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YUCCA MOUNTAIN - REQUEST FOR ADDITIONAL INFORMATION - VOLUME 2, CHAPTER 2.1.1.3, SET 3 (U.S. DEPARTMENT OF ENERGY'S SAFETY ANALYSIS REPORT SECTIONS 1.6 AND 1.7) - Identification of Hazards & Initiating Events

Reference: Ltr, Jacobs to Williams, dtd 04/23/09, "Yucca Mountain -Request for Additional Information -Volume 2, Chapter 2.1.1.3, Set 3 (U.S. Department of Energy's Safety Analysis Report Sections 1.6 and 1.7)"

The purpose of this letter is to transmit one (1) U.S. Department of Energy (DOE) response to Request for Additional Information (RAI) Number 2. DOE previously submitted its response to RAI Number 1 of this set, related to ash fall hazards, on April 17, 2009. DOE responses to RAI Numbers 3, 4, 5, 7, 13, 14, 18, 19, and 21, identified in the above-referenced letter, were provided on May 11, 2009. DOE expects to submit the remaining RAIs in this set on or before July 31, 2009.

This response provides the document and electronic attachments requested by Nuclear Regulatory Comission related to flood frequency analysis. The requested document is available on the Licensing Support Network (LSN). The document contains electronic attachments which are not available on the LSN. These attachments will be made available to the public upon request.

There are no commitments in the enclosed RAI response. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

Jeffrey R. Williams, Supervisor
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Regulatory Affairs Division
Office of Technical Management

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Enclosures (2):

1. Response to Request for Additional Information, Volume 2, Chapter 2.1.1.3, Third Set, Number 2
2. BSC (Bechtel SAIC Company) 2008. *Flood Hazard Curve of the Surface Facility Area in the North Portal Pad and Vicinity.* 000-PSA-MGR0-01900-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080204.0007.

cc (with Enclosure 1):
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RAI Volume 2, Chapter 2.1.1.3, Third Set, Number 2:

(a) Provide a technical basis for the estimated input parameters used in the flood frequency analysis using the HEC–1 hydrological model.

(b) Provide the flood frequency analysis and any other supporting information that justifies DOE's conclusions for its external flooding assessment. DOE references the following documents, but these have not been provided:

BSC 2004. "Hydrological Engineering Studies for the North Portal Pad and Vicinity." 000–00C–CD04–00100–000–00A. Las Vegas, Nevada: Bechtel SAIC Company.

BSC 2008. "Flood Hazard Curve of the Surface Facility Area in the North Portal Pad and Vicinity." 000–PSA–MGR0–01900–000–00A. Las Vegas, Nevada: Bechtel SAIC Company.

1. RESPONSE

In the NRC clarification call of April 9, 2009, the DOE agreed to provide *Flood Hazard Curve of the Surface Facility Area in the North Portal Pad and Vicinity* (BSC 2008), which contains the flood frequency analysis and the technical bases for the estimated input parameters, and supports the conclusion documented in SAR Section 1.6.3.4.5 that external flooding can be screened from further consideration. This document is provided with this response. The electronic files for Attachments 1, 2, and 3 of the flood analysis (BSC 2008), which contain the HEC-1 input and output files, are also provided with this response.

The methodology and input parameters, along with their technical bases, can be found in Sections 4 and 6 of the flood analysis (BSC 2008).

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2008. *Flood Hazard Curve of the Surface Facility Area in the North Portal Pad and Vicinity.* 000-PSA-MGR0-01900-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080204.0007.

BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

1. QA: QA
2. Page 1

3. System	4. Document Identifier
Monitored Geologic Repository	000-PSA-MGR0-01900-000-00A

5. Title
Flood Hazard Curve of the Surface Facility Area in the North Portal Pad and Vicinity

6. Group
PCSA

7. Document Status Designation
☐ Preliminary ☒ Committed ☒ Confirmed ☐ Cancelled/Superseded

8. Notes/Comments

a. Procedure compliance, documentation, input/output data verification checking: Yue Hao
b. Hydrologic methodology and documentation checking: Reed Maxwell

Attachments	Total Number of Pages
Attachment 1: GIS files for basin delineation	1 page and 1 CD-ROM
Attachment 2: Excel and Matlab script files	1 page and 1 CD-ROM
Attachment 3: HEC-1 input and output Files	1 page and 1 CD-ROM

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	Initial issue	40	40	Q. Duan 01/31/08	Y. Hao 1/31/08 R.M. Maxwell 1/31/08	M.V. Frank 2/1/08	M.R. Wisenburg 2/1/2008

DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC), and are intended solely for the use of BSC in its work for the Yucca Mountain Project (YMP).

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ACRONYMS AND ABBREVIATIONS

Acronyms

ARF	areal reduction factor
BSC	Bechtel SAIC Company, LLC
CD-ROM	compact disc read-only memory
GROA	geologic repository operations area
HEC-1	Hydrologic Engineering Center-1
NOAA	National Oceanic and Atmospheric Administration
NPP	North Portal pad
NRCS	Natural Resources Conservation Service
PCSA	preclosure safety analysis
PMF	probable maximum flood
PMP	probable maximum precipitation
PRF	peak rate factor
YMP	Yucca Mountain Project

Abbreviations

cfs	cubic feet per second
elev	elevation
ft	foot
ft/mi	feet per mile
hr	hour
in.	inch
in/hr	inches per hour
mi	mile
sq mi	square mile

1. PURPOSE

Per 10 CFR Part 63 (*Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada* (Ref. 2.3.1)), the preclosure safety analysis (PCSA) for the geologic repository operations area (GROA) must identify and analyze naturally occurring hazards, which may lead to event sequences that could result in exposure of individuals to radiation. The technical basis for inclusion or exclusion of a hazard must be provided. The purpose of this study is to develop a probabilistic flood hazard curve in order to determine if floods should be fully developed into such event sequences.

The key result of this study is the estimation of the severity of a flood, in terms of volumetric flow rate, for a return frequency of 10^{-6} per year (i.e., a return period of 1 million years). In accordance with 10 CFR Part 63, event sequences associated with preclosure operations at or below this return frequency do not require evaluation of dose and criticality consequences. Therefore, demonstration that the designed volumetric flow rate flood capacity exceeds the million year return period flood is deemed to be sufficient to demonstrate that flood event sequences may be excluded from the further event sequence analysis in the PCSA.

In the process of development of the flood hazard curve, a probable maximum precipitation (PMP) and a probable maximum flood (PMF) were estimated. The PMP and PMF developed in this analysis are simply a part of the independent development of the hazard curve. These estimates are not intended to replace the PMP and PMF used as the basis for the flood design features of the GROA.

A secondary purpose of this calculation is to provide a comparison to the results of *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6), and *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10), which are a series of deterministic analyses used as the basis for the design of the flood protection for the GROA. As shown in the conclusion of this analysis, the results of *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10) are validated by this analysis.

2. REFERENCES

2.1 PROJECT PROCEDURES/DIRECTIVES

2.1.1 BSC (Bechtel SAIC Company) 2007. *Quality Management Directive*. QA-DIR-10, Rev. 2. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20080103.0002.

2.1.2 EG-PRO-3DP-G04B-00037, Rev. 10. *Calculations and Analyses*. Las Vegas, Nevada. Bechtel SAIC Company. ACC: ENG. 20071018.0001.

2.1.3 IT-PRO-0011, Rev. 7. *Software Management*. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20070905.0007.

2.1.4 LS-PRO-0201, Rev. 5. *Preclosure Safety Analysis Process*. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071010.0021.

2.2 DESIGN INPUTS

2.2.1 ANSI/ANS-2.8-1992. 1992. *American National Standard for Determining Design Basis Flooding at Power Reactor Sites*. La Grange Park, Illinois: American Nuclear Society. TIC: 236034.

2.2.2 ArcGIS V. 9.2. 2007. Windows XP. STN: 11205-9.2-00.

2.2.3 Bonnin, G.M.; Martin, D.; Lin, B.; Parzybok, T.; Yetka, M.; and Riley, D. 2006. *Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah)*. Volume 1 Version 4.0 of *Precipitation-Frequency Atlas of the United States*. NOAA Atlas 14. Silver Spring, Maryland: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. ACC: MOL.20071018.0294.

2.2.4 Boufadel, M.C. 2000. "Estimation of the HEC1 Loss Parameters for Routing the Probable Maximum Flood." *Journal of American Water Resources Association, 36* (1), 203–213. Middleburg, Virginia: American Water Resources Association. TIC: 259734.

2.2.5 BSC 2002. *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity*. ANL-EBS-MD-000060 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20021028.0123.

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2.2.7 BSC 2006. *LMY Storm Drainage Calculations*. 780-CDC-MND0-00100-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20060712.0001; ENG.20071015.0004.

2.2.8 BSC 2007. *Geologic Repository Operations Area Overall Site Plan.* 000-C00-MGR0-00201-000 REV 00D. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071116.0003.

2.2.9 BSC 2007. *IED Surface Facility and Environment.* 100-IED-WHS0-00201-000 REV 00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071026.0013.

2.2.10 BSC 2007. *Yucca Mountain Project Drainage Report and Analysis.* 000-CDC-MGR0-00100-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070924.0043.

2.2.11 BSC 2008. *Geologic Repository Operations Area North Portal Site Plan.* 100-C00-MGR0-00501-000 REV 00F. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080125.0007.

2.2.12 CRWMS (Civilian Radioactive Waste Management System) M&O (Management and Operating Contractor). 1999. *Software Qualification Report for HEC-1 V4.0.* CSCI: 30078 V4.0, DI: 30078-2003, REV. 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990521.0220.

2.2.13 DOE (U.S. Department of Energy) 2007. *Software Independent Verification and Validation Report ArcGIS Version 9.2.* Document ID: 11205-IVVR-9.2-01. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: MOL.20070312.0260.

2.2.14 FERC (Federal Energy Regulatory Commission) 2001. "Determination of the Probable Maximum Flood." Chapter 8 of *Engineering Guidelines for the Evaluation of Hydropower Projects.* Washington, D.C.: Federal Energy Regulatory Commission. ACC: MOL.20071012.0075; MOL.20071024.0355.

2.2.15 Hansen, E.M.; Schwarz, F.K.; and Riedel, J.T. 1977. *Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages.* Hydrometeorological Report No. 49. Silver Spring, Maryland: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. TIC: 220224.

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2.2.17 Hui, S. 2006. "Review of Yucca Mountain PMF Studies." E-mail from S. Hui to A. Findikakis, July 19, 2006. ACC: MOL.20071018.0292.

2.2.18 Hydrology Subcommittee of the Interagency Advisory Committee on Water Data 1986. *Feasibility of Assigning a Probability to the Probable Maximum Flood.* Reston, Virginia: U.S. Geological Survey. ACC: MOL.20071012.0073.

2.2.19 Maidment, D.R., ed. 1993. *Handbook of Hydrology.* New York, New York: McGraw-Hill. ISBN: 0-07-039732-5. TIC: 236568.

2.2.20 MO0002SPATOP00.001. Topographic Grid Data. Submittal date: 02/24/2000.

2.2.21 Newton, D.W. 1983. "Realistic Assessment of Maximum Flood Potentials." *Journal of Hydraulic Engineering, 109* (6), 905–918. New York, New York: American Society of Civil Engineers. TIC: 259732.

2.2.22 NOAA (National Oceanic and Atmospheric Administration) 2005. *Semiarid Precipitation Frequency Project*. Update of Paper No. 49 and NOAA Atlas 2. Silver Spring, Maryland: National Oceanic and Atmospheric Administration. ACC: MOL.20071017.0002.

2.2.23 SNF29041993001.002. Percolation Test Data, EFS Muck Storage Area. Submittal date: 12/21/1994.

2.2.24 Solanki, H. and Suau, S.M. 1996. "Reconciliation of Hydrologic Models to Coastal Flatland Watersheds." Chapter 4 of *Advances in Modeling the Management of Stormwater Impacts*. James, W., ed. Chelsea, Michigan: Ann Arbor Press. TIC: 259876.

2.2.25 U.S. Army Corps of Engineers 1990. *HEC-1, Computer Program, User's Manual*. CPD-1A, Version: 4.0. Davis, California: U.S. Army Corps of Engineers. TIC: 243325.

2.2.26 USDA (U.S. Department of Agriculture) 1998. *Tables of Percentage Points of the Pearson Type III Distribution*. Technical Release 38 (TR-38). Washington, D.C.: U.S. Department of Agriculture. ACC: MOL.20071213.0002.

2.2.27 Wang, B-H. and Revell, R.W. 1983. "Conservatism of Probable Maximum Flood Estimates." *Journal of Hydraulic Engineering, 109*, (3), 400–408. New York, New York: American Society Civil Engineers. TIC: 259733.

2.3 DESIGN CONSTRAINTS

2.3.1 10 CFR 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada.

2.4 DESIGN OUTPUTS

This calculation report is part of the PCSA.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

None

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Homogeneity of Watershed Hydrologic Characteristics

Assumption—All precipitation inputs used in this calculation are assumed to be uniformly distributed over the watershed, and the composition of the soils within the watershed is assumed to be homogeneous.

Rationale—This assumption is justified because the watershed under study is relatively small, less than 20 sq mi, as determined by ArcGIS in Section 6.1.1.

3.2.2 Precipitation Areal Reduction Factor

Assumption—The annual maximum precipitation values of different frequencies (from 1-year to 1,000-year events) are obtained from National Oceanic and Atmospheric Administration (NOAA) Atlas 14 (*Semiarid Southwest [Arizona, Southeast California, Nevada, New Mexico, Utah]* (Ref. 2.2.3)). Those values are developed for point-scale applications. If they are used for large-scale modeling, an areal reduction factor (ARF) is usually applied ((Ref. 2.2.3), Section 7, p. 62). The Hydrometeorological Design Studies Center is currently developing the ARF for area sizes of 10 to 400 sq mi for semiarid regions (*Semiarid Precipitation Frequency Project* (Ref. 2.2.22), Section 3.3). However, this work is still continuing, and no values are available. In this calculation, it is assumed that ARF is equal to 1 (i.e., no reduction factor is applied).

Rationale—This assumption is reasonable because the area size in this calculation is small (approximately 13.75 sq mi) and is close to the minimum area size of 10 sq mi considered by the Hydrometeorological Design Studies Center. By assuming an ARF value of 1, the flood peak estimation is slightly more conservative.

3.2.3 Layout of Surface Facilities

Assumption—The locations of the surface facilities, including the North Portal pad (NPP) nuclear waste receiving and processing facilities, aging pad, roads, dikes, and ditches are assumed to follow the *Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.8) and the *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.11). This assumption is used throughout because the calculation is dependent on the configuration of the surface facilities in relation to the flood plain.

Rationale—Although the final design of the surface facilities is not complete and it is likely to be different from the two site plans used in this calculation, the calculation results are valid as long as the locations and dimensions of the facilities are approximately the same.

3.2.4 Man-Made Channels

Assumption—The GROA site plans (*Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.8) and *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.11)) include man-made channels to divert water around and away from the surface facilities. The exact geometric dimensions of the man-made channels are not known at present because the final surface facility design is still not complete. This calculation follows approximately the

geometric dimensions of man-made channels as specified in *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10, Table 6-2). A list of the man-made channels and their geometric dimensions is presented in Section 6.1.1.

Rationale—Even though the exact design of the man-made channels is yet to be finalized, the geometric dimensions in Ref. 2.2.10 are reasonable. Furthermore, the exact geometry, which was used to determine the Manning's roughness coefficient, has little effect on the flood peak flow rate because the sensitivity study in Section 6.4.4 shows that flood peaks are not sensitive to Manning's roughness coefficient. The flood stage height, however, is dependent on the channel geometry. If the flood stage height exceeds the design standard, it may become necessary that the bottom width of the channel design be widened to lower the flood stage height or a higher dike be built to prevent channel floodwater flowing over the bank.

3.2.5 Probability of PMF Components

Assumption—It is assumed that there are three major independent events contributing to the calculation of probability of PMF: (1) the PMP, (2) the antecedent moisture condition, and (3) storm orientation and temporal distribution. PMF peak discharge was computed using an initial loss of 0 in. and a uniform loss of 0.1 in./hr, which represents a totally saturated watershed condition. It is assumed that the probability of a saturated condition occurring prior to a PMP event in the study area is 7.69×10^{-4} (i.e., a 25-year storm has hit the area within one week prior to the PMP hitting the area, which results in a probability of $0.04/52 = 7.69 \times 10^{-4}$, where 0.04 is the frequency of 25-year storm and 52 is the number of weeks in a year). It is further assumed that a probability value of 0.1 is assigned to the condition such that the storm is perfectly aligned to the basin shape and that temporal distribution is optimized, with the center of the storm situated in the later half of the storm.

Rationale—This assumption is justified because PMF is always associated with PMP, and a 25-year storm, which has a total of 1.75 in. of precipitation during the storm period, represents the smallest storm that has enough water to satisfy the initial and infiltration losses while producing some runoff. Additionally, it is conservative to assume that the basin remains saturated after a 25-year storm has occurred within the past week, storms rarely align perfectly with the basin shape, and temporal distribution of the storm is rarely optimized. A probability value of 0.1 for this situation is a conservative estimate.

3.2.6 Temporal Distribution of Precipitation Events of Different Frequencies

Assumption—The temporal distribution of precipitation events of different frequencies is assumed to be similar to the PMP temporal distribution.

Rationale—This assumption is justified because all of the extreme storm events in the YMP area are storm events of the same type.

3.2.7 Initial and Uniform Loss Parameters

Assumption—The initial loss parameter for the Hydrologic Engineering Center-1 (HEC-1) model is assumed to be equal to 1 in. for floods, whose frequency ranges from 1 to 1,000 years. For PMF simulation, the initial loss parameter is assumed to be equal to 0 in. The uniform loss parameter is assumed to have a value of 0.1 in./hr for all flood events.

Rationale—Section 4.4.1 discusses how these loss parameters are derived. Ideally, they are calibrated using historical hydrologic data. Because there are no historical hydrologic data for the YMP area (i.e., the area draining through the surface facility layout location), these parameters were estimated based on available literature values.

3.2.8 Exceedance Probability of Annual Maximum Flood Peaks and Annual Maximum Precipitation Events

Assumption—It is assumed that the flood peak discharge has the same frequency or exceedance probability as the annual maximum precipitation, which is used as input to the HEC-1 hydrologic model to compute flood peak. This assumption is applied to all events except PMP and PMF.

Rationale—The probability values of annual maximum precipitation and maximum flood events depend on how the basin initial and boundary conditions are set up. If these conditions reflect proper hydroclimatic conditions of the underlying events, then the floods resulting from the underlying storms should have the same frequency. Because there are no historical data to judge the proper conditions, conservative initial and boundary conditions were used in this calculation report.

3.2.9 Flow Bulking Factor

Assumption—A bulking factor of 10% is assumed, which would increase flood peak estimates by 10% to account for sediment and debris transport, as well as air entrainment.

Rationale—Flood volume can be bulked up at the basin outlet by air entrainment and by sediment and debris transported from upstream subbasins. The HEC-1 hydrologic model used to compute flood peaks does not consider this effect. A 10% bulking factor is assumed because there are no data to estimate the bulking factor. A bulking factor of 10% is conservative according to *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5, Section 5.10).

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Ref. 2.1.2), and LS-PRO-0201, *Preclosure Safety Analysis Process* (Ref. 2.1.4). QA-DIR-10, *Quality Management Directive* (Ref. 2.1.1), Section 2.1.C.1.1.a.iii, applies to this calculation, and the final version is designated as "QA: QA" because it is part of the PCSA.

The *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.11), the *Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.8), Manning's Roughness Coefficient (*LMY Storm Drainage Calculations* (Ref. 2.2.7), Section 4.3.7), and properties of channels used in the HEC-1 model (*Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10), Table 6-2) are obtained from "QA: N/A" sources. However, the use of these sources as inputs is justified because these sources depict information for systems classified as not important to safety and not important to waste isolation.

4.2 USE OF SOFTWARE

This calculation used both qualified software obtained from Software Configuration Management and commercial off-the-shelf software. The list of qualified software used is shown in Table 1. The HEC-1 hydrologic model, developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center, was used to calculate flood hydrographs and flood peaks (*HEC-1 V4.0. 1999* (Ref. 2.2.16); *HEC-1 Computer Program, User's Manual* (Ref. 2.2.25)). HEC-1 was run on a Dell Optiplex Gn personal computer operated under the Windows 95 operating system. The computer is located at Lawrence Livermore National Laboratory in Livermore, California. The HEC-1 software has been used within the range of validation according to *Software Qualification Report For Hec-1 V4.0* (Ref. 2.2.12). The ArcGIS software was used to delineate hydrologic basin units and flow paths (*ArcGIS V. 9.2. 2007. Windows XP* (Ref. 2.2.2)). The run was made on November 28, 2007, using the qualified ArcGIS version 9.2 on a Dell Optiplex 745 computer operated under the Windows XP operating system located at BSC Building 1450 in Las Vegas (Computer identification number: YMP005035). The ArcGIS software has been used within the range of validation according to *Software Independent Verification and Validation Report: ArcGIS v9.2-00* (Ref. 2.2.13).

Table 1. List of Software Usage

Name	STN/CSCI Identifier	CPU Operating Platform	CPU Operating System
HEC-1 V4.0	30078-V4.0	PC	Windows 95/DOS
ArcGIS V9.2	11205-9.2-00	PC	Windows XP

NOTE: CPU = central processing unit; CSCI = computer software configuration item; DOS = disk operating system;; HEC-1 = Hydrologic Engineering Center-1; PC = personal computer; STN = software tracking number.

Source: Original.

The commercial off-the-shelf software used in this calculation includes Word and Excel from Microsoft Office 2003 and MATLAB 7.0.1. The use of the aforementioned software is classified as Level 2 per IT-PRO-0011, *Software Management* (Ref. 2.1.3), Attachment 12. Excel, run on a Lawrence Livermore National Laboratory Dell OptiPlex GX270 operated under the Windows XP operating system (Computer identification number: 55274-640-1062534-23906), was used to calculate PMP values and hydrologic parameters such as the time-lag parameter of the unit hydrograph and stream slopes used in HEC-1. Word, run on the same computer, was used to develop this report. MATLAB, also run on a Lawrence Livermore National Laboratory OptiPlex GX270 under Windows XP, was used to make graphics and compute statistics for this calculation report. Word documents, Excel calculations, and MATLAB calculations have all been verified by hand calculations. All other computations are hand calculations, and results in all figures have been verified by visual inspection.

4.3 DELINEATION OF THE HYDROLOGIC BASINS AND FLOW PATHS

ArcGIS V9.2 was used to delineate hydrologic basins and flow paths for this calculation. ArcGIS processes a gridded digital elevation model dataset with a spatial resolution of 100 ft for the YMP area (*IED Surface Facility and Environment* (Ref. 2.2.9); DTN: MO0002SPATOP00.001 (Ref. 2.2.20)) to produce a map of hydrologic basins and flow paths. The delineation is accomplished by the hydrologic analyst tool within ArcGIS V9.2. The delineation procedure is briefly described as follows: (1) compute the flow directions for the entire data domain; (2) identify and fill the sinks so that the flow path from any point within the basin to the basin outlet can be clearly defined; (3) compute the flow accumulation areas; (4) create basins of interest at pertinent locations using the interactive properties tool within the hydrologic analyst; (5) overlay surface facilities, as outlined in the surface facility site plans (*Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.8) and *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.11)) on the watershed map; and (6) compute the basin area sizes and channel lengths. The ArcGIS software has an internal function that computes the number of pixels of each basin unit. The basin area is equal to the number of pixels times grid cell size (e.g., 100 × 100 sq ft). The channel length is obtained using the measuring tool in ArcGIS. The output of the delineation is shown in Section 6.1.1. The list of basins and flow paths and associated physical properties is presented in Section 6.1. Attachment 1 contains all of the ArcGIS files, including input files, output files, and a Microsoft Word file that describes the steps in using ArcGIS software to perform basin and flow path delineation ("Steps in Delineating Hydrologic Basins Using ArcGIS.doc").

It should be noted that the surface facility site plans (Ref. 2.2.11 and Ref. 2.2.8) are still not finalized, and further changes to these plans may result in different basin delineation and flow paths. However, any changes to the surface facility site plans in the future are not expected to affect this calculation (Assumption 3.2.3 and Assumption 3.2.4).

4.4 SPECIFICATION OF HEC-1 MODEL PARAMETERS

Flood hydrographs and flood peaks at pertinent locations in the NPP and vicinity area were calculated using the HEC-1 computer software. The HEC-1 software treats the watershed as a series of interconnected networks of hydrologic and hydraulic components (*HEC-1 Computer Program, User's Manual* (Ref. 2.2.25), Section 2). To run HEC-1, precipitation inputs must be provided, and model parameters for each of the hydrologic and hydraulic components must be specified. Section 4.5 describes the procedure for computing precipitation inputs for HEC-1. The procedure for specifying HEC-1 model parameters is discussed here. The HEC-1 software uses a conceptual hydrologic model, and ideally its parameters should be calibrated using historical precipitation and streamflow data (*HEC-1 Computer Program, User's Manual* (Ref. 2.2.25), Section 4); however, there are no historical hydrologic data for the YMP area. Therefore, the HEC-1 parameters were defined based on the assumptions given in Assumption 3.2.7 in the case of initial and uniform loss parameters.

4.4.1 Initial and Uniform Loss Parameters

There are two loss parameters in the HEC-1 model: initial loss and loss during a precipitation event. There are several options within the HEC-1 software to simulate these losses in the

model. The *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* flood analysis established that it is reasonable to use the initial loss and uniform loss option ((Ref. 2.2.5), Section 5.8). This calculation also adopts the same option. In both the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analyses, the initial loss was 1 in., and the uniform loss was 1.5 in./hr throughout the precipitation event. The uniform loss rate in these analyses was based on a percolation test conducted in the YMP area (DTN: SNF29041993001.002 (Ref. 2.2.23)). There were questions raised on the specification of loss parameters in these analyses. The value of 1.5 in./hr for uniform loss is regarded as too high in *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) according to the comments in the Hui e-mail *Review of Yucca Mountain PMF Studies* (Ref. 2.2.17). It was pointed out that the use of percolation capacity to represent the uniform loss is not reasonable because the percolation test is not indicative of how the infiltration process occurs during a storm runoff event. Infiltration during a storm is a surficial phenomenon that is dependent on local surface conditions (e.g., initial wetness, soil degradation, vegetation cover), slope, rainfall intensity, and saturation extent during the storm. On the other hand, percolation capacity of the soil represents the standing (or ponding) water condition, in contrast to storm runoff conditions. Therefore, the uniform loss should be much smaller than 1.5 in./hr. This is especially true for the PMF calculation, which would occur only under extremely moist conditions. As pointed out in "Determination of the Probable Maximum Flood," Chapter 8 of *Engineering Guidelines for the Evaluation of Hydropower Projects* (Ref. 2.2.14), published by the U.S. Federal Energy Regulatory Commission, "For PMF runoff computations, the soil should be assumed to be saturated with infiltration occurring at the minimum rate applicable to the area-weighted average soil type covering each subbasin."

In "Estimation of the HEC1 Loss Parameters for Routing the Probable Maximum Flood," Boufadel (Ref. 2.2.4) optimized the HEC-1 loss parameters for a PMF for a basin in southwest Ohio using 20 historical extreme events and reported that the initial loss parameter is about 1 in., but the uniform loss parameter is only 0.1 in./hr. Because loss parameters cannot be calibrated for the YMP area due to the lack of historical data, it is necessary to estimate them based on local soil group information and on storm conditions. For the North Portal pad (NPP) and vicinity, the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* flood analysis reported that the soil group of the area belongs predominantly to soil groups B and D, but soil group A and C are also present in a few soil samples (Ref. 2.2.5), Appendix II. According to the Federal Energy Regulation Commission guidelines for the evaluations of hydropower projects, the minimum loss for soil group A is 0.3 to 0.45 in./hr, for soil group B 0.15 to 0.3 in./hr, for soil group C 0.05 to 0.15 in./hr, and for soil group D 0 to 0.05 in./hr ("Determination of the Probable Maximum Flood" (Ref. 2.2.14), p. 55).

For this calculation, a range of initial and uniform loss parameters for a PMF were tested, as well as flood events of various frequencies (Section 6.4.2). It was found that flood peaks of all frequencies are sensitive to the uniform loss parameter. The sensitivity of flood peaks to initial losses is dependent on storm intensity. The higher the storm intensity, the less sensitive are the flood peaks to initial loss parameter. Because initial loss represents precipitation loss due to canopy interception, filling of surface depressions, and surface absorption, this term should be

relatively constant for all design storms except PMF. Consequently, several initial loss values were examined, and a value of 1 in. for all events except the PMF was ultimately used. For the PMF, the initial loss parameter was assigned a value of 0 in. to reflect the most extreme moist condition. For the uniform loss parameter, a conservative value of 0.1 in./hr was used for all flood events (Assumption 3.2.7).

4.4.2 Unit Hydrograph Time-Lag Parameter

The unit hydrograph method was used to develop the precipitation-runoff hydrograph for each basin. Two parameters prescribe a unit hydrograph: the basin area and the time lag between the storm midpoint and the flood peak. Basin area was determined by the ArcGIS software in this calculation. There are different ways to determine the time-lag parameter. Previous BSC flood analyses adopted the U.S. Natural Resources Conservation Service (NRCS) Dimensionless Unit Hydrograph (*Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), Section 5.6, and *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6), Section 4.2.4). The equation for computing time lag in hours using the NRCS method is:

$$lag = C\left(\frac{L \cdot L_{ca}}{\sqrt{S}}\right)^{0.33} \qquad \text{(Eq. 1)}$$

where

C	=	coefficient
L	=	length of the main channel (mi)
L_{ca}	=	length along the main channel from the basin outlet to the point nearest the basin centroid (mi)
S	=	slope of the main channel (ft/mi).

In the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analyses, C took the value of 1.1. It was pointed out in the Hui e-mail (*Review of Yucca Mountain PMF Studies* (Ref. 2.2.17)) that a C value of 1.1 corresponds to an average terrain condition, with a "peak rate factor (PRF)" of 484. PRFs range from 600 for steep terrain down to 300 in very flat, swampy terrain (*Advances in Modeling the Management of Stormwater Impacts* (Ref. 2.2.24), p. 51). For the NPP and vicinity, the terrain is in the steep category, with a slope of >7%. Accordingly, a conservative PRF value of 600 is chosen instead of a value of 484. This would result in a C value of 0.887, which was used in this calculation.

4.4.3 Manning's Roughness Coefficient for Flow Channels

This calculation used two methods to route water from upstream basins to downstream confluence points: Muskingum-Cunge and kinematic wave. The Muskingum-Cunge method is a superior method compared to the kinematic wave method (*HEC-1 Computer Program, User's Manual* (Ref. 2.2.25), Section 3.6.10). It was used for channel routing of all natural channels.

For flow routing for short man-made channels, the simpler kinematic wave method was used. For both methods, Manning's roughness coefficient (*n*) must be specified. In the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analyses, Manning's *n* was set to 0.09. This calculation report used the same value as these two analyses. In Samuel Hui's e-mail, a comment was made that the selection of Manning's *n* might impact peak flow simulation (*Review of Yucca Mountain PMF Studies* (Ref. 2.2.17)). To address Hui's comment, a sensitivity study of Manning's *n* was done (Section 6.4.4).

4.5 CALCULATION OF PRECIPITATION INPUTS TO THE HEC-1 HYDROLOGIC MODEL

Precipitation inputs are needed to drive the HEC-1 model. In this calculation, two types of precipitation events were considered: the PMP and the annual maximum precipitation for different frequencies. The PMP is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible at a particular location at a particular time of the year (*Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages* (Ref. 2.2.15), Section 1.4). The annual maximum precipitation of a given frequency represents the annual maximum precipitation event that would, on average, not recur within a specified time period, also known as the return period. The annual maximum precipitation of a given frequency is sometimes known as the design storm (e.g., 1-year storm, 2-year storm, 1,000-year storm). For both PMP and design storms, only 6-hour events were considered because the flood peaks for the basin size under consideration occur within a 6-hour time frame. Further, it is assumed that all precipitation events are uniformly distributed over the watershed because of the relative small watershed size (Assumption 3.2.1).

The procedure for calculating PMP is described in NOAA Hydrometeorological Report No. 49 (*Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages* (Ref. 2.2.15), Section 6). There are two types of storms that would likely result in PMP: a convective summer local storm (local) and a large-scale winter frontal storm (general). Both the general and the local 6-hour PMP for the NPP and vicinity were computed. The local PMP is more intense and about 2 times higher than the general PMP. Therefore, this calculation used the local PMP to compute flood peaks.

The annual maximum precipitation values of different frequencies are obtained from NOAA Atlas 14 (*Semiarid Southwest [Arizona, Southeast California, Nevada, New Mexico, Utah]* (Ref. 2.2.3)), whose data are in the form of isohyet precipitation maps. The 6-hour data for the location corresponding to the centroid of the watershed were extracted. As pointed out in Assumption 3.2.2, no ARF is applied here. The precipitation values for the NPP and vicinity area are presented in Section 6.2.

5. LIST OF ATTACHMENTS

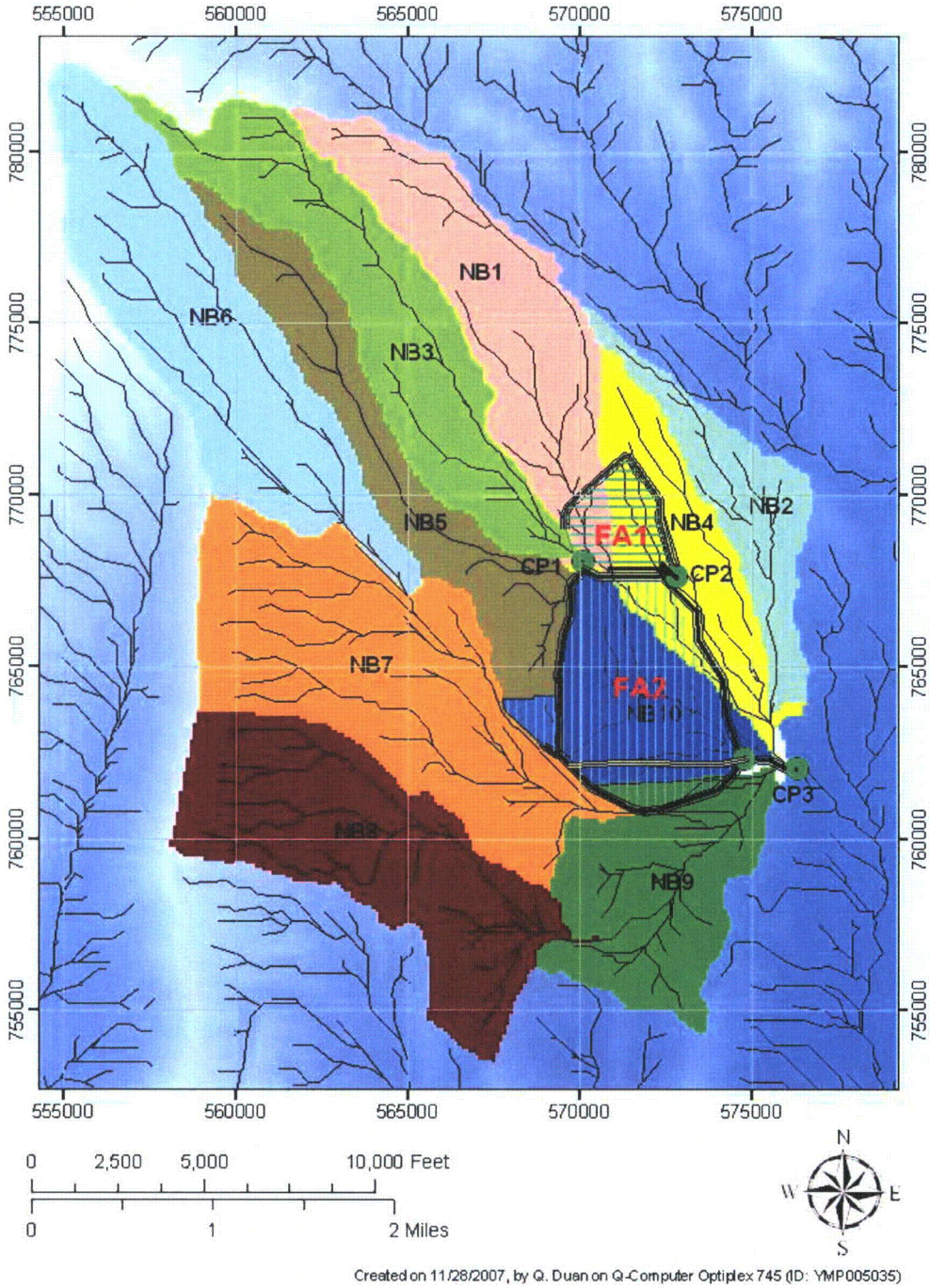
		Number of Pages
Attachment 1.	GIS files for basin delineation	1 page and 1 CD-ROM
Attachment 2.	Excel and Matlab script files	1 page and 1 CD-ROM
Attachment 3.	HEC-1 input and output files	1 page and 1 CD-ROM

6. BODY OF CALCULATION

6.1 PHYSICAL PROPERTIES OF HYDROLOGIC BASINS AND FLOW PATHS

6.1.1 Delineation of Hydrologic Basins and Flow Paths

Using the procedures described in Section 4.3, a map of hydrologic basins and flow paths was derived using the ArcGIS software (Figure 1) (*ArcGIS V. 9.2* (Ref. 2.2.2)). There are nine natural basins and two overland flow elements, which were drawn based on surface facilities site plans (*Geologic Repository Operations Area Overall Site Plan* (Ref. 2.2.8) and *Geologic Repository Operations Area North Portal Site Plan* (Ref. 2.2.11)). The centroid of the watershed is located at 36°52' North, 116°29' West (*Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), Section 4.1.2.1). Table 2 shows the list of hydrologic basins and associated physical properties. Table 3 displays the list of channels used by the HEC-1 software to route flow from upstream basins to downstream outlets, along with their geometry and properties. Table 4 lists the properties of the two overland flow elements. Data for Tables 2 through 7 in this section are included in Attachment 2 on a CD-ROM.



Source: Original.

Figure 1. Delineation of Hydrologic Basins and Flow Paths

Table 2. Hydrologic Basins and Physical Properties

Name	Area (sq mi)	Flow Path Length (mi)	Elevation at Head of Basin (ft)	Elevation at Basin Outlet (ft)	Average Channel Slope (ft/mi)	Average Channel Slope (ft/ft, %)
NB1	1.336	3.37	4,850	3,780	317.47	6.01%
NB2	0.671	2.88	4,000	3,500	173.80	3.29%
NB3	1.540	3.95	5,600	3,750	468.05	8.86%
NB4	0.675	2.61	3,950	3,500	172.59	3.27%
NB5	1.159	3.40	5,250	3,750	440.82	8.35%
NB6	1.957	3.77	5,800	4,000	477.98	9.05%
NB7	2.187	3.09	4,900	3,650	404.12	7.65%
NB8	1.764	2.60	4,900	3,700	462.29	8.76%
NB9	1.054	1.67	3,800	3,500	179.51	3.40%
FAC1	0.273	0.72	3,850	3,700	209.86	3.97%
FAC2	1.135	1.33	3,820	3,550	203.14	3.85%
Total	13.751	29.38	4,611	3,671	319.06	7.23%[a]

NOTE: [a]Area weighted average slope for basins NB1 through NB9.

Source: Original.

Table 3. Stream Channels and Physical Properties

Channels Name	Length (ft)	Max Elev (ft)	Min Elev (ft)	Slope (ft/ft, %)
NB1CP1	1,534	3,780	3,750	1.96%
CP1CP2	2,576	3,750	3,700	1.94%
FAC2CP3	1,630	3,550	3,500	3.07%
CP2CP3	7,013	3,700	3,500	2.85%
NB6NB7	9,934	4,000	3,650	3.52%
NB7CP3	5,304	3,650	3,500	2.83%
NB8CP3	8,824	3,700	3,500	2.27%
FAC1 Main Channel	3,774	3,850	3,700	3.97%
FAC2 Main Channel	7,018	3,820	3,550	3.85%

Source: Original.

Table 4. Properties of the Overland Flow Elements

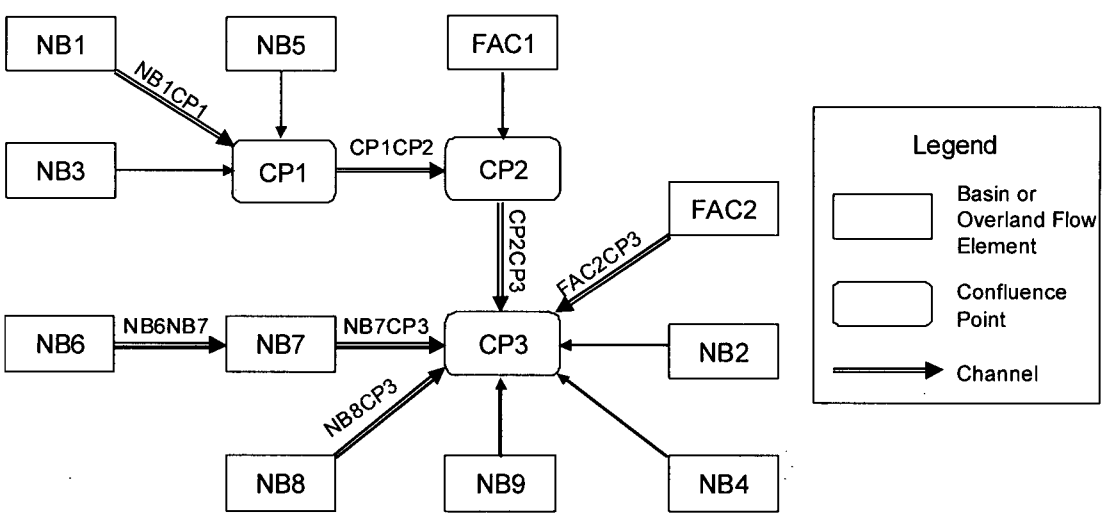
	Overland flow length (ft)	Max elev (ft)	Min elev (ft)	Slope (ft/ft)	Resistance Factor[a]	% area	% Impervious[b]
FA1							
Impervious	3,960	3,850.00	3,700	3.79%	0.100	25.00%	100.00%
Pervious	4,462	3,850.00	3,700	3.36%	0.100	75.00%	0.00%
FA2							
Impervious	3,200	3,820.00	3,550	8.44%	0.100	50.00%	100.00%
Pervious	7,290	3,820.00	3,550	3.70%	0.100	50.00%	0.00%

NOTE: [a]Based on Ref. 2.2.6, p. 16 of Section 4.3.2.
[b]Approximation based on facility layout plans, Ref. 2.2.11, and Ref. 2.2.8.

Source: Original.

Figure 2 displays the schematic diagram of the watershed network. There are several key confluence points over the watershed, marked by CP1, CP2, and CP3. The confluence points are locations where floodwater from upstream basins and channels collects.

For this calculation, the focus is the peak flow from the hydrologic drainage area above CP3, which has a total area size of 13.75 sq mi. The final flood hazard curve is based on the drainage area above CP3 because CP3 is the outlet of the entire watershed, and it experiences the largest flood peak.



Source: Original.

Figure 2. Schematic Diagram of the Watershed Network

6.1.2 Hydrologic and Hydraulic Parameters of the Watershed

Based on the physical properties of the basins and flow paths, the hydrologic and hydraulic parameters were computed using the methods presented in Section 4.4. The loss parameters

were specified in a manner described in Section 4.4.1, with initial loss ranging from 0 in. for the PMF and 1 in. for all other flood events. The uniform loss is equal to 0.1 in./hr for all flood events. The time-lag parameters were computed using the NRCS method (Eq. 1). The time-lag results are presented in Table 5. This calculation report uses the time-lag parameters corresponding to the last column, with $C = 0.887$ instead of $C = 1.1$, because the watershed is relatively steep. The two overland flow elements are not listed in the table because the time-lag parameters are not used in the overland flow calculation by HEC-1.

Table 5. Time-Lag Parameters of Hydrologic Basins Computed by NRCS Method

Name	L (mi)	Lca (mi)	S (ft/mi)	LLca/S0.5	Lag (C=1.1) (hrs)	Lag (C=0.887) (hrs)
NB1	3.370	1.685	317.47	0.319	0.754	0.608
NB2	2.877	1.438	173.80	0.314	0.750	0.605
NB3	3.953	1.976	468.05	0.361	0.786	0.634
NB4	2.607	1.304	172.59	0.259	0.704	0.568
NB5	3.403	1.701	440.82	0.276	0.719	0.580
NB6	3.766	1.883	477.98	0.324	0.759	0.612
NB7	3.093	1.547	404.12	0.238	0.685	0.552
NB8	2.596	1.298	462.29	0.157	0.597	0.481
NB9	1.671	0.836	179.51	0.104	0.522	0.421

NOTE: C = coefficient; hrs = hours; L = total channel length; L_{ca} = length along the flow path from the basin outlet to the point opposite the centroid of the basin area; Lag = time lag; NRCS = Natural Resources Conservation Service; S = slope of the channel.

Source: Original.

To run channel flow routing schemes, parameters including channel length, side slope, channel shape, and Manning's roughness coefficient (n) need to be specified. Channel lengths and channel slopes can be determined using the ArcGIS software. The shape of all channels is trapezoidal in this calculation report, the same as in *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* flood analysis (Ref. 2.2.6). The bottom width and side slopes of all channels are based on the *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10, Table 6-2). Because Manning's n is not measurable, it should be determined based on channel physical properties. Previous flood analyses in the Yucca Mountain area suggested that Manning's n is in the range of 0.03 to 0.055 (*Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), Section 4.1.2.3). In the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analyses, a value of 0.09 was assigned to Manning's n to take into account the sediment and debris effect on channel flow (*Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), Table 5-1). This calculation report also used the same Manning's n as in these flood analyses. The Hui e-mail (*Review of Yucca Mountain PMF Studies* (Ref. 2.2.17)) raised a question concerning the selection of Manning's n on flood peak simulation and flood inundation in the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) flood analysis. A sensitivity study presented in Section 6.4.4 shows that the selection of Manning's n is not critical to flood peak simulation because it is not sensitive to Manning's n

(*Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), Section 5.9). Channel characteristics including Manning's *n* and channel dimensions are listed in Table 6.

Table 6. Characteristics of Flow Channels

Channel Name	Manning's na	Shapeb	Bottom Width (ft)b	Side Bank Slope (h:1)b	Channel Liningc
NB1CP1	0.09	TRAP	68	3	Concrete
CP1CP2	0.09	TRAP	88	3	Concrete
FAC2CP3	0.09	TRAP	30	4	Concrete
CP2CP3	0.09	TRAP	30	4	Natural
NB6NB7	0.09	TRAP	30	10	Natural
NB7CP3	0.09	TRAP	30	10	Natural
NB8CP3	0.09	TRAP	30	10	Natural
FAC1 main channel	0.09	TRAP	30[c]	3[c]	Concrete
FAC2 main channel	0.09	TRAP	30[c]	3[c]	Concrete

NOTE: [a]Based on Ref. 2.2.6, Section 4.3.3.
[b]Based on Ref. 2.2.10, Table 6-2.
[c]Based on Ref. 2.2.11 and Ref. 2.2.8.

Source: Original.

6.2 CALCULATION OF PRECIPITATION INPUTS

6.2.1 Probable Maximum Precipitation

Using *Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages* ((Ref. 2.2.15), Section 6) procedures with the geographic data (namely the area and location of the watershed) as described in Section 6.1.1, the local PMP values were calculated for the drainage area above CP3 (13.75 sq mi). The general PMP for the drainage area above CP3 was also computed. The Excel spreadsheet for calculating the PMP is included as Attachment 2 of this calculation ("PMP calculation final.xls"). The final PMP values are shown in Table 7.

Table 7. Local and General PMP Values for Hydrologic Drainage Area above CP3

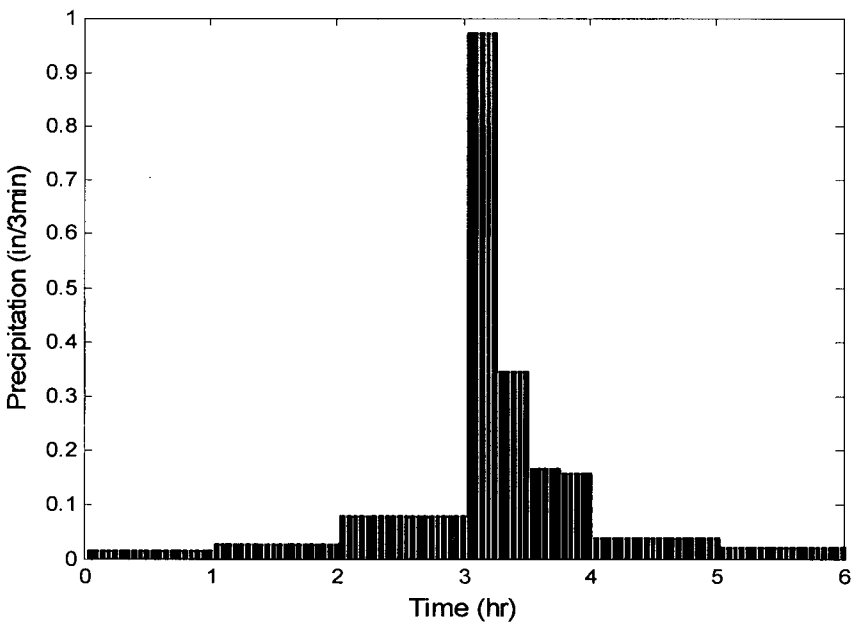
Area	sq mi	13.751
Local PMP	in./6hr	11.907
General PMP	in./6hr	5.535

NOTE: hr = hour; in. = inch; PMP = probable maximum precipitation.

Source: Original.

Local PMP is much more intense than general PMP (11.907 vs. 5.535) and is, therefore, used in this calculation report. For hydrologic drainage above CP3, the PMP value is 11.91 in./6 hr.

There are different ways to distribute precipitation temporally over the storm duration. Two temporal distributions are recommended in *Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages*, which place the maximum intensities in the middle of the storm period (Ref. 2.2.15, Section 4.7). The difference between the two distributions is that one distribution places the precipitation peak in the later half of the period, while the other places it in the first half. The temporal distribution with a later precipitation peak would result in higher peak flow. Therefore, the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* ((Ref. 2.2.5), Figure 2) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* ((Ref. 2.2.6), Figure 4.3) flood analyses adopted this temporal distribution. This calculation report also adopts the same distribution as these flood analyses. Figure 3 shows the PMP temporal distribution hyetograph.



NOTE: hr = hour; in = inch; min = minute.

Source: Original.

Figure 3. PMP Temporal Distribution

6.2.2 Annual Maximum Precipitation of Different Frequencies

The annual maximum precipitation values of different frequencies for 6-hour duration at the centroid of the watershed were obtained from *Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah)* (Ref. 2.2.3). Because the watershed size is small, no ARF was applied to the precipitation values (Assumption 3.2.2). Table 8 lists the annual maximum precipitation values and associated return periods. The PMP value is also included in the table and is assigned to a return period calculated in Section 6.5.1. In Section 6.5.1, a reasonable probability value for PMP is discussed. The temporal distribution for precipitations of all frequencies follows a typical distribution as described in Assumption 3.2.6. Precipitation multiplied by the series of all frequencies is included in an Excel file included in Attachment 2 ("precip_all_freq.xls").

Table 8. Annual Maximum Precipitation Values and Associated Return Periods

Return Period (yr)	Nonexceedance Probability	Precipitation (in.)[a]
1	0	0.65
2	0.5	0.84
5	0.8	1.12
10	0.9	1.40
25	0.96	1.75
50	0.98	2.00
100	0.99	2.40
1,000	0.999	4.00
70,000[b]	0.9999857[b]	11.91

NOTE: [a]All precipitation values except PMP are obtained from *Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah)* (Ref. 2.2.3).
[b]Obtained from Section 6.5.1.

Nonexceedance probability is equal to 1 minus the reciprocal of the return period.

in. = inch; PMP = probable maximum precipitation; yr = year.

Source: Original.

6.3 FLOOD PEAK SIMULATIONS

6.3.1 Flood Peak Discharge Simulations for the Hydrologic Drainage Area above CP3

Section 6.1 and Section 6.2 presented the inputs needed to run the HEC-1 model (*HEC-1 V4.0* (Ref. 2.2.16)). The HEC-1 model was run using the precipitation and parameter values described in these sections. Table 9 summarizes the peak discharges at CP3 for all precipitation events. The last row of Table 9 shows the PMF value, which is the peak discharge value that resulted from the PMP event. As stated in Assumption 3.2.8, the exceedance frequency of the peak discharges of all storms except PMP was assigned at the same value as the associated annual maximum precipitation events. The frequency of PMF is calculated in Section 6.5.1. Based on Assumption 3.2.9, a bulking factor was applied to the flood peak discharges (Column 4 of Table 9). Table 10 shows the PMF peak discharges for different basins and confluence points. The flood peaks for 1-year and 2-year return periods are not listed because there are no floods resulting from 1-year or 2-year precipitation events (i.e., the combined initial and uniform loss for these events exceeds the precipitation input). Attachment 3 contains all of the input and output files of HEC-1 model runs.

Table 9. Peak Discharges for All Precipitation Events at CP3

Return Period (yr)	Nonexceedance Probability	Peak Discharges @ CP3 (cfs)	Peak Discharges w/ 10% bulking factor @ CP3 (cfs)
5	0.8	243	267
10	0.9	1,437	1,581
25	0.96	3,343	3,677
50	0.98	5,033	5,536
100	0.99	7,745	8,520
1,000	0.999	19,003	20,903
90.9×10^{9} [a]	0.9999999989 [a]	68,842	75,726

NOTE: [a]Obtained from Section 6.5.2.

Nonexceedance probability is equal to 1 minus the reciprocal of the return period.
cfs = cubic feet per second; PMF = probable maximum flood; yr = year.

Source: Original.

6.4 SENSITIVITY OF THE PEAK FLOW SIMULATION TO PARAMETER UNCERTAINTY

The peak flow simulations presented in Section 6.3 used some of the parameters that were specified differently from the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analyses. This section examines the sensitivity of flow peaks to parameter uncertainty.

Table 10. PMF Peak Discharges for Different Basins and Confluence Points for the Hydrologic Drainage Basin above CP3

Basins and Confluence Points	Peak Discharge (cfs)	Peak Discharge w/10% Bulking Factor (cfs)
FA1	1,904	2,094
FA2	7,951	8,746
NB1	6,962	7,658
NB2	3,507	3,858
NB3	7,817	8,599
NB4	3,669	4,036
NB5	6,219	6,841
NB6	10,156	11,172
NB7	20,961	23,057
NB8	10,603	11,663
NB9	6,852	7,537
CP1	20,955	23,051
CP2	21,965	24,162
CP3	68,842	75,726

NOTE: cfs = cubic feet per second.

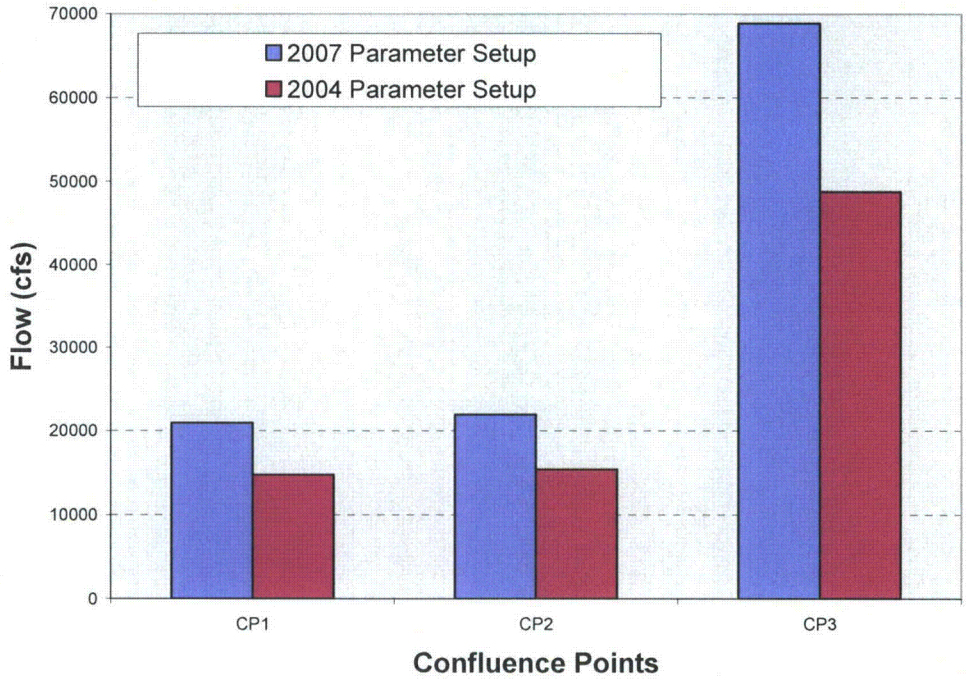
Source: Original.

6.4.1 PMF Simulation Using the Parameter Setup from the 2004 BSC Flood Analysis

Using the parameter setup from the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* ((Ref. 2.2.6), Sections 4.2 and 5.2) flood analysis, the HEC-1 model was run for the hydrologic drainage basins above CP3. The peak flows at key confluence points are compared to those presented in Section 6.3 (Figure 4). For the drainage area above CP3, the peak flow at basin outlet CP3 simulated using *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) parameter setup is 29% less than the peak flow simulated using the parameter setup presented in this calculation report (Figure 4). This information shows that the new parameter setup results in peak flow simulations that are significantly higher than the previous flood analysis. In the following sections, the individual parameters contributing most to the difference in peak flows are discussed.

6.4.2 Sensitivity of Peak Flows to Loss Parameters

This section examines the sensitivity of peak flows to the specification of loss parameters in the HEC-1 model. In both the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analyses, the initial loss was set to 1 in., and the uniform loss was set to 1.5 in./hr. Section 4.4.1 describes how the loss parameters were specified in this calculation report. For the PMF, the initial loss parameter was set to 0 in., and the uniform loss parameter was set to 0.1 in./hr. For flood events of lesser magnitude, the initial loss parameter was set to 1 in., and the uniform loss parameter was set to 0.1 in./hr for all flood events.



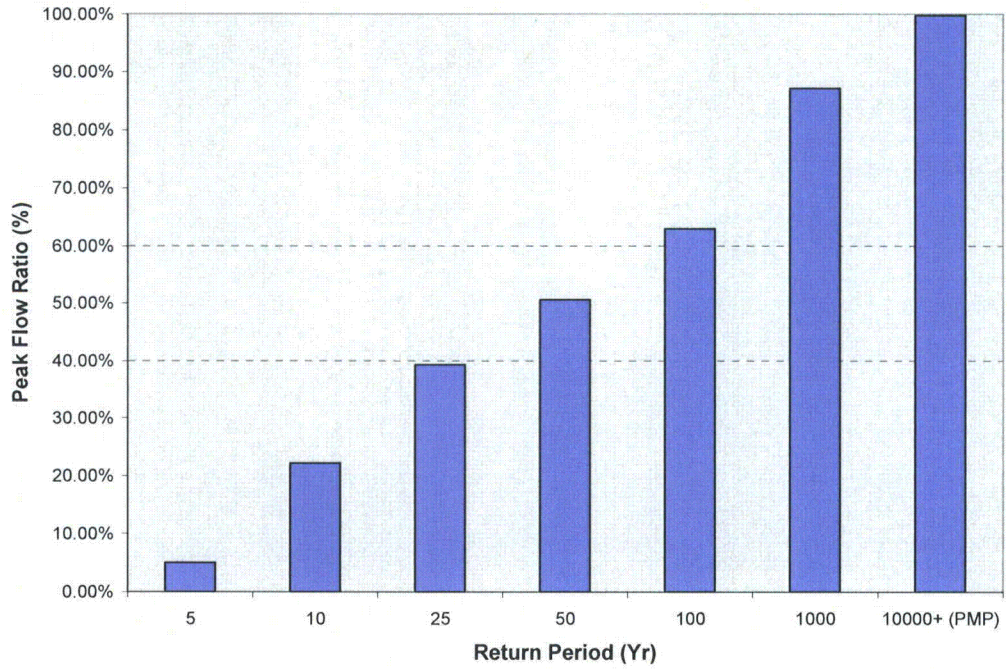
NOTE: cfs = cubic feet per second.

Source: Original.

Figure 4. Comparison of Peak Flows for the Hydrologic Drainage Basin above CP3 Due to Different Hydrologic Model Parameters

Figure 5 illustrates the effect of initial loss parameter on flood peaks. This figure shows the ratio of flow peaks simulated using an initial loss parameter equal to 1 in., divided by flow peaks simulated using an initial loss parameter equal to 0 in. For a 5-year flood event, the flood peak ratio is approximately 5%, while for the PMF, the difference is very low (<1%).

Figure 6 shows the difference in peak flows due to the specification of the uniform loss parameter. Peak flow is very sensitive to the specification of the uniform loss parameter. The use of a uniform loss parameter of 1.5 in./hr (as in the case of *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6)) would result in an 18% lower peak flow compared to the use of 0.1 in./hr (as in this calculation report). These sensitivity results show that the specification of loss parameters can significantly influence the flood peak calculation.

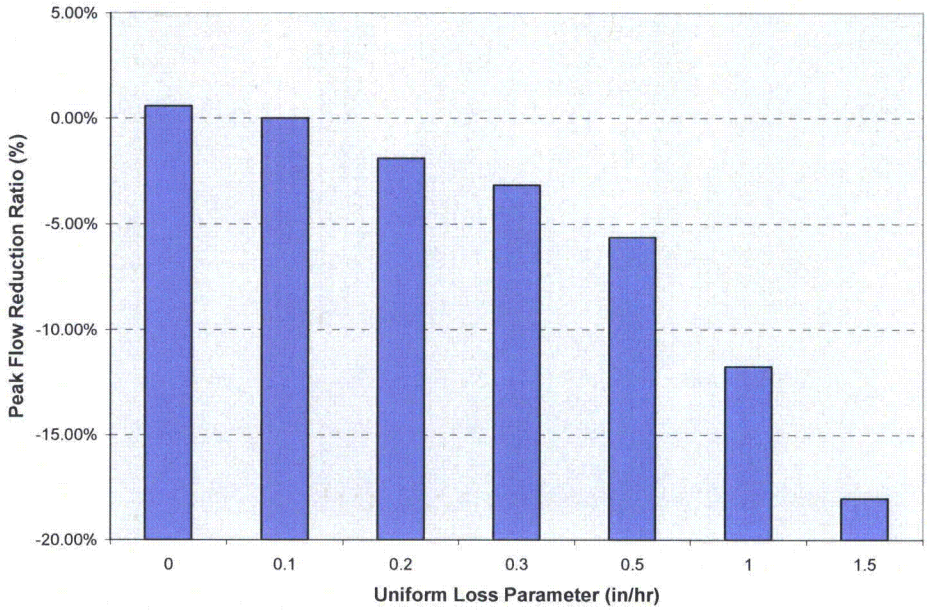


Source: Original.

Figure 5. Sensitivity of Peak Flows to Specification of Initial Loss Parameter for Floods of Different Magnitude

6.4.3 Sensitivity of Peak Flow to the Time-Lag Parameter

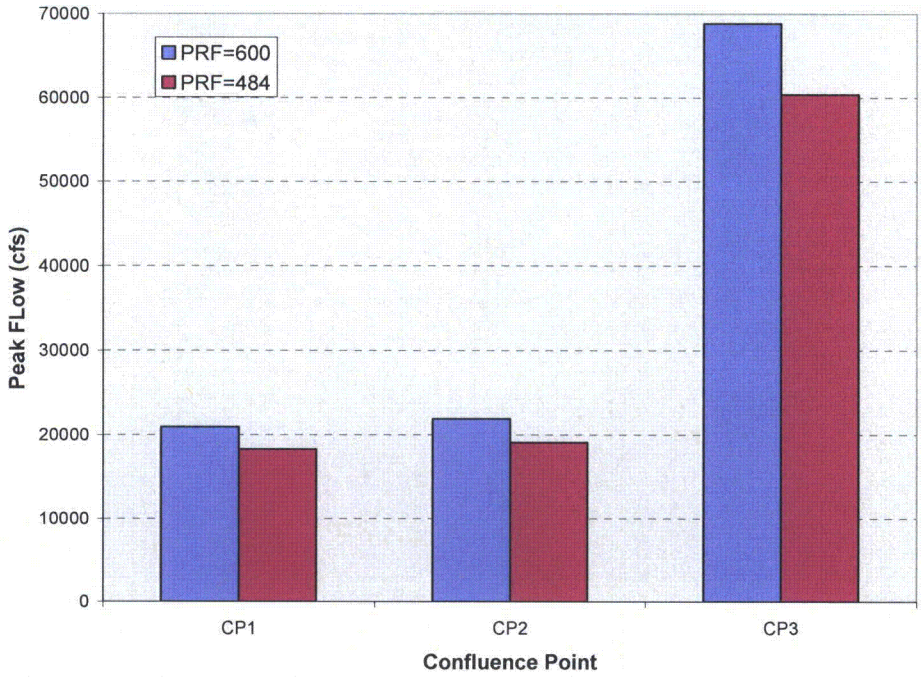
This section investigates the sensitivity of peak flow to the specification of the time-lag parameter. As discussed in Section 4.4.2, the time-lag parameters used in *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) correspond to the average basin condition with a PRF of 484, as compared to the steep basin condition of the Yucca Mountain area, which should have a PRF of 600. Figure 7 displays the difference in peak flows due to differences in time-lag parameters. The flood peaks for CP1, CP2, and CP3 using the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) time-lag parameters are about 12 to 13% less than the flood peaks using the time-lag parameter used in this calculation report.



NOTE: in/hr = inches per hour.

Source: Original

Figure 6. Sensitivity of PMF Peak Flow to Specification of the Uniform Loss Parameter



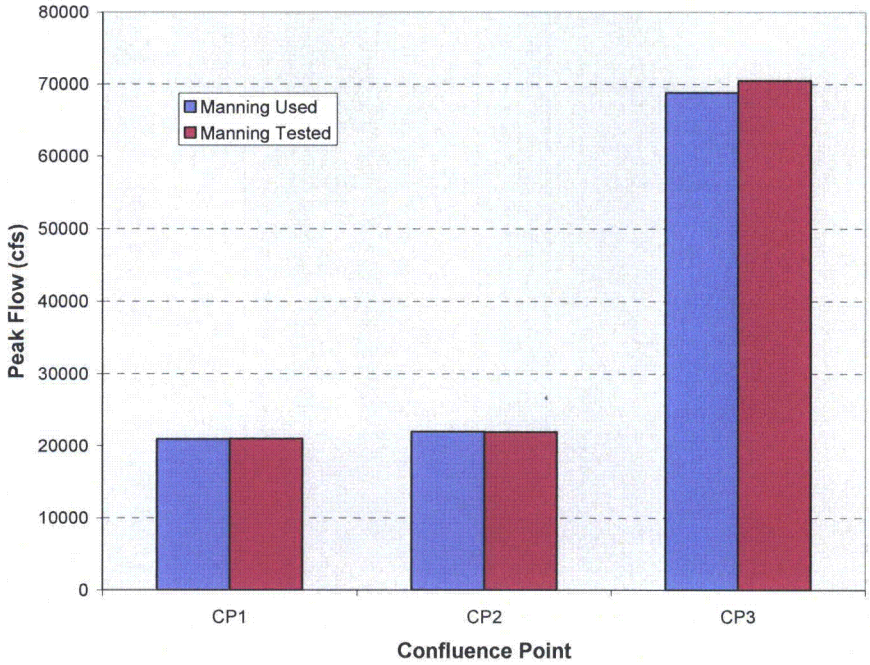
NOTE: cfs = cubic feet per second; PRF = peak rate factor.

Source: Original.

Figure 7. Sensitivity of PMF Peak Flow Due to Specification of the Time-Lag Parameter

6.4.4 Sensitivity of Peak Flow to Manning's Roughness Coefficient, *n*

Manning's roughness coefficient, *n*, is the parameter needed for channel flow and overland flow routing. The *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), Table 5-1 and the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6, Section 4.2.5) flood analyses assigned a value of 0.09 for both natural and man-made channels. This calculation report tested Manning's *n* based on channel lining materials. As specified in Section 4.3.7 of *LMY Storm Drainage Calculations* (Ref. 2.2.7), the *n* value is set to 0.013 for concrete channel lining. Based on *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5, Section 4.1.2.3), a value of 0.045 was assigned to natural channels. The peak flows simulated using the two different sets of Manning's *n* are displayed in Figure 8. The peak flow using both sets of Manning's *n* is virtually the same. This result confirms the finding from the *Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5) flood hazard study.



NOTE: cfs = cubic feet per second.

Source: Original.

Figure 8. Sensitivity of PMF Peak Flow Due to Specification of Manning's *n*

6.4.5 Summary of Parameter Sensitivity Studies

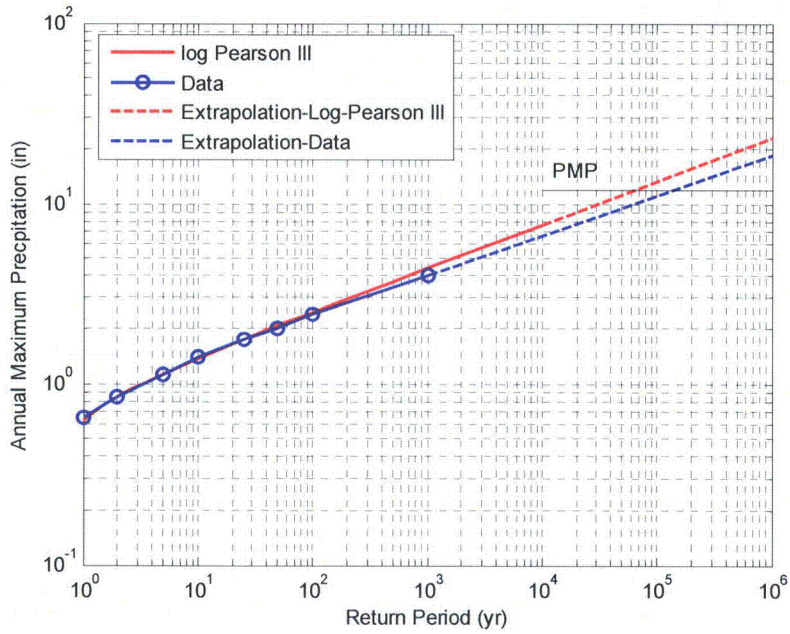
Section 6.4 examines the sensitivities of peak flows to different parameters in the HEC-1 model. The results from Section 6.4.1 show that the peak flows simulated using the parameter setup from the *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6) flood analysis are up to 29% less than those using the parameter setup in this calculation report. In other words, using the parameter setup from this calculation to simulate flood peaks would result in more conservative estimates of flood peaks. The most sensitive parameters are the uniform loss parameter and the time-lag parameter, in the case of PMF simulation. The combined effect of these two parameters accounts for almost all of the PMF peak discharge difference. The sensitivity of flood peaks to the specification of the initial loss parameter depends on the flood magnitude, with lesser floods having higher sensitivity.

6.5 DEVELOPMENT OF THE FLOOD HAZARD CURVE

Section 6.3 calculates the flood peaks resulting from annual maximum precipitation events of different frequencies, and Section 6.4 demonstrates the sensitivity of flood peaks to different parameter specifications. This section uses the results from the preceding sections to develop the flood hazard curve (i.e., the frequency curve of flood peaks).

6.5.1 Probability of PMP

Before discussing how the flood hazard was derived and how probability was assigned to the PMF, the probability of the PMP, which was used as input by the HEC-1 model to simulate the PMF, will be investigated. Figure 9 displays the scattergram of maximum annual precipitation value and return period (or frequency). Also plotted on the figure is the log-Pearson type III distribution curve, which is the widely accepted probability distribution for extreme storms in the United States (*Handbook of Hydrology* (Ref. 2.2.19), Section 18.7.2; *Tables of Percentage Points of the Pearson Type III Distribution* (Ref. 2.2.26), Table 1). From the figure, the log-Pearson type III curve fits the data reasonably well. Based on the extrapolation of the log-Pearson curve, the 10,000-year storm event has a precipitation value close to 8 in. Further extrapolating the log-Pearson curve (i.e., the red dashed line) to intersect the PMP line gives a return period of about 70,000 years, equivalent to an exceedance probability of 1.43×10^{-5} for the PMP. The blue dashed line in the figure is the extrapolation based on storm data alone. This line intersects the PMP line at 150,000 years, equivalent to an exceedance probability of 0.67×10^{-5}. Considering that the log-Pearson curve overpredicts the 1,000-year event, an exceedance probability of 1.43×10^{-5} assigned to the PMP is a conservative and reasonable estimate. The estimate of the PMP probability is used in Section 6.5.2 to derive the PMF probability.



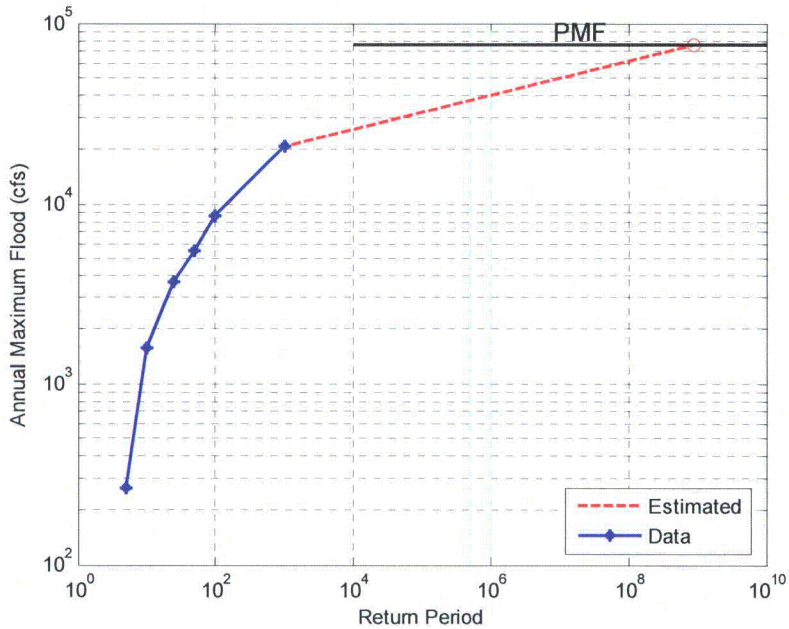
NOTE: in = inch; PMP = probable maximum precipitation; yr = year.

Source: Original.

Figure 9. Precipitation Frequency Curve

6.5.2 Flood Hazard Curve

The key to developing the flood hazard curve is the estimation of the exceedance probability of the flood events. As stated in the assumption (Assumption 3.2.8), the frequencies of all flood events considered in this calculation, except the PMF, are assumed to follow the same frequencies as the underlying precipitation events, provided that the initial and boundary conditions of the basin reflect the proper hydroclimatic condition. The estimation of proper hydroclimatic condition is achieved through the proper specification of hydrologic model parameters. In this calculation report, it was done through the proper choice of the HEC-1 loss parameters. If there are adequate historical hydrometeorological data available, it would be advisable to calibrate these parameters to the data. Since there are no historical data in this case, the loss parameters were selected such that the estimated flood peaks are biased toward the conservative side. Using the loss parameters as presented in Section 4.4.1, the flood peak discharges were simulated (Section 6.3.1). Figure 10 displays the flood peak discharges and associated return periods at confluence point CP3 for all flood events.



NOTE: cfs = cubic feet per second; PMF = probable maximum flood.

Source: Original.

Figure 10. Flood Frequency (Hazard) Curve

It is important to design the surface facilities such that the annual exceedance frequency of PMF is less than 10^{-6}. Ensuring that the frequency of PMF is less than 10^{-6} is not a trivial issue because of the difficulty in assigning a probability value to the PMF. According to the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data, "no procedure proposed to date is capable of assigning an exceedance probability to the PMF or to near-PMF floods in a reliable, consistent, and credible manner" (*Feasibility of Assigning a Probability to the Probable Maximum Flood* (Ref. 2.2.18), p. 43). This document concludes that "Given the paucity of rare-flood data and the lack of an adequate theoretical foundation, it does not appear possible to objectively define the probability of the PMF, at least within reasonable confidence limits" ((Ref. 2.2.18), p. 44). Nevertheless, the committee discussed several alternative methods, including extrapolation of frequency curve, joint probability, regional data methods, paleohydrology methods, and Bayesian techniques. Each of the methods has advantages and disadvantages.

The extrapolation method is based on statistical analysis of measured discharge data at the site. The regional data approach combines flood frequency curves from several sites of similar climatic, physiographic, and hydrologic properties located within a homogeneous region including the site of interest. The paleohydrology method estimates the probability of the PMF by utilizing historical records of floods that occurred several thousand years ago at the site. The Bayesian technique makes inferences about the likelihood of future events by exploiting many sources of information at the site in a Bayesian framework. These four methods all rely on historical data of different sorts, which are not available in the YMP area, making the joint probability method the logical approach employed for this calculation.

A number of researchers have investigated the joint probability approach ("Realistic Assessment of Maximum Flood Potential" (Ref. 2.2.21); and "Conservatism of Probable Maximum Flood Estimates" (Ref. 2.2.27)). The joint probability method estimates the PMF probability by computing the joint probability of several events relevant to PMF. The relevant events may include antecedent moisture condition, loss rate during the storm, storm orientation, and temporal distribution. For a series of independent events, the joint probability, $P(PMF)$, can be expressed as:

$$P(PMF) = P(A) \cdot P(B) \cdot P(C) \qquad \text{(Eq. 2)}$$

where

A, B, and C represent the independent events relevant to PMF.

For this calculation report, there are three major independent events contributing to the PMF: (1) the PMP (A), (2) the antecedent moisture condition (B), and (3) storm orientation and temporal distribution (C) (Assumption 3.2.5). From Section 6.5.1, the exceedance probability of the PMP is less than 1.43×10^{-5} (i.e., $P(A) \leq 1.43 \times 10^{-5}$). Based on Assumption 3.2.5, P(B) = 7.69×10^{-4} and P(C)=0.1. The three events are obviously independent. If all the probabilities of the relevant events are combined, the joint probability obtained, $P(PMF) = 1.43 \times 10^{-5} \times 7.69 \times 10^{-4} \times 0.1 = 1.0997 \times 10^{-9}$, is equivalent to a return period of approximately 90.9 million years.

With the PMF and the associated return period plotted in Figure 10, the solid and dashed blue lines form the flood hazard curve. From this figure, the peak discharge corresponding to 1,000,000-year and 500,000-year return periods (i.e., probability of 10^{-6} and 2×10^{-6}) can be interpolated. The 1,000,000-year peak discharge is equal to approximately 40,000 cfs, and the 500,000-year peak discharge is equal to approximately 37,500 cfs.

7. RESULTS AND CONCLUSIONS

Using the flood peaks simulated with the more conservative parameters recommended in *Review of Yucca Mountain PMF Studies* (Ref. 2.2.17), a flood hazard curve (Figure 10) was developed. The analysis presented in Section 6 demonstrates that the exceedance probability of the PMP is less than 1.43×10^{-5}, and the exceedance probability of the PMF is less than 1.0997×10^{-9}. This calculation uses the same procedure for deriving the PMP values and employs the same HEC-1 hydrologic model as existing BSC flood analyses (*Preliminary Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.5), *Hydrologic Engineering Studies for the North Portal Pad and Vicinity* (Ref. 2.2.6), and *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10)). However, this analysis used more conservative input parameters, as recommended in *Review of Yucca Mountain PMF Studies* (Ref. 2.2.17). These more conservative parameters are shown to yield as much as 29% higher runoff volume than those derived using the parameter setup from the previous flood analyses. Nevertheless, the 1,000,000-year peak (exceedance probability less than 1×10^{-6}) discharge of approximately 40,000 cfs is less than the minimum design capacity of 55,000 cfs provided in the *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10). Therefore, this analysis is deemed to be sufficient to demonstrate that flood event sequences may be excluded from further

event sequence analysis in the PCSA. This analysis also confirms that the design presented in the *Yucca Mountain Project Drainage Report and Analysis* (Ref. 2.2.10) satisfies the probabilistic criteria of ANSI/ANS 2.8 (*American National Standard for Determining Design Basis Flooding at Power Reactor Sites* (Ref. 2.2.1)).

ATTACHMENT 1

GIS FILES FOR BASIN DELINEATION

(Electronic Files)

ATTACHMENT 2

EXCEL AND MATLAB SCRIPT FILES

(Electronic Files)

ATTACHMENT 3

HEC-1 INPUT AND OUTPUT FILES

(Electronic Files)