Final Quality Assurance Report for the INL Flood Hazard Study - Reducing Uncertainty for Paleohydrologic Bounds and 2-D Hydraulic Routing
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1. INTRODUCTION

As stated in the Quality Assurance Plan for the Big Lost River Floodplain Study (the QAP), "an effective quality assurance (QA) program is essential to achieving the reasonableness, acceptability and defensibility objectives of the current Big Lost River Floodplain Study." This report will serve as documentation of how the various processes used throughout the study meet the stated QA objectives. As part of this process a data assessment based on the data quality objectives detailed in the QAP is also presented.

The Idaho National Laboratory (INL) Flood Hazard Study (FHS) of the Big Lost River is intended to support determination of the design basis flood (DBFL) for use in evaluation of the flood hazard at the Idaho Nuclear Technology and Engineering Center (INTEC) and the Advance Test Reactor (ATR) at the Test Reactor Area (TRA) both located on the INL. The basis of the flood hazard evaluation is determined according to potential risk and the associated performance category (PC). Low hazard facilities are designated as PC-1 while facilities with significant potential for risk to workers and the public are designated as PC-4 facilities. A PC-4 facility must continue to function (including confinement of hazardous materials and provision of occupant safety) given a flood hazard with a combined mean-annual exceedance probability (AEP) of $10^{-5}$ (1 in 100,000). The ATR is an operating reactor that automatically is designated as a PC-4 facility. Certain activities at the INTEC also require natural phenomena hazards (NPH) characterization up to PC-4.

Following guidance described in DOE standard 1020 “Natural Phenomenon Hazards Design and Evaluation Criteria for Department of Energy Facilities” (DOE-STD-1020-01) the QAP was based on the requirements in 10 CFR 830, Subpart A. It also captured the provisions of DOE O 414.1A and EPA QA/R-2. The participatory and peer reviewer process used throughout the FHS followed the guidance detailed in NUREG/CR-6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts.” Although written for seismic hazard analysis much of the guidance is applicable to any NPH characterization. NPH characterization efforts at DOE facilities require independent peer review to ensure the quality of deliverables (DOE-STD-1020-01).

1.1. Project Description

The Big Lost River (BLR) is the major surface water feature on the INL. The BLR drains an area of approximately 3,652 km$^2$ (1,410 mi$^2$). Due to diversions of the BLR for irrigation before reaching the INL boundary, flow in the river onsite is often intermittent or non-existent. However, of the eight operational facilities, five are located on or near the current or historic floodplain of the BLR. As stated above, two of these facilities are characterized as PC-4 facilities. Federal regulations require a determination of the potential impact from a flood stage with a combined mean annual exceedance probability of $10^{-5}$ (a return frequency of 100,000 years) for any PC-4 facility.

The overall objective for this project is to develop probabilistic estimates of flood stage at regulated locations at INTEC and TRA following DOE-STD-1020, 1022, and 1023, as well as other related guidance and requirements. Flood discharge probability estimates developed from studies of the BLR will be used to define a range of discharges and associated flood hazard risks. Representative discharges will have been input into two-dimensional (2-D) flow models that are used to predict the resultant inundation at the key INL facilities.
Variations in stage at the facilities result from assumptions and variables including:

- The use of differing hydraulic models (i.e., TrimR2D versus RiCOM);
- Variations in hydraulic model parameters;
- Assumptions and models of flow at bridges and culverts (i.e., open versus close);
- Assumptions regarding infiltration (i.e., none or full [10-15%]); and
- Assumptions regarding the duration of flow (e.g., in order to maintain the wetted surface each successive flood discharge was built on the results of the previous discharge model run).

A logic tree approach is used to combine the flood stage variations developed through the modeling efforts with input discharge probability distributions to arrive at final stage-probability estimates for the regulated locations at INTEC and TRA.

A second objective of the study is to reduce the estimates of uncertainty associated with the conclusions developed by prior paleoflood studies at the INL (Ostenaa et. al., 1999). Studies in support of this objective include geomorphic mapping, trenching, and hydraulic modeling of a study reach of the BLR immediately downstream of the INL Diversion Dam. These studies are the basis for the paleohydrologic analyses used to estimate the low probability flood discharge for the BLR.

1.2. Project Organization

To maintain a proper level of QA during the FHS a formalized project organization was established. A project manager was designated who had overall control and supervision of the various project task leads. The project task leads (PTL) were assigned by each of the organizations participating in the FHS. There was unconstrained contact between the PTLs, but all contacts were also copied to the project manager.

1.2.1. Project Manager

The Project Manager (PM) maintained overall responsibility for each of the subtasks conducted as part of the FHS. Mr. Robert Creed with the Department of Energy – Idaho Operations Office (DOE-ID) served as the PM for this project. He had the ultimate authority for approval of all project activities.

1.2.2. Project Task Leads

Each participating organization assigned an individual to serve as PTL. For this FHS the PTLs and their responsibilities were as follows:

Mr. Dean Ostenaa, Bureau of Reclamation (BOR), was responsible for conducting fieldwork, interpretation of paleohydrologic and geomorphologic data, and preparation of the final FHS report. He was supported by Mr. Dan O'Connell who was responsible for the 2-dimensional (2-D) modeling and inundation mapping. Both Mr. Ostenaa and Mr. O’Connell developed the final stage/probability plots.

Mr. Charles Berenbrock, United States Geological Survey (USGS), provided support for the 2-D modeling effort by developing rating curves for the bridge and culvert hydraulics of the FHS reach.
Dr. Fritz Fiedler, University of Idaho (UI), also supported the BOR hydraulic modeling by providing infiltration loss estimates. Three estimates (high, low and expected) were to be developed based on existing data collected through literature review of relative studies and masters' theses and the INL soils map. Dr. Fiedler provided oversight of university students working on the project.

Dr. Glenn Thackray and Dr. Paul Link, Idaho State University (ISU), supported the field effort of the BOR. In this capacity they provided supervised oversight of a graduate student (Ms. Val Sheedy) for soil lithologic mapping, description and collection within the trenches excavated in the diversion dam study reach. Dr. Link also provided information on sediment providence through radio-spectral analysis of detrital zircons recovered from various layers within the trenches.

Mr. Chris Martin, S. M. Stoller Corporation, provided support to all organizations throughout the FHS with QA oversight.
2. PEER REVIEW

DOE requires that FHS work for all facilities must undergo an independent peer review to evaluate design assumptions and philosophy. Reviewers are recognized experts in the major technical disciplines employed as part of this study including paleohydrology, hydraulics, and probabilistic risk assessment. Reviews have been assigned, based on expertise, as follows.

2.1. Participatory Peer Reviewers

Dr. P. K. House of the University of Nevada provided critical review of the paleoflood and geomorphic aspects of the work. Dr. Nikolas Katapodes of the University of Michigan provided review of the hydraulic modeling, and Dr. Kevin Coppersmith of Coppersmith Consulting provided review of the probabilistic aspects of the project.

All three reviewers participated in a project “kick-off” meeting held November 1-2, 2001. All project participants were introduced and made presentations to the participatory reviewers on their proposed approach to their part of the project. Participatory reviewers continued to provide guidance and direction throughout the project via direct site visits and/or document reviews. Their input was crucial to development of the draft final report for assuring critical issues were properly addressed and resolved in that report.

2.2. Final Peer Reviewers

Dr Manu Lall of Columbia University provided final peer review with emphasis on the uncertainty analysis. Dr. Klaus Jorde of the University of Idaho provided final peer review with emphasis on the flood hydraulics and geomorphology, while Dr. Victor Baker of the University of Arizona provided final peer review emphasizing the paleohydrologic information/interpretation and geomorphology.

In their positions as recognized experts in their respective fields, Drs. Lall and Baker also participated in detailed reviews of the 1999 BOR report.

All three final peer reviewers participated in a peer review meeting held October 5-7, 2004. At this meeting the process used for data collection, modeling and stage-probability curve generation were presented. Dr. Baker was unable to attend the meeting due to an unfortunate injury and subsequent surgery the week of the meeting. Minutes from the meeting were collected and distributed to all three reviewers (see Appendix A).

Because of Dr. Bakers previous field and paleohydrologic modeling experience at the INL, his physical absence at this meeting did not limit his ability to provide a rigorous review. To assure information consistency for the peer review Dr. Baker was also provided a compressed presentation by Mr. Ostenaa and Mr. O'Connell while attending a conference in Denver. The PM and QA oversight were in attendance at this meeting via conference call, to answer any questions related to overall project objectives or QA. At the completion of the meeting each of the peer reviewers were asked to provide a thorough review of the draft final report, and provide comments on the appropriateness of how the models were applied and methods used.

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3. **RESOLUTION OF DATA QUALITY OBJECTIVES**

Detailed data quality objectives (DQOs) were developed for this project and are explained in the QAP. The decisions and inputs outlined below are based on factors encountered during performance of the project. The following sections present details on each of the DQO steps to be applied to the FHS at the start of the project. It was recognized early on in the development of the QAP, that the final products of this project are dependent on scientific data and methodologies. Strict adherence to QA/QC requirements typically intended for engineering design, construction, and analytical (laboratory) data were seen as creating an unnecessary documentation burden on project participants without adding value to the QA/QC process. Therefore, certain modifications of procedures normally consistent with those types QA/QC requirements were undertaken for this project.

3.1. **State the Problem**

Part of the NPH analysis requirements of DOE is determination of the flood hazard at designated facilities based on their performance category. Flood hazard evaluations are based on the DBFL for that facility. This DBFL value is obtained from plots of return period versus water surface elevation (UCRL-15910). The return period is the hypothetical probability of a flood of given discharge occurring in a given time period. Differing DBFLs need to be determined for each performance category facility as a function of combined mean annual exceedance probability. DOE further requires that uncertainties associated with the DBFL be formally characterized. The goal of the current project is to utilize peer reviewed methods to quantitatively evaluate flood stage probability at key PC-4 INL facilities consistent with DOE and related requirements.

A related follow-on task to this project will be the determination of a total flood hazard. This flood hazard will include additional discharge inputs from events such as failure of the Mackay Dam, failure/storage by the INL diversion dam, over-land flow (i.e., rain fall on frozen ground), and surface water/groundwater management of the BLR.

3.2. **Identify the Decisions**

This step lays out the principal study questions, alternative actions, and corresponding decision statements that must be answered to effectively address the above stated problem. The primary decision supported by the FHS is to determine if and what type of mitigation would be required at INL facilities given the probability distribution of flood stage at those facilities. In addition to this, another goal is to show what impacts these peak flows could be expected to produce.

3.2.1. **Principal Study Questions.**

The purpose of a principal study question (PSQ) is to identify key unknown conditions or unresolved issues that, when answered, provide a solution to the problem being investigated, as stated above. The PSQ’s for this project are summarized here and detailed in the QAP.
PSQ-1: Using 2-D flow modeling, what are the variations in flood stage at the INL facilities that result from differing flow models, model parameters, infiltration scenarios, and culvert/bridge flow models for a range of discharges on the Big Lost River?

The discharges to be modeled ranged from approximately 355 cubic feet per second (cfs) to the current RCRA value for the 100-year flood of 24,720 cfs. The significance of 355 cfs is that this is the maximum gauge measured flow downstream of the INL diversion dam since 1984. Other modeled discharges are presented in Table 1.

Two different 2D flow models were used to generate the inundation maps of the regulated INL locations. TrimR2D is a finite-difference model that used a 20-foot grid. RiCOM is a finite-element model that was used a variable mesh based on 5- to 20-ft grid spacing. Results of model comparisons and quality control tests are contained in Appendix C of the final flood hazard report from BOR.

Two Manning roughness numbers (n) based on sand bed streams (n = 0.030) and gravel bed streams (n = 0.038) were modeled as bounding parameters. Only slight differences were observed.

Model runs were made to test the sensitivity of flows to various bridge/ culvert ratings and infiltration rates. As a result of this sensitivity testing four options for bridge/culvert and infiltration were developed for use in the final modeling. The options were: full bridge/culvert conveyance, full infiltration of 15 percent throughout the study reach; full bridge/culvert conveyance, no infiltration throughout the study reach; partial bridge/culvert conveyance, full infiltration of 15 percent throughout the study reach; and partial bridge/ culvert conveyance, no infiltration throughout the study reach. Partial culvert conveyance was defined as only the structures within the Big Lost River channel remained open (the Highway 20/26 bridge, Lincoln Boulevard culverts, and the INL railroad bridge). Also some limited testing was performed for complete blockage of the Lincoln Boulevard culverts.

It was found that conveyance through the small culverts had little effect on modeled inundation. This appeared to be related to the placement of culverts in low spots, so when they were closed the water overtopped the roads at those locations and flowed on in the same patterns.

Because of the very flat nature of the Snake River Plain in the central portion of the INL most of the flood flows are controlled by small topographic features (old levees, abandoned channels, etc). These features include common items such as road embankments, drainage ditches, and concrete barriers used for security purposes. These small features have little impact on the flood hazard uncertainty. However, because of the "mobile" nature of items such as concrete barriers, they can have a large impact on facility inundation.
Table 1  Discharge and modeling scenarios used to construct the stage - probability estimates.

<table>
<thead>
<tr>
<th>Modeled Discharge^1 m^3/s (ft^3/s)</th>
<th>Infiltration^2</th>
<th>Potential Significance of Modeled Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Full</td>
</tr>
<tr>
<td></td>
<td>Full Culverts</td>
<td>Partial Culverts</td>
</tr>
<tr>
<td>13 (~460)</td>
<td>T T</td>
<td>T T</td>
</tr>
<tr>
<td>25 (~885)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>63 (~2225)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>87</td>
<td>R R</td>
<td>R R</td>
</tr>
<tr>
<td>97</td>
<td>R R</td>
<td>R R</td>
</tr>
<tr>
<td>106 (~3740)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>110</td>
<td>R R</td>
<td>R R</td>
</tr>
<tr>
<td>130</td>
<td>R R</td>
<td>R R</td>
</tr>
<tr>
<td>150 (~5295)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>176 (~6215)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>200 (~7060)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>250 (~8830)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>300 (~10,595)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>400 (~14,125)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
<tr>
<td>700 (~24,720)</td>
<td>T T, R</td>
<td>T R</td>
</tr>
</tbody>
</table>

Notes:

1 Steady-state discharge input at upstream end of reach near INEEL Diversion Dam

2 Entries in table indicate flow model used for each scenario: T - TRIMR2D with 20-ft rectangular grid as input topography; R - RICOM with 5-, 10-, and 20-ft variable grid as input topography. Limits of 5-ft mesh were defined by extent of inundation from TRIMR2D model of 100 m3/s with no infiltration and partial culverts; limits of 10-ft mesh by extent of TRIMR2D 200 m3/s inundation for same scenario.
PSQ-2: How appropriate is the characterization, and range of uncertainty, of the paleohydrologic bounds and paleoflood inputs to flood frequency analyses used in prior INL paleoflood studies?

The paleohydrologic bounds from the previous study have been extensively revised as discussed in Section 3 of the final report. Major changes in the discharge estimates for the bounds resulted from the recognition of inaccuracies in the input topography used in hydraulic modeling for the previous study (Described in Appendix A of the final report and reproduced here in Appendix B), and new modeling, using new, detailed topographic data, was completed for this study.

In the previous study, the criteria for determining modification of a surface were subjective and very general in nature. The present study provided a very thorough, objective development for the hydraulic bounds used to determine geomorphic modifications. The framework for development of these bounds is detailed in Appendix D of the final report.

The characterization of soils and geomorphology performed as part of the previous paleoflood studies was limited to cut-bank and surface geomorphology. A detailed geomorphic map was completed and extensive trenching work allowed for a three dimensional view of soil characteristics in key locations that provided additional evidence to constrain the paleoflood bounds. These results are discussed in Section 2 of the final flood hazard report and trench logs and field/laboratory data presented in Appendix B of that report.

In addition, although the 1999 study underwent a rigorous peer review before going final, it did not include participatory peer reviewers during project performance.

PSQ-3: What are the flood frequency inputs to be used in the probabilistic flood stage logic tree?

A revised flood frequency analyses based on updated paleohydrologic bounds is presented in Section 4 of the final flood hazard report.

PSQ-4 What is the character of the logic tree to facilitate calculation of the probability of flood stage at INL facilities?

The initial intent for the development of a "standard" logic tree with appropriately weighted branches was seen as becoming more impractical as the project progressed and new constraining data were compiled. As a result the final "logic tree" is a straight line (see Figure 1), with the various PDFs and discharges input for the starting AEPs.

3.2.2. Alternative Actions.

Alternative actions (AA) are possible actions resulting from resolution of the above PSQ’s. The types of actions considered depend on the answers to the PSQ’s.

AA-1: There were three possible alternatives to PSQ-1: 1) the PDFs for flood stage at the facilities was not sensitive to variations in modeling or inputs, 2) the PDFs of flood stage show a broad range of uncertainty due to variations in modeling or input uncertainties, or 3) modeling and analyses show that well-constrained results can be obtained only for a limited range of discharges and/or probabilities.
Figure 1  Logic tree for probabilistic inundation modeling at the INL.
The results presented above for PSQ-1 support alternative 1 for AA-1. That is the PDFs were essentially insensitive to variations in models and inputs such as for bridges/ culverts and infiltration as compared to uncertainty in topography.

AA-2: AA for PSQ-2 are 1) characterizations of the paleofloods and paleohydrologic bounds contained in earlier reports are adequate, or 2) the paleofloods and paleohydrologic bounds need to be revised to include other values of age and/or discharge.

As discussed in the resolution for PSQ-2 above, alternative 2 for AA-2 was selected. Quality checking of topographic data determined that the topography used in the original studies was inadequate. Updated modeling based on new, more detailed topography led to increases in discharge values associated with the paleohydrologic bounds. In addition, the characterizations of previous paleohydrologic bounds were largely subjective in nature. For this study it was deemed necessary to establish a strong formal method for assigning bounds. This was done through a review of available literature on the movement of various particle types and the development of probabilistic thresholds for erosion based on stream power and shear stress results from the updated hydraulic modeling as described in Appendix D of the final flood hazard report.

AA-3: AA for PSQ-3 are 1) the flood frequency characterization of the existing paleoflood study (Ostenaa et al., 1999) adequately represents the necessary inputs for describing flood frequency, 2) the flood frequency characterization in the paleoflood study needs to be weighted and used as one of several branches in a logic tree that contains other flood frequency relations, or 3) the flood frequency relations in the paleoflood study need to be revised as a result of revisions to paleofloods and paleohydrologic bounds developed from PSQ-2.

Initially it was felt that alternative 1 would be used for AA-3. However, significant differences were noted in initial flow modeling. These differences were found to be associated with errors in the initial 1993 topographic data. For this reason, alternative 3 was selected as the final outcome for AA-3.

AA-4: AA for PSQ-4 are 1) the logic tree is a single stem in which all probability information is derived from a single flood frequency relation from the existing paleoflood study, 2) the logic tree is moderately complex due to the need for including more than one flood frequency input and a moderate range of sensitivity in modeled stage/discharge at INL facilities, or 3) the logic tree has many branches and high potential variability in the weightings due to the large diversity of opinions on flood frequency and the broad range of uncertainty associated with hydraulic modeling of the stage/discharge relationships at the INL facilities.

As proposed by the BOR, the logic tree is essentially a straight line process as described by alternative 1. The stage probability values are derived from a single line process for the case of unregulated natural flow; however, the AEP and discharge assigned for other cases (i.e., Mackay Dam failure) will dictate what the final range of stage probability curves look like.
3.2.3. Decision Statements.

The decision statements (DS) combine the PSQ and AA into a concise statement of action. The DS for each of the PSQ's are stated below.

DS-1: Determine the probability distribution for flood stage at key INL locations at TRA and INTEC.

These are developed in Section 5 of the final flood hazard report and detailed in Appendix F of the final report.

DS-2: Determine probabilistic characterizations of paleofloods and paleohydrologic bounds in light of new field evidence and 2-D flow modeling for the Diversion Dam study reach of the BLR.

A framework for evaluating paleohydrologic information with the 2-D flow modeling results is developed and detailed in Appendix D. Geologic and hydraulic modeling results from these new studies in the Diversion Dam reach are discussed in Section 2 of the final report and revised probability distributions are developed in Section 3 of the final flood hazard report.

DS-3: Determine flood frequency inputs for the logic tree assessment of flood stage probability at the critical TRA/INTEC sites.

A revised flood frequency analyses is contained in Section 4 of the final flood hazard report.

DS-4 Determine the structure and weightings of inputs and branches in a logic tree for calculation of flood stage probability at the TRA/INTEC facilities.

This has been developed in section 5.3 of the final flood hazard report.

3.3. Identify Inputs to the Decision

This step identifies the informational inputs that are required to answer the decision statements made above.

3.3.1. Inputs for PSQ-1.

PSQ-1 will be answered by compiling the results of a suite of flow simulations from hydraulic models into probabilistic descriptions of flood stage versus discharge. Model inputs include topography of the BLR and facility area based on the INL 2-ft contour map, discharge input into the hydraulic model at the INL Diversion Dam, model parameters such as friction, viscosity, scenarios for infiltration, and scenarios for flow at culverts and bridges. The effects of variations in model inputs will form the basis for developing probabilistic descriptions of the uncertainty in flood stage at INL facilities over the range of modeled discharges.

One of the major efforts for resolving this PSQ centered on the INL 2-foot contour map and the 1993 aerial data from which it was derived. Initial hydraulic modeling results from the paleoflood study reach based on topographic data acquired in 2000 were found to be significantly different than modeling results from previous studies. Extensive analyses of the topographic data used in each of the modeling studies was undertaken in an effort to characterize the accuracy of each to the topographic data sets used in the
flood hazard analyses. Grids derived from the 1993 INL 2-ft contour map appeared to be significantly warped in some areas. In 2002/2003 reprocessing of the 1993 data for the diversion dam study reach and the regional study reach was undertaken to correct for earlier processing errors.

3.3.2. Inputs for PSQ-2.

The inputs to PSQ-2 will be answered through a combination of direct field methods and hydraulic modeling. Field studies and hydraulic modeling for PSQ-2 will utilize 1-ft contour interval base maps and images derived from aerial photography flown in August 2000 of a 3 mile long study reach along the BLR located downstream of the INL Diversion Dam. These products will be used as base maps for detailed geomorphic mapping of the study reach and site maps for trenching investigations.

Trenching studies at three sites provided soils and stratigraphic data, which were used to corroborate geomorphic surface ages and identify deposits and ages of past floods. Samples were collected from the trenches for soils and radiocarbon analyses to develop a framework for estimating age(s) and age uncertainty distributions. Soil trench work followed the procedures included in Birkeland (1999) and Appendix B of the QAP. Hydraulic modeling of the study reach provided discharge estimates for paleohydrologic bounds and paleofloods that were identified based on the trenching results. Uncertainty characterizations of the discharge estimates were developed similar to PSQ-1. The resulting age and discharge characterizations were compared to the characterizations of paleohydrologic bounds and paleofloods developed in previous paleoflood studies.

3.3.3. Inputs for PSQ-3.

Inputs to PSQ-3 will be subjective weightings of the inputs to the logic tree based on participatory and final peer reviewer input, empirical data, and the professional judgment of project participants.

Paleohydrologic inputs for flood frequency are displayed as probability density functions (PDF's). The primary functional shape developed was a triangular distribution, although some PDF’s developed trapezoidal shapes based on the data available for each of the inputs. Flood frequency inputs are portrayed as continuous frequency distributions and associated uncertainties for a range of annual probabilities and discharges. Flood frequency inputs from the previous study were given a weight of zero because hydraulic modeling results were based on inadequate topographic data, thus only the current study results are used. Other flood frequency studies by USGS have been revised such that continuous frequency distribution data is not available. The only available inputs are singular estimates for a 100-yr flood, which has statistical overlap with results of the current study and therefore was not explicitly used.

3.3.4. Inputs for PSQ-4.

The principle inputs to PSQ-4 include the probability distributions for stage/discharge from PSQ-1 and the flood frequency inputs and weightings from PSQ-3.

PSQ-4 inputs were compiled from the hydraulic modeling using the reprocessed topographic data generated in PSQ-1, and the PDFs developed from PSQ-3.
3.4. Define the Boundaries of the Study

This step defines the spatial and temporal boundaries for the problem. Without establishing firm boundaries one can never be sure if the problem has been solved.

Hydraulic modeling studies for PSQ-1 will include a three to four mile wide area along the BLR, extending from the vicinity of the INL Diversion Dam downstream to the intersection of the BLR channel and the INL Railroad that leads to the Naval Reactors Facility (NRF). This area includes the natural channel of the BLR, artificial channels constructed by settlers, channels constructed for flood management at INL, large areas of floodplain and alluvial surfaces flanking the BLR, and the areas of key facilities at INTEC and TRA (see Figure 1-2 of the final flood hazard report). Temporal boundaries for these studies are restricted to the period after 1993, the date of aerial photography flown to develop topographic base maps used in the hydraulic modeling, to present.

Studies for PSQ-2 will focus on a study reach of the BLR extending approximately 3-miles downstream from the INL Diversion Dam that was used in the previous paleoflood study, and where detailed topographic mapping has been done based on the August 2000 aerial photography. Trench sites were selected within this area based on the results of prior studies and the constraints imposed by cultural resource issues.

Temporal boundaries associated with paleohydrology will be restricted from the present to the late Pleistocene (< 100,000 yr. bp). Specific timeframes were developed as field work progressed, based on evidence for the largest observable flood and paleohydrologic bounds.

The spatial boundaries for flood frequency inputs to PSQ-3 and PSQ-4 potentially include the entire BLR drainage basin if data from sites upstream of the INL are considered in the flood frequency analyses. Temporal limits are the Late Pleistocene (last 10,000 years) for paleohydrologic data, and 1905 for the earliest gaging information, to the present.

DOE requirements for NPH characterization specify the development of a combined mean annual exceedance probability from all flood modes. In this study only the hazard associated with natural, unregulated flooding of the BLR is being analyzed. Other flood hazard modes, which are potential contributors to the mean flood hazard, include local run-on/run-off, effects of the INEEL Diversion Dam, and failure of the Mackay Dam.

3.5. Develop a Decision Rule

The Decision Rule (DR) brings together the outputs from steps 1 through 4 into a single statement describing the basis for choosing among the listed alternatives.

DR-1: Based on the flow simulation results conducted using the 2-D models, determine the characteristics of the probability distributions for flood stage/peak discharge at the key TRA/INTEC locations.

Stage-probability results for these sites are discussed in Sections 5.3 to 5.5 of the final flood hazard report. A full set of curves for each site is contained in Appendix F.
DR-2: Based on trenching studies and hydraulic modeling studies of the Diversion Dam study reach, compare the updated characterizations of paleohydrologic bounds and paleofloods for the BLR with those used in flood frequency analyses of the prior studies.

Characterizations and discussions of comparability are developed and detailed in Sections 2 and 3 of the final flood hazard report.

DR-3: Based on the evaluations conducted for DR-2 determine the inputs and weightings for flood frequency in the logic tree that will be used to evaluate the probability of flood stage at key TRA/INTEC sites.

As work progressed it became evident that the discharge AEP was the controlling variable in the analysis of flood hazard. As a result the logic tree developed into a single branch with the starting discharge AEP dictating the additional variables used. Variation due to other factors was determined to be less than the uncertainty associated with topographic resolution in the hydraulic models.

DR-4: Based on the results of DR-1, DR-2, and DR-3, calculate the stage/probability curves for the INL facilities.

A detailed discussion of the development of the stage/probability curves is provided in Section 5 of the Final flood hazard report. Appendix F provides additional curves for each of the modeled discharges at each critical facility.

3.6. Specify Tolerable Limits on Decision Errors

This step sets out the acceptable limits on decision error. These limits are typically used to establish performance goals for the data collection design. Because of the empirical nature of the data it is difficult to place limits on the data use. Discussions will be carried out between all parties concerned, with considerable input from the peer reviewers, to determine what qualifies as sufficient supporting data. The emphasis in all studies is to develop a probabilistic description of each of the inputs and modeled parameters in order to allow the propagation of potential uncertainty through the full study.

Peer reviewers provided comments and recommendations for follow-on work/additional research. Although this work is outside the scope of the present project, certain aspects would serve to potentially further constrain uncertainties or provide additional support for various actions.

3.7. Optimize the Design

The limits of the area selected for flow simulations to develop stage/discharge probability information have been defined by the limits of inundation shown by previous studies, critical facility locations, and sites where flood frequency inputs are developed and applied based on previous work. The study area encompassed an approximate three to four mile wide strip, centered on the present Big Lost River channel, and extending from the INL diversion dam to the railroad bridge east of INTEC.

The areas and trench sites for the evaluation of paleohydrologic bounds were based on the results of previous studies. This detailed study reach encompassed the Big Lost River channel and immediate overbank areas from the INL diversion dam to approximately
three miles downstream at the old pioneer diversion. This area was selected based on multiple areas of channel control due to basalt outcrops.

Trench locations for paleohydrologic/geomorphologic study were selected using information and comments from the previous BOR study. The "Big Loop" site was chosen to evaluate the many earth mounds in the area, some of which occur in paleochannels of presumed Pleistocene age. Excavations through the mounds and channels showed that soils and stratigraphy were generally continuous across the channels, providing no evidence of post-late Pleistocene Big Lost River flow at these sites.

Trench excavations at "the Saddle" were carried out to determine constraints on flow through the saddle. This location included a 900 meter (2953 foot) long trench that yielded definitive evidence that water had not flowed through the saddle in Holocene times. Trenches on terrace sites adjacent to the channel showed evidence of a paleofloods about 400-600 years ago, but this evidence was limited to lower sites that did not reach a stage required for flow through the Saddle.

The final trench location was on a terrace on at sharp bend in the river. Previous modeling showed that as flood stage increased, this area became subject to increasing erosive forces. It was anticipated that trenches at this site would provide additional constraint on flood frequency. However, due to cultural resource restrictions, the project was unable to complete a continuous trench and unable to extend trenches to critical locations near the banks. A series of smaller disconnected trenches were dug which exposed a consistent soil and stratigraphic sequence, although absolute correlation could not be established due to the disconnected nature of the exposures. There was some evidence of flood erosion/overtopping, and a stage limit for this evidence at the site, but positive evidence of paleoflood stratigraphy was limited.
4. DATA QUALITY ASSESSMENT

A data quality assessment (DQA) is a formal process for examining the data results to see that they meet the users end needs as stated in the project DQO’s. Therefore, data quality assessment can also be thought of as reconciling the reported data to the project DQO’s. The EPA provides guidance for this reconciliation through EPA QA/G-9, “Guidance for Data Quality Assessment” (EPA, 1998).

The DQA process is the scientific and statistical evaluation of data to determine if the data produced are of the right type, quality, and quantity to support their intended use. Like the DQO process, which it supports, the DQA is an iterative process, consisting of five steps:

- Review the DQO's and sampling design.
- Conduct a preliminary data review.
- Select a statistical test.
- Verify the assumptions of the statistical test.
- Draw conclusions from the data.

As stated in the discussion on DQOs certain exceptions were made for this project as it is not a typical engineering design. The data for this project consists of empirical data such as model simulations, field observations, and narrative descriptions of the methods used to create the graphical end-products (stage/probability plots). In line with those changes the DQA that follows will present narrative explanations to the various questions posed under the DQO process rather than actual numbers.

4.1. Review the Data Quality Objectives and Sampling Design

The main objective of this activity is to provide a context for analyzing the data in later steps. The goal is to familiarize the data analyst with the main features of the program used to generate the data. The data analyst will review all documents associated with the data being reviewed. This will include the QAP, associated DQO’s, and the draft and final reports. The DQO’s, through the established principal study questions, will guide the assessment by providing an understanding of what the end use of the data is.

For PSQ-2, paleohydrologic bounds and development of paleohydrologic inputs for use in flood frequency analyses were expected to generally follow the conclusions reached by the previous study (Ostenaa et. al., 1999). These inputs are characterized with a best estimate or best estimate range, and an associated range of uncertainty. The study reach used for modeling is termed the INEEL Diversion Dam study reach. This is an approximate three mile stretch of the Big Lost River from immediately downstream of the INEEL diversion dam to the old Pioneer diversion structure. This stretch has been used by other researchers in the past because of the fixed channel constraints provided by frequent basalt outcrops.

Criteria for paleohydrologic bounds in the diversion dam study reach were developed based on data available in the literature, the framework developed in Appendix D of the final flood hazard report, and the site specific sediments evident in the trenches. The first step in the criteria development was to designate different geomorphic surfaces. These ranged from the upper-most Pleistocene gravel surface to the present channel bottom and most recent accretionary bars and terraces.
The next step in the process was to perform detailed soil mapping of the trench faces for the identification of specific facies that could be extended across the area or that represented a specific event. Standard geomorphic relationships (truncation of soil horizons, interfingering of different soil compositions, soil development/calcium carbonate leaching) were observed and recorded. As part of this task radiocarbon age dates were obtained for different well defined zones. Sediment provenance studies were also performed as part of this step.

The final step in this process was the application of the erosion thresholds developed in Appendix D and the field observations for whether a particular geomorphic surface had been modified. As such, PDFs for the various geomorphic surfaces observed were developed consisting of a minimum required value, a best/most probable value and a maximum value. The minimum value represented the minimum value of stream power per unit area or bed shear stress to cause modification of the surface. The best/most probable values represented the value that corresponded best with the observed field data, while the maximum value represented the stream power/shear stress value at which there was virtual certainty that a given geomorphic surface would be modified. These values were derived from field observations of material composition and literature values on their movement. Independent estimates from multiple subareas on each geomorphic surface were combined subjectively into a single probability statement for each paleohydrologic bound.

For PSQ-1, the 2-D flow modeling and a range of discharges determined from previous flood hazard studies were simulated. A sufficient number of simulations were conducted to adequately portray the variability in the model results that result from variations in the inputs and model used. Sensitivity testing of the models was used to determine the total number of simulations required for the analyses as described in Appendix C of the final flood hazard report.

Discharges were modeled with four adjustable variables related to infiltration (full or none) and bridge and culvert conveyance (full or partial). Full infiltration assumed an infiltration capacity of approximately 15%, while none assumed no infiltration loses. This is detailed in Appendix D of the final report. Full conveyance of culverts assumes that all culverts are 100% open. Partial conveyance assumes only the bridges/culverts in the Big Lost River channel are open to flow. Appendix C of the final report also provides details on bridge and culvert conveyance.

For PSQ-3, potential flood frequency inputs from the current and previous studies were weighted according to participatory and final peer reviewer input, empirical data, and the professional judgment of project participants for input into the logic tree assessment for PSQ-4. Inputs from previous studies were not used due to incomplete results or discrepancies in the previous data determined through the present study.

The stage-probability plots for the selected areas of INTEC and TRA were developed from the inundation flows performed under PSQ-2. The probabilities were assigned based on revised flood frequency analyses completed for the present study.

For PSQ-4, a logic tree for flood frequency and hydraulic modeling scenarios was developed (Figure 1). Based on the modeling results, the primary variable for the logic tree is the input discharge AEP. Examples of final AEP/stage diagrams derived from the logic tree for selected discharges are shown in the final flood hazard report.
To derive a set of AEP/stage curves using the conceptual logic tree developed for this study one starts by selecting an AEP of interest. The hydrograph shape for that AEP is propagated downstream to the point of interest. The discharges associated with the AEP are interpolated and constrained by known AEP relations (see Figure 2-12 of the final flood hazard report). Finally infiltration and bridge/culvert effects are applied. The final product is a set of AEP/stage (depth) curves for the different infiltration and bridge/culvert combinations with 95 percent upper and lower bounds. Depending on the distance downstream of the INL diversion dam, different discharges may appear as inflection points on the graph.

4.2. Conduct a Preliminary Data Review

In this step the data analyst will normally perform a preliminary data evaluation, calculate some basic statistics, and graph the data. The goal here is for the data analyst to get a feel for the “structure” of the data. Basic statistics are often used to provide a numerical determination of whether the data will meet the project DQO’s. Because of the empirical nature of this projects data this evaluation is done less mathematically.

Outputs from the 2-D hydraulic modeling for each simulated discharge are displayed as plots of inundation extent displaying water surface and additional contour information for depth, stream power and shear stress.

Paleohydrologic inputs for flood frequency are displayed as PDF’s. The primary functional shape developed was a triangular distribution, although some PDF’s developed trapezoidal shapes based on the data available for each of the inputs. The peer reviewers were fully presented with all the assumptions made during PDF determination and asked to carefully evaluate those assumptions during their review.

Flood frequency inputs are portrayed as continuous frequency distributions and associated uncertainties for a range of annual probabilities and discharges. Differing weights of previous frequency analyses will be required because not all previous frequency analyses extend over the same ranges of discharge or annual probability.

Logic trees were to be portrayed in graphical form with simplified titles for each branch to show the relative weights and relationships of each of the elements used in the calculation of flood stage probability at the facility sites. In the final report the logic tree turned out to be a single linear process with results dependent on the initial AEP used.

One of the major setbacks to the completion of the project was the unplanned requirement to reprocess the input topographic data. The accuracy of topographic data used in the flood hazard studies was called into question when initial hydraulic modeling results based on newly acquired topographic data from the paleoflood study reach downstream of the INL Diversion Dam were found to be significantly different than modeling results from previous studies. Extensive analyses of the topographic data used in these modeling studies was undertaken in an effort to characterize the accuracy of each to the topographic data sets used in the flood hazard analyses.

Each group of topographic data used in these analyses has been compared to an independent, more accurate, set of GPS field survey data. Aerial photography flown in 2000 was used to generate 3-ft grid data for detailed hydraulic modeling of a paleoflood study reach downstream of the INL Diversion Dam. More than 800 points were surveyed
with GPS in this reach to evaluate the accuracy of the topographic grid. National Map Accuracy Standards (NMAS) and American Society for Photogrammetry and Remote Sensing (ASPRS) accuracy measures indicate that the grid data is sufficient for mapping with contour intervals of approximately 1.3 to 1.5 ft or larger. For the same reach, grids derived from the 1993 INL 2-ft contour map did not meet standards for 4-ft contour mapping and appeared to be significantly warped in some areas. For the main Big Lost River corridor between the INL Diversion Dam and areas downstream of INTEC and TRA, comparisons indicated that the original INL 2-ft contour map was close but generally does not meet ASPRS standards for class 1 mapping as a 4-ft contour map, the standard cited in Federal Emergency Management Agency (FEMA) Bulletin 37 for flood hazard mapping. The original 2-ft map also does not meet NMAS standards for a 4-ft contour map based on the present comparison data. The 2003 BOR 5-ft grid developed from the 1993 photography and original Aerographics control data meets both ASPRS and NMAS standards for approximately 3-ft contour mapping. Measured accuracy values on the 2003 BOR 5-ft grid are generally 25 to 50% better than values measured on surfaces derived from the 1993 INL 2-ft contour map. The level of accuracy achieved by the 2003 BOR 5-ft grid appears to be limited by the underlying accuracy of the original control network used for the 1993 photography.

4.3. Select a Statistical Test

The main objective of this step is for the data analyst to select an appropriate statistical hypothesis for testing the data. In a classical sense the data being tested are analytical values. These lend themselves directly to statistical comparisons. However, the primary data produced by the FHS study are not measured values but are empirical in nature. The data produced often consists of outputs derived from models or scientific judgments. Unlike analytical values this type of information does not center on an "expected" value. As such, most of these outputs do not lend themselves readily to statistical testing. The emphasis in this study is to develop probabilistic characterizations and to draw upon inputs from expert peer reviewers to assess and test whether sufficient basis exists for drawing the presented conclusions.

Expert peer reviewers were consulted at key phases during the study in order to assess the data and confirm underlying assumptions. Expert peer reviewers in hydraulics, paleoflood hydrology, and probabilistic characterization were included as study participants (see Section 2.1). Both participatory and final peer reviewers received detailed presentations, including a visit to the field area/trench sites, on the proposed methods and the final outcomes.

Multiple sensitivity analyses were performed on both the TrimR2D and RiCOM codes. Details of these analyses are presented in Appendix C of the final report.

4.4. Verify the Assumptions of the Statistical Test

The goal of this step is to determine whether the underlying assumptions of the statistical test are still valid given the data collected.

Participatory peer reviewers provided comments on the validity of data and assumptions throughout the project. Documentation of participatory peer reviewer comments are maintained by the PM. Comments provided by the final peer reviewers on the draft final
flood hazard report covered application of the assumptions made for this project and are included in Appendix C.

4.5. **Draw Conclusions from the Data**

Once the statistical test has been chosen and it has been determined that the underlying assumptions are valid then the chosen statistical hypothesis is run and tested. Based on the results of the hypothesis test the data analyst draws a conclusion from the data.

Based on expert peer reviews, the draft report was revised and comment/response documents were prepared to document how peer reviewer recommendations were implemented into the final study report. Recommendations not implemented are documented and described, along with rationale for not implementing recommendations.

Conclusions drawn from the paleohydrologic data are detailed in the final flood hazard report. Draft final report peer reviewers provided comments (Appendix C) on the application of the paleohydrologic data to the final decisions. They also provided comments on the use and results of the 2-D hydraulic model inundation maps.

The results for PSQ-4, calculations from the logic tree, were to provide the principal conclusions from the study. As work progressed it became evident that a formal logic tree approach was not necessary as the discharge AEP was the controlling variable in the analysis of flood hazard. As a result the logic tree developed into a single branch with the starting AEP dictating the values of the follow-on variables. The peer reviewers felt that formal weighting of the AEP for other factors was inappropriate given the increasing uncertainties with the longer AEPs and the detailed bounding constraints developed in the report.

The final outcome is a detailed set of AEP vs. stage diagrams for different discharges at each critical facility location. The development of these diagrams is detailed in Section 5 of the final flood hazard report. This section also addresses constraints on extending the curves beyond and AEP of 2 x 10^{-4}. Appendix F provides a complete set of diagrams of the final probability/stage curves at the selected facilities at INTEC and TRA.
5. CONCLUSION

The overall objective of this project was to develop and document a relationship between AEP and stage/discharge for PC-1 to PC-4 facilities at the INL. Following guidance described in DOE standard 1020 and using the peer review process detailed in NUREG/CR-6372 as guidance, the design process and final curve development underwent a rigorous review by experts in the fields of hydraulics, uncertainty analysis, and paleohydrology.

This report documents the QA used in each step of the development process throughout the study to meet the stated DQOs. As part of this process a data assessment based on the DQOs detailed in the QAP is also presented. Assessment shows that all DQOs for the project were met. Peer review comments supported the documented process and generally recommended additional activities to provide further constraints on uncertainty in areas such as infiltration losses. The peer reviewers concurred with the final analytical process and outcomes as being reasonable and well thought-out.

The final outcome of this project revealed that the anticipated multi-branch logic tree approach was unnecessary. A single controlling variable (AEP) was found for the analysis of flood hazard at the INL. The initial discharge AEP determined the values for the additional variables used in the analysis. Plots of inundation depth for AEPs out to at least 1 in 100,000 years ($10^{-5}$) were generated for each critical location at the INL. Peer reviewers agreed that formal weighting of AEPs for other factors in the logic tree approach was uncalled for.
6. REFERENCES


