Contents

Figure

Table

3.0 Key Tasks and Activities

This chapter concludes the general introduction to and overview of the Hanford PSHA project by providing information about the key tasks and activities that made up the Hanford PSHA. As noted in Chapters 1.0 and 2.0, the Hanford PSHA was conducted in conformance with Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 guidance. Hence, the overall project structure is consistent with NUREG/CR-6372 (Budnitz et al. 1997), NUREG-2117 (NRC 2012), and the ANSI/ANS-2.29-2008, which provide criteria and guidance for PSHA performance and documentation. More specifically, the SSHAC implementation guidance (NUREG-2117) provides a description of the essential steps and activities that are required for a SSHAC Level 3 project. The tasks and activities described in this chapter are consistent with the implementation guidance. Additional details about these tasks and activities, plus the outputs they produced, are presented in Chapters 4.0 through 10.0 of this report.

The sequence of steps for a SSHAC Level 3 project is illustrated in Figure 3.1. In the diagram, the initiation of the project lies at the top and time runs from top to bottom.

3.1 Hanford PSHA Work Plan

The first step in the project was the development of the Hanford PSHA Work Plan, which identified all of the project activities, roles and responsibilities of project participants, schedules, milestones, and products to be developed. The Participatory Peer Review Panel (PPRP) was put in place early in the project and its members were provided with the Work Plan to provide an early understanding of the manner in which the project would be conducted. The Work Plan included a discussion of DOE's process for arriving at the decision to conduct the Hanford PSHA using a SSHAC Level 3 process (summarized in Section 2.1.1). The Work Plan provided a convenient vehicle for informing all project participants with a clear and consistent description of the scope, schedule, and products of the Hanford PSHA. In many cases, the Work Plan provided the scope of work descriptions needed to issue contracts for project participants. The key activities included in the Work Plan are described in Sections 3.2 through 3.15.

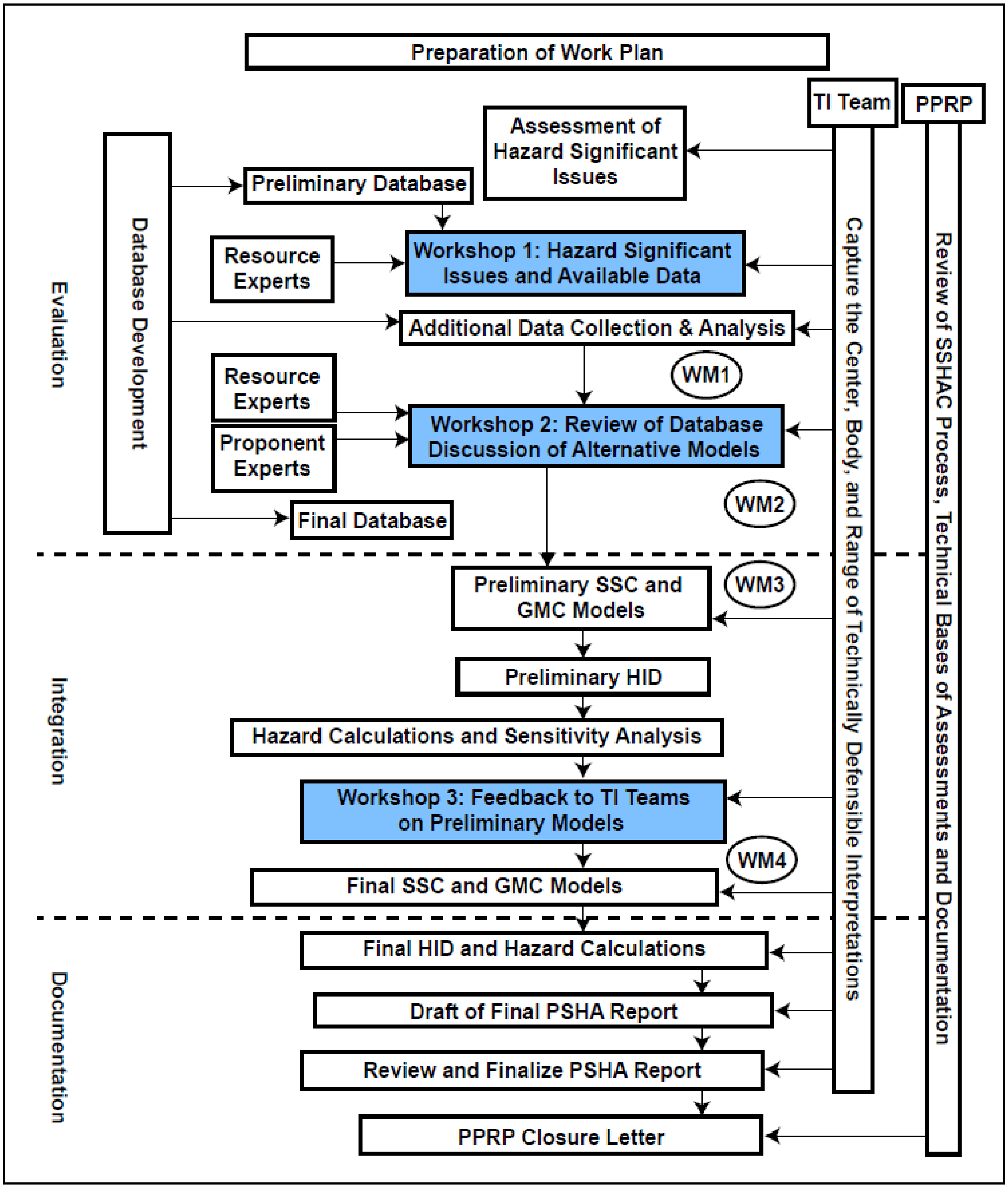

Figure 3.1. Schematic overview of the activities involved in the execution of a SSHAC Level 3 PSHA (modified from Coppersmith and Bommer 2012).

3.2 Database Development

This task included the compilation of applicable SSC and GMC data and information for use by the Technical Integration (TI) Teams in their evaluations. The data sets were identified early in the project by the TI Teams, with additional input from the PPRP (Workshop 1 [WS1] included identification of pertinent data to address the significant issues). The database includes both data that were originally gathered specifically for the Hanford Site as well as applicable data that have been developed elsewhere. As a technical resource to the PSHA, Hanford geologic and seismic documents were collected and the data they contain were analyzed as the basis for producing summary presentations of the available data by selected resource experts at the appropriate workshops. In addition to the compilation of existing data (as described in Section 3.2.1), this task also entailed the collection of new data (as described in Section 3.2.2).

3.2.1 Compilation and Evaluation of Available Data

Gathering existing documents for the project (both for seismic source characterization and ground motion characterization) is an important part of the evaluation phase of the project. The data compiled by the TI Teams include references from the literature, site-specific information developed for Hanford, publicly available information developed by other agencies, and other hazard studies. Relevant topics include geologic, geophysical, seismologic, and geotechnical data related to characteristics throughout the Hanford Site and region. As part of this activity, data focused on specific technical issues of interest were presented at the workshops. As the project progressed, the database development activity included preparation of derivative maps and products that are directly applicable to the PSHA (e.g., seismicity maps). Aspects of the database development task that are specific to the SSC and GMC subprojects are described in the following sections.

3.2.1.1 SSC Data

Data compilation began at the time of project authorization and continued to the point at which the final SSC and GMC models were developed. To the extent possible, mapped information was compiled in GIS formats that allowed for various combinations of layers. The Database Manager(s) took an active role in compiling data, including the information made available at the first workshop and identified through interaction with members of the technical community. Data sources included readily available information from the following:

- professional literature
- data held in the public domain
- private domain data such as those developed as part of exploration activities
- unpublished data.

In addition, the TI Team requested that additional data sets (regional and local) be incorporated into the GIS database. New data that were developed during fieldwork and other efforts are also included in the database. In addition to the GIS database, a comprehensive bibliography of literature was compiled for use by the TI Team. This bibliography built upon the seismic/geologic bibliography already developed by PNNL.

This task also included the evaluation of the data, following the guidance provided by the NRC (2012). The SSC TI Team developed data summary/evaluation tables that are appropriate for the types of data that were compiled for the Hanford Site. The purpose of the data tables was to clearly document all data that had been considered by the SSC TI Team and, for those data that were actually used to develop the SSC model, to document the degree of reliance afforded to specific data sets in the development of the SSC model.

3.2.1.2 GMC Data

Three components of the database were used to carry out the GMC model development for the Hanford PSHA: 1) a list of the ground motion prediction equations available worldwide that can potentially be applicable to the project, together with their characteristics; 2) data that can be used to constrain the applicability of any equation to the Hanford Site; and 3) characterization of the representative near-surface geological profiles at the Hanford Site that define the target site conditions to which the prediction equations will need to be adjusted. These profiles also define the dynamic site response models used to transfer the baserock hazard to the top of the basalts.

In terms of available equations, the starting point was the next-generation attenuation equations for shallow crustal seismicity, as well as those derived for comparable tectonic settings including active parts of Europe, New Zealand, and Japan. The database also included equations from subduction zone tectonic regions to provide predictions for ground motions from the Cascadia region. The equations were classified in terms of the date and location of their publication, the data set on which they are based, their range of applicability in terms of magnitude and distance ranges, the other explanatory variables included in the equation, the functional form of the equation, and the type of regression analysis used to derive the equation. The exact definitions of the predicted ground motion parameter, including definition of the horizontal component of motion and each of the independent variables in the equation, were included. Particular attention was given to the definition of different site classes in the equations and the conditions represented by rock sites.

The usual starting point for deriving, assessing, or adjusting ground motion prediction equations for a region would be the database of strong-motion (accelerograph) recordings from that area. In the Hanford Site region, such recordings are limited in number and in amplitude. Nevertheless, all available site ground motion data were cataloged in terms of the data, time, magnitude, depth, and location of the earthquake; the location and geological/geotechnical classification of the recording site; and the instrumental characteristics (component orientation, sampling rate, etc.). Strong-motion records from the broader region in which the site is located were also compiled.

An appropriate data evaluation process was developed by the GMC TI Team to document the process followed, consistent with the NRC (2012) guidance. This documentation included "white papers" that discussed particular GMC topics and the data available to address those topics. Topics of the GMC white papers included single-station sigma, kappa, and the use of a backbone approach for the GMC model. The purpose of this effort was to provide clear documentation of the data that were considered during the course of developing the GMC model and the reliance placed on various components of the data. The contents of these white papers were finally subsumed into Chapters 7.0 and 9.0 of this report.

3.2.2 Focused Data-Collection and Analysis Activities

This subtask addressed new data-collection and analysis activities judged as warranted by the TI Teams for their value in reducing uncertainties in key inputs to the Hanford PSHA. The activities were identified as a result of issues and data discussed at WS1, including sensitivity analysis designed to identify hazard-significant issues. Activities conducted to supplement existing data included the following:

- Quaternary Geologic Studies: Field mapping, geomorphic analyses, and structural geologic data analyses to support the quantitative structural analysis of the Yakima folds. These analyses were conducted in conjunction with tectonic geomorphic analyses of the Yakima River terraces and other geologic investigations designed to characterize the timing and rate of Quaternary uplift—or lack of uplift—associated with various folds. The structural analyses included limited field reconnaissance and topographic analyses to establish the relationship between topographic relief and structural relief associated with each Yakima fold in the site region. In turn, these data were used with simple fault models to assess the downdip geometry of the folds and faults, as well as the amount and rates of fault slip. The results of this effort are reported in Appendix E.
- High-Resolution Seismicity Relocations: Using state-of-the-art double-difference relocation techniques, high-resolution three-dimensional (3-D) earthquake locations were determined using the programs HypoDD and TomoDD and existing high-quality seismicity data. This task also involved a review of the focal mechanisms and consideration of the spatial distribution of seismicity relative to hypocentral depth distributions and possible associations with faults. The results of this effort are reported in Appendix F.
- Shear-Wave Velocity Measurements: To provide information that was useful for assessing kappa, shear-wave velocity profiles were assessed based on spectral analysis of surface wave measurements at HAWA (the seismograph at the Nike missile facility on Rattlesnake Mountain) and other seismograph locations at Hanford Site. The results of this study are reported in Appendix H.
- Review Available Recordings for Kappa: Available strong-motion and seismograph recordings on the Hanford Site were compiled, reprocessed, and analyzed to better constrain kappa values to be used in the GMC evaluations. The results of this study are included in Appendix I.
- Modeling of Possible Basin Effects: Possible basin effects on ground motions from both local crustal and distant subduction earthquakes were investigated using the modeling approach developed by the U.S. Geological Survey (USGS). The results of this study were reported by Thorne et al. (2014) and Frankel et al. (2013).

3.3 Identification of Significant Issues

A key task at the outset of a PSHA project is to identify which elements of the SSC and GMC models exert the greatest influence on the hazard results, so that the TI Teams can focus their efforts on the development of those parts of the hazard input models. At the same time, identifying the greatest contributors to the overall uncertainty allows data-compilation and data-collection efforts to be focused on activities where the largest rewards—in terms of reduced uncertainty—may be expected. To meet these objectives, it is customary during WS1 of a SSHAC Level 3 project to present hazard-sensitivity calculations based on existing models, if available, or otherwise use very simple preliminary models of the regional seismic sources in combination with available ground motion prediction equations.

For the Hanford PSHA, prior to WS1 the TI Team made a preliminary assessment of the key SSC and GMC issues that would be most important to the seismic hazard at the Hanford Site. This assessment was based on the results of prior Hanford hazard studies (Geomatrix 1996), the results of the Mid-Columbia PSHA (JBA et al. 2012), hazard studies in analogous areas (e.g., BC Hydro 2012), and associated sensitivity analyses. A preliminary hazard assessment was conducted to further identify significant SSC and GMC issues. The results of the sensitivity analyses were presented by the TI Leads at WS1 to identify the hazard-significant issues that needed to be addressed by the available data.

3.4 Workshop 1: Hazard-Significant Issues and Available Data

Consistent with a SSHAC Level 3 process, the evaluation phase of the project, during which applicable data, models, and methods are identified and evaluated by the TI Teams, is assisted by conducting two workshops. At WS1data are identified and resource experts describe the data; at Workshop 2 (WS2), alternative models and methods are discussed and proponent experts provide their viewpoints regarding the technical support that the alternative interpretations possess.

The goals of this WS1, conducted July 23−27, 2012, were 1) to identify the SSC and GMC issues of highest significance to a PSHA at the Hanford Site, and 2) to identify the data and information that would be required to address those issues. The workshop brought together the project sponsors, TI Teams, resource experts, specialty contractors (as appropriate), PPRP, and observers to discuss the significant issues and to identify the existing databases. Prior to the workshop, workshop participants, including observers, were apprised of their workshop roles and the ground rules.

The resource experts present at the workshop were members of the technical community who had an understanding of data related to seismic source characterization and ground motion characterization pertinent to the Hanford PSHA. They included researchers who have been involved in the development of pertinent databases, such as those at PNNL, the USGS, and in university-based groups. Resource experts involved with the development of seismicity catalogs and ground motion databases also participated in the workshop. Discussions were held regarding all databases that may be available for use by the project, and identification of researchers who should be contacted to gain access to the data.

The duration of WS1 was 5 days: 3 days each for the SSC portion and the GMC portion with an overlapping day in the middle attended by both the SSC and GMC TI Teams. The 3-day SSC portion began with a session that addressed the goals and methodology for the PSHA, the results of the hazard-sensitivity analyses, and the hazard-significant SSC issues. A similar session conducted at the beginning of the GMC portion of the workshop focused on GMC issues. During the day of overlap, data of common interest to both the SSC and GMC groups were discussed, such as the seismicity catalog.

All workshop sessions were documented in a Workshop Summary (PNNL 2013a) that includes 1) the meeting agenda, 2) a list of participants and their contact information, 3) a summary of the presentations and discussions, and 4) a copy of all presentations. The document also includes the written responses of the TI Leads to the written comments from the PPRP.

3.5 Workshop 2: Review of Database and Discussion of Alternative Models

The goals of WS2, conducted December 3−8, 2012, were to 1) present, discuss, and debate alternative models, methods, and interpretations regarding key SSC and GMC issues; 2) identify the technical bases for the alternative hypotheses and discuss the associated uncertainties; and 3) provide a basis for the subsequent development of preliminary SSC and GMC models that consider these alternative viewpoints. The workshop also provided an opportunity to review the progress being made on the database and seismicity catalog activities. Resource experts were also invited to present additional data and information that might have potential relevance to the SSC and GMC models.

A key attribute of WS2 was the discussion and debate of the technical merits of alternative viewpoints regarding key technical issues. Proponent experts were invited to present their interpretations and the data supporting them. Prior to the workshop, the TI Teams developed questions and comments to provide to each proponent expert to ensure that important issues and uncertainties would be addressed during the course of their presentations. In some cases, proponent experts with differing interpretations of models and methods were juxtaposed in the agenda to allow the TI Teams to understand the technical bases for the different viewpoints. Facilitated discussions occurred with a focus on implications to seismic source characterization and ground motion characterization for hazard analysis (not just on scientific viability) and on uncertainties (e.g., which conceptual models would capture the range of interpretations). Individuals not present at the workshop and their relevant interpretations were also identified during the course of the discussions, so that all applicable viewpoints could be considered.

The WS2 activities included documentation of the workshop in a Workshop Summary (PNNL 2013b).

3.6 Working Meetings

The work conducted during the evaluation and integration phases of the project was largely accomplished by the TI Teams in a series of four working meetings for each team. The SSC and GMC TI Team working meetings were conducted separately and each was usually convened over 3 to 5 days. As shown in Figure 3.1, the first working meeting occurred between WS1 and WS2, followed by two working meetings between WS2 and Workshop 3 (WS3), and a final working meeting followed WS3. The working meetings were attended by all members of the respective TI Team, a representative of the PPRP, and, optionally, the Project Manager (PM). In addition, a database expert was usually present at the SSC meetings along with appropriate tools for retrieving and projecting, as needed, elements of the project database. The dates, locations, and members of the PPRP attending the working meetings (WMs) are listed in Table 3.1.

The topics and emphasis at each working meeting were a function of the timing of the meeting relative to the overall project schedule. WM1 focused on the progress of the evaluation process, identifying the proponent and resource experts to participate in WS2, and specifying the questions to be asked of the proponent experts for them to address at the workshop. WM2 and WM3 occurred during the integration phase of the project and focused on the construction of the preliminary SSC and GMC models. WM4 included a review of the feedback obtained at WS3 and discussions focused on the assessments needed to finalize the SSC and GMC models.

Table 3.1. Summary of working meetings held by the SSC and GMC TI Teams and observed by members of the PPRP.

TI Team	Meeting	Date	Location	PPRP Attendance
SSC	WM1	Sep. 17-19, 2012	AMEC, Oakland	Bill Lettis Carl Stepp
	WM2	Feb. 25-28, 2013	AMEC, Oakland	Bill Lettis Woody Savage
	WM3	August 13-16, 2013	AMEC, Oakland	Bill Lettis Carl Stepp[(a)]
	WM4	Jan. 13-16, 2013	AMEC, Oakland	Woody Savage
GMC	WM1a	Sep. 11, 2012	Teleconference 8:00-12:00 PDT	Ken Campbell[(a)]
	WM1b	Oct. 24, 2012	Teleconference 9:00-13:00 PDT	Ken Campbell[(a)] Woody Savage[(a)]
	WM2	Feb. 18-21, 2013	AMEC, Oakland	Brian Chiou Ken Campbell
	WM3	August 13-16, 2013	AMEC, Oakland	Ken Campbell Brian Chiou
	WM4	Jan. 13-17, 2013	AMEC, Oakland	Brian Chiou

(a) Attended via web conference.

In addition to the four working meetings of each TI Team, numerous conference calls were held by both teams during the entire course of the project to discuss a wide variety of issues.

3.7 SSC and GMC Preliminary Model Development

With the completion of WS2, the project moved from the evaluation phase into the integration phase, during which preliminary and final SSC and GMC models are constructed. The development of the preliminary SSC and GMC models was the responsibility of the SSC and GMC TI Teams and marked the first series of assessments that provided input to the PSHA. Based on the results of the first two workshops (which identified the key issues, available data, and alternative models and methods) as well as the database and earthquake catalog, preliminary SSC and GMC models were developed for the Hanford PSHA. The TI Teams used the results of new data-collection activities and the discussions by proponents of alternative views that occurred during the workshops. Logic trees and other uncertainty tools were used to represent the range of technically defensible interpretations. A key component of the models was the quantification of uncertainties in alternative conceptual models as well as in parameter values. The preliminary SSC and GMC models were transmitted to the Hazard Analyst via the hazard input documents (HIDs; see Section 3.10) for the hazard calculations and were presented at the third workshop (see Section 3.8).

An important use of the preliminary SSC and GMC models is to explore the relative hazard significance of various elements of the models and the relative contributions that the uncertainties in the elements make to the total uncertainty in hazard. Therefore, the preliminary models included a full range of assessments to explore these hazard sensitivities.

In preparation for the hazard-sensitivity calculations, the TI Teams let the Hazard Analyst know which specific sensitivity analyses that they wanted to see to give them insight into their preliminary models. These included typical “one-off” sensitivity analyses that show the influence that a range of values for a particular parameter has on the mean hazard results. In addition, the influences of all logic nodes and branches were identified as well as “deaggregation” calculations to show the relative influence that various sources, distances, magnitudes, and ground motion variabilities have on the calculated hazard. Importantly, sensitivity analyses were also identified to show the contributions that the uncertainties in certain aspects of the preliminary models make to the total hazard uncertainties. The results of the specified hazard-sensitivity analyses were presented by the Hazard Analyst at WS3.

3.8 Workshop 3: Feedback to TI Teams About Preliminary Models

The purpose of the third workshop, conducted November 11−15, 2013, was to provide feedback to the TI Teams regarding their preliminary models, their success in representing the range of knowledge and uncertainty, and the hazard significance of various components of the SSC and GMC models. In particular, the goal of this workshop was to present and discuss the preliminary SSC and GMC models in a forum that provided the opportunity for feedback from the PPRP. Feedback was also given in the form of hazard results and sensitivity analyses to shed light on the most important technical issues. The feedback gained at this workshop ensured that no significant issues had been overlooked and it allowed the TI Teams to understand the hazard implications of the SSC and GMC models, uncertainties, and assessments of weights. This information provided a basis for focusing subsequent project efforts on issues of most significance to the seismic hazard, thereby assisting with the finalization of the SSC and GMC models.

WS3 consisted of separate workshops for the GMC and SSC components of the project. Each workshop consisted of 2 days and all presentations were made by members of the TI Team. In addition, both teams were present on 1 day during which SSC-GMC interface issues were addressed and overall hazard-sensitivity feedback was presented. The presentations of the hazard calculations and sensitivity analyses provided a means of focusing the discussions on the issues that had the greatest hazard significance, including the largest contributors to uncertainty. Unlike at the previous workshops, the PPRP members were encouraged to ask questions and to participate in the discussions regarding elements of the preliminary SSC and GMC models. The workshop began with the TI Team presenting the preliminary models, with particular emphasis on the manner in which alternative viewpoints and uncertainties have been captured. The technical bases for the assessments and weights were described to allow for a reasoned discussion of the constraints imposed by the available data. Following the discussions, action items for the path forward were discussed and decided upon by the respective TI Teams regarding the assessments and analyses that remained to be completed in order to finalize the SSC and GMC models.

This WS3 activity included documentation of the workshop in a Workshop Summary (PNNL 2014). The summary included the written comments made by the PPRP, which assisted the TI Teams in clarifying the actions that they would take to finalize their models and points of emphasis to be made in the documentation of the models in the PSHA report. The report also includes responses to the PPRP comments prepared by the TI Team leads.

3.9 Finalization of SSC and GMC Models

In light of the feedback discussed during WS3, and using the final database and seismicity catalog, the TI Teams finalized the SSC and GMC models as part of this model-finalization task. Uncertainties were fully characterized using logic trees (for alternative conceptual models) and probability distributions (for parameter distributions). Each of the TI Teams held a working meeting to facilitate finalization of the models.

An innovative part of the Hanford PSHA project was the conduct of a PPRP Briefing on May 6−7, 2014 following the finalization of the SSC and GMC models. This briefing occurred over 2 days and provided the PPRP with a review of all elements of the final models and their technical justification. The briefing had two purposes: 1) to inform the PPRP about the final SSC and GMC models and the technical justification for the decisions made during the model-finalization process, prior to the start of the final hazard calculations, and 2) to provide the TI Teams with an indication of the elements of the models that would require particular emphasis during the documentation phase of the project.

3.10 Development of the Hazard Input Documents

According to the definition given in NUREG-2117 (NRC 2012), the HID provides the essential elements of the SSC and GMC models that the Hazard Analyst needs to calculate the seismic hazard. The HID is owned by the TI Teams and expresses all details of the models, including logic trees, parameter distributions, and derived parameters, but it does not include any discussion or description of the technical bases for the model elements. Two rounds of HID development occurred during the course of the project: 1) one following the development of the preliminary SSC and GMC models, and 2) one following the finalization of the SSC and GMC models. The final HID is included in this report as Appendix D.

3.11 Hazard Calculations

After finalization of the SSC and GMC models, the final hazard calculations were conducted for the five sites specified by the project sponsors. To provide insights into the important contributors to the hazard results, sensitivity analyses were conducted. These analyses identified the SSC and GMC issues of greatest significance to mean hazard at the annual frequencies of interest. Likewise, the key contributors to the uncertainty in the hazard were identified in terms of various annual frequencies of interest and specific response periods.

3.12 Development of the Draft Report

After finalization of the SSC and GMC models and the final hazard calculations, the TI Teams under the direction of the TI Leads drafted this Hanford PSHA report presenting the SSHAC process followed, databases used, the discussions and deliberations at the project workshops, and detailed descriptions of the final SSC and GMC models, including their technical bases and the rationale underlying the final model definitions. The report documents in detail the hazard results and presents interpretations of their significance, plus the main sensitivities and uncertainties.

3.13 Draft Report PPRP Review

A draft report on the Hanford PSHA project was submitted to the PPRP and sponsors for review and feedback. The review focused on the adequacy and completeness of the documentation. The PNNL PM also reviewed the draft report. The PPRP comments on the Draft PSHA report were provided to the TI Teams in written form and a conference call was held between the PPRP and the TI Leads to ensure that the content and intent of each comment was understood.

3.14 Final Report Development

Taking into account the feedback and observations from the PPRP and sponsors, the TI Teams produced a final draft of the Hanford PSHA report. The draft final report was then delivered to the PPRP along with written responses to the PPRP comments for final concurrence.

3.15 PPRP Closure Letter

The final step in the Hanford PSHA SSHAC Level 3 project was the issuance of the PPRP Closure Letter. The letter summarizes the participatory review process followed during the course of the project, the adequacy of the project in adhering to the SSHAC Level 3 process, and the adequacy of the project documentation in providing the technical bases for expressing the center, body, and range of the technically defensible interpretation. The PPRP Closure Letter became part of the project report (Appendix B) and was issued to the project sponsors.

3.16 References

ANSI/ANS (American National Standards Institute/American Nuclear Society). 2008. *Probabilistic Seismic Hazard Analysis*. ANSI/ANS-2.29-2008, Le Grange Park, Illinois.

BC Hydro. 2012. Probabilistic Seismic Hazard Analysis (PSHA) Model. Volume 2: Seismic Source Characterization (SSC) Model. Report No. E658, Vol. 2, WPR-3030, Vancouver, British Columbia.

Budnitz RJ, G Apostolakis, DM Boore, LS Cluff, KJ Coppersmith, CA Cornell, and PA Morris. 1997. *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts – Main Report*. NUREG/CR-6372, Vol. 1, U.S. Nuclear Regulatory Commission, Washington, D.C.

Coppersmith KJ and JJ Bommer. 2012. Use of the SSHAC methodology within regulated environments: cost-effective application for seismic characterization at multiple sites. Nuclear Engineering & Design 245:233−240.

Frankel A, P Thorne, and A Rohay. 2013. *Three-Dimensional Ground-Motion Simulations of Earthquakes for the Hanford Area, Washington*. USGS Open-File Report 2013-1789, U.S. Geological Survey, Reston, Virginia.

Geomatrix. 1996. Probabilistic Seismic Hazard Analysis – DOE Hanford Site, Washington. WHC-SD-W236A-TI-002, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

JBA (Jack Benjamin & Associates), URS Corporation Seismic Hazards Group, Geomatrix Consultants, Inc., and Shannon & Wilson. 2012. Probabilistic Seismic Hazard Analyses Project for the Mid-Columbia Dams. Final Report prepared for the Public Utility Districts of Chelan, Douglas, and Grant Counties. Chelan County PUD, Wenatchee, Washington.

NRC (U.S. Nuclear Regulatory Commission). 2012. *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies*. NUREG-2117, Rev. 1, Washington, D.C.

PNNL (Pacific Northwest National Laboratory). 2013a. *Workshop Report Hanford Probabilistic Seismic Hazard Analysis Workshop 1: Hazard-Significant Issues and Available Data*. PNNL-21985, Richland, Washington.

PNNL (Pacific Northwest National Laboratory). 2013b. *Workshop Report Hanford Probabilistic Seismic Hazard Analysis Workshop 2: Review of Database and Discussion of Alternative Models*. PNNL-22254, Richland, Washington.

PNNL (Pacific Northwest National Laboratory). 2014. *Workshop Report Hanford Probabilistic Seismic Hazard Analysis Workshop 3: Feedback to Technical Integration Teams on Preliminary Models*. PNNL-23141, Richland, Washington.

Thorne PD, AC Rohay, and SP Reidel. 2014. *Development of a Basin Geologic and Seismic Property Model Used to Support Basin-Effects Modeling for the Hanford Probabilistic Seismic Hazards Analysis*. PNNL-23305, Pacific Northwest National Laboratory, Richland, Washington.