Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Site-Specific Seismic Hazard Study
Study Plan Section 16.6

Final Study Plan

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

July 2013

16.6. Site-Specific Seismic Hazard Study

On December 14, 2012, Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC or Commission) its Revised Study Plan (RSP), which included 58 individual study plans (AEA 2012). Section 16.6 of the RSP described the Site-Specific Seismic Hazard Study. This study focuses on conducting deterministic and probabilistic seismic hazard evaluations to estimate earthquake ground motion parameters at the Project site, assessing the risk at the site and the loads that the Project facilities would be subject to during and following seismic events, and proposing design criteria for Project facilities and structures considering the risk level. RSP 16.6 provided goals, objectives, and proposed methods for data collection regarding seismic hazards.

On February 1, 2013, FERC staff issued its study plan determination (February 1 SPD) for 44 of the 58 studies, approving 31 studies as filed and 13 with modifications. RSP Section 16.6 was one of the 31 studies approved with no modifications. As such, in finalizing and issuing Final Study Plan Section 16.6, AEA has made no modifications to this study from its Revised Study Plan.

16.6.1. General Description of the Proposed Study

16.6.1.1. Study Goals and Objectives

The goals of this study are to conduct deterministic and probabilistic seismic hazard evaluations to estimate earthquake ground motion parameters at the Project site, assess the risk at the site and the loads that the Project facilities would be subject to during and following seismic events, and propose design criteria for Project facilities and structures considering the risk level. The intent of the study is to fulfill specific objectives including, but not limited to the following:

- identify the seismic sources along which future earthquakes are likely to occur, including the potential for reservoir-triggered seismicity;
- characterization of the degree of activity, style of faulting, maximum magnitudes, and recurrence information of each fault;
- develop maps and tables depicting the spatial and geometric relations of the faults and seismic source zones together with specific distance parameters to evaluate ground motion parameters from each source;
- assemble available historical and instrumental seismicity data for the region, including maximum and minimum depth of events;
- determine the distance and orientation of each fault with respect to the site;
- estimate the earthquake ground motions at the proposed dam site, updating previous studies to include changes in practice and methodology since the 1980s;
- propose the seismic design criteria for the site;
- prepare a supporting design report that include the seismic criteria and results of dam stability analysis under seismic loading (this will be addressed as part of the dam analysis, not as part of the initial seismic characterization); and
- use a BOC for independent technical review and guidance during development of site-specific studies.

The FERC study request (FERC 2012) refers to assessing the stability of Project facilities during seismic events and performing a dynamic analysis that identifies any damage caused by the earthquake and shows that the dam can continue to resist applied static loading in the damaged condition with any possible resulting loading changes. This aspect of dam engineering will be carried out during the ongoing analytical phase and design process; it is not proposed that such dam analyses form part of the initial seismic hazard analysis studies. While the seismic studies are in progress, dam engineering analyses and design will also be in progress and the requirements and initial dam analysis results will be incorporated into the seismic study to the extent necessary before final designs are completed using the results of the seismic studies.

16.6.2. Existing Information and Need for Additional Information

Several geology and seismic characterization studies were conducted for the APA Project in the 1980s. The most important studies relating to the seismic characterization were

- site-specific seismic hazard evaluations, including fault trenching, geologic mapping and age-dating, microseismic network operations, and ground motion evaluations (Woodward Clyde Consultants 1980; and Woodward Clyde Consultants 1982); and
- evaluation of reservoir induced seismicity (RIS) (Harza-Ebasco 1985).

Other associated geological studies of the region and site have included

- regional mapping of surficial deposits (rock and soil) using aerial photography and geologic reconnaissance (Acres 1982a);
- studies of reservoir slope stability (Acres 1982a);
- subsurface explorations through geophysics, borings, test pits, and trenches (USACE 1975; USACE 1979; Acres 1982a; Acres 1982b; Harza-Ebasco 1983, Harza-Ebasco 1984;); and
- laboratory testing of physical and strength properties of rock and soil (USACE 1979; Acres 1981; Acres 1982, Harza-Ebasco 1983; Harza-Ebasco 1984).

These previous studies and site investigations represent a dataset of substantial magnitude that will be beneficial to the proposed studies.

Despite the large amount of data, it is acknowledged that there are data gaps, and thus the proposed studies essentially are an update and expansion of the studies carried out in the 1980s by Woodward Clyde Consultants.

The following examples indicate topics or aspects of the region that will be addressed in the proposed studies:

- Since the 1980s there has been a magnitude 7.9 earthquake on the Denali fault.
- Regional probabilistic seismic hazard maps by the USGS (e.g., Wesson 2007) and the 2008 probabilistic seismic hazard analysis were prepared for the Port of Anchorage.
- The USGS has opined that the Denali fault is fairly well studied, but the Broad Pass fault, a pre-Quaternary thrust fault in the project area, has not been extensively studied. The USGS recommends that information be gathered to verify its existence and characterize its history.

16.6.3. Study Area

The study area for the seismic hazard evaluation is necessarily large in order to include potentially significant seismic sources throughout the region. The study area encompasses subduction-related sources (plate interfaces between the North American and Pacific Plates, which were the source of the 1964 earthquake, and intraslab sources within the down-going Pacific Plate) and all applicable Quaternary crustal seismic sources within about 125 miles (200 kilometers) of the site (Figure 16.6-1). Crustal seismic sources beyond these distances are not expected to provide significant ground motion contributions at the dam site relative to nearby sources. A more focused study area will include the dam site and reservoir areas, and a minimum area defined by an approximately 62-mile (100-kilometer) radius around the proposed dam location. The focused study area will therefore include much of the Talkeetna block and surrounding fault zones such as the Denali; Castle Mountain; Northern Foothills fold and thrust fault zone; Talkeetna fault; and Broad Pass Fault.

16.6.4. Study Methods

16.6.4.1. General

The study methods shall generally be in accordance with Chapter 13 of the FERC Engineering Guidelines for the Evaluation of Hydropower Projects. The site-specific seismic hazard evaluation for assessing the seismic risks and developing the seismic design criteria in support of licensing and detailed design will include of the following tasks:

- Update the understanding of geologic conditions and seismo-tectonic setting for the dam site area;
- Identify and characterize the seismic sources, including detailed geologic studies and lineament analyses;
- Identify whether a fault may be encountered beneath or adjacent to the dam and assess the activity of the feature and, if active, the likelihood for potential fault displacement or ground offset;
- Perform a deterministic and probabilistic seismic hazard assessment in order to define earthquake ground motions for structural analyses;
- Evaluate the potential for Reservoir Triggered Seismicity (RTS);
- Assess risks to Project structures and operation associated with seismic loading conditions; and
- Propose appropriate seismic design criteria.

These tasks and the associated study methods will generally be as presented below.

16.6.4.2. Board of Consultants Review

As requested by FERC (FERC 2012), a BOC will be established for technical review of the dam analyses and design. The BOC review will be primarily focused on appropriate aspects of the Seismic Hazard Evaluation, the determination of response spectra, and the crafting of design criteria. The BOC will meet and review study progress at appropriate intervals. The study methods and tasks described herein may be subject to suggested modification by the BOC.

16.6.4.3. Review of Project Documentation

A review will be conducted of the existing documentation, including all available previous applicable Project reports, to characterize the geologic, geotechnical, and seismic conditions in support of feasibility and licensing studies and detailed design so as to take maximum advantage of the large body of knowledge that already exists for the site. Documentation will include work from the studies performed in the 1970s and 1980s. A geologic and geotechnical database will be developed in order to build upon the earlier studies as they pertain to the current Project development.

16.6.4.4. Seismic Hazard Analysis

A deterministic and probabilistic seismic hazard evaluation will be undertaken to update the seismic hazard studies from the 1980s in order characterize the seismic sources, to define the earthquake ground motion parameters, and to develop seismic design criteria for the Project structures. The methods follow general guidance defined according to Chapter 13 of the Federal Energy Regulatory Commission's Engineering Guidelines. Subtasks will include the following:

- Update evaluations of geologic, seismologic, and seismotectonic literature for the Project study area to identify data gaps and uncertainties that may require further evaluations.
- Update seismicity catalogue for evaluation of seismicity rates, depths, magnitudes, and focal mechanisms. This will include evaluation of recent and ongoing data collected by the Alaska Seismographic Network and augmented by the additional seismic stations installed in the Project area as part of the long term earthquake monitoring program.
- Develop a seismotectonic model that identifies and characterizes seismic sources of engineering significance to the Project.
- Conduct geologic studies using newly acquired Light Detection and Ranging (LiDAR) and Interferometric Synthetic Aperture Radar (IFSAR) datasets to aid in the identification and evaluation of potential seismic sources and geohazards.
- Collect field geologic data for characterization of potential seismic sources and surface displacement hazards.
- Perform surface fault displacement hazard analysis to evaluate the significance (likelihood and amount) of potential ground surface displacement from faulting in the area of the Project, including beneath the dam, if such a feature is present.
- Sensitivity studies will be performed on selected surface tectonic features, faults and lineaments, identified and being considered as potential seismic sources of engineering significance on the design of the Project.
- Monitoring and detection of local earthquakes to understand the seismic hazards in the Project area.
- Conduct ground motion analyses and assessments to estimate the expected ground motions at the Project facilities using a probabilistic seismic hazard analysis (PSHA) and deterministic seismic hazard analyses (DSHA) based on the seismic source characterization, and FERC guidelines.
- Develop seismic design criteria to develop appropriate seismic design parameters for use in dam analyses and considerations for construction.
- Perform Dynamic Analysis of the dam (in other studies).

Ground motion estimates from the PSHA and DSHA will be developed for a number of critical seismic sources using weighted ground motion prediction equations (GMPE's) appropriate for each source in the analyses. Results from the PSHA analyses will consist of hazard curves for a range of spectral response frequencies, uniform hazard spectra (UHS) for a range of return periods, and deaggregation of seismic source contributions for design-specific return periods and spectral frequencies. The purpose of the deaggregation is to provide parameters for the development of Conditional Mean Spectra (CMS). CMS will be generated using the methodology of Baker (2011). As recommended in FERC guidelines, the CMS will be extended so that the envelope of the CMS for a given return period equals the UHS. The PSHA will then be used to guide the selection of a deterministic event. Ultimately, the ground motion will be estimated through a risk-based approach, and AEA will work with FERC and BOC to establish the ground motion and criteria for the dam analysis.

Results of the site-specific seismic hazard assessment studies will be documented with Project reports.

16.6.4.5. Long-Term Earthquake Monitoring System

A long-term earthquake monitoring system will be installed for the purpose of continuously monitoring earthquakes that occur in the Project area, both pre- and post-construction, and to record strong shaking of the ground at the Project site during moderate to strong earthquakes. The long-term monitoring system will consist of four 6-component strong motion and broadband seismograph station at the Watana Dam site area and two 3-component broadband seismograph stations in the vicinity of the proposed dam site and reservoir area. The seismograph stations will be operated as part of the Alaska Seismographic Network by the University of Alaska. These stations will provide additional resolution on the seismicity rates and characteristics of earthquakes in the Project area.

16.6.4.6. Reservoir Triggered Seismicity

The potential for RTS to occur during and after filling of the reservoir will be evaluated. This examination of the potential for RTS will include information from the seismic hazard analysis including the potential possibility of faults capable of being triggered close to the site. The attributes that will be considered in evaluating the probability of RTS include reservoir depth; reservoir volume; the tectonic stress state; and the rock type and structure underlying the reservoir. The probabilities that are considered are conditional and represent the total chance for RTS to occur as a result of reservoir filling and operation. Conditional probabilities will be developed for each attribute, as well as for all attributes combined. For the multi-attribute analysis, each attribute will be considered independently and also in a discrete-dependent model focusing on depth and volume.

Additionally, a literature review, case study, and numerical analysis will be performed of RTS based on other projects with large, deep reservoirs in order to develop an understanding of the potential of RTS at the Susitna-Watana site.

The long-term earthquake monitoring system will provide a baseline of the rates and seismological characteristics of local seismic events prior to the impoundment of the reservoir. Seismicity data collected before and after installation of the long-term monitoring system will be used to perform seismological analyses to help define local seismotectonic characteristics. Such

analyses would include activities such as development of local velocity models, focal mechanism and regional stress analysis, analysis of spatial patterns, and relationship of seismicity to reservoir operation. The ultimate purpose of this study is to assure that possible RTS earthquakes are accounted for by the dam seismic design parameters.

16.6.4.7. Reservoir Slope Stability Study

An assessment will be made of the reservoir rim stability based on the geologic conditions in the reservoir area, particularly in the reservoir drawdown zone. Geologic information from the previous study on reservoir slope stability (1982), as well as mapping, geotechnical investigations, and instrumentation monitoring will be used to assess the stability concerns of the reservoir rim not only under drawdown but also from seismic loads. Key factors in this study are the planned reservoir level and anticipated range of drawdown, soil conditions, presence of permafrost, topography and slope conditions.

16.6.4.8. Engineering Analysis

A dynamic analysis will be performed (separately under the engineering studies and design) to identify the performance of the major hydraulic structures under earthquake loading conditions. The analyses will optimize the design of the structures, assessing the potential damage that may occur during an earthquake event, and verify that the dam can continue safe operation in a damaged state until any necessary repairs are performed.

14.6.4.9 Reporting

Several technical reports will be prepared for each stage for the study for the BOC. A summary report will be prepared for the Initial Study Report and Updated Study Report. AEA proposes to submit technical reports and all supporting information for this study only to the BOC, FERC, and the Alaska Department of Geological and Geophysical Surveys pursuant to FERC's Critical Energy Infrastructure Information (CEII) regulations, which are designed to ensure that critical energy infrastructure is protected from security threats. Licensing participants who wish to review this information can request it from FERC pursuant to FERC's CEII regulations.

16.6.5. Consistency with Generally Accepted Scientific Practice

The seismic hazard analyses and development of seismic design criteria will be performed in accordance with general industry accepted scientific and engineering practices, following the guidance and procedures outlined in FERC Chapter 13. Recently, the industry has shifted towards selection of ground motions and criteria based on risk. AEA will work with FERC and BOC to establish the criteria for the dam analysis and ensure that each task complies with accepted scientific practice.

Independent senior technical staff and industry consultants will review the appropriateness of the field investigations and testing, seismic source characterization, deterministic and probabilistic seismic hazard assessment, selection of appropriate ground motions at the site and determination of critical seismic design criteria and decisions. Several working sessions and site visits will be scheduled to review the results of the field investigations and testing, characterize the seismic source, assess seismic hazards, select earthquake ground motions, perform a dynamic analysis, and determine design criteria and assumptions.

16.6.6. Schedule

The proposed study plan includes a seismic source evaluation using recently acquired LiDAR and INSAR data to delineate faults and lineaments in the study area, performing a paleoseismic analysis, reconnaissance geologic mapping, installation of a long-term earthquake monitoring system, assessment of slope stability for the proposed reservoir rim area, and conducting an assessment of reservoir triggered seismicity in 2012. For 2013-14, a field program is envisioned for investigating significant seismic sources or ground displacement features, updating seismic source characterization, and continuing collection of microseismic and strong motion data with the long-term earthquake monitoring system.

Deterministic and probabilistic seismic hazard assessment and engineering analysis will be performed through the 2012-2014 time period. A summary of the studies and results will be provided in the Initial Study Report in February014 and Updated Study Report in February 2015. The primary activities and planned schedule is shown in Table 16.6-1.

16.6.7. Relationship with Other Studies

As depicted in Figure 16.6-2, the Site-Specific Seismic Hazard Study will use some information from the Geology and Soils study related to basic geologic conditions and reference materials. The outputs of this study will feed back into the Engineering studies to assist in designing Project features to meet appropriate seismic design criteria.

16.6.8. Level of Effort and Cost

The level of effort for the studies outlined in this document, using a phased multiple year approach is estimated to be in excess of 50 person-months or approximately $1.5 million.

16.6.9. Literature Cited

Acres. 1982b. Susitna Hydroelectric Project 1980-81 Geotechnical Report, Volumes 1 through 3. Prepared for Alaska Power Authority.

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Woodward-Clyde Consultants Inc. (WCC). 1980. Interim Report on Seismic Studies for Susitna Hydroelectric Project. Prepared for Acres American Inc.

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16.6.10. Tables

Table 16.6-1. Schedule for implementation of the Site-Specific Seismic Hazard Study.

Activity	2012				2013				2014				2015
	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q	2 Q	3 Q	4 Q	1 Q
Paleoseismic (Lineament) Analysis		——	——	——	——								
Field Investigations						——	——	——					
Seismic Source Characterization	——					——	——	——					
Long-Term Local Earthquake Monitoring				——	——	——	——	——	——	——	——	——	——
Reservoir Triggered Seismicity				——	——			- - -	- - -				
Initial Study Report								——	Δ				
Reservoir Slope Stability Analysis					——	——							
PSHA					——			——	——	——			
Seismic Design Criteria										——	——		
Updated Study Report											——	——	▲

Legend:

—— Planned Activity
----- Follow up activity (as needed)

Δ Initial Study Report

▲ Updated Study Report (end of 1Q15)

16.6.11. Figures

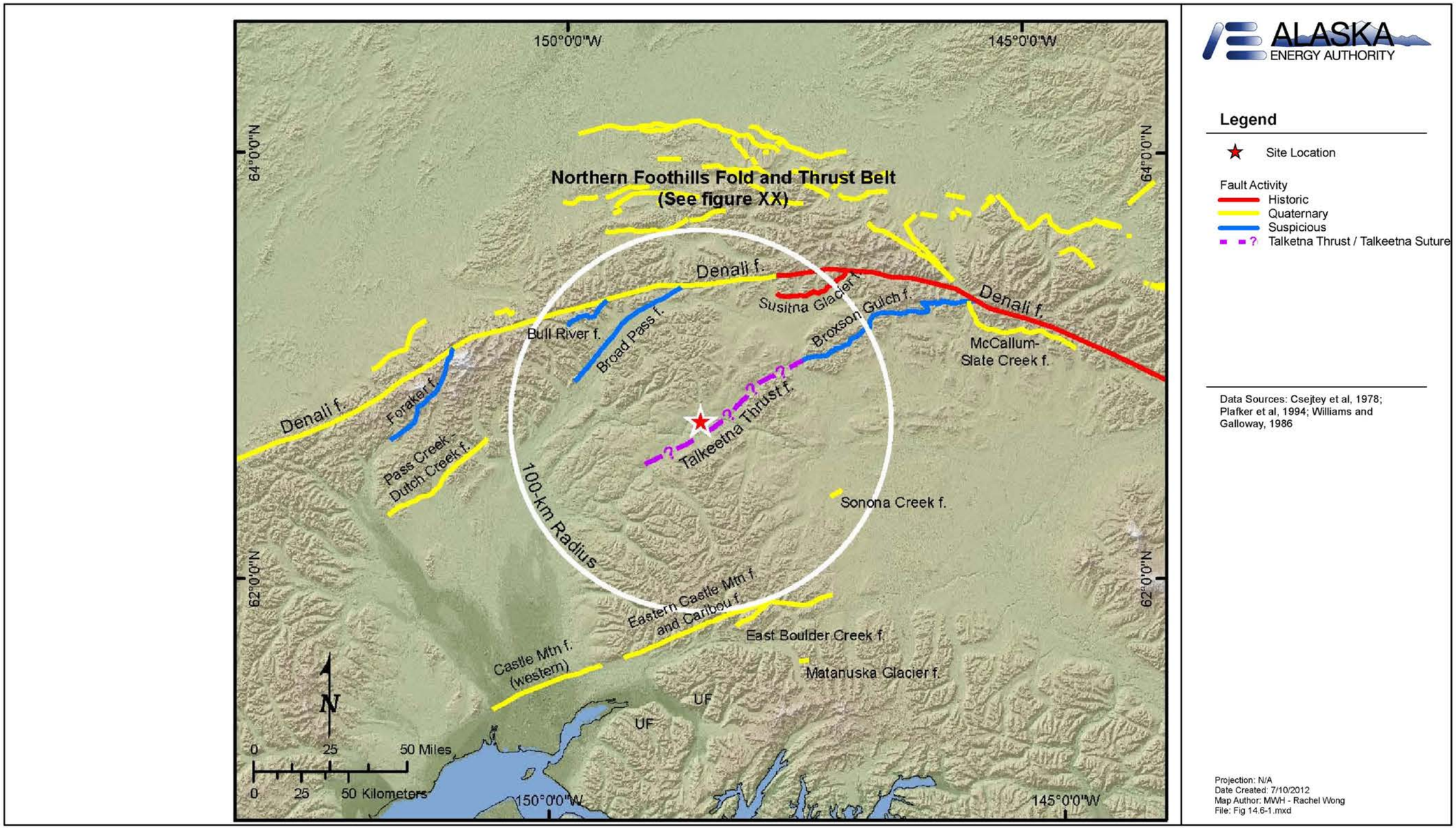

Figure 16.6-1. Regional Faults (Csejtey et al, 1978; Plafker et al, 1994; Williams and Galloway, 1986).

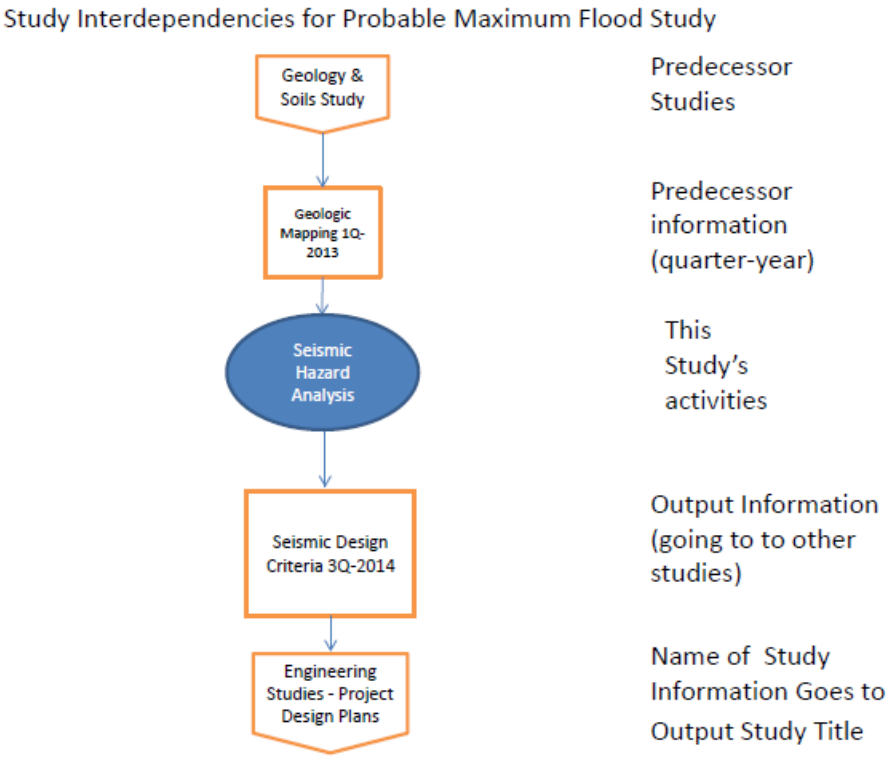

Figure 16.6-2. Interdependencies for Site-Specific Seismic Hazard Study.