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SUSITNA-WATANA HYDRO

Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Site-Specific Seismic Hazard Study
Study Plan Section 16.6

Initial Study Report
Part A: Sections 1-6, 8-9

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

MWH / Fugro

June 2014

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LIST OF ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

Abbreviation	Definition
AEA	Alaska Energy Authority
AEIC	Alaska Earthquake Information Center
BOC	Board of Consultants
CMS	Conditional Mean Spectra
DSHA	Deterministic Seismic Hazard Assessment
FERC	Federal Energy Regulatory Commission
GMPE	Ground Motion Prediction Equations
INSAR	Interferometric Synthetic Aperture Radar
ILP	Integrated Licensing Process
ISR	Initial Study Report
LiDAR	Light Detection and Ranging
PSHA	Probabilistic Seismic Hazard Assessment
RTS	Reservoir Triggered Seismicity
SPD	study plan determination
UHS	Uniform Hazard Spectra

1. INTRODUCTION

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 31studies approved with no modifications.

Following the first study season, FERC's regulations for the Integrated Licensing Process (ILP) require AEA to "prepare and file with the Commission an initial study report describing its overall progress in implementing the study plan and schedule and the data collected, including an explanation of any variance from the study plan and schedule." (18 CFR 5.15(c)(1)) This Initial Study Report (ISR) on the Site Specific Seismic Hazard Study has been prepared in accordance with FERC's ILP regulations and details AEA's status in implementing the study, as set forth in the FERC-approved RSP (referred to herein as the "Study Plan").

2. STUDY 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 includes 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 of Board of Consultants for independent technical review and guidance during development of site-specific studies.

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 interface between the North American and Pacific Plates, which was the source of the 1964 earthquake, the epicenter of which is a significant distance south of the Project, and intraslab sources within the down-going Pacific Plate) and all applicable Quaternary crustal seismic sources within about 62 miles (100 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. The 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; inferred Talkeetna fault; and Broad Pass Fault.

4. METHODS AND VARIANCES IN 2013

4.1. Methods

4.1.1. General

The study methods proceeded 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 included 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.

Work on these tasks and the associated study methods are discussed below.

4.1.2. Review of Project Documentation

A review was conducted of the existing documentation, including 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 reviewed included work from the seismic studies performed in the 1970s and 1980s. A geologic and geotechnical database was developed in order to build upon the earlier studies as they pertain to the current Project development.

4.1.3. Variances

There were no variances from this section of the Study Plan.

4.1.4. Seismic Hazard Analysis

A preliminary deterministic and probabilistic seismic hazard evaluation was undertaken to update the seismic hazard studies from the 1980s that included an update of the site-specific seismic source model. Initial ground motion parameters were developed based on a desk-top study. The methods follow general guidance defined according to Chapter 13 of the Federal Energy Regulatory Commission's Engineering Guidelines. Once this initial task had been completed a comprehensive study plan approach was implemented that will lead to a final deterministic and probabilistic seismic hazard assessment (DSHA, PSHA). Subtasks 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 includes 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 (INSAR) 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.
- Perform sensitivity studies 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.

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

4.1.5. Variances

The field investigations and mapping associated with the crustal seismic source evaluation were not completed in 2013 due to land access restrictions in the area of the proposed dam site and Stephan Lake to Watana Creek area. The LiDAR coverage was to be expanded for other studies, which data was also to be used for this hazard study, and would include upper Watana Creek to the north and a larger area south of Stephan Lake. The LiDAR was to be acquired in Fall 2013 however, the imagery was not obtained because of weather. In addition, a new field technique and method was used to obtain shear wave velocity measurements at each of the seismograph locations. A total of seven shear wave velocity measurements were obtained. In the next field season, the crustal seismic source evaluation will be continued following which the project site specific hazard assessment will be updated.

4.2. Long-Term Earthquake Monitoring System

The long-term earthquake monitoring system was expanded in 2013. The earthquake monitoring system was installed to monitor earthquake activity and to record strong shaking of the ground in the Project area during moderate to strong earthquakes. Three new 3-component broadband stations, four 3-component strong motion stations, and a GPS station were added to the network. The long-term earthquake monitoring system now consists of four 6-component strong motion and broadband seismograph stations, three 3-component broadband seismograph stations, and a single GPS station within about 31 miles of the proposed dam site. Data on seismic events in the Project area is obtained in real-time for processing. The seismograph stations are operated as part of the Alaska Seismographic Network by the University of Alaska. These seismograph stations provide additional resolution on the seismicity rates and characteristics of earthquakes in the Project area.

4.2.1. Variances

There were no variances from this section of the Study Plan.

4.3. Preliminary Reservoir Triggered Seismicity

The potential for reservoir triggered seismicity (RTS) to occur during and after filling of the reservoir was evaluated. A preliminary assessment of the potential for RTS was undertaken and includes information from the seismic hazard analysis and a review of the earthquake events recorded by the long-term earthquake monitoring system. The attributes that were 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 were also developed for each attribute, as well as for all attributes combined. For the multi-attribute analysis, each attribute is considered independently and also in a discrete-dependent model focusing on depth and volume.

Additionally, a literature review, case study, and numerical analysis was 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.

Data from the long-term earthquake monitoring system provides a baseline of the rates and seismological characteristics of local seismic events prior to the impoundment of the reservoir. Seismicity data collected as part of the long-term monitoring system data collection was used to perform seismological analyses to help define local seismotectonic characteristics. Such analyses include 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 preliminary study is to account for possible RTS earthquakes in the development of seismic design parameters.

4.3.1. Variances

There were no variances from this section of the Study Plan.

5. RESULTS

The results of the study to-date include:

- Review of the -available documentation on the geologic, geotechnical, and seismic conditions within the Project area from previous studies and research.
- Development of an initial geological and seismotectonics database and library.
- Update of 1980s-era seismic source evaluation and development of a Preliminary DSHA and PSHA.
- Expansion of the previously installed 2012 seismic monitoring system, addition of three 6-component broadband and strong motion seismographs and one GPS station at the proposed Watana dam site.
- In situ shear-wave velocity measurements at seismograph stations for development of improved site velocity models.

- Collection and analysis of microseismicity event data for the Project area (Figure 16.6-2 through 16.6-4).
- Preliminary Reservoir Triggered Seismicity (RTS) studies.
- Lineament mapping and analysis for fault studies using LiDAR and IFSAR data.
- Field reconnaissance of mapped lineaments and other features using digital elevation models for crustal seismic source evaluation. This task will be continued when site access is obtained.

5.1. Review of Project Documentation

This task included research, compilation, and review of relevant scientific literature, studies, and maps necessary to update the geologic and seismologic understanding of the region. This included review of the existing seismic studies by WCC (1980; 1982) and R&M (2009) and published literature and fault rupture maps following the 2002 Denali earthquake. This task also included contacting technical experts in the Alaskan seismotectonics to elucidate the current understanding of shallow crustal seismic sources and Quaternary faulting in the Talkeetna Terrain. Based on this literature review, a geological and seismotectonics database and library were created.

5.2. Preliminary PSHA

Based on the review of the literature and the previous studies, an updated site-specific seismic source model was developed and preliminary ground motion parameters (based on FERC guidelines) were developed for the Project for use in initial dam analyses. As part of the hazard update, a new seismic source characterization model of the dam region and site was developed. Most recent ground motion prediction equations (GMPEs) including next generation attenuation (NGA) relationships for shallow crustal sources, and a recently developed GMPE for the Cascadia subduction zone, were used in the probabilistic and deterministic seismic hazard analysis for the Susitna-Watana Dam.

5.3. Crustal Seismic Source Assessment

An assessment was made of existing and additional crustal seismic sources utilizing two high-resolution elevation datasets, a coarser resolution IFSAR dataset and a high resolution LiDAR dataset recently made available for the Project site area. These datasets were used to identify lineaments and faults in the Project area, within 62 miles (100 km) from the Watana dam site (IFSAR) with a certain focus of lineament mapping within a 25 mile radius (LiDAR) around the Watana dam site in order to strengthen confidence in the seismic source characterization. This task includes using the more-extensive IFSAR elevation data and terrain models for a coarse evaluation, a "second" pass in the assessing the surface faulting hazard was made using the detailed LiDAR elevation data. After this compilation of lineament and fault features, criteria were developed for determining significant crustal seismic source potential (e.g., rupture length and earthquake magnitude, length – distance screening criteria) and select features were identified for further study.

The crustal seismic source evaluation included a field evaluation involving aerial survey and on the ground inspection of mapped lineaments delineated during the desk-top studies. Due to land access restrictions, with no ground access to CIRWG lands, as discussed under Subsection 4.1.5, the field evaluation of lineaments and faults was not completed. Field reconnaissance and mapping of the dam site and reservoir areas on lands owned by CIRWG has been delayed till the 2014 field season.

5.4. Seismic Monitoring

Over the past year, the long-term earthquake monitoring system has recorded a total of 1507 earthquakes which were located within a region roughly 50 miles east-west and 30 miles north-south, between November 1, 2012 and September 30, 2013. The earthquake event data developed in support of this study is available for download at http://gis.suhydro.org/reports/isr.

The earthquakes in the Project area form two distinct groups, crustal events between 0 and 25 km depth and intermediate depth events below 30 km in the subducting Pacific plate. This can be seen clearly in the cross-section and depth histogram plots (Figures 16.6-3 and Figure 16.6-4).

The largest earthquake within the subducting plate, a magnitude 4.0 earthquake, occurred on January 21, 2013 at a depth of 66.4 km (40.1 miles) and located 53 km (32.6 miles) WSW of the dam site. The largest earthquake magnitude within the crust, a magnitude 3.8, occurred on July 24, 2013 at a depth of 11.1 km (6.9 miles) and was located 14.2 km (8.8 miles) NW of the dam site. About 10 small aftershocks (M=0.9-2.3) were located within a few days of the 3.8 event.

Shear wave seismic velocity measurements were taken at each of the seismograph stations. The results of the measurements ranged from 2415 ft/s to 10345 ft/s.

5.5. Preliminary Reservoir Triggered Seismicity

An assessment of the potential for the future occurrence of RTS to occur in the vicinity of the proposed reservoir was made expanding upon the earlier study prepared by Woodward Clyde consultants in the 1980s (WCC, 1980). The preliminary assessment and analysis of RTS is a work in progress as additional background information from the seismic hazard studies (see Subsection 5.3) and long-term earthquake monitoring data (see Subsection 5.4) are essential to this study.

The location and magnitude of any future RTS event associated with the Watana Reservoir are highly uncertain. However, empirical data suggest that most RTS events will have relatively small magnitudes and would most likely occur within 10 years of initial reservoir filling. From these types of observations, ICOLD (2011) and Allen (1982) suggest that maximum RTS magnitudes may be on the order of 6.3 and 6.5, respectively. Others (USGS) have suggested potentially a higher magnitude. At this time, the results of the crustal seismic source assessment are needed to improve the understanding of the local geologic and seismotectonic characteristics that are significant to RTS assessment and therefore determining a possible maximum magnitude that could occur in the region.

6. DISCUSSION

Progress in the overall Seismic Hazard Study Plan has been made to-date with the completion of a preliminary DSHA and PSHA studies, preliminary RTS studies, lineament mapping for crustal seismic source evaluation, installation of seismometers and ground motion instruments, and analysis of seismicity data. The study also evaluated the potential effects of various scenarios characterizing the subduction slab earthquake, and incorporated recently acquired site shear-wave velocity information. Several of these studies are still on-going, and will provide a basis for developing seismic criteria to support a risk-informed hazard analysis for dam design.

7. COMPLETING THE STUDY

[Section 7 appears in the Part C section of this ISR.]

8. LITERATURE CITED

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9. FIGURES

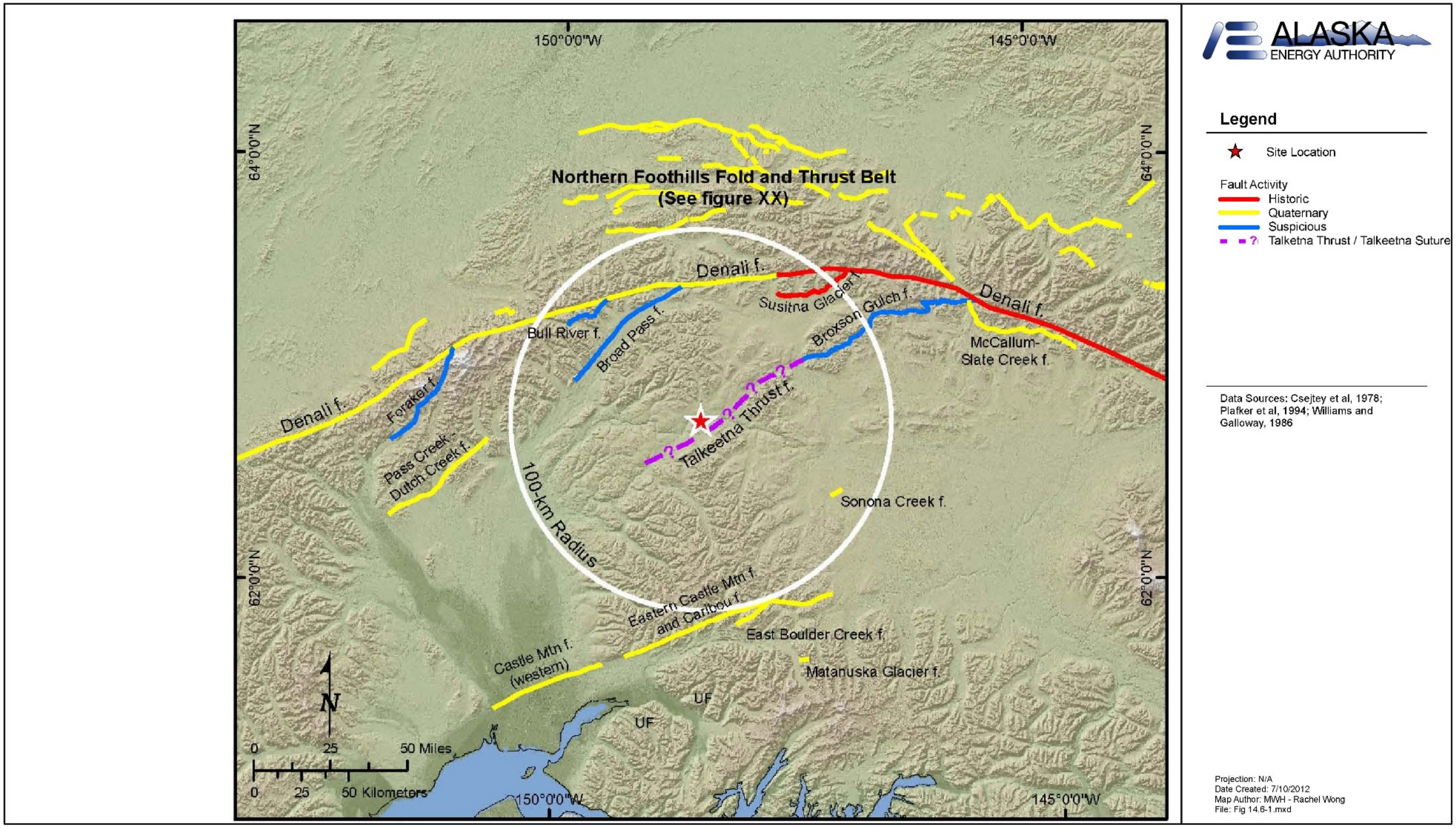

Figure 16.6-1. Regional Faults (Csejtey et al. 1978; Plafker et al. 1994; Williams and Galloway 1986)

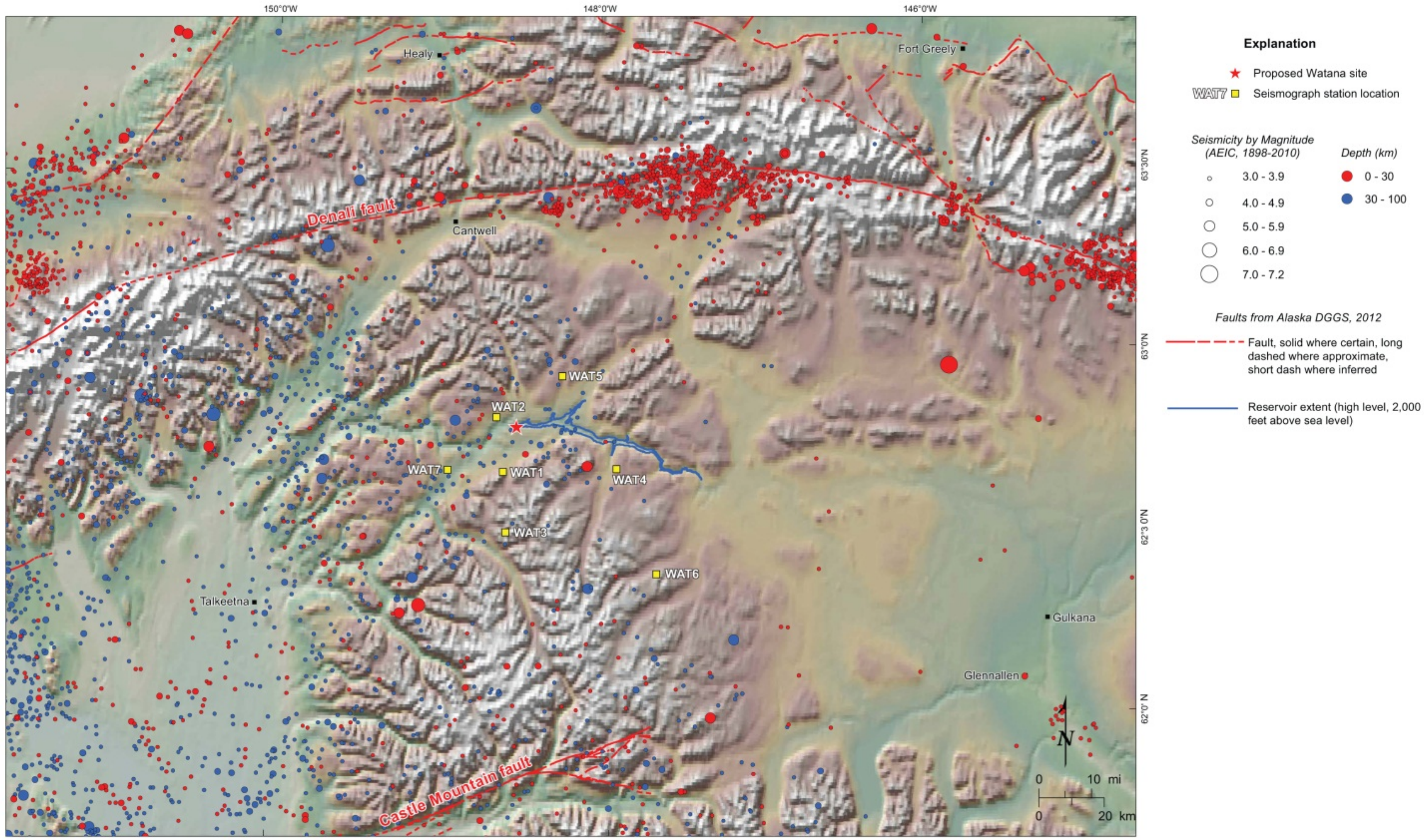

Figure 16.6-2. Regional Seismicity Map showing AEIC data from 1898-2010.

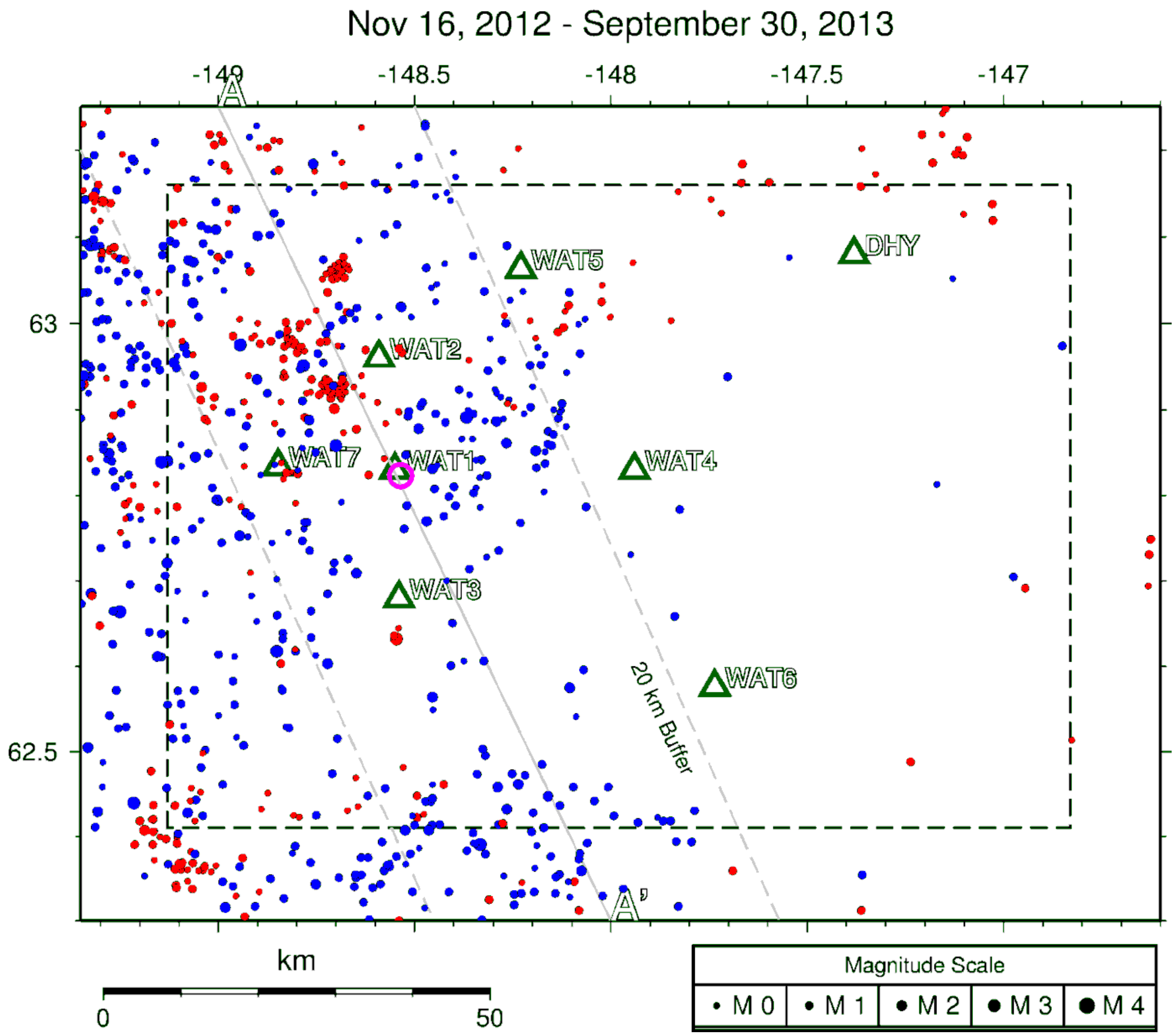

Figure 16.6-3. Earthquake Events Recorded by Project Long-Term Seismic Monitoring System, inception through September 30, 2013. X-axis is latitude and y-axis is longitude. Red epicenters are < 30km deep and blue are >30km depth. Magenta circle is Watana dam site. Green triangles are seismograph stations.

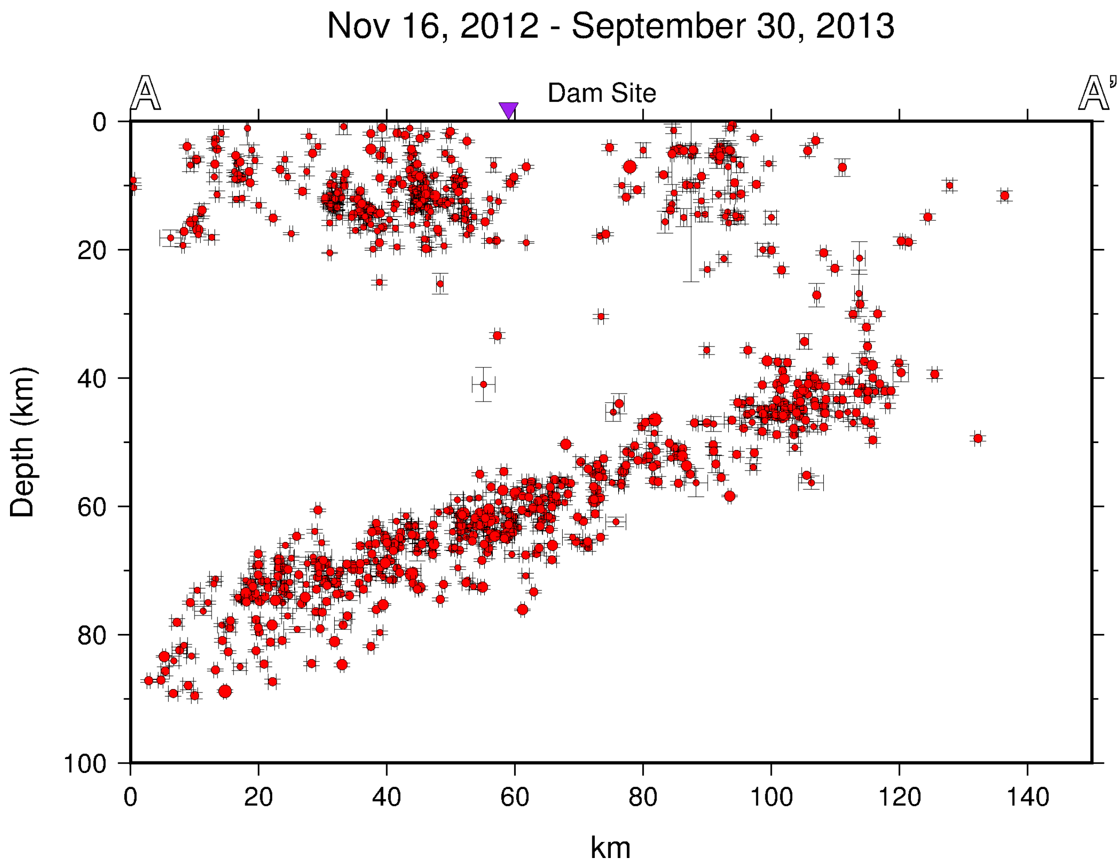

Figure 16.6-4. Depth of Earthquake Events Recorded by Long-Term Seismic Monitoring System, November 16, 2012, through September 30, 2013. Location of cross section A-A' (NW-SE) shown in Figure 16.6-3.

Figure 16.6-5. Relationship between depth and volume of reservoir for reported cases of Reservoir Triggered Seismicity (RTS).

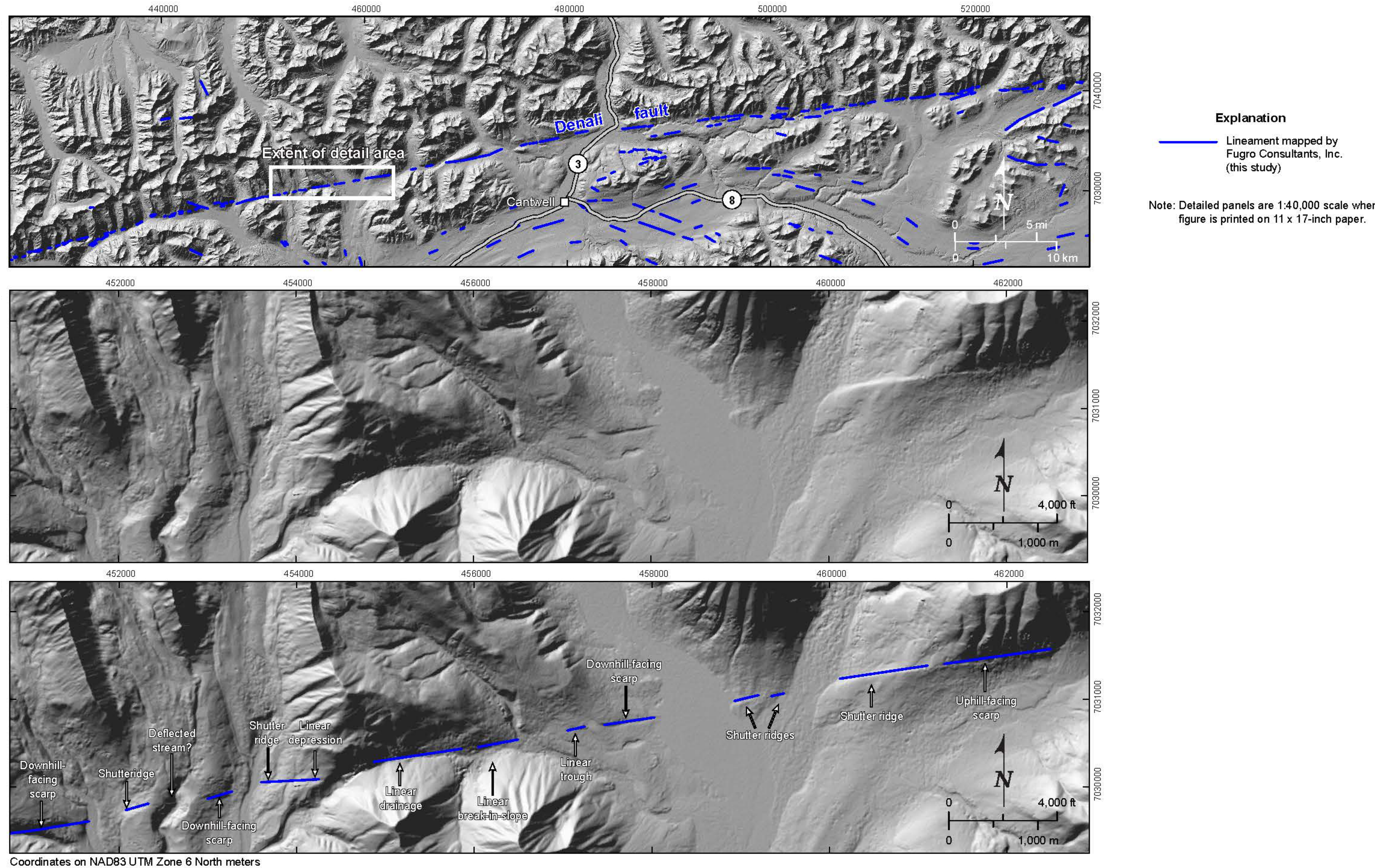

Figure 16.6-6. Example of lineament mapping and analysis along the Denali Fault using IFSAR data, 46 miles north of the Dam Site.