulation in 10 CFR 100.23 requires that geologic and seismic factors be considered when determining the suitability of the site for each nuclear power plant. In particular, 10 CFR 100.23(d)(4) requires that such factors as the physical properties of materials underlying the site and cooling water supply be evaluated. The regulation in 10 CFR 100.23 is applicable to SSAR Section 2.4.12 because it addresses requirements for investigating vibratory ground motion, including the hydrologic conditions at and near the site. Static and dynamic engineering properties of the materials underlying the site should be determined, including the properties (e.g., density, water content, porosity, and strength) needed to determine the behavior of those materials in transmitting earthquake-induced motions to the foundations of a plant or plants of a specified type (or falling within a PPE) that might be constructed on the site.

Meeting this guidance provides reasonable assurance that the effects of a safe-shutdown earthquake would pose no undue risk to the type of facility proposed for the site.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

To meet the requirements of the hydrologic aspects of 10 CFR Part 52 and 10 CFR Part 100, the following specific criteria are used:

- A full, documented description of regional and local ground water aquifers, sources, and sinks is necessary. In addition, the type of ground water use, wells, pump, and storage facilities, as well as the flow needed for a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the site should be described. If ground water is to be used as an essential source of water for safety-related equipment, the design basis for protection from natural and accident phenomena should be compared with the RG 1.27 guidelines. Bases and sources of data should be adequately described and referenced.

- A description of present and projected local and regional ground water use should be provided. Existing uses, including amounts, water levels, location, drawdown, and source aquifers should be discussed and tabulated. Flow directions, gradients, velocities, water levels, and effects of potential future use on these parameters, including any possibility for reversing the direction of ground water flow, should be indicated. Any potential ground water recharge area within the influence of a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the site and the effects of construction, including dewatering, should be identified. The influence of existing and potential future wells with respect to ground water beneath the site should also be discussed. Bases and sources of data should be described and referenced. References 6 through 12 of RS-002 discuss certain studies concerning ground water flow problems.

- The need for and extent of procedures and measures to protect present and projected ground water users, including monitoring programs, must be discussed. These items are site specific and will vary with each application.

2.4.12.3 Technical Evaluation

As set forth below, the staff determined that onsite and offsite ground water use is adequately described in the SSAR. The site is located adjacent to Lake Anna. Lake Anna and other water bodies exist between the ESP site and the nearest offsite ground water users. This spatial relationship and the relatively small withdrawal rates, both onsite and offsite, contribute to the hydrological isolation of the ESP site from offsite ground water users.

The applicant conducted slug tests in the newly installed wells to provide estimates of saturated hydraulic conductivities. The staff determined that the method used in the SSAR to estimate the saturated hydraulic conductivities (i.e., the Bouwer-Rice method) is appropriate because this is a well established method that is widely accepted in standard engineering practice. While the estimate of hydraulic conductivity derived with the Bouwer-Rice method is appropriate for shallow unconsolidated strata, the failure to satisfy the constraints of the Bouwer-Rice method in well tests in the deeper consolidated strata is consistent with conditions where the movement of water is limited to flow in fractures. Dominant subsurface transport pathways will be bounded by the hydraulic conductivities in the shallow unconsolidated strata.

Observed increases in water levels in the new wells ranged from less than 0.3 m (1 ft) to more than 1 m (3 ft) over the period of December 17, 2002, through June 17, 2003. The applicant included previously existing wells monitored at the same time in the analysis. The observed variation in water levels in wells could be significant, but represented only a 6-month period. The staff evaluated additional information the applicant provided in response to RAI 2.4.12-1, but found that it needed additional data to determine whether the new ground water level measurements correlate with data from the long-term piezometers. Groundwater measurements should contain at least one full year of data to determine recent seasonal fluctuation in ground water levels at the ESP site. This is **Open Item 2.4-7.**

Ground water discharge to streams and to Lake Anna is significant, ranging from 32 to 67 percent of streamflow, according to several studies conducted in the province cited by Trapp and Horn. The staff was unable to independently estimate the ground water flowpath from the powerblock of the proposed additional units to Lake Anna, since the applicant did not provide the precise location of the powerblock. In the following assessment, the staff used applicant-provided values for effective porosity and distance from the powerblock to Lake Anna.

The staff used the following relationship to determine average ground water velocity:

Velocity = Hydraulic Gradient x Saturated Hydraulic Conductivity/Effective Porosity

The applicant used the geometric mean of the measured hydraulic conductivity values (0.4 m/d (1.3 ft/d)). Use of the geometric mean is not conservative because it results in slower ground water velocity and increased travel time to the environment. Using 1.0 m/d (3.4 ft/d) as the conservative value for hydraulic conductivity, 0.03 m/m (3 ft/100 ft) as the hydraulic gradient, and 0.33 as the effective porosity, the staff estimated the ground water velocity to be 0.09 m/d (0.31 ft/d), as opposed to 0.04 m/d (0.12 ft/d) as reported by the applicant. The staff's calculated travel time from the powerblock to the lake, using 548.6 m (1800 ft) as the distance to the environment, is approximately 16 years, as opposed to the applicant's estimate of 40 years. The applicant needs to explain why a more conservative hydraulic conductivity was not used. This is **Open Item 2.4-8.** The staff intends to identify hydraulic conductivity as a site characteristic in any ESP that might be issued for this application.

The distance to the lake is still uncertain. The applicant's response to RAI 2.4.1-1 included a figure that listed the coordinates of the corners of the ESP PPE (site footprint). However, the staff needs additional information regarding the reference system and the units of these coordinates to determine the distance from the powerblock to the lake. Consequently, the staff has identified the need for information on the coordinate system for the ESP site boundaries in Open Item 2.4-1.

The applicant proposes a site characteristic of ground water elevation less than 82.3 m (270 ft) MSL, and it proposes an ESP plant grade (PPE value) of 82.6 m (271 ft) MSL. The applicant identified the general location of the proposed additional units in Figure 2.4-16. Based on the ground water level data presented in SSAR Figure 2.4.16 and the updated final safety analysis report, the staff concludes that the applicant's design elevations are adequate from the perspective of the location of the water table, if the proposed additional units are constructed within the area where the ground water levels do not exceed 82.3 m (270 ft) MSL. This requirement constrains the location of the proposed units toward the northeast corner of the proposed footprint and is **Permit Condition 2.4-12**.

2.4.12.4 Conclusions

As set forth above, and with the exceptions and permit conditions noted, the applicant has provided sufficient information pertaining to ground water. Therefore, the staff concludes that, with the noted conditions, the applicant has met the requirements related to ground water in 10 CFR 52.17(a) and 10 CFR 100.20(c)(3), except for the matters identified in the open items noted in Section 2.4.12.3 of this SER.

2.4.13 Accidental Releases of Liquid Effluents to Ground and Surface Waters

The North Anna site is located within the Piedmont Physiographic Province in an area underlain by crystalline bedrock. The powerblock for the proposed additional units would be sited on soil disturbed during construction of the now-abandoned NAPS Units 3 and 4.

2.4.13.1 Technical Information in the Application

In SSAR Section 2.4.13, the applicant stated that all analysis of accidental releases to ground and surface waters would be deferred to the COL stage. However, pursuant to 10 CFR 52.17(a)(1) and 10 CFR 100.20(c)(3), the applicant is required at the ESP stage to obtain factors for applicable hydrological radionuclide release pathways for a site-suitability determination. The staff requested, in RAI 2.4.13-1, that the applicant provide a conceptual model of the subsurface environment, with reference to drill logs, as-built fill, and compaction plans. The staff stated that the subsurface conceptual model should provide estimates, and the basis for these estimates, for the hydraulic conductivity of the soil, surface recharge rates, soil and ambient ground water chemical properties, and piezometric boundary conditions. In its response, the applicant stated that it developed a conceptual model of the subsurface for the ESP site, based primarily on data presented in the ESP application and supplemented by other published data. The applicant obtained data included in the ESP application from site-specific subsurface investigations and from published sources.

The applicant stated that the ground surface at the existing units and some parts of the ESP site are located at an elevation of 82.6 m (271 ft) MSL. The ground surface rises to an elevation of over 91.4 m (300 ft) MSL to the west and to the south of the ESP site. The ESP site is filled with fabricated material, residual soil, or saprolite. The powerblock area of the abandoned Units 3 and 4 was partially filled. The applicant stated that existing fill and residual soil would be removed from the ESP site before any future construction.

The applicant stated that saprolite overlies bedrock at the NAPS site. Based on drilling results at the site, saprolite ranges in thickness from 0.6 m to 31.1 m (2 ft to 102 ft). The saprolite at the NAPS site varies in its lithology, depending on its parent material and its degree of weathering, and it may be classified into the following categories, sand, silty sand, clayey sand, sandy silt, clayey silt, and clay. The bedrock beneath the ESP site, which belongs to Cambrian and Ordovician age Ta River Metamorphic Suite, is at depths ranging from 2.4 to 14.9 m (8 to 49 ft), and consists of mostly quartz gneiss with variable weathering with joints and fractures. These joints and fractures have clay filling.

The applicant stated that ground water beneath the ESP site is unconfined, both in saprolite and in bedrock. Saprolite and bedrock are hydrologically connected to each other. The applicant measured potentiometric head difference between the bedrock and the saprolite at only one location (OW-845 and OW-846 in Figure 5 of the applicant's responses to staff RAIs (Dominion, "Supplemental Response to Request for Additional Information No. 4," August 19, 2004). The measured head difference was 0.09 m (0.3 ft), with an upward hydraulic gradient.

The applicant prepared a piezometric head contour map (Figure 5 of the same RAI response) using ground water levels measured in March 2003. The applicant concluded from this contour map that ground water flow across the ESP site is to the north and east towards Lake Anna, with a hydraulic gradient of about 0.03 m/m (3 ft/100 ft). The applicant stated that this gradient is expected to be typical of ground water flow at the ESP site, despite seasonal and long-term fluctuations caused by the controlling influence of Lake Anna and surrounding drainages.

The applicant provided a conceptual hydrogeologic model based on site investigation. The primary system for migration of radionuclides is ground water flow in unconsolidated deposits (i.e., the saprolite) and in the bedrock. Ground water in saprolite is stored and is transmitted through the pore spaces. In the crystalline bedrock, ground water is stored and is transmitted through joints and fractures. The number, extent, and opening width of joints and fractures are expected to decrease with depth, thus limiting significant water transmission in the bedrock to its upper few hundred meters.

The applicant stated that recharge to the aquifers at the NAPS site occurs largely as infiltration of rainfall and snowmelt. Average annual precipitation in the NAPS area is about 112 cm (44 in.), and average annual recharge is estimated to be 20 to 25 cm (8 to 10 in.). A minor source of recharge to the ground water at the NAPS site is the clay-lined service water reservoir for the existing NAPS units. Infiltration of water from the service water reservoir locally alters ground water levels. A series of underdrains beneath the existing pumphouse for Units 1 and 2 control ground water levels, as well. Some ground water discharge occurs through the five active water supply wells and four minor wells, and some evapotranspiration occurs at the foundation area for the abandoned Units 3 and 4.

The applicant stated that ground water underlying the ESP site is expected to be in hydrologic connection with Lake Anna. Therefore, the water level in Lake Anna serves as a piezometric boundary condition for ground water flow towards the lake. The ground water flow at the ESP site discharges to Lake Anna and the WHTF. The applicant stated that a ground water divide is expected to exist upgradient of the ESP site and to approximately coincide with the topographic divide.

The applicant stated that no site-specific data are available to determine the chemical characteristics of ground water at the ESP site. The applicant assumed that the water quality of crystalline aquifers in the Piedmont Physiographic Province is representative of the water quality at the ESP site.

The applicant stated that in case of an accidental release of liquid radioactive material at the ESP site, the contaminants will infiltrate to the ground water table and then flow laterally with regional ground water flow towards Lake Anna and the WHTF. Depending upon the location of the accidental release with respect to water supply wells, some wells may be impacted by contaminants. The applicant stated that no offsite ground water users would be impacted as a result of the direction of ground water flow and the presence of ground water boundary conditions between the ESP site and these users. Finally, the applicant stated that a detailed numerical model will be developed as part of any COL application to be submitted for the proposed ESP site.

2.4.13.2 Regulatory Evaluation

Section 1.8 of the SSAR presents a detailed discussion of how the applicant proposes to conform to NRC regulations and regulatory guidance. The applicant identified the applicable regulations as Appendix B to 10 CFR Part 20 and 10 CFR Part 100, and the applicable regulatory guidance as RGs 1.27, 1.70, and 1.113, as well as RS-002. The staff finds that the applicant correctly identified the applicable regulations and guidance, with the exception that an ESP applicant need not demonstrate compliance with 10 CFR Part 20.

Acceptance criteria for this section relate to 10 CFR Part 52 and 10 CFR Part 100, as they require the evaluation of the hydrologic characteristics of the site with respect to the consequences of the escape of radioactive material from the facility.

The regulations in 10 CFR Part 52 and 10 CFR Part 100 require that local geological and hydrological characteristics be considered when determining the acceptability of a nuclear power plant site. The geological and hydrological characteristics of the site may have a bearing on the potential consequences of radioactive materials escaping from a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. Special precautions should be planned if a reactor or reactors were to be located at a site where a significant quantity of radioactive effluent could accidentally flow into nearby streams or rivers or find ready access to underground water tables.

These criteria apply to SSAR Section 2.4.13 because site hydrologic characteristics are evaluated with respect to the potential consequences of radioactive materials escaping from a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. Radionuclide transport characteristics of ground water and surface water environments are reviewed with respect to accidental releases to ensure that current and future users of ground water and surface water are not adversely affected by an accidental release from a nuclear power plant or plants of a specified type (or falling within a PPE) that might be constructed on the proposed site. RGs 1.113 and 4.4 provide guidance in selecting and using surface water models for analyzing the flowfield and dispersion of contaminants in surface waters.

Meeting the requirements of 10 CFR Part 52 and 10 CFR Part 100 provides reasonable assurance that accidental releases of liquid effluents to ground water and surface water, and their adverse impact on public health and safety, will be minimized.

For those cases in which a reactor design is not specified, the ESP applicant may instead provide a PPE to characterize a facility or facilities for comparison with the hydrologic characteristics of the site. A PPE can be developed for a single type of facility or a group of candidate facilities by selecting limiting values of the relevant parameters.

To meet the requirements of 10 CFR Part 52 and 10 CFR Part 100, with respect to accidental releases of liquid effluents, the following specific criteria are used:

- Radionuclide transport characteristics of the ground water environment, with respect to existing and future users, should be described. Estimates and bases for coefficients of dispersion, adsorption, ground water velocities, travel times, gradients, permeabilities, porosities, and ground water or piezometric levels between the site and existing or known future surface water and ground water users should be described and should be consistent with site characteristics. Potential pathways of contamination to ground water users should also be identified. Sources of data should be described and referenced.

- Transport characteristics of the surface water environment, with respect to existing and known future users, should be described for conditions which reflect worst-case release mechanisms and source terms, so as to postulate the most pessimistic contamination from accidentally released liquid effluents. Estimates of the physical parameters necessary to calculate the transport of liquid effluent from the points of release to the site of existing or known future users should be described. Potential pathways of contamination to surface water users should be identified. Sources of information and data should be described and referenced. Acceptance is based on the staff's evaluation of the applicant's computational methods and the apparent completeness of the set of parameters necessary to perform the analysis.

- Mathematical models are acceptable to analyze the flowfield and dispersion of contaminants in ground water and surface water, providing that the models have been verified by field data and that conservative site-specific hydrologic parameters are used. Furthermore, conservatism should be the guide in selecting the proper model to represent a specific physical situation. Radioactive decay and sediment adsorption may be considered, if applicable, providing that the adsorption factors are conservative and site specific. RG 1.113 provides guidance in selecting and using surface water models. References 7 through 15 of RS-002 discuss the transport of fluids through porous media.

2.4.13.3 Technical Evaluation

SSAR Section 2.4.13 does not contain an analysis of accidental releases to ground and surface waters, which the staff needs to evaluate currently applicable hydrological accidental radionuclide release pathways. The applicant should provide a conceptual model of the subsurface environment, with reference to drill logs, as-built fill, and compaction plans. The subsurface conceptual model should provide estimates, and the basis for these estimates, for the hydraulic conductivity of the soil, surface recharge rates, soil and ambient ground water chemical properties, and piezometric boundary conditions. These model attributes are necessary for the staff to conduct a site-suitability evaluation in accordance with RG 1.113. The staff requested this information in RAI 2.4.13-1.

In its response, the applicant provided details of the hydrogrologic characteristics at the ESP site, including a conceptual model of ground water movement through the saprolite and the bedrock underlying the ESP site.

The applicant reported that the only observation of piezometric head difference made between the saprolite and the bedrock indicated an upward hydraulic gradient. The staff needs to understand the implications of an upward hydraulic gradient, with respect to the transport of effluents to the environment. The applicant therefore needs to provide more details about the magnitude, frequency, and spatial location of these upward hydraulic gradients at the ESP site. This is **Open Item 2.4-9.** The staff intends to identify upward hydraulic gradient as a site characteristic in any ESP that might be issued for this application.

The applicant stated that the typical hydraulic gradient of ground water flow across the ESP site to Lake Anna and the WHTF is 0.03 m/m. The applicant based this estimate on only one piezometric head contour map constructed using ground water level observations from March 2003. The applicant stated that this hydraulic gradient is typical of the ESP site, despite seasonal and long-term variation in the ground water regime. However, the applicant should provide data to support this statement and to define the range of seasonal and long-term variation in hydraulic gradient from the ESP site into Lake Anna and the WHTF. This is **Open Item 2.4-10.** The staff intends to identify hydraulic gradient from the ESP site to Lake Anna and the WHTF as a site characteristic in any ESP that might be issued for this application.

The site suitability evaluation with respect to radionuclide transport characteristic as defined by 10 CFR Part 100.20(c)(3) requires the use of observed site specific parameters important to hydrological radionuclide transport (such as soil, sediment, and rock characteristics, adsorption and retention coefficients, ground water velocity, and distances to the nearest surface body of water) obtained from on-site measurements. The applicant has not provided the onsite measured values of adsorption and retention coefficients for radioactive materials. This is **Open Item 2.4-11.** The staff intends to identify onsite measured values of adsorption and retention coefficients for radioactive materials as a site characteristic.

The staff concluded that the applicant has adequately described the conceptual model of the subsurface environment. However, the applicant needs to provide more site-specific data related to hydraulic gradients, as discussed above.

2.4.13.4 Conclusions

As set forth above, and with the exceptions noted, the applicant has provided sufficient information pertaining to liquid pathways. Therefore, the staff concludes that the applicant has met the requirements related to liquid pathways of 10 CFR 52.17(a) and 10 CFR 100.20(c)(3), except for the matters identified in the open items noted in Section 2.4.13.3.

2.4.14 Site Characteristics Related to Hydrology

Based on its review of SSAR Section 2.4, the staff has determined that the following site characteristcis should be inlcuded in any ESP that might be issued for the proposed site.

Table 2.4.14-1 Staff's Proposed Site Characteristics Related to Hydrology

SITE CHARACTERISTIC	VALUE
Proposed Facility Boundaries	**Open Item 2.4-1**
Site Grade	82.6 m (271 ft) MSL
Highest Ground Water Elevation	82.3 m (270 ft) MSL
Flood Elevation	82.3 m (270 ft) MSL
Low Water Elevation	73.8 m (242 ft) MSL
Local Intense Precipitation	46.61 cm (18.35 in) / hour
Minimum lake water temperature	**Open Item 2.4-5**
Lake Surface Icing	43.4 cm (17.1 in) thick
Minimum Intake WaterTemperature	1.7 EC (35 EF)
Hydraulic Conductivity	**Open Item 2.4-8**
Hydraulic Gradient	**Open Items 2.4-9 & 2.4-10**
Absorption and Retention Coefficients for Radioactive Materials	**Open Item 2.4-11**