2.0 SITE CHARACTERISTICS

2.4 Hydrologic Engineering

To ensure that a nuclear power facility or facilities can be designed, constructed, and safely operated on the applicant's proposed Clinch River Nuclear (CRN) Site and in compliance with U.S. Nuclear Regulatory Commission (NRC) regulations, the staff evaluated the hydrologic characteristics of the site and surrounding vicinity that may affect the safety of a potential nuclear power plant at the site. These site characteristics describe the potential for flooding due to precipitation, riverine processes (runoff, dam breach discharge, channel blockage or diversion), coastal effects (storm surges and tsunamis), and associated effects (e.g., from coincident wind waves). In addition, the staff reviewed the maximum elevation of surface water during floods and as combined with other events, associated static and dynamic characteristics, minimum water-surface elevation during low-water events, maximum elevation of groundwater, and the characteristic ability of the site to attenuate postulated accidental releases of radioactive liquid effluents in ground and surface waters. The surface water hydrologic site characteristics determine the design-basis flood for the proposed CRN Site, and provide the basis for determining whether flood protection will be required. The groundwater hydrologic site characteristics determine the design-basis groundwater loadings and provide the basis for radiological dose analysis for a potential receptor from the postulated accidental release of radioactive liquid effluents in surface and ground waters.

The staff prepared Sections 2.4.1 through 2.4.14 herein in accordance with the review procedures described in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Sections 2.4.1 through 2.4.14, using information presented in the applicant's Site Safety Analysis Report (SSAR), Revision 1, Section 2.4, "Hydrologic Engineering," (Agencywide Documents Access and Management System (ADAMS) Accession No. ML18003A374) and generally available reference materials (e.g., those cited in applicable sections of NUREG-0800). The Tennessee Valley Authority (TVA) is the applicant for the subject Early Site Permit (ESP) application and is referred to as "the applicant" herein.

2.4.1 Hydrologic Description

The applicant described the CRN Site adjacent to the Clinch River. The plant will utilize a Clinch River water intake and a river outfall. The applicant proposed that the site will be graded to a new elevation which will be higher than the normal stream surface elevation by approximately 80 ft. The applicant provided the hydrosphere information to describe the upstream and downstream tributaries and dams that could flood the plant site. The hydrosphere information also includes the surface water withdrawals for various water supply and uses within the neighboring sites. The applicant provided an overview description of groundwater conditions on the site and surrounding area and summarized information regarding groundwater users. The applicant noted that detailed descriptions of the groundwater conditions, and regional and local groundwater resources and users, are described in Section 2.4.12.

2.4.1.1 *Introduction*

The SSAR states that the CRN Site is located on the northern (right) bank of the Clinch River between Clinch River Mile (CRM) 19 and CRM 14.5, which is a tributary (or 'arm') of the Watts Bar Reservoir (Figure 2.4.1-1). River miles are defined as the flow path distance measured from CRM 0, which is the mouth of the Clinch River. SSAR Section 2.4.1 provides an overview of the hydrologic characteristics and phenomena that have the potential to affect the plant design basis of a reactor technology to be determined within the plant parameter envelope (PPE) in the Combined License Application (COLA). The applicant stated that designs under consideration within the PPE include:

- BWXT mPower™ (Generation mPower LLC design);
- NuScale (NuScale Power, LLC, design);
- SMR-160 (Holtec SMR, LLC, design); and,
- Westinghouse SMR (Westinghouse Electric Company, LLC, design).

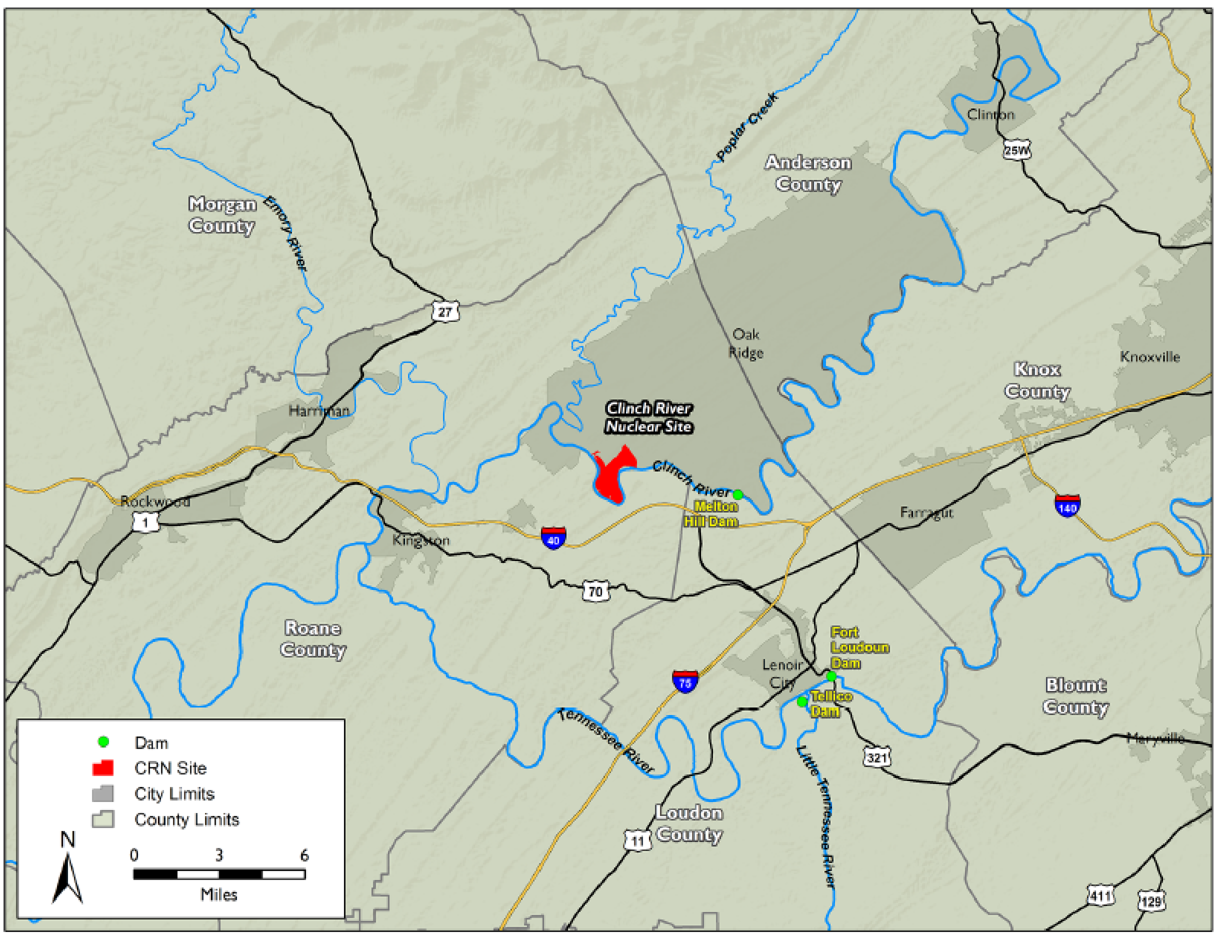

Figure 2.4.13-1 CRN Site Region (after SSAR Revision 1, Figure 2.4.1-2).

The hydrologic description of the CRN Site includes the interface of the plant with the hydrosphere, hydrological causal mechanisms, surface and groundwater uses, hydrologic data, and alternate conceptual models. The staff review discusses the interface of the plant with the hydrosphere including descriptions of site location, major hydrologic features in the site vicinity, surface water and groundwater-related characteristics, and the proposed water supply to the plant and, any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.1.2 *Summary of Application*

In SSAR Section 2.4.1, the applicant described the site and stated that all safety-related structures, systems and components would be set above the maximum postulated flood level from the standpoint of hydrologic considerations and provided a brief discussion of proposed changes to natural drainage features. Since a reactor technology has not been selected, final proposed changes to existing grade, a plant site grading plan, and a drainage design will be evaluated in the COLA.

2.4.1.3 *Regulatory Basis*

The relevant requirements of NRC regulations for the hydrologic description, and the associated acceptance criteria, are specified in NUREG–0800, Standard Review Plan (SRP) 2.4.1, “Hydrologic Description.”

The applicable regulatory requirements for identifying the site location and describing the site hydrosphere are set forth in the following:

- Title 10 of the *Code of Federal Regulations* (10 CFR) 52.17(a)(1)(vi), “Contents of applications,” as it relates to the hydrologic characteristics of the proposed site with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, “Reactor Site Criteria,” as it relates to identifying and evaluating hydrologic features of the site. The requirements to consider physical site characteristics in site evaluations are specified in 10 CFR 100.20(c).

The staff also used the appropriate sections of the following regulatory guides (RGs) for the acceptance criteria identified in NUREG–0800, Section 2.4.1:

- RG 1.27, “Ultimate Heat Sink for Nuclear Power Plants,” as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, “Design Basis Floods for Nuclear Power Plants,” as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.1.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.1 and found that the information in the application acceptably addressed the requirements related to the site's hydrologic description. The staff's technical evaluation of the information included supplemental information provided by the applicant as a result of a site audit the staff needed to assist with part of the evaluation related to this section (ADAMS Accession No. ML17341A276). The staff conducted the site audit from April 24 - 27, 2017, and reviewed the information provided by the applicant during the audit. This information included United States Geological Survey (USGS) topographic maps, topographic maps of the site, available studies and references developed by the applicant, and reports from independent reviews completed by the applicant's contractors. The NRC staff used this information to verify the hydrologic description. The following sections describe the staff's evaluation of the technical information submitted by the applicant.

2.4.1.4.1 Site and Facilities

<u>Information Submitted by the Applicant</u>

The applicant proposed a plant location that is on the north bank of the Clinch River (Figure 2.4.1-1). The location is surrounded by an oxbow bend of the Clinch River path. The oxbow flow bounds the site on the east, south, and west.

The applicant provided elevation information for the site in terms of the North American Vertical Datum of 1988 (NAVD88) and the National Geodetic Vertical Datum of 1929 (NGVD29), as amended by the 1936 South Eastern Supplemental Adjustment (1936 SESA). NGVD29 and the amendment are referred to together as NGVD29 by the applicant and staff. For the CRN Site, the applicant stated that the elevations in NAVD88 equal the elevations in NGVD29 minus 0.371 ft.

The CRN Site PPE states that the minimum finished ground elevation in the power block area is 821.0 ft NAVD88 or 821.4 ft NGVD29. This elevation is also referred to as the CRN site grade. The applicant calculated flood surface elevations that were based on the NGVD29. The local site topography and the site boundary are shown in Figure 2.4.1-2.

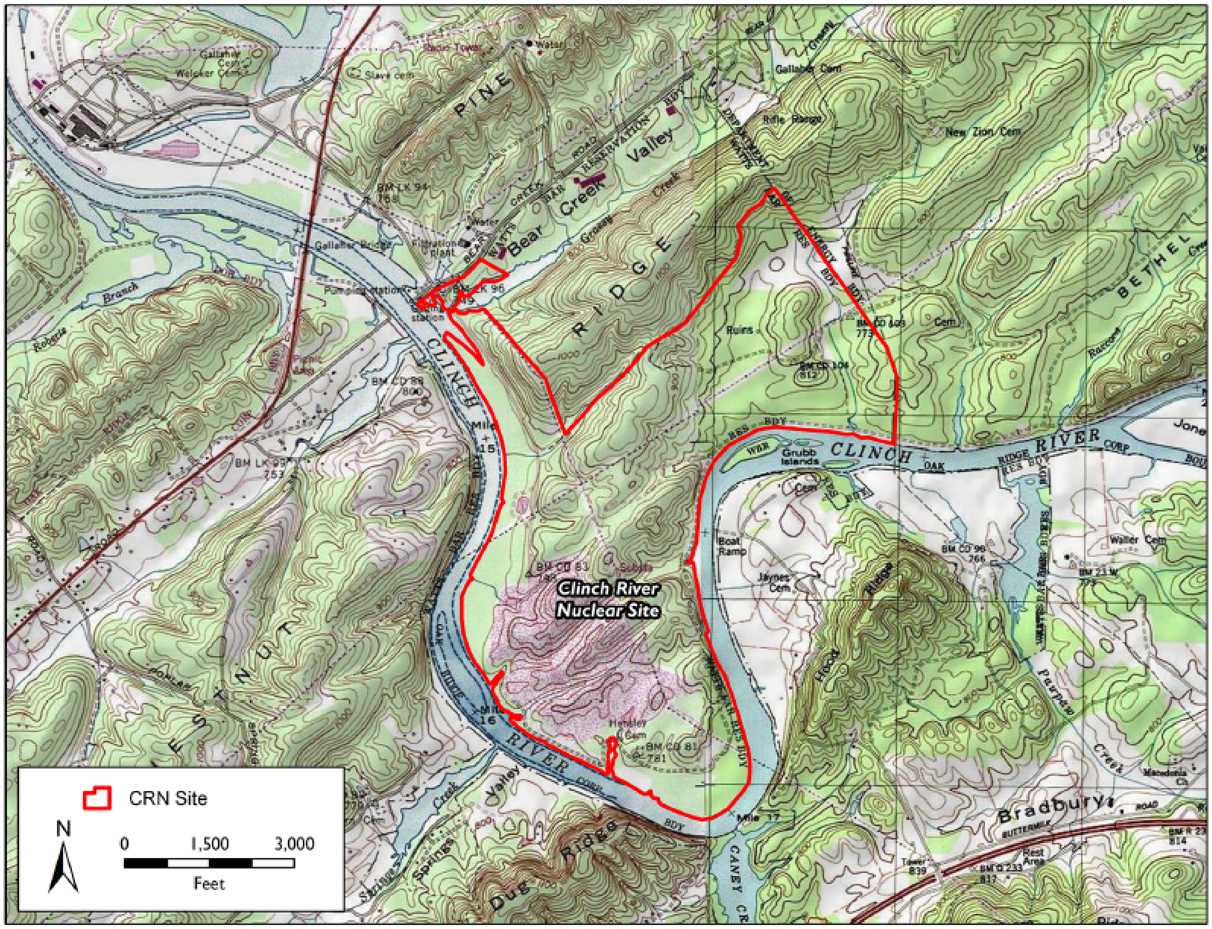

Figure 2.4.13-2 CRN Local Site Boundary and Topography (after SSAR Revision 1, Figure 2.4.1-3).

The applicant stated that the plant facilities, including any entry point to below grade structures, will be built above the maximum postulated flood event. A specific reactor technology has not been selected for construction at the CRN Site but will be provided with the COLA. Therefore, the applicant described the site hydrology and the principal plant structures in general terms. The general layout of facilities and structures is shown in Figure 2.4.1-3 and includes locations of intake and discharge structures.

The applicant stated the source water for the Circulating Water System (CWS) and the cooling towers would be the Clinch River. The applicant stated that closed cooling systems would supply internal plant reservoirs. Additionally, the applicant stated that Clinch River water would not be used directly for any safety-related systems. The applicant described the location of the outfall of discharge structure at CRM 15.5 (Figure 2.4.1-3) which is located 2.4 river miles downstream from the water intake.

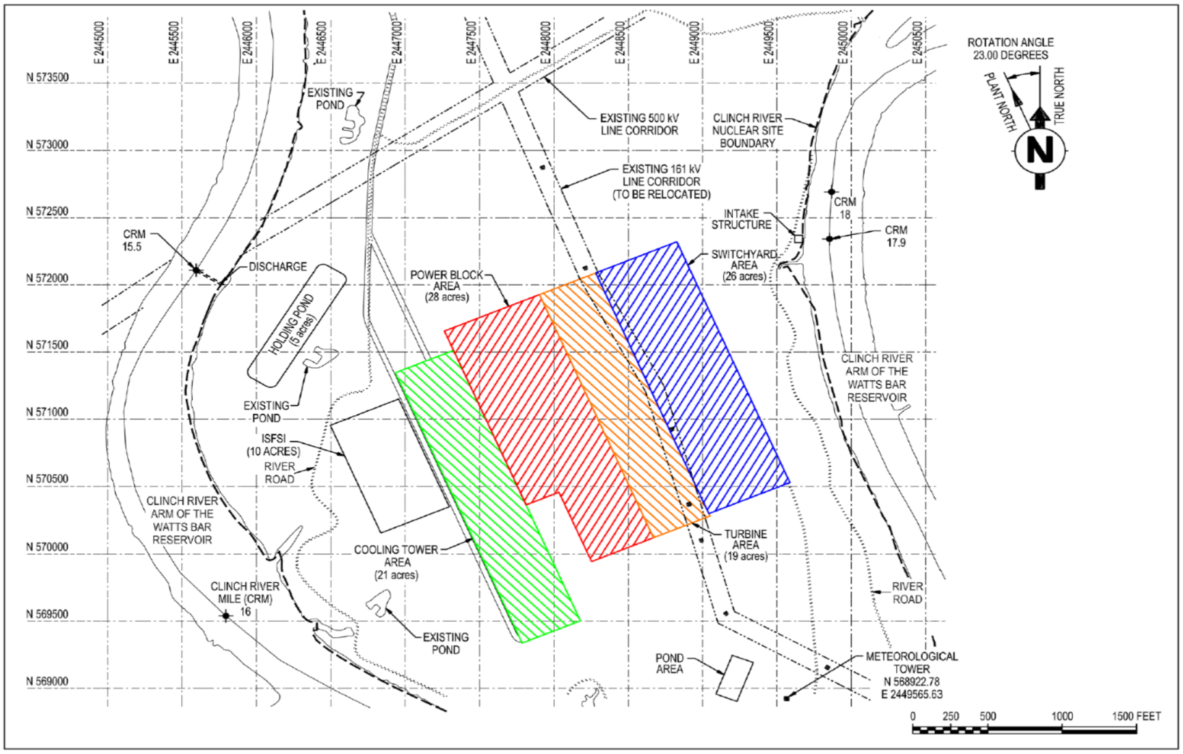

Figure 2.4.13-3 CRN General Layout of Facilities and Structures at the Site (after SSAR Revision 1, Figure 2.4.11-2).

Based on the selected technology, the design of the site grading plan and site drainage will be completed in the COLA. Therefore, the applicant stated that in the COLA they will provide a site grading plan and drainage system that will be designed to route runoff from the local probable maximum precipitation (PMP) into swales and pipes draining toward the Clinch River.

Staff's Technical Evaluation

Using the NOAA vertical datum tool (NOAA, 2017), the staff found the elevation conversion to NGVD29 ft to be NAVD88 ft plus 0.388 ft, which is consistent with the applicant's value.

Staff compared the summer normal pool elevation of 741 ft NGVD29 and the winter normal pool elevation of 737 ft NGVD29 (Figure 2.4.1-5a) of the Watts Bar Reservoir to the applicant's proposed grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88) as indicated in Section 2.4.0 of the SSAR. The staff notes that the elevation difference between the CRN site grade and the normal water surface elevation of the reservoir near the site is approximately 80 ft.

Based on a review of the material presented by the applicant in the SSAR Sections 2.4.1 and Section 2.4.10, the staff's observations of the CRN Site during the April 24 - 27, 2017 site audit, and the supplemental information provided by the applicant, the staff finds that the applicant has acceptably described the hydrologic characteristics of the CRN Site within this section.

2.4.1.4.2 Hydrosphere

This section describes the hydrosphere conditions in the vicinity of the CRN Site. The applicant categorized the hydrosphere into (1) site location, (2) tributaries, (3) reservoir water flow, (4) reservoir water levels, and (5) water supply withdrawals. These five items are detailed as discussed below.

<u>*Information Submitted by the Applicant*</u>

Site Location

The site is located between Clinch River Mile (CRM) 19 and CRM 14.5 (Figure 2.4.1-2). Above CRM 16, the upstream drainage area is 3,382 mi^2 (SSAR Section 2.4.1.2.1). The applicant stated that the Clinch River's average slope from Norris Dam (CRM 79.8) to CRM 7.0 is approximately 1.5 ft per mile (SSAR Section 2.4.1.2.1).

The applicant described the Clinch River path, flowing 350 miles in a southwesterly direction, from the headwaters near Tazewell, Virginia, to its confluence with the Tennessee River at Kingston, Tennessee. The Clinch River flows in the valley between the Cumberland Mountains on the northwest and the Clinch Mountain and Black Oak Ridge on the southeast. The mountain ridges have elevations up to 4,200 ft NGVD29.

Tributaries

The applicant described two large tributaries with drainage areas greater than 800 mi^2 contributing flows to the Clinch River: the Powell River, which enters the Clinch River at CRM 88.8; and, the Emory River which enters the Clinch River at CRM 4.4. The Powell River has a drainage area of 938 mi^2, and the Emory River has a drainage area of 865 mi^2. In addition to those two large tributaries, there are seven minor tributaries with drainage areas greater than 5 mi^2 upstream of the CRN Site and downstream of the Norris Dam. Each of those seven minor tributaries has a drainage area that is much less than 800 mi^2.

Reservoir Water Flow

The applicant identified three dams that control water surface elevations at the CRN Site. They are Norris Dam (CRM 79.8) and Melton Hill Dam (CRM 23.1), both upstream from the CRN Site, as well as Watts Bar Dam at Tennessee River Mile (TRM 529.9), which is downstream from the CRN Site.

(SRI/CEII) Norris Dam is a large structure located approximately 62 river miles upstream from the CRN Site built in the mid-1930s. The dam has a maximum height of 265 ft and its overall length is 1570 ft. The dam has **[[** **]]** in two sections, and an ancillary **[[** **]]** ft in length. When a water level reaches the top of the spillway gates (1034 ft NGVD29), Norris Dam will impound approximately 2,552,000 ac-ft of water. When the forebay water surface elevation reaches the dam crest elevation of 1061 ft NGVD29, Norris Dam can discharge approximately 344,000 cubic feet per second (cfs). In addition to the flood control function of the Norris Dam, the dam also provides hydroelectric power production, navigation benefits, dissolved oxygen improvements, and low flow regulation.

(SRI/CEII) Built in the early 1960s, Melton Hill Dam is located 5.2 river miles upstream from the CRN Site, having a maximum height of 84 ft and an overall length of 1020 ft. The dam has **[[ ]]**, **[[ ]]** ft of earthen embankment in **[[ ]]**, and concrete lock and power house structures **[[ ]]** ft in length. When the forebay water elevation reaches the top of the spillway gates (796 ft NGVD29), Melton Hill Dam will impound approximately 126,000 ac-ft of water. If the forebay water elevation reaches 802 ft NGVD29, Melton Hill Dam can discharge approximately 146,000 cfs. In addition to the navigation and hydroelectric power production, Melton Hill Dam also provides a function to control low flow requirements.

(SRI/CEII) Watts Bar Dam is located more than 50 river miles downstream from the CRN Site and its impoundment creates a backwater that extends up to the tailwater of Melton Hill Dam. The Watts Bar Dam has a maximum height of 112 ft with a length of approximately 2960 ft and was built in the early 1940s. The Watts Bar Dam has **[[ ]]** spillway gates. Each gate is **[[ ]]**-ft wide. The dam has **[[ ]]** ft of earthen embankments in **[[ ]]** sections and **[[ ]]** ft of concrete sections with the powerhouse, navigation lock, and ancillary structures. When the forebay water surface elevation reaches the top of the spillway gates (745 ft NGVD29), Watts Bar Dam will impound approximately 1,175,000 ac-ft of water. If forebay water elevation reaches 767 ft NGVD29, Watts Bar Dam can discharge approximately 1,144,000 cfs.

The applicant operates many other dams (Figure 2.4.1-4) that can indirectly influence flood levels both in the Watts Bar Reservoir and at the CRN Site. These dams are the Fort Loudoun Dam (Tennessee River); the Watauga, South Holston, Boone, Fort Patrick Henry, and Cherokee Dams (Holston River); the Douglas Dam (French Broad River); and the Fontana and Tellico Dams (Little Tennessee River).

The applicant stated that there are several stream gauges in the vicinity of the CRN Site that were operated by the USGS through 1968, as well as other stream gauges that have been operated by the applicant since 1937. In the SSAR, the applicant showed that the average daily discharge at the CRN Site was approximately 4800 cfs after the completion of Melton Hill Dam in 1963. Between February and March in 1966, there was a 29-day period of no flow below the Melton Hill dam.

The SSAR states that a Reservoir Operations Study (ROS) was adopted in 2004 and resulted in changes to minimum flow requirements. Appendix A of the ROS shows that for the base case condition the minimum flow from Melton Hill Dam was 400 cfs as a daily average. The ROS indicates there were no changes to the base case minimum flow commitments at Melton Hill Reservoir. The applicant states in the SSAR that 400 cfs is the minimum reservoir-release requirement for the Melton Hill Dam (TVA, 2014).

The applicant stated that since implementation of the ROS during 2004, the monthly average releases from Melton Hill Dam have ranged from a minimum of 589 cfs in November 2008 to a maximum of 14,900 cfs in December 2004.

Reservoir Water Levels

The applicant has summarized the reservoir water surface elevations (WSEs) recorded since completion of Watts Bar Dam in 1942. The reservoir water level at the Watts Bar Dam located downstream from the CRN Site had a maximum forebay water elevation of 747.4 ft NGVD29, which occurred on May 7, 2003, and a minimum forebay water elevation of 733.7 ft NGVD29, which occurred on March 20, 1945. The Melton Hill Dam located upstream from the CRN Site had a maximum tailwater WSE of 765.1 ft NGVD29, which occurred on April 2, 2000, and a minimum tailwater WSE of 735.0 ft NGVD29, which occurred both on January 9, 2002 and December 15, 2005. The seasonal operating curve for Watts Bar, Melton Hill, and Norris Dams are shown in Figures 2.4.1-5a, 2.4.1-5b, and 2.4.1-5c, which provide the months and targeted reservoir levels regulated by the reservoir discharge facilities. Seasonal operating curves are also provided in the SSAR for other dams, including the Fort Loudoun, Tellico, Boone, Cherokee, Douglas, Fontana, Fort Patrick Henry, South Holston, and Watauga Dams, though they are not presented herein.

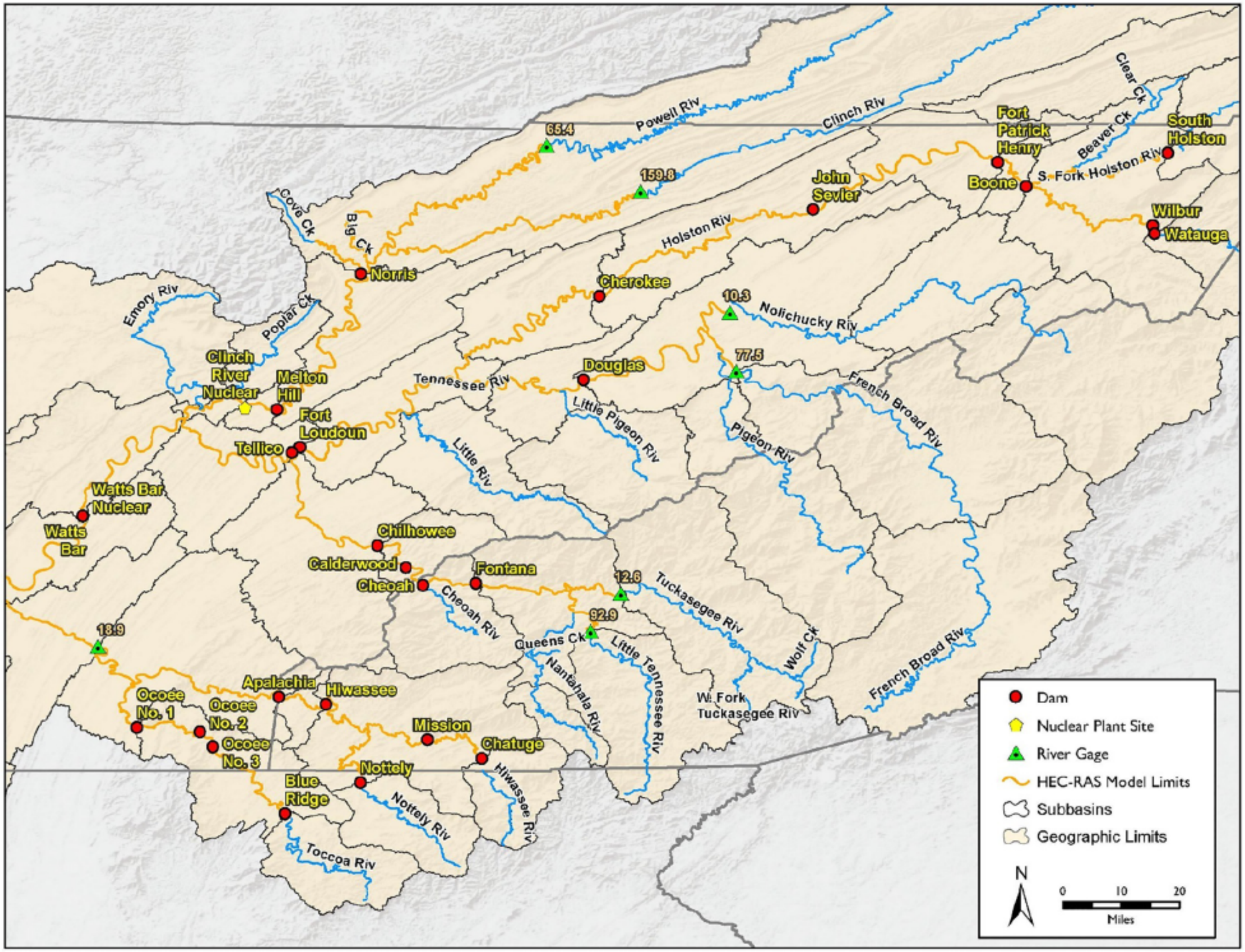

Figure 2.4.1-4 (Sheet 1 of 2) Geographic Map of Tennessee River and its Tributaries, and Location of Dams

(After SSAR Revision1, Figure 2.4.1-5)

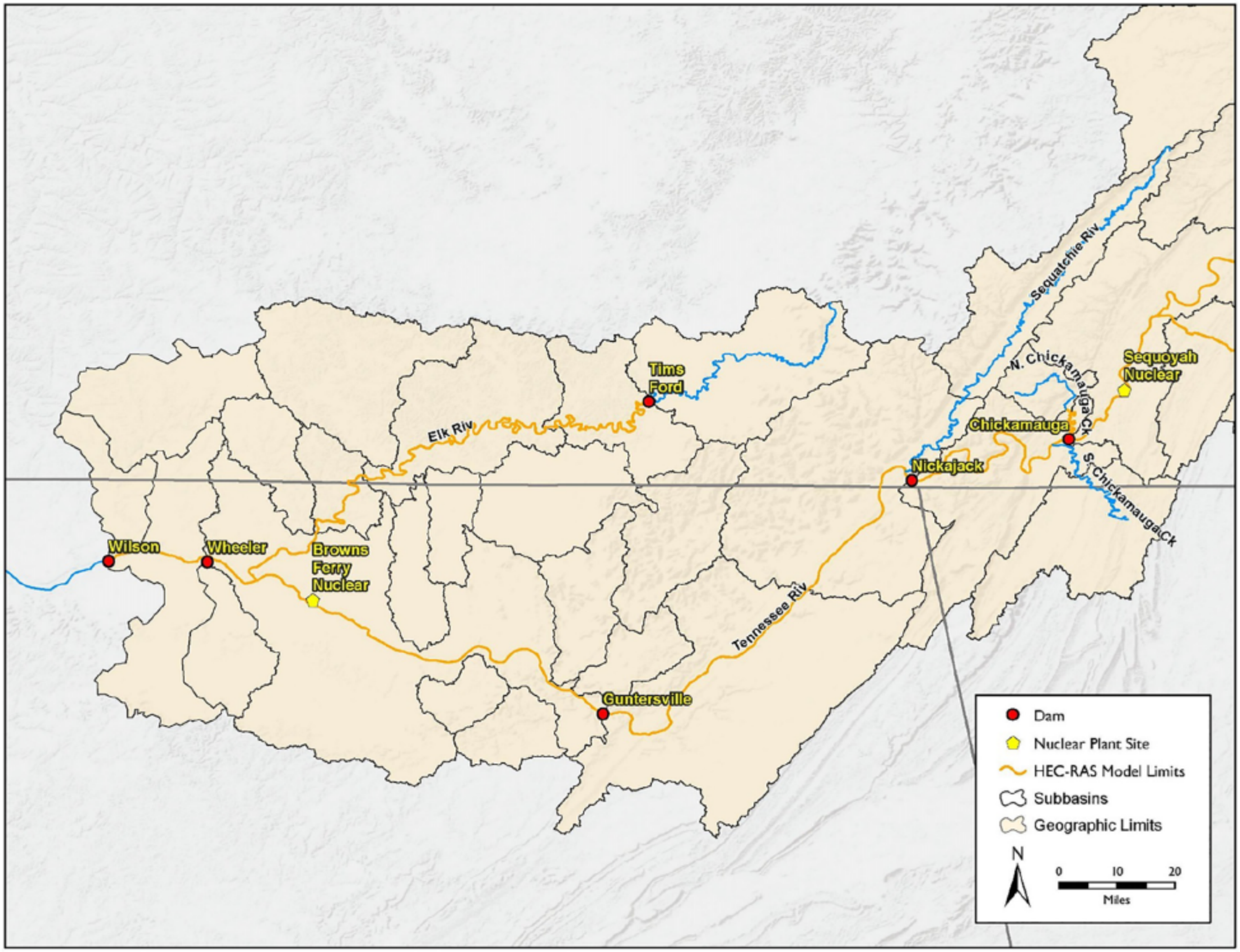

Figure 2.4.1-4 (Sheet 2 of 2) Geographic Map of Tennessee River and its Tributaries, and Location of Dams

(After SSAR Revision1, Figure 2.4.1-5)

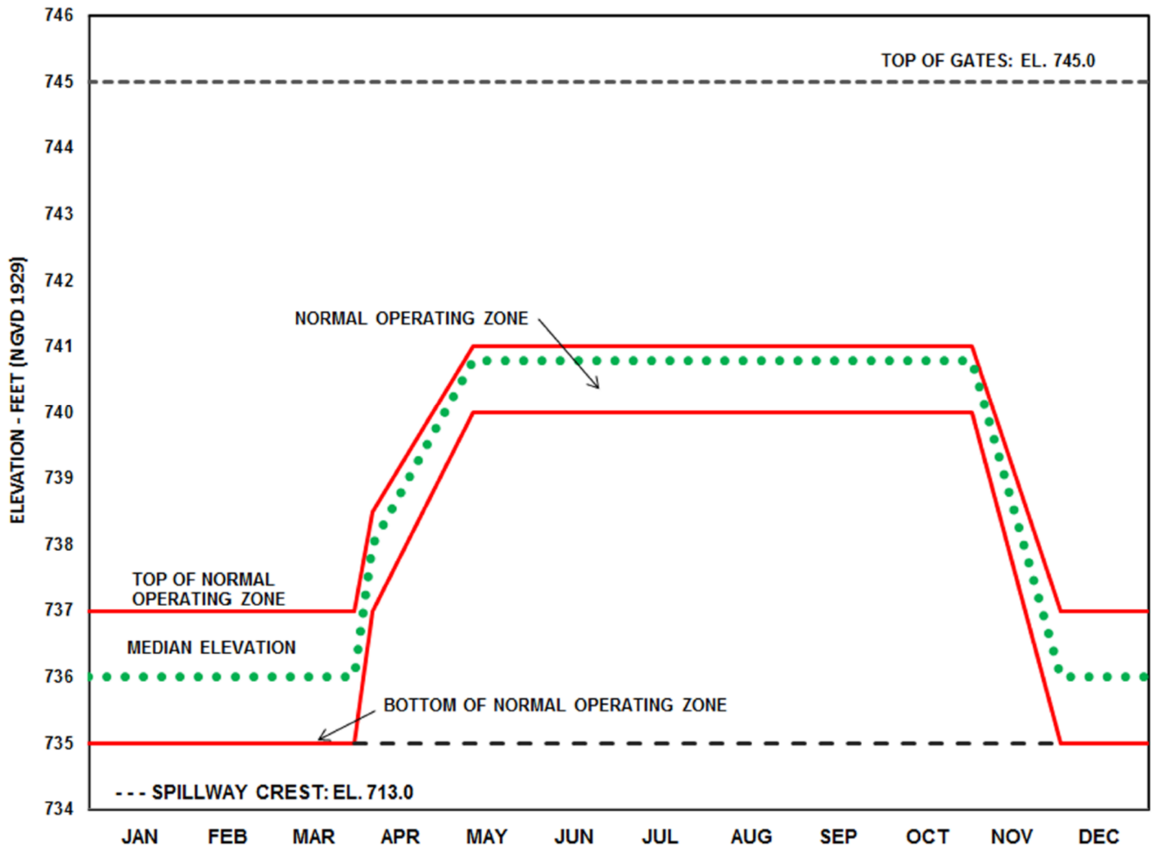

Figure 2.4.13-5a Seasonal Operating Curve for Watts Bar Dam (after SSAR Revision 1, Figure 2.4.1-6, sheet 1 of 11).

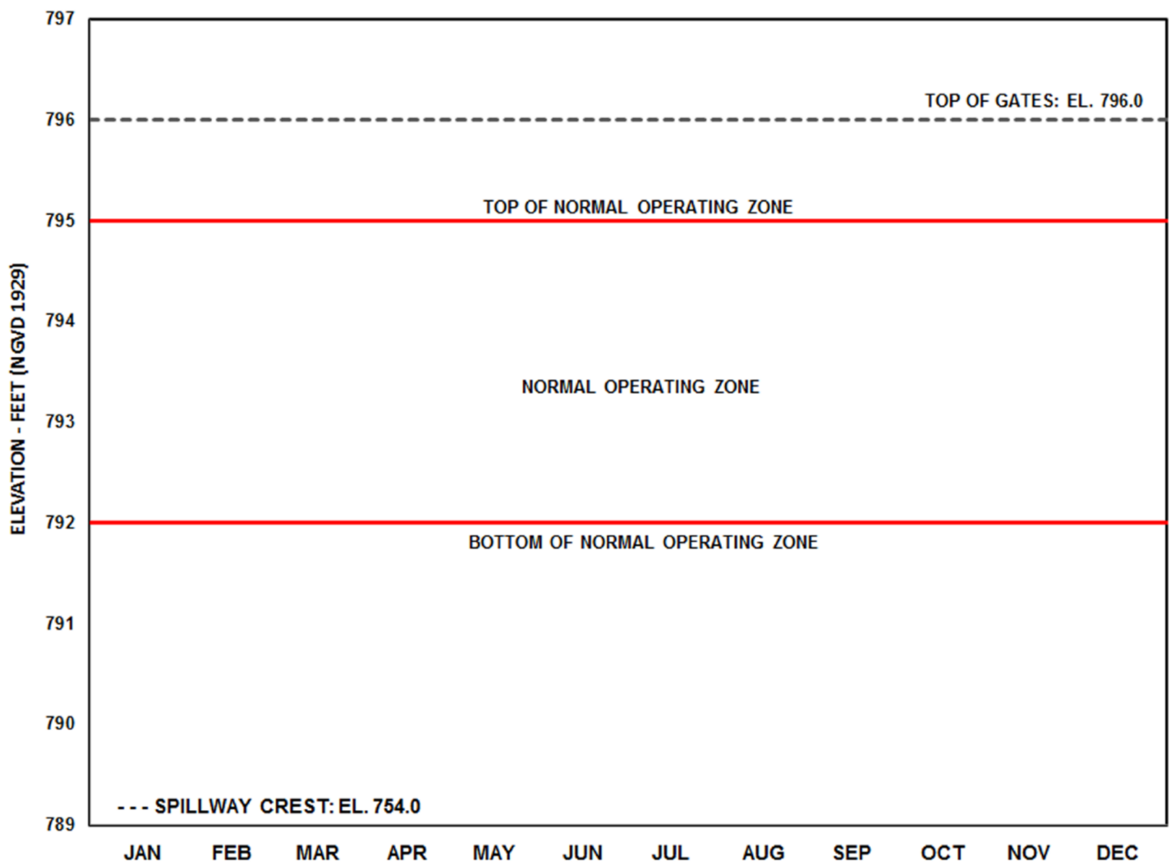

Figure 2.4.13-5b Seasonal Operating Curve for Melton Hill Dam (after SSAR Revision 1, Figure 2.4.1-6, sheet 8 of 11).

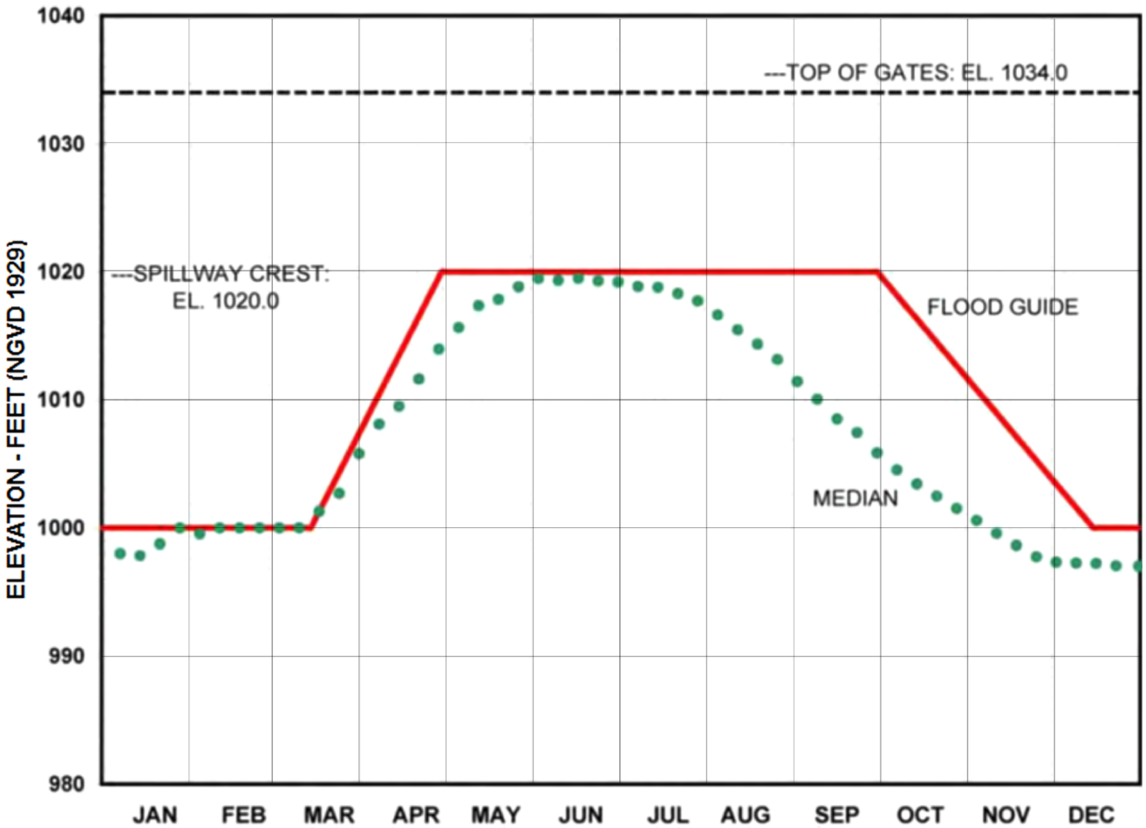

Figure 2.4.13-5c Seasonal Operating Curve for Norris Dam (after SSAR Revision 1, Figure 2.4.1-6, sheet 9 of 11).

Water Supply Withdrawals

The applicant stated that there are 58 surface water supply withdrawals within the Clinch River basin (SSAR Table 2.4.1-1). Three of these water withdrawals located on the Clinch River downstream from the CRN Site are: (1) Oak Ridge Bear Creek Plant (industrial), which has an intake in the Watts Bar Reservoir, (2) Kingston Fossil Plant (thermoelectric), which has intakes in the Watts Bar Reservoir and the Emory River, and (3) Kingston Water System (public supply), which has intakes in the Watts Bar Reservoir and the Tennessee River.

During an April 24-27, 2017 audit, the staff discussed the absence of groundwater information in Section 2.4.1 with the applicant. The applicant committed to developing and including information on groundwater in this section in a future SSAR revision (ADAMS Accession No. ML17200C887). Staff reviewed the summary providing descriptions of groundwater resources and users and, confirmed that this information was included in the SSAR revisions.

Staff's Technical Evaluation

The staff reviewed the applicant's five items included in the SSAR Sections 2.4.1.2.1, "Surface Water" and 2.4.1.2.2, "Groundwater:" (1) site location, (2) tributaries, (3) reservoir water flow, (4) reservoir water levels, and (5) water supply withdrawals. Following those items, the staff examined the completeness of the hydrologic data of the CRN Site, relevant reservoir operation data, and watershed characteristics. The staff made several checks to confirm that the specific data was consistent with data sources, such as basin physiography, regulated discharges from the dams, structural dimensions of the dams, record of peak flood flows, and historical water surface elevations in the Tennessee River. During the site audit April 24 - 27, 2017, the staff identified and confirmed various site characteristics that were considered in the applicant's flood analyses.

Based on the information in the SSAR which was confirmed with information provided during the site audit April 24 - April 27, 2017, as well as the applicant's Reservoir Operations Study (ROS) reports (TVA, 2004), the staff finds that the applicant has acceptably described the hydrosphere for the CRN Site.

2.4.1.5 Post Early Site Permit Activities

There are no post ESP activities related to this section.

2.4.1.6 Conclusion

The staff reviewed the application and confirmed that the applicant acceptably described the hydrosphere and there is no outstanding information required to be addressed in the SSAR related to this section. As set forth above, the applicant has provided sufficient information pertaining to the site description. Therefore, the staff concludes that the applicant has met the relevant requirements of 10 CFR 52.17(a)(1) and 10 CFR 100.20 with respect to the hydrologic description of the site.

2.4.2 Floods

2.4.2.1 *Introduction*

SSAR Section 2.4.2 discusses historical flooding at the proposed site and in the region of the site. The information summarizes and identifies the individual types of flood-producing phenomena, and combinations of flood-producing phenomena, which are considered in establishing the flood design basis for safety-related plant features.

Section 2.4.2 herein provides a review of the specific areas as follows: (1) local flooding on the site and drainage design; (2) stream flooding; (3) surges; (4) seiches; (5) tsunamis; (6) dam failures; (7) flooding caused by landslides; (8) effects of ice formation on water bodies; (9) combined event criteria; (10) other site-related evaluation criteria; and (11) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.2.2 *Summary of Application*

In SSAR Section 2.4.2, the applicant addresses the information related to site-specific and regional flood causal mechanisms. The applicant provided reasons for excluding some specific flood events in their detailed flood analysis. The applicant used the detailed flood analysis to determine a worst flooding condition at the CRN Site. Three types of floods were studied and presented in the detailed flood analysis, including (1) floods due to probable maximum precipitation (PMP) coincident with dam failures, (2) floods due to seismic failures of dams coincident with a 25-year or 500-year flood, and (3) floods due to sunny-day failures of dams.

2.4.2.3 *Regulatory Basis*

The relevant requirements of NRC regulations for the identification of floods and flood design considerations, and the associated acceptance criteria, are specified in NUREG–0800, SRP 2.4.2, "Floods."

The applicable regulatory requirements for considering probable maximum flooding resulting from flood events are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to the hydrologic characteristics of the proposed site with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG–0800, Section 2.4.2:

- RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.2.4 *Technical Evaluation*

The staff reviewed Section 2.4.2 in the SSAR and confirmed that the applicant addressed the appropriate information related to site floods. The staff reviewed the information for this section including the applicant's SSAR, the information gathered during the site visit, and the applicant's responses to the staff information needs identified in the site audit plan (ADAMS Accession No. ML17341A276). The staff supplemented this information with other publicly available sources of data during the review. The staff's review areas included:

- Local site flooding
- Stream flooding
- Surges and seiches
- Tsunamis
- Dam failures
- Effects of ice formation in water bodies
- Channel diversions
- Combined events criteria as described in SRP 2.4.2
- Consideration of other site-related evaluation criteria

The staff used the information observed during the site visit to verify the characteristics of important hydrologic features. The staff also performed the site audit to resolve some of the staff's identified information needs. The staff concludes that the applicant provided sufficient details describing the methodology used for surface water modeling for the flood levels at the site. Sections 2.4.2.4.1 to 2.4.2.4.3 describe the staff's evaluation of the technical information submitted by the applicant.

2.4.2.4.1 Flood History

Information Submitted by the Applicant

The applicant provided flood data and flood reports for historical stream floods during the site audit. The data and report show the flood elevations, either based on measured or modeled flood profiles.

SSAR Table 2.4.2-1 provides the record of flood elevations of various large flood events in the Clinch River tributary of Watts Bar Reservoir. These flood elevations resulted from natural flow conditions, unregulated by any dams before 1936, and from the flow conditions, regulated by the applicant's dams after 1936. The largest unregulated flood elevation was 767.8 ft NGVD29 at CRM 18.0 occurring in 1886, and 762.3 ft NGVD29 at CRM 16.0 occurring in 1867. The largest regulated flood elevation was 748.7 ft NGVD29 at CRM 18.0 occurring in 2003, and 748.4 ft NGVD29 at CRM 16.0, which occurred in both 1973 and 2003. Both CRM 18.0 and CRM 16.0 are within the CRN Site and near the intake and outlet of the water circulation system (Figure 2.4.1-3). The staff also notes that all historical flood elevations discussed above are well below the CRN site's minimum finished ground elevation 821.4 ft NGVD29 (821.0 ft NAVD88) for the power block area.

Staff's Technical Evaluation

The staff confirmed the flood historical record with information provided by the applicant during the audit. In addition, the staff has reviewed the applicant's hydrologic modeling analyses used to estimate more recent flood elevations as described in the following sections. Based on this information, the staff finds that the applicant provided appropriate and sufficient information to establish the history of flooding near the CRN Site.

2.4.2.4.2 Flood Design Considerations

Information Submitted by the Applicant

In the flood design considerations, the applicant studied three types of events (flood mechanisms) that were used to determine the worst potential flood at the CRN Site. The applicant's three types of events are shown as follows.

1. Probable maximum precipitation (PMP) on critical watersheds with the potential of hydrologic dam failures:

(SRI/CEII) The applicant identified flooding from rivers and streams as the mechanism that produced the most critical flood level calculated at the CRN Site. The critical flood elevation among the probable maximum flood (PMF) events was discussed in SSAR Section 2.4.3. Based on National Oceanic and Atmospheric Administration (NOAA) hydrometeorological reports (HMRs) HMR-51 (NOAA, 1982) and HMR-52 (NOAA, 1982), the applicant determined the critical flood elevation that was computed based on a 7980-mi^2 PMP event centered at Bulls Gap in the Tennessee River Watershed during a March storm. This PMP event produced a peak discharge of 536,000 cfs and a maximum stillwater flood elevation of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) at the CRN Site. The applicant included 2-year wind waves as a potential associated effect on the PMF event. The applicant computed the wind-generated wave height to be 6.1 ft above the PMF elevation. Adding the wave height 6.1 ft to the maximum stillwater flood elevation of **[[ ]]** ft, the applicant gets **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) for the CRN Site. Details of this type of event combined with hydrologic dam failure is be discussed in Section 2.4.4.4.2.2 herein.

2. Seismic dam failures with concurrent riverine flooding:

(SRI/CEII) The applicant examined the combined event using JLD-ISG-2013-01 criteria, entitled "Guidance for Assessment of Flood Hazards Due to Dam failure" (ADAMS Accession No. ML13151A153) that could produce a flood elevation for flood design consideration. This combined event was the seismic dam failures coincident with a 500-yr riverine flood. Combining half of the annual exceedance probability of a 10^{-4} (10,000 year recurrence interval) seismic event with a 500-year flood, the applicant calculated the peak discharge to be 162,000 cfs with a maximum water surface elevation (WSE) of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) at the CRN Site. This combined event is be discussed in
Section 2.4.4.4.2.1 herein.

3. Sunny-day dam failures:

(SRI/CEII) The applicant examined the sunny-day failure of **[[ ]]** Dam and a subsequently overtopping failure of **[[ ]]** Dam. The applicant showed that this sunny day failure produced a maximum water surface elevation of **[[ ]]** ft NGVD29 at the CRN Site. This sunny-day failure event is be discussed in Section 2.4.4.4.2.3 herein.

Other than the three types of events shown above, the applicant also considered the following five flood mechanisms, but the applicant did not analyze them. The applicant found that these five types of flood mechanisms were not plausible or were not expected to produce a flood hazard at the CRN Site. The flood mechanisms that were not in the applicant's detailed studies were:

1. Surges and seiches (related to Section 2.4.5 herein)
2. Landslide-induced tsunamis (Section 2.4.6)
3. Snow melt and ice jams (Section 2.4.7)
4. Cooling water canals and reservoirs (Section 2.4.8)
5. Channel migration and diversion (Section 2.4.9)

The applicant also discussed the potential for flooding due to local intense precipitation (LIP) events. The applicant calculated the LIP depth of 1-hour duration to be 17.4 inches (see Section 2.4.2.4.3 herein). Due to the lack of a specific reactor technology selected for the CRN Site, the applicant did not include a grading plan and a site drainage design. Therefore, the applicant did not provide the flood elevation resulting from a LIP event. The SSAR states that a detailed grading plan and drainage design will be included in the COLA. The applicant indicated in the SSAR that the drainage design will prevent safety-related structures, systems, and components of the plant from the flooding.

(SRI/CEII) As described in SSAR Section 2.4.3.5, the applicant reported that the maximum stillwater flood elevation (MSWFE) for the new plant is **[[ ]]** ft NGVD29 which is associated with the probable maximum flood (PMF) from streams and rivers. The design basis flood (DBF) level is **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) as described by the applicant in SSAR Section 2.4.3.7, which is the result of adding a wind wave height of 6.1 ft to **[[ ]]**. For context, the CRN PPE states that the minimum site grade elevation in the power block area is elevation 821 ft NAVD88 (821.4 ft NGVD29).

Staff's Technical Evaluation

Based on a review of the applicant's information contained in the SSAR, the staff finds that the applicant considered flood-causing phenomena and their combinations that were relevant to the CRN Site.

The staff finds that the applicant's MSWFE due to flooding from streams and rivers as the bounding event is consistent with the historical record and physiography of the Tennessee River basin. The staff finds that the CRN minimum site grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88) precludes impacts to safety-related SSCs from flood hazard scenarios in the

Tennessee River basin. Thus, the staff finds that the applicant's historical flood-design considerations are acceptable.

The detailed discussion of the staff's evaluation of the applicant's flood design considerations (e.g., including PMP event, seismic dam failures plus 500-year flood, sunny-day dam failure, and other flooding mechanisms) are addressed in the subsequent Sections 2.4.3.4.2, 2.4.4.4.2.1, 2.4.4.4.2.3, and 2.4.5.4 etc.

2.4.2.4.3 Effects of Local Intense Precipitation

Information Submitted by the Applicant

For the CRN Site, the applicant estimated the PMP values and rainfall distributions using the reports prepared by NOAA, including Hydrometeorological Report No. 52 (HMR-52) (NOAA, 1982) and HMR No. 56 (NOAA, 1986).

The applicant used "rough terrain" setting with a corresponding a moisture adjustment factor from HMR-56 (NOAA, 1986) to estimate the 1-hour precipitation depth of 17.40 inches for the CRN Site. The 17.40 inches are for a 1-mi^2 storm size. In the SSAR supplement, the applicant indicated that three temporal distributions were used to distribute the 17.4 inches (ADAMS Accession No. ML17157B212) in 5-minute increments with a 1-hour duration. The temporal distributions were developed and described in the SSAR markup. The applicant showed the 1-hour precipitation accumulations of three temporal distributions in Table 2.4.2-2 of the SSAR. Each of those three temporal distributions has a different precipitation peak either located at the early 20-minute, middle 20-minute, or late 20-minute interval within the total 1 hour-duration. This supplement information was also included in SSAR.

The applicant noted that neither HMR 52 nor HMR 56 provided specific guidance to establish a temporal rainfall distribution in 5-minute-increments for a 1-hour duration. The applicant created a temporal distribution for the 1-hour precipitation depth, which is similar to the temporal distribution for a 72-hour precipitation depth arranged in 6-hour increments that were described in the HMR 52. The licensee states in the SSAR that additional analyses will be performed in the COLA.

As previously stated, the applicant did not include a site drainage plan for the CRN Site. The SSAR states that the final graded site will take advantage of the topography to facilitate site drainage, and the site drainage plan will be provided in the COLA. The SSAR also states that the site drainage will not be affected by tailwater effects from discharge of surface runoff into the Watts Bar Reservoir. As noted in Section 2.4.1.4.1 herein, the reservoir elevations are well below the minimum site grade elevation.

Staff's Technical Evaluation

As stated in SRP Section 2.4.2, HRMs are acceptable methodologies for estimating the PMP. Staff independently assessed the 1-hr PMP one-square mile area using HRM-56 (NOAA, 1986) methods to obtain the PMP depth of 18.2 inches. After using a moisture adjustment factor of 95.6 percent, as provided in HMR-56, Figure 20, the staff calculated 17.39 inches for a 1-hour duration, which is negligibly different from the applicant's computed precipitation depth of 17.40 inches for the same rainfall duration. Therefore, the staff determined that the applicant's local intense precipitation rate at the CRN Site is reasonable.

The staff found that the applicant's temporal distribution for the 1-hour duration is reasonable. The applicant's presented three different temporal precipitation peaks, which are similar to the peaks analyzed in HMR-52 for the temporal distribution of a 72-hour PMP.

Based on the above technical evaluation, the staff finds that the applicant has appropriately considered flood-causing phenomena related to local intense precipitation for the CRN Site for the ESP application.

Finally, the staff agrees that the site grading plan and storm water management system related to the local flooding analysis will be specific to the reactor technology. Those design details are not available until the reactor technology is selected by the COL applicant. Accordingly, the staff identified **COL Action Item 2.4-1** to address this future local flooding analysis:

COL Action Item 2.4-1:

> An applicant for a combined license (COL) or construction permit (CP) that references this early site permit should design the site grading to provide flooding protection to safety-related structures at the ESP site based on a comprehensive flood water routing analysis for a local intense precipitation (LIP) event.

2.4.2.5 *Post Early Site Permit Activities*

The staff will review the applicant's modeling, which incorporates site-specific grading plans and storm water management system design features, to determine the potential for flooding due to a LIP event. This action is associated with **COL Action Item 2.4-1**.

2.4.2.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant has demonstrated that flooding has no-safety related impact on the CRN Site and that there is no outstanding information required to be addressed in the SSAR related to this section.

As set forth above, the applicant has provided sufficient information pertaining to flooding from LIP. Further, the applicant has considered the most severe natural phenomena that have 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, in establishing site characteristics pertaining to LIP flooding that are acceptable for design purposes. Therefore, the staff concludes that the applicant has met the relevant requirements of 10 CFR 52.17(a)(1) and 10 CFR 100.20 with respect to determining the acceptability of the site. Since LIP effects are dependent on future side grading and drainage system design, the COL applicant will address **COL Action Item 2.4-1**.

2.4.3 Probable Maximum Flood on Streams and Rivers

2.4.3.1 *Introduction*

SSAR Section 2.4.3 describes the hydrological site characteristics associated with the PMF on streams and rivers, and combinations of flood-producing phenomena resulting in any potential hazard to the plant's safety-related facilities.

Section 2.4.3 herein provides a review of the following specific areas: (1) design basis for flooding in streams and rivers; (2) design basis for site drainage; (3) consideration of other site-related evaluation criteria; and (4) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.3.2 *Summary of Application*

(SRI/CEII) In SSAR Section 2.4.3, the applicant addresses the information about flooding hazards from streams and rivers. The applicant followed the HMR 41 (NOAA, 1965), HMR 51 (NOAA, 1978), HMR 52 (NOAA, 1982), and HMR 56 (NOAA, 1986) methods to develop the site-specific PMPs for different sizes of storms. The applicant's PMPs were generated to reflect specific precipitation spatial patterns, the orographic effect on the precipitation, and different storm centers. Through many trials of selecting PMPs and combining them with hypothetical dam failures, the applicant identified a worst flood hazard, a site-specific PMF that could occur at the CRN Site. After the search, the applicant determined the maximum flood elevation would be **[[ ]]** ft NVGD29, due to a 7,980 square-mile PMP combined with dam failures and wind wave height. This maximum flood elevation is approximately **[[ ]]** ft below the site grade elevation 821.4 ft NGVD29 (821.0 ft NAVD88).

2.4.3.3 *Regulatory Basis*

The relevant requirements of NRC regulations for identifying the PMF on streams and rivers, and the associated acceptance criteria, are specified in NUREG–0800, SRP 2.4.3, "Probable Maximum Flood (PMF) on Streams and Rivers."

The applicable regulatory requirements for identifying the PMF on streams and rivers are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirements to consider physical site characteristics in site evaluations are specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.3:

- RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.3.4 *Technical Evaluation*

The staff reviewed SSAR Section 2.4.3 and confirmed that the information contained in the application addresses the relevant information related to this section. In addition to the systematic review of information provided by the applicant, the staff also visited the site during the site audit on April 24 - 27, 2017, verified the location and elevation of important streams and hydrologic features, and supplemented this information with other publicly available sources of data. The review topics included the following:

- Design basis for flooding in streams and rivers
- Combined events criteria
- Design basis for site drainage
- Consideration of other site-related evaluation criteria

As discussed in Section 2.4.2.5 herein, the potential for flooding due to LIP and associated surface-water drainage systems will be evaluated in the COLA after a reactor technology is selected.

2.4.3.4.1 Watershed Characteristics

Information Submitted by the Applicant

As presented in the SSAR to describe the watershed characteristics, the applicant divided the Tennessee River Watershed into 65 sub-basins above Wilson Dam. The total watershed area of the applicant's hydrologic model is 30,747 mi^2 including 65 sub-basins. The delineated sub-basins are depicted in Figure 2.4.3-1 herein. The applicant delineated each sub-basin according to watershed topography and stream gauge locations. Wilson Dam is located at the outlet of Sub-basin No. 68 (Figure 2.4.3-1). Directly above the CRN Site, there are Sub-basin Nos. 33 and 34. The upstream Norris Dam from the CRN Site is located at the outlet of Sub-basin No. 26. Melton Hill Dam is located in Sub-basin No.27 upstream from the CRN Site. The major downstream flow control is at Watts Bar Dam, located at the outlet of Sub-basin No. 37. The other sub-basins are in the downstream of the CRN Site or in the tributary watersheds of the Tennessee River. The applicant established hydrologic parameters for each sub-basin and used rainfall rate as input for the watershed hydrologic simulations.

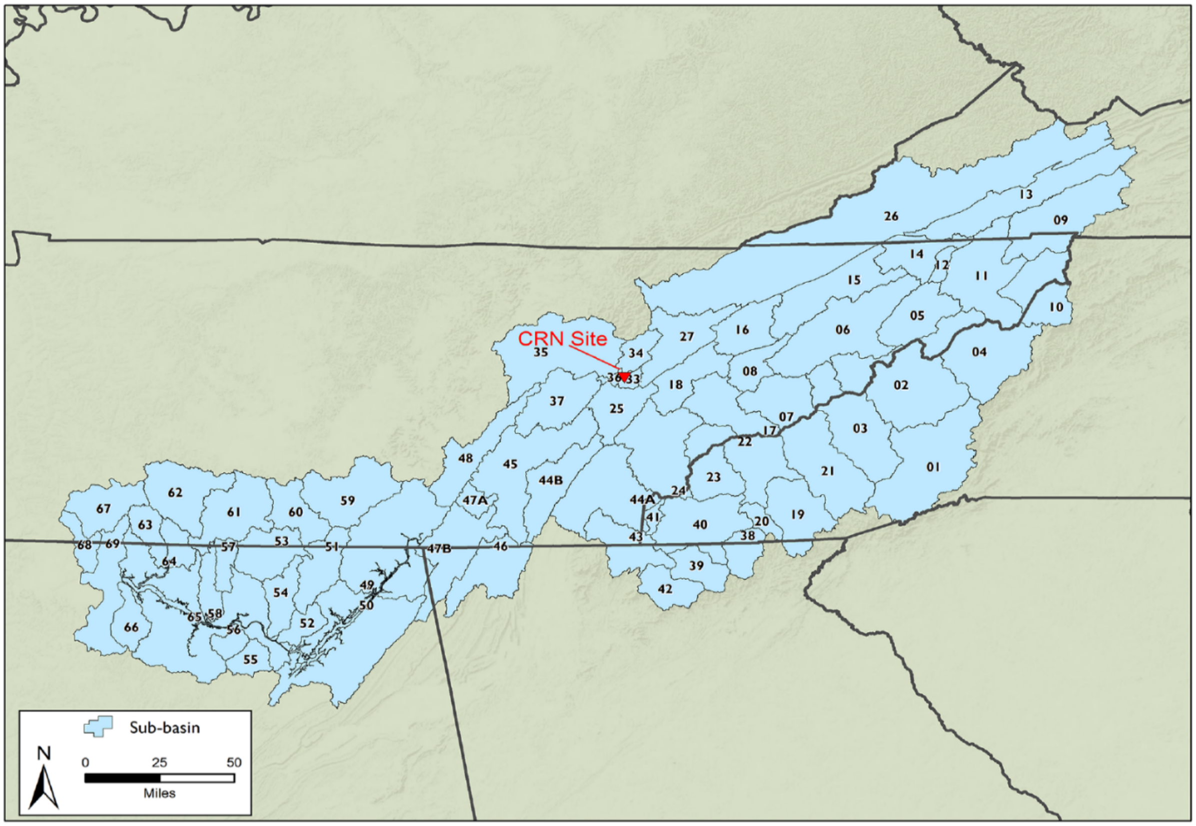

Figure 2.4.3-1 Tennesee River Watershed Subbasins used by the applicant for Hydrologic Analysis (after SSAR Revision 1, Figure 2.4.3-1).

Staff's Technical Evaluation

The staff reviewed the sub-basin information by comparing the topography map published by the United States Geological Survey (USGS, 2017a) to the applicant's sub-basin map. The staff found that the applicant's choice of sub-basins are acceptable because sub-basins were delineated based on the basin ridges and stream flow outlets and stream gauge locations. The staff also reviewed the applicant's description of sub-basin sizes and found that the sizes are compatible with the staff's measurements using the geographic information system tool (GIS). The staff used ArcHydro Tools (ESRI, 2013) in the ESRI's ArcMap GIS software and worked on the USGS digital elevation model (DEM) files (USGS, 2017b) to check the applicant's sub-basin map in a portion area above Chattanooga, Tennessee. The staff previously evaluated the relevant hydrologic parameters for the watershed during a technical review in 2014 for the Watts

Bar License Amendment Request (ADAMS Accession No. ML15005A314). Based on the current review on the USGS topography maps and the comparison to the technical review in 2014, the staff finds that the applicant provided the most updated information for the watershed characteristics.

2.4.3.4.2 Probable Maximum Precipitation

Information Submitted by the Applicant

To consider the flood hazards at the CRN Site due to severe meteorological conditions, the applicant adopted the methodologies addressed in Hydrometeorological Report (HMR) 41 (HMR 41), HMR 51, HMR 52, and HMR 56 (NOAA 1965, NOAA 1978, NOAA 1982, NOAA 1986), to compute the probable maximum precipitation (PMP).

The applicant presented four groups of candidate storms in the SSAR (ADAMS Accession No.ML16144A074) and additional information in the SSAR's supplements (ADAMS Accession No. ML17157B212) for computing the PMP. Among the candidate storms, the applicant searched for one storm that could create a maximum flood level at the CRN Site. The four groups of candidate storms included:

(1) A storm center in 3,382 mi^2 of the watershed area above the CRN Site, developed according to HMR 51 and HMR 52, which provide the guidance applicable for the generalized PMP in the watershed areas east of the 105^{th} meridian and the watershed areas from 10 mi^2 to 20,000 mi^2 in the United States;

(2) A storm center in 2,912 mi^2 of the watershed area above Norris Dam, developed according to HMR 56 which provides the guidance applicable for watershed areas less than 3,000 mi^2 in the Tennessee River watershed;

(3) A storm center in 469 mi^2 of the watershed area between Norris Dam and the CRN Site, developed according to the guidance of HMR 56; and,

(4) A storm center at Bulls Gap or at Sweetwater in the 7,980 mi^2 of watershed area above the Chickamauga Dam and below the major tributary storage dams, or a storm center in the 21,400 mi^2 of watershed area above Chattanooga, developed according to HMR 41, which provides the guidance applicable for the basin areas larger than 3,000 mi^2 in the Tennessee River watershed.

To develop the first candidate storm covering the 3,382 mi^2 watershed as indicated in group No.1 above, the applicant located the centroid of the watershed on Figures 18 through 47 in HMR-51 to create storm depth-area-duration (DAD) curves. The storm areas of the DAD curves range from 10 mi^2 to 20,000 mi^2, and the storm durations of the curves range from 6 hours to 72 hours. The applicant assigned the interpolated precipitation depths from those DAD curves to the isohyet lines of a standard storm pattern that was quoted from HMR-52. The isohyet lines form a total storm area in an elliptical shape and provide the spatial distribution of the storm over the 3,382 mi^2 watershed. By orienting the axis of the elliptical storm area and trying smaller and larger total storm areas, the applicant identified a critical 6,500 mi^2 storm area that could produce the maximum precipitation over the 3,382 mi^2 watershed. The applicant used the isohyets of the 6,500 mi^2 storm area to compute the sub-basin average precipitations that would be carried later into a hydrologic modeling as the input data for computing PMF elevation at the CRN Site.

To generate the second and third candidate storms over watershed areas less than 3,000 mi^2 as indicated in the above group Nos. 2 and 3, the applicant used the HMR-56 method, which is similar to the procedure of developing the first candidate storm. The applicant included the second and third candidate storms to maximize the uncontrolled discharges from Norris Dam and Melton Hill Dam, and to evaluate the potential flood hazard for the CRN Site.

In the fourth group of candidate storms, the applicant followed the HMR 41 method to generate three storms. Two storms are over the watershed areas of 7,980 mi^2 either centered at Bulls Gap or Sweetwater above Chickamauga Dam. Another storm is over 21,400 mi^2 above Chattanooga.

All the above candidate storms were 9-day events which would occur over the time sequence of a three-day antecedent storm to saturate the watershed, followed by a three-day dry interval, and then the three-day main storm. The applicant assigned the rainfall depth of a three-day antecedent storm to have a uniform areal distribution over the watershed area above Guntersville Dam that was equal to 30 percent of the areal average rainfall depth of a three-day main storm when the storm belonged to the first 3 groups of candidate storms, including the storms over the different watershed sizes 3,382 mi^2, 2,912 mi^2, 469 mi^2. The applicant used 40 percent of the areal average rainfall depth of a three-day main storm when the storm belonged to the fourth group of candidate storms. The fourth group of candidate storms are over the watershed sizes of 7,980 mi^2 and 21,400 mi^2. The applicant assigned the temporal rainfall distribution of the three-day main storm in accordance with methods in HMR 52 or HMR 41 or HMR 56, depending on the method applicable to different storm candidates. As presented in the SSAR, the applicant formulated the temporal distribution by setting the group of the four greatest 6-hour increments of the 72-hour rainfall in the middle, the group of the four smallest 6-hour increments at the end, and the group of median four 6-hour increments at the beginning. With this formulation, the applicant could have the heaviest rainfall depth to occur in the second day of the three-day main storm. The applicant used the HMR procedures to set the temporal distributions for the three-day antecedent storms. The applicant assigned the temporal distribution of three-day antecedent storms as the same pattern of the three-day main storm.

Among all candidate storms, the applicant found that the 7,980 mi^2 storm centered at Bulls Gap, in March (ADAMS Accession No. ML17157B212) could generate the worst flood condition at the CRN Site. The applicant stated that this 7,980 mi^2 storm event would have 17.02 inches of areal average rainfall depth over the watershed above Watts Bar Dam for the three-day main storm (ADAMS Accession No. ML17157B212). This event would also provide 6.00 inches of areal average rainfall depth over the watershed area above Guntersville Dam for the three-day antecedent storm.

Staff's Technical Evaluation

Including the four groups of candidate storms, the staff reviewed the applicant's PMP computational steps that followed HMR guidance. The staff notes that the applicant's first candidate storm covering a 3,382 mi^2 watershed was one of the candidate storms in the Clinch River watershed and was generated by the procedures described in HMR-51 (NOAA, 1978) and HMR-52 (NOAA, 1982). HMR-51 and HMR-52 are applicable for the Clinch River watershed in the areas east of the 105^{th} meridian, but are not applicable where orographic effects are significant. Because the terrain variation in the Clinch River watershed may have significant orographic effects on the PMP, the staff checked the appropriateness of using HMR-51 and HMR-52 to compute the precipitation for the first candidate storm. The staff finds that the applicant's justification of using HMR-51 and HMR-52 for estimating the first storm over 3,382 mi^2 watershed is based on the Addendum to HMR-45 (NOAA, 1973), which states the ridges within the Clinch River watershed are relatively low and generally parallel with the direction of inflow of moisture during extreme storms. The Addendum also stated that topographic effects within the Clinch River basin are minimal and were not applied in determining rainfall volume or distribution. Therefore, the staff considers that the applicant's usage of HMR-51 and HMR-52 for the PMP computation of the 3,382 mi^2 watershed is acceptable without considering the topographic effects when computing the PMP for the first candidate storm.

Based on calculations provided by the applicant, the staff noted that the applicant developed Depth-Area-Duration curves (DAD) for sub-basins and considered the Terrain Adjustment Factor (TAF) in the PMP computations when using HMR-56 and HMR-41 for the second through fourth groups of candidate storms. The TAF as described in HMR-56 can be used to adjust the computed PMP according to the percentages of rough, smooth, and intermediate terrain in the sub-basins. The staff finds that the non-mountainous flat area or the low ridge area, such as the Clinch River watershed, does not need the TAF as described in the HMRs. The staff also finds that the applicant followed the HMRs to consider the TAF, except when HMR-51 and HMR-52 were used. The staff concludes the applicant's PMP was reasonably computed to represent a critical precipitation pattern since the results were generated with the HMR TAF and in accordance with HMR guidance.

The staff checked the applicant's areal average 72-hour PMP depth centered at Bulls Gap over the watershed above the Watts Bar Dam. The staff calculated the areal average 72-hour PMP of 17.05 inches for the three-day main storm (72-hour PMP) above Watts Bar Dam, which has a minimal difference from the applicant's calculated 17.02 inches. The staff also checked the applicant's calculated antecedent rainfall depth by calculating an areal average PMP of 5.95 inches above Guntersville Dam for the three-day antecedent storm, which is negligibly different from the applicant's 6.0 inches. The staff selected Guntersville Dam (see Figure 2.4.1-4, Sheet 2 of 2) for checking the areal average of antecedent rainfall depth because the dam approximates the outer isohyet boundary of the storm pattern. Based on comparing the minimal differences between the applicant's and the staff's calculations, the staff determined that the applicant acceptably computed the spatially averaged PMP of 17.02 inches for the three-day main storm (72-hour PMP) over the watershed area above Watts Bar Dam and 6.0 inches for the three-day antecedent storm over the watershed area above Guntersville Dam. The staff also confirmed that the applicant's 72-hour PMP depth for each sub-basin shown on Table

2.4.3-2 of the SSAR Revision 0 (ADAMS Accession No. ML16144A074) matched the applicant's calculations reviewed during the audit (ADAMS Accession No. ML17341A276).

The staff used HMR-41 guidance and calculated the temporal PMP distribution of the main storm (72-hour PMP) over the watershed area above the Watts Bar Dam and found negligible differences in the applicant's temporal PMP distribution as shown in SSAR Table 2.4.3-3. Due to these small differences, the staff determined that the temporal PMP values shown in Table 2.4.3-3 are reasonable.

The staff reviewed the applicant's calculations for the four groups of the candidate storms provided by the applicant. Based on a review of the applicant's calculations and information provided, the staff determined that the applicant's temporal rainfall distributions were appropriate.

The staff noted that the current PMP isohyet patterns of the fourth group of candidate storms for the 7980 mi^2 and 21,400 mi^2 watersheds are similar to the PMP isohyet patterns reviewed by the NRC staff in 2014 and 2015 (ADAMS Accession No.ML15005A314) for the Watts Bar Nuclear Power Plant license amendment request (WBN LAR). The staff also notes that the applicant used similar parameters and steps for computing the storms over 7,980 mi^2 and 21,400 mi^2 watersheds that were examined by the NRC staff in the previous review of WBN LAR (ADAMS Accession No.ML15005A314).

The staff noted that the applicant's computed PMP for the storm over the 7,980 mi^2 watershed above Chickamauga Dam is a controlling storm when compared to the other candidate storms described in SSAR Table 2.4.3-1. The controlling storm could generate a maximum flood elevation at the CRN Site in the Watts Bar Reservoir's upstream area as described in in Section 2.4.3.4.5 herein.

2.4.3.4.3 Precipitation Losses

Information Submitted by the Applicant

The applicant made an assumption of no precipitation losses for surface runoff computations. That means 100 percent of the precipitation was transformed into surface runoff.

Staff's Technical Evaluation

Precipitation losses typically occur during rainfall events. These losses are the result of natural soil absorption, the filling-up of surface depressions, vegetal interception, and other factors. The staff considers the applicant's assumption of no losses, which directly converts all precipitation to surface runoff, to be acceptable because it is a conservative assumption.

2.4.3.4.4 Runoff and Stream Course Models

The evaluation of the Runoff and Stream Course Models is in SER sub-sections 2.4.3.4.4.1 to 2.4.3.4.4.4, which describe the Runoff Model, Stream Course Model Extent, Stream Course Geometry Development and Calibration, and Design Storm Implementation, respectively.

2.4.3.4.4.1 Runoff Model

Information Submitted by the Applicant

The applicant developed a rainfall-runoff model using Microsoft Excel (ADAMS Accession No. ML16216A115) to convert rainfall discussed in SSAR Section 2.4.3.4.1 into surface runoff using the unit hydrograph method for all the sub-basins (Figure 2.4.3-1) in the Tennessee River watershed.

The applicant derived unit hydrographs based on the flood record between 1940 and 1973. The applicant followed a reverse process (ADAMS Accession No. ML17157B212) called deconvolution (Newton and Vineyard, 1967) to derive the unit hydrographs. When a sub-basin was lacking rainfall-runoff data, the applicant derived synthetic unit hydrographs from the available data of other similar sub-basins.

The applicant validated the unit hydrographs as described in the SSAR supplements (ADAMS Accession No. ML17157B212) that could reproduce the rainfall-runoff results of large storms recorded from 1997 through 2007. When large storm data was not available in this period for some sub-basins, the applicant either used the data back to 1985 or routed the computed runoff to a downstream point where the data was available for validation. The applicant provided the validated unit hydrographs in the SSAR supplements (ADAMS Accession No. ML17157B212) for the sub-basins above Chickamauga Dam.

In consideration of the non-linearity between the effective rainfall depth and the surface runoff during an extreme large flood, such as a PMF, the applicant increased the validated unit hydrograph peak by 20 percent and decreased the time-to-peak by one-third. The applicant used the adjusted unit hydrographs (ADAMS Accession No. ML16216A115) to calculate the surface runoffs of hypothetical storms at outlets of the sub-basins above Wilson Dam. Each sub-basin, including sub-basin Nos. 1 through 65 (Figure 2.4.3-1), has its own adjusted unit hydrograph, except for sub-basin Nos. 66 through 69. The applicant treated the sub-basin Nos. 66 through 69 as a reservoir area. Thus, the surface runoff hydrographs for sub-basin Nos. 66 through 69 were calculated by multiplying the sub-basin area by the rainfall intensity without using the unit hydrograph method.

Within SSAR Section 2.4.3.3, the applicant set no precipitation losses for any of the PMP events. The applicant used zero-loss of rainfall depths and the adjusted unit hydrographs to generate the surface runoff hydrographs for a PMP event.

Additionally, the applicant considered that the reservoir volumes of many small dams could become non-detainable flows if the small dams were assumed to fail during a PMP event. The applicant counted these non-detainable flows from the small dams as additional surface runoff flows and identified approximately 700 dams in the Tennessee River watershed above Wheeler Dam. The applicant used the list of the National Inventory of Dams (NID) to acquire the storage volumes of the 700 dams. The NID is maintained by the United States Army Corps of Engineers. Not counting the reservoir storage effect of the 700 small dams, the applicant simply converted the storage volumes into rectangular hydrographs of surface runoffs with 6 day-flow durations. All the rectangular hydrographs in the different sub-basins have a starting day at one day after the peak rainfall of the antecedent storm. For a demonstration, the applicant included the rectangular hydrographs that were added to the discharges at Norris Dam, Melton Hill Dam, and Watts Bar Dam in the Figure 2.4.3-18, 19, and 20 of the SSAR supplements (ADAMS Accession No. ML17157B212). As demonstrated in the SSAR supplement, the applicant directly added the rectangular hydrographs as input data to the applicant's surface runoff model (ADAMS Accession No. ML16216A115).

Staff's Technical Evaluation

The staff reviewed the peak flows, peaking times, and unit volumes of the applicant's unit hydrographs presented in the SSAR supplements (ADAMS Accession Nos. ML17157B212 and ML17333A789). Through reviewing the details of the unit hydrograph development during the NRC audit (ADAMS Accession No. ML17341A276), the staff confirmed that the applicant's unit hydrographs were updated and validated by comparing simulated results to several storm events from 1997 through 2007.

The sub-basin unit hydrographs and their validations are discussed in the April 2017 audit summary report (ADAMS Accession No. ML17341A276). The staff found that the applicant utilized acceptable methodologies and procedures to derive and validate the unit hydrographs because the applicant used common practices in hydrologic engineering that are consistent with NRC guidance. The staff reviewed the applicant's detailed validations of unit hydrographs, including the selected large storms, the stream base-flow separation, and the computations of effective rainfalls that were generated from the observed precipitations and the Antecedent Precipitation Index (API) method (Linsely, Kohler and Paulus, 1982). The staff examined the comparison between the applicant's simulated surface runoff hydrographs and the observed stream flow hydrographs.

Based on the staff's review of the applicant's results for unit hydrograph validation, the staff confirmed that the applicant's unit hydrographs can be used to reproduce the recorded large floods and to reflect the current watershed characteristics acceptably. The staff also finds that the reproduced flow rates or flow elevations by the unit hydrographs are within small variances when compared to the recorded flow rates or flow elevations of the storm events. Therefore, the staff considers that the applicant's unit hydrographs are acceptable.

The staff noted that the applicant's rectangular-shape hydrographs, treated as additional surface runoffs to the sub-basins, were obtained by converting small reservoir storage volumes of the NID into surface runoffs. The staff concludes the rectangular-shape hydrographs are acceptable since the applicant conservatively converted the storage volumes into the rectangular hydrographs with no consideration of flow attenuation between the NID dams and the sub-basin outlets. The staff observed that Figures 2.4.3-18 through 20 of the SSAR supplement indicate that the rectangular-shape hydrographs would not be significant inflows to the reservoirs when compared to the PMF flows.

The staff reviewed the applicant's runoff model and confirmed that the non-linearity of the unit hydrographs was included as recommended by NUREG/CR-7046 (ADAMS Accession No.

ML11321A195). Therefore, the staff confirmed the applicant's Microsoft Excel runoff model contains non-linearity that can be further used to generate surface runoff values with relevant PMP events.

The staff determined that the applicant's computation of surface runoffs resulting from a PMP event was conservative because the applicant-computed surface runoffs were developed based on rainfall depth without any reduction of infiltration loss, without considering peak flow attenuation of rectangular hydrographs converted from NID storage volumes, and without considering lag times between the rainfall events and surface runoffs for instantaneous runoffs created for Sub-basins 66 through 69. More detailed information on Stream Course Models and Design Storm Implementation is presented in Sections 2.4.3.4.4.2 through 2.4.3.4.4.4 below.

2.4.3.4.4.2 **Stream Course Model Extent**

Information Submitted by the Applicant

The applicant used the calibrated HEC-RAS model (USACE, 2010) to simulate the flood profiles that connected in the main river channel and many other tributary channels in the Tennessee River Watershed (ADAMS Accession No. ML16216A115). The flood profiles converge to the downstream end at Wilson Dam, which is the outlet of Sub-basin No. 69 (Figure 2.4.3-1). The upstream boundaries of the HEC-RAS model were located at various control points, including upstream dams and reservoirs, critical stream gauge stations, confluences of tributaries or rivers, and the hydraulic control structures. Details of the upstream boundary points of the HEC-RAS model are shown in Figure 2.4.1-4. These upstream points receive inflows from the surface runoff hydrographs that were generated by the applicant's runoff model described in Section 2.4.3.4.4.1 herein.
The applicant stated that dams and reservoirs modeled below the Chickamauga Dam (Figure 2.4.1-4, Sheet 2 of 2) would have little effect on the predicted flood profiles at the CRN Site. The Chickamauga Dam is located immediately downstream of Watts Bar Dam.

Staff's Technical Evaluation

The staff reviewed the upstream boundary and hydrologic control points in the HEC-RAS model. The staff examined the applicant's inflows stored in the Hydrologic Engineering Center's Data Storage System (HEC-DSS) files (ADAMS Accession No. ML16216A115), which were consistent with the output data stored in the spreadsheet of the applicant's runoff model. Based on the staff review and examination of the inflow files, the staff finds that the applicant acceptably set up the upstream boundary and control points. The staff notes that the HEC-DSS files meet both the HEC-RAS model input requirements and input format.

In accordance with the HEC-RAS computational results, the staff agrees with the applicant's conclusion that floods occurring downstream of the Watts Bar Dam or Chickamauga Dam would have minimal effect to water levels near the CRN Site.

2.4.3.4.4.3 Stream Course Model Geometry Development and Calibration

Information Submitted by the Applicant

The applicant developed elevation-storage relationships for main stem reservoirs (ADAMS Accession No. ML18003A374), using reservoir level-storage information and sediment range survey maps. The reservoir elevation-storage relationships are for uses in the HEC-RAS model. The applicant also measured the reservoir areas on the composite maps consisting of U.S. Army Corps Engineers (USACE) survey maps, the applicant's land maps, USGS topographic maps, and the applicant's navigation maps. The applicant used the measured reservoir areas above the projected flood elevation to extend the range of elevation-storage relationships when the extension was needed.

In addition to the reservoir elevation-storage relationships, the applicant developed stream channel profiles and effective flow areas of main stem and tributaries, which would be used in the HEC-RAS model. The applicant developed those channel profiles and effective stream flow areas from the cross-section data of the applicant's historical hydrology model, USACE hydrographic survey data, aerial photos, and Digital Terrain Model (DTM) data of water surface topography.

The channel profiles in the HEC-RAS model above Watts Bar Dam included major hydraulic structures and stream gage stations (ADAMS Accession No. ML16216A115). The upstream main stem and tributaries above Watts Bar Dam include the Little Tennessee River, Clinch River, French Broad River, and Holston River (Figure 2.4.1-4, Sheet 1 of 2.)

The applicant also extended the cross section areas to be large enough to contain the Probable Maximum Flood (PMF) for flow simulations in the HEC-RAS model. Those extended cross sections include off-channel ineffective flow areas that allow reach storage volumes to closely replicate the reservoir elevation-storage relationships. The average overbank-flow lengths were also considered with the off-channel ineffective flow areas to compute the reach storage volume. The applicant also simulated the complex off-channel volumes by adding flow cross sections with lateral discharge structures that connected to the designated flood plains. The applicant provided examples of the replicated reach storage volumes as shown in Figures 2.4.3-22 through 24 of the SSAR supplements (ADAMS Accession No. ML17157B212). As the replication of the reservoir volume needed in the constriction flow areas of reaches, the applicant augmented ineffective off-channel flow areas in the specific stream cross-sections to increase reach volume by utilizing the triangulated irregular network (TIN) file of the related reservoir and channel.

After setting up the stream geometric data in the HEC-RAS model, the applicant calibrated the hydraulic parameters in the model by selecting the two largest flood events, occurring in March 1973 and May 2003.

The applicant separated 3 sequential segments of the Clinch River and calibrated the Clinch River as a portion of the HEC-RAS model. The downstream segment is from the Clinch River mouth at 0.0 river mile to its upstream Melton Hill Dam at 23.1 river miles. The middle segment is from Melton Hill Dam to Norris Dam at 79.8 river miles. The upstream segment stretches from Norris Dam to the reservoir upstream limit at a location of 153.6 river miles. The downstream and middle segments were calibrated with March 1973 and May 2003 events that were the same events used to calibrate the main stem of the Tennessee River. The upstream segment, comprised of two tributaries, was calibrated with 2002 and 2003 flood events, as well as FEMA flood profiles. The applicant also calibrated the other sequential segments of the Tennessee River in the HEC-RAS model. In each segment, the upstream boundary conditions were the observed discharges at upstream dams and the downstream boundary conditions were the observed headwater elevations at downstream dams. The applicant calibrated the HEC-RAS model to replicate the flood events in segments by adjusting hydraulic parameters, including friction coefficient of the flow, and also by checking ineffective flow areas and reservoir storage volumes. The adjustments of the hydraulic parameters were iterative during the calibration process until they could make the peak flood elevation difference from the observed flood elevation within a range from 0.5 to 1.5 ft at the headwater levels of the dams. The applicant presented the calibration results of the Clinch River in Figures 2.4.3-10 through 2.4.3-15 in the SSAR as a portion of the HEC-RAS model calibrations. After calibrations, the applicant combined all the Clinch River segments with other segments in the Tennessee River watershed into one model. The applicant later used the calibrated HEC-RAS model (ADAMS Accession No. ML16216A115) to simulate the stream flows and reservoir volume changes in the Tennessee River watershed (see Section 2.4.3.4.5 and 2.4.3.4.6 herein).

As requested by the staff during the audit (ADAMS Accession No. ML17341A276), the applicant added stream cross sections and analyzed the backwater effect due to a high flow constriction at the Tennessee State Highway 58 Bridge, located about 2 miles downstream from the CRN Site, and provided supplemental data, including the reduced intervals between stream cross sections and the Highway 58 Bridge (ADAMS Accession Nos. ML17171A335 and ML17206A090) that could be used as geometry files to the HEC-RAS model. For validating the configuration of Highway 58 Bridge, the applicant provided the bridge profile and plan shown in the SSAR supplements (ADAMS Accession No. ML17157B212). The applicant used these geometry files (ADAMS Accession Nos. ML17171A335 and ML17206A090) in the sensitivity study of backwater effects on the flood elevation changes. The applicant stated the sensitivity study result in the SSAR supplements (ADAMS Accession No. ML17157B212) and indicated minimal changes of the flood elevations adjacent to the CRN Site.

Staff's Technical Evaluation

The staff noted that the applicant used available data acquired from Federal and State government agencies to develop and validate the elevation-storage relationship of main stem reservoirs as shown in the SSAR. The staff also notes that the applicant developed stream cross sections based on the applicant's previous hydrologic model and validated the stream cross sections with the reliable data that was established by Federal government agencies. The staff concludes that the applicant data sources used in both developing the reservoir elevation-storage relationship and deriving the stream cross sections are acceptable since the data sources are reliable and generated by government agencies.

The staff used GIS tools to extract stream cross sections from USGS topographic maps and USGS DTM files. By comparison, the staff finds that the extracted cross sections are consistent with the applicant's cross sections above normal flow elevations shown in the HEC-RAS model

(ADAMS Accession No. ML16216A115). Based on the geometrical consistency within the comparisons, the staff concludes that the applicant's stream cross sections are acceptably used in the HEC-RAS model to represent the stream geometry.

The staff examined the applicant's reservoir volume calculations in which the applicant used reservoir surface areas and elevations to calculate incremental and cumulative volumes of reservoir storage. Based on the staff's comparisons between the USGS contour maps and the evaluations used in the applicant's calculations, the staff confirmed that the elevation-storage relationship shown in the HEC-RAS model reasonably represented the field conditions of the reservoirs. The staff determined that the reservoir elevation-storage data is valid and acceptably used in the HEC-RAS model to represent the field conditions since the applicant validated the elevation-storage relationship with various reliable data sources including those from government agencies as described in the SSAR supplements (ADAMS Accession No. ML17157B212).

The staff reviewed the applicant-determined effective flow areas from the validated stream geometry in the HEC-RAS model and reviewed the hydraulic parameters used in the model (ADAMS Accession Nos. ML16216A115, ML17171A335, and ML17206A090). Based on the review, the staff found: (1) the applicant's HEC-RAS model setup and the effective flow areas were based on reliable topographic data; (2) the applicant's hydraulic parameters were calibrated within a reasonable range when compared to the values of the HEC-RAS Reference Manual (USACE, 2016); and, (3) the calibrated peak elevations remain higher than the observed elevations by a range from 0.5 to 1.5 ft. With those findings, the staff determined that the applicant's HEC-RAS model was acceptably calibrated and that the HEC-RAS model is applicable for probable maximum flood (PMF) simulations.

The staff also noted that the applicant simulated a series of reach volumes by the HEC-RAS model under the steady-state flat-pool storage condition to replicate a reservoir volume in the HEC-RAS model. For confirmation, the staff calculated the reservoir volumes under the steady-state flat-pool simulation using the staff's spreadsheets and got similar results as described in the applicant's SSAR supplements (ADAMS Accession No. ML17157B212). Based on the staff's similar results compared to the applicant's demonstrations shown in the SSAR supplements (ADAMS Accession No. ML17157B212), the staff determined that the applicant-determined stream reaches acceptably represent the reservoirs in the HEC-RAS model.

The staff noted that the applicant added a statement in the SSAR supplements (ADAMS Accession No. ML17157B212) to include a sensitivity study result regarding the backwater effect on the CRN Site when the Tennessee Highway 58 Bridge was added to the HEC-RAS model for PMF simulations. Using the applicant's bridge geometry data (ADAMS Accession Nos. ML17206A090 and ML17157B212), including the bridge profile and plan, the staff calculated PMF elevations of various locations to confirm the applicant's conclusion that there were minimal increases in the PMF elevations. The staff's calculated PMF elevations show a minimal increase in the PMF elevation at the CRN Site when the bridge is included in the HEC-RAS model. Therefore, the staff determined that accounting for the bridge does not substantially affect the PMF elevations and that including the bridge in the PMF simulation is unnecessary.

In addition to the reservoirs and streams being established in the HEC-RAS model, reservoir operational guides are other dominant factors that affect the PMF simulation in the HEC-RAS model. The operational guides are described in detail in Section 2.4.3.4.4.4 below.

2.4.3.4.4.4 Design Storm Implementation

Information Submitted by the Applicant

To control floods, the applicant implemented flood operational guides for the reservoirs in the Tennessee River Watershed. The floods controlled by the operational guides can be the outcomes of various seasonal design storms, such as a PMP event occurring in March. The flood operational guides for warm seasons are different from the ones for cold seasons. The applicant used SSAR Figure 2.4.3-4 as an example to demonstrate the complexity of operational guides for controlling reservoir headwater levels in March and June at Norris Dam (SSAR supplement, ADAMS Accession No. ML17157B212). Using the diagram as shown on SSAR Figure 2.4.3-4, the applicant explained the steps for managing flow discharges between 4,500 cfs and 24,000 cfs, as well as headwater levels between 1,005 ft and 1,034 ft. SSAR Figure 2.4.3-4 showed the primary guide curve to be used to raise the reservoir level when flood flows enter the reservoir, and the recovery curve to be used to draw down the reservoir level when the flood flows recede. The applicant also described that 1,034 ft was the upper limit of the operational guides for Norris Dam. The applicant provided transition conditions to extend the limit of flood operational guides into dam rating curves when the reservoir headwater exceeded 1,034 ft. The submergence effects between the reservoir headwater and tailwater were included in the dam rating curves.

Because Melton Hill Dam is not for flood control, a simple flood operational guide for all seasons was provided in SSAR Figure 2.4.3-5. For Watts Bar Dam, the applicant showed different and complex flood operational guides in SSAR Figure 2.4.3-6.

The flood operational guides and the dam rating curves were both scripted as computer program lines embedded as portions of “HEC-RAS unsteady flow rules” in the applicant’s HEC-RAS model. During a flood profile simulation, the applicant’s scripted “HEC-RAS unsteady flow rules” can be executed to compute the reservoir outflows by following the dam rating curves or the operational guides. The computations were incorporated with the reservoir headwater and tailwater levels. The applicant used the median or normal pool level of a season as the initial reservoir water elevations to start the flood profile simulation in the HEC-RAS model.

For the hypothetical dam breach during various design storms, the applicant scripted other program lines embedded in the “HEC-RAS unsteady flow rules” to compute the breach flows. These scripted program lines describe weir flow equations and dam breach parameters. The applicant adopted the weir flow equation to calculate the breach outflows when the geometrical breach section did not reach the channel bottom. If the breach section reached the channel bottom, the applicant calculated the outflow by the unsteady flow equations formulated in the HEC-RAS model. Sections 2.4.4 and 2.4.4.4.2 herein provide details regarding potential dam failures and dam breach parameters, respectively.

Staff's Technical Evaluation

The staff reviewed the numerical values of the flood operational guides and dam rating curves (ADAMS Accession No. ML16280A065). By examining the numerical values, the staff finds that the relationship between the headwater levels at dams and discharges from dams can reflect the flood operational guides and dam rating curves. The staff confirms that the numerical values match the computational results of the applicant's HEC-RAS model (ADAMS Accession No ML16216A115).

The staff reviewed weir flow equations and their coefficients that described dam rating curves that were used in the applicant's HEC-RAS model. The staff confirms that the weir flow equations are in standard engineering applications and that the coefficients of the equations are within a standard range.

The staff noted that "HEC-RAS unsteady flow rules" is one of the programming functions in the HEC-RAS model, and that it allows users to prescribe unsteady flow rules according to dam rating curves or flood operational guides. The staff reviewed the unsteady flow rules embedded in the applicant's HEC-RAS model and found that the unsteady flow rules matched the applicant's flood operational guides and the applicant's dam rating curves. To examine the tailwater submergence effects on the applicant's dam rating curves, the staff checked the model by increasing the tailwater elevations at Melton Hill Dam. Based on the checks, the staff found that the applicant's dam rating curves embedded in the "HEC-RAS unsteady flow rules" can respond to the tailwater submergence effects. The staff finds that the dam rating curves generated by the applicant's HEC-RAS model for Norris, Melton Hill, and Watts Bar Dams match the diagrams shown on SSAR Figures 2.4.3-7 through 2.4.3-9.

Based on the above staff's examinational results, the staff considers that the dam rating curves and the flood operational guides were appropriately simulated with the applicant's HEC-RAS model.

For the other dam rating curves of dam failures, the staff reviewed the applicant's dam breach parameters that were used in the HEC-RAS model, and also reviewed the applicant's computed breach outflows that were generated from the HEC-RAS model. As to the dam breach parameter, the staff confirms that the applicant used the acceptable methods described in JLD-ISG-2013-01, "Guidance for Assessment of Flooding Hazards Due to Dam Failure" (ADAMS Accession No. ML13151A153) to develop the breach depth, breach width and breach side slope (staff's evaluation on the dam breach parameters are described Section 2.4.4.4.2.1 herein). As to the computed breach outflows, the staff compared the applicant's computed results from the spreadsheets (ADAMS Accession No. ML16280A065) and the computed breach outflows from the HEC-RAS model (ADAMS Accession No. ML16280A065). Based on the consistency between the spreadsheets and the HEC-RAS results, the staff determined that the applicant's weir flow equations and the applicant's weir flow discharge coefficients for dam breach outflows were acceptably used and embedded in the HEC-RAS model.

2.4.3.4.5 Probable Maximum Flood Flow

Information Submitted by the Applicant

(SRI/CEII) The applicant included the prescribed reservoir operational guides and the established dam rating curves in the HEC-RAS model to compute flood elevations of various storm events. The applicant compared the computed flood elevations of various storms, including the 7,980 square-mile, 21,400 square-mile, 3,382 square-mile, 2,912 square-mile, and 469 square-mile storms. Based on the comparison as shown in Table 2.4.3-1 of the SSAR supplement (ADAMS Accession No. ML17157B212), the applicant stated that the maximum flood elevation at the CRN Site (described in Section 2.4.3.4.6 herein) was the result of the 7,980 square-mile storm as a PMP event, in which the storm center was set at Bulls Gap and assumed to occur in March. The applicant presented the calculated PMF elevation, **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88), and the maximum flood flow, 536,000 cfs, in SSAR Figure 2.4.3-3. This PMP event could cause overtopping flows, as described in the Section 2.4.4.2.2 herein. The applicant selected the normal reservoir levels in March as initial pool conditions according to the applicant's flood operational guides to match the timing of the 7,980 square-mile PMP occurrence. For the other storm events, the applicant set the normal reservoir levels in June as initial conditions to match the timing of the other storm occurrences. All reservoir normal levels in June would be at their highest elevations of the year according to the applicant's flood operational guides.

(SRI/CEII) The applicant performed a sensitivity study, assuming all the discharge gates were inoperable for **[[ ]]** Dam and reducing the gate discharge rate of **[[ ]]** Dam during the 7,980 square-mile storm. The sensitivity study showed that overtopping failures of both the **[[ ]]** Dam and its downstream **[[ ]]** Dam would occur due to the assumption. With these overtopping failures, the applicant presented that the flood elevation at the CRN Site would increase by **[[ ]]** ft above the **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88). The elevation of **[[ ]]** ft NGVD29 is the result under the condition of all gates being operable during the 7,980 square-mile storm. The applicant noted the assumption of inoperable gates is unrealistic because the reliability of the discharge gates are monitored by daily operation. The applicant stated that the TVA has the means and resources to resolve any gate operation issues.

Staff's Technical Evaluation

The staff reviewed the applicant's calibrated HEC-RAS model (ADAMS Accession No. ML16216A115) and supporting calculations provided during the NRC's safety audit during April through October 2017. The staff's review items including the applicant's model setup, stream augment sections for ineffective flows, the geometry of stream cross sections, energy loss coefficients of stream flows, the unsteady flow rules, inflow data as input to the model, storage volumes of the reservoirs, and distances between the stream cross sections within the flood plain. In the above review items, the staff noted a warning message produced by the HEC-RAS model for additional stream cross-sections between the CRN Site and the Melton Hill Dam. To resolve the warning message, the staff interpolated additional cross sections. Based on the sensitivity study, the staff confirms that the addition of stream cross sections eliminates the warning message and has a minimal impact on the flood elevation at the CRN Site.

(SRI/CEII) The staff reviewed the applicant's various storm events as inputs to the applicant's HEC-RAS models. The staff notes that the applicant necessarily adjusted some hydraulic parameters and changed the inputs in the HEC-RAS model to satisfy the requirements of the hydraulic condition changes. For example, discharge gates off and on, dam breach parameters, and dam failure timing are required to be changed to describe dam failure conditions in different storm events. The staff reviewed the flood profiles resulting from: (1) the 7,980 square-mile storm; (2) the 21,400 square-mile storm; (3) the 3,382 square-mile storm; (4) the 2912 square-mile storm; and, (5) the 469 square-mile storm. Based on comparing the applicant's simulation results, the staff confirms that the calculated PMF elevation is **[[ ]]** ft NGVD29 (shown in SSAR Figure 2.4.3-3) at the CRN Site resulting from the 7,980 square-mile storm.

(SRI/CEII) The staff reviewed the applicant's calculation package for the sensitivity study that the applicant hypothetically set all spillway gates of **[[ ]]** Dam inoperable and reduced the gate discharge rate of **[[ ]]** Dam by 20 percent during the 7,980 square-mile storm. The staff finds that applicant's dam failure timing and dam breach cross sections shown in the calculation package are reasonable. The staff confirms that the calculation is acceptable and the applicant's MSWFE is **[[ ]]** ft above the calculated flood elevation of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88), which is the result of the inoperable spillway gates at **[[ ]]** Dam and 20 percent discharge reduction at **[[ ]]** Dam.

2.4.3.4.6 Water Level Determinations

Information Submitted by the Applicant

(SRI/CEII) The applicant presented that the calculated PMF elevation at the CRN Site is **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88). This elevation is below the applicant's MSWFE of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88). To define the MSWFE, the applicant has added **[[ ]]** ft above **[[ ]]** ft as the margin for future changes.

Staff's Technical Evaluation

(SRI/CEII) The staff evaluated the applicant's HEC-RAS model and the flood profiles generated from the applicant's HEC-RAS model. The staff finds that the applicant's MSWFE of **[[ ]]** ft was well established above all calculated flood elevations. Additionally, the staff considers that the backwater effect due to the Tennessee Highway 58 Bridge, which is downstream approximately 2 miles from the CRN Site (ADAMS Accession Nos. ML17206A090, ML17171A335) as described in Section 2.4.3.4.4.3 , and the assumption of inoperable discharge gates at **[[ ]]** and **[[ ]]** Dams as described in Section 2.4.3.4.5, are both bounded within the MSWFE for the CRN Site.

(SRI/CEII) Without including the wind wave effect, the staff confirms that the **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) is the MSWFE which provides a **[[ ]]** ft margin above the calculated PMF elevation of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88).

2.4.3.4.7 Coincident Wind Wave Activity

Information Submitted by the Applicant

The applicant provided the 2-year wind-generated wave height under the controlling PMF generated from the 7980 square-mile storm, in which the storm center was set at Bulls Gap and to occur in March. The summary of the applicant's coincident wind wave information in this section is similar to Section 2.4.4.4.5 herein

The applicant stated that since Melton Hill Dam would be overtopped during the controlling PMF event, the wind-generated waves at the dam site were not calculated. At the Norris Dam, the applicant computed the wave height and provided information to demonstrate sufficient margin exists to prevent overtopping of the structure.

Staff's Technical Evaluation

The staff's evaluation for the wind-generated wave height is as described in the Section 2.4.4.4.5. The staff reviewed the headwater level (1,056 ft NGVD29) plus the wind wave height at Norris Dam. By comparing with the embankment top elevation at 1,065 ft NGVD29, the staff confirms that the 3-foot freeboard of Norris Dam and the embankment height is sufficient to prevent overtopping during the controlling PMF event.

2.4.3.5 *Post Early Site Permit Activities*

There are no post ESP activities for this section.

2.4.3.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant has demonstrated that the probable maximum flood on streams and rivers has no safety-related impact on the CRN Site and that there is no outstanding information required to be addressed in the SSAR related to this section. As set forth above, the applicant has presented and substantiated information to establish the site description. Further, the applicant has considered the most severe natural phenomena that have 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, in establishing site characteristics pertaining to the probable maximum flood on streams and rivers that are acceptable for design purposes. Therefore, the staff concludes that the applicant has met the relevant requirements of 10 CFR 52.17(a)(1), 10 CFR 100.20 and 10 CFR 100.23(d) with respect to determining the acceptability of the site.

2.4.4 Potential Dam Failures

2.4.4.1 *Introduction*

SSAR Section 2.4.4 addresses potential dam failures to ensure that any potential hazard to safety-related structures due to the failure of onsite, upstream, and downstream water control structures is considered in the plant design. As described in SSAR Section 2.4.1.1, the applicant stated that internal plant reservoirs will be utilized as part of closed cooling systems.

As such, the potential for onsite flooding due to onsite water storage structures was not evaluated.

Section 2.4.4 herein presents a review of the specific areas related to dam failures. The specific areas of review are as follows: (1) flood waves resulting from severe dam breaching or failure, including those due to hydrologic failure, routed to the site and the resulting highest water surface elevation that may result in the flooding of SSCs important to safety; (2) failures of dams in the path to the plant site caused by the failure of upstream dams due to earthquakes and the effect of the highest water surface elevation at the site under the failure conditions; (3) dynamic effects of dam failure-induced flood waves on SSCs important to safety; (4) effects of sediment deposition or erosion during dam failure-induced flood waves that may result in blockage or loss of function of SSCs important to safety; and (5) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.4.2 *Summary of Application*

Within SSAR Section 2.4.4, the applicant addressed the site-specific information for potential dam failures. There are approximately 700 dams counted above Wheeler Dam in the Tennessee Watershed. More specifically, within the areas upstream and downstream from the CRN Site, there are two major dams, Norris and Melton Hill Dams, regulating stream flow that passes around the site. The other upstream and downstream dams in the tributaries may have either backwater effects or minor contribution flows to the site. Therefore, dam failures and cascading dam failures were considered in the applicant's analyses. No safety-related water storage structures will be constructed on the site. Therefore, the potential failure of onsite water control or storage facilities was not be evaluated. There are also no plans to construct dams and reservoirs that could adversely affect flood levels at the CRN Site. In summary, the areas for review in this SER section include flood waves from hypothetical severe breaching of upstream dams, simultaneous dam failures due to storm events or seismic events, and effects of sediment deposition. Details of relevant flood hazards due to the potential dam failure is provided in the staff's technical evaluation below.

2.4.4.3 *Regulatory Basis*

The relevant requirements of NRC regulations for the identification of floods, flood design considerations, and potential dam failures, and the associated acceptance criteria, are specified in NUREG-0800, SRP 2.4.4, "Potential Dam Failures."

The applicable regulatory requirements for identifying the effects of dam failures are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirements to consider physical site characteristics in site evaluations are specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.4:

- RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.4.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.4. The staff confirmed that the applicant addressed information related to the flood elevation and site characteristics associated with the most severe plausible dam failure event. The staff's technical review of SSAR Section 2.4.4 included an independent review of the applicant's information and technical computations (ADAMS Accession Nos. ML17171A335 and ML16280A065) for the HEC-RAS model simulations. In the next six sub-sections from Section 2.4.4.4.1 through 2.4.4.4.6 herein, the staff describes the technical evaluation in sequence by following the applicant's sub-section titles provided in the SSAR Section 2.4.4.

2.4.4.4.1 *Dam and Reservoir Description*

<u>*Information Submitted by the Applicant*</u>

(SRI/CEII) The applicant followed NRC guidance (JLD-ISG-2013-01, "Interim Staff Guidance for Assessment of Flooding Hazards Due to Dam Failure") and adopted the American National Standards Institute/American Nuclear Society (ANSI/ANS, 1992) methods (ANSI/ANS-2.8) to screen single or multiple hypothetical dam failures that would potentially impact the plant site. According to the reservoir storage volumes and dam locations, the applicant first identified 11 dams upstream from Watts Bar Dam that might potentially cause a flood elevation at the site. The 11 dams are as follows: **[[**

1.
2.

3.
4.
5.
6.
7.
8.
9.
10.
11. **]]**

Among the 11 dams, **[[ ]]** Dam is located **[[ ]]** river-miles upstream from the plant site while **[[ ]]** Dam is further upstream and **[[ ]]** river-miles from **[[ ]]** Dam. These two dams have direct impacts on the plant site. The other 9 dams shown above are distributed either downstream or in the adjacent watersheds of the plant site (Figure 2.4.4-1). Those other dams (Item Nos 3 through 11) do not have a direct impact on the plant site, but they contribute stream flows to the downstream Watts Bar Dam. The applicant stated that contributing flows from the 11 dams to the downstream Watts Bar Dam can produce back water effect on the CRN Site. The reservoir elevation-storage relationship for each of the 11 dams plus Watts Bar Dam is shown on Figure 2.4.4-1 (12 sheets) of the SSAR. More detail for the development of the elevation-storage relationship is addressed in Section 2.4.3.4.4.3. The applicant provided the seasonal operational curve for each of the 12 dams (SSAR Figure 2.4.1-6) to illustrate that the reservoir levels are controlled and adjusted during flood or normal status in different months.

Staff's Technical Evaluation

(SRI/CEII) The staff determined that the applicant has followed the current NRC guidance (ADAMS Accession No. ML13151A153) and the recommended procedures (ANSI/ANS, 1992) to evaluate the dams that may have an influence on flood levels the CRN Site. Based on reviewing the applicant's supporting information, including the calculation package provided during the NRC audit performed in April 2017, the staff notes that the applicant chose the HEC-RAS model to further analyze breach outflow from the above 11 dams. Based on the NRC staff's review of the applicant's calculation package, including examination of the dam locations and the reservoir storage volumes of the 11 dams, the staff determined that the identified 11 dams are acceptable for dam breach outflow analysis. The staff noted that the applicant conservatively assumed the **[[ ]]** Dam would not fail under any conditions in order to create the maximum back water effect during the flood event at the CRN Site.

2.4.4.4.2 Dam Failure Permutations

Information Submitted by the Applicant

To calculate maximum water level, peak flow, and velocities at the CRN Site for any postulated dam failures, the applicant selected the HEC-RAS model. The dam breach parameters of the postulated dam failure, including the timing of instantaneous dam failure, breach configuration, and breach size, were scripted in the unsteady flow rules embedded in the HEC-RAS model.

The applicant organized the 11 included dams into 3 different failure modes, including (1) hydrologic failure, (2) seismic failure, and (3) sunny day failure. These dam failure modes will be described in the next sub-sections from 2.4.4.4.2.1 to 2.4.4.4.2.3.

(SRI/CEII) In each dam failure mode, the SSAR includes discussion on the analyses of the stabilities of concrete dams and earthen embankments. When the stability of the concrete section or its embankment is outside of the acceptance criteria, the dam or the embankment was assumed to fail. The concrete dams were evaluated for overturning and for horizontal sliding resistances. The post-earthquake earth embankment stability was examined for potential soil-wedge sliding on the embankment slope without overtopping flows. The applicant stated that sediment deposition from the hypothetical dam failures of upstream **[[ ]]** and **[[ ]]** Dams would not affect the intake structure at the CRN Site.

Staff's Technical Evaluation

The applicant postulated three dam failure modes for the flood hazard evaluation. The staff determined that the applicant followed the TVA's current dam stability criteria and adopted the US Army Corps of Engineers (USACE) design standards to determine the dam and embankment stability. The staff noted that the applicant also used NRC guidance (ADAMS Accession No. ML13151A153; NRC, RG 1.59) and acceptable standards (ANSI/ANS, 1992) to evaluate the dam failure modes that would create breach outflows resulting from either seismic or storm events. Based on reviewing the applicant's HEC-RAS model, the staff confirms that the applicant's HEC-RAS model reflects the dam failure modes that were acceptably analyzed using standard methodology and procedures.

The staff determined that the applicant evaluated overturning and sliding resistances to determine the stability of concrete dams, and used the soil-wedge sliding method to justify the stability of soil embankments. Since the applicant's evaluation and method are common and standard in the engineering practices, the staff concluded that the determination of dam stability is acceptable.

2.4.4.4.2.1 Seismic Failure Analysis

Information Submitted by the Applicant

A seismic dam failure was defined by the applicant as a dam failure due to a 10,000-year seismic event coincident with a 25-year flood, or a half-10,000-year seismic event coincident with a 500-year flood. For the seismic failure, the applicant considered two critical seismic events. One is a half-10,000-year Douglas-centered seismic event in coincident with a 500-year flood. Another is a 10,000-year Fort Loudoun-centered seismic event in combination with a 25-year flood. The applicant adopted 1.1 as a lowest bound factor of safety and used it to justify the post-earthquake embankment failure. If the safety factor is less than 1.1, the applicant further justifies that the post-earthquake embankment will not fail when the embankment deformation is less than both 2 ft and the half filter zone thickness inside the earth embankment. The applicant also examined the dams to determine if they should be either an individual failure or in a group of multiple failures under two critical seismic events.

(SRI/CEII) The applicant found **[[ ]]** Dam would fail due to either the half-10,000-year Douglas centered seismic event coincident with a 500-year June flood, or the 10,000-year Fort Loudoun centered seismic event coincident with a 25-year June flood. Under the same seismic events and the coincident floods, the applicant also found **[[ ]]** Dam would not fail. Both dams are located upstream of the CRN Site. The other dams are outside the Clinch River watershed, but the applicant included those dams in the seismic failure analysis.

The applicant calculated inflows to dams at their upstream interest points for 500-year and 25-year floods that included higher base flows occurring in June when compared to other seasonal base flows. The applicant derived its own scaled hydrograph method to develop the hydrographs for 500-year and 25-year floods. The scaled hydrograph method is based on daily flow records between 1903 and 2013 to calculate 25-year or 500-year maximum accumulated flow-volumes within each duration from 1 to 5 days. The applicant used these accumulated flow-volumes as target volumes to adjust the surface runoff volumes generated by unit hydrograph method using 25-year and 500-year storms of the published National Weather Service Atlas 14 data (Bonnin, G.M., et al., 2006). After the volume adjustment, the 25-year and 500-year hydrographs are used as inflow hydrographs to the dams.

(SRI/CEII) For small dam failures, the applicant included the corresponding dams listed in the NID and calculated the peak outflows by adopting the Froehlich method (Froehlich, 1995) for these failed dams. These outflows would be added to the coincident 500-year and 25-year floods. The applicant set the peak time at 20 minutes for each outflow hydrograph and routed to upstream interest points of the HEC-RAS model. These outflow hydrographs were added to the upstream interest points at the boundary of the HEC-RAS model as input data for simulating seismic dam failure flows in the watershed. The applicant showed that the half-10,000-year Douglas centered seismic event coincident with the 500-year flood is a controlling event to the CRN Site. The simulated peak water elevation of the seismic dam failure scenario coincident with a 500-year flood event is **[[ ]]** ft at the CRN Site.

Staff's Technical Evaluation

The staff noted that the applicant followed NRC guidance using the simplified volume method to identify 11 dam failures that were potentially critical to the plant site. The staff reviewed the applicant's procedures and methods for calculating the 500-year and 25-year floods. The staff noted the computational results of the 500-year and 25-year floods are acceptable since they are based on 110 years of stream flow data from 1903 to 2013. Furthermore, the staff finds that the applicant adopted the Froehlich method (Froehlich, 1995) to estimate the outflows of dam failures listed in NID. The Froehlich method is commonly used and accepted in dam safety design and hydrological engineering practice (ADAMS Accession No. ML13151A153). The staff examines the applicant's HEC-RAS model (ADAMS Accession No. ML16280A065) for the seismic failures and confirms that the computed flood elevation is reasonable for the plant site. Based on the reviews and examinations, the staff confirmed that the applicant's Douglas centered seismic event coincident with a 500-year flood is reasonable as the controlling event for seismic failures of the dams.

(SRI/CEII) The staff confirmed that the applicant used a widely-used and standard method to calculate potential soil-wedge sliding for embankment stability. The staff concluded that the applicant's lowest factor of safety 1.1 for post-earthquake embankment stability is reasonable since the factor is larger than 1 and complies with the applicant's dam safety standards. The staff did not review the structural computations related to dam stability against the seismic events since the flood hazard resulting from the seismic failures of the dams are below the peak water elevation associated with the PMF flood event scenario. Based on examination of the applicant's hydraulic calculations (ADAMS Accession No. ML16280A065), the staff confirmed that the maximum flood elevation after considering multiple seismic dam failure scenarios at the CRN site is elevation **[[ ]]** ft NGVD29.

2.4.4.4.2.2 Hydrologic Failure Analysis

<u>*Information Submitted by the Applicant*</u>

(SRI/CEII) Hydrologic failure occurs when a dam cannot sustain the external loads during a flood event produced by rainfall, snowmelt, or a combination thereof. The most common failure modes associated with hydrologic dam failure include overtopping, structure overstressing, and surface erosion due to high velocity flow or wave action. For concrete sections of dams, including spillways and lock gates, the applicant evaluated the structural stability against critical headwater elevation levels and tail water conditions. The applicant investigated the 11 dams listed in Section 2.4.4.4.1 herein. The applicant found that the following 7 dams listed below would fail: **[[**

1.
2.
3.
4.
5.
6.
7. **]]**

(SRI/CEII) Although the **[[ ]]** Dam would likely fail, the applicant assumed the **[[ ]]** Dam would never fail during the flood event simulation to create the maximum backwater flood elevation at the CRN Site. After including the above 7 dams, the applicant added 9 other dams to the list of assumed dam failures. These dams and their embankments were assumed to totally and instantaneously fail during the PMF event: **[[**

1.
2.
3.
4.
5.
6.
7.
8.
9. **]]**

(SRI/CEII) Of the earth embankments adjoining any of the above 11 potentially failing dams, shown in Section 2.4.4.4.1 herein, the applicant considered that an overtopping flow over the embankment and the flow erosion on the embankment slope can reduce the embankment stability. The applicant evaluated the following earth embankments of the dams for a PMF event and determined that the embankments should fail: **[[**

1.
2.
3.
4.
5.
6.
7.

]]

The applicant applied the Von Thun and Gillette method for calculating breach parameters at embankments smaller than the cross-section of the channel (**[[ ]]** Dam embankment failure shown above listed item No. 7). Although the **[[ ]]** Dam would likely fail, the applicant assumed the **[[ ]]** Dam embankment would not fail to maximize flood elevation at the CRN Site. Finally, the applicant allowed the maximum (total) breach cross-section to coincide with the downstream channel cross-section width for embankment failures No. 1 through 6.

(SRI/CEII) Including the above hydrologic failures of 7 concrete dams, 9 unevaluated dams, and 7 embankments of dams, the applicant applied the HEC-RAS model to compute the PMF elevation at the CRN Site. The computed peak elevation during the PMF and dam failure event is **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) without addition of coincident wind waves (see Section 2.4.4.4.5 herein). The controlling rainfall event used to generate the PMF (see Section 2.4.3.4.5) is the 7980 square-mile March PMP with the storm centered at Bulls Gap.

Staff's Technical Evaluation

The staff noted that the applicant maximized the potential effects of dam failure on the plant site by synchronizing the critical failure timing with the peak headwater level, and conservatively assuming the instantaneous failure of dams or embankment. The staff reviewed the applicant's calculation packages (ADAMS Accession No. ML16216A115) of the flood routing model HEC-RAS for the hydrologic failures, as well as examined the computational procedures and results. Based on reviewing the HEC-RAS model shown in the calculation package, the staff accepted the computed flood elevation as the result of PMF simulation that included coincident hydrologic dam failures.

(SRI/CEII) The staff confirmed that the HEC-RAS simulation assumed failure of 7 concrete dams, 9 unevaluated dams, and 7 embankment dams listed above. Among those dam failures, the staff tested the sensitivity response of the HEC-RAS model by arbitrarily changing dam failure or non-failure conditions. The staff selected **[[ ]]** for the test since they detain and control large flood volumes. Based on the testing results, the staff finds that during the PMP event when setting **[[ ]]** embankment dams either to fail or not fail, flood elevation increases from the **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) at the CRN Site are within **[[ ]]** ft. The **[[ ]]** ft tolerance is acceptable when compared to the **[[ ]]** ft margin that is between the PMF elevation of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) and the proposed grade elevation 821.4 ft NGVD29 (821.0 ft NAVD88) at the CRN Site.

(SRI/CEII) Further, the staff tested the sensitivity of the HEC-RAS model results and assumed a failure of the upstream **[[ ]]**. Similar to the applicant, the staff's sensitivity test assumed the **[[ ]]** would not fail in order to maximize the backwater effect at the CRN Site. The staff's sensitivity test results in a **[[ ]]** increase above the applicant's peak elevation of **[[ ]]** which is well below the CRN grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88).

The staff confirmed that the applicant acceptably used the Von Thun method to determine the breach parameters since the applicant scripted Von Thun's breach equations in the HEC-RAS model. The staff confirms that Von Thun's calculation procedures (Von Thun, et al., 1990) are acceptable (ADAMS Accession No. ML13151A153).

2.4.4.4.2.3 **Failure by Other Methods**

Information Submitted by the Applicant

(SRI/CEII) Dam failures not associated with a concurrent extreme flood or seismic event may arise from a variety of causes. A sunny day failure is a hypothetical failure mode resulting from the breach of the postulated weakest portion of a specific dam during sunny day (or fair weather) conditions. Dams in a hypothetical sunny day failure mode are classified by the applicant as dam failures by other methods. The applicant found that the most likely sunny day failure of **[[ ]]** Dam would be the **[[ ]]** of the dam. The failure has the potential to affect the plant site, and could result in a subsequent overtopping failure of **[[ ]]** Dam. These sequential failures of the **[[ ]]** and **[[ ]]** Dams in sunny day conditions would produce a flood elevation of **[[ ]]** at the plant site.

Staff's Technical Evaluation

(SRI/CEII) The staff reviewed the applicant's HEC-RAS model (ADAMS Accession No. ML16280A065) for the sunny day failure. The staff examined the initial reservoir level in the model, the **[[ ]]** dam rating curve for the **[[ ]]** failure, and the unsteady flow rules embedded in the model. From the HEC-RAS modeling results, the staff notes that the computed flood elevation at the plant site is **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88). Based on the initial reservoir level, dam rating curve, and unsteady flow rules, the staff confirms the computed flood elevation of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) is reasonable and acceptable.

2.4.4.4.3 Unsteady Flow of Potential Dam Failures

Information Submitted by the Applicant

To simulate the floods due to the postulated dam failure in three different modes (seismic, hydrologic, and sunny day), the applicant provided the HEC-RAS models (ADAMS Accession

No. ML16216A115 for hydrological failure and ADAMS Accession No. ML16280A065 for seismic and sunny day failures) for NRC review. To create a HEC-RAS model for dam failure simulations, the applicant modified the input parameters in the HEC-RAS model that was used for the stream flood simulation (See Section 2.4.3.4 of the SSAR). The following input parameters were necessarily modified for various dam failure modes: (1) initial reservoir level; (2) reservoir inflows; (3) breach flows with breach configuration; and, (4) the scripted instantaneous dam failure at specific timings. The breach configuration and dam failure timing were scripted in the unsteady flow rules that were embedded in the HEC-RAS model. For any earth embankment failure, the Von Thun and Gillette method was scripted in the unsteady flow rules.

Staff's Technical Evaluation

The staff reviewed the input parameters used to modify the numerical simulations among the three dam failure modes scripted in the HEC-RAS model. The staff determined that the input parameters and data used for the dam failures are acceptable and reasonable since the inputs reflect both of the operation rules prior to dam failure and the Von Thun formula after the dam breach. The staff confirmed that the applicant's dam failure modeling is acceptable since the applicant added the dam failure modeling as components to the original HEC-RAS model that was calibrated using historical flood records.

2.4.4.4.4 Water Level

Information Submitted by the Applicant

The flood elevations at the CRN Site resulting from the three dam failure modes computed by the HEC-RAS models (ADAMS Accession No. ML16216A115 for hydrological failure and ADAMS Accession No. ML16280A065 for seismic and sunny day failures) are summarized in Table 2.4.4.4.4-1 below.

(SRI/CEII) Table 2.4.4.4.4-1 Summary of flood elevations at the CRN Site (CRM 17.9)

Dam Failure Modes	CRN Site maximum stillwater elevation (Clinch River Mile 17.9)	Comments
Hydrologic Failure	**[[ ]]** ft NGVD29 (SSAR Section 2.4.3.6)	The 7,980 square-mile, Bull Gap centered, PMF March event plus multiple dam failures **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) is the SSAR Table 2.0-1 maximum stillwater flood elevation (MSWFE) for the CRN site including a safety margin **[[ ]]** ft above the hydrologic failure stillwater elevation.

Seismic Failure	**[[ ]]** NGVD29 (**[[ ]]** ft NAVD88)	Douglas Center seismic event coincident with a 500-year flood event
Sunny Day Failure	**[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88)	**[[ ]]** of **[[ ]]** Dam and the whole **[[ ]]** Dam fails upstream from CRN

<u>Staff's Technical Evaluation</u>

The staff reviewed and examined the applicant's HEC-RAS models. Based on the staff's examination of the model, the staff confirms that the model acceptably generated the flood profiles of the different dam failure modes. The staff also determined that the applicant-calculated flood elevations resulting from the three dam failure modes are reasonable.

2.4.4.4.5 Coincident Wind Wave

<u>Information Submitted by the Applicant</u>

(SRI/CEII) The applicant followed the computational procedures of the USACE Coastal Engineering Manual (USACE, 2002) to compute the water wave height induced by the wind. The applicant addressed the wind-generated wave effect on the maximum stillwater elevation, which is associated with the PMF event (see SSAR Section 2.4.3.6). The wind-generated waves associated with the PMF event were treated as one of the associated effects of the flood hazard against the plant site. The applicant analyzed available wind data from 2000 to 2014 from the neighboring meteorological stations at Huntsville in Alabama, as well as Chattanooga, Knoxville, and the Tri-Cities in Tennessee. Based on the recorded wind data, the applicant developed the statistic wind speed with the average period of a 2-year occurrence for the plant site. The applicant's computational results show that the 2-year wind speed over water surface is 33 miles per hour, and that the critical fetch distance of the wind over water surface is 4.25 miles, measured along a prevailing direction from the plant site to the PMF inundation boundary. The applicant used the computed wind speed associated with the wind duration and the fetch distance to determine that the wind wave height would be 6.1 ft at the plant site. Linearly adding the wind wave height to the PMF's MSWFE results in a total flood elevation at the plant site that is **[[ ]]** ft above the National Geodetic Vertical Datum of 1929 (NGVD29). This maximum flood elevation **[[ ]]** ft NGVD29) is well below the site grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88). Therefore, the applicant stated that the maximum flood event, including coincident wind-generated waves will not inundate the plant site.

<u>Staff's Technical Evaluation</u>

(SRI/CEII) The staff reviewed the applicant's computational procedures for the wind-generated wave height, including wave run-up and wind setup, and examined the intermediate results of the calculations. The staff finds that the wind wave computations are complete and acceptable since the applicant followed NRC guidance (ADAMS Accession No. ML12311A214) and NRC-recommended methodologies (ADAMS Accession No. ML11321A195), and followed the

USACE design manual (USACE, 2002). The staff examined the fetch distance in the prevailing wind direction shown on the SSAR Figure 2.4.3-16. Through the staff's examination on the inundation area and the prevailing wind direction, the staff confirms that the applicant's fetch distance of 4.25 miles is reasonable. Based on a review of the applicant's analysis, the staff notes that the applicant's computed maximum elevation of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) at the plant site results from the MSWFE of **[[ ]]** ft plus coincident wind-wave height of 6.1 ft. The staff notes that this flood elevation is well below the site grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88). Therefore, the staff concludes that the plant would not be inundated by the dam failure flood event including coincident wind-wave effects.

2.4.4.4.6 Erosion and Deposition Effects

<u>*Information Submitted by the Applicant*</u>

(SRI/CEII) The applicant assumed the erodible material would be transported by breach outflows from all the earthen embankments and saddle dams above the Watts Bar Dam. The erodible volume was calculated to be 200,000,000 cubic yards or approximately 124,000 acre-ft. Assuming that the erodible material would completely deposit in the downstream Watts Bar Reservoir reducing the existing reservoir volume, the applicant computed the increase of reservoir level to be less than **[[ ]]** ft. This increased level of **[[ ]]** ft is far below the CRN Site grade elevation by **[[ ]]** ft. Based on the computed reservoir volume reduction and the reservoir level increase, the applicant showed the insignificant effect of the erodible material with respect to flood events on the CRN Site.

<u>*Staff's Technical Evaluation*</u>

(SRI/CEII) The staff noted that the CRN Site is above the normal reservoir water surface level by approximately 80 ft, and above the MSWFE **[[ ]]** ft NGVD29) by **[[ ]]** ft. Based on the applicant's **[[ ]]** increase of the reservoir level, the staff notes that the erodible material will have an insignificant impact on the flood elevation at the CRN Site.

Since the reactor technology PPE proposed by the applicant for the CRN Site will not rely on the Clinch River as a safety-related water source, the staff confirms that the erosion and deposition have no effect on safety-related conditions at the CRN Site.

2.4.4.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.4.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant demonstrated that floods due to dam failures have no adverse impacts on the CRN Site and that there is no outstanding information required to be addressed in the SSAR related to this section. As set forth above, the applicant has provided sufficient information pertaining to potential dam failures. Further, the applicant has considered the most severe natural phenomena that have 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, in establishing site characteristics pertaining to potential dam failures that are acceptable for design purposes. Therefore, the staff concludes that the applicant has met the requirements 10 CFR 52.17(a), 10 CFR 100.20, and 10 CFR 100.23(d) relating to dam failures.

2.4.5 Probable Maximum Surge and Seiche Flooding

2.4.5.1 *Introduction*

This section of the SSAR addresses the probable maximum surge and seiche flooding to ensure that any potential hazard to the safety-related SSCs at the proposed site were appropriately considered in compliance with NRC regulations.

This section presents the evaluation of the following topics based on data provided by the applicant in the SSAR and information available from other sources: (1) probable maximum hurricane (PMH) that causes the probable maximum surge as it approaches the site along a critical path at an optimum rate of movement; (2) probable maximum wind storm (PMWS) from a hypothetical extratropical cyclone or a moving squall line that approaches the site along a critical path at an optimum rate of movement; (3) a seiche near the site and the potential for seiche wave oscillations at the natural periodicity of a water body that may affect the elevations of the floodwater surface near the site or cause a low water-surface elevation affecting safety-related water supplies; (4) wind-induced wave runup under PMH or PMWS winds; (5) effects of sediment erosion and deposition during a storm surge and seiche-induced waves that may result in blockage or loss of function of SSCs important to safety; (6) the potential effects of seismic and non-seismic information on the postulated design bases and how they relate to a surge and seiche in the vicinity of the site and the site region; and, (7) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.5.2 *Summary of Application*

This section addresses information related to probable maximum surge and seiche flooding in terms of impacts on structures and water supply.

2.4.5.3 *Regulatory Basis*

The relevant requirements of NRC regulations for the effects of probable maximum storm surge (PMSS), and the associated acceptance criteria, are specified in NUREG-0800, SRP 2.4.5, “Probable Maximum Surge and Seiche Flooding.”

The applicable regulatory requirements for identifying surge and seiche hazards, design considerations, and the associated acceptance criteria, are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.5:

- RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.5.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.5. The staff's review confirmed that the information in the application addresses the probable maximum surge and seiche flooding. The staff's technical review of this section includes an independent review of the applicant's information in the SSAR.

This section describes the staff's evaluation of the technical information presented in the SSAR Section 2.4.5.

Information Submitted by the Applicant

The SSAR Section 2.4.5 states that storm surge is not a plausible flood hazard mechanism for the CRN Site since the site, located on the Clinch River tributary of Watts Bar Reservoir, is approximately 1,580 river miles from the Gulf of Mexico. The SSAR also notes the proposed CRN Site grade elevation is approximately 80 ft above the normal pool elevation (741 ft. NGVD29) of the Clinch River tributary of Watts Bar Reservoir, implying that any possible surge would be well below the site.

As for a seismic seiche recorded in the Tennessee Valley area, the SSAR stated that the seiche amplitude is very small. Based on the analyses by the USGS following the March 27, 1964 earthquake in Alaska, the SSAR reported that the maximum seiche on reservoirs was 0.6 ft at gauges in Kentucky and a maximum of 0.1 ft at gauges in Tennessee. Consequently, the applicant concludes the size of an earthquake-generated seiche is small. The SSAR states that the CRN Site is within an Eastern Tennessee Seismic Zone (USGS, 2014), but that no significant seiches have been recorded due to earthquake activity in the Tennessee Valley. The SSAR also states that there is no evidence for landslide-induced seiches and that the slopes around the CRN Site are stable.

The SSAR also examines possible wind-generated seiches and states that there is no flood hazard from this mechanism due to the limited fetch (4.25 miles) and a large elevation difference of 79 ft between the normal pool and CRN Site grade elevation.

Staff's Technical Evaluation

The staff examined the surge and seiche information provided in the SSAR Section 2.4.5. Consequently, the staff finds that the applicant provided sufficient and acceptable evidence in the SSAR to support the insignificant impact of surges or seiches on the CRN Site. As the staff noted in Section 2.4.1.4.1 herein, the CRN Site is approximately 80 ft above the normal pool elevation of the Clinch River tributary of Watts Bar Reservoir. Therefore, based on the staff's examinations, and the 80 ft of marginal difference between the site grade elevation and the normal reservoir level, the staff concurs with the applicant's assessment that storm surge and seiche motion in the lakes, reservoirs, and ponds in the Tennessee River watershed should produce minimal water level changes and are not plausible flood-hazard mechanisms for the CRN Site.

2.4.5.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.5.6 *Conclusion*

The staff concludes that the applicant's identification and consideration of the surge and seiche hazards set forth above is acceptable and meets the requirements of 10 CFR 52.17(a)(1)(vi), 10 CFR 100.20(c), and 10 CFR 100.23(d). The staff also confirms that storm surge and seiche motion in the Clinch River tributary of Watts Bar Reservoir are not a plausible external flooding hazard mechanism at the CRN Site.

2.4.6 Probable Maximum Tsunami Hazards

2.4.6.1 *Introduction*

This section of the SSAR addresses the hydrological design basis developed to ensure that any potential tsunami hazards to the SSCs important to safety are considered in plant design.

This section presents the staff's review of the flood levels caused by postulated tsunami wave-forming scenarios. The specific areas of the review include the description of the Probable Maximum Tsunami (PMT), historical tsunami records, source generator characteristics, tsunami analyses, tsunami water levels, hydrograph and harbor or breakwater influences of a tsunami-like wave, and its effects on safety-related facilities.

2.4.6.2 *Summary of Application*

In SSAR Section 2.4.6, the applicant provides site-specific information about potential tsunami effects on the site.

2.4.6.3 *Regulatory Basis*

The relevant requirements of NRC regulations for the consideration of probable maximum tsunami hazards, design considerations, and the associated acceptance criteria, are specified in NUREG-0800, SRP 2.4.6, "Probable Maximum Tsunami Hazards."

The applicable regulatory requirements for identifying PMT hazards are as follows:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The related acceptance criteria are as follows:

- RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.6.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.6. The staff confirmed that the information in the application addresses the relevant information related to the PMT. The staff's technical review of this section includes an independent review of the applicant's information in the SSAR. This section describes the staff's evaluation of the technical information in SSAR Section 2.4.6.

Information Submitted by the Applicant

As stated in the SSAR, the CRN Site lies more than 300 miles from the nearest seacoast.

As discussed in SSAR Section 2.5.3, there are no surface deformations near the site and the potential for tectonic fault rupture is minimal. Consequently, there is little likelihood of triggering a tsunami from vertical ground motion in the Watts bar Reservoir adjacent to the CRN Site. Also, there is no evidence of landslide or slumping hazards found at the site location. A tsunami hazard was also considered at Norris and Melton Hill dams and is considered bounded by possible dam failures considered in SSAR Section 2.4.4. Since the CRN site grade elevation is approximately 80 ft above the normal pool elevation of the Watts Bar Reservoir near the site, the site inundation potential from a landslide-induced tsunami is negligible.

Staff's Technical Evaluation

The staff reviewed the hydrologic and geological information provided in the SSAR. The staff also examined USGS topographic maps (USGS, 2017b) in the vicinity of the CRN Site and noted steep bluffs on the opposite side of the Clinch River tributary of Watts Bar Reservoir. However, no slides or slumps are apparent in this topographic data. The staff concurs with the assessment in the SSAR that the flood hazard from tsunamis is negligible.

2.4.6.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.6.6 *Conclusion*

The staff concludes that the tsunami hazard is negligible at the proposed CRN Site. Therefore, the staff finds that the identification and consideration of the tsunami hazards set forth above is acceptable and meets the requirements of 10 CFR 52.17(a)(1)(vi), 10 CFR 100.20(c), and 10 CFR 100.23(d).

2.4.7 Ice Effects

2.4.7.1 *Introduction*

SSAR Section 2.4.7 addresses ice effects to ensure that safety-related facilities and water supply are not affected by ice-induced hazards.

The ice effects are addressed to ensure that safety-related facilities and water supply are not affected by ice-induced hazards. The specific areas of review are as follows: (1) regional history and types of historical ice accumulations (e.g., ice jams, wind-driven ice ridges, floes, frazil ice formation); (2) potential effects of ice-induced, high or low flow levels on safety-related facilities and water supplies; (3) potential effects of a surface ice sheet to reduce the volume of available liquid water in safety-related water reservoirs; (4) potential effects of ice to produce forces on, or cause blockage of, safety-related facilities; (5) potential effects of seismic and non-seismic data on the postulated worst-case icing scenario for the proposed plant site; and (6) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.7.2 *Summary of Application*

In this section, potential ice effects at the proposed plant location are evaluated, including the review of ice formations or ice jams; modeling combined events to ensure protection of the safety-related facilities from ice-affected floods, and mitigation to protect safety-related structures from ice. Analysis of ice effects at the proposed plant includes review of historic winter conditions and the simulation of flooding due to an upstream ice jam break.

2.4.7.3 *Regulatory Basis*

The relevant requirements of the NRC regulations for identifying ice effects and the associated acceptance criteria, are in NUREG-0800, SRP 2.4.7, “Ice Effects.”

The applicable regulatory requirements for identifying ice effects are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirements to consider physical site characteristics in site evaluations are specified in 10 CFR 100.20(c).

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.7:

- RG 1.27, “Ultimate Heat Sink for Nuclear Power Plants,” as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, “Design Basis Floods for Nuclear Power Plants,” as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, “Flood Protection for Nuclear Power Plants,” as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.7.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.7. The staff's review confirmed that the information in the application addresses the relevant information related to the site ice effects.

The next Sections 2.4.7.4.1 through 2.4.7.4.6 of the SER provide the staff's evaluation of the technical information presented in SSAR Section 2.4.7.

2.4.7.4.1 Historical Ice Accumulation

Information Submitted by the Applicant

The applicant examined the temperature records from 1871 to the present (NOAA, 2014) to determine the minimum temperature in the region. The lowest air temperature of -24 Fahrenheit (F) occurred in January 1985. The SSAR provides that the lowest recorded water temperature in the Watts Bar Reservoir for the periods 1942 to 1953 and 1967 to 1973 was 39 F in January 1970.

As reported in the SSAR, the USACE Ice Jam Database (1780 through February 7, 2014) had one ice jam event on the Clinch River in 1940 near Clinton, located 15 miles upstream of the CRN Site. The ice obstruction was in place from January 22 through February 6, 1940. According to the SSAR, 5-in thick ice was the record in Chattanooga, Tennessee, apparently during this same period. Also, according to the SSAR, since the first historical record of freezing conditions in 1796, the Tennessee River froze more than 16 times and had floating ice 6 other times. The most severe event was in January 1918 with an ice jam height of 10 ft.

Based on the historical data, the applicant maintains that the flood hazard from ice jams is not credible.

Staff's Technical Evaluation

The staff reviewed historical temperature records and found the applicant's characterization to be reasonable and acceptable for representation of potential surface and frazil ice formation. Although ice jam flooding has occurred upstream of the CRN Site, the staff reviewed the Cold Region Research and Engineering Laboratory (CRREL) Ice Jam Database, and concurs with the applicant's assessment that an ice-induced flood hazard is not physically credible because of a 80 ft difference in normal pool elevations and the site grade as previously noted in Section 2.4.1.4.1 herein. The staff determined that the applicant's review and characterization of the historical record was acceptable.

2.4.7.4.2 High and Low Water Levels

Information Submitted by the Applicant

While the site grade plans have not been developed, the SSAR considers the possibility of blockage of the drainage system due to freezing conditions. However, the SSAR notes that the drainage system (culverts, catch basins, and storm drains) are all assumed to be blocked and that since the proposed site grade elevation is above the natural grade, there is a sufficient hydraulic gradient for site drainage.

The SSAR includes a brief analysis of a hypothetical ice dam just upstream of the CRN Site. A maximum elevation of 771 ft NGVD29 (770.6 ft NAVD88) is assumed, which is the maximum design elevation of the Melton Hill Dam tailwater and the maximum known flood elevation (from March 1886). The storage created by such a hypothetical ice dam is bounded by storage behind Melton Hill Dam as well as by storage behind Norris Dam. Accordingly, the effect of a breach of such a hypothetical ice dam would be bounded by failures of either Melton Hill or Norris Dams.

Consideration of a hypothetical ice dam downstream of the CRN Site was also included in the SSAR. The SSAR assumes a hypothetical ice dam forms at Watts Bar Dam that builds up to the top of earthen embankments at approximately 772 ft NGVD29. This would produce a water level at the CRN Site that is approximately 30 ft higher than the summer normal pool water level. With the site grade at 821 ft NGVD29 (821.0 ft NAVD88), there is more than 40 ft of freeboard available before inundating the site. Consequently, the flood hazard from a downstream ice dam is negligible.

Section 2.4.7.2 of the SSAR stated that low water considerations do not apply to the CRN Site since the reactor technology PPE does not rely on an external water source for safety-related and risk-significant water supply.

Staff's Technical Evaluation

(SRI/CEII) The staff examined these hypothetical cases of upstream and downstream ice dams and the flood hazard they could produce. The staff finds the SSAR assessment, which was based on comparing the water volumes retained by a hypothetical ice dam upstream of the CRN Site, to be appropriate. For the upstream ice dam case, an ice dam failure would be bounded by **[[ ]]** Dam and **[[ ]]** Dam upstream sunny day failures because the retention volume between the ice dam and **[[ ]]** Dam would be significantly less than the combined volumes of the **[[ ]]** Dams. For a downstream ice dam, the elevation of the CRN Site grade above the Clinch River precludes inundation.

Based on the staff's review of the topography of the site location, the staff's review of the CRREL ice jam database, and the applicant's reasonable application of conservative ice jam analyses, the staff concluded that ice jams would have no high water safety-related impacts to the water supply intake or the water supply for the CRN Site. Based on the reactor technology PPE not relying on an external water source for safety-related and risk-significant water supply to the CRN Site, the staff determined that ice jams would also have no low water safety-related impacts. The staff found that the applicant's analysis was acceptable.

2.4.7.4.3 Ice Sheet Formation

Information Submitted by the Applicant

The SSAR states that the reactor technology PPE considered for the CRN Site does not require external water supply to provide SSCs important to safety or open storage of water supply for safety-related uses. Hence, ice sheet formation will not affect SSCs important to safety.

The SSAR stated the maximum ice sheet thickness at the CRN Site is approximately 11 inches as calculated from data according to the peak accumulated freezing degree-days.

Staff's Technical Evaluation

Because the SSAR states that the proposed reactor technology PPE does not require safety-related cooling water from the Clinch River, the staff concludes that any ice sheet formation on the Clinch River would not impact site safety. The staff finds the computed ice sheet thickness acceptable since the computations were based on 65 years of meteorological data. The staff reviewed and found acceptable the formula of the USACE (USACE, 2004) used to compute the ice thickness based on the meteorological data.

2.4.7.4.4 Potential Ice-Induced Forces and Blockages

Information Submitted by the Applicant

The SSAR states that the CRN Site does not have SSCs important to safety that could be affected by ice-induced forces or blockages.

Staff's Technical Evaluation

Because the reactor technology PPE considered for the CRN Site does not rely on an external safety-related water supply, the staff concludes that ice sheet formation would have no safety-related impact.

2.4.7.4.5 Consideration of Other Site-Related Evaluation Criteria

Information Submitted by the Applicant

The SSAR states there is no additional information to indicate that other icing scenarios would occur that are more severe than the scenarios already examined above.

Staff's Technical Evaluation

The staff finds the SSAR assessment to be acceptable based on the applicant's description of the proposed site climatology and meteorological assessment.

2.4.7.4.6 Consideration of Cold-Region Hydrology

Information Submitted by the Applicant

As noted in the SSAR, the CRN Site is not subject to cold region conditions, such as permafrost. The precipitation events, including rain-on-snow or snowmelt, for local site drainage from LIP and site inundation from flooding of streams and river are discussed in SSAR Sections 2.4.2 and Section 2.4.3, respectively.

Staff's Technical Evaluation

The staff finds the SSAR assessment to be acceptable based on the applicant's description of the proposed site climatology and meteorological assessment.

2.4.7.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.7.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant has demonstrated that the ice effects have no safety-related impact on the CRN Site and that there is no outstanding information required to be addressed in the SSAR related to this section.

As set forth above, 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)(1)(vi) 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 with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, in establishing site characteristics pertaining to ice effects that are acceptable for design purposes.

2.4.8 Cooling Water Canals and Reservoirs

2.4.8.1 *Introduction*

The cooling water canals and reservoirs used to transport and impound water supplied to the SSCs important to safety are reviewed to verify their hydraulic design basis. The specific areas of review are as follows: (1) design bases postulated and used by the applicant to protect structures such as riprap, inasmuch as they apply to safety-related water supply; (2) design bases of canals pertaining to capacity, protection against wind waves, erosion, sedimentation, and freeboard and the ability to withstand a PMF (surges, etc.), inasmuch as they apply to a safety-related water supply; (3) design bases of reservoirs pertaining to capacity, PMF design basis, wind wave and run-up protection, discharge facilities (e.g., low-level outlet, spillways), outlet protection, freeboard, and erosion and sedimentation processes inasmuch as they apply to a safety-related water supply; and (4) potential effects of seismic and non-seismic information on the postulated hydraulic design bases of canals and reservoirs for the proposed plant site.

2.4.8.2 *Summary of Application*

This section of the SSAR addresses the cooling-water canals and reservoirs used to transport and impound water supplied to the safety-related SSCs. This section of the report presents an evaluation of the design basis for the capacity and operating plan for safety-related cooling-water canals and reservoirs.

2.4.8.3 *Regulatory Basis*

The relevant requirements of NRC regulations for the cooling-water canals and reservoirs, and the associated acceptance criteria, are specified in NUREG-0800, SRP 2.4.8, "Cooling Water Canals and Reservoirs."

The applicable regulatory requirements for describing cooling-water canals and reservoirs are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.8:

- RG 1.27, "Ultimate Heat Sink for Nuclear Power Plants," as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, "Design Basis Floods for Nuclear Power Plants," as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, "Flood Protection for Nuclear Power Plants," as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.8.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.8. The staff confirmed that the information in the application addresses the relevant information related to the site cooling water canals and reservoirs. The staff's technical review of this section included an independent review of the applicant's information in the SSAR. The staff supplemented this information with other publicly available sources of data. The staff's technical review of this section described below includes an independent review of the applicant's information provided in the SSAR.

Information Submitted by the Applicant

The SSAR states that the proposed reactor technology PPE at the CRN Site does not rely on the Clinch River tributary of the Watts Bar Reservoir as a safety-related water supply. The CRN Site does not have a cooling water canal or reservoirs. The applicant does not propose any safety-related canals or reservoirs used to transport or impound plant cooling water.

Staff's Technical Evaluation

The staff reviewed SSAR Section 2.4.8. The staff confirmed that the information in the application addresses the relevant information related to this section and is sufficient and appropriate. The staff concludes that because there are no safety-related reservoirs or canals proposed for the reactor technology PPE, Section 2.4.8 is not applicable to the CRN Site.

2.4.8.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.8.6 *Conclusion*

The staff reviewed the application and confirmed that there are no safety-related cooling water reservoirs or canals proposed for the reactor technology PPE. There is no outstanding information required to be addressed in the SSAR related to this section.

2.4.9 Channel Diversions

2.4.9.1 *Introduction*

This section of the SER evaluates the applicant's plant and essential water supplies to ensure that they will not be adversely affected by stream or channel diversions. The evaluation includes stream channel diversions away from the site (which may lead to a loss of safety-related water) and stream channel diversions toward the site (which may lead to flooding). This section also reviews the applicant's proposal to ensure that alternate water supplies are available to safety-related equipment, if needed.

This section of the report presents an evaluation of the following specific areas: (1) historical channel migration phenomena including cutoffs, subsidence, and uplift; (2) regional topographic evidence that suggests a future channel diversion may or may not occur (used in conjunction with evidence of historical diversions); (3) thermal causes of channel diversion, such as ice jams, which may result from downstream ice blockages that may lead to flooding from backwater or upstream ice blockages that can divert the flow of water away from the intake; (4) potential for forces on safety-related facilities or the blockage of water supplies resulting from channel migration-induced flooding (flooding not addressed by hydrometeorologically induced flooding scenarios in other sections); (5) potential of channel diversion from human-induced causes (i.e., land-use changes, diking, channelization, armoring, or failure of structures); (6) alternate water sources and operating procedures; (7) potential effects of seismic and non-seismic information on the postulated worst-case channel diversion scenario for the proposed plant site; and, (8) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.9.2 *Summary of Application*

The applicant described the potential hazards of channel diversions in SSAR Sections 2.4.9.4.1 through 2.4.9.4.7. Based on the reactor technology PPE for the CRN Site, there is no need for external water sources to supply the safety-related cooling systems. Consequently, a loss of water supply due to channel diversions will not affect the safety-related cooling system. The applicant also considered the potential for a flood from a channel diversion by reviewing hydrologic, hydraulic, climatic, topographic and geologic evidence, and anthropogenic impacts near the CRN Site. The applicant concluded that channel diversions will not cause flooding at the CRN Site.

2.4.9.3 *Regulatory Basis*

The relevant requirements of NRC regulations for channel diversions, and the associated acceptance criteria, are specified in NUREG-0800, SRP 2.4.9, “Channel Diversions.”

The applicable regulatory requirements for identifying and evaluating channel diversions are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.9.

- RG 1.27, “Ultimate Heat Sink for Nuclear Power Plants,” as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, “Design Basis Floods for Nuclear Power Plants,” as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, “Flood Protection for Nuclear Power Plants,” as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.9.4 *Technical Evaluation*

The staff reviewed the information in SSAR Section 2.4.9. The staff’s review confirmed that the information in the application addresses the relevant information related to channel diversions. The staff’s technical review of this section includes an independent review of the applicant’s information in the SSAR. The staff supplemented this information with other publicly available sources of data.

2.4.9.4.1 Historical Channel Diversions

Information Submitted by the Applicant

The applicant examined the recent (2013) and historic (1935, 1953, and 1968) USGS topographic maps, presented as SSAR Section 2.4.9, Figures 2.4.9-1 through 2.4.9-4, for changes in Clinch River channel locations and found little change in the channel over the period. Several Clinch River flood events occurred in 1957, 1962, 1963, 1973, and 1977 at the USGS stream gauge (03528000) near Tazewell, Tennessee, with no recorded change in river location.

As described in Section 2.4.5 of the SSAR, the age and morphology of the Clinch River terraces date back many thousands of years into the Pleistocene, which indicates a stable landscape. Material in the Clinch River floodplain has been dated to approximately 2500 years before the present.

A diversion of the Clinch River around St. Paul, VA to prevent flooding of the town is reported in the SSAR. According to the SSAR, the diversion required blasting of solid rock to construct a new channel.

Shoreline erosion by various means (boat traffic, wind waves, etc.), is listed as being local in nature and readily mitigated, and hence is a negligible influence on bank stability.

Staff’s Technical Evaluation

The staff examined the most current USGS topographic maps for the CRN Site (USGS, 2017c) and compared them to the USGS quadrangle maps of Bethel Valley and Elverton, Tennessee, published in 1935 (USGS, 2017d). The staff noted that the USGS quadrangle maps published in 1935 can present the original stream course of the Clinch River at the CRN Site because Norris Dam was completed in March 1936, which is a flood control dam upstream from the CRN Site. Based on the staff's map examinations and comparisons, the staff confirmed that no change in location of the Clinch River channel is evident in these records.

The staff also examined other geologic information provided in the SSAR. The staff also noted the shoreline erosion prevention program is implemented as part of TVA's Shoreline Management Policy. Based on the above information, the staff determined the applicant's evaluation to be acceptable.

2.4.9.4.2 Regional Topographic Evidence

Information Submitted by the Applicant

The region around the CRN Site consists of ridges and valleys formed by folding and faulting of the sedimentary strata. The major rivers of the area are thought to be stable and older than the current valley and ridge formation since they cut through ridges as they formed (SSAR Section 2.4.9.2).

The region around the CRN Site and the Clinch River tributary of Watts Bars Reservoir has a moderate susceptibility for landslides with a low incidence rate, as shown in SSAR Figure 2.4.9-5. The applicant considered the potential for large-scale slope failure to be negligible.

Staff's Technical Evaluation

The staff examined the geologic information provided in the SSAR. Based on the topographic map, geologic evidence of stable stratigraphy not prone to landslides, stable stream course, and USGS landslide incidence and susceptibility map provided by the applicant, the staff determined that that a channel diversion could be reasonably excluded as a flood causing mechanism at the CRN Site.

2.4.9.4.3 Ice Causes

Information Submitted by the Applicant

Ice blockages are discussed in SSAR Section 2.4.7, "Ice Effects." Upstream and downstream river ice blockages would not be a threat to site SSCs.

Staff's Technical Evaluation

SSAR Section 2.4.7 discusses the potential for an ice jam or blockage to flood the CRN site. The staff finds the applicant's evaluation of the potential for ice to induce a channel division to be acceptable. The staff concludes that river blockage could not inundate the CRN site.

2.4.9.4.4 Flooding of Site Due to Channel Diversions

Information Submitted by the Applicant

Based on examinations in the SSAR sub-sections 2.4.9.1 through 2.4.9.3, the applicant stated that there is no credible evidence for channel diversions at or near the CRN Site.

Staff's Technical Evaluation

Based on the staff's evaluations described in Sections 2.4.9.4.1 through 2.4.9.4.3, the staff concludes that there is no credible evidence for channel diversions.

2.4.9.4.5 Human-Induced Causes of Channel Diversion

Information Submitted by the Applicant

Norris Dam provides flood protection in downstream areas, while Melton Hill Dam is run-of-the-river and provides no flood protection. The SSAR states that with the presence of the dams, it is anticipated that channels tend to be stabilized since sediment transport through the river system is reduced by the dams. The reduction in sediment transport and bank erosions occurs due to reducing large floods by the dams. Failure of the upstream dams is examined in SSAR Section 2.4.4. According to the applicant, the site is not affected by flood waters from such potential dam failures, and diversion is not likely even with high flows and velocities. The applicant concludes that diversion of the Clinch River due to dam operations or dam failure is highly unlikely.

Staff's Technical Evaluation

(SRI/CEII) The staff reviewed the information provided by the applicant and also examined potential dam failures as described in SER Section 2.4.4. The dam failures with a PMF event produce the PMF elevation **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) at the CRN Site, which is far below the proposed site grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88). Thus, the staff concludes the CRN Site could not be inundated by channel diversion flooding.

2.4.9.4.6 Alternative Water Sources

Information Submitted by the Applicant

The SSAR states that the reactor technology PPE for the CRN Site does not rely on a water source for safety-related purposes from the Clinch River tributary of Watts Bar Reservoir.

Staff's Technical Evaluation

The staff determined that the applicant's evaluation of alternate water sources is acceptable because the reactor technology PPE for the CRN Site does not rely on a water source from the Clinch River for safety-related purposes.

2.4.9.4.7 Consideration of Other Site-Related Evaluation Criteria

Information Submitted by the Applicant

The applicant provides no additional considerations related to channel diversions.

Staff's Technical Evaluation

(SRI/CEII) The staff finds that the applicant's computed PMF elevation **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88) is well below the proposed site grade elevation of 821.4 ft NGVD29 (821.0 ft NAVD88). Therefore, the CRN Site cannot be inundated by channel diversions in the region, and additional considerations related to channel diversions are not needed.

2.4.9.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.9.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant demonstrated that channel diversions have no impact on the CRN Site since the reactor technology PPE does not rely on safety-related water supply from the Clinch River, and that there is no outstanding information required to be addressed in the SSAR related to this section.

As set forth above, the applicant has provided information pertaining to channel diversions showing that channel diversion above the CRN Site is not likely. Further, the applicant has considered the most severe natural phenomena that have 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, in establishing site characteristics pertaining to channel diversions that are acceptable for design purposes. Therefore, the staff concludes that the applicant has met the requirements regarding channel diversions in 10 CFR 52.17(a), 10 CFR 100.20 and 10 CFR 100.23(d).

2.4.10 Flooding Protection Requirements

2.4.10.1 *Introduction*

This SER section considers and reviews the locations and elevations of safety-related facilities and those structures that require protection from flooding. These requirements are then compared with design-basis flood conditions to determine whether flood effects need to be considered in the plant's design or emergency procedures. The specific areas of review are as follows: (1) safety-related facilities exposed to flooding; (2) type of flood protection (e.g., "hardened facilities," sandbags, flood doors, bulkheads) provided to the SSCs exposed to floods; (3) emergency procedures needed to implement flood protection activities and warning times available for their implementation reviewed by the organization responsible for reviewing issues related to plant emergency procedures; (4) potential effects of seismic and non-seismic information on the postulated flooding protection for the proposed plant site; and (5) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.10.2 *Summary of Application*

In SSAR Section 2.4.10, the applicant addressed the need for site-specific information on flood protection requirements.

2.4.10.3 *Regulatory Basis*

The relevant requirements of NRC regulations and the associated acceptance criteria for flood protection are specified in NUREG-0800, SRP 2.4.10, “Flooding Protection Requirements.”

The applicable regulatory requirements for identifying and evaluating flood protection are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.10.

- RG 1.27, “Ultimate Heat Sink for Nuclear Power Plants,” as it relates to providing high assurance that the water sources relied on for the ultimate heat sink will be available where needed.

- RG 1.59, “Design Basis Floods for Nuclear Power Plants,” as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, “Flood Protection for Nuclear Power Plants,” as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.10.4 *Technical Evaluation*

The staff reviewed information in SSAR Section 2.4.10 and confirmed that the information in the application addresses the necessary information related to flooding protection requirements. The staff's technical review of this section includes an independent review of the applicant's information presented in SSAR Section 2.4.10.

Information Submitted by the Applicant

Subsequent to selection of a technology, the applicant will design the final site grading, including slopes and diversion ditches to drain runoff resulting from the LIP, away from safety-related SSCs into swales and pipes toward the Clinch River located around three sides of the CRN Site. These site drainage systems will be designed to prevent the flooding of safety-related SSCs given the LIP event. SSAR Section 2.4.2.3, stated the requirements for the site grading plan that will be provided in the COLA. The SSAR Section 2.4.2.3 also stated that a fully effective drainage system would be designed at the COL stage. Potential flooding at buildings due to the LIP event and associated effects is dependent on a final plant grading plan and storm drainage design that will be determined in the COLA.

(SRI/CEII) In addition to the LIP flood hazard, the SSAR identified the MSWFE of **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88). The applicant stated in SSAR Table 2.0-1 that the site characteristic flood elevation is **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88), which is the MSWFE plus wave height 6.1 ft. This flood event does not include the potential for flooding from LIP and associated site drainage.

Staff's Technical Evaluation

The staff reviewed the information submitted by the applicant related to flood protection at the CRN Site. Since the SSAR Table 2.0-2 site-related design parameter minimum site grade is elevation 821.4 ft NGVD29 (821.0 ft NAVD88), flood protection requirements are not applicable for the SSAR Table 2.0-1 site characteristic maximum flood.

Because the potential for flooding from LIP and the CRN site grading plan will be finalized in the COLA, the staff includes **COL Action Item 2.4-2.**

COL Action Item 2.4-2:

> An applicant for a Combined License (COL) or Construction Permit (CP) referencing this Early Site Permit (ESP) should address whether the local flood elevation exceeds the site grade elevation and whether the local flood elevation needs to be incorporated with flood protection measures to prevent flooding of any safety-related Structures, Systems and Components (SSCs). If so, the applicant should address necessary flooding protection for safety-related SSCs based on the flooding event and associated effects.

2.4.10.5 *Post Early Site Permit Activities*

The procedure to be developed for addressing flooding protection requirements based on the designed local flood elevation consistent with the detailed site grading and drainage design is being tracked as **COL Action Item 2.4-2**.

2.4.10.6 *Conclusion*

The staff reviewed the application and confirmed that there is no outstanding flood protection information required to be addressed in the SSAR related to this section.

As set forth above, the applicant has provided sufficient information pertaining to flood protection. The staff concludes that the applicant has provided sufficient information pertaining to flood protection to satisfy the requirements of 10 CFR 52.17(a)(1), 10 CFR 100.20(c) and 10 CFR 100.23(d). The COL applicant will address **COL Action Item 2.4-2**.

2.4.11 Low Water Considerations

2.4.11.1 *Introduction*

This SSAR section addresses natural events that may reduce or limit the available safety-related cooling-water supply. The applicant ensures that an acceptable water supply will exist to shut down the plant under conditions requiring safety-related cooling.

This section of the report provides an evaluation of the following specific areas: (1) low-water conditions due to the worst drought considered reasonably possible in the region; (2) the effects of low water surface elevations caused by various hydrometeorological events and a potential blockage of intakes by sediment, debris, littoral drift, and ice possibly affecting the safety-related water supply; (3) the effects of low water on the intake structure and pump design bases in relation to the events described in SSAR Sections 2.4.7, 2.4.8, 2.4.9, and 2.4.11, which includes the consideration of the range of water supply required by the plant (including minimum operating and shutdown flows during anticipated operational occurrences and emergency conditions) as compared to water supply availability (considering the capability of the UHS to provide acceptable cooling water under conditions requiring safety-related cooling); and, (4) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.11.2 *Summary of Application*

In SSAR Section 2.4.11, the applicant addresses the impacts of low water on safety-related water supply.

2.4.11.3 *Regulatory Basis*

The relevant requirements of NRC regulations and the associated acceptance criteria for low water considerations are specified in NUREG-0800, SRP 2.4.11, “Low Water Considerations.”

The applicable regulatory requirements for identifying and evaluating low water considerations are set forth in the following:

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrologic features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d), as it sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

The staff also used the appropriate sections of the following regulatory guides for the acceptance criteria identified in NUREG-0800, Section 2.4.11.

- RG 1.27, “Ultimate Heat Sink for Nuclear Power Plants,” as it relates to providing high assurance that the water sources relied on for the sink will be available where needed.

- RG 1.59, “Design Basis Floods for Nuclear Power Plants,” as supplemented by best current practices, as it relates to providing assurance that natural flooding phenomena that could potentially affect the site have been appropriately identified and characterized.

- RG 1.102, “Flood Protection for Nuclear Power Plants,” as it relates to providing assurance that SSCs important to safety have been designed to withstand the effects of natural flooding phenomena likely to occur at the site.

2.4.11.4 *Technical Evaluation*

By reviewing the information in SSAR Section 2.4.11, the staff confirmed that the information in the application addresses the relevant information related to low water considerations. The staff’s technical review of this section includes an independent review of the applicant’s information in the SSAR. The staff also supplemented this information with other publicly available sources of data.

This section describes the staff’s evaluation of the technical information presented in SSAR Section 2.4.11.

Information Submitted by the Applicant

The reactor technology PPE for the CRN Site does not rely on water supply from the Clinch River tributary of Watts Bar Reservoir to support SSCs important to safety.

The Clinch River tributary of Watts Bar Reservoir is anticipated to supply normal cooling water with a peak withdrawal rate of about 30,708 gallons per minute (gpm), equal to 68 cfs. That normal cooling water supply provides make-up water to maintain the cooling system supply following evaporation and blowdown losses from a mechanical draft cooling tower system. Return flow from the normal water system to the Clinch River tributary of Watts Bar Reservoir would be via a discharge structure, with a peak discharge of about 17,900 gpm, equal to 40 cfs. This results in a consumptive water use of approximately 12,808 gpm, equal to 28.5 cfs.

Staff's Technical Evaluation

According to SSAR Section 2.4.1.1, the staff notes that the makeup water for normal cooling operations comes from the Clinch River tributary of Watts Bar Reservoir. The potable and other water are supplied from the Oak Ridge Department of Public Works. The staff finds the applicant's information to be acceptable for evaluating non-safety related water supply. Sections 2.4.11.4.1 through 2.4.11.4.6 are related to evaluating these makeup water needs.

2.4.11.4.1 Low flow in Rivers and Streams

Information Submitted by the Applicant

The SSAR notes that in the Clinch River tributary of Watts Bar Reservoir the flow is regulated primarily by releases from Melton Hill Dam and the water level is regulated by Watts Bar Dam. Therefore, the operation of both dams, addressed separately as follows, can affect the surface water elevation in the Clinch River near the site.

Melton Hill Dam

According to the SSAR, Melton Hill Dam is operated for several purposes, although not for flood control due to limited capacity: navigation, hydroelectric power production, water supply, water quality and aquatic ecology enhancement, and recreation. The dam has a minimum daily-average release requirement of 400 cfs for downstream water supply and water quality enhancement. The SSAR supplements (ADAMS Accession No. ML17158B342) indicated that the occurrence of the minimum release flow (400 cfs) is infrequent from historical record. Periods of zero flow from Melton Hill Dam do occasionally occur. Since the adoption of the Reservoir Operations Study policy in 2004 (TVA 2004), the frequency of zero-flow days was 0.06 percent.

Watts Bar Dam

According to the SSAR, Watts Bar Dam is operated for several purposes: navigation, flood control, hydroelectric power production, water supply, water quality, aquatic ecology, and recreation. Watts Bar Dam has a minimum flow daily-average release requirement of 1,200 cfs for downstream water supply and water quality management (TVA, 2004). Watts Bar Reservoir is managed at two normal operating pool levels corresponding to winter (normal minimum level) and summer (normal maximum level). The normal minimum level is maintained in the winter to provide flood storage since most flooding events occur in the winter. The normal summer level is 6 ft higher than the winter level.

The primary inflows to Watts Bar Reservoir are the releases from Fort Loudoun Dam and flow from the Clinch River at Melton Hill Dam. The primary outflows from Watts Bar Reservoir are releases from hydroelectric power generation, water supply to Watts Bar Nuclear Plant for condenser cooling water, and flood flow releases.

The SSAR analyzes the effects on water level of Watts Bar Reservoir based on a set of conservative assumptions that only include (1) an inflow from minimum flow release from Melton Hill Dam, (2) outflows from consumptive uses, evaporation, and Watts Bar Dam minimum flow requirements, and (3) the Watts Bar Reservoir stage-storage curve.

Staff's Technical Evaluation

There are no safety-related water supply needs for the reactor technology PPE at the CRN Site. The SSAR states that 30,708 gpm (68 cfs) represents the water needs for non-safety related purposes, primarily condenser cooling water for normal operations. The staff notes that the needs (68 cfs) are less than 400 cfs of minimum release flow from Melton Hill Dam under drought conditions. The 400 cfs is a minimum release flow based on the installation of an upstream bypass at the Melton Hill Dam to maintain hydrothermal requirements for operation of the proposed units. The staff notes that the operating pool levels of Watts Bar Reservoir used for the drought condition analysis are illustrated in Figure 2.4.1-5a herein. Based on the availability of minimum release flow from Melton Hill Dam and the Watts Bar Reservoir level during drought conditions, the staff confirmed that this low flow study for non-safety related water supply is acceptable. This minimum release flow frequency for drought conditions (ADAMS Accession No. ML17158B342) is included in the SSAR revisions.

Based on the staff's review of the information in the SSAR, the SSAR supplements (ADAMS Accession No. ML17157B212), and the site audit, the staff determined that the applicant's low flow information provided was reasonable to analyze the non-safety related water supply.

2.4.11.4.2 Low Water from Surges, Seiches, or Tsunamis

Information Submitted by the Applicant

SSAR Section 2.4.11.2 states the CRN Site does not rely on the Clinch River for safety-related water supply purposes. SSAR Sections 2.4.5, 2.4.6, and 2.4.7 discuss surges, seiches, tsunamis, and ice jams, and concludes these hazard mechanisms could not affect safety-related SSCs at the CRN Site.

Staff's Technical Evaluation

Based on the previous review of SSAR Sections 2.4.5, 2.4.6, and 2.4.7, the staff finds the applicant's information to be acceptable.

2.4.11.4.3 Historical Low Water

Information Submitted by the Applicant

According to the SSAR Section 2.4.11.3 the drought of 1986 to 1987 was the most severe of record in the state of Tennessee. Water level records for Watts Bar Reservoir show that the water level did not drop below 735 ft NGVD29 (734.6 ft NAVD88), as discussed in Section 2.4.11.4.1 herein. SSAR Figure 2.4.11-3 shows the annual minimum water levels between 1943 and 2012 in Watts Bar Reservoir.

Staff's Technical Evaluation

The staff determined that the applicant used a sufficient period of annual low flow record to identify and analyze the low flow conditions.

2.4.11.4.4 Future Controls

Information Submitted by the Applicant

SSAR Section 2.4.11.4 states that the technology of the CRN Site does not rely on water supply from the Clinch River for safety-related purposes. Additionally, the SSAR states that the applicant would control any future water uses of the Clinch River arm of the Watts Bar Reservoir, and future users would need to account for the surface water use of the CRN Site.

Staff's Technical Evaluation

Because the applicant's reactor technology PPE does not require an external water supply to protect SSCs important to safety, the staff determined the applicant's assessment of future controls to be acceptable.

2.4.11.4.5 Plant Requirements

Information Submitted by the Applicant

The applicant refers to the SSAR Section 2.4.11.3 in which an analysis of water availability during a drought is evaluated. That analysis concluded that reservoir operations would maintain sufficient water levels to operate the CRN Site intake.

Staff's Technical Evaluation

Because the applicant's reactor technology PPE does not require an external water supply to protect SSCs important to safety, the staff determined that the applicant's assessment of plant requirements was acceptable.

2.4.11.4.6 Heat Sink Dependability Requirements

Information Submitted by the Applicant

SSAR Section 2.4.11.6 states that the reactor technology PPE for the CRN Site does not rely on water from the Clinch River for safety-related purposes.

Staff's Technical Evaluation

Because the reactor technology PPE does not require an external water supply to protect SSCs important to safety, the staff determined that the applicant's assessment of the heat sink dependability was acceptable.

2.4.11.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.11.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant has demonstrated that the low water considerations have no safety-related impact on the CRN Site since the UHS for the CRN Site does not rely on the Clinch River, and that there is no outstanding information required to be addressed in the SSAR related to this section.

As set forth above, the applicant provided sufficient information pertaining to low-water considerations. Further, the applicant has considered the most severe natural phenomena that have 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, in establishing site characteristics pertaining to low water that are acceptable for design purposes. Therefore, the staff concludes that the applicant has met the requirements related to low-water considerations with respect to 10 CFR 52.17(a)(vi) and 10 CFR 100.20(c).

2.4.12 Groundwater

2.4.12.1 *Introduction*

SSAR Section 2.4.12, "Groundwater" describes the hydrogeological characteristics of the site. One objective of groundwater investigations and monitoring at this site is to evaluate the effects of groundwater on plant foundations. The evaluation is performed to assure that the maximum groundwater elevation remains below the PPE design parameter value. Other objectives are to examine whether groundwater provides any safety-related water supply; to determine whether dewatering systems are required to maintain groundwater elevation below the required level; to measure characteristics and properties of the site needed to develop a conceptual site model of groundwater movement; and, to estimate the direction and velocity of movement of potential radionuclide contaminants.

Section 2.4.12 herein presents an evaluation of the following specific areas: (1) identification of the aquifers, types of onsite groundwater use, sources of recharge, present withdrawals and known and likely future withdrawals, flow rates, travel time, gradients (and other properties that affect the movement of accidental contaminants in groundwater), groundwater levels beneath the site, seasonal and climatic fluctuations, monitoring and protection requirements, and manmade changes that have the potential to cause long-term changes in local groundwater regime; (2) effects of groundwater levels and other hydrodynamic effects of groundwater on design bases of plant foundations and other SSCs important to safety; (3) reliability of groundwater resources and related systems used to supply safety-related water to the plant; (4) reliability of dewatering systems to maintain groundwater conditions within the plant's design bases; (5) potential effects of seismic and non-seismic information on the postulated worst-case groundwater conditions for the proposed plant site; and, (6) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.12.2 *Summary of Application*

This subsection of the ESP SSAR addresses groundwater conditions in terms of effects on site structures and the water supply. The applicant addressed these issues as follows:

- The applicant described geologic formations, and regional and local groundwater aquifers, sources, and sinks.
- The applicant stated that there are no current or projected groundwater uses for the CRNS site.
- The applicant described dewatering that will be required during construction. Due to the proposed plant grade elevation, no dewatering will be required when the plant is operational.
- The applicant described the historical, present and projected future regional use relying on reports and databases of the Tennessee Valley Authority (TVA), Department of Energy (DOE), Tennessee Department of Environment and Conservation (TDEC), the Environmental Protection Agency (EPA) and, the U.S. Geological Survey (USGS).
- The applicant described water levels and flow directions both regionally and onsite. The applicant provided groundwater level contour maps of the site and regional maps showing major hydrologic features.
- The applicant described regional and onsite field investigations and studies used to characterize aquifer parameters, the groundwater flow system, and hydrostatic loading.

2.4.12.3 *Regulatory Basis*

The relevant requirements of the NRC's regulations for groundwater, and the associated acceptance criteria, are described in NUREG-0800, SRP 2.4.12, "Groundwater."

The applicable regulatory requirements are:

- 10 CFR Part 100, as it relates to identifying and evaluating hydrological features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d) sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

The staff also used the acceptance criteria identified in NUREG-0800, Section 2.4.12:

- Local and Regional Groundwater Characteristics and Use: The applicant should supply a complete description of regional and local groundwater characteristics and groundwater use, groundwater monitoring and protection requirements, and any man-made changes with a potential to affect regional groundwater characteristics over a long period of time.

- Effects on Plant Foundations and other SSCs Important to Safety: The applicant should supply a complete description of the effects of groundwater-surface elevations and other hydrodynamic effects on the design bases of plant foundations and other SSCs important to safety.

- Reliability of Groundwater Resources and Systems Used for Safety-Related Purposes: The applicant should supply a complete description of all SSCs important to safety that depend on groundwater, as well as data and analysis regarding the reliability of the groundwater source.

- Reliability of Dewatering Systems: The applicant should supply a complete description of the site dewatering system, including its reliability to maintain the groundwater conditions within the groundwater design bases of SSCs important to safety.

- Consideration of Other Site-Related Evaluation Criteria: The applicant should supply an assessment of the potential effects of the postulated worst-case scenario related to groundwater effects for the proposed plant site.

2.4.12.4 *Technical Evaluation*

The staff reviewed the information in SSAR Subsection 2.4.12 which included the applicant's supplemental information related to the hydrogeologic site characterization. The staff confirmed that the information in the application addresses the relevant information related to the groundwater considerations. The staff's technical review of this subsection includes an independent review of the applicant's information in the SSAR and the applicant's responses to the staff's requests for supplemental information as cited in the CRN Site audit report (ADAMS Accession No. ML17341A276). The staff supplemented this information with other publicly-available sources of data and information.

The applicant identified aquifers, groundwater use categories, sources of recharge, present and future withdrawals, flow rates, travel times and gradients and other properties that affect transport of radionuclides, groundwater levels in the site vicinity including seasonal and climatic variations, monitoring and protection plans, and manmade changes that have the potential to cause long-term changes in the localized flow system. This SER subsection provides the staff's evaluation of the technical information presented in SSAR Subsection 2.4.12.

2.4.12.4.1 Aquifer Descriptions, Onsite Use and Site Setting

The applicant provided a narrative of the hydrogeology of the region and the CRN Site located in the Valley and Ridge Province of Roane County, TN. Within the region, the aquifer system sequence (Figure 2.4.12-1) contains the following formations*:*

- Chickamauga Group
- Knox Group
- Conasauga Group
- Rome Formation

The carbonate rock sequences of the Chickamauga and Knox Group are an important source of water for rural domestic water supplies. The CRN Site reactor technology PPE will not require groundwater as a source for cooling water, potable water, or other plant needs. Makeup to a safety-related UHS (if necessary) and the non-safety-related CWS for a proposed plant will be drawn from the Clinch River. Dewatering may be required during construction but not when the proposed plant is operational.

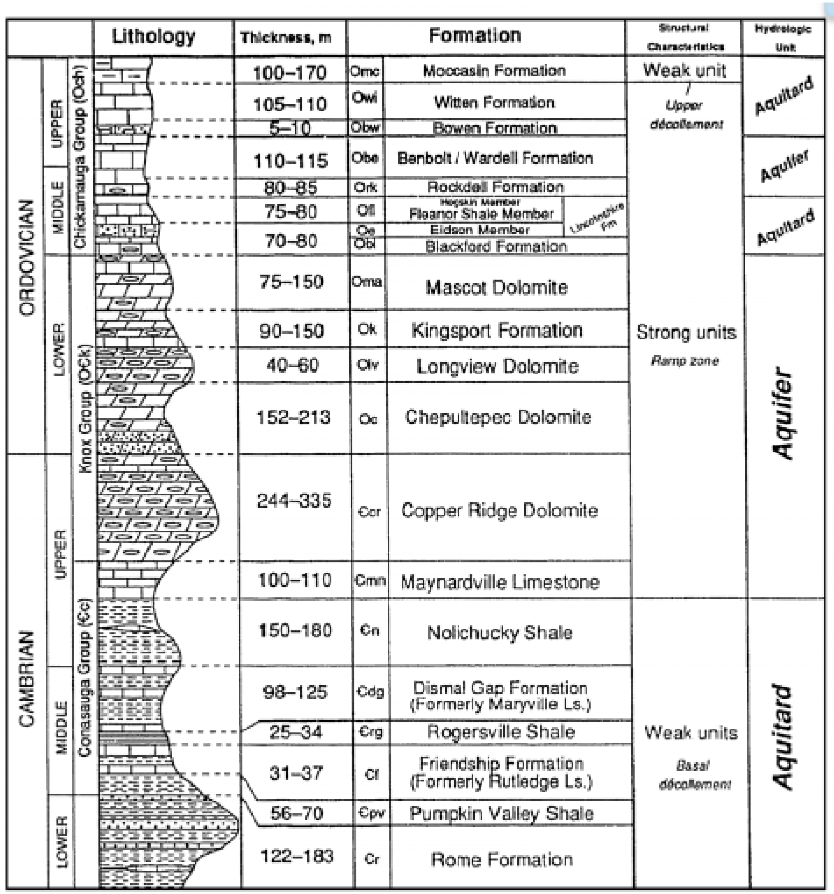

Figure 2.4.12-1. Hydrogeologic Stratigraphy of the Site and Surrounding Area (after SSAR, Revision 1 Figure 2.4.12-9)**.**

Information Submitted by the ESP Applicant

The applicant described a multi-step approach to developing a conceptual site model which included desktop studies based on existing publications, a review of the Clinch River Breeder Reactor Project (CRBRP) studies, review of the preliminary site layout, site-specific studies and observations conducted for the site, and an evaluation of these site-specific studies and observations in conjunction with regional and local information.

The applicant described the physiography and geomorphology of the CRN Site which is located in the Valley and Ridge Physiographic Province. In the site area, folding, faulting and erosion have created a series of northeast-southwest trending ridges and valleys (USGS, 2004). The dip of the northeast-southwest trending formations in the vicinity of the site is approximately 50 to 60 degrees to the southeast (Tucci, 1992) and varies to more shallow dips away from faults and higher dips in close proximity to faults.

Located in Roane County, TN, the minimum site grade is 821.0 ft NAVD88 or approximately 81 ft above the normal summer pool elevation of 740 ft NAVD88 of the adjacent Clinch River tributary of the Watts Bar Reservoir. The site lies within an oxbow bend of the Clinch River between Clinch River Miles (CRM) 14.5 and 19.0 (Figure 2.4.1-2). Existing elevations range from approximately 740 ft NAVD 88 at the Clinch River shoreline to over 1,100 ft NAVD88 along Chestnut Ridge in the northwest corner of the CRN Site boundary. The site has been altered by pre-construction activities associated with the CRBRP Limited Work Authorization (LWA) activities which included excavation in the area of the proposed nuclear island. Upon termination of the CRBRP, the Atomic Safety Licensing Board (ASLB) issued a revocation of the CRBRP LWA (ADAMS Accession No. ML16357A775) under a condition that TVA perform site reparations in accordance with a final redress plan (TVA, 1984). The CRBRP Preliminary Safety Analysis Report (PSAR) describes the pre-construction topography, and documents the site preparation activities and the associated site characterization studies (BRC, 1985).

NRC Staff's Technical Evaluation

The staff reviewed the applicant's multi-step approach to the site characterization. Staff evaluated the applicant's hydrogeologic characterization of the region including physiography and geomorphology and confirmed that this characterization was acceptable based on publicly available information including USGS topographic maps and physiographic characterization (USGS, 2004).

During the April 24-27, 2017 audit, staff requested the applicant provide the Historical Site Assessment (HSA) site redress plan (TVA, 1984) developed by the TVA and DOE for the staff's review. Subsequently, the staff reviewed the site redress plans as described in the HSA and the final plan selected. Based on the staff's review of the HSA plan, the ASLB's hearing on the plan (ADAMS Accession No. ML16357A775), and information in the CRBRP PSAR (BRC, 1985) the staff found the applicant's description of the current site disposition acceptable as described in the SSAR.

2.4.12.4.2 Regional Hydrogeology and Groundwater Aquifers

Information Submitted by the ESP Applicant

The applicant described the principal Valley and Ridge Province aquifers as primarily carbonate rocks present in the valleys between ridges. Dissolution activity within these carbonate rocks can result in solution cavities within these aquifers. Fractures and solution openings in the carbonate rock aquifers may result in highly permeable zones with high localized well yields. The applicant stated that majority of groundwater flow takes place within 200 to 300 ft of land surface in valleys between the ridges with springs, streams, and the Clinch River as primary discharge points. Groundwater discharges to springs are highly dependent on and correlated to rainfall. Groundwater in the aquifers moves primarily through fractures, bedding planes and solution openings in the rocks. Preferential flow paths trend along the strike of the aquifer units. Dissolution from slightly acidic water circulating primarily within the upper 200 to 300 ft of the aquifers may enlarge solution openings and increase permeability in these zones (USGS, 1986).

The applicant noted important aquifers in the area, which are within the Knox Group. Portions of these aquifers may have a direct hydraulic connection to surface water (e.g., rivers and lakes). The applicant summarized regional groundwater use and stated that the lower Chickamauga and the Knox Group aquifers characterize the largest well yields in the area. In the vicinity of the site, water quality gradually decreases with depth transitioning from fresh "hard" water to sodium-bicarbonate at intermediate depths and to sodium-calcium-chloride (briny or saline water) at deep depths (greater than approximately 1,000 ft).

The applicant described the unconsolidated deposits on the site which included residuum, colluvium and anthropogenic (backfill) material. Residuum consists of the weathered bedrock; colluvium, a mixture of residuum and alluvial material; and anthropogenic material, or the backfill and broken rock associated with past CRBRP site activities. The applicant characterized the subdivisions of the two (Chickamauga Group and Knox Group) primary aquifers on and around the site (Figure 2.4.12-1). The nature of groundwater movement in these aquifers is consistent with groundwater fracture and solution opening flow and bedding planes orientation as described previously for the carbonate aquifers. Below the Knox Group, the applicant described the Conasauga Group which has an upper (Maynardville Limestone) member that is considered part of the Knox aquifer. The remainder of the lower members of the Conasauga are described as an aquitard (Figure 2.4.12-1). Beneath the Conasauga Group is the Rome Formation which is generally considered to be an aquitard. The applicant noted that there are no sole-source aquifers within the area of the CRN Site and corresponding hydrogeologic boundaries.

NRC Staff's Technical Evaluation

Staff reviewed the applicant's characterization of the regional aquifers and confirmed through reviews of independent studies and reports (e.g., Tucci, 1992 and USGS, 1986) that dissolution and the resulting solution openings and fractures result in permeable zones, and that the majority of groundwater flow takes place within 200 to 300 ft of land surface. Previous regional studies (Tucci, 1992, USGS, 1986 and USGS, 2000) confirm the applicant's characterization that the majority of solution cavities and fractures are within 200 to 300 ft of land surface and coincide with the most permeable groundwater flow zone.

Principal aquifers of East Tennessee consist of carbonate rocks which comprise the most productive aquifers. Typically, these rocks are hydraulically connected to sources of discharge or recharge, such as rivers or lakes through fractures and solution activity that may enlarge the original openings in the carbonate rocks (USGS, 2000). In the vicinity of the CRN Site, these carbonate aquifers include the limestones and dolomites of the lower Chickamauga and Knox Groups (Dorsch and Katsube, 1999) which are overlain by weathered rock, soil and backfill from CRBRP site activities. The Conasauga Group, with the exception of the uppermost Maynardsville Limestone, is considered an aquitard (Dorsch and Katsube, 1999 and DOE, 2001). Water quality of the aquifers varies from fresh hard water within the upper 300 ft of the aquifers decreasing in quality beyond this depth grading into a briny characteristics at depths greater than 1,000 ft. The staff reviewed the applicant's description of the regional aquifers and the aforementioned publications and confirmed that the applicant acceptably described the regional hydrology and groundwater aquifer system.

2.4.12.4.3 Local Hydrogeology

In addition to site specific studies to characterize the local hydrogeology, the applicant reviewed several studies performed on the nearby Oak Ridge Reservation (ORR) which borders the northeastern portion of the CRN Site.

Information Submitted by the ESP Applicant

The applicant described local hydrologic studies based on information derived from USGS studies (Tucci, 1992 and USGS, 1986) and extensive studies (e.g., Moore, 1991, Parr and Hughes, 2006, and Hatcher et al., 1992) conducted on the adjacent ORR (e.g., Moore, 1991, Parr and Hughes, 2006, and Hatcher et al., 1992). The northeast trending valleys and ridges and the broad extent of the carbonate rocks are the result of a combination of folding, thrust faulting and erosion. These forces have resulted in repeated rock sequences in the province that have been fractured by compressive forces which have displaced older rocks (primarily the Conasauga Group and the Rome Formation) over the top of younger rocks (the Chickamauga and the Knox Group) along thrust fault planes for sequences of permeable and less permeable hydrogeologic units. The repeated sequences form a series of adjacent and shallow groundwater flow systems (USGS, 1986 and Dorsch and Katsube, 1999).

The ORR studies included permeabilities and porosities for approximately 200 aquifer tests which included bedrock and overburden aquifer material for the same or similar hydrogeologic units found at the CRN Site. The ORR site is directly northeast and adjacent to the CRN Site. From the data, the applicant noted a general trend of decreasing hydraulic conductivity with depth with the exception of the Knox Group where fracturing and solutioning may contribute to the porosity throughout the unit.

NRC Staff's Technical Evaluation

The hydrologic studies conducted at the ORR are particularly relevant to supplementing the CRN Site characterization as the ORR is adjacent to the CRN Site and the ORR studies incorporate sampling and testing information for many of the same hydrogeologic units found on the CRN Site. The staff reviewed the permeability and porosity studies conducted for the ORR adjacent to the CRN Site and determined that the applicant's characterization of the ORR studies and information as applicable to the CRN Site was acceptable.

2.4.12.4.4 Site-Specific Hydrogeology

The CRNS field investigations included drilling 82 borings, 3 test pits, installation of 44 wells, and associated testing and observations of the information from these activities.

Information Submitted by the ESP Applicant

The applicant noted that the CRBRP investigation included 129 borings, installation of 37 observation wells, 11 piezometers, and 117 bedrock borehole permeability tests. The applicant identified no abandoned CRBRP wells while performing the CRN Site subsurface investigation activity. The applicant stated that the CRBRP wells were likely destroyed and/or removed during the excavation and subsequent CRBRP site redress. However, during a 2018 site walk-down, one CRBRP well was found. Further searches resulted in the discovery of two additional wells. The applicant is currently evaluating these wells for closure in accordance with TVA and TDEC requirements (ADAMS Accession No. ML18253A095). Although no documentation of CRBRP well closures were identified, the applicant assumed that the DOE followed standard well closure procedures during subsequent site redress activities.

The CRBRP site investigation identified predominate joint sets of N52^{o}E 37^{o}SE with a total of four bedrock joint set orientations at the site:

- N52^{o}E 37^{o}SE
- N52E^{o} 58^{o}NW
- N25^{o}W 80^{o}SW
- N65^{o}W 75^{o}NE

From CRBRP hydraulic conductivity tests performed at the site, the applicant noted a similar trend to the ORR data of decreasing hydraulic conductivity at depths greater than 100 ft. The applicant noted that maximum groundwater levels were observed in January/February and minimum water levels observed in October/November with approximately 20 ft of fluctuation. Groundwater flow patterns generally follow topography but are tempered relative to the extent of bedrock weathering. Ridges are generally considered groundwater divides with groundwater use primarily limited to agricultural and residential use. The CRN Site is bounded to the northwest by the Chestnut Ridge highlands with the Clinch River oxbow surrounding the remaining site boundary.

CRN Site groundwater characterization activities included monitoring groundwater levels, performing slug, packer, aquifer performance tests, and geochemical sampling. The applicant monitored intervals ranging from 15 feet to 297 ft below ground surface (bgs) in three monitoring zones: an upper (15 to 105 ft bgs); an intermediate (89 to 178 ft bgs); and a deep (176 to 297 ft bgs). Upper, middle, and lower zone monitoring well identifications were designated with a “U”, “L”, or “D” suffix, respectively. The applicant supplemented the CRN Site characterization with information from the CRBRP studies, including packer hydraulic permeability testing in the Chickamauga and Knox Group aquifer materials which exhibited a trend of decreasing hydraulic conductivity at depths beyond 100 ft.

The applicant noted that petroleum groundwater contamination has been observed in well OW-422L. The oversight authority for the contamination issue is the TDEC. TDEC (TDEC, 2013) described the contamination as diesel petroleum hydrocarbons with further TDEC analysis indicating the presence of low levels of radionuclides potentially originating from ORR sources northeast of CRN Site. TDEC (TDEC, 2016) indicated that the radionuclides are characteristic of past ORR waste streams and disposal operations. During the April 24-27, 2017 audit, the applicant described the petroleum contamination as diesel characteristic of a 1970s fuel blend based on past studies. The applicant indicated that the petroleum contamination is localized and is likely an artifact of leakage associated with heavy construction equipment fuel used during the CRBRP site construction activities in the late 1970s. Based on observing no related petroleum contamination in any other monitoring wells during long-term monitoring or in monitoring wells during the CRN Site aquifer pumping test, the applicant concluded that the petroleum contamination is restricted to the immediate vicinity of OW-422L. The TDEC continues to monitor the disposition of OW-422 and characterize the associated contaminant level measurements. The locations of TDEC monitoring wells, ORNL, the Hood Ridge Area and the applicant's aquifer pumping test wells are shown in Figure 2.4.12-2.

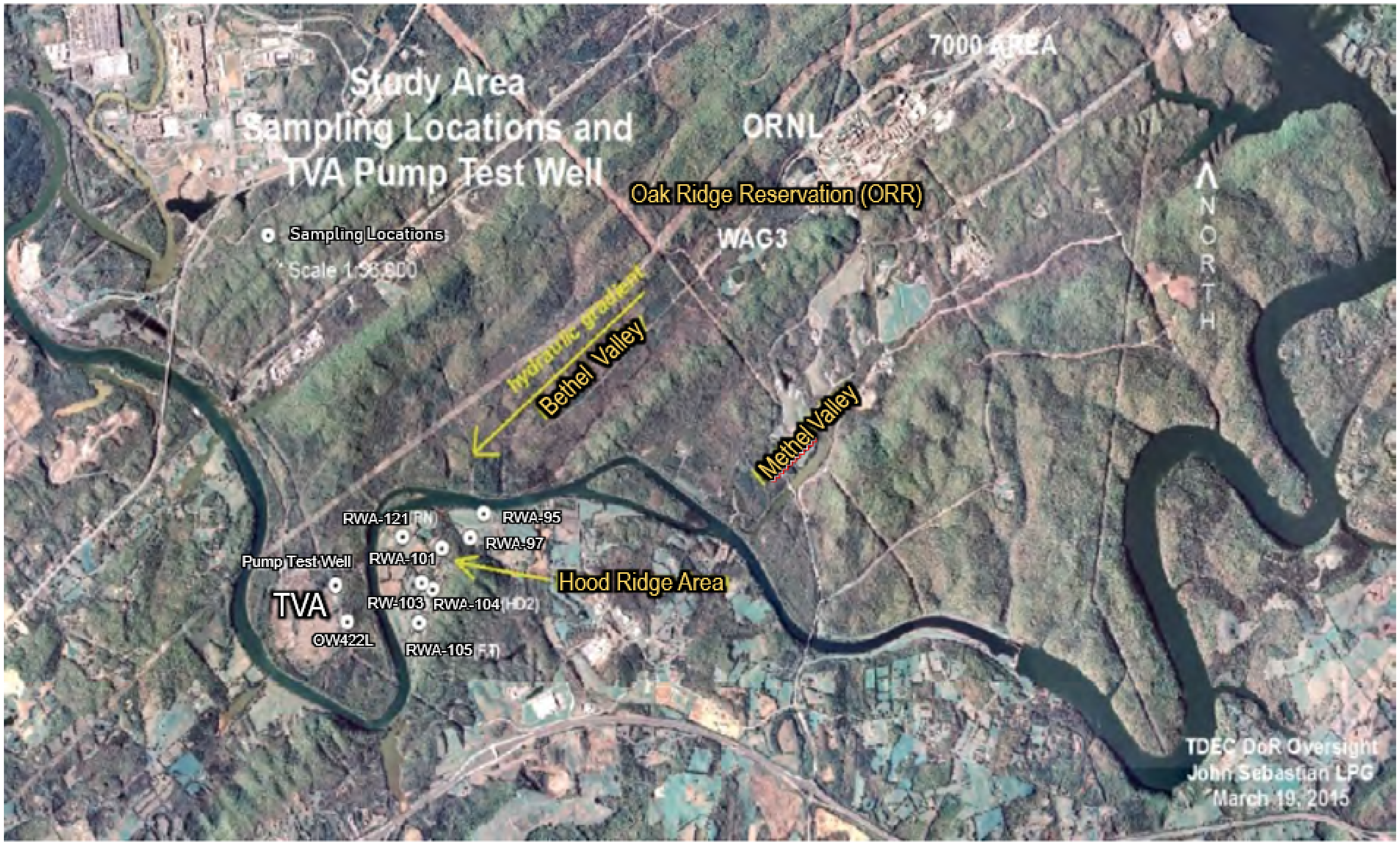

Figure 2.4.12-2. Study Area Sampling Locations and TVA Aquifer Pumping Test Well (after TDEC, 2016, Figure C.1).

NRC Staff's Technical Evaluation

Staff reviewed the studies conducted for the CRBRP and requested that the applicant provide clarification on the disposition of the wells and borings installed during the CRBRP activities. During a site audit conducted April 24-27, 2017, the applicant provided the CRBRP site redress plan (TVA, 1984) for the staff's review which was developed by the TVA and the DOE. Staff reviewed the CRBRP site redress plan and the Atomic Safety and Licensing Board's 1985 order (ADAMS Accession No. ML16357A775) related to the review of the plan which described the orderly shutdown of site construction activities for the CRBRP. Staff found that the redress plan and the ASLB order described the last known status of the site, but not the disposition of borings and wells used to characterize the CRBRP.

The applicant noted that many of the CRBRP wells and borings would have been removed or destroyed during the site excavation. During the April 24-27, 2017 audit, the applicant indicated that the disposition of the CRBRP wells and borings installed are unknown. During 2018 site walk down activities and subsequent searches, the applicant identified three of these wells. The applicant is currently investigating their disposition and evaluating these wells for closure in accordance with TVA and TDEC requirements (ADAMS Accession No. ML18253A095). No evidence of CRBRP borings were found during the CRN Site characterization or in field study activities prior to 2018. Improperly abandoned wells have the potential to channel shallow groundwater flow into lower levels of the aquifer system (i.e., "short-circuiting"). The applicant submitted supplemental information (ADAMS Accession Nos. ML17237C084 and ML17286A615) to address potential short-circuiting of liquid effluents and included this additional information in the SSAR.

Below the shallow groundwater system on the CRN Site, the applicant stated that there is no evidence of enhanced permeability or fractures in the deepest borings (ADAMS Accession No. ML17237C084) including MP-101 near the center of the proposed power block which is 540 ft bgs (260 ft NAVD88). The applicant noted a lack of dissolution cavities and healed (mineral sealed) fractures in other (MP-417 and MP-421 drilled to 320 ft NAVD88) deep bore holes on the CRN Site. The lack of permeability at depth is consistent with CRBRP studies (BRC, 1985) which describe permeabilities that are sharply reduced with depth as fracture discontinuities become tighter and less frequent, thereby strongly subduing hydraulic flow connections. The decreasing permeability is also consistent with the applicant's characterization of fracture frequencies based on CRN Site borehole data (Figure 2.4.12-3). Within the supplemental information (ADAMS Accession Nos. ML17237C084 and ML17286A615) provided, the applicant noted that minimal groundwater seepage was observed into and through the bottom of the CRBRP excavation which measured approximately 480 ft long, 360 ft wide and 100 feet deep (i.e., a bottom elevation of approximately 714 ft NAVD88) and included this information in the SSAR. The minimal seepage in the CRBRP excavation, which was 27 feet below the Clinch River median water level and below the water table, is consistent with decreasing fracture permeability with depth (Figure 2.4.12-3), as corroborated by CRN Site borehole investigations.

The proposed CRN Site excavations will take place within the Chickamauga Group. In a response to a request for supplemental information (ADAMS Accession No. ML17237C084), the applicant described two dominant flow systems within the Chickamauga: a shallow and a deep groundwater system as characterized for the adjacent Bethel Valley based on core fracture analysis (USGS, 2000) and included this information in the SSAR. The shallow system was described as extending to a depth of approximately 150 ft and separated from the deep system by a subhorizontal interface that occurs where oxidized and reduced waters mix (Native et al., 1997). In their supplemental response (ADAMS Accession No. ML17237C084), the applicant noted that Total Dissolved Solids (TDS) of typically less than 5,000 mg/l in the shallow groundwater zone are characteristic of TDS measurements for the CRN Site which range from 290 to 1,100 mg/l over a depth range of 28 to 130 ft bgs. Consistent with CRN Site samples, staff notes that TDS measurements of 497 mg/l were obtained from the deepest sample depth (160 ft bgs) during the CRBRP investigations (USGS, 2004). The TDS measurements characteristic of the CRBRP and CRN Site investigation borings indicate that the borings for these investigations remained within the shallow ground water system on the CRN Site.

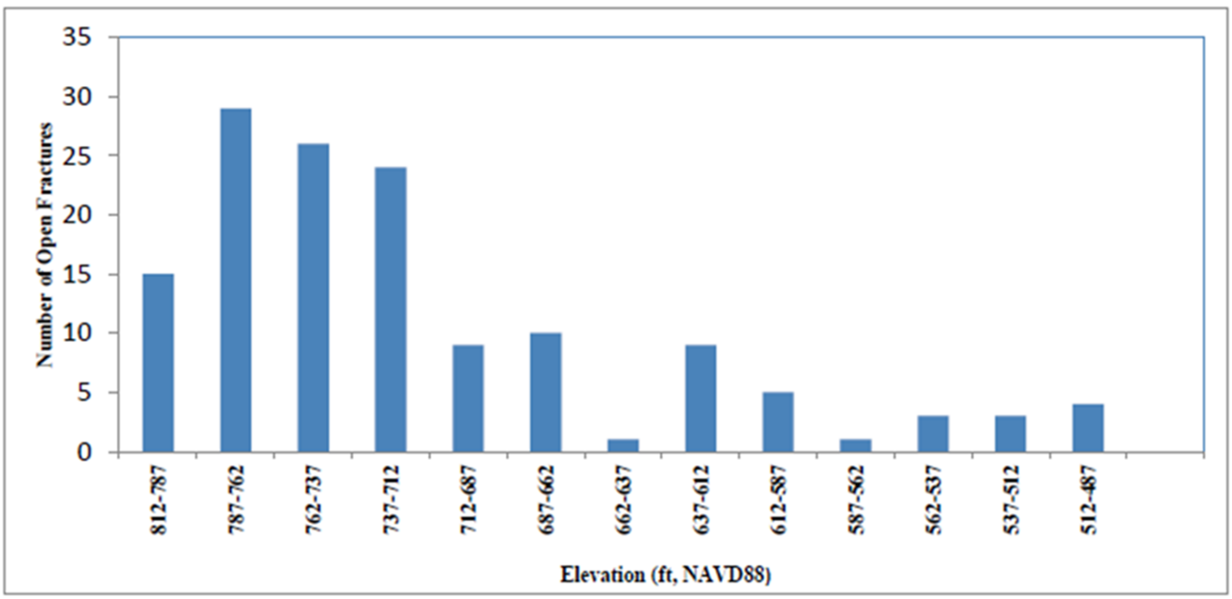

Figure 2.4.12-3. Frequency Distribution of Open Fractures with Elevation. (After SSAR Figure 2.4.12-33).

During the monitoring period (September 2013 to August 2015), groundwater gradients from OW 417 U/L were consistently upward at this well pair which is adjacent to the Clinch River. The upward groundwater gradient (Figure 2.4.12-4) exhibited no observable correlation with the Clinch River stage over the monitoring period, indicating steady state conditions. The consistent downward gradients in the upland areas of the site indicating precipitation recharge (e.g., at OW-202U/L/D well cluster) areas and upward hydraulic gradients near the Clinch River (e.g., at OW-417U/L) indicates that the Clinch River acts as a discharge point for the shallow groundwater system flow from the CRN Site.

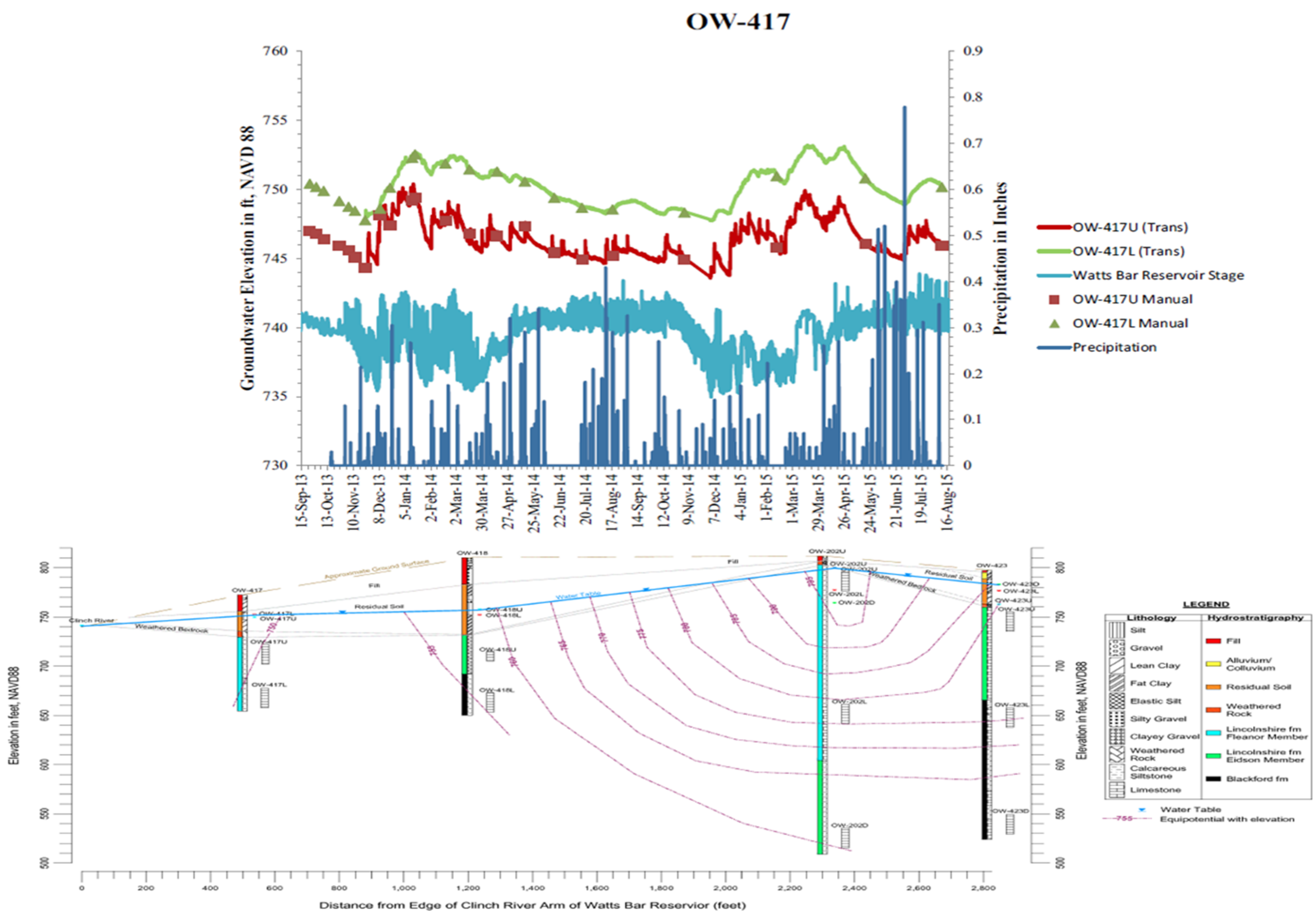

Figure 2.4.12-4. Hydrograph of OW-417 Well Pair (top) and, (bottom) Hydrologic Cross-section through the Clinch River, OW-417, OW-418, OW-202 and OW-423 from Left to Right (After SSAR Figure 2.4.12-29 and 2.4.12-32).

This trend is consistent with gradients near the Clinch River as observed in nearby ORR studies (Bechtel Jacobs Company, 2011 and Dorsch and Katsube, 1996), indicating upward groundwater gradients towards the Clinch River at depth (Figure 2.4.12-5).

Given the low and decreasing fracture permeabilities of the deeper zones beyond 712 ft NAVD88, TDS measurements characteristic of the shallow groundwater system, and upward groundwater gradients indicating groundwater discharge to the Clinch River, the staff finds that the applicant’s evaluation acceptably bounds potential short-circuiting pathways.

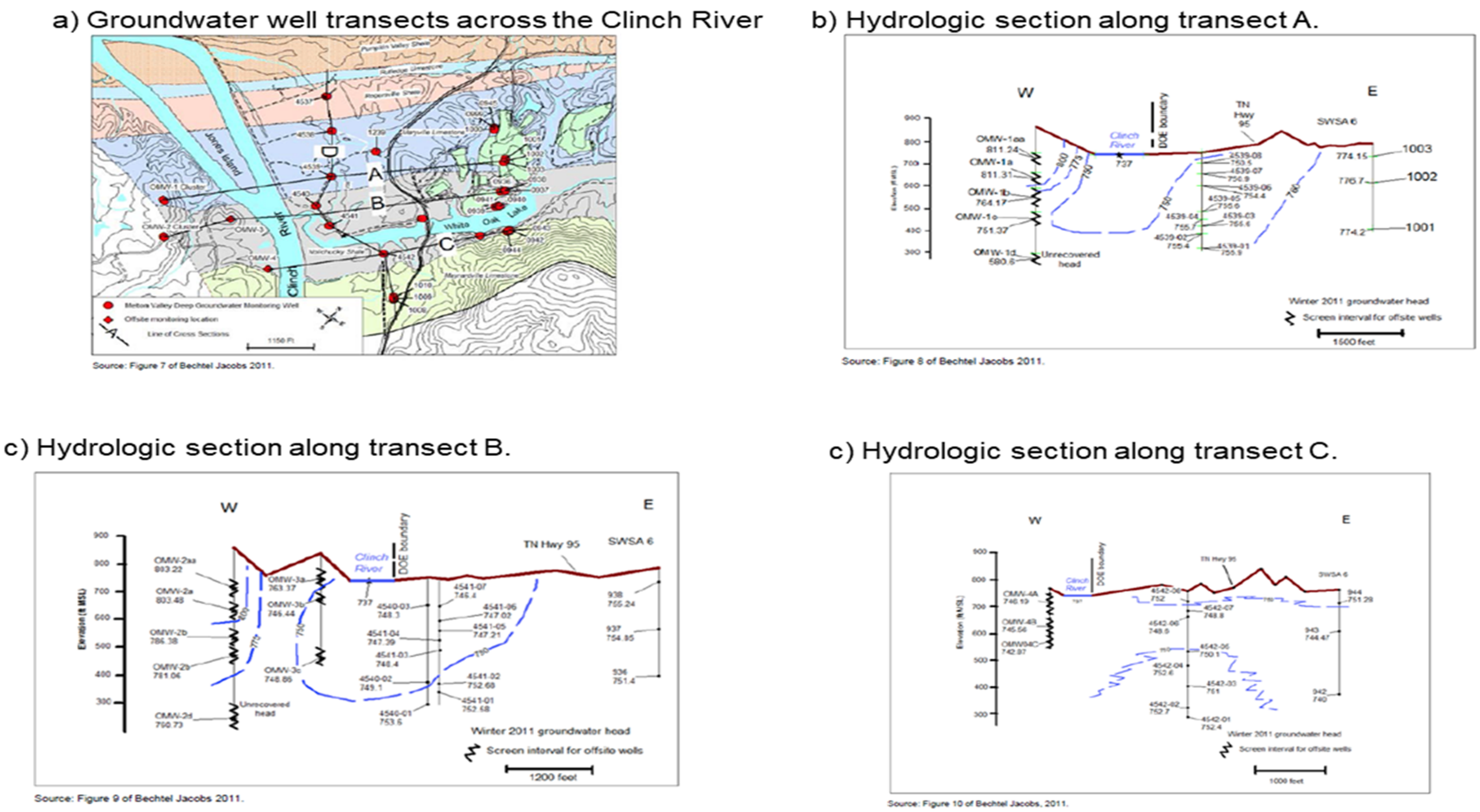

Figure 2.4.12-5. Location of Wells and Hydrologic Transects Along the Clinch River and, Cross Sections Along Transects A, B and C. (After Bechtel Jacobs Company, 2011 Figures 7, 8, 9 and 10).

The staff reviewed the disposition of groundwater contamination observed in well OW-422L. During an April 24-27, 2017 audit, the staff discussed the disposition of the well with the applicant. The applicant indicated that the groundwater contamination and associated monitoring and sampling of the well continues to be under the purview of TDEC in cooperation with the applicant. Past TDEC sampling results (TDEC, 2016) from the applicant's wells have indicated that radionuclides are present at or below detection limits and drinking water Maximum Contaminant Level-Derived Concentration (MCL-DC) levels in CRN Site wells PT-PW and OW422L. TDEC (TDEC, 2016) and DOE (DOE, 2017) studies have indicated that low levels of radionuclides prevalent in down gradient wells in the Hood Ridge area have likely migrated off of the ORR towards the Hood Ridge area and OW422L in the past. Staff confirmed that the radionuclides present are consistent with ORR operations and waste disposal practices that commenced in the 1940s. The extent of the resulting legacy contamination in the vicinity of the ORR is being characterized by ongoing DOE (DOE, 2017) remediation and monitoring studies.

Based on a review of the CRN Site investigation information, the staff determined that the applicant's spatial extent of the vertical (borehole and well) data, associated aquifer test data and description of the hydrogeology is acceptable to characterize the CRN Site groundwater flow system.

2.4.12.4.5 Groundwater Sources and Sinks

The applicant described the regional, local, and site-specific discharge, recharge areas, mechanisms, and characteristics of the groundwater flow system.

Information Submitted by the ESP Applicant

The applicant described precipitation as the primary source of surficial recharge to the aquifer system with minor contributions from the Clinch River during high stages. As described above, the applicant cited a study by the DOE (Bechtel Jacobs Company, 2011) indicating discharge to the Clinch River from the surrounding shallow groundwater flow system in the vicinity of the ORR (Figure 2.4.12-5) consistent with patterns on the CRN Site.

During the April 24-27, 2017 site safety audit and subsequent discussions with the applicant, the staff noted that a study by TDEC (TDEC, 2016) indicated that the CRN Site pumping test performed on March 21-24, 2018 likely influenced the groundwater flow field in the Hood Ridge area approximately 3,000 ft east of the pumping well and across the Clinch River (Figure 2.4.12-2). Staff noted that the CRN pumping test's ability to influence wells across the Clinch River was contrary to the applicant's conceptual model of the Clinch River as a hydraulic boundary for the CRN Site. In response (ADAMS Accession No. ML17237C084), the applicant evaluated the TDEC (TDEC, 2016) study. The applicant stated that TDEC based the conclusion on contaminant sampling patterns obtained from three separate sample events at Hood Ridge wells over an approximate 9-month period (October 29, 2013, March 25, 2014 and July 22, 2014). The applicant noted that the CRN Site pumping test occurred over a 72-hour period from noon on March 21, 2014, to noon on March 24, 2014. The applicant stated that while selected contaminant level measurements may have exhibited trends over the 9-month interval of the three sampling periods, there was no consistent or discernable trend for groups of similar contaminants such as volatile organic compounds or radionuclides (Tc-99 and Sr-90) that could be correlated with the pumping test. The applicant stated that the lack of discernable trends in the measured contaminant levels from the three sampling events in the TDEC study (TDEC, 2016) precludes the conclusion that the CRN Site pumping test influenced water quality in the Hood Ridge area. Based on CRN Site wells monitored during the pumping test, the applicant described the pumping test radius of influence as limited to approximately 150 ft from the pumping with a vertical influence limited to a depth range of approximately 160 to 248 ft bgs. The applicant stated that the Hood Ridge area wells (RWA-121 and RWA-104), identified as having potential contaminant level trends correlated with the CRN Site pumping test, are across the Clinch River and approximately 3,000 ft away from the pumping test well. The applicant further stated that these wells have depths of 400 to 610 ft, with casing depths of 105 to 126 ft, and are beyond the influence demonstrated by the CRN Site monitoring wells near the pumping well.

The applicant described current and projected groundwater use. The applicant characterized surface water as the primary source of water for all uses in the Tennessee Valley accounting for over 98 percent of total withdrawals with groundwater providing the remainder. No sole source aquifers were identified by EPA in the study area. The applicant summarized groundwater withdrawals in the study area as 3.5 million gallons per day (mgd) which is generally trending downward over time by category (i.e., industrial, public supply and irrigation). The applicant included information in the SSAR on local groundwater use and well characteristics within a 1.5 mi radius of the CRN Site.

The applicant stated that the proposed plant design does not require groundwater for plant operations or potable use. The applicant stated that makeup water will be sourced from Clinch River surface water and there are no current or projected groundwater users on the CRN Site (SSAR Subsection 2.4.12.1 “Description of Onsite Use”). Therefore, the applicant concluded that groundwater resources would not be affected by plant operations.

NRC Staff’s Technical Evaluation

As described in Subsection 2.4.12.4.4 herein, staff determined that gradients observed in well pairs and the spatial groundwater gradient pattern over the CRN Site is consistent with recharge in central upland areas of the site and discharge of the CRN Site shallow groundwater to the Clinch River.

The staff reviewed the TDEC (TDEC, 2016) monitoring report and associated contaminant level trends with respect to the potential influence of the CRN Site pumping test. The staff determined that the applicant’s evaluation of the contaminant level measurement trends (ADAMS Accession No. ML17237C084), coupled with the limited temporal and spatial influence of the CRN pumping test as described in the SSAR, provide an acceptable rationale for the applicant’s conclusion that the pumping test influence is limited to an area within the CRN Site boundary.

Based on the staff’s review of the PPE, the operation of the proposed units would not use groundwater for any safety related purposes and potable water would be obtained from public supplies. Because no pumping for groundwater use will take place on the CRN Site, the ambient groundwater flow field would not be significantly altered. As included in the SSAR, the applicant provided a discussion of individual groundwater users and well characteristics within a 1.5 mi radius of the CRN Site (ADAMS Accession No. ML17200C887). Staff finds that the applicant's description of groundwater use on the CRN Site and in the site vicinity to be acceptable.

2.4.12.4.6 Groundwater Flow Directions

Information Submitted by the ESP Applicant

As discussed in Subsection 2.4.12.4.4 herein, groundwater gradients and flow patterns indicate recharge in the central portion of the CRN Site and shallow groundwater discharge to the corresponding drainage features and the adjacent Clinch River. The applicant characterized pre-development groundwater flow directions from the CRBRP PSAR as generally towards the southeast or southwest from the center of the site based on CRBRP monitoring wells with long screen intervals, which provide an average water level over the monitoring interval. In general, the CRN Site investigation water levels and flow directions agreed with the CRBRP investigation indicating flow towards the southeast and southwest from the CRBRP excavation area. The applicant calculated hydraulic gradients ranging from approximately 0.03 to 0.17 ft/ft over the September 2013 to August 2015 period of record for various transects and wells and developed maximum potentiometric contour maps based on maximum water levels for the period of record.

Regionally, the applicant cited trends in the nearest USGS wells. Water level fluctuations were noted as approximately 5 ft over a period of several years. The applicant noted that observed measurement of groundwater levels on the CRN Site vary from 10 to 25 ft with maximum water levels occurring in January/February. The applicant digitally recorded cluster well water levels at five locations. Wells in these clusters show correlations with changes in the Clinch River stage, but the changes correlated primarily with precipitation events. Groundwater level responses to precipitation events were noted in all of the CRN Site wells.

NRC Staff's Technical Evaluation

The staff reviewed the information evaluated in the application and found the applicant's characterization of groundwater gradients and flow patterns to be acceptable. The applicant provided acceptable hydrogeologic descriptions and references in the SSAR.

2.4.12.4.7 Aquifer Properties

The applicant performed on-site aquifer testing and laboratory sample testing of rock and soil samples collected during the CRN Site investigation. Effective porosities for the CRN Site were based on DOE studies characterizing the same hydrogeologic units found at the adjacent ORR (Dorsch and Katsube, 1996).

Information Submitted by the ESP Applicant

Based on fracture frequency analysis of boreholes, the applicant stated that the fracture density decreases with depth over three general elevation zones: 1) pervasive fractures from 812 to 712 ft; 2) moderately fractured from 712 to 612 ft; and 3) slightly fractured from 612 to 487 ft (Figure 2.4.12-3). The applicant noted that fracture density in the upper zone is likely under-reported due to casing on the upper end of boreholes masking the fractures in this zone. The applicant noted that the decreasing fracture density with depth is consistent with CBRP investigations (BRC, 1985) and studies conducted on the ORR which compare hydraulic conductivities with the depth of the testing interval (Tucci, 1992, Moore, 1991 and Bittner and Dreier, 1991).

The applicant performed 41 packer tests in 12 boreholes with 19 tests yielding no analysis, (5 tests exhibited flow by passing the packers and 14 had negligible formation flow rates). The packer tests resulted in a geometric mean for hydraulic conductivity of 0.54 and 0.44 ft/day for the Knox (9 tests) and Chickamauga (13 tests) intervals, respectively. In general, the decreasing hydraulic conductivities below a depth of 150 ft bgs are consistent with decreasing fracture frequency.

The applicant conducted slug (or sudden water displacement) tests in the most fractured (permeable) portion of selected observation well intervals. The applicant noted that the representative hydraulic conductivity of the low permeability intervals on the ORR is 8.7×10^{-8} meters/day (m/d) or (2.8×10^{-7} ft/d) indicating that negligible flow occurs through the rock matrix and fracture flow predominates. In general, the geometric mean of the Knox (0.14 ft/d for 20 tests), and that of the Chickamauga (0.14 ft/day for 6 tests), are in agreement with the values derived for the packer tests described above. Although the slug test values exhibit a wide range of values, the hydraulic conductivity exhibited a general trend of decreasing with depth. The applicant stated that the broad range may be due to the long length of the test intervals as compared to the packer tests, with longer lengths representative of a greater variety of aquifer material.

The applicant performed a pumping test and included the data and analysis in the SSAR as Appendix 2.4.12B. The test included pumping test well PT-PW and nine observation wells. The pumping well was screened in the calcareous siltstone (Fleanor member) and limestone (Eidson member) of the Lincolnshire Formation and, the Blackford (siltstone, limestone and dolomitic limestone) within the Chickamauga Group. The pumping test was performed over a period of 72 hours (from noon March 21, 2014 to noon March 24, 2014), with an average pumping rate of 14.5 gallons per minute (gpm). The applicant stated that the highest transmissivity and hydraulic conductivity resulting from the test was for a well (OW-423L) located along the strike (N52^{o}E) of the bedding planes while analysis for wells perpendicular to the bedding plane (PT-OW-U2 and PW-OW-L2) yielded transmissivities and conductivity values that were an approximate order of magnitude lower that those along the strike. The higher permeabilities along the strike of the bedding planes are consistent with the principle groundwater flow direction along the strike. In general, the hydraulic conductivities derived for wells oriented perpendicular to the strike were an order of magnitude lower than calculated (2.6 ft/d) for OW-423L. Based on the position and distance of the pumping test observation wells relative to the pumping well, the applicant noted that the pumping influence of PT-PW was limited to a radius of approximately 150 ft.

Based on petrophysical testing of rock samples on the ORR similar to the aquifer material on the CRN Site, the mean effective porosity was determined to be approximately 4 percent (0.04). The applicant summarized unit weights ranging from 120 to 175 pounds per cubic ft and specific gravities ranging from 2.75 to 2.8 based on rock and soil samples, as described in SSAR Subsection 2.5.4. The applicant noted that the properties of the backfill to be used for site construction will be established in the COLA as described in SSAR Subsection 2.5.4.5.3, "Backfill Sources."

The applicant stated that shallow groundwater is characteristic of mixed cation-bicarbonate water grading to sodium-bicarbonate at intermediate depths and sodium-chloride (saline) water at deep depths (below an approximately 100 m (328 ft) depth). Information for an ORR well adjacent to the northwestern CRN Site (Nativ et al., 1997) boundary indicated that the saline water is at an approximate depth of 126 m (413 ft). None of the CRN Site wells intercepted the saline layer characteristic of the deep groundwater system.

NRC Staff's Technical Evaluation

Consistent with the applicant's evaluation of aquifer properties, ORR studies (Moore, 1991, Tucci, 1991 and Bittner and Dreier, 1991) confirm that most groundwater flow is transmitted through a layer of shallow fractures near the water table and that this open fracture density decreases with depth with only a small (approximately one percent) fraction reaching the lower (greater than 250 ft depth) portion of the aquifer system (Tucci, 1992).

During the April 24-27, 2017 audit, the applicant and staff discussed the results of the packer slug, and aquifer tests. Staff noted that the slug test values are an estimate of the local hydraulic conductivity in the area surrounding the well which may be affected by disturbance from drilling activity; therefore, significant variability in the slug test values derived from water level observations are expected. The packer and aquifer test results are more representative of a larger volume of the aquifer and thus are more representative of average conditions. The staff reviewed the applicant's analysis of the aquifer test data and results and found the applicant's evaluation acceptable. Because the studies used to derive the CRN Site's effective porosity are from the ORR adjacent to the site and are within the same shallow groundwater system aquifer material as that of the CRN Site, the staff finds the applicant's characterization of the porosity acceptable.

The staff determined that the applicant's characterization of the hydrogeochemical characteristics of the aquifer system is acceptable and consistent with studies performed on the ORR (Nativ et al., 1997) and those by the DOE (Bechtel Jacobs Company, 2011).

Staff notes that the construction backfill properties will be established in the COLA as described in SSAR Subsection 2.5.4.5.3, "Backfill Sources." As discussed in SER Subsection 2.5.4.4.5, "Excavation and Backfill", the staff is tracking this issue as **COL Action Item 2.5-8**.

2.4.12.4.8 Subsurface Pathways and Monitoring or Safeguard Requirements

Information Submitted by the ESP Applicant

The applicant noted that the topographic high of Chestnut Ridge creates a groundwater divide while the Clinch River serves as the primary discharge point for the CRN Site shallow groundwater system. SSAR Subsection 2.4.12.3, "Subsurface Pathways" provides site-specific information supporting the premise of the Clinch River as a sink for shallow groundwater migrating from the CRN Site. The applicant's rationale included: a demonstrated lack of dissolution and fracture (i.e., permeability) features at depth; CRBRP excavations below the water table and the bottom of the Clinch River exhibiting negligible groundwater inflow; and, CRN Site groundwater gradients consistent with DOE studies (Bechtel Jacobs Company, 2011) showing the Clinch River as a hydrologic boundary.

The applicant used a groundwater travel time of 359 days based on advective transport parameters derived from aquifer tests in the shallow aquifer and hydraulic gradients derived from observed groundwater levels. The applicant stated that groundwater flow in the lower portion of the shallow groundwater system is controlled by discrete fractures with over 90 percent of the groundwater flow occurring in the upper zone. The applicant assumed a postulated receptor location at the Clinch River site boundary located the closest distance (1,400 ft) from the edge of the proposed power block. Based on a maximum hydraulic conductivity (2.6 ft/d), a mean hydraulic gradient (0.07 ft/ft), a mean effective porosity (0.05), and a 1,400 ft receptor distance, the applicant calculated a linear velocity of 3.90 ft/day and the resulting travel time of 359 days to the postulated receptor point at the Clinch River. The applicant's characterization of advective transport was based site-specific data and parameters, and porosities derived from ORR studies (Dorsch and Katsube, 1996) for the same aquifer material as found at the CRN Site.

In the SSAR, the applicant committed to follow NRC endorsed NEI 07-07 (ADAMS Accession No. ML17158B342) and perform groundwater monitoring consistent with this initiative as an acceptable approach to help minimize contamination. The NEI 07-07 groundwater protection initiative identifies actions to improve a utility's management and response to instances where the inadvertent release of radionuclides may result in low but detectible levels of plant-related materials in subsurface soils and water and describes an acceptable site groundwater monitoring program. The applicant described the groundwater level and geochemical monitoring that will take place during construction and plant operations. Consistent with NEI 07-07, the applicant will establish an on-site ground water monitoring program in the COLA to ensure timely detection of inadvertent radiological releases to ground water. The applicant states in the SSAR that the operational accident monitoring includes quarterly sampling of groundwater from downgradient bedrock and backfill observation wells.

NRC Staff's Technical Evaluation

As described in Sections 2.4.12.4 and 2.4.12.4.5 herein, the applicant provided further rationale (ADAMS Accession Nos. ML17237C084 and ML17286A615) to describe the Clinch River as a hydrologic boundary for CRN Site shallow groundwater. The staff reviewed the applicant's information including: the significant decrease in cavities and contiguous fractures below an elevation of 720 ft NAVD88; CRBRP excavations below the water table and the bottom of the Clinch River which exhibited negligible groundwater inflow; and, potentiometric head relationships developed for nearby DOE studies (Bechtel Jacobs Company, 2011) consistent with CRN Site groundwater gradients indicating that the Clinch River is a hydrologic boundary. Based on staff's review of the site-specific information provided by the applicant and information contained in DOE studies, the staff found the applicant's provided rationale to be acceptable.

During the April 24-27, 2017 audit, the staff requested that the applicant clarify the SSAR reference to the NEI 07-07 groundwater initiative for evaluation of monitoring and safeguard requirements at the time of the proposed plant operation. The applicant included this information in the SSAR (ADAMS Accession No. ML17158B342). Before the start of operations, the applicant will select observation wells to be included in the monitoring program based on well condition, the well position relative to the proposed plant site and adjacent wells, and the well location relative to construction and plant operations. The applicant will also monitor field parameters (pH, temperature, specific conductance, oxidation-reduction potential, and dissolved oxygen), major cations and anions, total dissolved solids, silica, and additional water quality parameters as needed.

As discussed in Section 2.4.12.4.4 herein, radionuclides characteristic of past ORR activities have been identified as being present from TDEC sampling of CRN Site wells (TDEC, 2016). While NEI 07-07 identifies applicant actions necessary for implementation of a timely and effective ground water protection program, the presence of pre-existing radionuclide concentrations on the CRN Site would make determination of a potential accidental release inconclusive or indeterminate without initial background concentrations to differentiate existing concentrations from accidentally released radionuclide concentrations.

Consistent with the 10 CFR 20.1406 "Minimization of contamination", the staff identified **COL Action Item 2.4-3** to address future site characterization data, groundwater monitoring plans and to minimize the potential for release of contamination from accidental releases.

COL Action Item 2.4-3

> An applicant for a combined license (COL) or construction permit (CP) that references this early site permit will establish, as part of its plan to minimize contamination in accordance with 10 CFR 20.1406, a baseline for background radionuclide concentrations.

2.4.12.4.9 Subsurface Hydrostatic Loading and Dewatering

Information Submitted by the ESP Applicant

The applicant developed two two-dimensional groundwater profile models along the geologic strike (principal flow direction) of the bedding planes to estimate maximum groundwater levels. Both within the Chickamauga Group, the northern site profile incorporated the Fleanor Shale and the southern site profile, the Benbolt Formation. The applicant based the model parameters primarily on CRN Site investigations, past CRBRP investigation information, and studies conducted by ORNL in Melton Valley (e.g., Rothschild et al., 1984, Moore and Young, 1992 and SAIC, 1995). The surface elevations along the model profile were extracted from Tennessee Light Detection and Ranging (LiDAR) data sets (Tennessee GIS Clearing House, 2017). From upper top layers to bottom layers, the groundwater profile models consist of six layers with a top fill layer, a soil layer, a highly fractured bedrock layer, and three lower layers of progressively decreasing fracture density. A uniform hydraulic conductivity was used for each of the six layers. A constant head boundary was assigned to the Clinch River with an elevation set at approximately 741.0 ft NAVD88, which is an approximate average of the regulated tail water values of the Melton Hill dam. Below an elevation of 658 ft NAVD88, the model assumed no flow which was based on the trend of decreased fractures and hydraulic conductivity with depth. The applicant calibrated the profiles by varying hydraulic conductivity and recharge within the ranges of the site studies to simulate the observed heads, which were measured during subsurface investigations. Groundwater levels used for the model calibration included 34 observation wells, which included 6 locations consisting of 3-well clusters and 8 locations consisting of 2-well clusters. From the calibrated model, sensitivity of the model parameters were evaluated by adjusting hydraulic conductivity within the range of aquifer test values and precipitation recharge within the ranges of site studies (Bailey and Lee, 1991) to evaluate the maximum groundwater level.

For the post-construction profile models, modifications were made to the pre-construction model including the addition of an extra layer representing granular backfill extending to the base of the reactor technology PPE excavation to determine maximum head at the proposed foundation base. Surface elevations were based on the PPE’s minimum site grade elevation of 821.0 ft NAVD88. Building foundations were simulated as no-flow groundwater model cells and included: a radwaste building with foundation embedment at 818 ft NAVD88; a reactor building foundation embedment elevation selected at approximately 681 ft NAVD88 for the deepest reactor technology PPE excavation and at approximately 770 ft NAVD88 for the shallowest reactor technology PPE excavation; and an auxiliary building at approximately 748 ft NAVD88 for the deepest reactor technology excavation in the PPE and about 770 ft NAVD88 for the shallowest reactor technology excavation in the PPE. Independent of the PPE, the embedment depth of the turbine building was assumed to be at an elevation of 814 ft NAVD88.

Based on the calibrated and post-construction models, the applicant determined a post-construction recharge rate of 8.76 in/year resulting in a range of maximum heads from 807.3 to 816.1 ft, which is consistent with the PPE’s maximum groundwater elevation of 816.1 ft for hydrostatic loading.

NRC Staff's Technical Evaluation

The staff reviewed the applicant's conceptual model, post-construction groundwater model parameters, and model surface elevations and determined that the models acceptably represent the CRN Site topography and hydrogeology. The staff determined that the simulated post-construction conditions for a shallow and deep embedment depth bound the proposed PPE for the CRN Site and acceptably represent maximum groundwater levels based on the resulting model calibration and parameter sensitivity simulations.

The maximum measured water level during CRN Site monitoring (September 2013 through March 2014) was 800.3 ft at OW-201U. Staff notes that the monitoring period includes the relatively wet year of 2013 when the total annual rainfall was approximately 37 percent higher than the area's average annual rainfall (University of Tennessee, 2017). Staff notes that maximum observed ground levels during the September 2013 to August 2015 monitoring period would be relatively high and near an overall maximum for the CRN Site due to the relatively high precipitation during the monitoring period. Based on the applicant's groundwater modeling results, which are consistent with water level observations over the monitoring period, staff finds that the applicant's determination of the maximum groundwater level is acceptable.

2.4.12.4.10 Construction Dewatering

Information Submitted by the ESP Applicant

The applicant described dewatering plans based on the CRBRP excavation studies (BRC, 1985) which included potential horizontal gravity drains in excavated rock faces and sump pumping around the base of the excavation. The excavation of the CRBRP power block to elevation 714 ft NGVD29 (713.6 ft NAVD88), or below the water table and 6 ft below the invert of the Clinch River, showed no evidence of continuous groundwater flow into the excavation (BRC, 1985). The applicant noted that localized grouting may be necessary if high groundwater flows are encountered. The applicant stated that these methods localized to the power block area coupled with the Clinch River forming a shallow groundwater system boundary on the east, south, and west side of the site, would limit the impact of dewatering to the immediate vicinity of the power block excavations.

In a response (ADAMS Accession No. ML17237C084) to the staff's request for supplemental information related to dewatering (ADAMS Accession No. ML17341A276), the applicant provided further bases for their conclusion that there would be no anticipated impacts to offsite groundwater users and included this information in the SSAR. As discussed in Section 2.4.12.4.5, TDEC studies (TDEC, 2016) suggested potential hydraulic communication across the Clinch River based on the response of Hood Ridge area wells to the CRN Site pumping test (Figure 2.4.12-2). The applicant stated that the Hood Ridge area wells are approximately 3,000 ft away from the CRN Site pump test well while the Clinch River is approximately 1,200 ft from the pump test well, far beyond the radius of pumping well influence of approximately 150 ft. The applicant stated that CRN Site observation wells near the Clinch River show an upward gradient (Figure 2.4.12-4) while wells in upland areas show downward gradients. This indicates that the Clinch River is a hydrologic sink for the shallow groundwater system of the site, consistent with the findings in past DOE studies (Bechtel Jacobs Company, 2011) (Figure 2.4.12-5). The applicant noted groundwater occurs primarily within 65 ft of the surface, with negligible groundwater flow below 714 ft NAVD88 due to sharp reductions in fracture and cavity porosity (permeability) with depth. This is consistent with CRBRP investigations (Drakulich, 1984).

NRC Staff's Technical Evaluation

The applicant evaluated potential dewatering using an estimated configuration of the nuclear island and support structures. Staff evaluated the CRN Site data including the pumping test data, TDEC reports (TDEC, 2016), and relevant DOE studies (Bechtel Jacobs Company, 2011) and determined that the applicant's evaluation of dewatering effects are acceptable.

Staff noted that the applicant will coordinate proposed dewatering actions associated with CRN Site construction activities with TDEC. The applicant described anticipated dewatering rates consistent with the negligible rates observed during the CRBRP excavation activities (Drakulich, 1984). However, the applicant acknowledged that localized grouting may be necessary if groundwater flow into the excavation is higher than anticipated. The staff determined that the applicant's estimates of dewatering effects are consistent with CRN Site and CRBRP site characterizations and are therefore acceptable.

2.4.12.5 *Post Early Site Permit Activities*

The groundwater characterization and monitoring plan developed at the COL stage is being tracked as **COL Action Item 2.4-3**. As discussed in SER Subsection 2.5.4.4.5, "Excavation and Backfill" herein, the review of the CRN Site backfill characteristics is being tracked as **COL Action Item 2.5-8**.

2.4.12.6 *Conclusion*

The staff reviewed the application and confirmed that the applicant has demonstrated that the groundwater characteristics have no safety-related impact on the CRN Site and that there is no outstanding information required to be addressed in the SSAR related to this section.

As set forth above, the applicant has provided sufficient information pertaining to groundwater at the CRN Site. Further, the applicant has considered the most severe natural phenomena that have 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, in establishing site characteristics pertaining to groundwater that are acceptable for design purposes. Therefore, the staff concludes that the applicant has met the requirements related to groundwater in 10 CFR 52.17(a)(1)(vi), 10 CFR 100.20(c) and 10 CFR 100.23(d). The COL applicant will address **COL Action Items 2.4-3 and 2.5-8**.

2.4.13 Accidental Releases of Radionuclides in Ground and Surface Waters

2.4.13.1 *Introduction*

SSAR Section 2.4.13, "Accidental Releases of Radioactive Liquid Effluents in Ground and Surface Waters" considers the potential effects of relatively large accidental releases from systems that handle liquid effluents generated during normal plant operations. Such releases would have relatively low levels of radionuclides but could be large in volume. Normal and accidental releases are considered in the applicant's environmental report. The accidental release of radionuclides in ground and surface waters is evaluated based on the hydrogeological characteristics of the site that govern existing uses of groundwater and surface water and their known and likely future uses consistent with NUREG-0800 (SRP) Section 2.4.13, "Accidental Releases of Radioactive Liquid Effluents in Ground and Surface Waters."

The source term from a postulated accidental release is reviewed under SRP Section 11.2, "Liquid Waste Management" following the guidance in Branch Technical Position (BTP) 11-6, "Postulated Radioactive Releases Due to Liquid-containing Tank Failures." The source term is determined from a postulated release from a single tank outside of the containment. The results of a consequence analysis are evaluated against SRP Section 11.2 and BTP 11-6 guidance and effluent concentration limits (ECLs) of Table 2, Column 2, in 10 CFR Part 20, Appendix B, "Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage." Under SRP guidance, the ECLs of 10 CFR Part 20, Appendix B, are applied as acceptance criteria only for the purpose of assessing the acceptability of the results of the consequence analysis, and are not intended for demonstrating compliance with the public dose limit in 10 CFR 20.1301 and 10 CFR 20.1302.

Section 2.4.13 herein presents an evaluation of the following specific areas: (1) alternate conceptual models of the hydrology that reasonably bound hydrogeological conditions at the site inasmuch as these conditions affect the transport of liquid radionuclide effluent in the ground and surface water environment; (2) bounding set of plausible surface and subsurface pathways from potential points of an accidental release to determine the critical pathways that may result in the most severe impact on existing uses and known and likely future uses of ground and surface water resources in the vicinity of the site; (3) ability of the groundwater and surface water environments to delay, disperse, dilute, or concentrate accidentally released liquid radionuclide effluent during its transport; and (4) any additional information required by the regulations discussed below in the Regulatory Basis subsection.

2.4.13.2 *Summary of Application*

This section provides the applicant's analysis of an accidental liquid release of effluents or radioactive wastes into the groundwater at the CRN Site. The applicant's postulated accident scenario is combined with the conceptual site model to evaluate potential impacts to receptors should a catastrophic tank rupture occur during plant operations and instantaneously release radionuclides to the groundwater environment. The applicant's resulting calculated concentrations that would reach the potential surface water receptors are then compared to the ECLs in 10 CFR Part 20, Appendix B. The applicant's calculated results are then assessed using the unity rule where the sum of the ratios of the calculated concentrations to the corresponding ECLs for all radionuclides in the effluent release may not exceed one. Further, the dose limit to a member of the public in the nearest unrestricted area must meet 10 CFR 20.1301 and 10 CFR 20.1302 requirements.

2.4.13.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for the pathways of liquid effluents in ground and surface waters, and the associated acceptance criteria, are described in SRP Section 2.4.13.

The applicable regulatory requirements for liquid effluent pathways for groundwater and surface water are as follows:

- 10 CFR 20.1301, 10 CFR 20.1302, and Table 2, Column 2, and Note 4 of Appendix B to 10 CFR Part 20, as they relate to radioactivity in liquid effluents released to unrestricted areas and doses to offsite receptors located in unrestricted areas.

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

- 10 CFR Part 100, as it relates to identifying and evaluating hydrological features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

The staff also used the acceptance criteria identified in SRP Section 2.4.13:

- Alternate Conceptual Models: Alternate conceptual models of hydrology in the vicinity of the site are reviewed.

- Pathways: The bounding set of plausible surface and subsurface pathways from the points of release are reviewed.

- Characteristics that Affect Transport: Radionuclide transport characteristics of the groundwater environment with respect to existing and known and likely future users should be described.

- Consideration of Other Site Related Evaluation Criteria: The applicant’s assessment of the potential effects of site proximity hazards, seismic, and non-seismic events on the radioactive concentration from the postulated tank failure related to accidental release of radioactive liquid effluents to ground and surface waters for the proposed plant site is needed.

- DC/COL-ISG-013, “Assessing the Radiological Consequences of Accidental Releases of Radioactive Materials from Liquid Waste Tanks in Ground and Surface Waters for Combined License Applications” clarifies guidance defining the mechanism of the assumed tank failure, development of the radioactive source term, assumptions and level of conservatism used in the analysis, and approach applied in assessing the radiological impacts. DC/COL-ISG-013 was incorporated into BTP 11-6, Revision 4.

- BTP 11-6, Revision 4, provides guidance in assessing a potential release of radioactive liquids resulting from the postulated failure of a tank and its components, located outside of containment, and effects of the release of radioactive materials at the nearest potable water supply, located in an unrestricted area, for direct human consumption or indirectly through animals, crops, and food processing.

- DC/COL-ISG-014, "Assessing the Radiological Consequences of Accidental Releases of Radioactive Materials from Liquid Waste Tanks in Ground and Surface Waters for Combined License Applications" a revision to SRP Section 2.4.13, which clarifies the radionuclide transport analyses methods in groundwater and surface water through the use of a structured hierarchical approach emphasizing the hydrogeologic conditions that control radionuclide transport.

The staff used current best practices to analyze groundwater transport of radioactive liquid effluents. In addition, the staff compared the hydrologic characteristics described in the application to relevant sections from RG 1.113, "Estimating Aquatic Dispersions of Effluents from Accidental and Routine Reactor Releases for the Purpose of Implementing Appendix I."

2.4.13.4 *Technical Evaluation*

The staff reviewed the SSAR Subsection 2.4.13 submitted by the applicant related to the accidental release of radioactive liquid effluents in ground and surface waters.

2.4.13.4.1 Accident PPE Liquid Effluent Release Source Term

The staff evaluated the applicant's methodology and basis for developing the accident PPE liquid effluent release source term used for the postulated accidental release of radionuclides to the aquifer system (groundwater) at the CRN Site.

Information Submitted by Applicant

The applicant provided radionuclides and their associated activities to create a composite or surrogate source term at the CRN Site for developing the accident PPE liquid effluent release source term in SSAR Table 2.0-5. In the postulated accidental release of radionuclides to the groundwater, the applicant assumed that a 10,000-gal liquid radwaste tank would rupture and release 80 percent (8,000 gal) instantaneously into the groundwater system at a point outside of containment. No credit was taken for the travel time and the associated decay of radionuclides in traveling from the Liquid Waste Management System (LWMS) to the saturated groundwater flow system, nor was credit taken for any mitigating design features. During an April 24-27, 2017 audit (ADAMS Accession No. ML17341A276), the applicant further explained their methodology and basis for evaluating source term information submitted by vendors from the four light-water-cooled small modular reactor (SMR) technologies considered for the postulated accidental release of radionuclides to the groundwater. The staff noted that the failed fuel fraction used by the applicant for the accident PPE liquid effluent source term was 1 percent while the radionuclide concentrations and total inventory of radioactive materials based on BTP 11-6 guidance suggests a 0.12 percent failed fuel fraction of the fuel producing power in a pressurized-water reactor. The applicant provided supplemental information on the basis for developing the accident PPE liquid effluent release source term (ADAMS Accession No. ML17167A150).

NRC Staff's Technical Evaluation

The staff reviewed the applicant's methodology and basis for developing the accident PPE liquid effluent release source term. The staff reviewed source term information from two vendors with preliminary designs that the applicant stated did not include features to mitigate a postulated accidental liquid release of radionuclides. Therefore, a site-specific analysis would be performed in the COLA for these two vendor designs. The staff also reviewed the applicant's comparison of source term information from these vendors and justification for selection of radionuclides and activities in the surrogate plant to develop the accident PPE liquid effluent release source term. Further, the staff reviewed the applicant's comparison of the accident PPE liquid effluent source term at the CRN Site to that approved by the NRC in the Public Service Enterprise Group ESP, which considered four large light-water (pressurized- and boiling-water) reactor designs. Based on the above, the staff found that the applicant developed an accident PPE liquid effluent release source term that was reasonable to evaluate a postulated accidental release of radionuclides to the groundwater at the CRN Site. The calculated exposure pathway dose resulting from the postulated accidental liquid effluent release of radionuclides to the groundwater at the CRN Site is evaluated by the staff in Section 2.4.13.4.6 of this SER.

2.4.13.4.2 Receptors, Primary Conceptual Model, and Alternative Conceptual Model

The applicant considered a receptor at a point beyond the site boundary where the applicant has no administrative control. For the release, the applicant developed a primary conceptual model to evaluate the postulated radionuclide release and considered an alternative conceptual model for the release.

Information Submitted by Applicant

The nearest boundary where the applicant has no administrative control is the right bank (looking downstream) of the Clinch River. There are no surface water users at this location. The applicant noted that the nearest surface water intake is the City of Oakridge's West End Water Treatment Plant (WEWTP), which was idled in September 2014. The WEWTP is located near the northwestern CRN Site boundary. During an April 24-27, 2017 audit (ADAMS Accession No. ML17341A276), the applicant provided further information on the WEWTP, stating that the City of Oakridge has no plans to make use of the plant but retains the surface water permit from the State of Tennessee (ADAMS Accession No. ML17157B212).

For the primary conceptual model, the applicant assumed that the radionuclides released from the radwaste tank travel through the surface and into the backfill and pervasively fractured bedrock before reaching the Clinch River. The applicant assumed the shortest travel distance (1,400 ft) from the release point to the Clinch River. As an alternative conceptual model, the applicant considered groundwater discharge directly to surface drainages and runoff into the surface waters of the Clinch River; however, the applicant considered this conceptualization less conservative than the primary conceptual model due to added dilution from surface runoff before exiting the applicant's administrative control area. The applicant stated that the added dilution would result in radionuclide concentrations lower than those of the primary conceptual model.

The applicant stated that shallow groundwater flow underneath the Clinch River and resulting exposure to water users across the river is very unlikely based on: 1) the absence of cavities and contiguous fractures below elevation 720 ft NAVD88; 2) the head relationships observed at the Melton Valley Exit Pathway monitoring wells (Bechtel Jacobs Company, 2011); and, 3) the observed vertical hydraulic gradients that demonstrate that the Clinch River acts as a hydrologic sink. As further corroboration, the applicant stated that:

- There is no evidence of contiguous cavities or fractures originating from the power block area and extending below the Clinch River tributary of the Watts Bar Reservoir based on geologic core analysis from CRN Site subsurface investigations;

- The CRBRP excavation, completed to an elevation of 714 ft NGVD29 (713.6 ft NAVD88) and 6 ft below the invert elevation of the Clinch River tributary of the Watts Bar Reservoir, showed no evidence of any continuous groundwater flow; this is likely due to an absence of cavities and continuous fractures below elevation 720 ft NAVD88;

- Only five percent of the observed cavities fall below elevation 718.4 ft NAVD88 with the average elevation of observed cavities being 782.6 ft NAVD88; and,

- An analysis of site-specific geologic core analysis, fracture frequency analysis, and groundwater vertical gradient data provides no evidence supporting a pathway for radionuclide transport occurring underneath the Clinch River tributary of the Watts Bar Reservoir within the shallow groundwater system.

NRC Staff's Technical Evaluation

The staff reviewed the primary conceptual model assuming that the radionuclide concentrations travel through the most permeable material of the backfill and pervasively fractured rock. The flow through these upper units is consistent with groundwater flow directions based on CRN Site monitoring data and studies which show that greater than 99 percent of the groundwater flow occurs in the upper 250 to 300 ft of the aquifer material within the study area (Tucci, 1992 and USGS, 1986).

Staff reviewed the applicant's alternative conceptual model assuming direct discharge to surface water, seeps, and springs, and found the applicant's conclusion that there would be lower radionuclide concentrations (less conservative) due to additional dilution from runoff to be acceptable. Because the seeps and springs flow primarily during wet periods, the applicant's assumption that additional dilution would take place due to precipitation runoff is acceptable.

As described above and discussed in Section 2.4.12.4 and Section 2.4.12.5 herein, the applicant expanded upon the bases for the Clinch River as a CRN Site hydrologic boundary by providing site-specific supporting information (ADAMS Accession Nos. ML17237C084 and ML17286A615). The staff reviewed and evaluated information related to the CRN Site including pumping test results, groundwater gradients, previous TVA (Drakulich, 1984) and DOE (Bechtel

Jacobs Company, 2011), TDEC (TDEC, 2016) studies, and site boring logs. Staff confirmed that the SSAR's site-specific description of the hydraulics, hydrogeology and boring information described as the basis for the Clinch River as a CRN Site boundary is acceptable.

2.4.13.4.3 *Radionuclide Transport Analysis and Estimation of Initial Concentrations*

The applicant conducted a radionuclide transport analysis to estimate the concentrations and resulting radiometric dose from the postulated release scenario.

Information Submitted by Applicant

The applicant based the radionuclide transport analysis on methodology described in NUREG/CR-3332, “Radiological Assessment, A Textbook on Environmental Dose Analysis." Using this methodology, the applicant derived the dilution factor as a function of time to find the minimum dilution factor to yield the maximum concentration for the instantaneous radwaste tank release to the Clinch River. The dilution factor, D_L, is calculated as:

$$D_L = 1/\left[\frac{V_T}{Q} \cdot \frac{(x + \frac{U \cdot t}{R_d})}{4 \cdot \sqrt{\frac{\pi \cdot Dx \cdot t^3}{R_d}}} \cdot \exp\left(-\frac{\left(x + \frac{U \cdot t}{R_d}\right)^2}{\frac{4 \cdot Dx \cdot t}{R_d}} - \lambda t\right)\right]$$

Equation 2.4.13-1

Where:

D_L = dilution factor [C_0/C]
V_T = tank volume [L^3]
Q = flow rate of river [L^3/T]
x = distance [L]
U = groundwater pore velocity [L/T]
t = time [T]
R_d = retardation coefficient
D_x = α_L*U [L^2/T]
λ = radionuclide decay constant ($\lambda = \ln(2)/T_{1/2}$) [1/T]
$T_{1/2}$ = radionuclide half-life [T]
α_L = longitudinal dispersivity [L]

The equation accounts for advection, dispersion, sorption (retardation), and radionuclide decay in addition to dilution due to the groundwater mixing with the Clinch River at the point of release. The applicant introduced conservatism by decaying terms to 50 years to allow the peak activities of the daughter products to be used in the dose calculations. Further, time to peak concentrations were evaluated by the applicant based on a transport travel time to the postulated receptor of less than one year for all peak concentrations, regardless of when the time to peak concentrations were calculated. This approach overestimates the total activity that would be released, as the parent radionuclide activities are not decreased while daughter products are increased. As described previously, all radionuclides except Nb-93m and U-235 reach peak activity within 50 years. Nb-93m has a relatively short (14 year) half-life and will not accumulate, thereby contributing negligible concentrations to the final estimated concentrations. U-235, which occurs from the decay chain of NP-239 -- Pu-239 -- U235m -- U-235, would not occur for thousands of years and would be on the order of a million times lower than the ECL. As such, the U-235 will also have negligible effects on the final estimated concentrations.

NRC Staff's Technical Evaluation

Staff reviewed the applicant's approach to estimating radionuclide transport in groundwater. The applicant used analytical methods in NUREG/CR-3332 developed to simulate groundwater flow and radionuclide transport. The analytical equations consider the processes of advection, dispersion, sorption and decay during the groundwater transport and dilution due to surface water bodies intercepting the groundwater. Staff reviewed available publications outlining the methodology (Taylor and Guha, 2017) used in NUREG/CR-3332 and confirmed that the radionuclide transport equations presented in SSAR Section 2.4.13, as used by the applicant, were applied correctly to the radionuclide analysis. Staff notes that the applicant applied a tank volume fraction ($\boldsymbol{f}$) of (0.80) to the resulting radionuclide concentrations per BTP 11-6 while the initial concentrations assumed a 10,000-gal tank. The applicant's methodology of assuming these initial concentrations results in a conservative estimate of the concentrations such that the dilution factor, D_L, is as follows:

$$D_L = 1/\left[\frac{\boldsymbol{f}\cdot V_T}{Q}\cdot\frac{\left(x+\frac{U\cdot t}{R_d}\right)}{4\cdot\sqrt{\frac{\pi\cdot Dx\cdot t^3}{R_d}}}\cdot \exp\left(-\frac{\left\{x+\frac{U\cdot t}{R_d}\right\}^2}{\frac{4\cdot Dx\cdot t}{R_d}}-\lambda\cdot t\right)\right]$$

Equation 2.4.13-2

Where the Equation 2.4.13-2 terms are as previously described in Equation 2.4.13-1 and $\boldsymbol{f}$ is defined as the tank volume fraction (0.80) released to the aquifer.

As discussed in the CRN Site audit report (ADAMS Accession No. ML17341A276), the applicant provided a spreadsheet in native format incorporating radionuclide transport analysis calculations consistent with guidance NUREG-3332. The staff performed confirmatory analyses of the applicant's approach to estimate radionuclide transport concentrations in groundwater for comparison with SSAR Table 2.4.13-5. In the staff's confirmatory analysis, six radionuclides were selected for sampling: H-3, C-14, Co-60, Tc-99, I-129, and Cs-137. Dilution factors, D_L, were calculated with sorption ($R_d > 0$) and without sorption ($R_d = 1$) for each of the six radionuclides and compared with the equations, parameters, and assumptions used in the applicant's calculations. The minimum D_L (most conservative value) is determined by iteratively varying the time (t) in Equation 2.4.13-2 to find the smallest (most conservative) value of D_L that produces the largest radionuclide concentrations at the postulated receptor location where the ECL ratios and exposure pathway doses to a member of the public are calculated. Based on the staff's review of NUREG/CR-3332, the applicant's implementation of guidance methods, and the applicant's site conceptualization, the staff found the applicant's methodology and approach acceptable.

Based on the PPE developed with input from the four vendor technologies being considered in the SSAR, the applicant developed initial concentration estimates based on a failed fuel fraction of 1 percent (ADAMS Accession No. ML17341A276). This is conservative because BTP 11-6 guidance states that a failed fuel fraction of 0.12 percent is sufficient for derivation of a source term. The applicant also conservatively assumed that parent and daughter products were at peak concentrations during the initial release, which maximized the concentrations of the source term for the postulated release. The applicant provided acceptable clarification of the basis for the accidental liquid effluent release source term and included this information in the SSAR (ADAMS Accession Nos. ML16340A258 and ML17178A330). Based on the applicant's conservative assumptions of limited dilution of radionuclides, conservative source term release, and initial concentration estimates, the staff finds the applicant's evaluation of radionuclide transport acceptable.

2.4.13.4.4 *Input Parameters*

The applicant used the transport parameters as described below to determine the dilution factor, D_L, as defined in Equation 2.4.13-1, for the postulated accidental release scenario.

Information Submitted by Applicant

The applicant used a tank release volume, V, of 8,000 gal based on a release of 80 percent of a 10,000-gal radwaste tank. For the groundwater pore velocity, U, a value (3.9 ft/day) was calculated as follows:

$$U = -\frac{K}{n_e}\frac{dH}{dx}$$

Where the hydraulic conductivity, K, of 2.6 ft/day was based on the CRN Site aquifer pumping test, the effective porosity ,n_e, of 0.0467 was derived from ORR studies (ORNL, 1996 and ORNL, 1997) and the hydraulic gradient, $\frac{dH}{dx}$, of 0.07 was calculated as the mean from CRN Site data.

The retardation coefficient (Rd) was calculated using the equation:

$$Rd = 1 + \frac{\rho_b K_d}{n_e}$$

The aquifer bulk density, ρ_b, was selected as the lowest value (1.4 g/cm^3) derived from laboratory analysis of site samples for faster, and therefore more conservative, transport travel times. The applicant noted that these lower, ρ_b, values neglect the higher values (approximately 2.7 gm/cm^3) based on measurements within the primary transport material of the weathered/fractured bedrock for added conservatism. Site-specific distribution coefficients, K_d, were used where available, others were based on the available literature, many of which were values taken from the Oak Ridge National Laboratory studies (e.g., Bechtel Jacobs Company, 1998) performed on land adjacent to the CRN Site. For Yttrium (Y), no site-specific value was available; however, Y is a lanthanide, and is often associated with the lanthanide Cerium (Ce) (NUREG/CR-5512, "Residual Radioactive Contamination from Decommissioning, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose). Therefore, the site-specific geometric K_d mean for Ce (54 ml/g) was used. If no K_d value was available for a specific radionuclide, the applicant substituted a conservative value of zero (no retardation). The effective porosity, n_e, used was based on ORR studies, as described above (0.0467). The values of K_d based on laboratory testing of CRN Site samples are listed in SSAR Table 2.4.13-4.

Dependent on the field scale (Gelhar et al., 1992), longitudinal dispersivity was estimated by the applicant using a relationship scaled between dispersivity (α_L) (in meters) and transport distance (in meters) based on Xu and Eckstein (Xu and Eckstein, 1995):

$$\alpha_L = 0.83(log_{10}x)^{2.414}$$

Where x is 426.7 m (1,400 ft) or the distance from the edge of the power block to the edge of the Clinch River. The dispersivity, α_L, was estimated as 8.57 m (28.1 ft). The equation above weighs field study measurements according to reliability (Xu and Eckstein, 1995). The data with the highest reliability are weighed more than those of lower reliability as ranked by Gelhar et al. (Gelhar et al., 1992).

The applicant selected half-lives for the radionuclides based on available studies (Xu and Eckstein, 1995, ORNL 1996) to determine the decay constant for each radionuclide.

The applicant used a value of 400 cfs for the value of flow, Q, in the Clinch River to estimate radionuclide dilution. The applicant stated that the value of 400 cfs is a minimum flow based on the installation of an upstream bypass at the Melton Hill Dam to maintain hydrothermal requirements for operation of the proposed units.

NRC Staff's Technical Evaluation

The staff reviewed the input parameters used for the transport analysis. The tank release volume, V, represented by a release of 80 percent of the tank volume was based on the PPE and is consistent with the guidance of BTP 11-6, Revision 4. For calculating the groundwater pore velocity, U, the applicant used values of hydraulic conductivity derived from the aquifer test data for wells along the geologic strike. Using the hydraulic conductivities derived along the geologic strike is consistent with conservative assumptions of the highest hydraulic conductivities (i.e., a fast travel time with less decay), and the preferred groundwater flow path. The relatively low effective porosity (0.0467) selected from nearby ORR studies (ORNL, 1996 and ORNL, 1997) is also conservative and contributes to a relatively fast groundwater velocity, as the groundwater pore velocity is inversely proportional to the porosity. For the hydraulic gradient, $\frac{dH}{dx}$, the applicant utilized a mean of 0.07 ft/ft for the CRN Site, as derived from site-specific water level measurements. Based on these values, the applicant estimated travel time from the proposed power block area to the Clinch River as approximately 359 days. The staff reviewed the applicant's selection of parameter values and determined that the groundwater matrix pore velocity estimated by the applicant was based on plausible and conservative parameters is therefore acceptable.

Staff reviewed the input parameters used in the calculation of retardation coefficients. Where available, the applicant used site-specific values for the parametric components of the retardation equation. The bulk density, ρ_b, values were derived from shallow site samples which were the lowest values while higher values were derived from bedrock which is the primary aquifer transport material at the CRN Site. Distribution coefficients, K_d, were derived from laboratory tests on site-specific CRN Site samples with the exception of Yttrium. The K_d for Cerium, comparable to a lanthanide like Yttrium, was used for Yttrium as no site-specific value was measured for Yttrium. The effective porosity used was based on testing performed on the same or similar aquifer materials at the ORR as are found at the CRN Site (Dorsch and Katsube, 1999 and Dorsch and Katsube, 1996). Based on the staff's review of the parameters and methods used to determine the retardation coefficients, the staff finds that the applicant's calculation methods are based on plausible and conservative parameters and are therefore acceptable.

Dispersivity is particular to a specific site (field) scale for predicting the subsurface movement and spreading of the radionuclides. Field scale is defined as the distance traveled from the source for ambient conditions, or the distance between the injection well and the observation well for the case of an induced flow configuration (Gelhar et al., 1992). For the CRN Site, the "injection point" is represented as the release point and the "observation well" is the postulated receptor location. The applicant applied methods that account for the CRN Site scale given the 1,400 ft distance from the power block to the Clinch River resulting in a dispersivity of 28.1 ft. The staff reviewed the dispersivity equation and determined that the weighted field scale measurements (Xu and Eckstein, 1995) relative to the measurement reliability (Gelhar et al., 1992) are reasonable. Based on the staff's evaluation of the studies (Gelhar et al., 1992 and Xu and Eckstein, 1995) used by the applicant, and the scale applied to the dispersivity equation, staff finds the applicant's dispersivity value of 28.1 ft acceptable for the CRN Site.

The staff reviewed the studies and reports used for the applicant's characterization of radioactive decay and subsequent calculation of radionuclide half-life and resulting decay constants, and finds the applicant's resulting decay constants is consistent with published literature (ORNL, 1996, ADAMS Accession No. ML071100143, and ICRP, 2008) and is therefore acceptable.

A summary of the applicant's radionuclide transport equation parameters used in Equation 2.4.13-2 are included in the table below:

Table 2.4.13-1. Summary of Equation 2.4.13-2 Radionuclide Transport Parameters.

Parameter	Calculation	Value	Units
Source term tank volume (V_T)	-	10,000	gallons
Tank release volume (V)	$V = f \cdot V_T$	8.000	gallons
Tank volume fraction (f)	-	0.8	-
Hydraulic conductivity (K)	-	2.6	feet per day
Effective porosity (η_e)	-	0.0467	-
Hydraulic gradient (dh/dx)	-	0.07	feet per foot
Groundwater velocity (U)	$U = \frac{K}{\eta_e} \cdot \frac{dh}{dx}$	3.90	feet per day
Distance (L)	-	1,400	feet
Longitudinal dispersivity (α_L)	$\alpha_L = 0.83(log_{10}L)^{2.414}$	28.1	feet
Longitudinal dispersion coefficient (D_x)	$D_x = \alpha_L \cdot U$	109.6	square feet per day
Flow rate of Clinch River (Q)	-	400	cubic feet per second
Bulk density (ρ_b)	-	1.4	gram per cubic centimeter
Retardation factor (R_d)	$R_d = 1 + \frac{\rho_b \cdot Kd}{\eta_e}$	Calculated per Kd (SSAR Table 2.2.13-4)	-
Decay constant (λ)	$\lambda = \frac{\ln(2)}{T_{\frac{1}{2}}}$	Calculated per $t_{\frac{1}{2}}$ (SSAR Table 2.2.13-5)	per day

Where applicable, an appropriately consistent metric equivalent of the parameters above were used in Equation 2.4.13-2 calculations for the resulting radionuclide concentrations (SSAR Table 2.4.13-4). The staff determined that the parameters used by the applicant for the calculation of radionuclides at the postulated receptor location are acceptable.

2.4.13.4.5 Radionuclide Concentrations at the Clinch River

Based on the postulated release, the applicant calculated dilution factors and concentrations with sorption ($K_d \neq 0$) and without sorption ($K_d = 0$) to estimate the radionuclide concentrations at the CRN Site boundary at the Clinch River.

Information Submitted by Applicant

The applicant's calculated minimum dilution factors and associated maximum concentrations in the Clinch River assume no sorption exceeded the ECLs in 10 CFR Part 20 Appendix B, for several radionuclides. Accounting for sorption and retardation, the applicant's calculations resulted in estimated concentrations at the Clinch River site boundary below the ECLs for all radionuclide isotopes.

For the radionuclide release, the applicant assumed that the release to groundwater was instantaneous with no credit for mitigating design features and that all radionuclide and associated daughter product concentrations were at their peak. The flow in the Clinch River was assumed to be 400 cfs which represents the minimum upstream release requirement for the Melton Hill Dam reservoir operating policy (TVA, 2014). The applicant noted that the value of 400 cfs is 4.4 times lower than the minimum daily average flow rate over one year and 12.2 times lower that the daily average (4,876 cfs) flow rate. The rate of 400 cfs assumes no tributary or groundwater inflows between the Melton Hill Dam and the CRN Site, (a distance of approximately 5 river miles) which would increase the downstream flow rate and dilution capability of the Clinch River between dam and the CRN Site. The applicant stated that the lower assumed flow rate would result in relatively higher radionuclide concentrations/doses at the receptor location. The applicant stated that the distribution coefficients with no site-specific distribution coefficients were assumed to be zero resulting in shorter travel times (i.e., less decay) towards the receptor location.

NRC Staff's Technical Evaluation

The staff reviewed the applicant's radionuclide concentration calculations for the Clinch River and requested clarification of the applicant's methodology described in the SSAR. During the April 24-27, 2017, audit (ADAMS Accession No. ML17341A276), the applicant provided clarification on the methodology for the calculated concentrations based on NUREG/CR-3332. The applicant referred to a technical publication (Taylor and Guha, 2017), describing the applicability of the NUREG/CR-3332 equations as used by the applicant. The staff reviewed the applicant's methodology using NUREG/CR-3332 and Taylor and Guha (2017) and performed independent confirmatory analyses of the applicant's methods and calculations. Based on the staff's review and confirmatory analysis, the staff determined that the applicant's methodology and resulting radionuclide concentration calculations are consistent with the staff's results and are therefore acceptable.

The applicant states in the SSAR that 400 cfs is the minimum reservoir-release requirement for the Melton Hill Dam (TVA, 2014). Staff determined that in addition to groundwater inflow to the Clinch River, tributaries along the 4.5 river miles between Melton Hill Dam and the CRN Site contribute additional flow to the Clinch River before reaching the site, thereby increasing the minimum flow. Correspondingly, this increased flow would increase the radionuclide dilution and lower the resulting concentrations at the postulated receptor location. Therefore, the applicant's assumption of 400 cfs for the Clinch River minimum flow rate near the CRN site is acceptable for the characterization of the resulting radionuclide dilution at the postulated receptor location because it is conservative.

2.4.13.4.6 Dose Evaluation

The applicant is required to meet the 10 CFR 20.1301 dose limit for a member of the public in addition to meeting 10 CFR Part 20, Appendix B, Table 2, ECLs.

Information Submitted by Applicant

The applicant used the LADTAP II computer code to calculate exposure pathway dose associated with the accidental release using the radionuclide concentrations at the Clinch River site boundary. To calculate the Total Effective Dose Equivalent (TEDE) required to satisfy 10 CFR 20.1301, the applicant modified the dose conversion factors within the LADTAP II code using the dose-conversion factors for ingestion from Federal Guidance Report (FGR) 11, and the dose conversion factors for ground deposition and immersion from FGR 12 because the LADTAP II code calculates total body and organ doses, not TEDE. The applicant evaluated the following exposure pathways for consideration of the resulting estimated dose:

- Consumption of the water, fish and invertebrates from the Clinch River;
- Consumption of vegetables, milk, and meat affected by irrigation water from the Clinch River; and,
- Boating, swimming, and shoreline activities on the Clinch River.

The applicant's primary inputs and assumptions are as follows:

- No dilution is credited beyond the calculated radionuclide concentrations at the postulated receptor location (SSAR Table 2.4.13-5);
- Transit time to dose receptors is assumed to be zero;
- Irrigation rate is assumed to be 1 inch/week, which bounds the actual rate near the proposed site of 0.24 inch/week (SSAR Reference 2.4.13-13);
- Consumption and usage rates are the default values for the maximally exposed individual from RG 1.109, Table E-5, while assuming that the time spent boating and swimming are the same as that for shoreline activities;
- Exposure duration is assumed to be 1 year;
- TEDE dose conversion factors for ingestion were obtained from the FGR 11 (SSAR Reference 2.4.13-14); and,
- TEDE dose conversion factors for ground deposition and immersion were obtained from FGR 12 (SSAR Reference 2.4.13-15).

The resulting total annual dose from all exposure pathways was 93 millirem (mrem) TEDE to an adult receiving the maximum dose which is below the 100 mrem TEDE dose limit in 10 CFR 20.1301.

NRC Staff's Technical Evaluation

The staff reviewed the applicant's dose evaluation based on the estimated radionuclide calculations for the postulated accidental release. The staff reviewed the applicant's modification of the dose conversion factors within the LADTAP II computer code and found the modifications to be reasonable and acceptable for calculation of the TEDE. The staff reviewed the exposure pathways and found them to be consistent and acceptable for calculating the dose for a postulated accidental liquid effluent release of radionuclides to the groundwater at the CRN Site based on the applicant's inputs and assumptions described in SSAR Section 2.4.13.4. During the April 24-27, 2017 audit (ADAMS Accession No. ML17341A276), the staff discussed the maximum dose estimate with the applicant noting that the calculated annual dose of 93 mrem TEDE is close to the dose limit of 100 mrem TEDE in 10 CFR 20.1301. In response, the applicant noted several conservatisms in the radionuclide calculations that resulted in the maximum dose estimate including:

- A source term based on a 1 percent failed fuel fraction where 0.12 percent is suggested within NRC guidance (BTP 11-6);
- A catastrophic tank release assuming no credit for mitigating design features;
- An instantaneous and direct release of the tank contents to the groundwater flow system;
- Assumed minimal Clinch River flow (400 cfs) for dilution, a flow which has not occurred during the period of current protocols for reservoir operations (TVA, 2014);
- A minimal radionuclide travel distance from the release point to the Clinch River;
- Incorporation of transport parameters that minimize radionuclide travel time (and radionuclide decay) to maximize radionuclide concentrations at the postulated receptor; and,
- Assumption that all radionuclides (including daughter products) are at peak concentrations upon release.

The staff agrees that the above inputs and assumptions result in conservative radionuclide calculations for deriving the estimated dose for the postulated accidental release. As described in the CRN Site audit report (ADAMS Accession No. ML17341A276), the staff noted that Technetium (Tc)-99 is identified as a radionuclide in the normal PPE liquid effluent release source term, but is excluded in the accidental PPE liquid effluent release source term in SSAR Table 2.0-5. Although Tc-99 is excluded in SSAR Table 2.0-5, the applicant considered Tc-99 in SSAR Tables 2.4.13-1, 2.4.13-2, and 2.4.13-5 in the radionuclide transport analysis and estimation of initial liquid effluent release concentrations evaluated by the staff below.

The guidance in DC/COL-ISG-013 (as incorporated into BTP 11-6 Revision 4) states that long-lived, hard-to-detect, radionuclides such as Tc-99 that are highly mobile in the environment should be included in any assessment of an accidental release of radioactive material from liquid radwaste tanks. Therefore, the staff requested the applicant include Tc-99 in the accidental PPE liquid effluent release source term and exposure pathway dose analysis or justify its exclusion. Subsequently, the applicant calculated the impact of Tc-99 in the accidental PPE liquid effluent release source term.

The staff reviewed the applicant's calculation to evaluate an accidental release from a failed tank and groundwater transport that included a Tc-99 radioactivity concentration of 4.67E-11 microcuries/cm^3 in the accidental PPE liquid effluent release source term resulting in a Tc-99 release rate of 4.17E-05 Ci/yr. In the applicant's calculation, conservative assumptions were used such as: a zero transit time, default parameters in Table E-5 of RG 1.109 for boating, swimming, and shoreline recreational activities, assumed exposure time of one year, irrigation rate of 110 L/m^2/month, the FGR 11 ingestion dose conversion factors, and the FGR 12 external dose conversion factors. The applicant performed additional calculations using Nb-95 to confirm that the FGR 11 and FGR 12 dose conversion factors were properly modified for each exposure pathway change (ingestion, shoreline activities, and swimming and boating). The resulting calculated dose of 93 mrem/yr TEDE at the Clinch River site boundary that includes Tc-99 meets the public dose limit of 100 mrem/yr TEDE in 10 CFR 20.1301.

Based on the staff's review of the applicant's method, model, and assumptions used in the dose calculation, the staff determined that the applicant's dose calculation meets the requirements of 10 CFR 20.1301, and is acceptable.

As described above, the staff confirmed the adequacy of the applicant's dose calculation from a postulated accidental liquid effluent release of radionuclides to the groundwater using an accident PPE liquid effluent release source term. The staff determined that because the source term information for the reactor technology is not known at the ESP stage, a COL applicant or a CP applicant that references this ESP will need to verify that the calculated dose to members of the public from a postulated accidental liquid radionuclide effluent release to the groundwater from a chosen reactor technology at the CRN Site is bounded by the dose evaluated by the staff in this SER. A COL or CP applicant referencing this ESP should address and justify any discrepancies. This would include justifying any changes made to address differences in the reactor design used to calculate the dose (e.g., basis of the accident PPE liquid effluent release source term, radionuclide transport analysis and initial concentrations, and exposure pathway dose modeling). The staff identified these items collectively as **COL Action Item 2.4-4**.

COL Action Item 2.4-4

> An applicant for a combined license (COL) or a construction permit (CP) referencing this early site permit (ESP) should verify that the calculated dose to members of the public from a postulated accidental liquid radionuclide effluent release to the groundwater from a chosen reactor design at the CRN Site is bounded by the dose evaluated in this ESP application as reviewed by the NRC staff. The applicant should evaluate discrepancies and justify any changes made to address differences in the source term for the reactor design used to calculate the dose for a COL or CP application.

2.4.13.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.13.6 *Conclusion*

The staff has reviewed the application and confirmed that the applicant has demonstrated that accidental release of radionuclides has no safety-related impact and that there is no outstanding information required to be addressed in the SSAR related to this section. As set forth above, the applicant presented and substantiated information to establish the potential effects of accidental releases from the LWMS. Therefore, the staff concludes that the applicant has met the requirements of 10 CFR 52.79(a)(1)(vi), and 10 CFR 100.20(c) with respect to determining the acceptability of the site, and with respect to 10 CFR 20 as it relates to ECLs, and compliance with the dose limit to a member of the public.

2.4.14 Technical Specifications and Emergency Operation Requirements

2.4.14.1 *Introduction*

This section of the SSAR addresses the technical specifications and emergency operation requirements and includes descriptions of bounding site characteristics and design parameters. Because a specific reactor technology will be selected for the COLA, there are no requirements for technical specifications or emergency operation protective measures designed to minimize the impact of hydrology-related events on safety-related or risk-significant facilities at the ESP application stage. Therefore, the ESP application does not include technical specifications or emergency operating procedures.

2.4.14.2 *Summary of Application*

The information in the SSAR was provided to the staff to assess the suitability of the CRN Site given the PPE provided. In the COLA, the applicant will choose a specific reactor technology and evaluate technical specifications and emergency operating procedures.

2.4.14.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for consideration of emergency protective measures, and the associated acceptance criteria, are described in Section 2.4.14 of NUREG-0800.

The applicable regulatory requirements are:

- 10 CFR Part 100, as it relates to identifying and evaluating hydrological features of the site. The requirement to consider physical site characteristics in site evaluations is specified in 10 CFR 100.20(c).

- 10 CFR 100.23(d) sets forth the criteria to determine the siting factors for plant design bases with respect to seismically induced floods and water waves at the site.

- 10 CFR 52.17(a)(1)(vi), as it relates to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

2.4.14.4 *Technical Evaluation*

Information Submitted by Applicant

(SRI/CEII) In SSAR Section 2.4.14, the applicant presented a summary of the hydrologic engineering evaluations presented in the preceding SSAR Sections. Where applicable, the applicant retained elevation datum consistent with the historical record for comparison of corresponding values in the SSAR analyses. The applicant restated site characteristics and bounding design parameters including the plant design grade of the CRN Site as 821.0 ft NAVD88 (821.4 ft NGVD29) and the Clinch River design basis flood as **[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88). The applicant stated that the maximum groundwater elevation is 816.1 ft NAVD88 (816.5 ft NGVD29). The applicant stated that there are no requirements for emergency protective measures to minimize the impact of hydrology related events and none are necessary for incorporation into the technical specifications or emergency operating procedures.

NRC Staff's Technical Evaluation

The staff reviewed the SSAR Section 2.4.14 and found the applicant's summary of hydrologic engineering evaluations, site characteristics, and bounding parameters to be acceptable. For the ESP application, the staff determined that the there are no applicable technical specifications or emergency operating procedure necessary and finds the applicant's evaluation acceptable.

As described in the preceding SER Sections, the staff determined that the site characteristics and bounding design parameters as given in Tables 2.4.14-1 and 2.4.14-2 below, should be included in an ESP that may be granted for the CRN Site. Figure 2.4.14-1 below, reproduced based on SSAR Figure 2.1-1-3, depicts the proposed CRN Site boundary areas.

(SRI/CEII) **Table 2.4.134-1. Proposed Site Characteristics Related to Hydrology.**

Site Characteristic	**CRNS Site Value[1]**	**Definition**
Proposed Facility Boundaries	Figure 2.4.14-1 depicts the proposed facility area boundaries.	CRN Site boundary areas within which all safety-related SSCs will be located.
Maximum Groundwater	816.1 ft NAVD88 (816.5 ft NGVD29)	The maximum elevation of groundwater at the CRNS Site.
Maximum Stillwater Flood Elevation (MSWFE)	**[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88)	The stillwater surface, without accounting for wind-induced waves, reaches the elevation equal to the computed PMF elevation (**[[ ]]** ft) plus a **[[ ]]** ft of margin.
Wave Runup (2-year wind)	6.1 ft	The height of water reached by wind-induced waves running up on the site.

Site Characteristic	CRNS Site Value[1]	Definition
Combined Effects Maximum Flood Elevation (Design Basis Flood)	**[[ ]]** ft NGVD29 (**[[ ]]** ft NAVD88)	The water surface elevation at the point in time where the combination of the stillwater level and wave run-up is at its design basis maximum.
Local Intense Precipitation	17.4 in. per hour	The depth of PMP for duration of 1 hour on a 1 square-mile drainage area, including moisture adjustment. The surface water drainage system should be designed for a flood produced by the local intense precipitation (See COL Action Item 2.4-1).
Frazil, Surface or Anchor Ice	The CRN Site does not have the potential for frazil and surface ice.	Potential for accumulated ice formation in a turbulent flow condition.
Minimum River Water Surface Elevation	733.7 ft NGVD29 (733.3 ft NAVD88)	The river surface water elevation for which the low water level conditions recorded at the headwater of Watts Bar Dam which extends backwater level to the CRN Site.
Maximum Ice Thickness	11 in.	Maximum calculated potential ice thickness on the Clinch River at the CRN Site.
Hydraulic Conductivity	SSAR Table 2.4.12-12	Groundwater flow rate per unit hydraulic gradient.
Hydraulic Gradient	SSAR Table 2.4.12-8	Slope of groundwater surface under unconfined conditions or slope of hydraulic pressure head under confined conditions.

[1]First datum listed is the native datum as recorded in the historical record and/or associated analyses.

Table 2.4.134-2 Bounding Design Parameters

Bounding Design Parameter	Value[1]	Definition
Site Grade	821.0 ft NAVD88 (821.4 ft NGVD29)	Finished site grade elevation for the power block area on the CRN Site.

[1]First datum listed is the native datum of the associated analyses.

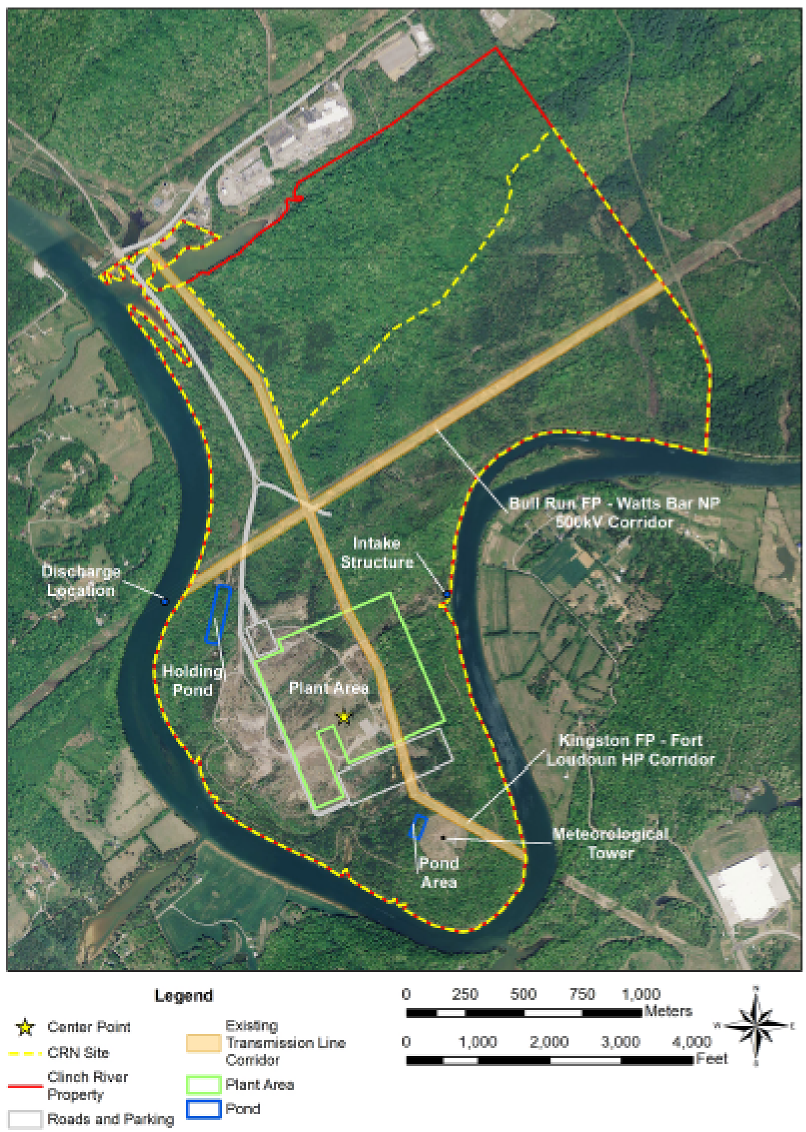

Figure 2.4.14-1. Proposed CRN Site Layout (after SSAR Revision 1, Figure 2.1-1).

2.4.14.5 *Post Early Site Permit Activities*

There are no post ESP activities related to this section.

2.4.14.6 *Conclusions*

The staff concludes no technical specifications or emergency operation procedures are required in the ESP application for the CRN Site. Therefore, the staff finds it acceptable that the ESP application does not include the identification and consideration of technical specifications and emergency operation procedures. As summarized above and as supported by the staff's evaluations in Sections 2.4.1 through 2.4.13 of this report, staff finds that the bounding site characteristics and design parameters of site grade meet the requirements of 10 CFR 52.17(a)(1)(vi), 10 CFR 100.20(c), and 10 CFR 100.23(d).

2.4.15 References

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