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GNRO-2013/00020

March 11, 2013

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

SUBJECT: Required Response 2 for Near-Term Task Force Recommendation 2.1: Flooding - Hazard Reevaluation Report
Grand Gulf Nuclear Station, Unit 1
Docket No. 50-416
License No. NPF-29

REFERENCE: NRC Letter, *Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident*, March 12, 2012 (ML12056A046)

Dear Sir or Madam:

On March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued the referenced letter requesting information to support the evaluation of the NRC staff recommendations for the Near-Term Task Force (NTTF) review of the accident at the Fukushima Dai-ichi nuclear facility. Enclosure 2 of the referenced letter contains specific requested actions, requested information, and required responses associated with Recommendation 2.1: Flooding. Pursuant to Required Response 2 of Enclosure 2, Entergy Operations, Inc. is providing the Hazard Reevaluation Report for Grand Gulf Nuclear Station in the attachment.

This letter contains no new regulatory commitments. If you have any questions regarding this report, please contact Mr. Thomas Thornton at (601) 437-6176.

I declare under penalty of perjury that the foregoing is true and correct; executed on March 11, 2013.

Sincerely,

KJM/slw

Attachment: Grand Gulf Nuclear Station's Hazard Reevaluation Report

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Attachment to

GNRO-2013/00020

Grand Gulf Nuclear Station's Hazard Reevaluation Report

AREVA

AREVA NP Inc.

Engineering Information Record

Document No.: 51 - 9195288 - 000

Entergy Fleet Fukushima Program
Flood Hazard Reevaluation Report for Grand Gulf Nuclear Station

Entergy Fleet Fukushima Program
Flood Hazard Reevaluation Report for Grand Gulf Nuclear Station

Safety Related? ☒ YES ☐ NO

Does this document establish design or technical requirements? ☐ YES ☒ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

Does this document contain Customer Required Format? ☐ YES ☒ NO

Signature Block

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Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial issue.

Overview

This report describes the approach, methods, and results from the reevaluation of flood hazards at Grand Gulf Nuclear Station (GGNS). It provides the information, in part, requested by the U.S. Nuclear Regulatory Commission (NRC) to support the evaluation of the NRC staff Recommendation 2.1 for the Near-Term Task Force (NTTF) review of the accident at the Fukushima Dai-chi nuclear facility.

Section 1 provides information related to the flood hazard. The section begins with an introduction that includes background information, scope, general method used for the reevaluation, the vertical datum used throughout the report, and a conversion to determine elevations in other common datums.

Section 2 describes detailed GGNS site information, including present-day site layout, topography, and current licensing basis flood protection and mitigation features. The section concludes by identifying relevant changes since license issuance to the local area and watershed as well as flood protections.

Section 3 presents the results of the flood hazard reevaluation. It addresses each of the eight flood causing mechanisms required by the NRC as well as a combined effect flood. In cases where a mechanism does not apply to the GGNS site, a justification is included. The section also provides a basis for inputs and assumptions, methods, and models used.

Section 4 compares the current and reevaluated flood-causing mechanisms. It provides an assessment of the current licensing and design basis flood elevation to the reevaluated flood elevation for each applicable flood-causing mechanism.

Section 5 contains potential mitigation measures necessary to address new flooding elevations developed by this evaluation. Based on the results of the evaluation, no mitigation measures are necessary.

Section 6 describes other changes proposed or anticipated by the plant that impact flooding at the GGNS site.

The report also contains one appendix. Appendix A describes the software models used in the reevaluation that are not specifically addressed by NUREG/CR-7046, "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America", including the quality assurance criteria and a discussion of validation of model-derived results.

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Acronyms and Abbreviations

Acronym/Abbreviation	Description
ANS	American Nuclear Society
ANSI	American National Standards Institute
CFR	Code of Federal Regulations
cfs	Cubic feet per second
CLB	Current Licensing Basis
COLA	Combined License Application
CMP	Corrugated Metal Pipe
DEM	Digital Elevation Model
DPF	Design Project Flood
DTM	Digital Terrain Model
GGNS	Grand Gulf Nuclear Station
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center River Analysis System
HHA	Hierarchical Hazard Assessment
HMR	Hydrometeorological Report
ISFSI	Independent Spent Fuel Storage Installation
LIP	Local Intense Precipitation
MSL	Mean Sea Level, also known as Sea Level Datum of 1929
NAVD88	North American Vertical Datum of 1988
NGDC	National Geophysical Data Center
NGVD29	National Geodetic Vertical Datum of 1929, also known as Mean Sea Level

Acronyms and Abbreviations
(continued)

Acronym/Abbreviation	Description
NOAA	National Oceanic And Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NTTF	Near-Term Task Force
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PMWE	Probable Maximum Water Elevation
SCS	Soil Conservation Service
SSC	Structures, systems and components
SSW	Standby Service Water
UFSAR	Updated Final Safety Analysis Report
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
VBS	Vehicle Barrier System

1.0 INTRODUCTION

Following the Fukushima Daiichi accident on March 11, 2011, which resulted from an earthquake and subsequent tsunami, the U.S. Nuclear Regulatory Commission (NRC) established the Near-Term Task Force (NTTF) to review the accident. The NTTF subsequently prepared a report with a comprehensive set of recommendations.

In response to the NTTF recommendations, and pursuant to Title 10 of the Code of Federal Regulations, Section 50.54 (f), the NRC has requested information from all operating power licensees (NRC, 2012). The purpose of the request is to gather information to re-evaluate seismic and flooding hazards at U.S. operating reactor sites.

Grand Gulf Nuclear Station (GGNS), located near Port Gibson, Mississippi, is one of the sites required to submit information. GGNS consists of one operational unit (Unit 1) and one unit that did not complete construction. This report addresses flooding conditions for Unit 1 only.

The NRC information request relating to flooding hazards requires licensees to re-evaluate their sites using updated flooding hazard information and present-day regulatory guidance and methodologies and then compare the results against the site's current licensing basis (CLB) for protection and mitigation from external flood events.

1.1 Purpose

This report satisfies the "Hazard Reevaluation Report" Request for Information pursuant to 10CFR50.54(f) by the Nuclear Regulatory Commission dated November 12, 2012, NTTF Recommendation 2.1 Flooding Enclosure 2.

The report describes the approach, methods, and results from the reevaluation of flood hazards at GGNS.

1.2 Scope

This report addresses the eight flood-causing mechanisms and a combined effect flood, identified in Attachment 1 to Enclosure 2 of the NRC information request (NRC, 2012). No additional flood causing mechanisms were identified for GGNS.

Each of these flood causing mechanisms and the potential effects on the GGNS site is described in Section 3 and 4 respectively of this report.

1.3 Method

This report follows the Hierarchical Hazard Assessment (HHA) approach, as described in NUREG/CR-7046, "Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America" (NRC, 2011) and its supporting reference documents.

A HHA consists of a series of stepwise, progressively more refined analyses to evaluate the hazard resulting from phenomena at a given nuclear power plant site to structures, systems, and components

(SCC) important to safety with the most conservative plausible assumptions consistent with the available data. The HHA starts with the most conservative, simplifying assumptions that maximize the hazards from the maximum probable event. If the assessed hazards result in an adverse effect or exposure to any safety-related SSC, a more site-specific hazard assessment is performed for the probable maximum event.

The HHA approach was carried out for each flood-causing mechanism listed in Sections 3 and 4, with the design-basis flood being the event that resulted in the most severe hazard to the safety-related SSC at GGNS. The steps involved to estimate the design-basis flood typically included the following:

1. Identify flood-causing phenomena or mechanisms by reviewing historical data and assessing the geohydrological, geoseismic, and structural failure phenomena in the vicinity of the site and region.

2. For each flood-causing phenomenon, develop a conservative estimate of the flood from the corresponding probable maximum event using conservative simplifying assumptions.

3. If any safety-related SSC is adversely affected by flood hazards, use site-specific data and/or more refined analyses to provide more realistic conditions and flood analysis, while ensuring that these conditions are consistent with those used by Federal agencies in similar design considerations.

4. If safety-related SSC is adversely affected by flood hazard, repeat steps 2 and 3 using further refined analyses; if all safety-related SSC are unaffected by the estimated flood, or if all justified site-specific refinements have been used, identify the most severe flood hazard from each flood mechanism.

Section 3 of this report provides additional HHA detail for each of the flood-causing mechanisms evaluated.

Due to use of the HHA approach, the results (water elevation) for any given flood hazard calculation may be significantly higher than results that could be obtained using more refined, realistic approaches. Where initial, overly conservative assumptions and inputs result in water elevations bounded by the CLB, no subsequent refined analyses are required to develop flood elevations that are more realistic or reflect a certain level of probability.

1.4 Assumptions

Any assumptions indicated in this report are discussed and justified in sections discussing the flood mechanism evaluations and in supporting calculations.

1.5 Elevation Datums

Reference to elevation values in this report are based on the National Geodetic Vertical Datum of 1929 (NGVD29), also known as the Sea Level Datum of 1929 (MSL), unless otherwise stated. To convert NGVD29 to the North American Vertical Datum of 1988 (NAVD88) at this site, subtract 0.059 feet from the NGVD29 elevation.

1.6 References

NRC, 2011. NUREG/CR-7046: Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America" U.S. Nuclear Regulatory Commission (U.S. NRC), Springfield, VA: National Technical Information Service, 2011.

NRC, 2012. Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(F) Regarding Recommendations 2.1,2.3, And 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident, U.S. Nuclear Regulatory Commission, March 2012.

2.0 INFORMATION RELATED TO THE FLOOD HAZARD

2.1 Detailed Site Information

GGNS is located approximately 6 miles northwest of Post Gibson, Mississippi. The site is situated on an elevated terrace approximately one mile east of the Mississippi River at river mile 406 (Figure 2.1-1). The plant site property boundary encompasses approximately 2,015 acres.

2.1.1 Present-day Site Layout

The GGNS site grade elevation is 132.5 ft, well above the eastern Mississippi River floodplain elevation which ranges from 55 to 75 ft in the vicinity of GGNS. Near GGNS, the natural Mississippi River floodplain is approximately 60 miles wide. However, the flow is confined to a width of about two to four miles by high bluffs on the east bank and man-made levees with top elevations ranging from 101 to 103 ft on the west bank. The river has a width of about one mile during dry seasons, increasing to about four miles during flooding. GGNS is located approximately 0.5 miles from the bluffs bounding the eastern edge of the Mississippi River floodplain. In addition, two unnamed streams are located on the GGNS site, designated Stream A and Stream B (Figure 2.1-2).

GGNS has a site grade elevation of 132.5 ft, and a finished floor grade of 133.0 ft. All entry locations to safety-related SSC are located at or above 133.0 ft elevation (GGNS, 2012a, GGNS, 2012b).

2.1.2 Site Topography

GGNS site layout and topography is shown in Figure 2.1-3 (Sanborn, 2013). As shown in Figure 2.1-3, the site is completely surrounded by concrete vehicle barriers (VBS). Flow penetrations in the VBS allow surface water to flow through the VBS into drainage channels. The drainage channels convey water to Stream A and Stream B, which ultimately drain into the Mississippi River. The site is located on a relatively flat site grade of elevation 132.5 ft. The switchyard shown to the east of the site is situated at approximately elevation 160 ft.

Figure 2.1-1: GGNS Location Map

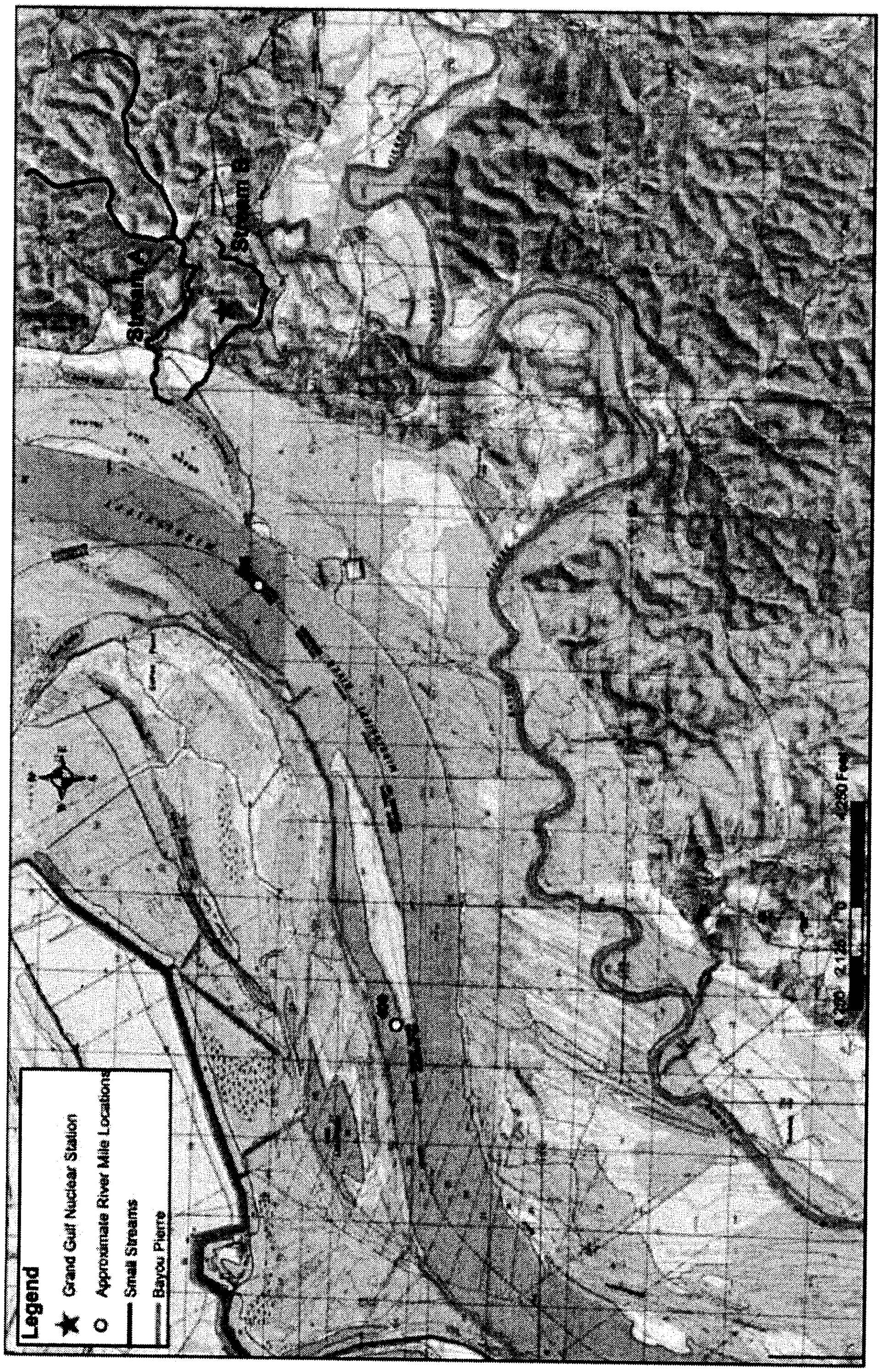

Figure 2.1-2: GGNS Streams and Rivers

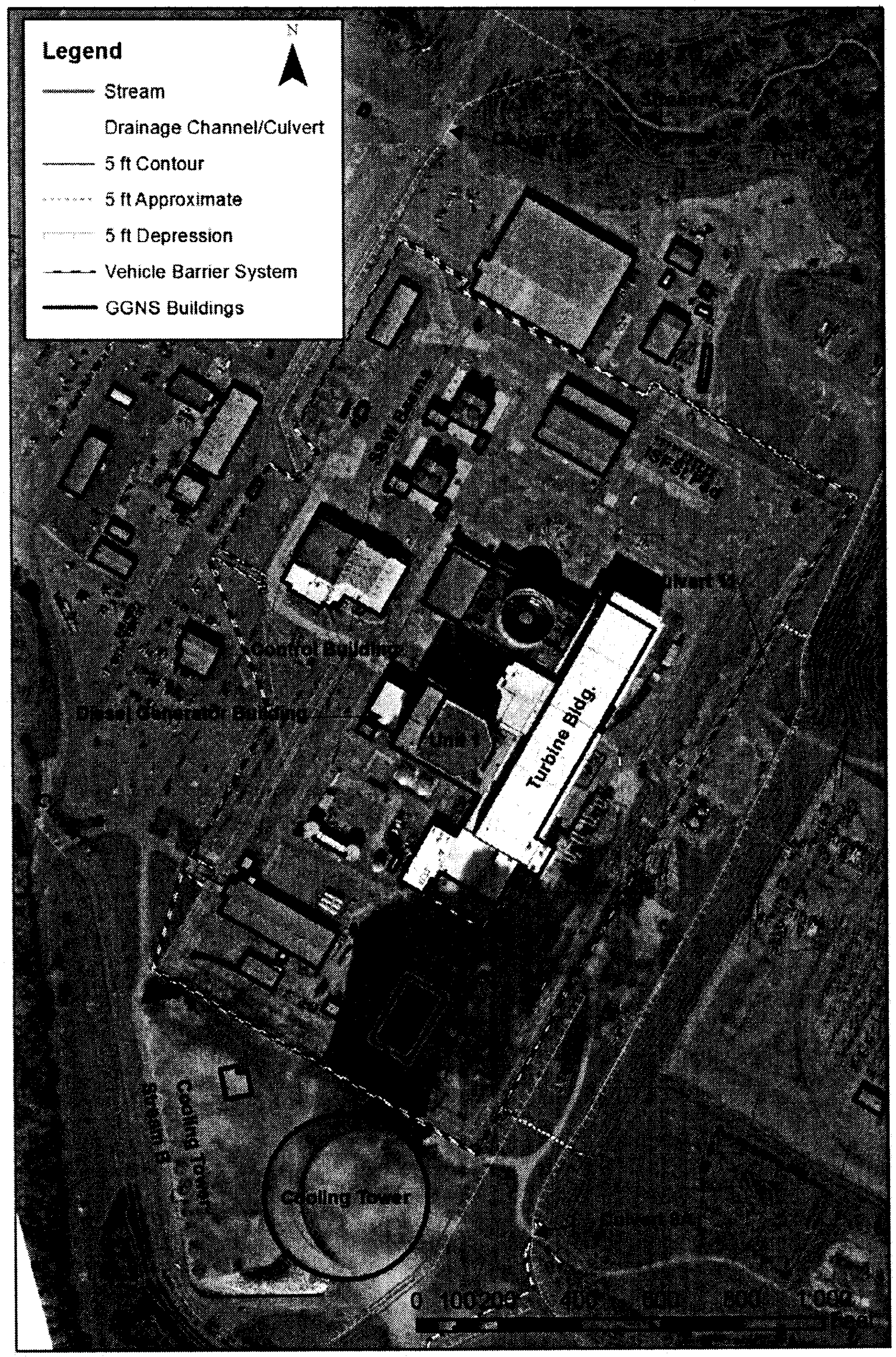

Figure 2.1-3: Site Topography and Layout

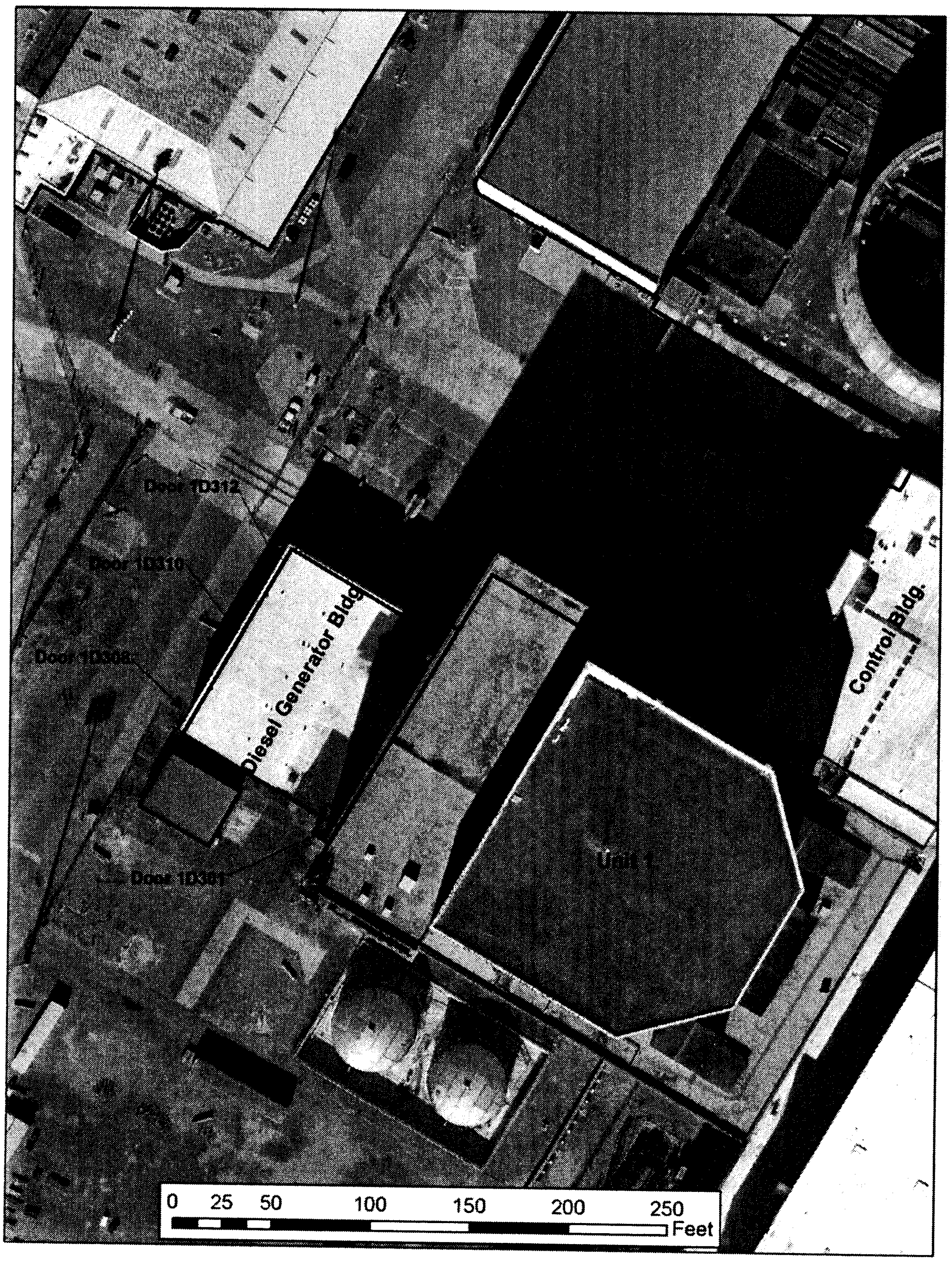

Figure 2.2-1: PMP Sealed Doors Near Unit 1

Figure 2.2-2: PMP Sealed Doors Near SSW Pump Houses

2.2 Current Design Basis Flood Elevations

The current design basis and related flood elevations for GGNS are described in the GGNS Updated Final Safety Analysis Report (UFSAR) (GGNS, 2012a) as well as the recent walkdown report (GGNS, 2012b) required as part of the 10 CFR 50.54(f) letter.

GGNS was designed to satisfy the requirements stated in NRC Regulatory Guide 1.59, Design Basis Floods, and the maximum flood level is based on the assumptions that the storm drains are inoperable and the culverts are blocked with the exception of Culvert 1 (Figure 2.1-3). Due to the vertical margin between the Mississippi River and the site, Probably Maximum Flood (PMF) conditions on the Mississippi River are not the design basis flooding event for GGNS. The flood mechanism considered to be controlling plant flood design is the probable maximum precipitation (PMP) on the watersheds for the two local streams (Stream A and Stream B) which includes the site (GGNS, 2012a, Section 2.4.2.2).

The PMP values were computed using publication of the NOAA, U.S. Department of Commerce: Hydrometeorological Report (HMR) No. 33. HMR-33 determined a maximum PMP of 30.5 inches per 6-hours, with a maximum intensity of 16.4 inches per hour, resulting in a maximum flood level of 133.25 ft (GGNS, 2012a, Sections 2.4.2.3.1 and 2.4.3.5.3).

2.3 Current Licensing Basis Flood Protection and Mitigation Features

The CLB for GGNS is defined from the GGNS UFSAR documents (GGNS, 2012a) and supporting plant calculations.

2.3.1 Flooding Mechanisms

Flooding hazard evaluations for GGNS include a screening for the following flood mechanisms (GGNS, 2012a, Section 2.4.3):

1. Local Intense Precipitation (LIP) – 133.25 ft (GGNS, 2012a, Section 2.4.3.5.3)
2. Probable Maximum Flood (PMF) on Rivers and Streams
    a. Mississippi River – 103 ft (GGNS, 2012a, Section 2.4.3.5.1)
    b. Stream A – 128.93 ft (GGNS, 2012a, Section 2.4.3.5.2)
    c. Stream B – 132.8 ft (GGNS, 2012a, Section 2.4.3.5.2)
3. Coincident Wind-Wave Activity
    a. Mississippi River – 108.8 ft (GGNS, 2012a, Section 2.4.3.6)
4. Dam Failures (Screened Out)
5. Surge and Seiche Flooding (Screened Out)
6. Tsunami Flooding (Screened Out)
7. Ice Effect Flooding (Screened Out)
8. Cooling Water Canal and Reservoir Flooding (Screened Out)

9. Channel Diversions (Screened Out)

2.3.2 Flood Protection and Mitigation

Based on the design basis precipitation event, flood water elevations at GGNS may exceed elevation 133.0 ft for approximately 7 hours. With calculated water surface elevations near the power block above elevation 133.0 ft there is a potential for leakage through external doors leading into Unit 1, including the standby service water basin buildings. Water can also enter through openings not associated with Unit 1 and flow into Unit 1 spaces through common doorways or openings. Therefore, all leakage, and its effects on the safe operation of the plant, was evaluated.

Based on the leakage analyses, water leaking into the control and diesel generator buildings could affect safety-related equipment. Therefore, door seals were provided at the exterior doorways for these buildings to assure safe plant operation. Also, water entering the Standby Service Water (SSW) pump houses through doorways, equipment hatches, and various floor penetrations could affect floor mounted safety-related electrical equipment. Several modifications to the floor, exterior walls, and doors in the form of seals, penetration sleeves, toe plates, and curbs were provided to prevent water from reaching the floor mounted safety-related equipment and to assure safe plant operation. Watertight door seals were installed on a total of eleven doors to the Control Building, the Diesel Generator Building, and the SSW pump houses. Seals were installed across the door bottoms and along the lower portions of the sides. The seals provide protection between 0.75 ft to 1.0 ft above floor level. Figure 2.2-1 shows the location and identifications of the PMP sealed doors in the vicinity of the Unit 1 Reactor Building. Door OC313 is protected 0.75 ft above floor level, and the other doors identified in Figure 2-1 are protected 1.0 ft above floor level. Figure 2.2-2 shows the location of PMP sealed doors in the vicinity of the SSW pump houses, all of which are protected 1.0 ft above floor level. Water may also penetrate the SSW pump houses by flowing directly into the SSW retention basins which are open structures. Other modifications in the SSW pump houses (curbs and toe plates which isolate safety related equipment from potential flooding) provide protection for internal equipment 0.625 ft above floor level. (GGNS, 2012a, Section 2.4.10)

In addition, passive features are required to be installed per existing Off-Normal Event Procedures. These procedures require sand bags to be installed around all PMP sealed doors whenever the 24 hour weather forecast calls for rainfall amounts of 12 inches or more. (GGNS, 2012d).

2.4 Licensing Basis Flood-Related and Flood Protection Changes

No new flood protection enhancements or mitigation measures have been installed or enacted at GGNS (GGNS, 2012b).

2.5 Watershed and Local Area Changes

2.5.1 General GGNS Site Hydrological Description

The dominant hydrologic feature in the vicinity of the site is the Mississippi River. The site is located in the Water Resources Planning Area No. 7 of the Lower Mississippi River Region. The streamflow system within the region is composed chiefly of the Mississippi River and its tributary streams between

Cairo, Illinois, and the Gulf of Mexico and the coastal area streams of southern Louisiana. The total drainage area of the Mississippi River is approximately 1.2 million square miles.

At the plant site, the natural Mississippi River floodplain is about 60 miles wide. However, the flow is confined to a width of about two to four miles by high bluffs on the east bank and man-made levees with top elevations ranging from 101 to 103 ft on the west bank. The river has a width of about one mile during dry seasons. The width increases to about four miles during floods.

Several lakes are in the floodplain in the vicinity of the site. However, their hydrologic characteristics have no influence at the elevation of the plant site. In the vicinity of the GGNS site, there are two small unnamed streams. Stream A, located to the north of the site is perennial, draining 2.8 square miles. Stream B, located to the south of the site is intermittent, draining 0.6 square miles. Both streams drain into Hamilton and Gin Lakes to the West in the floodplain of the Mississippi River.

2.5.2 Watershed Changes

There have been no significant watershed changes to the site vicinity (GGNS, 2008, Section 2.4). The The Mississippi River watershed is extremely large, and many contributing tributaries and subwatersheds have experienced both man-made and natural changes since the construction of GGNS. Mississippi River in the vicinity of GGNS, however, has been stabilized to maintain navigability and flood control measures by the U.S. Army Corps of Engineers (USACE). The numerous programs in place to stabilize the Mississippi River channel are discussed in Section 3.8.

2.5.3 Site Changes

The primary site changes pertinent to flood considerations are the installation of the VBS. For the purpose of the flood hazard evaluation, the VBS represents an impermeable obstacle to surface water flow. To maintain the design basis flood elevation and drain the site in an LIP scenario, the VBS was designed to include flow pathways (GGNS, 2012c). The VBS is discussed in more detail in Section 3.1.

2.6 Additional Site Details

N/A

2.7 References

GGNS, 2008. Combined License Application Final Safety Analysis Report, Revision 0, 2008.

GGNS, 2012a. Grand Gulf Nuclear Station UFSAR, 2012, see AREVA Document No. 38-9193642-000.

GGNS, 2012b. Engineering Report No. GGNS-CS-12-00003, Rev. 0, "Grand Gulf Nuclear Station Flooding Walkdown Report for Resolution of Fukushima Near-Term Task Force Recommendation 2.3: Flooding", November 2012, see AREVA Document No. 38-9200169-000.

GGNS, 2012c. Calculation No: CC-Q1Y13-93002, Rev. 2, "Backwater Analysis of External Flooding (HMR51PMP Data), May 2012, see AREVA Document No. 38-9193642-000.

GGNS, 2012d. Plant Operations Manual 05-1-02-VI-2, Volume 05, Section 02, Revision 120, "Off-Normal Event Procedure - Hurricanes, Tornados, and Severe Weather - Safety Related", December 2012, see AREVA Document No. 38-9200169-000.

Sanborn, 2013. Grand Gulf Topographic Survey Data, Sanborn Map Company, Inc., January 2013, AREVA Document No. 38-9196955-000.

3.0 INFORMATION RELATED TO THE FLOOD HAZARD

This section details the evaluation of the eight flood causing mechanisms and combined effects for GGNS as detailed in Attachment 1 to Enclosure 2 of the NRC information request. No additional flood causing mechanisms were identified for GGNS. Flooding due to LIP is the only scenario that results in standing water in the vicinity of safety-related SSC at GGNS. Debris loading and transportation during the LIP scenario is not considered a hazard for safety-related SSC at GGNS (see Section 3.1.3).

3.1 Local Intense Precipitation

This section addresses the potential for flooding at GGNS due to the LIP event. The LIP event is a distinct flooding mechanism that consists of a short-duration, locally heavy rainfall centered upon the plant site itself. Based on NUREG-7046, the LIP is deemed equivalent to the 1-hr, 1-mi^2 PMP (NRC 2011, Section 3.2).

3.1.1 Method

3.1.1.1 Local Intense Precipitation

The hierarchical hazard assessment (HHA) approach described in NUREG/CR-7046 (NRC, 2011, Section 2) was used for the evaluation of the LIP and resultant water surface elevation at GGNS.

The HHA approach is consistent with the following standards and guidance documents:

1. NRC Standard Review Plan, NUREG-0800, revised March 2007;
2. NRC Office of Standards Development, Regulatory Guides:
   a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
   b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977; and
3. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

With respect to LIP, the HHA used the following steps:

1. Define FLO-2D model limits for LIP analysis.
2. Develop the FLO-2D computer model with site features.
3. Develop LIP/PMP inputs.
4. Perform flood simulations in FLO-2D and estimate maximum water surface elevations at GGNS.

3.1.2 Results

The safety-related SSC at GGNS are enclosed within a series of connected concrete security barriers (Vehicle Barrier System, (VBS)) (GGNS, 2012b). Openings are provided within the VBS to allow flow away from the safety-related SSC (AREVA, 2013a, Appendix C; Sanborn, 2013; GGNS, 2012b).

These openings through the VBS represent the primary flow path for LIP water to exit the vicinity of the safety-related SSC.

The FLO-2D model for LIP flooding analysis at GGNS utilizes 2012 topographic mapping results (Sanborn, 2013) to generate ground elevations and associated flood water surface elevations. Elevations used in the LIP analysis were found to be inconsistent with the plant design elevations due to different calibration and survey techniques. The discrepancies fall within documented error ranges of the two surveys, between 0.2 ft and 0.3 ft depending on the specific site location. In order to determine potential for flood impacts to safety-related SSC, the depth of LIP-related flood water will be directly compared to the UFSAR documented height of protection above a given ground level (see Section 2.3.2). This approach provides a consistent means by which to judge flood levels for this study, eliminating any potential for misinterpretation due to the different survey results.

3.1.2.1 Local Intense Precipitation (AREVA, 2013a)

3.1.2.1.1 FLO-2D model limits for LIP analysis

Due to anticipated unconfined flow characteristics, a two-dimensional hydrodynamic computer model, FLO-2D, was used for the LIP Analysis. FLO-2D is a physical process model (see Appendix A.1) that routes flood hydrographs and rainfall-runoff over unconfined flow surfaces or in channels using the dynamic wave approximation to the momentum equation (AREVA, 2012a). The watershed applicable for the LIP Analysis was computed internally within FLO-2D based on the digital terrain model (DTM) limits input into FLO-2D.

3.1.2.1.2 FLO-2D computer model with site features

The FLO-2D model developed for the LIP analysis was based on GGNS site features including: topography, site location, VBS, channels and culverts, and structures. The selected grid element size for the project was 20 feet by 20 feet. The elevation data used to develop the FLO-2D model consist of DTM data (Sanborn, 2013) for GGNS. Flow obstructions due to buildings were also included in the model. Outflow grid elements along the model computational boundary were selected as outflow grid elements. Channels and culverts which have maintenance procedures in place to ensure that they free from debris that can block them were also included in the model (GGNS, 2013). The channels and culverts included in the model are shown in Figure 2.1-3 and discussed below:

- Stream B and the 15 ft diameter corrugated metal pipe (CMP) culvert (Culvert #1) that runs beneath the Plant Access Road;
- The Northwest Drainage Ditch and the three 4 ft diameter CMP culverts (Culvert #9A) that discharge into Stream A;
- The channel west of the Switchyard at the toe of the slope and the 6 ft wide by 4 ft high concrete box culvert (box Culvert #11) and 4 ft diameter CMP culvert (Culvert #8A) located in the channel at the northwest and southwest ends of the Switchyard respectively.

The culverts included in the model were conservatively assumed to be 50-percent blocked as discussed in NUREG/CR-7046 Appendix B (NRC, 2011). The depth-discharge relationship for each of

these culverts, with the exception of Culvert 1, was calculated using CulvertMaster (see Appendix A.2) (AREVA, 2012b) and the depth-discharge relationships were reduced by 50-percent. Culvert 1 was modeled within FLO-2D as a 10.6 ft diameter culvert instead of a 15 ft diameter culvert. The 10.6 ft diameter culvert has an opening area 88.3 square ft, which is equivalent to 50-percent of the area of the 15 ft diameter culvert (177 square ft). The culvert upstream and downstream invert elevations were also set at 4.4 ft (15 – 10.6 ft) above the actual invert elevations.

The VBS was modeled using the levee structure component in FLO-2D and openings within the VBS were modeled as 30-percent blocked (GGNS, 2012b). There are three types of openings in the VBS system to convey water (GGNS, 2012b):

1. 0.6 feet diameter PVC pipes;
2. 5 feet wide by 1 foot high openings in series (125 total); and
3. 16 feet wide by 2 feet high openings in series (7 total).

The smallest of the openings (0.6 feet diameter PVC pipes) were assumed to be completely blocked based on guidance in NUREG/CR-7046 (NRC, 2011, Section 3.2.2). Both the 5 feet wide by 1 foot high and the16 feet wide by 2 feet high openings in the VBS were modeled using the hydraulic structure component in FLO-2D.

The area within the VBS at GGNS is completely impervious and does not contain natural sources of vegetation such as trees, brush, or other vegetation that may block culverts. Also, since the area within the VBS does not contain channelized flow, depths and flow velocities are unlikely to be sufficient to transport debris that could result in significant blockages of the VBS openings. However, the VBS openings that were included in FLO-2D were conservatively assumed to be 30 percent blocked based on the security screens in place at each opening (GGNS, 2012b). The depth-discharge relationship for each of the modeled openings in the VBS was calculated using CulvertMaster (see Appendix A.2) (AREVA, 2012b). The calculated discharges were reduced by 30-percent. Tailwater effects were modeled in FLO-2D. The head (depth) used in FLO-2D was the difference in water surface elevations inside and outside of the VBS at each opening.

Selected Manning's roughness coefficients used in the model were based on recommended values in the FLO-2D Manual (FLO-2D, 2012, Table 1).

3.1.2.1.3 LIP/PMP inputs

The LIP parameters were defined using National Weather Service Hydrometeorological Reports #51 and #52 (HMR-51 and HMR-52) as prescribed in NUREG/CR-7046 (NRC, 2011, Section 3.2). The total rainfall depth for the 1-hour, 1-mi^2 PMP is 19.3 inches, with peak intensity of 6.2 inches during the first 5 minutes. The total rainfall depth for the 6-hour PMP is 31.4 inches. The 6-hour PMP hyetograph was constructed using the 1-hour PMP for the first hour and equal rainfall increments for the next 5 hours (Figure 3.1-1). (AREVA, 2013b)

3.1.2.1.4 LIP Simulation Results

Figure 3.1-2 shows the FLO-2D grid with modeled maximum water depth. Figure 3.1-3 shows the FLO-2D grid with modeled maximum flow velocity vectors, indicating the direction and speed of overland

flow. Figure 3.1-4 shows the FLO-2D grid with modeled LIP water surface elevations. Figure 3.1-5 shows the ground surface elevations used in the FLO-2D model based on the 2012 mapping as discussed in Section 3.1.2.

Based on the LIP model simulation, maximum water depths at the location of GGNS Unit 1 safety-related SSC range from 0.29 ft to 0.81 ft. Maximum water surface elevations, based on the 2012 topographic survey, at the locations GGNS Unit 1 safety-related SSC range from 133.3 to 133.7 feet.

Figures 3.1-6 through 3.1-18 are time-series plots of water depth for each SSC location or door entry identified as potentially impacted by flooding at the GGNS site (See Section 2.3.2). Impacts of LIP water depths are discussed in Section 4.3, and summarized in Table 4.3-1. Figure 3.1-19 is a time-series plot of water depth near the ISFSI pad.

3.1.3 Conclusions

The maximum water surface elevation due to the LIP at GGNS results from a total rainfall depth of 19.3 inches within an hour and 31.4 inches within 6 hours. In the immediate vicinity of GGNS Unit 1, predicted maximum water depths resulting from the LIP range from approximately 0.3 ft to 0.8 ft above floor level. Based on the 2012 topographic mapping, these flow depths correspond to water surface elevations ranging from 133.3 ft to 133.7 ft.

Impacts of the LIP water elevations are discussed in Section 4.3.

Significant debris loading/transportation is not a safety hazard due to the relatively low velocity and depth of LIP flood waters in the vicinity of safety-related SSC at GGNS, in addition to the lack of natural debris sources on site.

3.1.4 References

AREVA, 2012a. AREVA Document No. 38-9192635-000, “Computer Software Certification – FLO-2D® Pro”, GZA GeoEnvironmental, Inc., October, 2012.

AREVA, 2012b. AREVA Document No. 38-9192493-000, “Computer Software Certification – Bentley CulvertMaster v.3.3”, GZA GeoEnvironmental, Inc., 2012.

AREVA, 2013a. AREVA Document No. 32-9195573-000, “Local Intense Precipitation – Generated Flood Flow and Elevation at Grand Gulf Nuclear Station”, January 2013.

AREVA, 2013b. AREVA Document No. 32-9195574-000, “Probable Maximum Precipitation (PMP) at Grand Gulf Nuclear Station”, GZA GeoEnvironmental, Inc., January 2013.

GGNS, 2008. Combined License Application Final Safety Analysis Report, Revision 0, 2008.

GGNS, 2012a. Grand Gulf Nuclear Station UFSAR, 2012, see AREVA Document No. 38-9193642-000.

GGNS, 2012b. Calculation No: CC-Q1Y13-93002, Rev. 2 “Backwater Analysis of External Flooding (HMR51PMP Data), May 2012, see AREVA Document No. 38-9193642-000.

GGNS, 2013. Plant Operations Manual 06-TE-1000-V-0001, Volume 06, Section 09, Revision 101, "Surveillance Procedure Culvert No. 1 Embankment Stability Inspection/Survey – Safety Related," see AREVA Document No. 38-9200169-000.

FLO-2D, 2012. FLO-2D® Pro Reference Manual, FLO-2D Software, Inc., Nutrioso, Arizona.

NRC, 2011. NUREG/CR-7046, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America, U.S. Nuclear Regulatory Commission, November 2011.

Sanborn, 2013. Grand Gulf Topographic Survey Data, Sanborn Map Company, Inc., January 2013, AREVA Document No. 38-9196955-000.

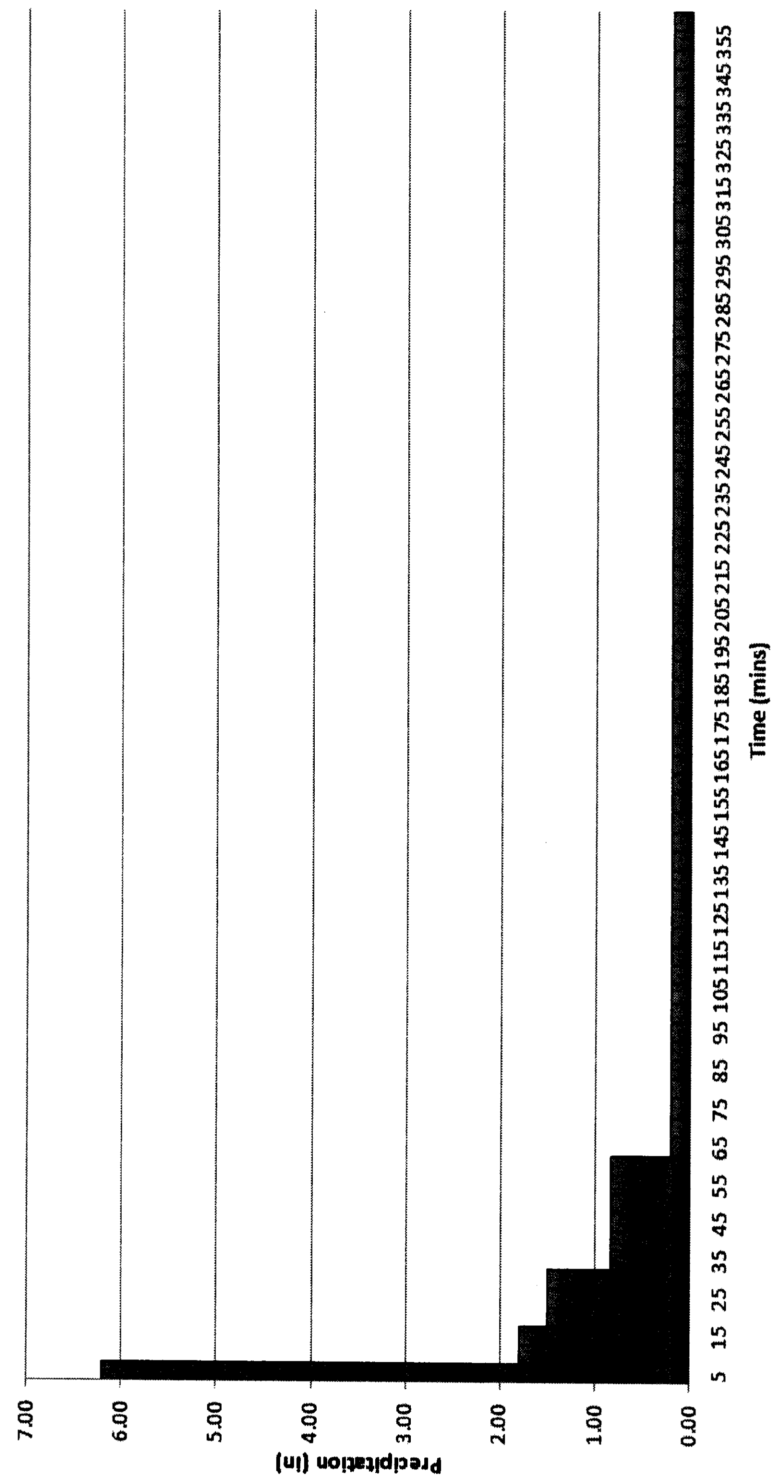

Figure 3.1-1: 6-hour PMP – Incremental Hydrograph

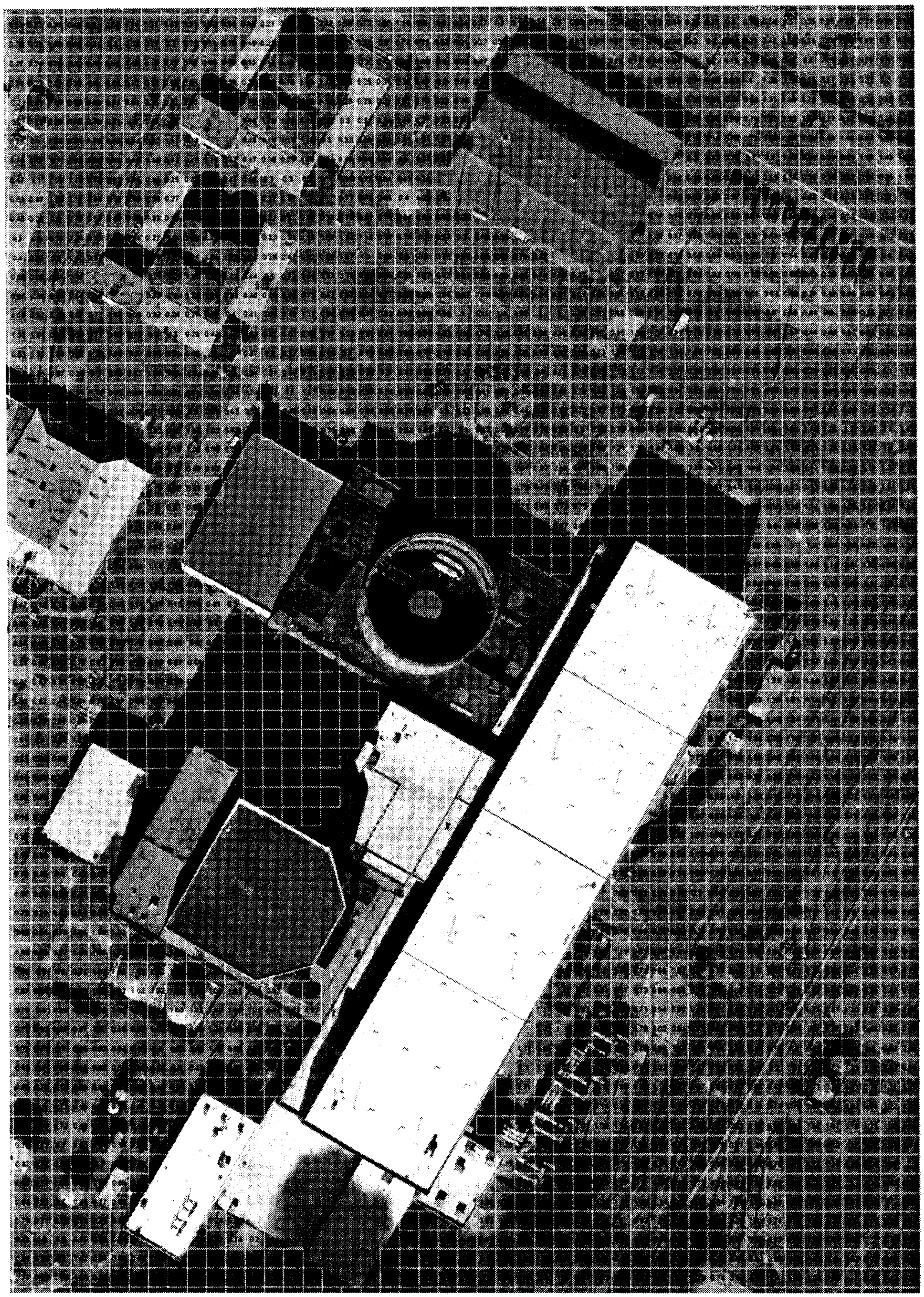

Figure 3.1-2: Grid Element Maximum Flow Depth (ft)

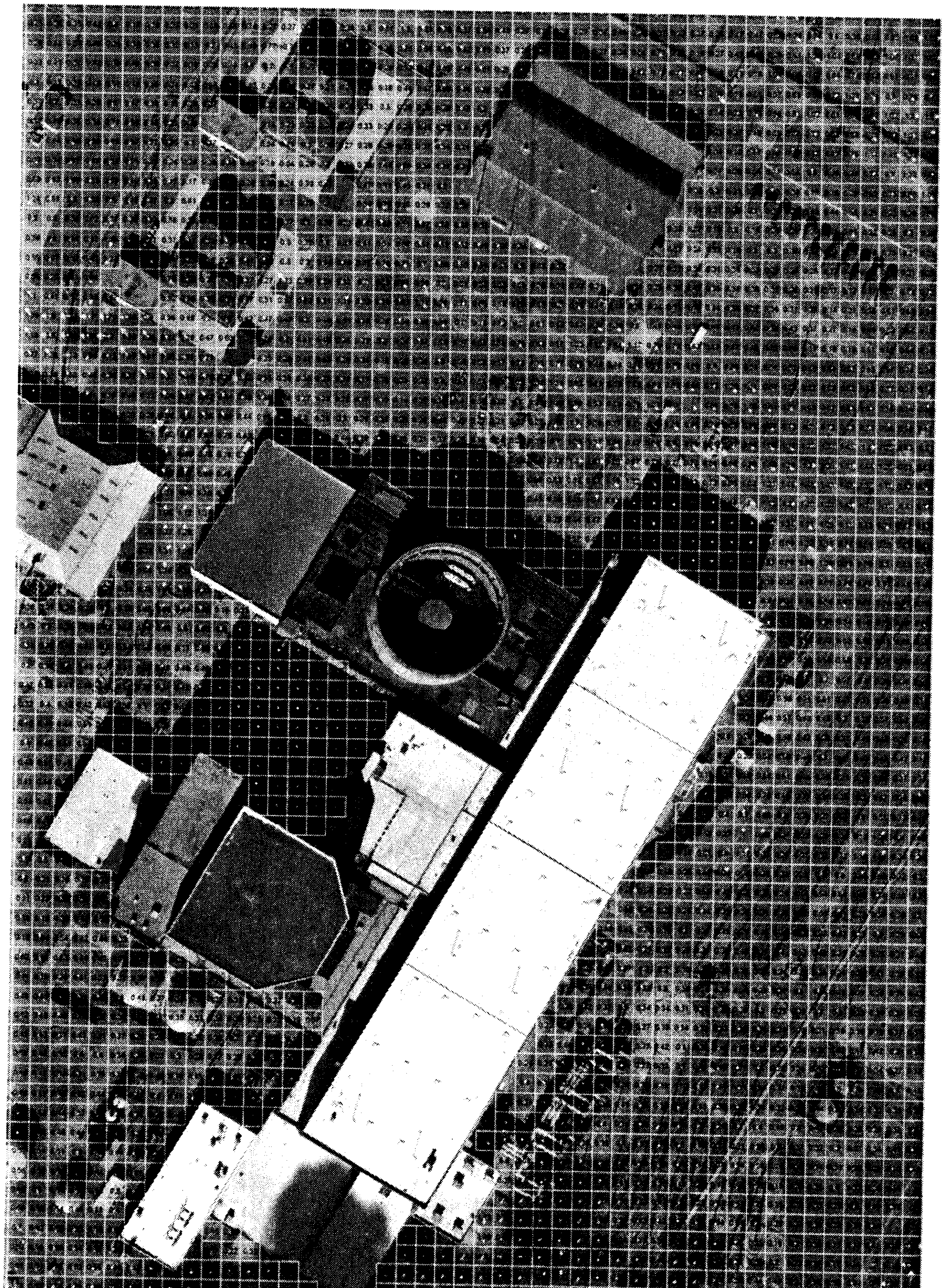

Figure 3.1-3: Grid Element Maximum Flow Velocity and Vector (ft/second)

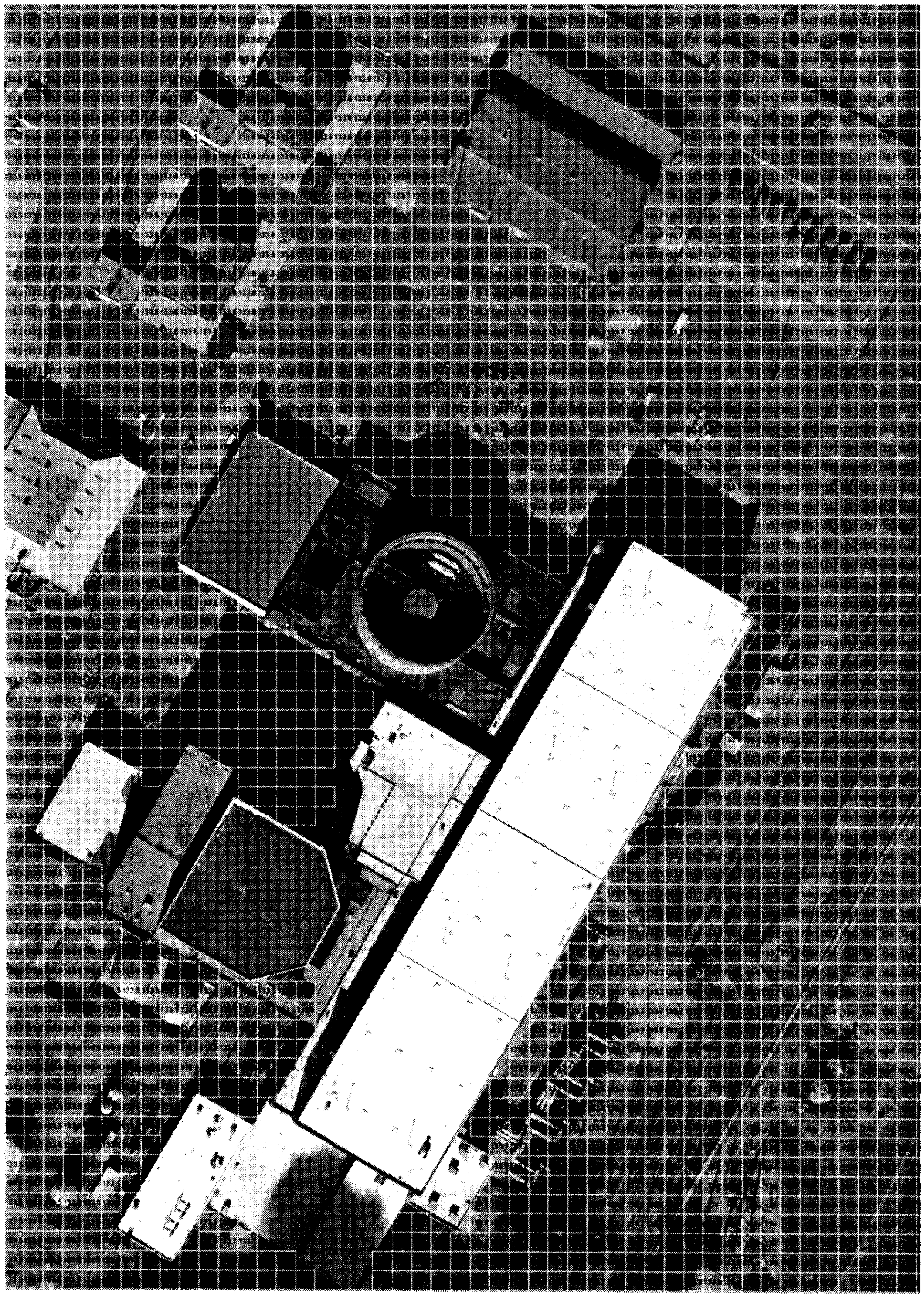

Figure 3.1-4: Grid Element Maximum Water Elevation (ft, NGVD29)

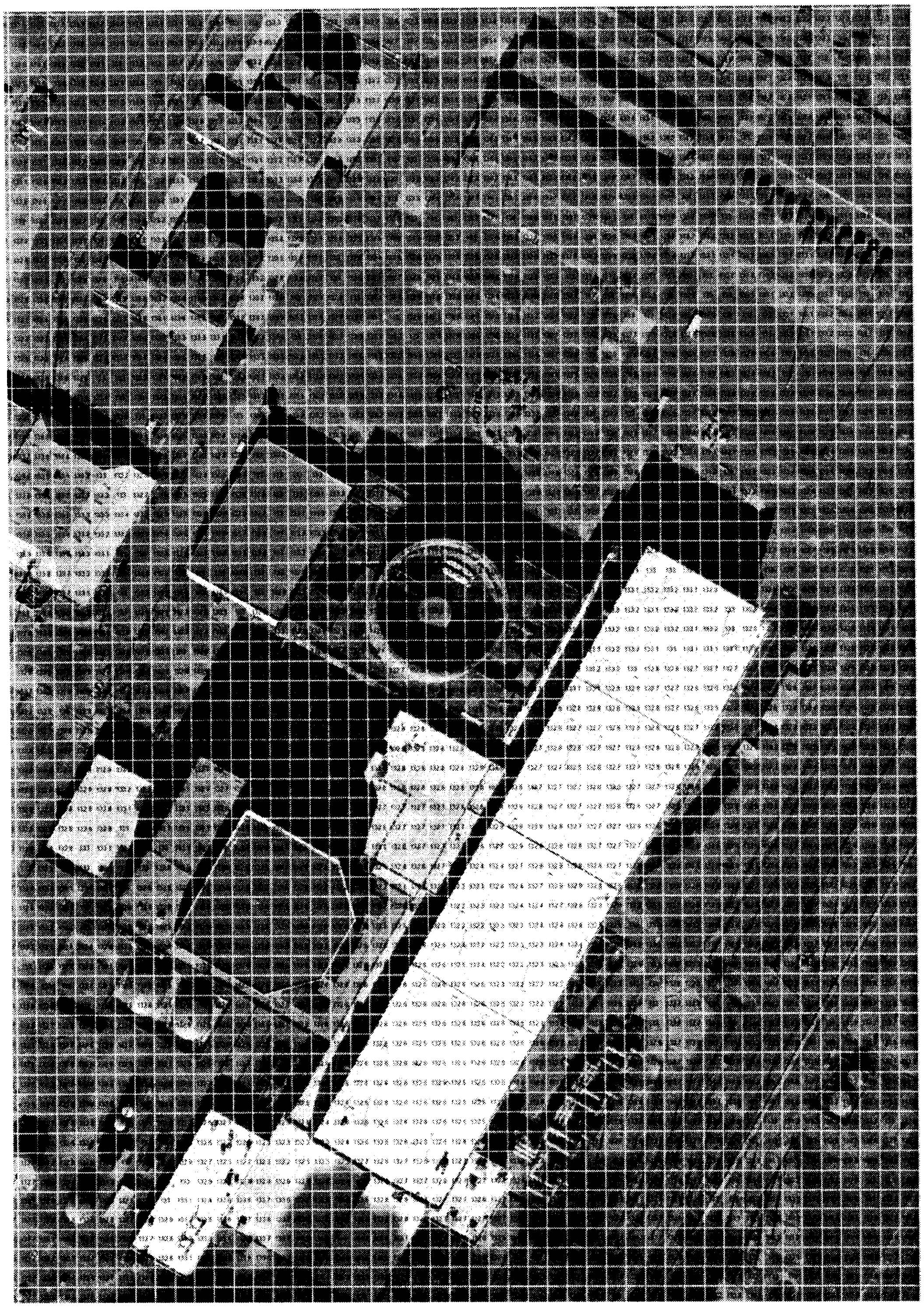

Figure 3.1-5: Grid Element Ground Elevation (ft, NGVD29)

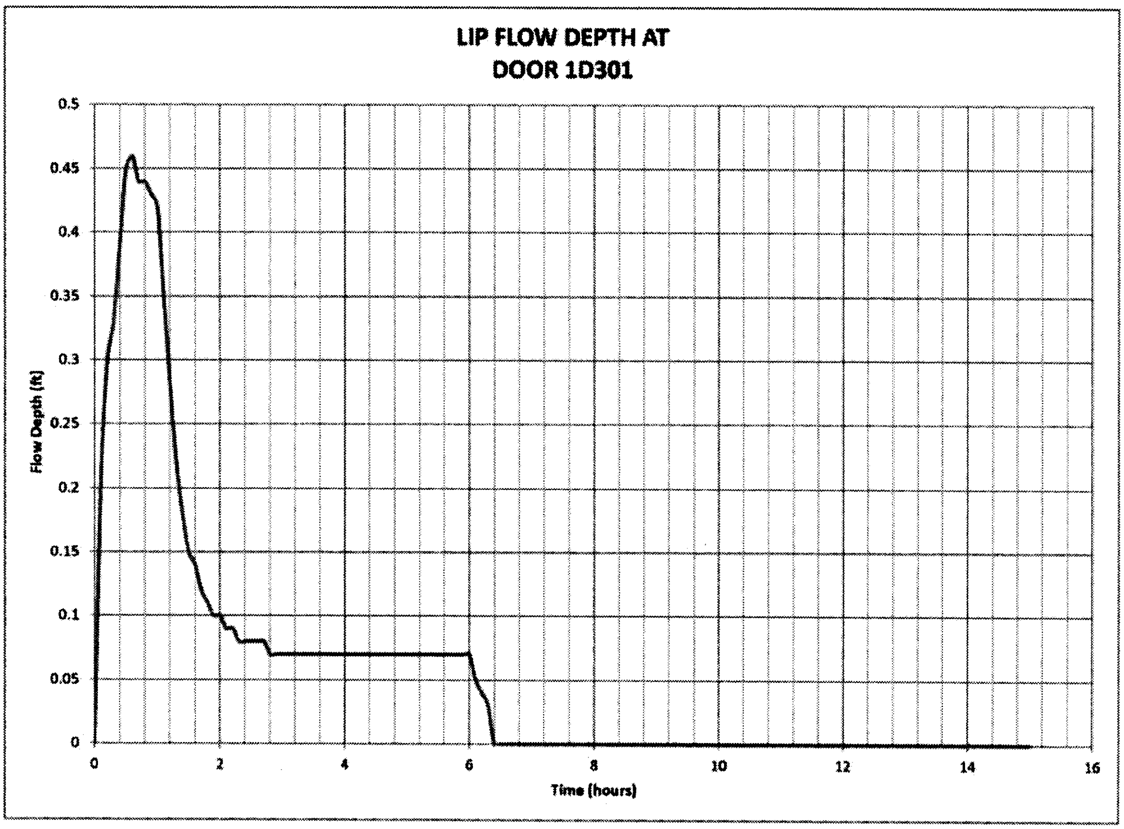

Figure 3.1-6: Water Depth at Door 1D301

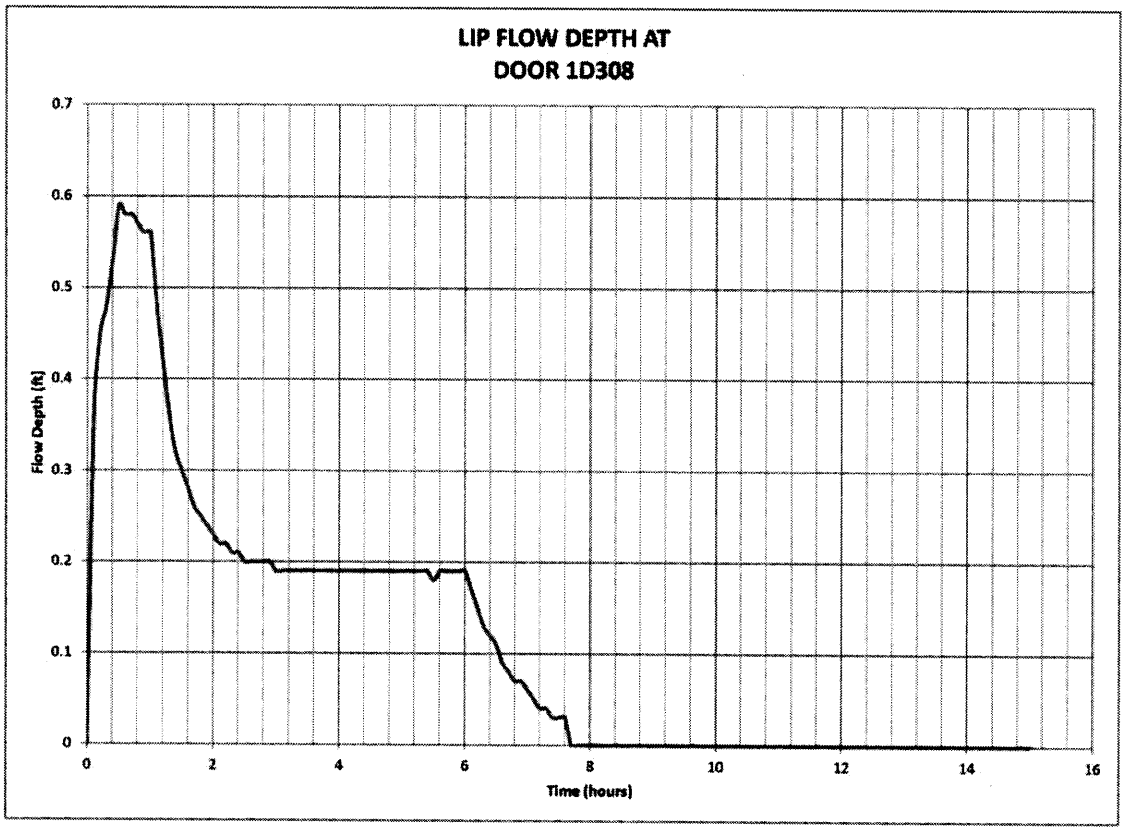

Figure 3.1-7: Water Depth at Door 1D308

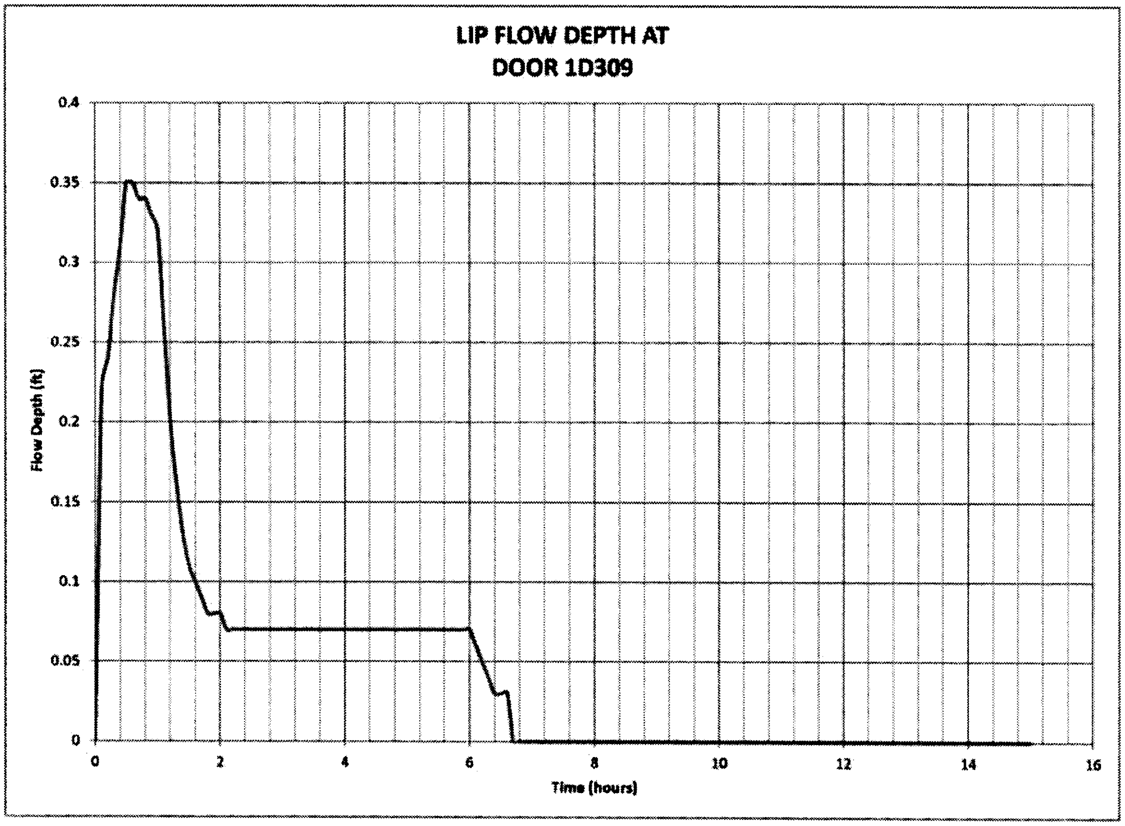

Figure 3.1-8: Water Depth at Door 1D309

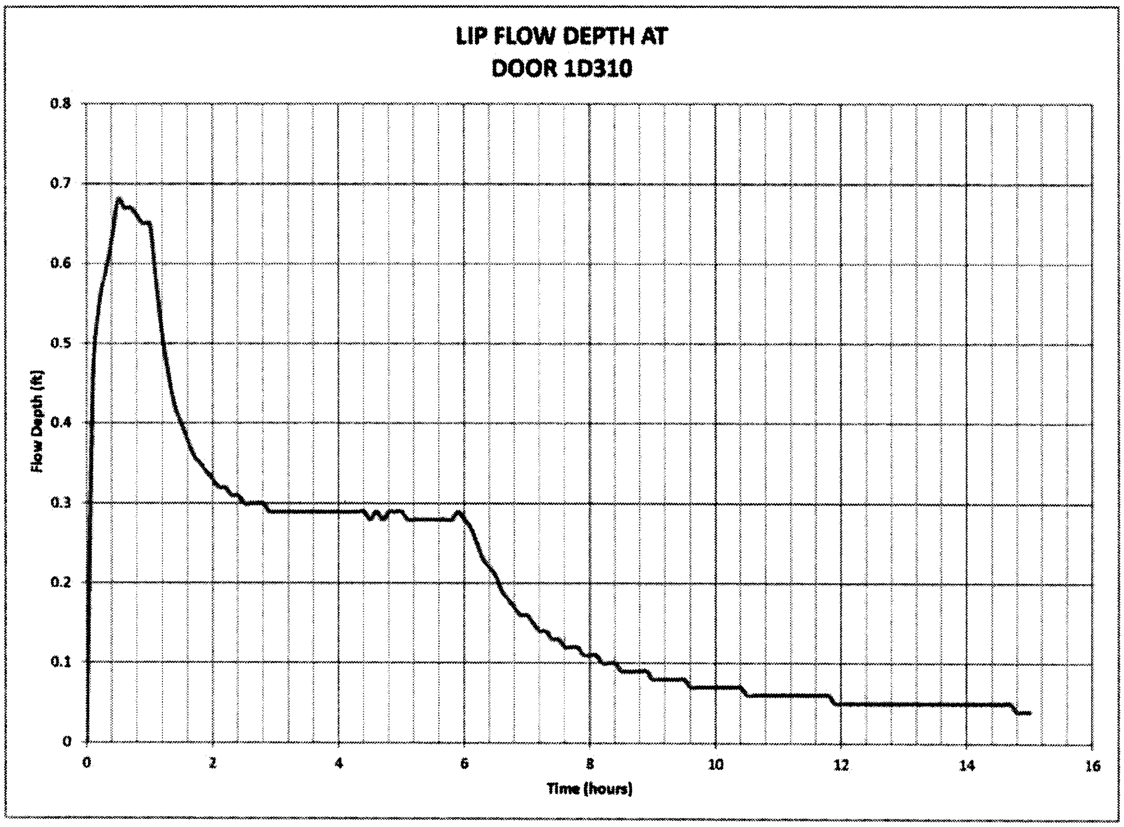

Figure 3.1-9: Water Depth at Door 1D310

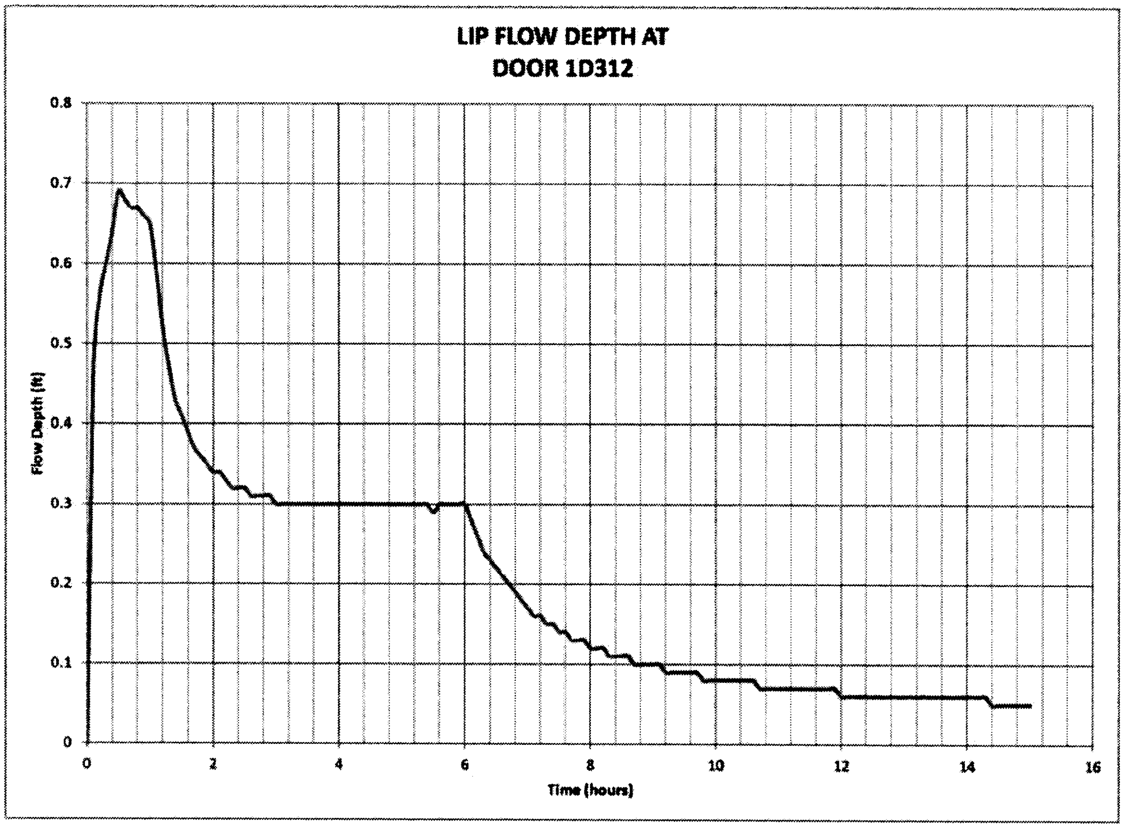

Figure 3.1-10: Water Depth at Door 1D312

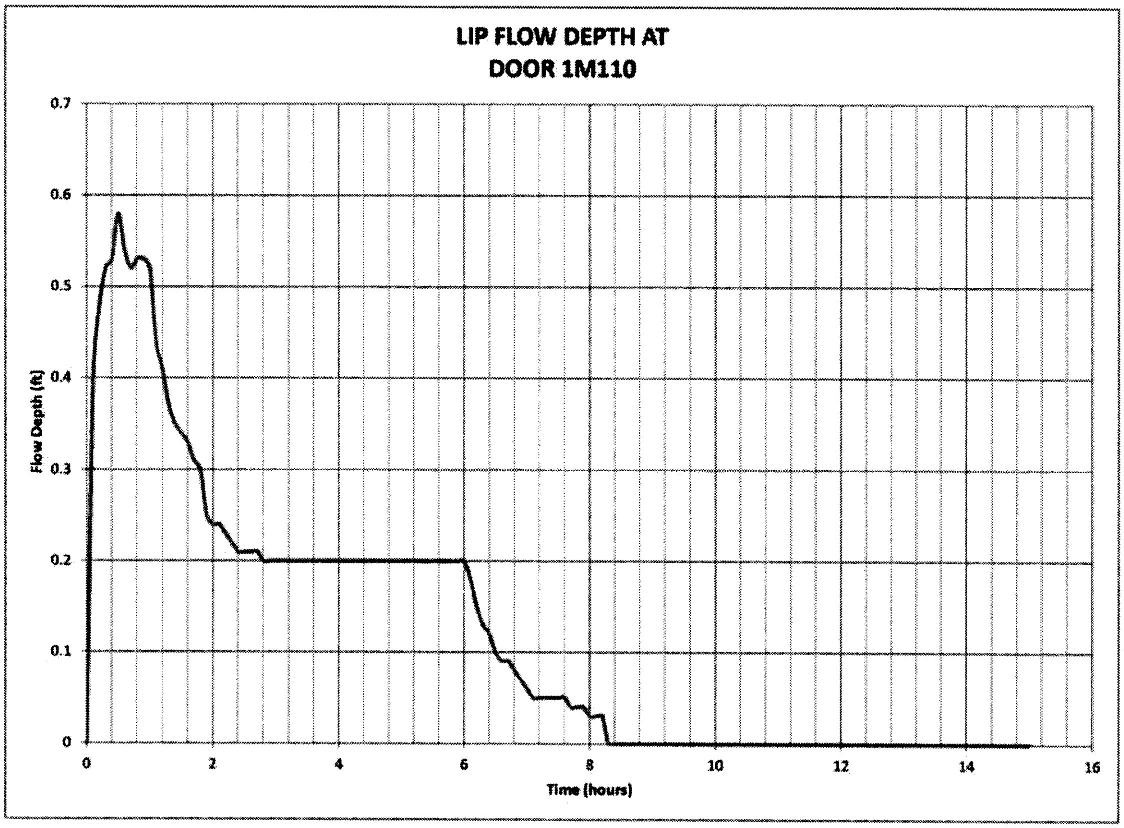

Figure 3.1-11: Water Depth at Door 1M110

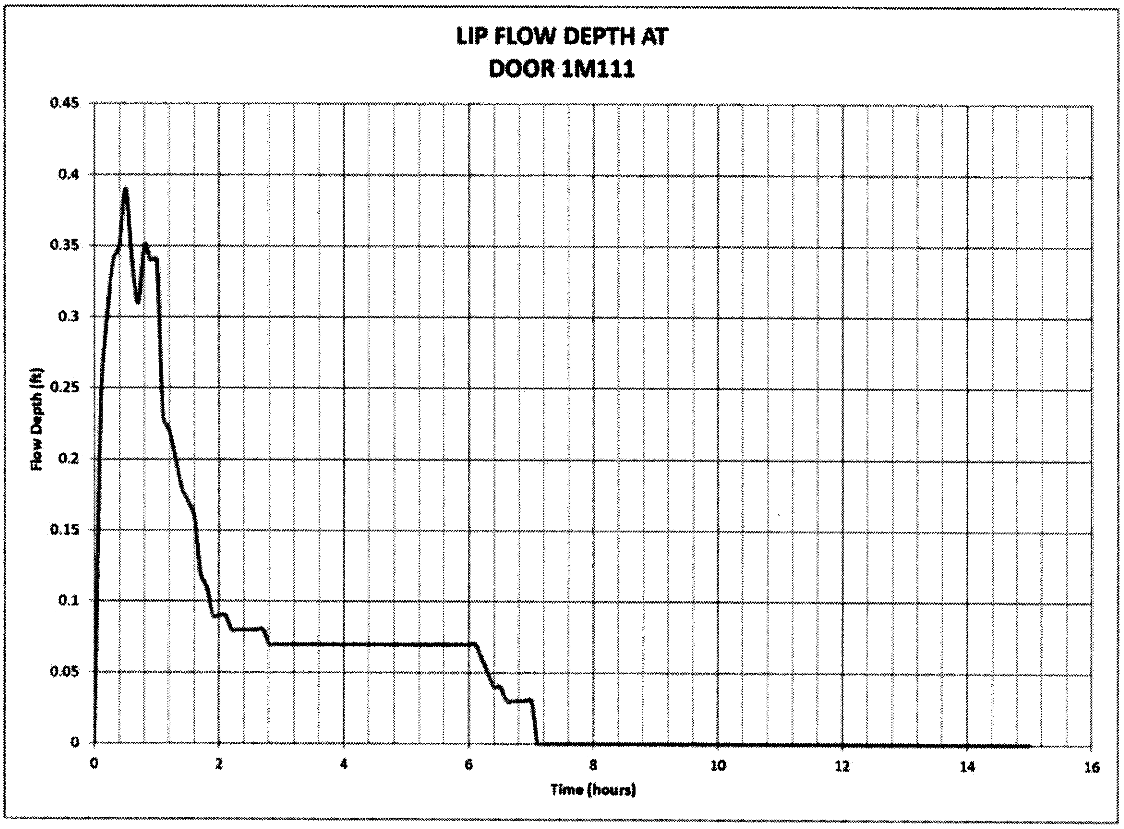

Figure 3.1-12: Water Depth at Door 1M111

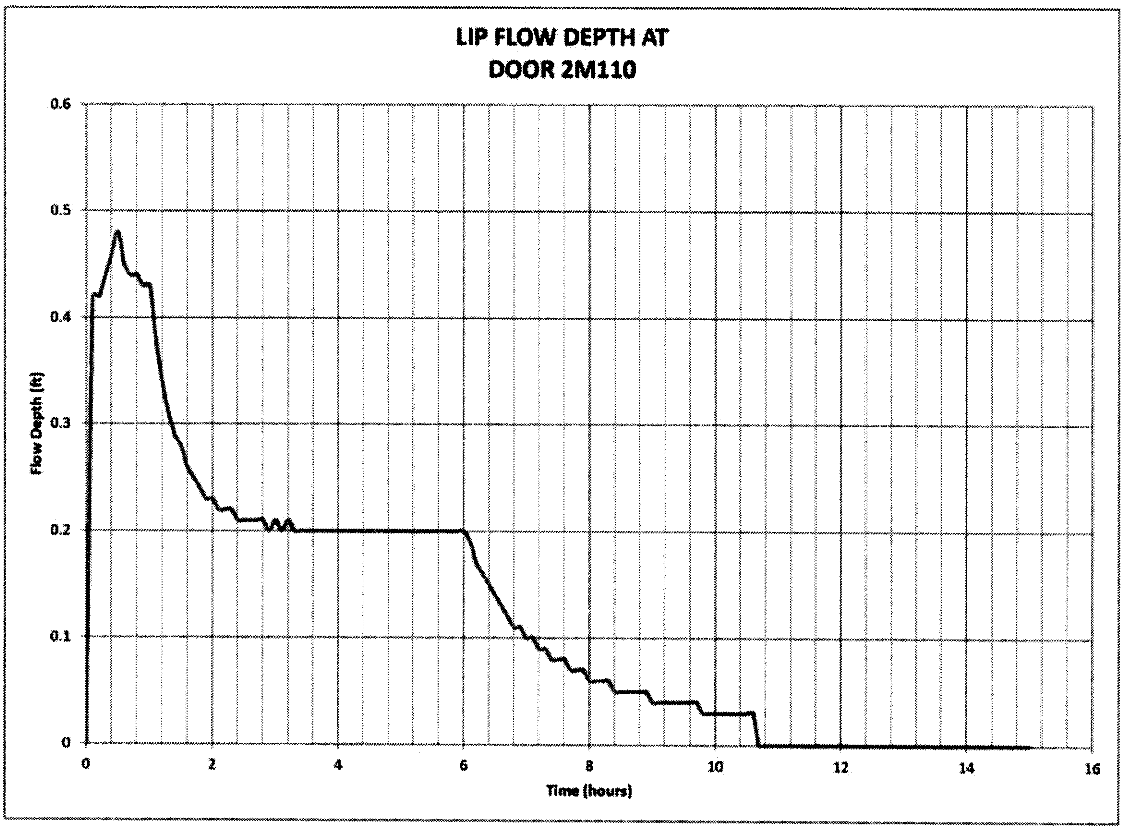

Figure 3.1-13: Water Depth at Door 2M110

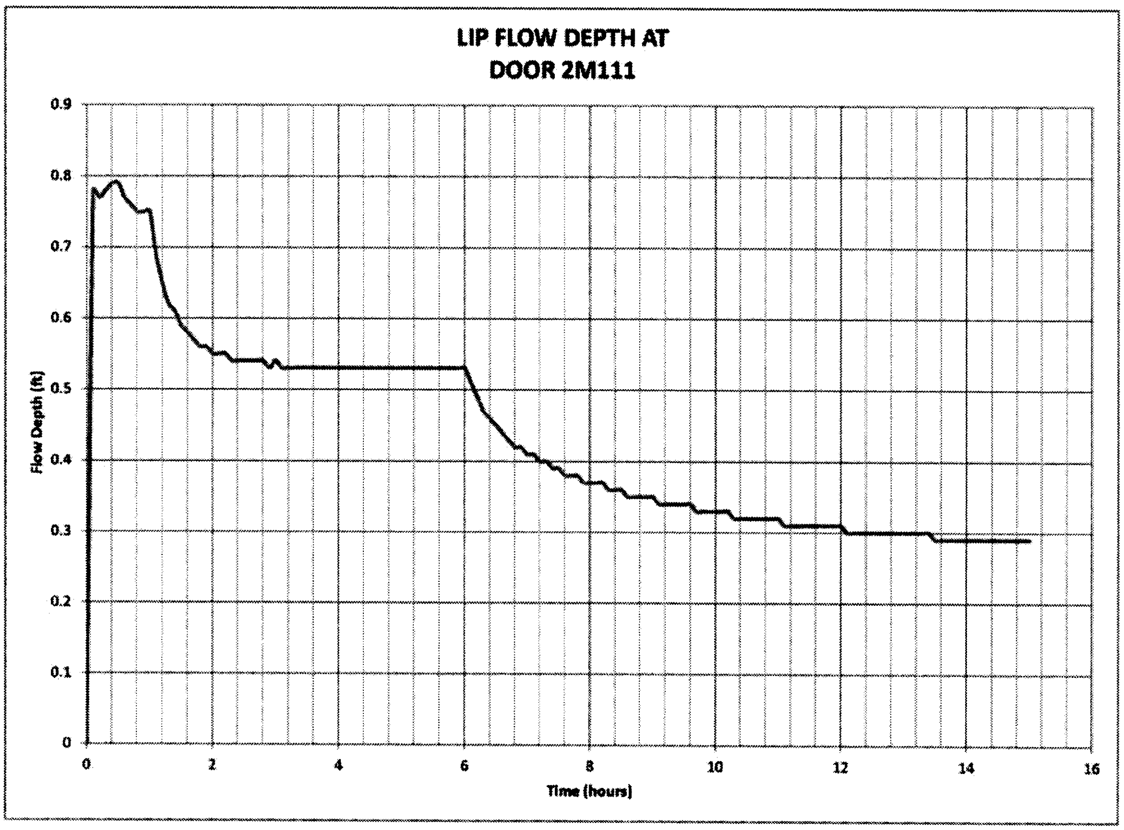

Figure 3.1-14: Water Depth at Door 2M111

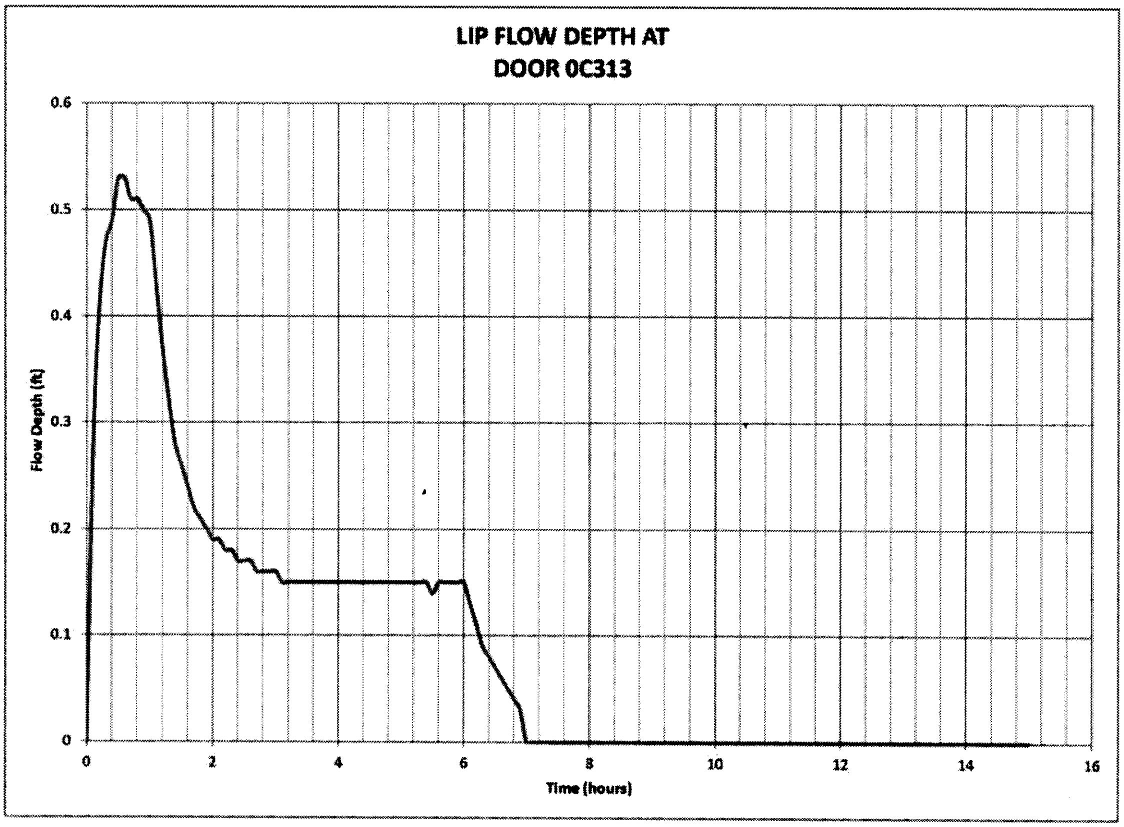

Figure 3.1-15: Water Depth at Door OC313

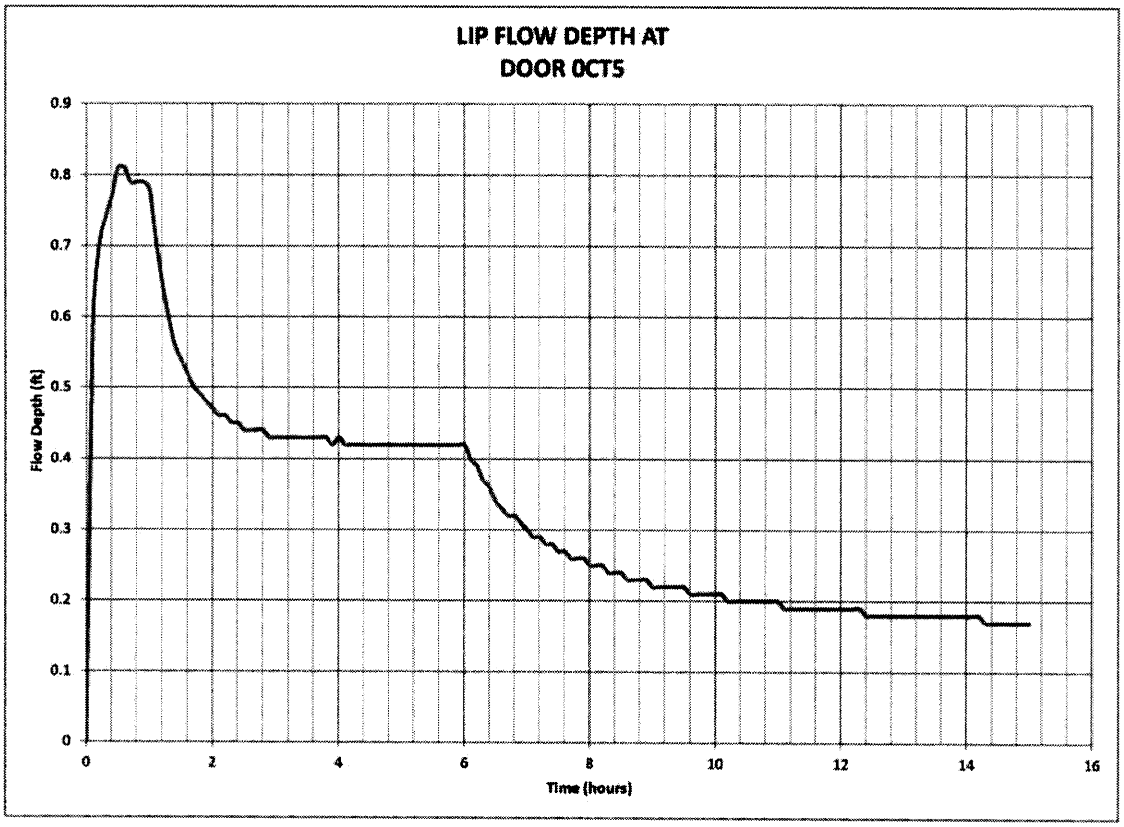

Figure 3.1-16: Water Depth at Door OCT5

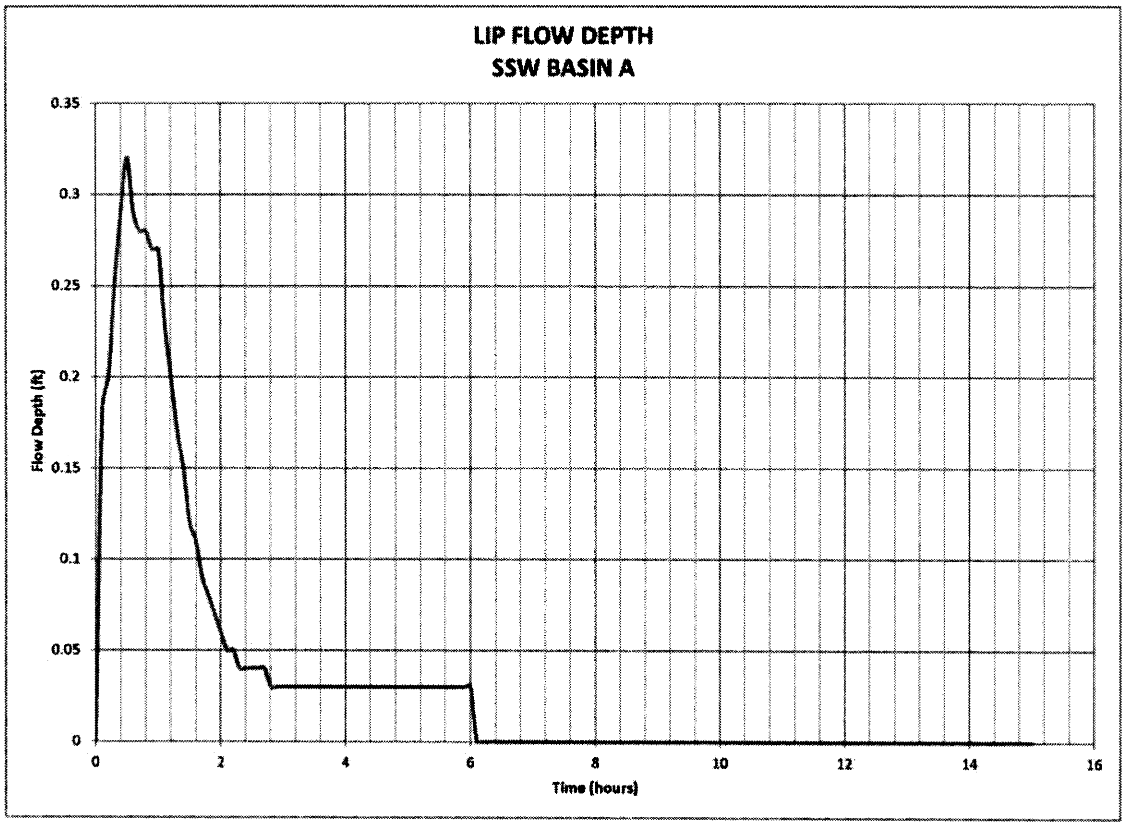

Figure 3.1-17: Water Depth on SWW Basin Alpha Pad

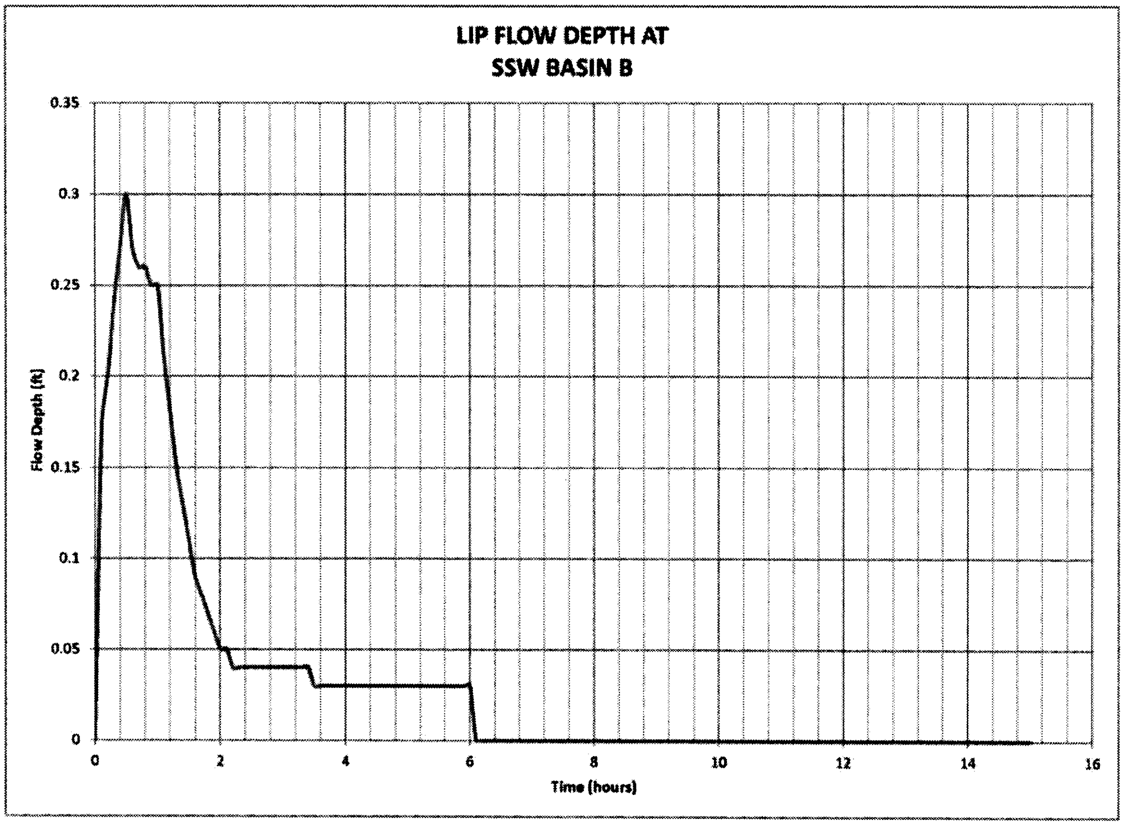

Figure 3.1-18: Water Depth on SWW Basin Bravo Pad

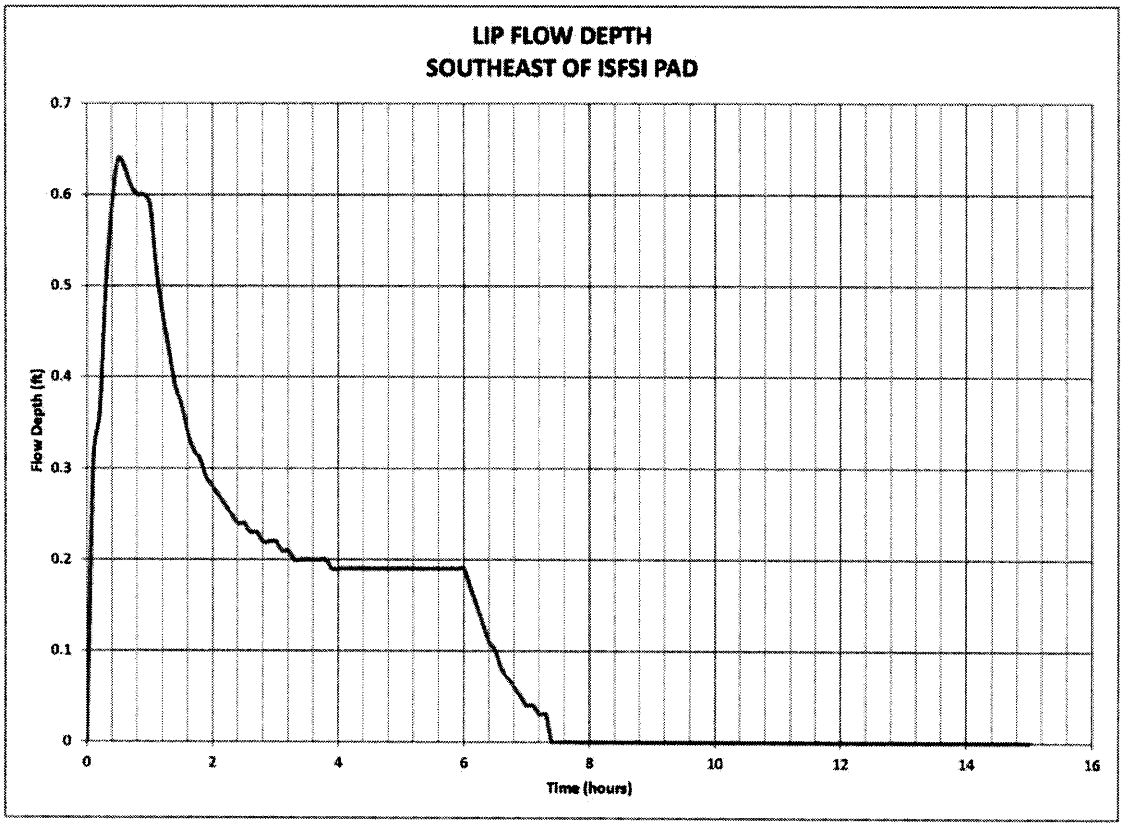

Figure 3.1-19: Water Depth near ISFSI Pad

3.2 Flooding in Rivers and Streams

This section addresses the potential for flooding at GGNS due to the PMF on streams and rivers. The PMF is the "hypothetical flood (peak discharge, volume, and hydrograph shape) that is considered to be the most severe reasonably possible, based on comprehensive hydrometeorological application of the probable maximum precipitation (PMP) and other hydrologic factors favorable for maximum flood runoff such as sequential storms and snowmelt." (NRC, 2011, Section 3.3)

The Mississippi River forms the western boundary of the site. GGNS is located on the east bank of the Mississippi River near river mile 406, approximately 25 miles south of Vicksburg, Mississippi, and 6 miles northwest of Port Gibson, Mississippi. In addition to the Mississippi River, Bayou Pierre is a natural stream located in a separate watershed south of the site and two unnamed streams (designated Stream A and Stream B) are located immediately north and south of GGNS (Figure 2.1-2). The Bayou Pierre watershed is separated from the watershed containing GGNS by a divide elevation of approximately 175 ft.

3.2.1 Method

HHA approach described in NUREG/CR-7046 (NRC, 2011, Section 2) was used for the evaluation of the PMF on rivers and streams and resultant water surface elevation at GGNS.

The HHA approach is consistent with the following standards and guidance documents:

1. NRC Standard Review Plan, NUREG-0800, revised March 2007;
2. NRC Office of Standards Development, Regulatory Guides:
    a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
    b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977; and
3. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

3.2.1.1 Probable Maximum Flood - Mississippi River

With respect to PMF on the Mississippi River, the HHA used the following steps:

1. Estimate the PMF flow on the Mississippi River at GGNS based on literature review and engineering judgment.
2. Develop HEC-RAS steady flow hydraulic computer model cross sections.
3. Calibrate HEC-RAS Model.
4. Perform PMF hydraulic simulations.

3.2.1.2 Probable Maximum Flood – Bayou Pierre

With respect to PMF on Bayou Pierre, the HHA used the following steps:

1. Calculate Probable Maximum Precipitation (PMP) using the methodology of Hydrometeorological Report Nos. 51 and 52 (HMR-51 and HMR-52).
2. Calculate the PMF on Bayou Pierre near GGNS.
    a. Delineate watershed and calculate subwatershed areas for input into USACE HEC-HMS rainfall-runoff hydrologic computer model.
    b. Identify rainfall-runoff model calibration and verification candidate floods.
    c. Estimate HEC-HMS rainfall-runoff model initial input parameters:
        i. Snyder Unit Hydrograph Method: Peaking Coefficient and Basin Lag Time.
        ii. Initial Loss and Constant Loss Rate.
    d. Calculate precipitation gage weights for calibration and verification floods.
    e. Calibrate and verify the HEC-HMS rainfall-runoff model utilizing observed USGS stream flow data by optimization of model input parameters: Peaking Coefficient, Basin Lag Time, Initial Loss, and Constant Loss Rate.
    f. Calculate rainfall-runoff parameters for ungaged subwatersheds.
    g. Perform PMF simulation with PMP input using calibrated and verified HEC-HMS model using nonlinearity adjustments to the subbasin unit hydrographs.
3. Calculate the PMF Elevation on Bayou Pierre River near GGNS.
    a. Develop HEC-RAS unsteady flow hydraulic computer model cross sections.
    b. Perform PMF hydraulic simulations.

3.2.1.3 Probable Maximum Flood – Streams A and B

With respect to PMF on Streams A and B, the HHA used the following steps:

1. Calculate PMP using the methodology of HMR-51 and HMR-52.
2. Delineate watersheds and perform PMF simulation using HEC-HMS. Since the streams are ungaged, calibration and verification of the HEC-HMS model is not possible. The Soil Conservation Service (SCS, now known as the Natural Resources Conservation Service, NRCS) Method was used to simulate the hydrology of the watersheds.
3. Perform 2-dimensional overland and channel flow simulation using the hydrodynamic computer program FLO-2D Pro with the calculated HEC-HMS PMF hydrograph from the PMF on Streams A and B as input to develop water surface elevations.

3.2.2 Results

3.2.2.1 Probable Maximum Flood – Mississippi River (AREVA, 2013a)

3.2.2.1.1 Estimate the PMF flow on the Mississippi River

The U.S. Army Corps of Engineers (USACE) Design Project Flood (DPF) was judged to be a reasonable basis for estimating the PMF for the Lower Mississippi River Basin and its 1.2 million-square-mile watershed (GGNS, 2008). The DPF is generally 40 to 60 percent of the PMF (Chow, 1964). This extrapolation is consistent with methodology used for the Grand Gulf Unit 3 Combined License Application (COLA) (GGNS, 2008). The DPF was conservatively assumed to be 40 percent of the PMF for this analysis.

The DPF for the Mississippi River at GGNS near river mile 406 is approximately 3,300,000 cfs (GGNS, 2008). The DPF as 40 percent of the PMF results in a PMF for the Mississippi River at GGNS of 8,250,000 cfs.

Peak stream flow data from United States Geological Survey (USGS) stream gage on the Mississippi River at Vicksburg, Mississippi (USGS 07289000) indicates that the highest recorded maximum daily average flow was 2,310,000 cfs on May 17, 2011 (USGS, 2012a). The PMF is therefore approximately 3.6 times higher than the flood of record at Vicksburg and judged to be appropriately conservative.

3.2.2.1.2 Develop HEC-RAS Hydraulic Computer Model Cross Sections

A hydraulic computer model (HEC-RAS v4.1) was developed for a 55-mile-long reach of the Mississippi River near GGNS using representative cross-section geometry data developed from bathymetric data from the U.S. Army Corps of Engineers (USACE, 2011) and digital elevation model (DEM) from the USGS (MGC, 2012). Due to the generally flat topography and wide extent of the floodplain, a limited number of cross-section elevation data points for the floodplain were selected for representative locations where elevation changes were noted. Levees, located along the west bank of the Mississippi River, were also added to the cross-sections in HEC-RAS (MRC, 2007). The HEC-RAS hydraulic model extends 29 miles upstream of the site and 26 miles downstream from the site. A steady flow (e.g., peak PMF flow rate) was then routed in the HEC-RAS model to establish flood elevations.

3.2.2.1.3 Calibrate HEC-RAS Model

Model calibration is the process of selecting and refining HEC-RAS input parameters to produce a simulated profile for a given flood that shows good agreement with an accepted water surface profile for the a given flood. For this application, the model is intended to produce a hypothetical flood (i.e., the PMF) derived from a USACE study and not intended to reproduce historical floods which are of much lower magnitude. The HEC-RAS model was calibrated using the USACE DPF flow and elevation at GGNS by adjusting the Manning's-n values for the cross-section geometry data and the friction slope used for the upstream and downstream boundary conditions until the flood elevation matched the USACE estimated DPF elevation at GGNS. The upstream and downstream boundary conditions were modeled within HEC-RAS as "normal depth."

3.2.2.1.4 Perform PMF Hydraulic Simulations

The peak PMF stage on the Mississippi River near GGNS was calculated to be 106.2 ft using the calibrated HEC-RAS model. This indicates that the levees on the west bank of the river (103 ft at this location) are overtopped during the flood (MRC, 2007).

3.2.2.2 Probable Maximum Flood – Bayou Pierre (AREVA, 2013b)

3.2.2.2.1 Estimate the PMP for the Bayou Pierre Watershed

The PMP was calculated for the 1,005-square-mile Bayou Pierre watershed using the methodology of HMR-51 and HMR-52. The HMR52 computer program was used for the calculations. The maximum duration of 72-hours used in HMR-51 and HMR-52 was conservatively adopted for the evaluation. The total rainfall amount was calculated to be 36.3 inches (AREVA, 2013d).

3.2.2.2.2 Estimate the PMF flow on Bayou Pierre

The general approach to modeling the hydrology of the watershed was to use observed USGS stream gage data (USGS gage 07290650, Bayou Pierre near Willows, Mississippi, USGS, 2012b) to calibrate the HEC-HMS model through optimization of the input parameters: (1) Snyder Peaking Coefficient, (2) Snyder Lag Time, (3) initial loss, and (4) constant loss rate. The USGS stream gage covers about 65 percent of the watershed. The input parameters for the ungaged portion of the watershed were estimated based on the calibrated / verified parameters for the gaged portion of the watershed. Ten storms / floods were used during the calibration / verification process.

The HEC-HMS results indicate that the calculated peak discharge is 638,500 cfs. Non-linearity adjustments were then applied to the input unit hydrograph as per NUREG/CR-7046 (NRC, 2011, Section 3.3, Appendix B, Case 2): the peak discharge of the unit hydrograph was increased by one-fifth and the time-to-peak was decreased by one third. The combined PMF peak discharge calculated using HEC-HMS and incorporating non-linearity adjustments is 734,000 cfs.

3.2.2.2.3 Estimate Water Surface Elevations for Bayou Pierre

A hydraulic computer model (HEC-RAS v4.1) was developed for a 22-mile-long reach of Bayou Pierre. The upstream and downstream limits of the GGNS HEC-RAS model are approximately 6 miles upstream and 16 miles downstream of GGNS, respectively. A total of 11 cross sections were used. One levee with a top elevation of 96.1 feet was added to the station representing confluence with the Mississippi River. No water level data within the reach of interest was available; therefore, calibration of the HEC-RAS model was not possible. The peak PMF stage was calculated to be 130.7 ft, which is well below the elevation of the Bayou Pierre watershed divide elevation of about 175 ft near GGNS.

3.2.2.3 Probable Maximum Flood – Streams A and B (AREVA, 2013c)

3.2.2.3.1 Estimate the PMP for Streams A and B Watershed

The PMP was calculated for the each watershed using the methodology of HMR-51 and HMR-52. The HMR-52 computer program was used for the calculations. The maximum duration of 72-hours used in

HMR-51 and HMR-52 was conservatively adopted for the evaluation. The 72-hour total rainfall amount was calculated to be 53.5 inches for both watersheds (AREVA, 2013d).

3.2.2.3.2 Estimate the PMF flow on Streams A and B

A HEC-HMS model using the SCS method was developed for the watersheds of Streams A and B. There is no recorded stream flow information available. Thus, conservative input parameters were used, including the use of Antecedent Runoff Condition III Curve Numbers (i.e., wet antecedent moisture conditions) (NRC, 2011, Appendix C). Watershed lag times were calculated based on the SCS Time of Concentration method (NRC, 2011, Appendix C). The calculated PMF on Streams A and B were 17,400 cfs and 5,700 cfs, respectively.

Non-linearity adjustments were then applied (see Section 2.2.2.2.3). The adjusted PMF peak flow rates for Streams A and B were 18,600 cfs and 6,000 cfs, respectively.

3.2.2.3.3 Estimate Water Surface Elevations for Streams A and B

Two-dimensional, overland flow modeling for Streams A and B is necessary to determine the impact of stream PMF events for the GGNS site. Therefore, a two-dimensional hydrodynamic computer model (FLO-2D Pro, a finite difference model) was developed to simulate water surface elevations for the PMF on Streams A and B. High resolution topographic information (Sanborn, 2007) was used to develop a representative 50 ft "grid" for the site vicinity. Manning's roughness coefficients judged appropriate based on observed land cover were also input into the FLO-2D Pro model. Infiltration losses were ignored.

Other channels (besides Streams A and B) and most culverts near GGNS were conservatively assumed to be non-functional. One exception was made for Culvert No. 1, located on Stream B, south of GGNS. Culvert No. 1 is a 15-foot corrugated metal pipe culvert that runs beneath a GGNS access road. Stream B is lined with concrete to a height to a height of 5 feet above the channel bottom and with riprap from a height of 5 feet above the channel bottom to plant grade elevation (GGNS, 2012, Section 2.4), limiting sources of debris (i.e., vegetation) which could block Culvert No. 1. GGNS also has a procedure to ensure that Culvert No. 1 is free from debris that can block the culvert (GGNS, 2012, Section 2.4). However, based on guidance in NUREG/CR-7046 (NRC, 2011, Section 3.2, Appendix B, Case 2), Culvert No. 1 was conservatively modeled as being 50-percent blocked by debris.

The calculated maximum water surface elevation at GGNS resulting from the PMF on Stream A is 132.1 feet. Flood wave progression onto the GGNS site was limited to the area north of GGNS Unit 2 warehouse and the depressed area at the northern end of the site. The calculated maximum PMF elevation in Stream B at the Plant Access Road is 131.7 feet.

3.2.3 Conclusions

At GGNS, impacts to the site from PMF events on rivers and streams are judged to be bounded by the current licensing basis for the following reasons:

The probable maximum flood on the Mississippi River near GGNS is conservatively estimated at 8,250,000 cfs. Historical records do not indicate flooding in excess of this PMF flow. The peak PMF

water surface elevation on the Mississippi River near Grand Gulf Nuclear Station is 106.2 ft, which is 26.3 ft below the site grade elevation of 132.5 ft (GGNS, 2012).

The PMF peak discharge for Bayou Pierre calculated using HEC-HMS and incorporating non-linearity adjustments is 734,000 cfs. The peak PMF stage was calculated to be 130.7 ft which is well below the elevation of the Bayou Pierre watershed divide elevation of about 175 ft near GGNS.

The PMF peak discharge for Streams A and B were 18,600 cfs and 6,000 cfs, respectively. The calculated peak PMF stage on Stream A is 132.1 feet, below the site grade elevation of 132.5 ft (GGNS, 2009). The calculated peak PMF stage on Stream B is 131.7 feet, below the site grade elevation of 132.5 ft (GGNS, 2012).

3.2.4 References

AREVA, 2012a. AREVA Document No. 32-9195575-000, Grand Gulf Nuclear Station Flood Hazard Re-Evaluation – Probable Maximum Flood on Streams and Rivers – Mississippi River, TBD 2013.

AREVA, 2012b. AREVA Document No. 32-9195576-000, Grand Gulf Nuclear Station Flood Hazard Re-Evaluation – Probable Maximum Flood on Streams and Rivers – Bayou Pierre, TBD 2013.

AREVA, 2012c. AREVA Document No. 32-9195577-000, Grand Gulf Nuclear Station Flood Hazard Re-Evaluation – Probable Maximum Flood on Streams and Rivers – Local Streams A and B Flow and Elevations, TBD 2013.

AREVA, 2012d. AREVA Document No. 32-9195574-000, Grand Gulf Nuclear Station Flood Hazard Re-Evaluation – Probable Maximum Precipitation, TBD 2013.

Chow, 1964. Chow, Ven Te Handbook on Applied Hydrology, McGraw-Hill, New York, 1964.

GGNS, 2008. Grand Gulf Nuclear Station Combined License Application Final Safety Analysis Report, Revision 0, 2008.

GGNS, 2012. Grand Gulf Nuclear Station UFSAR, 2012, see AREVA Document No. 38-9193642-000.

HMR-51. Probable Maximum Precipitation Estimates, United States, East of the 105th Meridian, NOAA Hydrometeorological Report No. 51, June 1978.

HMR-52. Application of Probable Maximum Precipitation Estimates, United States, East of the 105th Meridian, NOAA Hydrometeorological Report No. 52, August 1982.

MGC, 2012. USGS Digital Elevation Model (DEM)" Mississippi Geospatial Clearinghouse.

MRC, 2007. "The Mississippi River & Tributaries Project: Controlling the Project Flood", Mississippi River Commission, Information Paper 2007.

NRC, 2011. "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants - NUREG/CR-7046", U.S. Nuclear Regulatory Commission, November 2011. (ADAMS Accession No. ML11321A195).

USACE, 2011. "Mississippi River General Hydrographic Single beam Survey", U.S. Army Corps of Engineers, Vicksburg District, November 2011.

USGS, 2012a. USGS 07289000 Mississippi River at Vicksburg, MS, U.S. Geological Survey National Water Information System, Website: http://waterdata.usgs.gov/nwis/qw, accessed December, 2012, AREVA Document No. 32-9195575-000, Appendix A and Appendix I.

USGS, 2012b. USGS 07296500 Bayou Pierre at Willows, MS, U.S. Geological Survey National Water Information System, Website: http://waterdata.usgs.gov/nwis/qw, accessed December, 2012, AREVA Document No. 32-9195576-000, Appendix A and Appendix I.

Sanborn 2007. "01200745T(JTD)-nad27.dwg" Grand Gulf Nuclear Station Topographic Survey, Sanborn, LLC, February 2007 (in AutoCAD™ format), see AREVA Document No. 38-9193642-000.

3.3 Dam Breaches and Failures

This section addresses the effects of upstream dam failures on the Mississippi River PMF maximum water surface elevation at GGNS. Dam breaches and failures may cause flood waves that impact the PMF level of the receiving water body. Dam breaches and failures of onsite structures, such as retaining ponds, can also impact site safety (NRC, 2011, Section 3.4).

There are no dams on the Mississippi River within 100 river miles upstream of GGNS. The hypothetical failure of the largest dam on a tributary of the Mississippi River closest to GGNS was used in this analysis. There are no dams or reservoirs on the unnamed local streams adjacent to GGNS. As per AREVA Document No. 32-9195576-000 (AREVA 2012b), Bayou Pierre is not anticipated to overflow its watershed divide during PMF conditions. There are also no dams of significant height and storage in the Bayou Pierre watershed (USACE, 2012). Thus, dam failure was not evaluated within the Bayou Pierre watershed.

There are no on-site dams or levees which could impact site safety if breached (GGNS, 2012, Section 2.4).

3.3.1 Method

The HHA described in NUREG/CR-7046 (NRC, 2011, Section 2) was used for the evaluation of the effects of upstream dam failures on the Mississippi River PMF maximum water surface elevation at GGNS (AREVA, 2013b).

The HHA approach is consistent with the following standards and guidance documents:

1. NRC Standard Review Plan, NUREG-0800, revised March 2007;
2. NRC Office of Standards Development, Regulatory Guides:
    a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
    b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977; and
3. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

Based on a review of flow regulation structures and the nature of storage in the reservoirs on the different river basins within the Mississippi River drainage area (GGNS, 2003), the total number of significant dams in the Mississippi River drainage basin exceeds 300. Sixty-one of these dams have storage capacities exceeding one million acre-ft. A summary of the dams closest to GGNS is given in Table 3.3-1.

The criteria for flooding from dam breaches and failures evaluation is provided in NUREG/CR-7046, Appendix D (NRC, 2011). Two scenarios of dam failures are recommended and discussed in NUREG/CR-7046, Appendix D, including:

1. Failure of individual dams (i.e., group of dams not domino-like failures) upstream of the site; and

2. Cascading or domino-like failures of dams upstream of the site.

The PMF scenario discussed below bounds Sunny Day and Seismic failure modes, since upstream reservoir levels used in the calculations were higher (i.e., coincident with top of dam).

Due to the large number of dams upstream of GGNS, the application of the two scenarios of dam failure discussed in NUREG/CR-7046, Appendix D, for all dams is not realistic. Therefore, the methodology for selecting the dams in the flooding assessment at GGNS due to dam failures adopted in this calculation is as follows:

1. Identify the largest dam relatively nearby GGNS;
2. Calculate peak dam breach outflow;
3. In accordance with the Hierarchical Hazard Assessment approach, directly translate peak dam breach outflow to GGNS without attenuation;
4. Calculate resultant water surface elevation;
5. Demonstrate availability of additional channel and floodplain capacity to accommodate other coincident (extremely improbable) upstream dam failure effects.

3.3.2 Results (AREVA, 2013a)

The Kentucky Dam was selected for use in analyzing the effects of dam breach on flood elevations at GGNS because it the largest dam that is closest to GGNS. The Kentucky Dam is a hydroelectric facility (TVA, 2012) and is located approximately 450 miles upstream of GGNS on the Tennessee River which is a tributary to the Mississippi River. The selection of the Kentucky Dam for use in this analysis is judged to be appropriate even though it is not the closest dam to GGNS. This judgment stems from the use of the HHA approach (NRC, 2011), which ignores attenuation of the peak breach outflow from the dam. Hence, the use of the larger Kentucky Dam in the analysis is more conservative than the use of Grenada Dam, which is the closest major dam to GGNS (Table 3.3-1), 200 miles upstream (Figure 3.3-1).

Pertinent information on Kentucky Dam is summarized below:

Dam Height (ft)	206 (105 ft above ground level, GGNS 2003)
Dam Length (ft)	8,422
Reservoir Surface Area (acres)	160,300
Maximum Storage Capacity (acre-ft)	6,129,000
Flood Storage Capacity (acre-ft)	4,008,000
Spillway Length (ft)	1176 (TVA 1951)
Dam Type	Concrete

Source: Tennessee Valley Authority, TVA, 2012.

The peak breach outflow from the Kentucky Dam is estimated using the National Weather Service (NWS) peak breach outflow equation (Fread, 1991). The estimated peak breach outflow is based on the reservoir size, the size of the breach, and the length of time it takes for the breach to develop.

The peak breach outflow from the Kentucky Dam is estimated to be approximately 3,920,000 cfs. The PMF peak flow at GGNS is 8,250,000 cfs (AREVA, 2013b). Therefore, the total flow at GGNS with failure of the Kentucky Dam under PMF conditions is estimated to be 12,170,000 cfs.

The Mississippi River peak water surface elevation (or the flood stage) resulting from the combination of upstream dam breach and the PMF is calculated using the GGNS HEC-RAS model (AREVA, 2013b). Attenuation of dam breach outflow is conservatively ignored (i.e., peak dam breach outflow is directly translated to the HEC-RAS model). The estimated combined dam break and PMF flow on the Mississippi River at GGNS is used as inflow to perform the HEC-RAS simulation.

The peak stage resulting from the failure of the Kentucky Dam under PMF conditions was calculated to be 117.4 ft using the GGNS HEC-RAS model (AREVA, 2013b). The estimated combined peak flow rate (dam breach peak flow rate and the PMF at GGNS Mississippi) of 12,170,000 cfs was used as input to the HEC-RAS steady state simulation.

Additional iterations of the HEC-RAS model were also performed to estimate the floodplain and channel flow capacity corresponding to Elevation 132.5 ft at GGNS (i.e., site grade elevation).

The flow capacity of the Mississippi River channel and floodplain corresponding to Elevation 132.3 ft at GGNS was estimated using the Mississippi River PMF HEC-RAS (AREVA, 2012b) to be about 18,200,000 cfs.

3.3.3 Conclusions

At GGNS, the impact of dam breaches and failures on flooding hazard at the site is negligible for the following reasons:

- The Mississippi River PMF peak flow at the Grand Gulf Nuclear Station was estimated to be 8,250,000 cfs (AREVA, 2013b).
- The Kentucky Dam peak breach outflow is estimated to be 3,920,000 cfs.
- The combined dam break peak outflow and PMF at GGNS, conservatively assuming no attenuation of the breach outflow to the GGNS site 450 miles downstream, is estimated to be 12,170,000 cfs.
- The resultant peak water surface elevation from the combined dam breach peak outflow and PMF in the Mississippi River at Grand Gulf Nuclear Station is 117.4 ft, which is 15.1 ft below the site grade elevation of 132.5 ft, NGVD29.
- The estimated Mississippi River channel and floodplain capacity at GGNS is estimated to be about 18,200,000 cfs, with approximately 60 lateral miles of floodplain storage in the vicinity of GGNS. Therefore, an additional 6,030,000 cfs is available to accommodate other coincident dam failures without affecting the site.

Based on the re-evaluation of upstream dam failures on the Mississippi River, the peak water surface elevation on the Mississippi River at GGNS resulting from the failure of Kentucky Dam and the PMF is below the plant grade elevation and would not affect safety-related SSC important to safety at GGNS. Even in the unlikely event of multiple major upstream dams failing simultaneously, the Mississippi River channel and floodplain capacity at GGNS is expected to be adequate to contain the attenuated, non-synchronized peak flows without affecting safety-related structures, systems, or components. Additional refinement of the dam failure model is not necessary due to the sufficient margin indicated by the initial conservative analysis.

3.3.4 References

AREVA, 2013a. AREVA Document No. 32-9195578-000, "Grand Gulf Nuclear Station Flood Hazard Re-evaluation – Dam Failures", January 2013.

AREVA, 2013b. AREVA Document No. 32-9195575-000, "Probable Maximum Flood on Streams and Rivers – Mississippi River Flow and Elevations", January 2013.

Fread, 1991. "The NWS Simplified Dam-Break Flood Forecasting Model" Fread, Lewis and Wiele, 12/18/91.

GGNS, 2003. GGNS Early Site Permit Application, October 2003.

GGNS, 2012. Grand Gulf Nuclear Station UFSAR, 2012, see AREVA Document No. 38-9193642-000.

NRC, 2011. NUREG/CR-7046, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America, U.S. Nuclear Regulatory Commission, November 2011.

TVA, 2012. Tennessee Valley Authority. http://www.tva.gov/sites/kentucky.htm, date accessed December 2012, AREVA Document No. 32-9195578-000, Appendix B.

TVA, 1951. TVA's design plan for Kentucky Dam, on the Tennessee River in Marshall County, Kentucky, USA, Tennessee River Authority, The Kentucky Project: A Comprehensive Report on the Planning, Design, Construction, and Initial Operations of the Kentucky Project, Technical Report No. 13. 1951.

USACE, 2012. USACE National Inventory of Dams. http://geo.usace.army.mil/pgis/f?p=397:12:, AREVA Document No 32-9195578-000, Appendix E.

Table 3.3-1: Major Dams Closest to GGNS

Sub-Basin	River	Total Storage (million acre-ft)	Dam Closest to GGNS	Approximate Distance to GGNS (river miles)
Missouri	Missouri	6.30	Fort Randall Reservoir and Dam	1300
Ohio	Tennessee	6.129	Kentucky	450
	Cumberland	2.082	Barkley	450
White	White	1.983	Norfolk Reservoir and Dam	350
Arkansas	Arkansas	1.348	Keystone Reservoir and Dam	475
Lower Mississippi	Mississippi	2.722	Grenada Reservoir and Dam	200

Source: GGNS Early Site Permit Application (GGNS 2003)

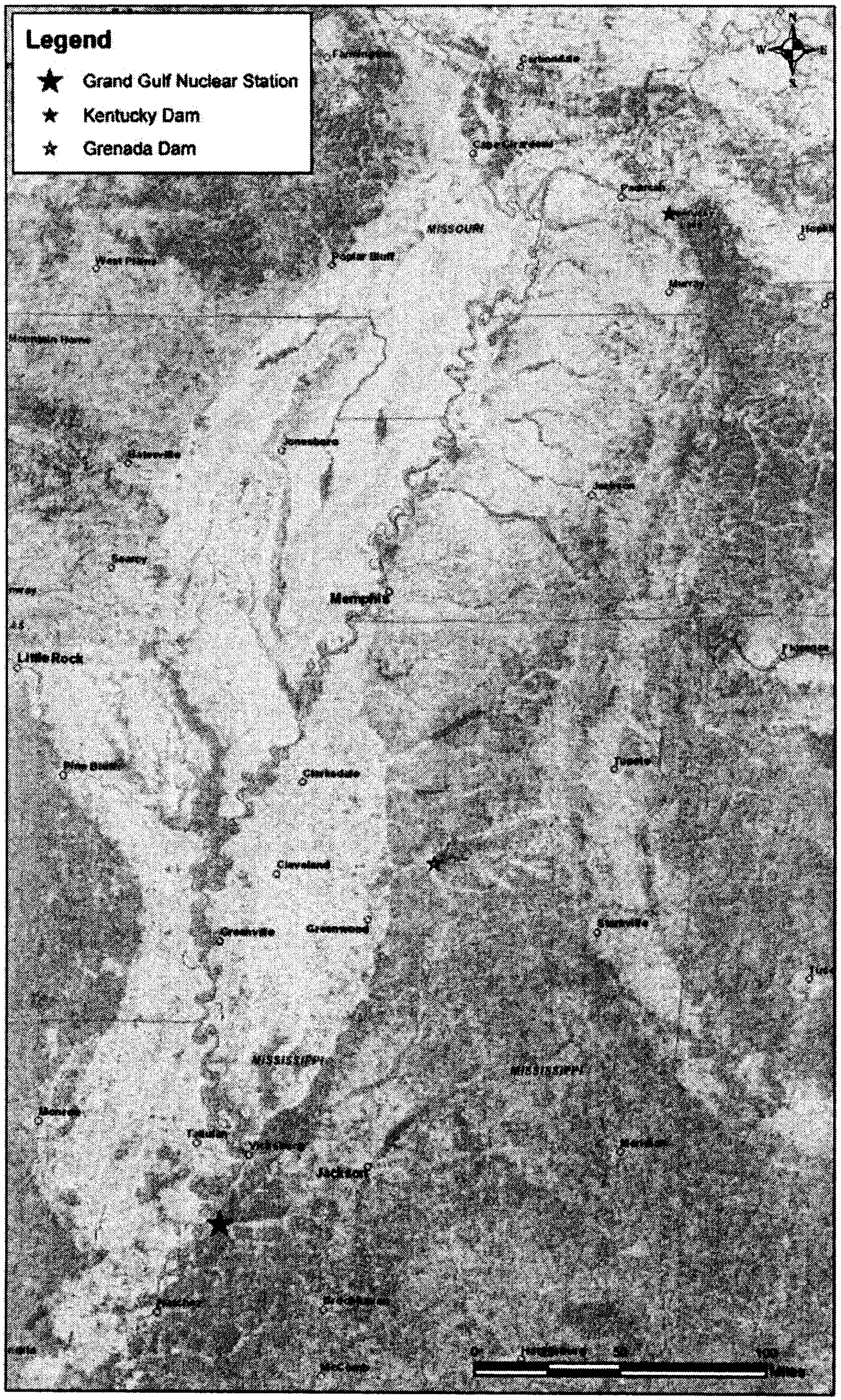

Figure 3.3-1: Dam Locations

3.4 Storm Surge

Storm surge is a rise in offshore water elevations caused principally by the sheer force of winds acting on the water surfaces, typically associated with hurricanes (NRC, 2011, Section 3.5).

GGNS is an inland site, and the potential of storm surge swells propagating from offshore waters upstream to GGNS is judged to be negligible for the following reasons.

GGNS is 406 river miles upstream from the Gulf of Mexico coastline, and over 132 feet above mean sea level. Due to the distance and elevation of the site, storm surges generated in offshore waters would be unable to propagate to the vicinity of the site. In addition, the Mississippi River in the vicinity of the site has a probable maximum flood elevation coincident with wind generated waves of 122.5 ft, well below the site grade of 132.5 ft MSL.

Given the horizontal distance from the site to the Mississippi River floodplain, and the vertical margin between the Mississippi River flood levels and the GGNS site grade, the flooding hazard contribution from storm surges is negligible for the GGNS site. As such, a detailed evaluation was not performed for storm surge induced flooding for the site.

3.4.1 References

NRC, 2011. "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants - NUREG/CR-7046", U.S. Nuclear Regulatory Commission, November 2011.

3.5 Seiche

A seiche is an oscillation of the water surface in an enclosed or semi-enclosed body of water initiated by an external cause. Once started, the oscillation may continue for several cycles; however, over time it gradually decays because of friction (NRC, 2011, Section 3.6).

3.5.1 Method

The seiche evaluation followed the HHA described in NUREG CR-7046, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America (NRC, 2011).

The approach used in the HHA approach is consistent with the following standards and guidance documents:

1. NRC Standard Review Plan, NUREG-0800, revised March 2007;
2. NRC Office of Standards Development, Regulatory Guides:
    a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
    b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977;
3. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

With respect to seiches, the HHA used the following step:

1. Determine whether a seiche in a nearby lake or reservoir can potentially lead to flooding at the site.

3.5.2 Results

Gin and Hamilton Lakes are two small water bodies in the vicinity of GGNS, both located in the Mississippi River floodplain. The distance from the lakes to the site (3,500 ft and 4,650 ft from Hamilton and Gin Lakes, respectively) precludes the possibility of seiche related flooding impacts for GGNS from these water bodies.

The Mississippi River in the vicinity of GGNS could be considered a semi-enclosed body of water in the case of east/west seiche oscillation (perpendicular to river flow). Seiche oscillations could also potentially propagate up/down stream due to the meandering nature of the Mississippi River, which could be considered to cause a semi-enclosed body of water. Seiche oscillation in the Mississippi River near GGNS in normal flow conditions would overtop the man-made levees on the western banks of the river (103 feet) prior to any impact to the GGNS site. Once the seiche oscillations were to overtop the levees, the water would drain to the floodplain west of the Mississippi River and away from the GGNS site, which has sufficient storage to accept any volume of seiche related flooding. In PMF flow conditions (See Section 3.2), the GGNS site is approximately 1,800 ft away from the inundated

Mississippi River flood plain and 26 ft higher in elevation. This lateral and vertical margin provides sufficient margin.

3.5.3 Conclusions

At GGNS, the potential of seiches impacting the site is judged to be negligible for the following reason.

The man-made levees bounding the western edge of the Mississippi River channel are approximately 29 feet below the site grade. Any seiche oscillations under normal flow conditions would overtop the levees and drain into the wide floodplain west of the Mississippi River before impacting the GGNS site. In PMF conditions on the Mississippi River, the lateral and vertical margin for the plant is sufficient to preclude any impact to the site.

3.5.4 References

NRC, 2011. "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants - NUREG/CR-7046", U.S. Nuclear Regulatory Commission, November 2011.

3.6 Tsunami

A tsunami is "a series of water waves generated by a rapid, large-scale disturbance of a water body due to seismic, landslide, or volcanic tsunamigenic sources" (NRC, 2009, Section 1.1). As an inland site, GGNS is not in a region typically susceptible to oceanic tsunamis (NRC, 2009, Section 2.1). However, the Mississippi River is a large enough water body that tsunami generating events could potentially result in tsunami-like waves.

3.6.1 Method

The GGNS tsunami evaluation followed the HHA described in NUREG/CR-6966, Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America (NRC, 2009).

With respect to tsunamis, the progressive HHA is considered as a series of three tests:

1. Is the site region subject to tsunamis?
2. Is the plant site affected by tsunamis?
3. What are the hazards posed to safety of the plant by tsunamis?

At GGNS, however, only the first test needed to be considered. The second and third steps were unnecessary based on the results of the first test.

The first test was answered by performing a regional survey and assessment of potential tsunamigenic sources. The regional survey was in four parts and included the relevant mechanisms that generate tsunamis. The first part was to review the Global Historical Tsunami Database, maintained by the National Oceanic Atmospheric Administration's National Geophysical Data Center (NGDC), to determine the history of tsunamis. The second, third, and fourth parts of the regional survey included an assessment of the mechanisms likely to cause a tsunami.

3.6.2 Results

3.6.2.1 Regional Survey

Tsunamis are generated by rapid, large-scale disturbance of a body of water. Therefore, only geophysical events that release a large amount of energy in a very short time into a water body generate tsunamis. The most frequent cause of tsunamis is an earthquake. Less frequently, tsunamis are generated by submarine and subaerial landslides and volcanic eruptions. (NRC, 2009, Section 1.3) Meteorite impacts, volcanoes, and ice falls can also generate tsunamis, but were excluded from the regional survey because meteorite impacts and volcanoes are very rare events and ice falls are generally associated with glacial ice processes.

3.6.2.1.1 NGDC Database Review

The National Geophysical Data Center (NGDC) tsunami-source-event database is global in extent with information dating from 2000 B.C. to the present. As an inland site, the GGNS regional survey considered tsunami-like waves in the Mississippi River.

Five events were recorded on the Mississippi River, all due to earthquakes associated with the New Madrid Seismic Zone. All events resulted in a seiche or disturbance in an inland river. There are no recorded maximum water heights for these events. Associated runups were primarily categorized as seiches.

3.6.2.1.2 Earthquakes

To generate a major tsunami, a substantial amount of slip and a large rupture area is required. Consequently, only large earthquakes with magnitudes greater than 6.5 centered within the water body generate observable tsunamis (NRC, 2009, Section 1.3.1). Due to the meandering nature of the Mississippi River, far-field tsunami generating events would be unable to propagate over long distances along the Mississippi River without losing significant energy to the meandering channel. Additionally, any tsunami-like wave elevations traveling parallel to river flow would be constrained from impacting the site by the man-made levees on the western banks. A tsunami-like wave elevation over 103 feet MSL would overtop the levee and spill into the floodplain to the west of the Mississippi River, away from the site.

Based on the geological and seismological information presented in the GGNS COLA (GGNS, 2008, Section 2.5.2), the site region is relatively aseismic. The probability of a magnitude 6.5 or greater earthquake in the Mississippi River centered near GGNS is judged to be negligible.

The New Madrid Seismic Zone is the most seismically active area in the vicinity of the Mississippi River, and is located approximately 292 miles (470 km) from the GGNS site (GGNS, 2008). All five recorded events in the NGDC database were associated with 1811/12 and 1895 seismic activity from the New Madrid Seismic Zone.

Seismic activity occurring outside the site region can also produce seismic seiches (USGS, 2012). Seismic waves from the Alaska earthquake of 1964, for example, caused water bodies to oscillate at many places in North America. Seiches were recorded at hundreds of surface-water gaging stations. The seismic seiche distribution did not have an obvious dependence on distance or azimuth from the epicenter. Instead, the distribution had a regional pattern, which reflected the influence of major geologic features. The southeastern part of the United States had the greatest density of seiches, while areas west of the Rockies, the Middle Atlantic States, and New England experienced few or no seiches. A favorable environment for seismic seiche generation includes thrust faults and locations controlled by structural uplifts and basins (USGS, 2012). The GGNS susceptibility to seiche events is discussed in Section 2.5.

3.6.2.1.3 Landslides

There are two broad categories of landslides: (1) subaqueous that are initiated and progress beneath the surface of the water body, and (2) subaerial that are initiated above the water and impact the water body during their progression or fall into the water body. In addition, landslide-generated tsunami-like waves have a very strong directivity in the direction of mass movement. Therefore, the outgoing wave from the landslide source propagates in the direction of the slide. The most common landslide mechanism is an earthquake. (NRC, 2009, Section 1.3.2)

Subaqueous Landslide – Mississippi River Bathymetry

The lower Mississippi River channel is regularly dredged to maintain navigability and to prevent migration and erosion. As a result, the bathymetry can be defined as relatively flat, unlikely to result in any significant subaqueous landslide events.

Subaerial Landslide – Mississippi River Floodplain Topography

The geographical areas where subaerial landslides occur are generally limited to areas of steep shoreline topography (NRC, 2009, Section 1.3.2). The Mississippi River Floodplain in the vicinity of the site is approximately 60 miles wide, and characterized by relatively flat topography. The eastern and western boundaries of the floodplain have the highest potential for slope failure. Due to the distance of the western edge of the floodplain to the active river channel, which is located adjacent to the eastern edge of the floodplain near the site, it is unlikely that a slope failure would cause a disturbance in the river.

In the improbably event of tsunami-like waves propagating towards GGNS in the Mississippi River, the vertical (approximately 24 ft) and horizontal separation (approximately 0.5 miles) of the site to the Mississippi River floodplain act as sufficient buffer to preclude any hazard at the site.

3.6.3 Conclusions

The Mississippi River floodplain is not likely to experience tsunami generating events capable of creating significant tsunami-like waves in the vicinity of GGNS. If any such events were to occur, the vertical and horizontal separation of the site from Mississippi River floodplain acts as a sufficient buffer to preclude any hazard at the site.

3.6.4 References

GGNS, 2008. Grand Gulf Nuclear Station Combined License Application Final Safety Analysis Report, Revision 0, 2008.

NRC, 2009. NUREG/CR-6966, Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America, U.S. Nuclear Regulatory Commission, March 2009.

USGS, 2012. U.S. Geological Survey, Seismic Seiches, Website: http://earthquake.usgs.gov/learn/topics/seiche.php, accessed August 23, 2012, AREVA Document No. 38-9197861-000.

3.7 Ice-Induced Flooding

Ice jams and ice dams can form in rivers and streams adjacent to a site and may lead to flooding by two mechanisms: (1) collapse of an ice jam or a dam upstream of the site can result in a dam breach-like flood wave that may propagate to the site and (2) an ice jam or a dam downstream of a site may impound water upstream of itself, thus causing a flood via backwater effects (NRC, 2011).

3.7.1 Method

The ice-induced flooding evaluation followed the HHA described in NUREGCR-7046, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America (NRC, 2011, Section 2).

The approach used in the HHA approach is consistent with the following standards and guidance documents:

1. NRC Standard Review Plan, NUREG-0800, revised March 2007;
2. NRC Office of Standards Development, Regulatory Guides:
    a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
    b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977;
3. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

With respect to ice effects, the HHA used the following two steps:

1. Review historical ice events and backwater effects due to ice jams in the Mississippi River close to GGNS.
2. Evaluate historical water temperatures and minimum daily air temperatures to assess the feasibility of the formation of ice jams in the Mississippi River close to GGNS.

3.7.2 Results

3.7.2.1 Review of historical ice events

The USACE maintains records of historical ice jams and dams on the Ice Jam Database (USACE, 2012a), which can be queried (using state name) to obtain information regarding historical ice events. There are no historic records of ice jams in the Mississippi River near GGNS within the USACE Ice Jam Database.

3.7.2.2 Review of water temperatures close to GGNS

Water temperature data for the Mississippi River is available for a USGS gage in Vicksburg, Mississippi for the period 1973 – 1999 (USGS, 2012), and is almost identical to the Mississippi River water temperatures near GGNS (GGNS, 2008). The Mississippi River water temperature data indicate that water temperatures in the Mississippi River are typically above freezing. The water temperatures recorded during 1973 – 1999 time period range from 34.7°F to 89.6°F.

For the period 2000 – 2012, water temperature data for the Mississippi River at Vicksburg were obtained from the USACE, Vicksburg District (USACE, 2012b). The data indicates that temperatures in the Mississippi River at Vicksburg during this period range from 33°F to 90°F.

The GGNS UFSAR (GGNS, 2012) contains water temperature data obtained from the USACE for the Mississippi River at Vicksburg for the period 1962-1979. The data indicates that water temperatures fell below 32°F once in the time period, in January 1970.

3.7.3 Conclusions

At GGNS, the potential of ice-induced flooding impacting the site is judged to be negligible for the following reasons.

The available water temperature data indicate that the water temperature in the Mississippi River near GGNS is unlikely to fall to near freezing levels for a sustained period of time that may be suitable for the formation of frazil ice, ice jams and ice dams.

In addition, the Lower Mississippi River (including the Mississippi River segment which forms the west boundary of GGNS) is heavily navigated, and USACE Vicksburg District maintains navigable conditions. Therefore, ice-induced flooding at GGNS due to ice effects is not anticipated.

In the event an ice jam were to occur, a rise in water level above 103 ft in the Mississippi River near the site would result in overtopping of the levees on the west bank of the river across from GGNS and diversion of water into the alluvial valley to the west. The plant would thus not be affected due to its location on higher bluffs at elevation 132.5 ft.

3.7.4 References

GGNS, 2008. Grand Gulf Nuclear Station Combined License Application Final Safety Analysis Report, Revision 0, 2008.

GGNS, 2012a. Grand Gulf Nuclear Station UFSAR, 2012, see AREVA Document No. 38-9193642-000.

NRC, 2011. "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants - NUREG/CR-7046", U.S. Nuclear Regulatory Commission, November 2011.

USACE, 2012a. Ice Jam Database, U.S. Army Corps of Engineers, Ice Engineering Research Group, Cold Regions Research and Engineering Laboratory, 2012.

USACE, 2012b. US Army Corps of Engineers, Vicksburg District, Website: http://www.mvk.usace.army.mil/, accessed November, 2012, AREVA Document No. 51-9195572-000, Appendix B.

USGS, 2012. U.S. Geological Survey National Water Information System, Website: http://waterdata.usgs.gov/nwis/qw, accessed November, 2012, AREVA Document No. 51-9195572-000.

3.8 Channel Migration or Diversion

Natural channels may migrate or divert either away from or toward the site. The relevant event for flooding is diversion of water towards the site. There are no well-established predictive models for channel diversions. Therefore, it is not possible to postulate a probable maximum channel diversion event. Instead, historical records and hydrogeomorphological data should be used to determine whether an adjacent channel, stream, or river has exhibited the tendency to meander towards the site. (NRC, 2011, Section 3.8)

3.8.1 Method

The channel migration and diversion flooding evaluation followed the HHA approach described in NUREGCR-7046, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America (NRC, 2011).

1. The HHA approach used is consistent with the following standards and guidance documents:
2. NRC Standard Review Plan, NUREG-0800, revised March 2007;
3. NRC Office of Standards Development, Regulatory Guides:
    a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
    b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977;
4. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

With respect to channel migration and diversion, the HHA used the following two steps:

1. Review historical records and hydrogeomorphological data to assess whether the Mississippi River has exhibited the tendency to meander towards the site GGNS.
2. Evaluate present-day channel protection and stabilization measures in place to mitigate channel migration of the Mississippi River.

3.8.2 Results

3.8.2.1 Review of Historical Records

Lateral shifting of the Mississippi River near the GGNS site is a known historical issue, as attested to by the presence of two oxbow lakes located west of the GGNS (Hamilton Lake and Gin Lake), low-lying swamps adjacent to the river, and sand bars along the river banks. The USACE constructed revetments along the eastern bank of the river in the vicinity of GGNS to stabilize the river alignment and protect the river banks. The revetments prevent caving and erosion of the river banks. The construction of the revetments was done in the late 1970s and early 1980s. The USACE also constructed submerged dikes across the western channel to divert flow to the eastern channel. (GGNS, 2008, Section 2.4)

3.8.2.2 Evaluation of Present Day Channel Protection and Stabilization

The 2011 Mississippi River Channel Improvement Master Plan (Master Plan) (USACE, 2011a) provides the locations of the dikes and revetments constructed on the Mississippi River and indicates where improvements and construction of additional features have been planned. The Master Plan indicates that Grand Gulf revetments are in place along the east bank of the Mississippi River from river mile 400.5 to river mile 410 with a small gap at the existing GGNS barge slip at approximately river mile 406.5 (USACE, 2011a, Map Nos. 55 and 56). Transverse dikes at frequent intervals on the Mississippi River channel along the Grand Gulf revetment from river mile 399 to river mile 410 are also in place. Additional revetment and dike construction have been planned just upstream of river mile 410. Channel stabilization work has also been planned from river mile 395 to river mile 411.

The presence of the Grand Gulf revetments is the primary means of preventing the erosion of the Mississippi River bank near GGNS. A review of the USACE flood map (USACE, 2011b) depicting the flooding extents of the 1927 flood to the 2011 flood indicates that Mississippi River was contained in its current channel during the 2011 flood and did not migrate towards GGNS. The eastern extents of flood plain in area of GGNS did not appreciably change when comparing the 1927 flood to the 2011 flood.

3.8.3 Conclusions

At GGNS, the potential for river channel migration to impact the site is judged to be negligible for the following reasons.

The Lower Mississippi River, including the Mississippi River segment which forms the western boundary of GGNS, is heavily navigated, and USACE Vicksburg District is responsible for maintaining navigable conditions. As part of this responsibility, USACE actively maintains revetments and dikes that are constructed to minimize the risk of channel diversions, bank erosion, and instability. A review of historical data indicates that the Mississippi River has not exhibited a tendency to meander towards the GGNS site since the construction of the revetments.

3.8.4 References

GGNS, 2008. Grand Gulf Nuclear Station Combined License Application Final Safety Analysis Report, Revision 0, 2008.

NRC, 2011. "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants - NUREG/CR-7046", U.S. Nuclear Regulatory Commission, November 2011.

USACE, 2011a. Mississippi River Channel Improvement Master Plan, U.S. Army Corps of Engineers, Mississippi Valley Division, March 2011.

USACE, 2011b. Flood Map 1927 vs. 2011, U.S. Army Corps of Engineers, Mississippi Valley Division, June 2011.

3.9 Combined-Effect Flood

This section addresses combined effect flooding at GGNS. This evaluation includes the impacts of the probable maximum flood (PMF) on the Mississippi River coincident with wind generated waves at Grand Gulf Nuclear Station (GGNS). This evaluation also addresses the impacts of the PMF combined with wind generated waves on the maximum water surface in the local Stream A on the northern boundary of the site.

3.9.1 Method

3.9.1.1 Combined-Effect Flood at GGNS

The HHA approach described in NUREG/CR-7046 (NRC, 2011) was used for the evaluation of the effects of the combined-effects floods on the Mississippi River and Local Stream A at GGNS.

The HHA approach is consistent with the following standards and guidance documents:

1. NRC Standard Review Plan, NUREG-0800, revised March 2007;
2. NRC Office of Standards Development, Regulatory Guides:
    a. RG 1.102 – Flood Protection for Nuclear Power Plants, Revision 1, dated September 1976;
    b. RG 1.59 – Design Basis Floods for Nuclear Power Plants, Revision 2, dated August 1977; and
3. American National Standard for Determining Design Basis Flooding at Power Reactor Sites (ANSI/ANS 2.8 - 1992)

The criteria for combined events are provided in NUREG/CR-7046, Appendix H, of which two apply to GGNS: floods caused by precipitation events (H.1) and floods caused by seismic events (H.2). Other criteria for the determination of the effects of the combined-effect flood described in NUREG/CR-7046 (NRC, 2011, Appendix H, Sections H.3 – H.5) do not apply to GGNS given the site is not a coastal site.

The criteria for floods caused by precipitation events were used (NUREG/CR-7046, Appendix H, Section H.1), which includes the following:

1. Alternative 1 - A combination of mean monthly base flow, median soil moisture, antecedent or subsequent rain, the PMP, and waves induced by 2-year wind speed applied along the critical direction;
2. Alternative 2 - A combination of mean monthly base flow, probable maximum snowpack, a 100-year, snow-season rainfall, and waves induces by 2-year wind speed applied along the critical direction; and
3. Alternative 3 - A combination of mean monthly base flow, a 100-year snowpack, snow-season PMP, and waves induced by 2-year wind speed applied along the critical direction.

Only Alternative 1 was considered, because snowpack in the vicinity of GGNS is negligible (AREVA 2013c and 2013d).

The criteria for floods caused by seismic dam failures (NUREG/CR-7046, Appendix H, Section H.2) criteria include:

1. Alternative 1 – A combination of a 25-year flood, a flood caused by dam failure resulting from a safe shutdown earthquake, and coincident with the peak of the 25-year flood, and waves induced by 2-year wind speed applied along the critical direction;
2. Alternative 2 – A combination of the lesser of one-half of PMF or the 500-year flood, a flood caused by dam failure resulting from an operating basis earthquake, and coincident with the peak of one-half of PMF or the 500-year flood, and waves induced by 2-year wind speed applied along the critical direction.

The results of the dam failure calculation (AREVA, 2013e) indicate that floods caused by seismic dam failures (NRC, 2011, Appendix H.2) are bounded by the PMF with coincident dam failure on the Mississippi River at GGNS.

Therefore "Alternative 1" under the "Floods Caused by Precipitation Events" sub-section H.1 of Appendix H has been judged to be the controlling scenario for Combined-Effects Floods.

The combined event evaluation for GGNS used the following steps:

1. Calculate the wind wave effects and wave runup on the Mississippi River and Local Stream A at GGNS using the CEDAS-ACES v4.3 Computer Program (AREVA, 2012);
2. Calculate the Probable Maximum Water Elevation (PMWE) on the Mississippi River and Local Stream A at GGNS resulting from the combined-effect flood.

3.9.2 Results (AREVA, 2013a)

3.9.2.1 Wind-Wave Effects

Many of the inputs used for the wave setup and wave runup calculations are judged to be conservative; therefore, the final effects of waves on the PMWE are judged to be likewise conservative. This approach is consistent with the HHA approach discussed in NUREG/CR-7046 (NRC, 2011, Section 2).

3.9.2.1.1 Greatest Straight Line Fetch

Fetch represents the unobstructed generating over-water pathway for wind-generated waves, with longer distance fetches allowing for larger wave generation.

Mississippi River Straight Line Fetch

A distance of 63.3 miles was determined to be the greatest straight line fetch for input to the CEDAS-ACES v4.03 module (AREVA, 2013b). This fetch is conservative; assuming the entire width of the Mississippi River floodplain is available for wind generated wave propagation.

Local Stream A Straight Line Fetch

The elevation contours (Sanborn, 2013) were used to determine the most conservative fetch length for wind generated waves on Local Stream A. The fetch used for this evaluation was the largest cross-sectional distance across the pond created on Stream A as it impounds at the site access road during PMF conditions (AREVA, 2013f).

3.9.2.1.2 Sustained Wind Speed

The Gumbel Distribution was applied to the 2-minute wind speed data from NCDC station at Tallulah Vicksburg Regional Airport, to determine the 2-year return period wind speed, which was calculated to be 45.2 mph.

3.9.2.1.3 Wave Height and Period

The Wave Prediction application of the CEDAS - ACES v.4.03 was used to determine the deep water significant wave height and period. Table 3.9-1 shows the inputs used in the application.

A negative 15°C (5°F) air/sea temperature difference was selected as a conservative input for wave prediction. This temperature difference indicates air temperatures lower than the water temperatures, which is likely during an extreme precipitation event such as the PMP. The duration of the final wind speed was selected to be 120 minutes or two hours. This is a conservative estimate used for a 2-year wind speed. The deep water significant wave height for the Mississippi River was determined to be 6.3 feet with a period of 5.1 seconds. The deep water significant wave height for Stream A was determined to be 0.53 feet with a period of 0.99 seconds.

3.9.2.1.4 Wave Set-up

The wave setup was calculated using the Wave Setup across the Surf Zone application of CEDAS-ACES v.4.03. Table 3.9-2 shows the inputs used in the application.

The refraction coefficient was set to 1.0 for head on, perpendicular waves. The Mississippi River wave setup across the surf zone is determined to be 2.2 feet. The Stream A wave setup across the surf zone is determined to be 0.1 feet.

3.9.2.1.5 Wave Run-up

The Wave Runup and Overtopping on Impermeable Structures application was selected to calculate the wave runup at GGNS from the CEDAS-ACES v.4.03 program. Table 3.9-3 describes the parameters used by the application to solve the wave runup at GGNS.

The water depth at the structure toe (i.e., toe of the river/stream bank) was calculated by subtracting the lowest Mississippi river valley elevation or Stream A river bottom elevation from the PMF elevation. The wave runup was calculated to be 14.1 feet for the Mississippi River and 0.29 feet for Stream A.

3.9.2.2 Calculate the Probable Maximum Water Elevation at GGNS resulting from the combined-effect flood

The probable maximum stillwater elevation on the Mississippi River at Grand Gulf Nuclear Station is 106.2 ft NGVD29 (AREVA, 2013b). The PMWE on the Mississippi River at GGNS is the combination of this stillwater elevation and wave setup and wave runup induced by the 2-year wind speed:

106.2 ft + 2.2 ft + 14.1 ft = 122.5 ft (NGVD29) (Mississippi River)

The probable maximum stillwater elevation on Local Stream A at Grand Gulf Nuclear Station is 132.1 ft NGVD29 (AREVA, 2013f). The PMWE on Local Stream A at GGNS is the combination of this stillwater elevation and wave setup and wave runup induced by the 2-year wind speed:

132.1 ft + 0.1 ft + 0.3 ft = 132.5 ft (NGVD29) (Stream A)

3.9.3 Conclusions

At GGNS, impacts to the site from flooding on the Mississippi River or Local Stream A coincident with wind generated waves are judged to be negligible for the following reasons:

The probable maximum wind generated wave setup plus wave runup on the Mississippi River at GGNS is calculated to be 16.3 ft. The PMWE on the Mississippi River at GGNS, including wave effects, is conservatively calculated to be 122.5 ft, which is approximately 10 ft below the site grade of 132.5 ft.

The probable maximum wind generated wave setup plus wave runup on Local Stream A at GGNS is calculated to be 0.4 ft. The PMWE on Local Stream A at GGNS including wave effects is conservatively calculated to be 132.5 ft, which is at the site grade of 132.5 ft. Safety-related SSC at the site are protected to a minimum elevation of 133.625 (SSW Building internal curbs protecting pumps and switchgear, see Section 2.3.2), resulting in a 1.1 ft safety margin.

Based on the re-evaluation of the combined-effect flood on the Mississippi River and Stream A at GGNS, the PMWE at GGNS resulting from combined-effect flooding is at or below the plant grade elevation and, thus, would not affect safety-related SSC important to safety- at GGNS.

3.9.4 References

AREVA, 2012. AREVA Document No. 38-9196713-000, "GZA Computer Program Certification for CEDAS-ACES Version 4.03 PC," December 2012.

AREVA, 2013a. AREVA Document No. 32-9195579-000, "Grand Gulf Nuclear Station Flood Hazard Re-evaluation - Combined Events Flood Analysis", January 2013.

AREVA, 2013b. AREVA Document No. 32-9195575-000, "Probable Maximum Flood on Streams and Rivers – Mississippi River Flow and Elevations", January 2013.

AREVA, 2013c. AREVA Document No. 51-9195572-000, "Ice-Induced Flood Screening", January 2013.

AREVA, 2013d. AREVA Document No. 32-9195574-000, "Probable Maximum Precipitation", January 2013.

AREVA, 2013e. AREVA Document No. 32-9195578-000, "Grand Gulf Nuclear Station Flood Hazard Re-evaluation – Dam Failures", January 2013.

AREVA, 2013f. AREVA Document No. 32-9195577-000, "Grand Gulf Nuclear Station Flood Hazard Re-Evaluation – Probable Maximum Flood on Streams and Rivers – Local Streams A and B Flow and Elevations", January 2013.

NRC, 2011. NUREG/CR-7046, Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America, U.S. Nuclear Regulatory Commission, November 2011.

Sanborn, 2013. Grand Gulf Nuclear Station (GGNS) Topographic Survey, Sanborn Map Company Inc., AREVA Document No. 38-9196955-000, January 2013.

Table 3.9-1: Wave Prediction Parameters for CEDAS-ACES

Input Parameter	Value	Units
Elevation of the Observed Wind Speed (Z_{obs})	10	Meters
Observed Wind Speed (U_{obs})	20.2	m/s
Air Sea Temperature Difference (dT)	-15	Degrees Celsius
Duration of the Observed Wind (DurO)	2	Minutes
Duration of the Final Wind Speed (DurF)	120	Minutes
Latitude of Observation (LAT)	32	Degrees
Wind Fetch Length (F)	102 (Mississippi River) 0.16 (Stream A)	Km
Wind Observation Type	Inland	n/a
Wind Fetch Options	Deep open water	n/a

Table 3.9-2: Wave Setup Parameters for CEDAS-ACES

Input Parameter	Value	Units
Acceleration due to gravity (g)	32.2 [9.81]	Ft/s^2 [m/s^2]
Deep water significant wave height (H_o)	6.2 [1.9] (Mississippi) 0.53 [.16] (Stream A)	Feet [Meters]
Wave period (T)	5.1 (Mississippi) 0.99 (Stream A)	Seconds
Slope (m)	0.5 (Mississippi) 0.47 (Stream A)	n/a
Refraction Coefficient (K_r)	1	n/a

Table 3.9-3: Wave Runup Parameters for CEDAS-ACES

Input Parameter	Value	Units
Wave Type	Irregular	n/a
Slope Type	Smooth (Mississippi) Rough (Stream A)	n/a
Breaking Criteria (k)	0.78	n/a
Incident Significant Wave Height (H_i)	6.2 [1.9] (Mississippi) 0.53 [0.16] (Stream A)	Feet [Meters]
Peak Wave Period (T)	5.1 (Mississippi) 0.99 (Stream A)	Seconds
COTAN of nearshore slope (cot phi)	111 (Mississippi) 20 (Stream A)	n/a
Water depth at the structure toe (d_s)	20.9 [6.4] (Mississippi) 32.1 [9.8] (Stream A)	Feet [Meters]
COTAN of structure slope (cot theta)	2	n/a
Structure height above toe (h_s)	74.97 [22.85] (Mississippi) 32.5 [9.9] (Stream A)	Feet [Meters]
Rough slope coefficient (a)	n/a [smooth] (Mississippi) 0.65 (Stream A)	n/a
Rough slope coefficient (b)	n/a [smooth] (Mississippi) 0.5 (Stream A)	n/a

4.0 COMPARISON OF CURRENT AND REEVALUATED FLOOD CAUSING MECHANISMS

4.1 Summary of Current Licensing Basis and Flood Reevaluation Results

This section compares the current and reevaluated flood-causing mechanisms. It provides a comparison of the CLB flood elevation to the reevaluated flood elevation for each applicable flood-causing mechanism. A comparison of the CLB elevations and the reevaluated flood elevations is provided in Table 4.1-1.

Screened mechanisms have been evaluated at a high level and determined to not be applicable to the flooding hazard for GGNS.

4.1.1 Local Intense Precipitation

4.1.1.1 Current Licensing Basis

The CLB did not include an evaluation of LIP flooding. The CLB evaluation for PMP-induced flooding at GGNS is the most comparable flood mechanism evaluated as part of the CLB.

The CLB PMP calculations yield flood elevations less than 133.25 ft at GGNS. This is based on runoff generated by a 30.5 inch 6-hour PMP design storm (based on HMR-33) and runoff to Streams A and B. The rainfall distribution used assumes 8.2 inches of rain in the first 30 minutes of the storm (GGNS, 2012a Section 2.4.2.3.3.2.1.2). Water surface elevations above 133.0 ft have a duration of approximately 7 hours. (GGNS, 2012a, Section 2.4.10)

4.1.1.2 Reevaluated Flood Elevation

The maximum water surface elevation due to the LIP at GGNS results from a total rainfall depth of 19.3 inches within an hour and 31.4 inches within 6 hours. In the immediate vicinity of GGNS Unit 1 safety-related SSC and doorways, predicted maximum water depths resulting from the LIP range from approximately 0.3 ft to 0.8 ft above floor level. Based on the 2012 topographic mapping, these flow depths correspond to water surface elevations ranging from 133.3 ft to 133.7 ft.

Details of this evaluation are provided in Section 3.1. Impacts of the LIP water elevations are discussed in Section 4.3.

4.1.1.3 Comparison

The reevaluated flood elevations from an LIP event are higher than the CLB. This is primarily due to the increased rainfall predicted by HMR-51 and HMR- 52 as opposed to HMR-33. The VBS does impact flood levels in the new evaluation, but was calculated to have no impact for the CLB PMP event (GGNS, 2012c). Impacts of LIP flood elevations are discussed in Section 4.3.

4.1.2 Flooding on Rivers and Streams

4.1.2.1 Current Licensing Basis

The Mississippi River flood potential is limited by the west-bank levees and significant flood plain storage to the west of the levees. PMF conditions would result in the levees overtopping and excess flood waters draining to the floodplain. As a result, the PMF for the Mississippi River is considered to be 103 ft, or 6.6 million cfs. (GGNS, 2012a, Section 2.4.3.4)

Bayou Pierre was not evaluated as part of the CLB (GGNS, 2012a, Section 2.4.3) and is only part of the reevaluation.

Stream A PMF conditions were modeled with a completely blocked culvert at the site access road crossing. The PMF peak discharge was calculated to be 13,490 cfs, and the peak flood elevation at the site access road was calculated at 128.9 ft. (GGNS, 2012a, Section 2.4.3.5.2)

Stream B PMF conditions were modeled to include a conservative Culvert 1 blockage of 45%. The channel is lined with concrete and riprap, limiting the potential for debris blockage. The peak discharge was calculated to be 2,775 cfs, and the peak flood elevation in the vicinity of the cooling towers was calculated at 132.8 ft. (GGNS, 2012a, Section 2.4.3.5.2)

4.1.2.2 Reevaluated Flood Elevation

The probable maximum flood on the Mississippi River near GGNS is conservatively estimated at 8,250,000 cfs. Historical records do not indicate flooding in excess of this PMF flow. The peak PMF water surface elevation on the Mississippi River near Grand Gulf Nuclear Station is 106.2 ft, which is 26.3 ft below the site grade elevation of 132.5 ft.

The PMF peak discharge for Bayou Pierre calculated using HEC-HMS and incorporating non-linearity adjustments is 734,000 cfs. The peak PMF stage was calculated to be 130.7 ft, which is well below the elevation of the Bayou Pierre watershed divide elevation of about 175 ft near GGNS.

The PMF peak discharge for Streams A and B were 18,600 cfs and 6,000 cfs, respectively. The calculated peak PMF stage on Stream A is 132.1 feet, below the site grade elevation of 132.5 ft. The calculated peak PMF stage on Stream B is 131.7 feet, below the site grade elevation of 132.5 ft.

Details of this evaluation are provided in Section 3.2.

4.1.2.3 Comparison

The new evaluation of PMF elevation on the Mississippi River is 3.2 ft higher than the CLB based on additional floodplain modeling after the water overtops the west-bank levees. There is no impact for this increase to GGNS due to the 26.3 ft margin between site grade and the Mississippi River PMF elevation.

The PMF on Bayou Pierre has no impact on the GGNS site due to the elevation of the intervening watershed divide.

The PMF elevation for Stream A has increased 3.2 ft compared to the CLB. The PMF elevation for Stream B has decreased 1.1 ft compared to the CLB. These changes have no impact on safety-related SSC at GGNS because the flood elevations remain lower than the site grade of 132.5 ft.

4.1.3 Dam Breaches and Failures

4.1.3.1 Current Licensing Basis

The CLB indicates that the peak flow of the Mississippi River at the Design Project Flow (2.7 million cfs) coincident with failure of the Kentucky Dam would be 5.7 million cfs. Assuming no attenuation, this flow is significantly below the CLB Mississippi River PMF of 6.6 million cfs. (GGNS, 2012a, Section 2.4.4.2)

4.1.3.2 Reevaluated Flood Elevation

The Mississippi River PMF peak flow at the GGNS was estimated to be 8,250,000 cfs (AREVA, 2012a). The Kentucky Dam peak breach outflow is estimated to be 3,920,000 cfs. The combined Kentucky Dam break peak outflow, conservatively neglecting channel and floodplain attenuation, and Mississippi River PMF at GGNS is estimated to be 12,170,000 cfs. The resultant peak water surface elevation from the combined dam breach peak outflow and PMF in the Mississippi River at Grand Gulf Nuclear Station is 117.4 ft, which is 15.1 ft below the site grade elevation of 132.5 ft.

The estimated Mississippi River channel and floodplain capacity at GGNS is estimated to be about 18,200,000 cfs. Therefore, an additional 6,030,000 cfs is available to accommodate other coincident dam failures without affecting the site.

Details of this evaluation are provided in Section 3.3.

4.1.3.3 Comparison

The new evaluation results are based on more conservative assumptions including a higher PMF stage for the Mississippi River, a dam failure coincident with PMF conditions as opposed to Design Project Flow conditions, and no dam break hydrograph attenuation. The CLB does not explicitly state a flood elevation from this mechanism, so no direct comparison is possible. There is no impact to GGNS due to the 15.1 ft margin between the site grade and the dam failure flood elevation.

4.1.4 Storm Surge

4.1.4.1 Current Licensing Basis

Flooding from storm surges was not evaluated because Grand Gulf is not a coastal site, and as such not susceptible to storm surges (GGNS, 2012a, Section 2.4.5).

4.1.4.2 Reevaluated Flood Elevation

GGNS is 406 river miles upstream from the Gulf of Mexico coastline, and over 132 feet above mean sea level. Due to the distance and elevation of the site, storm surges generated in offshore waters would be unable to propagate to the vicinity of the site. In addition, the Mississippi River in the vicinity

of the site has a PMF elevation coincident with wind generated waves of 122.5 ft (See Section 3.9), well below the site grade of 132.5 ft.

Given the horizontal distance from the site to the Mississippi River floodplain, and the vertical margin between the Mississippi River flood levels and the GGNS site grade, the flooding hazard contribution from storm surges is negligible for the GGNS site.

Details of this evaluation are provided in Section 3.4.

4.1.4.3 Comparison

The reevaluation concurs with the CLB determination that storm surge flooding hazard is not applicable to GGNS. The CLB does not explicitly state a flood elevation from this mechanism, so no direct comparison is possible.

4.1.5 Seiche

4.1.5.1 Current Licensing Basis

Flooding from seiches was not evaluated because Grand Gulf is not a coastal site, and as such not susceptible to seiches (GGNS, 2012a, Section 2.4.5).

4.1.5.2 Reevaluated Flood Elevation

The man-made levees bounding the western edge of the Mississippi River channel are approximately 29 feet below the site grade. Any seiche oscillations would overtop the levees and drain into the wide floodplain west of the Mississippi River before impacting the GGNS site.

Details of this evaluation are provided in Section 3.5.

4.1.5.3 Comparison

The reevaluation concurs with the CLB determination that seiche flooding hazard is not applicable to GGNS. The CLB does not explicitly state a flood elevation from this mechanism, so no direct comparison is possible.

4.1.6 Tsunami

4.1.6.1 Current Licensing Basis

Flooding from tsunamis was not evaluated quantitatively because of the non-coastal setting and the lack of geoseismic activity in the site vicinity (GGNS, 2012a, Section 2.4.6).

4.1.6.2 Reevaluated Flood Elevation

The Mississippi River floodplain is not likely to experience tsunami generating events capable of creating significant tsunami-like waves in the vicinity of GGNS. If any such events were to occur, the

vertical and horizontal separation of the site from Mississippi River floodplain acts as a sufficient buffer to preclude any hazard at the site.

Details of this evaluation are provided in Section 3.6.

4.1.6.3 Comparison

The reevaluation concurs with the CLB determination that tsunami flooding hazard is not applicable to GGNS. The CLB does not explicitly state a flood elevation from this mechanism, so no direct comparison is possible.

4.1.7 Ice-Induced Flooding

4.1.7.1 Current Licensing Basis

Water temperature data from 1962 to 1979 indicate that water temperatures for the Mississippi River are above freezing most of the time. Additionally, a rise in water level above 103 ft would overtop the west-bank levees and drain to the floodplain to the west. (GGNS, 2012a, Section 2.4.7)

4.1.7.2 Reevaluated Flood Elevation

The available water temperature data combined with the comparative air temperature data indicate that the water temperature in the Mississippi River near GGNS are unlikely to fall to near freezing levels for a sustained period of time that may be suitable for the formation of frazil ice, ice jams and ice dams.

In addition, the Lower Mississippi River (including the Mississippi River segment which forms the west boundary of GGNS) is heavily navigated, and USACE Vicksburg District maintains navigable conditions. Therefore, ice-induced flooding at GGNS due to ice effects is not anticipated.

In the event an ice jam were to occur, a rise in water level above 103 ft, MSL in the Mississippi River near the site would result in overtopping of the levees on the west bank of the river across from GGNS and diversion of water into the alluvial valley to the west. The plant would thus not be affected due to its location on higher bluffs at elevation 132.5 ft.

Details of this evaluation are provided in Section 3.7.

4.1.7.3 Comparison

The reevaluation concurs with the CLB determination that ice-induced flooding hazard is limited by the levees bounding the western bank of the Mississippi River, and will not exceed 103 ft.

4.1.8 Channel Migration or Diversion

4.1.8.1 Current Licensing Basis

USACE river stabilization projects prevent Mississippi River migration from impacting the site (GGNS, 2012a, Section 2.4.9).

4.1.8.2 Reevaluated Flood Elevation

The Lower Mississippi River, including the Mississippi River segment that forms the western boundary of GGNS, is heavily navigated, and USACE Vicksburg District is responsible for maintaining navigable conditions. As part of this responsibility, USACE actively maintains revetments and dikes that are constructed to minimize the risk of channel diversions, bank erosion, and instability. A review of historical data indicates that the Mississippi River has not exhibited a tendency to meander towards the site since the construction of the revetments.

Details of this evaluation are provided in Section 3.8.

4.1.8.3 Comparison

The reevaluation concurs with the CLB determination that Mississippi River migration flooding hazard is not applicable to GGNS due to USACOE river stabilization projects.

4.1.9 Combined Effect Flooding

4.1.9.1 Current Licensing Basis

The CLB Mississippi River PMF coincident with wind generated waves is calculated to be 108.8 ft. The maximum predicted wave height is 4.4 ft, with an additional wave runup of 1.4 ft. (GGNS, 2012a, Section 2.4.3.6)

4.1.9.2 Reevaluated Flood Elevation

The Probable Maximum Wind Generated Wave Setup plus Wave Runup on the Mississippi River at GGNS is calculated to be 16.3 ft. The Probable Maximum Water Elevation on the Mississippi River at GGNS, including wave effects, is conservatively calculated to be 122.5 ft, which is approximately 10 ft below the site grade of 132.5 ft.

The Probable Maximum Wind Generated Wave Setup plus Wave Runup on Local Stream A at GGNS is calculated to be 0.4 ft. The Probable Maximum Water Elevation on Local Stream A at GGNS including wave effects is conservatively calculated to be 132.5 ft which is at the site grade of 132.5 ft.

Based on the re-evaluation of the combined-effect flood on the Mississippi River at GGNS, the probable maximum water elevation on the Mississippi River at GGNS resulting from combined-effect flood on the Mississippi River is below the plant grade elevation and would not affect safety-related structures, systems, or components at GGNS.

Details of this evaluation are provided in Section 3.9.

4.1.9.3 Comparison

The difference in the combined effect flooding on the Mississippi River is due primarily to a much wider fetch conservatively used for wave generation in the new evaluation, coupled with increased PMF flow.

The combined effect flood elevation for the Mississippi River is conservative and has no impact on the site due to the 10 ft margin between the combined effect flood level and the GGNS site grade.

Combined effect flooding was not previously evaluated for Stream A or Stream B. However, in the PMF condition, Stream A can form a pond at the site access road due to blockage of the culvert. At this location, wind generated waves were conservatively modeled. The CLB does not explicitly state a flood elevation from this mechanism, so no direct comparison is possible. There is no impact for GGNS because the combined effect flood level for Stream A does not exceed the site grade.

4.2 Summary of Walkdown Findings

The walkdown identified three deficiencies in the design basis. Two PMP sealed doors (Door 1M110 and Door OC313) have door seals that are not functioning as required, allowing for potential leakage during the CLB flood (GGNS, 2012b). The PMP door seals are regularly inspected and maintained as necessary (GGNS, 2012d). GGNS currently plans on replacing the door seals with sandbagging as detailed in Section 6.

In addition, the topography west of the control building is not sloping away from the plant as indicated in the CLB (GGNS, 2012b). While the 2012 topographic mapping (Sanborn, 2013) does not indicate a well-defined slope towards the west from the control building, the grade of that area does not impact safety-related SSC. Water buildup in that area will flow west into the drainage ditch to the northwest of the site as detailed in Section 3.1.

4.3 Impacts of Flood Elevations

Flooding due to LIP is the controlling flood event for the new flood evaluation. No other flood mechanism generates water elevations with the potential to impact safety related SSC. Modeled LIP flood water heights are a maximum of 0.81 ft adjacent to GGNS safety-related SSC.

The current Design Basis of the site protects safety-related SSC from 0.625 ft above floor level at the SSW pump houses, and between 0.75 ft and 1.0 ft above floor level at the PMP sealed doors as indicated in Section 2.2. Table 4.3-1 shows the height of modeled LIP flood water at each safety-related SSC or PMP doorway that can be potentially impacted by this event.

As shown in Table 4.3-1, none of the protections in place for identified safety-related SSC or PMP sealed doors are exceeded by the modeled LIP flood water heights. The margin of safety ranges from 0.2 ft at Control Building door OC313 to 0.62 ft at Diesel Generator Building door 1D309.

The margin of safety from the CLB for the controlling flood event ranged from 0.37 ft at the SSW pump houses to a maximum of 0.75 ft at the PMP sealed doors (GGNS, 2012a).

Based on the results of the new flood evaluation, the CLB safety margin has decreased due to LIP flooding at GGNS. Despite the decrease in safety margin, the protective features at the PMP sealed doors and inside the SSW pump houses continue to bound the modeled LIP flood conditions. No further action is necessary.

4.4 References

GGNS, 2012a. Grand Gulf Nuclear Station UFSAR, 2012, see AREVA Document No. 38-9193642-000.

GGNS, 2012b. Engineering Report No. GGNS-CS-12-00003, Rev. 0, "Grand Gulf Nuclear Station Flooding Walkdown Report for Resolution of Fukushima Near-Term Task Force Recommendation 2.3: Flooding", November 2012, see AREVA Document No. 38-9200169-000.

GGNS, 2012c. Calculation No: CC-Q1Y13-93002, Rev. 2 "Backwater Analysis of External Flooding (HMR51PMP Data), May 2012, see AREVA Document No. 38-9193642-000.

GGNS, 2012d. Plant Operations Manual 07-S-14-310, Volume 07, Section 14, Revision 10, "General Maintenance Instruction – Inspection of Mechanical Seals on Doors - Safety Related", April 2012, see AREVA Document No. 38-9200169-000.

Sanborn, 2013. Grand Gulf Topographic Survey Data, Sanborn Map Company, Inc., January 2013, AREVA Document No. 38-9196955-000.

Table 4.1-1: Flood Elevation Comparison

Mechanism	CLB Elevation (ft)	New Elevation (ft)	Difference (ft)
Local Intense Precipitation†	133.25	133.7** (See Table 4.3-1)	+ 0.45** (See Table 4.3-1)
Flooding on Rivers and Streams			
Mississippi River	103	106.2	+ 3.2*
Bayou Pierre	Not Evaluated	130.7	NA
Stream A	128.9	132.1	+ 3.2*
Stream B	132.8	131.7	- 1.1*
Dam Breaches and Failures	Screened	117.4	NA
Storm Surge	Screened	Screened	NA
Seiche	Screened	Screened	NA
Tsunami	Screened	Screened	NA
Ice-Induced Flooding	103	103	0
Channel Migration or Diversion	Screened	Screened	NA
Combined Effect			
Mississippi River PMF + Wind	108.8	122.5	+ 13.7*
Local Streams PMF + Wind	Not Evaluated	132.5	NA

† Note: Local Intense Precipitation was not evaluated as part of the CLB. Probable Maximum Precipitation-induced flooding at the site is considered the most comparable flood mechanism evaluated as part of the CLB.

* Note: These flood elevations exceed the CLB, but are bounded by the GGNS design basis and as a result do not impact SSC important to safety.

** Note: Based on 2012 Survey elevations (Sanborn, 2013). Impacts of flood level to safety-related SSC determined by comparing height of protection to flood water depth. See Table 4.3-1.

Table 4.3-1: LIP Flood Heights at PMP Doors and Safety-Related SSC

SSC or PMP Sealed Door ID	Location	Protection Height above floor level (ft) (GGNS, 2012a)	LIP Flood Depth above floor level (ft)	Margin (ft)
Door OC313	Control Building	0.75	0.5*	0.2**
Door OCT5	Control Building	1.0	0.81	0.19
Door 1D301	Diesel Generator Building	1.0	0.59	0.41
Door 1D308	Diesel Generator Building	1.0	0.69	0.31
Door 1D309	Diesel Generator Building	1.0	0.38	0.62
Door 1D310	Diesel Generator Building	1.0	0.68	0.32
Door 1D312	Diesel Generator Building	1.0	0.69	0.31
Door 1M110	SSW Basin Alpha	1.0	0.59	0.41
Door 1M111	SSW Basin Alpha	1.0	0.41	0.59
Equipment/Switchgear	SSW Basin Alpha	0.625	0.32	0.30**
Door 2M110	SSW Basin Bravo	1.0	0.48	0.52
Door 2M111	SSW Basin Bravo	1.0	0.79	0.21
Equipment/Switchgear	SSW Basin Bravo	0.625	0.29	0.33**

*Note: Due to location of Door OC313 inside a corridor, flood and floor elevations are not available. Flood water height outside the corridor is approximately 1.0 ft above general site grade. By design, the floor at door OC313 is 0.5 ft higher than general site grade. Flood water height at Door OC313 is estimated to be 0.5 ft.

**Note: Values conservatively rounded down.

5.0 INTERIM EVALUATION AND ACTIONS TAKEN OR PLANNED

The new flood elevations are bound by existing plant protection features. No interim evaluation or mitigation actions are necessary.

6.0 ADDITIONAL ACTIONS

6.1 Door Flooding Protection Changes

The External Probable Maximum Precipitation (PMP) door seals are vulnerable to damage during normal door use and require exact adjustment to function correctly. To mitigate the effects of any possible damage to the seals, the applicable off-normal event procedure (ONEP) requires placement of sand bag dikes at PMP doors if the 24 hour weather forecast predicts 12 inches or more rain. In accordance with the ONEP, sand bag dikes will be placed in the vicinity of each door to provide additional protection to at least 1.5 ft above floor level. Based on these considerations, the existing external PMP door seals will be credited to provide additional protection only on inactive doors 1D301 and OCT05. All of the remaining external PMP door seals will no longer be credited. Sand bag dikes will take two people approximately six hours to install at the nine external PMP doors.

6.2 References

None

APPENDIX A: SIMULATION MODEL USE DESCRIPTIONS

A.1 FLO-2D for LIP Simulations

The example LIP calculation presented in Appendix B of NUREG/CR-7046 (NRC 2011) used HEC-HMS and HEC-RAS, developed by Hydrologic Engineering Center of US Army Corps of Engineers. The hydrologic part of the calculation was performed within HEC-HMS, whereas the hydraulic part of the calculation was performed within HEC-RAS. In this flood re-evaluation study, FLO-2D was selected for calculation of the LIP-induced PMF at Grand Gulf and PMF in streams and rivers (Stream A and Stream B) near Grand Gulf. For the LIP calculation, rainfall runoff was calculated internally by FLO-2D and translated into overland flow within FLO-2D.

This appendix was prepared as per Section 5.3 of NUREG/CR-7046 (NRC 2011).

A.1.1 Software Capability

The FLO-2D computer program was developed by FLO-2D Software, Inc., Nutrioso, Arizona. FLO-2D is a combined two-dimensional hydrologic and hydraulic model that is designed to simulate river overbank flows as well as unconfined flows over complex topography and variable roughness, split channel flows, mud/debris flows and urban flooding. FLO-2D is a FEMA-approved software (FLO-2D 2011).

FLO-2D is a physical process model that routes rainfall-runoff and flood hydrographs over unconfined flow surfaces using the dynamic wave approximation to the momentum equation. The model has components to simulate riverine flow including flow through culverts, street flow, buildings and obstructions, levees, sediment transport, spatially variable rainfall and infiltration and floodways. Application of the model requires knowledge of the site, the watershed (and coastal, as appropriate) setting, goals of the study, and engineering judgment. This software was used to simulate the LIP, propagation of storm surge, seiches, and riverine flow through overland flow and channels to establish stillwater levels at various Flood Hazard Re-evaluation Project sites.

The major design inputs to the FLO-2D computer model are digital terrain model of the land surface, inflow hydrograph and/or rainfall data, Manning's roughness coefficient and Soil hydrologic properties such as the SCS curve number. The digital terrain model of the land surface is used in creating the elevation grid system over which flow is routed. The specific design inputs depend on the modeling purpose and the level of detail desired.

The following executable modules compose the FLO-2D computer program:

*.exe File	Size
FLO.exe	10.76 MB
GDS.exe	6.00 MB
PROFILES.exe	2.84 MB

*.exe File	Size
HYDROG.exe	2.07 MB
Mapper_2009.exe	3.33 MB
MAXPLOT.exe	2.32 MB

FLO.exe is the model code that performs the numerical algorithms for the aforementioned components of the overall FLO-2D computer model.

GDS.exe graphically creates and edits the FLO-2D grid system and attributes and creates the basic FLO-2D data files for rainfall – runoff and overland flow flood simulation. PROFILES.exe displays the channel slope and permits interactive adjustment of the channel properties. HYDROG.exe enables viewing of channel outputs hydrographs and lists average channel hydraulic data for various reaches of river. Mapper_2009.exe and Maxplot.exe enables graphical viewing of model results and inundation mapping.

A description of the major capabilities of FLO-2D which was used for this project is provided in Section A.1.2 below.

A.1.2 Model Components

Overland Flow Simulation

This FLO-2D component simulates overland flow and computes flow depth, velocities, impact forces, static pressure and specific energy for each grid. Predicted flow depth and velocity between grid elements represent average hydraulic flow conditions computed for a small time step. For unconfined overland flow, FLO-2D applies the equations of motion to compute the average flow velocity across a grid element (cell) boundary. Each cell is defined by 8 sides representing the eight potential flow directions (the four compass directions and the four diagonal directions). The discharge sharing between cells is based on sides or boundaries in the eight directions one direction at a time. At runtime, the model sets up an array of side connections that are only accessed once during a time step instead of the dual algorithm required by searching for available elements. The surface storage area or flow path can be modified for obstructions including buildings and levees. Rainfall and infiltration losses can add or subtract from the flow volume on the floodplain surface.

Channel Flow Simulation

This component simulates channel flow in one-dimension. The channel is represented by natural, rectangular or trapezoidal cross sections. Discharge between channel grid elements are defined by average flow hydraulics of velocity and depth. Flow transition between subcritical and supercritical flow is based on the average conditions between two channel elements. River channel flow is routed with the dynamic wave approximation to the momentum equation. Channel connections can be simulated by assigning channel confluence elements.

Flood Channel Interface

This FLO-2D component exchanges channel flow with the floodplain grid elements in a separate routine after the channel, street and floodplain flow subroutines have been completed. An overbank discharge is computed when the channel conveyance capacity is exceeded. The channel-floodplain flow exchange is limited by the available exchange volume in the channel or by the available storage volume on the floodplain. Flow exchange between streets and floodplain are also computed during this subroutine. The diffusive wave equation is used to compute the velocity of either the outflow from the channel or the return flow to the channel.

Floodplain Surface Storage Area Modification and Flow Obstruction

This FLO-2D component enhances detail by enabling the simulation of flow problems associated with flow obstructions or loss of flood storage. This is achieved by the application of coefficients (area reduction factors (ARFs) and width reduction factors (WRFs) that modify the individual grid element surface area storage and flow width. ARFs can be used to reduce the flood volume storage on grid elements due to buildings or topography and WRFs can be assigned to any of the eight flow directions in a grid element to partially or completely obstruct flow paths in all eight directions simulating floodwalls, buildings or berms.

Rainfall – Runoff Simulation

Rainfall can be simulated in FLO-2D. The storm rainfall is discretized as a cumulative percent of the total. This discretization of the storm hyetograph is established through local rainfall data or through regional drainage criteria that defines storm duration, intensity and distribution. Rain is added in the model using an S-curve to define the percent depth over time. The rainfall is uniformly distributed over the grid system and once a certain depth requirement (0.01-0.05 feet) is met, the model begins to route flow.

Hydraulic Structures

Hydraulic structures including bridges and culverts and storm drains may be simulated in FLO-2D Pro. Discharge through round and rectangular culverts with potential for inlet and outlet control can be computed using equations based on experimental and theoretical results from the U.S. Department of Transportation procedures (Hydraulic Design of Highway Culverts; Publication Number FHWA-NHI-01-020 revised May, 2005).

Levees

This FLO-2D component confines flow on the floodplain surface by blocking one of the eight flow directions. A levee crest elevation can be assigned for each of the eight flow directions in a given grid element. The model predicts levee overtopping. When the flow depth exceeds the levee height, the discharge over the levee is computed using the broad-crested weir flow equation with a 2.85 coefficient. Weir flow occurs until the tailwater depth is 85% if the headwater depth. At higher flows, the water is exchanged across the levees using the difference in water surface elevations.

A.1.3 FLO-2D Model Theory

Governing equations and solution algorithms are presented in details in FLO-2D Reference Manual (FLO2D 2009). The general constitutive fluid equations include the continuity equation and the equation of motion (dynamic wave momentum equation) (FLO-2D 2009a, Chapter II):

$$\frac{\partial h}{\partial t} + \frac{\partial h V}{\partial x} = i$$

$$S_f = S_o - \frac{\partial h}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$$

where

h = flow depth;

V = depth averaged velocity in one of the eight flow directions;

x = one of the eight flow directions;

i = rainfall intensity;

S_f = friction slope based on Manning's equation;

S_0 = bed slope

g = acceleration of gravity

The partial differential equations are solved with a central finite difference numerical scheme, which implies that final results are just approximate solutions to the differential equations. Details on the accuracy of FLO-2D solutions are discussed in FLO-2D Validation Report (FLO-2D 2011).

A.1.4 Model Inputs and Outputs

Inputs to FLO-2D are entered through a graphical user interface (GUI), which creates ASCII text files used by the FLO-2D model (FLO-2d 2009b). The ASCII text files can be viewed and edited by other ASCII text editors such as MicroSoft WordPad.

Calculated results from FLO-2D simulations are saved in the ASCII text format in a number of individual files. The results can be viewed with the post-processor programs as follows:

- Mapper – to view grid element results such as elevation, water surface elevation, flow depth and velocity, to create contour maps and to generate shapefiles that can later be used by GIS mapping softwares such as ArcMap.
- MAXPLOT – to view grid element maximum flood elevation, flow depth, velocity, channel flow depth/elevation/velocity, and levee minimum free board/overtopping.
- HYDROG – to generate hydrographs for channel elements.

- PROFILES – to plot channel water surface and channel bed profiles.

A.1.5 Conclusions

FLO-2D is a FEMA-approved software (FLO-2D 2011). The model validation report prepared for FEMA and the FLO-2D software certification prepared for Flood Re-evaluation Projects (AREVA 2012) have demonstrated its modeling capabilities and numerical accuracy. It is therefore judged to be an appropriate modeling tool for the Grand Gulf flood re-evaluation study where 2-dimensional overland flow is predominant.

A.1.6 References

AREVA 2012. AREVA Document No. 38-9191747-000, Computer Software Certification – FLO-2D Pro, GZA GeoEnvironmental, Inc., October 2012.

FLO-2D 2009a. FLO-2D Reference Manual, FLO-2D Software, Inc.

FLO-2D 2009b. FLO-2D Data Input Manual, FLO-2D Software, Inc.

FLO-2D 2011. FLO-2D Model Validation for Version 2009 and up prepared for FEMA, FLO-2D Software, Inc, June 2011.

A.2 CulvertMaster for LIP Simulations

In this flood re-evaluation study, FLO-2D was selected for calculation of the LIP-induced PMF at Grand Gulf (see Section A.1, above). The Bentley CulvertMaster v.3.3 computer program (CulvertMaster) was used to develop hydraulic head versus discharge rating curve information for selected culverts, which was then used as input to FLO-2D.

This appendix was prepared as per Section 5.3 of NUREG/CR-7046 (NRC 2011).

A.2.1 Software Capability

CulvertMaster was originally developed by Haestad Methods Solution Center based in Watertown, Connecticut (Bentley, 2005). The company was later acquired by Bentley Systems, Inc. based in Exton, Pennsylvania. This computer program is a FEMA-approved software.

CulvertMaster is designed to analyze culvert hydraulics, from single barrel to complex multi-barrel culverts with roadway overtopping. The user has a choice of culvert barrel shapes, including circular pipes, pipe arches, boxes and more. Flow calculations handle pressure and varied flow situations such as backwater and drawdown curves. This software was used to simulate the flow through culverts at various Flood Hazard Re-evaluation Project sites.

A.2.2 CulvertMaster Model Theory

Bentley CulvertMaster uses the methodologies set forth in Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts (1985) (FHWA, 2005) as prepared for the U.S. Federal Highway Administration to perform hydraulic calculations. The controlling headwater depth at the culvert is calculated as the greater of the inlet control headwater or the outlet control headwater based on equations in HDS 5. Details on the accuracy of FLO-2D solutions are discussed in FLO-2D Validation Report (FLO-2D 2011).

A.2.3 Model Inputs and Outputs

Inputs to CulvertMaster are entered through a graphical user interface (GUI) in a Windows-based operating system. The major design inputs to the CulvertMaster computer model are: a) culvert size, shape, and material; b) length and upstream / downstream invert elevations; and c) minor losses due to culvert entrance geometry.

Calculated results from CulvertMaster simulations can be saved in a number of formats or exported into spreadsheets, etc within the Windows operating system. For the Grand Gulf analysis, a rating table (i.e., demonstrating the effects on the culvert of varying one system characteristic) was generated. The rating table presents this relationship in tabular form, with the incremental values of the independent variable in the first column (i.e., hydraulic head), and the corresponding computed values for the other variables in the other columns (i.e., discharge).

A.2.4 Conclusions

The CulvertMaster software certification prepared for Flood Re-evaluation Projects (AREVA 2012) have demonstrated its modeling capabilities and numerical accuracy. It is therefore judged to be an appropriate modeling tool for the Grand Gulf flood re-evaluation study where culvert flow is important.

A.2.5 References

FHWA, 2005. Hydraulic Design Series Number 5 - Hydraulic Design of Highway Culverts, Federal Highway Administration , Revised May 2005.

Bentley, 2005. Bentley CulvertMaster User's Guide (DAA038670-1/0001), Bentley Systems, Inc., 2005.