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Revision 0

Hanford Seismic Report for Fiscal Year 2019 (October 2018 – September 2019)

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of
Energy under Contract DE-AC06-09RL14728

Box 650
Richland, Washington 99352

Approved for Public Release
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Prepared for Mission Support Alliance

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Executive Summary

The Pacific Northwest Seismic Network (PNSN) and Mission Support Alliance (MSA) continue to provide uninterrupted collection of high-quality raw and processed seismic data from the Hanford Seismic Network (HSN). The HSN includes both onsite and offsite [Eastern Washington Regional Sub-Network (EWRSN)] stations that are operated for the U.S. Department of Energy and its contractors. The team is responsible for identifying and locating sources of seismic activity that might affect the Hanford Site, monitoring changes in the historical pattern of seismic activity surrounding the Hanford Site, and monitoring ground motion to provide data to constrain studies of earthquake effects on the Hanford Site. Seismic data are compiled, archived, and published for use by the Hanford Site for waste management, natural phenomena hazards assessments, and engineering design and construction. In addition, the team works with the Hanford Site Emergency Services Organization to provide assistance in the event of a significant earthquake on the Hanford Site. The HSN and the EWRSN together consist of 40 individual sensor sites and 14 radio relay sites maintained by the PNSN.

During FY2019, seismic activity was relatively quiet throughout eastern Washington. 251 earthquakes were cataloged in the region, of which about 55% (139) took place on or in the immediate vicinity of the Hanford Site. Several earthquakes took place in the historically active area of Entiat and Chelan. Within the vicinity of the Hanford Site, there was typical swarm-type activity, most strongly observed in the Wye Swarm Area.

Abbreviations and Acronyms

ANSS	Advanced National Seismic System
AQMS	ANSS Quake Management System
BB	Broadband (type of seismic station)
BPA	Bonneville Power Administration
CRBG	Columbia River Basalt Group
Dmin	Minimum distance (closest distance from an earthquake epicenter to a station)
DOE	U.S. Department of Energy
Etyp	Event type
EWRSN	Eastern Washington Regional Sub-Network
FY	Fiscal Year
g	typical value of gravitational acceleration at Earth's surface (~978 cm/sec/sec)
GPS	Global Positioning System
HLSMP	Hanford Lifecycle Seismic Monitoring Program
HNF	Hanford Nuclear Facility
HSN	Hanford Seismic Network
Lat	Latitude
Lon	Longitude
Km	kilometer
M_d	Coda-duration magnitude
M_L	Local magnitude
Mag	Magnitude of earthquake
MMI	Modified Mercalli Intensity
MOD	Wavespeed model
Mtyp	Magnitude type
NS/NP	Number of stations/number of phases
PNSN	Pacific Northwest Seismic Network
Q	Quality factor (of earthquake location)
Rms	Root Mean Square (error of earthquake location)
RSLW	Lower Rattlesnake (Mountain) data acquisition/telemetry site
SMA	Strong Motion Accelerometer (type of seismic station)
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
UW	University of Washington
WSUR	Washington State University Richland

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1.0 Introduction

This annual report documents the locations, magnitudes, and seismic interpretations of earthquakes recorded for the Hanford monitoring region of south-central Washington during the fiscal year (FY) 2019 (October 2018 through September 2019). The Mission Support Alliance (MSA), Safety and Health Program Support (SHPS) organization manages seismic monitoring for the Hanford Site with the monitoring work being performed under a sub-contract with the University of Washington (UW), PNSN.

1.1 Mission

The mission of the Hanford Lifecycle Seismic Monitoring Program (HLSMP) is to maintain seismic stations, report data from measured events, and to provide assistance in the event of an earthquake. This mission supports the U.S. Department of Energy (DOE) and the other Hanford Site contractors in their compliance with DOE Order 420.1C, Chapter IV, Section 3.e, "Seismic Detection," and DOE Order G 420.1-1A, Section 5.4.8, "Design for Emergency Preparedness and Emergency Communications." DOE Order 420.1C requires facilities or sites with hazardous materials to maintain instrumentation or other means to detect and record the occurrence and severity of seismic events. The HLSMP maintains the seismic network located on and around the Hanford Site. The data collected from the seismic network can be used to support facility or site operations to protect the public, workers, and the environment from the impact of seismic events.

In addition, the HLSMP provides an uninterrupted collection of high-quality raw seismic data from the HSN and the EWRSN and provides interpretations of seismic events from the Hanford Site and the vicinity. The program locates and identifies sources of seismic activity, monitors changes in the historical pattern of seismic activity, and builds a "local" earthquake database (processed data) that is permanently archived. The focus of this report is the precise location of earthquakes and explosions proximal to or on the Hanford Site, specifically, between 46°-47° north latitudes (LAT) and between 119°-120° west longitudes (LON). Data from the EWRSN and other seismic networks in the Northwest provide the HLSMP with necessary regional input for the seismic hazards analysis at the Hanford Site. These seismic data are used to support Hanford Site contractors for waste management activities, natural phenomena hazards assessments, and engineering design and construction.

1.2 History of Monitoring Seismic Activity at Hanford

The U.S. Geological Survey (USGS) under a contract with the U.S. Atomic Energy Commission initiated monitoring seismic activity at the Hanford Site in 1969. In 1975, the UW assumed responsibility for the network and subsequently expanded it. In 1979, the Basalt Waste Isolation Project (BWIP) became responsible for collecting seismic data for the Hanford Site as part of site characterization activities. Rockwell Hanford Operations, followed by Westinghouse Hanford Company (WHC), operated the local network, and were the contract technical advisors for the EWRSN operated and maintained by UW. Funding ended for BWIP in December 1988; the seismic program (including the UW contract) was transferred to the WHC Environmental Division. Maintenance responsibilities for the EWRSN also were assigned to WHC, who made major upgrades to EWRSN sites. Effective October 1, 1996, all seismic assessment activities were transferred to the Pacific Northwest National Laboratory (PNNL).

The Hanford Strong Motion Accelerometer (SMA) network was constructed during 1997, becoming operational in May 1997. It was shut down in FY 1998 due to lack of funding but became operational again in FY 1999 and has operated continuously since that time. During the third quarter of FY2011, operations of the seismic monitoring networks were assumed by HLSMP.

1.3 Documentation and Reports

The HLSMP issues quarterly reports of local activity, an annual catalog of earthquake activity in southeastern Washington, and special-interest bulletins on local seismic events. This includes information and special reports as requested by DOE and Hanford Site contractors. Earthquake information provided in these reports is subject to revision as new information becomes available. An archive of all cataloged seismic event locations and magnitudes and related waveform data from the HLSMP is maintained by PNSN on computer servers at the UW. Continuous waveform data and associated station metadata from all available seismic stations is permanently archived at the Incorporated Research Institutions in Seismology (IRIS) seismic data archive in Seattle, with backup copies at IRIS facilities in Seattle and in Boulder, Colorado.

2.0 Geology and Tectonic Analysis

The Hanford Site lies within the Columbia Basin, an intermontane basin between the Cascade Range and the Rocky Mountains filled with Cenozoic volcanic rocks and sediments. This basin forms the northern part of the Columbia Plateau physiographic province (Fenneman 1931) and the Columbia River flood-basalt province (Reidel et al. 1989). In the central and western parts of the Columbia Basin, the Columbia River Basalt Group (CRBG) overlies Tertiary continental sedimentary rocks and is overlain by late Tertiary, Quaternary fluvial, and glaciofluvial deposits (Campbell 1989; Reidel et al. 1989, 1994; DOE 1988). In the eastern part, little or no sediment separates the basalt and underlying crystalline basement, and a thin (<10 m) veneer of eolian sediments overlies the basalt (Reidel et al. 1989, 1994).

The Columbia Basin has two structural subdivisions or sub provinces—the Yakima Fold Belt and the Palouse Slope. The Yakima Fold Belt includes the western and central parts of the Columbia Basin and is a series of anticlinal ridges and synclinal valleys with major thrust faults typically along the northern flanks (Figure 2.1) (Reidel and Fecht 1994a, 1994b). The Palouse Slope is the eastern part of the basin and is less deformed than the Yakima Fold Belt, with only a few faults and low-amplitude long-wavelength folds on an otherwise gently westward dipping paleoslope.

2.1 Earthquake Stratigraphy

Seismic studies at the Hanford Site have shown that the earthquake activity is related to crustal stratigraphy (large groupings of rock types) (Rohay et al. 1985; DOE 1988). The main geologic units important to earthquakes at the Hanford Site and the surrounding area are

- Miocene Columbia River Basalt Group
- Sub-basalt sediments of Paleocene, Eocene, Oligocene, and Early Miocene age
- Precambrian and Paleozoic cratonic basement
- Mesozoic accreted terranes forming the basement west of the craton margin

2.2 Geologic Structure Beneath the Monitored Area

Between the late 1950s and the mid-1980s, deep boreholes were drilled for hydrocarbon exploration in the Columbia Basin. These boreholes provided accurate measurements of the physical properties of the Columbia River Basalt Group (CRBG) and the pre-basalt sediments (Reidel et al. 1989, 1994), but the thickness of the sub-basalt sediments and nature of the basement are still poorly understood. Table 2.1, derived from Reidel et al. (1994), was developed for the geologic interpretation in this report. The thicknesses of these units are variable across the monitored area. Table 2.1 summarizes the approximate thickness at the borders of the monitored area.

Table 2.1. Thicknesses of Stratigraphic Units in the Monitoring Area

(from Reidel et al., 1994)

Stratigraphy	North	South	East	West
Columbia River Basalt Group (includes suprabasalt sediments)	3.0 km	4.5 km	2.2 km	4.2 km
Pre-basalt sediments	3.0 km	>4.5 km	0	>6.0 km

The thickness of the basalt and the sub-basalt sediments varies because of different tectonic environments. The western edge of the North American craton (late Precambrian/Paleozoic continental margin and Precambrian craton) is located in the eastern portion of the monitored area (Reidel et al. 1994). The stratigraphy on the craton consists of CRBG overlying basement; the basement is continental crustal rock that underlies much of western North America. The stratigraphy west of the craton consists of 4 to 5 km of CRBG overlying up to 6 km of pre-basalt sediments. This in turn overlies accreted terranes of Mesozoic age. The area west of the craton was subsiding during the Eocene and Oligocene, accumulating great thickness of pre-CRBG sediments. Continued subsidence in this area during the Miocene resulted in thicker CRBG compared to that on the craton. Subsidence continues today but at a greatly reduced rate (Reidel *et al.,* 1994).

2.3 Tectonic Pattern

Studies have concluded that earthquakes can occur in the following six different tectonic environments (earthquake sources) at the Hanford Site (Geomatrix 1996):

Major Geologic Structures. Reverse/thrust faults in the CRBG associated with major anticlinal ridges such as Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge could produce some of the largest earthquakes.

Secondary Faults. These faults are typically smaller (1 to 20 km in length) than the main reverse/ thrust faults that occur along the major anticlinal ridges (up to 100 km in length). Secondary faults can be segment boundaries (tear faults) and small faults of any orientation that formed along with the main structure.

Swarm Areas. Small geographic areas produce clusters of events (swarms); usually located in synclinal valleys not known to contain any mapped geologic faults. These clusters consist of a series of small shocks with no outstanding principal event. Swarms occur over a period of days or months, and the events may number into the hundreds and then quit, only to start again later. This differs from the sequence of foreshocks, mainshock, and trailing-off aftershocks that have the same epicenter or are associated with the same fault system. In the past, swarms were thought to occur only in the CRBG. Most swarm areas are in the basalt, but swarm events also appear to occur in all geologic layers. However, typically a swarm event at a specific time is usually restricted to one layer. It is traditional to regard swarms as occurring within one of seven earthquake swarm areas in the HSN area. The Saddle Mountains, Wooded Island, Wahluke, Coyote Rapids, and Horse Heaven Hills swarm areas are typically active at one time or another during the year. The other earthquake swarm areas are active less frequently. There is, however, no compelling theory to suggest a generative mechanism active within these swarm areas. They are deduced purely empirically, are rather conjectural, and will likely be updated or reconfigured as new swarm areas develop.

Entire Columbia Basin. The entire basin, including the Hanford Site, could produce a "floating" earthquake. A floating earthquake is one that, for seismic design purposes, can happen anywhere in a tectonic province and is not associated with any known geologic structure. Seismic interpretation classifies it as a random event for purposes of seismic design and vibratory ground motion studies.

Basement Source Structures. Studies (Geomatrix 1996) suggest that major earthquakes can originate in tectonic structures in the basement. Because little is known about geologic structures in the basement beneath the Hanford Site, earthquakes cannot be directly tied to a mapped fault. Earthquakes occurring in the basement without known sources are treated as random events.

Cascadia Subduction Zone. This source has been postulated to be capable of producing a magnitude 9 earthquake. Because this source is along the western boundary of Washington State and outside the HSN, the Cascadia subduction zone is not an earthquake source that is monitored at the Hanford Site, so subduction zone earthquakes are not reported here. Because any earthquake along the Cascadia subduction zone can have a significant impact on the Hanford Site or can be felt like the February 2001 Nisqually earthquake, UW monitors and reports on this earthquake source for the DOE. Ground motion from any moderate or larger Cascadia subduction zone earthquake is detected by Hanford SMAs and reported.

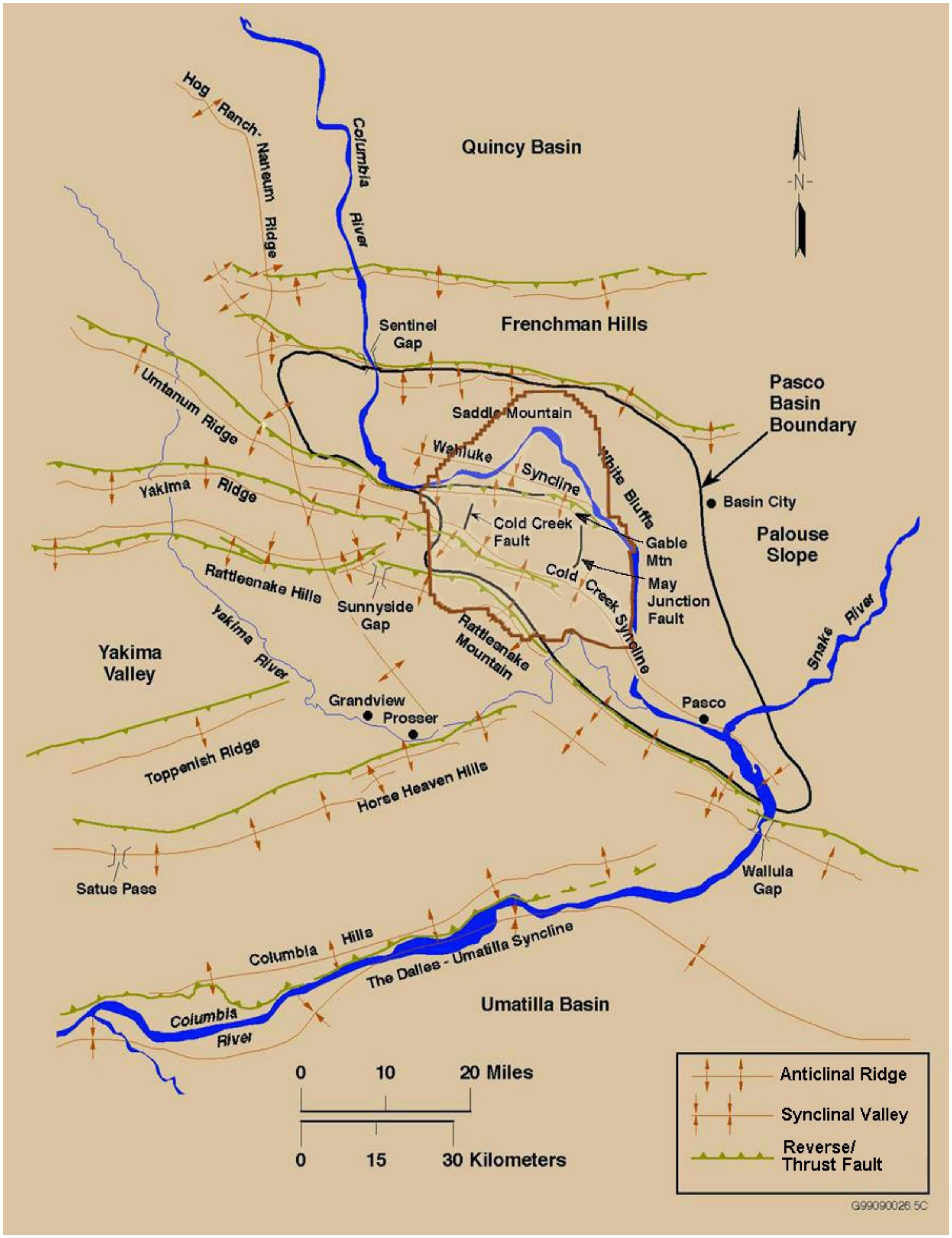

Figure 2.1. Tectonic Features of the Hanford Site within Eastern Washington

(from Rohay et al., 2010b)

3.0 Network Operations

3.1 Seismic Station Overview

The seismic network consists of three types of earthquake sensors—short-period seismometers, broadband seismometers, and strong motion accelerometers (SMAs).

Short-period seismometers are very sensitive passive sensors (they do not use external electric power) designed primarily to detect micro earthquakes. While most short-period stations have a single component, sensitive only to the vertical motion of the ground, several HLSMP short-period stations record the ground in three orthogonal directions. In a regional network like the HLSMP networks, the time of arrival of waves, and the signal duration derived from short-period stations are used to determine the locations and magnitudes of seismic events; the polarities of ground motions may be used to constrain estimates of the geometry of fault that ruptured in an earthquake.

Broadband seismometers are active sensors (they use electricity to power advanced electronic circuitry that is integral to the sensor) that faithfully record ground motions over a wide frequency range. The data they produce are acquired digitally with 24-bit dynamic range; a broadband system will therefore stay "on-scale" over a much broader range of ground motions than a short-period sensor. In addition to locations and magnitudes derived from signal durations, details of the observed waveforms are used to reveal the source processes of small to moderately large earthquakes. HLSMP broadband stations are all 3-component.

Both short-period and broad-band sensors will ultimately "clip", or fail to record properly, if subjected to more than moderate levels of shaking (well below damaging levels). SMA stations, however, are designed to measure even the damaging ground motions from larger earthquakes. They are 3-component stations and must be carefully and strongly anchored to the ground so that the details of ground shaking up to 2g (twice the vertical acceleration of gravity) are accurately recorded. In addition to helping to characterize the earthquake source, they are critically important in measuring the ground motions that impact a particular site. They aid in determining what the built environment has been exposed to for earthquake response activities and engineers and others use them in designing appropriate structures. Because of their importance to seismic monitoring on the Hanford Site, the distribution, design, and operations of SMA stations within the HLSMP is discussed separately in Section 3.2. Moreover, several HLSMP stations are now capable of recording 4 channels of seismic data. These sites will record 3 orthogonal components of strong motion and a vertical component of high-gain short period motion. The high-gain data is used to detect and locate earthquakes too small to generate ground motions above the strong-motion channels' noise level.

We further divide the seismic stations supported by MSA into two geographic sub-networks for discussion: HSN, which are sites located on the Hanford Site itself, and the EWRSN, which includes sites that surround the Hanford Site.

Combined, the HSN and the EWRSN include 40 stations. Most stations reside in remote locations and require solar panels and batteries for power. The HSN includes 18 stations (Table 3.1 and Figure 3.1), and the EWRSN consists of 22 stations (Table 3.2 and Figure 3.2).

Table 3.1. Hanford Seismic Network Onsite Stations

Station	Latitude	Longitude	Elevation (m)	Station Name
Strong Motion Accelerometer, 3-Channel Station				
H2E	46.5578	-119.5345	210	200 East Area (SMA)
H2W	46.5517	-119.6453	201	200 West Area (SMA)
H3A	46.3632	-119.2775	119	300 Area (SMA)
H4A	46.4377	-119.3557	171	400 Area (SMA)
6-Channel Station				
GBB	46.6087	-119.6290	185	Gable Butte
H2O	46.3956	-119.4241	175	Water Station
MDW	46.6130	-119.7622	330	Midway
SNI2	46.4648	-119.6552	267	Snively Ranch
WA2	46.7552	-119.5668	244	Wahluke Slope
4-Channel Station				
H1K	46.6447	-119.5929	152	100 K Area (SMA)
HGBL	46.5982	-119.4610	330	Gable Mountain
HWIW	46.4292	-119.2888	128	Wooded Island
GRUT	46.5512	-119.5102	219	Wet-Grout Plant
MJ2	46.5574	-119.3601	146	May Junction Two
3-Channel Station (Broadband)				
LIGO	46.4617	-119.4177	158	LIGO Observatory
Single Channel Analog (Short Period)				
BEN	46.5186	-119.7185	335	Benson Ranch
LOC	46.7169	-119.4320	210	Locke Island
RSW	46.3944	-119.5925	1045	Rattlesnake Mountain

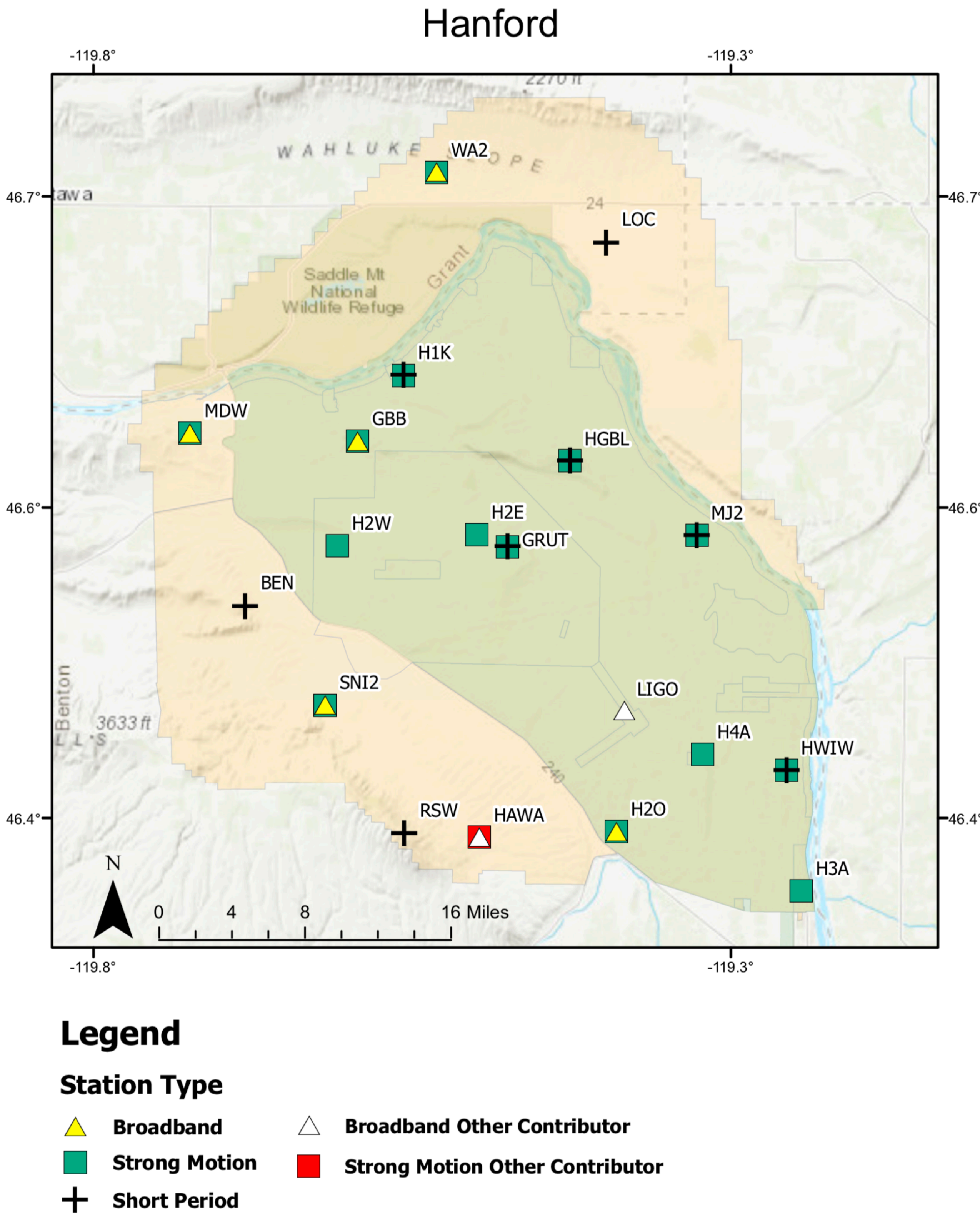

Figure 3.1. Hanford Seismic Network Onsite Stations

Table 3.2. Hanford Seismic Network Offsite Stations

Station	Latitude	Longitude	Elevation (m)	Station Name
Strong Motion Accelerometer, 3-Channel Station				
PHIN	45.8950	-119.9280	227	Phinney Hill
3-Channel Weak Motion Analog (Short Period)				
FHE	46.9518	-119.4981	455	Frenchman Hills East
6-Channel				
CCRK	46.5585	-119.8548	561	Cold Creek
DDRF	46.4911	-119.0595	233	Didier Farms
EPH2	47.3562	-119.5972	661	Ephrata
LNO	45.8717	-118.2862	771	Lincton Mountain Oregon
MANO	46.9511	-120.7247	1200	Manatash Ridge Observatory
MOX	46.5772	-120.2993	501	Moxee City
OT3	46.6689	-119.2341	322	Othello 3
PRO	46.2125	-119.6868	553	Prosser
YPT	46.0487	-118.9634	325	Yellepit
Single-Channel Analog (Short Period)				
BRV	46.4852	-119.9923	920	Black Rock Valley
BVW	46.8108	-119.8835	670	Beverly
CRF	46.8249	-119.3881	189	Corfu
ELL	46.9095	-120.5675	789	Ellensburg
NAC	46.7330	-120.8249	728	Naches
OD2	47.388	-118.7108	553	Odessa 2
PAT2	45.8836	-119.7578	259	Paterson 2
RED2	46.3053	-119.4526	330	Red Mountain 2
TRW	46.2921	-120.5431	723	Toppenish Ridge
VT2	46.9672	-120.0003	385	Vantage 2
WRD	46.9699	-119.1460	375	Warden

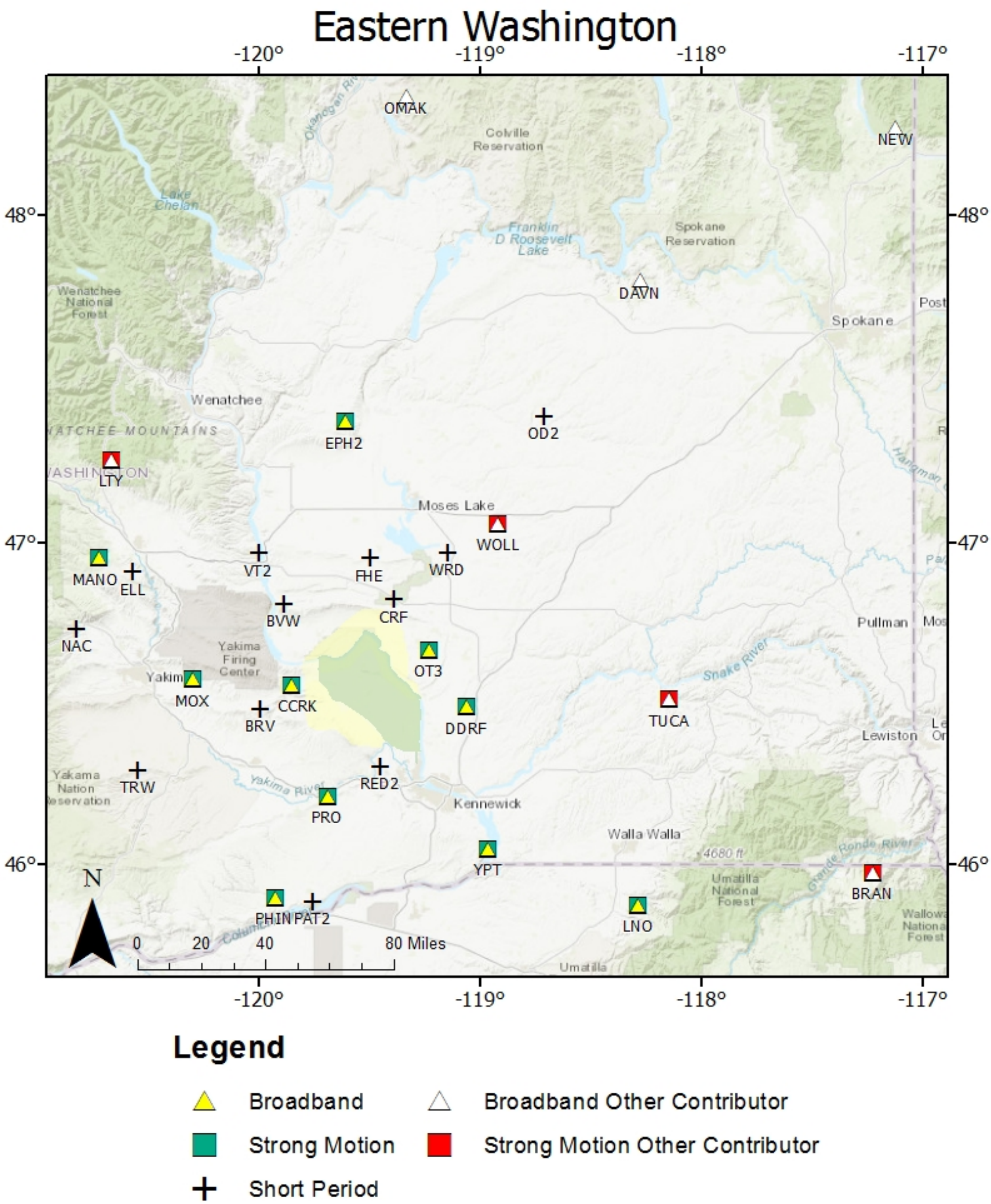

Figure 3.2. Hanford Seismic Network Stations of the Eastern Washington Region Sub-Network

The EWRSN is used by the HLSMP for two major reasons. A large earthquake located in the Pacific Northwest outside of Hanford could produce significant ground motion and damage to structures at the Hanford Site. For example, the magnitude 7.0 earthquake that occurred in 1872 near Chelan/Entiat or other earthquakes located in the region (*e.g.,* eastern Cascade mountain range) could have such an effect. The EWRSN would provide valuable information to help determine the impacts of such an event. Additionally, the characterization of seismicity throughout the surrounding areas, as required for the Probabilistic Seismic Hazard Analysis, supports facility safety assessments at the Hanford Site. Both the HSN and the EWRSN are fully integrated within the Pacific Northwest Seismic Network managed by the University of Washington.

The HSN and EWRSN networks have 139 combined data channels from: 14 single channel sites, 3 three-component seismometer sites (FHE, LIGO, and PHIN), 14 six-component sites (CCRK, DDRF, EPH2, GBB, H2O, LNO, MANO, MDW, MOX, OT3, PRO, SNI2, WA2, and YPT) and 9 other sites in the HSN (H1K, H2E, H2W, H3A, H4A, MJ2, GRUT, HGBL, and HWIW) that require additional data channels at each station. The tri-axial stations record motion in the vertical, north-south horizontal, and east-west horizontal directions. Fourteen radio telemetry relay sites are used by both sub-networks to transmit seismogram data continuously to the PNSN in Seattle, Washington, for processing and archiving.

3.2 Strong Motion Accelerometer Stations

3.2.1 Strong Motion Station Location

SMAs provided ground motion observations critical to understand the impacts of strong ground shaking that affect the Hanford Site itself. The Hanford SMA network consists of 16 free-field SMA stations (see Figure 3.1; Table 3.1). SMAs are located in the 200 East and 200 West Areas, in the 100-K Area adjacent to the K Basins, in the 400 Area near the former Fast Flux Test Facility, and at the south end of the 300 Area.

The locations of SMA stations were chosen based on two criteria: 1) density of workers, and 2) sites of hazardous facilities (Moore and Reidel 1996). The 200 East and 200 West Areas contain single-shell and double-shell tanks in which high-level radioactive wastes from past processing of fuel rods are stored. In addition, the Canister Storage Facility (holding encapsulated spent fuel rods) and the new Waste Treatment and Immobilization Plant being constructed are both located in the 200 East Area. The 100-K Area contained the K Basins, where spent fuel rods from the N Reactor were stored prior to encapsulation. The now inactive Fast Flux Test Facility is located in the 400 Area.

3.2.2 Strong Motion Station Design

All free-field SMA stations consist of a four-panel solar array and two 30-gallon galvanized drums that contain equipment. Each panel has a maximum 42-watt output. The two drums are set in the ground such that the base of each drum is about 1 m below the ground surface. One drum houses only the SMA; the other drum, which is connected via a sealed conduit to the SMA drum, contains the batteries. Cellular modems provide communication from all five SMAs. The enclosure serves as a junction box for all cabling that is routed through conduit inside and outside the equipment drums. The antenna for the cell modem is mounted on top of the enclosure. The enclosure permits quick access to check battery conditions and a connection directly to the RS-

232 port of the SMA without removing the drum lids. However, with continuous data telemetry via cell modem, most interrogation of the system is accomplished remotely.

Four of the SMA stations are three-component units consisting of vertical, north-south horizontal, and east-west horizontal seismometers manufactured by Nanometrics, Inc., and known as the Titan system. Each Titan unit contains a digital recorder, a data storage unit, and a Global Positioning System (GPS) receiver with the equipment housed in a watertight box. Five sites (H1K, HWIW, HGBL, GRUT, and MJ2) have 3 SMA channels and are supplemented by a high-gain vertical component.

The cell modem system provides the Internet address connection to access the system. Stations can be monitored from any computer with appropriate access, and data are continuously telemetered to UW. The data also can be downloaded directly at each site, via a built-in cable connection at the enclosure in case of communication failure. The GPS receiver provides timing of the ground motions accurate to several microseconds, coordinated to Universal Coordinated Time (UTC). The GPS receiver antenna is mounted on the enclosure at the rear of the solar array. The GPS receiver is activated internally approximately every 4 hours and checks the "location of the instrument" and the time. The SMA records any differences between the internal clock and the GPS time. Any corrections to the internal timing are made automatically. Typically, the greatest correction recorded is approximately 4 milliseconds (ms).

The combined operations, data recording, data interpretation, and maintenance facility is located in the PNSN offices at the UW in Seattle.

3.2.3 Strong Motion Operational Characteristics

Signals from the three-channel SMA stations use an 18-bit digitizer with data sampled at 200 samples/s. Data are sent continuously in real-time to the PNSN offices at the UW in Seattle. This permits the recording of ground motion data for smaller, non-damaging earthquakes that can be useful in estimating impacts of larger earthquakes. It also helps confirm the correct operation of the instruments.

For security and robustness, the Titan also stores triggered event files. When one of the accelerometer channels exceeds the trigger threshold (0.02%g), the recorders save information within the data buffers on memory cards within the Titan. Data recording begins 10 s before the actual trigger time, continues until the trigger threshold is no longer exceeded, and ends with an additional 40 s of data. The files created by a triggered event can be retrieved and examined by HLSMP staff, in the event of telemetry failure. The retrieval can be accomplished either remotely when telemetry is re-established, or manually by a technician traveling to the site.

Data from the SMA channels of the 4-channel stations are treated in a similar fashion. The primary difference is that the data from these channels (as well as the vertical high-gain channel) are digitized with 24-bit resolution.

3.3 Data Analysis

Signals from the seismometers are monitored in real time for changes in signal amplitudes and frequency that are expected from earthquakes. The seismic network is subdivided into spatial groupings of stations that are monitored for nearly simultaneous amplitude changes, triggering a permanent recording of the events. The groupings and associated weighting schemes are designed to allow very small seismic events to be recorded and to minimize false triggers. Events are classified as local (south-central Washington near the Hanford Site), regional (western United States and Canada), and teleseisms (from farther distances around the world). Local and regional events are usually earthquakes, but quarry and mining explosions also are recorded. Quarry and mining explosions usually can be identified from wave characteristics and the time of occurrence and may be confirmed with local government agencies and industries. Frequently, military exercises at the U.S. Army Yakima Training

Center produce a series of acoustic shocks that trigger the recording system. Sonic booms and thunder also produce acoustic signals that may trigger the recording system. All data, whether triggered or not, is saved in a permanent seismic data archive at the Seattle-based IRIS data management center, and is available for download and analysis.

The HLSMP uses Earthworm, an automated computer-based software system developed by the U.S. Geological Survey (USGS) and used throughout the region by the Pacific Northwest Seismic Network at the UW, to acquire seismic data and automatically detect and locate events. We currently run Earthworm Versions 7.4 through 7.6 on a variety of computer servers. Redundant Earthworm systems run continuously at the PNSN. If one fails, a second one serves as a "backup." Two complete systems are located in different buildings on separate computer servers with redundant power supplies, backed up by different uninterruptable power supplies and a diesel-powered electric generator capable of powering the network until refueling is needed. Seismic data from triggered events are collected on a Linux workstation for assessment by HLSMP staff. This information is evaluated to determine if the event is "false" (for example, due to a sonic boom) or is an earthquake or ground-surface or underground blast. Earthquake events are evaluated to determine epicenter locations, focal depths, and magnitudes (Section 4).

Data from HLSMP-operated seismic stations are combined at the UW analysis center with seismic data from regional seismic stations operated by other entities and contributed in real-time to PNSN. The earthquake locations and ground motion we report in this catalog include these valuable contributed data. This contributed data improves the accuracy of the seismic products we provide at Hanford, and adds to the robustness of the entire network in the event that any particular portion of the network suffers temporary data loss from environmental or other causes.

4.0 Earthquake Catalog

Within the Advanced National Seismic System (ANSS) Quake Management System (AQMS) seismic network processing software, an interactive program called Jiggle is used to manually review and revise automatic phase arrival picks and signal durations, as well as their polarities, uncertainties and quality factors. Arrival and duration times and uncertainties are used as input to an earthquake location program (Klein, 2002) to compute locations and magnitudes of the seismic events. Resulting locations for local earthquakes (46°-47° north latitude, 119°-120° west longitude) are reported in Table 4.1. Additional seismic events located outside the reporting region for this report are also evaluated. These surrounding events are not reported in this document, but are used as a check to confirm that the HSN and EWRSN are functioning properly (*e.g.,* quality checks on data recording). All processing results are available through the PNSN at www.pnsn.org.

4.1 Wavespeed Models

Earthquake location uses the arrival times of seismic phases at seismic stations and a model of the seismic wave speeds of crustal rocks of eastern Washington called a "wavespeed model" (MOD), to solve for the most likely location for the earthquake source. AQMS divides the eastern Washington region into 4 sub-regions. The wavespeed models for each sub-region were developed using available geologic information and calibrated from seismic data recorded from accurately located earthquake and blast events in eastern Washington. Time corrections (delays) are incorporated into the wavespeed models to account for significant deviations in station elevations or stations situated on sedimentary layers. Station delays also are determined empirically from accurately located earthquakes and blast events in the region.

Table 4.1. Wavespeed Model for Eastern Washington
(from Rohay et al. 1985)

Depth to Top of Layer (km)	Layer	Wavespeed (km/s)
0.0	Saddle Mountains and Wanapum Basalts and intercalated Ellensburg Formation	3.7
0.4	Grande Ronde Basalt and pre-basalt sediments	5.2
8.5	Basement, Layer 1	6.1
13.0	Basement, layer 2	6.4
23.0	Sub-basement	7.1
38.0	Mantle	7.9

4.2 Earthquake Magnitudes

AQMS computes several different magnitude estimates (Mtyp) for earthquakes. Table 4.1 shows the analyst-preferred value of either: 1) the coda-duration magnitude (M_d), or 2) the local magnitude (M_L) (Richter 1958). We report the median magnitude provided by all stations contributing estimates for an event.

The coda duration magnitude is based on a relationship developed for Washington State by Crosson (1972), modified for application within the AQMS software. The formula we use for M_d is:

$$M_d = -1.61 + 2.82 \log(D) - 2.46$$

Where *D* is the duration of the observed event (in seconds), starting from the P-wave arrival. Many earthquakes yield magnitude determinations that are very small ($M_d < 0$) and highly uncertain. Earthquakes with magnitudes (M_d) smaller than 3.0 are defined as "minor." Coda-duration magnitudes for events classified as explosions are reported although they may be biased by a prominent surface wave that extends the apparent duration in a way inconsistent with coda-length measurement.

M_L is computed from the maximum amplitudes of the signals on the horizontal components recording an event, filtered to mimic the instrument response of a Wood-Anderson torsion seismograph. The formula is:

$$M_L = \log(A) - \log(A_0) + S$$

Where *A* is the average zero-to-peak amplitude of the two horizontal components at a station after they have been converted to pseudo-Wood-Anderson traces. Log (A_0) is a distance correction, for which we use the Jennings and Kanamori (1983) values, and *S* is a site correction term that accounts for differences in local geological conditions amongst stations.

The choice of preferred magnitude type involves some subjectivity, as the relative strength of each depends on conditions that differ from event to event. In general, M_L is preferred for an event that is well recorded on a sufficient number of suitable channels. [This is because there may be subjectivity in determining the durations used by the M_d algorithm (although AQMS does this in a largely automatic, and hence objective, way), and because the determination of the duration is biased by background noise levels.] In practice, this usually means that M_L is preferred for earthquakes sufficiently large to be observed at several regional broadband stations (CCRK, DDRF, PHIN, HAWA), or approximately M2.5. Although occasionally smaller earthquakes yield robust M_L estimates, depending on the background noise level at the time of the earthquake. M_d, on the other hand can be obtained from smaller earthquakes, even if the recording should "clip." For earthquakes larger than about M4.5, only the M_L should be used. The two magnitude scales are defined to be consistent for the events for which they overlap.

4.3 Quality Factors

Table 4.1 tabulates a two-letter **Quality factor** (Q) for each event that indicates the general reliability of the solution (**A** is best quality, **D** is worst). The first letter of the quality code is a measure of the hypocenter quality based primarily on arrival time residuals. For example, quality **A** requires a root-mean-square residual (**RMS**) less than 0.15 s, while a **RMS** of 0.5 s or more is **D** quality (other estimates of the location uncertainty also affect this quality parameter). The second letter of the quality code is related to the spatial distribution of stations that contribute to the event location, including the number of stations (**NS**), the number of p-wave and s-wave phases (**NP**), the largest gap in event-station azimuth distribution (**GAP**), and the closest distance from the epicenter to a station (**Dmin – not shown**). Quality A requires a solution with NP >8, GAP <90○, and Dmin <5 km (or the hypocenter depth if it is greater than 5 km). If NP ≤ 5, GAP >180○, or Dmin >50 km, the solution is assigned Quality D. Uncertainties associated with estimated depths depend upon the number of stations and number of phase measurements (NS/NP) utilized by the Hypoinverse location program. If the number of phases exceeds 10 measurements, the depth estimate is considered reliable. In this case, the second letter in the quality evaluation is either "A" or "B" (cf. Table 4.1). For example, the number of phase measurements from earthquakes ultimately classified as "deep" events typically falls within the 10-20 measurement range; these depth estimates are considered reliable. However, the number of phase measurements from earthquakes classified as "shallow" or "intermediate" may be less than 10 readings; in this case the depth estimate is less certain and the event could be classified as occurring in the CRBG or pre-basalt layers.

4.4 FY 2019 Earthquake Catalog for Eastern Washington

October 2018												
Day	Time	Lat	Lon	Depth	Mag	Mtyp	NS/NP	Gap	RMS	Q	Mod	Typ
01	05:33:53	48.0225	-119.8845	4.0	0.8	Ml	005/008	128	0.12	AB	N3	eq
01	10:05:23	48.2070	-120.7992	8.6*	0.8	Ml	006/008	175	0.18	CC	C3	eq
01	12:34:25	48.4837	-119.5877	-0.9	1.7	Ml	012/014	234	0.14	BD	N3	eq
04	09:43:28	46.5697	-119.8323	8.3	0.3	Ml	009/012	136	0.06	AC	E3	eq
05	07:21:57	47.7257	-120.0137	2.5	1.0	Ml	008/011	99	0.08	AB	N3	eq
05	08:09:52	46.4090	-119.2587	0.3	2.3	Ml	033/039	91	0.09	AB	E3	eq
05	14:23:44	48.1700	-120.7935	4.6	1.2	Ml	011/012	118	0.13	AC	C3	eq
08	18:17:50	46.1673	-120.4113	8.2*	0.9	Md	005/007	177	0.08	CC	E3	eq
09	11:19:42	46.4132	-119.2525	0.2*	0.6	Ml	010/012	141	0.20	CC	E3	eq
09	22:34:27	46.1032	-120.4207	17.5	2.9	Ml	030/036	62	0.18	BB	E3	eq
10	00:49:05	44.3003	-120.8945	-1.4*	2.0	Ml	010/011	201	0.08	CD	E3	px
10	04:02:38	46.4153	-119.2492	0.3*	0.4	Ml	004/007	202	0.15	CD	E3	eq
10	08:40:50	46.1110	-120.3968	12.1	1.4	Ml	019/026	190	0.15	BD	E3	eq
10	12:11:59	47.7277	-120.0097	1.8	1.3	Ml	008/011	104	0.07	AB	N3	eq
10	22:48:22	46.4068	-119.2535	-0.4	0.6	Md	006/007	211	0.13	AD	E3	eq
11	04:10:44	46.5927	-119.8645	6.7	0.9	Ml	017/022	137	0.07	AC	E3	eq
11	21:48:56	45.8927	-119.3133	-0.2*	1.9	Ml	012/016	178	0.24	CC	E3	px
12	19:51:07	48.0585	-118.9285	5.6	1.1	Ml	006/006	120	0.08	AC	N3	eq
15	00:22:04	46.5920	-119.8657	6.6	1.1	Ml	017/023	89	0.10	AA	E3	eq
15	17:38:22	45.7948	-121.3975	-1.6*	1.8	Ml	005/007	327	0.27	CD	C3	px
17	18:30:32	47.0098	-120.3478	-0.8*	1.2	Ml	008/009	121	0.32	CC	N3	px
17	21:51:55	45.7197	-121.4448	-1.1*	1.5	Ml	009/009	186	0.19	CD	C3	px
17	22:15:44	46.6605	-120.5448	-0.7*	1.6	Ml	011/013	174	0.27	CC	E3	px
18	00:46:18	44.3143	-120.8583	-1.4*	2.0	Ml	009/008	284	0.10	CD	E3	px
18	11:34:42	46.6097	-119.8405	6.7	0.3	Ml	007/011	161	0.08	AC	E3	eq
19	21:02:43	47.6682	-120.4018	-0.1*	0.4	Md	005/007	174	0.10	CC	N3	eq
20	00:58:00	46.5723	-119.8342	7.7	0.6	Ml	011/015	120	0.05	AB	E3	eq
21	15:43:34	46.6852	-119.5552	6.0	-0.2	Md	004/006	211	0.07	BD	E3	eq
22	18:04:59	46.8483	-119.4732	-0.3*	1.0	Ml	008/010	88	0.10	CB	E3	px
23	00:44:34	44.3060	-120.8790	-1.4*	2.1	Ml	010/011	207	0.12	CD	E3	px
23	17:43:31	45.6770	-120.9383	-1.3*	1.7	Ml	005/006	310	0.32	DD	C3	px
24	05:28:41	47.8082	-120.0428	1.6	1.1	Ml	007/010	101	0.07	AB	N3	eq
26	17:36:04	47.2642	-121.4220	0.6*	1.6	Ml	010/013	70	0.10	CC	C3	eq
26	17:36:19	47.3013	-121.3778	6.3	1.8	Ml	005/008	181	0.30	CD	C3	eq
26	17:37:03	47.2653	-121.4168	-0.4*	1.8	Ml	011/012	70	0.13	CC	C3	eq
27	20:26:43	44.3048	-120.7820	-1.4*	1.8	Ml	012/012	285	0.28	DD	C3	px
29	08:34:38	46.5710	-119.8320	7.6	1.0	Ml	010/017	119	0.07	AB	E3	eq
30	01:02:59	44.1053	-121.3292	-1.5*	1.6	Ml	008/010	160	0.35	CC	E3	px
31	00:47:52	44.3315	-120.8552	-1.6*	1.8	Ml	013/012	221	0.13	CD	E3	px
31	18:15:51	46.7660	-119.2895	-0.2*	1.6	Ml	018/023	90	0.18	CB	E3	px
November 2018												
01	02:21:42	46.5347	-121.4150	2.7	1.2	Ml	013/018	113	0.18	BC	C3	eq
02	00:54:35	44.3335	-120.8243	-1.4*	2.0	Ml	009/008	258	0.11	CD	C3	px
03	00:33:08	47.2015	-119.4795	19.1	2.1	Ml	028/031	64	0.12	AB	N3	eq
03	01:33:02	47.2007	-119.4772	17.4	1.0	Ml	012/015	137	0.14	AC	N3	eq
03	09:50:52	46.4215	-119.2760	0.3	0.5	Ml	007/009	192	0.21	CD	E3	eq
03	19:54:22	47.6468	-120.3932	6.9	0.5	Md	005/007	186	0.29	CD	N3	eq
04	08:01:21	46.7430	-119.5492	13.7	0.1	Ml	009/016	87	0.09	AA	E3	eq
05	12:41:59	48.6840	-119.5942	4.0*	1.6	Ml	005/008	269	0.22	CD	N3	eq

06	06:22:38	46.5812	-119.8270	7.2	0.5	Ml	011/014	174	0.05	AC	E3	eq
07	00:17:19	44.3082	-120.9095	-1.5*	1.9	Ml	013/013	197	0.13	CD	E3	px
07	05:05:06	48.1115	-120.9518	8.9*	1.2	Ml	007/009	144	0.27	CC	C3	eq
07	05:49:41	46.7247	-119.9965	9.6	0.7	Ml	010/013	166	0.07	AC	E3	eq
08	00:14:19	44.3003	-120.9178	-1.4*	2.0	Ml	017/017	92	0.21	CC	E3	px
08	03:51:43	46.5822	-119.8307	7.4	0.9	Ml	012/018	121	0.07	AB	E3	eq
09	18:45:08	47.7378	-120.6900	1.7	0.5	Md	004/006	195	0.03	BD	C3	eq
11	16:26:16	46.5800	-119.8320	7.4	0.8	Ml	009/014	122	0.08	AB	E3	eq
12	23:47:20	46.6125	-119.8065	7.4	0.6	Ml	007/010	134	0.05	AB	E3	eq
13	23:27:03	46.5658	-119.8395	7.8	0.5	Ml	010/014	117	0.08	AB	E3	eq
14	00:46:00	44.3358	-120.8022	-1.6*	1.7	Ml	008/009	280	0.41	CD	E3	px
14	00:55:40	47.7152	-120.3052	2.1	0.7	Ml	005/008	132	0.04	BC	N3	eq
15	01:23:20	47.6562	-120.3828	0.6	1.0	Ml	008/011	95	0.06	BB	N3	eq
15	12:14:39	46.5682	-119.8388	8.2	0.2	Ml	007/010	124	0.07	AB	E3	eq
20	11:43:42	46.5715	-119.8275	7.7	0.3	Ml	007/009	168	0.07	AC	E3	eq
20	20:54:08	45.1298	-118.0658	-1.1	1.8	Ml	005/007	169	0.19	BD	E3	eq
21	07:39:39	46.3512	-119.5547	16.8	0.1	Ml	007/011	264	0.05	AD	E3	eq
22	00:04:34	44.2992	-120.9175	-1.3*	2.3	Ml	005/005	314	0.06	CD	E3	px
24	19:32:30	46.6012	-119.8045	7.5	0.5	Ml	011/016	126	0.10	AB	E3	eq
26	01:40:46	46.4143	-119.2565	-0.2	0.5	Ml	006/009	201	0.20	BD	E3	eq
26	23:00:55	47.6125	-120.2213	-1.3*	1.7	Md	005/006	200	0.03	CD	N3	px
27	22:44:12	45.5718	-120.2728	-0.5*	1.9	Ml	010/011	258	0.21	CD	E3	px
28	02:43:27	47.5730	-120.3207	5.0	1.5	Ml	014/017	90	0.10	AA	N3	eq
28	15:40:57	46.7240	-119.4375	14.7	0.6	Ml	013/020	93	0.08	AB	E3	eq
December 2018												
04	21:40:47	46.0108	-118.8170	-0.3*	1.7	Ml	013/012	293	0.22	CD	E3	px
05	00:38:52	44.3323	-120.8273	-1.5*	2.0	Ml	010/010	286	0.08	CD	E3	px
05	22:40:12	44.3530	-121.0358	-1.6*	1.7	Ml	008/011	139	0.44	CC	E3	px
06	00:25:20	44.2990	-120.8905	-1.4*	2.1	Ml	016/015	203	0.13	CD	E3	px
06	02:16:18	48.2440	-121.3202	7.9	1.5	Ml	006/008	156	0.10	AC	C3	eq
07	16:53:28	46.8678	-119.4827	11.8	0.4	Ml	009/013	135	0.04	AB	E3	eq
09	15:59:29	48.0988	-120.7415	6.0	1.7	Ml	012/012	113	0.15	BC	C3	eq
11	15:55:49	46.6005	-119.8722	6.3	1.1	Ml	013/017	142	0.08	AC	E3	eq
11	17:42:38	46.5942	-119.8643	6.5	1.1	Ml	017/019	137	0.08	AC	E3	eq
13	01:51:10	47.6910	-120.3433	2.6	0.7	Ml	006/009	125	0.04	BB	N3	eq
14	00:35:32	46.2718	-119.5547	20.5	1.1	Ml	025/029	152	0.09	AC	E3	eq
14	05:24:26	47.6890	-120.1802	0.1*	0.9	Ml	006/008	132	0.05	CC	N3	eq
15	16:18:57	46.6220	-119.8377	6.5	0.8	Ml	008/010	160	0.05	AC	E3	eq
19	23:35:57	45.6587	-120.3047	-0.7*	1.9	Ml	012/014	189	0.24	CD	E3	px
20	18:56:28	46.3027	-118.0007	-0.5	1.8	Ml	007/010	158	0.18	BC	E3	eq
22	10:34:45	46.6062	-119.8592	6.7	0.5	Ml	005/007	180	0.03	AC	E3	eq
January 2019												
02	18:41:52	46.8417	-119.2882	1.7	1.4	Ml	020/026	102	0.16	BB	E3	eq
02	23:17:20	47.6652	-120.3120	-0.8*	0.8	Ml	006/009	112	0.06	CB	N3	eq
03	00:09:51	47.3757	-117.8437	4.7*	2.2	Ml	010/014	166	0.60	DD	N3	px
03	01:30:48	46.8313	-119.7388	1.4	1.3	Ml	022/022	134	0.10	AC	E3	eq
03	22:40:39	45.9197	-119.3060	-0.3*	1.8	Ml	011/010	171	0.08	CC	E3	px
04	00:20:41	44.3202	-120.7995	-1.4*	2.2	Ml	007/008	269	0.14	CD	E3	px
04	22:34:48	46.6068	-119.8407	6.5	0.3	Ml	006/009	160	0.05	AC	E3	eq
09	10:54:11	46.4013	-119.2588	0.9	0.3	Ml	007/011	212	0.17	BD	E3	eq
10	06:24:05	46.4050	-119.2647	1.6	0.7	Ml	012/016	135	0.11	AB	E3	eq
11	04:47:30	47.7395	-120.2135	-1.2*	1.0	Ml	009/012	65	0.04	CC	N3	px
11	07:55:49	46.6822	-120.7123	11.9	1.9	Ml	024/031	118	0.23	BB	C3	eq

11	20:14:23	47.6705	-120.3165	2.4	0.1	Md	005/008	113	0.09	BB	N3	eq
13	20:16:44	47.6455	-117.5145	5.0*	-5.0	Mh	001/000	0	0.00	AD	N3	px
15	23:28:59	46.7213	-119.0083	-0.3*	1.2	Ml	007/008	184	0.07	CD	E3	px
18	05:07:13	46.5857	-119.8587	7.3	1.8	Ml	023/034	87	0.08	AA	E3	eq
18	14:15:38	48.2612	-121.2110	0.2*	1.5	Ml	005/005	154	0.02	CD	C3	eq
24	00:16:51	44.2945	-120.9107	-1.4*	2.1	Ml	012/012	172	0.15	CC	C3	px
27	07:05:19	47.7018	-120.1170	-0.4*	0.6	Ml	005/008	101	0.05	CB	N3	eq
29	15:58:56	48.6957	-120.3368	9.0*	1.8	Ml	008/013	161	0.26	CD	C3	eq
31	00:55:10	44.3685	-120.7762	-1.6*	2.1	Ml	008/008	294	0.15	CD	C3	px
31	17:58:35	48.8152	-120.1980	5.6	1.8	Ml	013/018	182	0.43	CD	C3	eq
February 2019												
01	00:03:33	46.7217	-119.0105	-0.3*	1.4	Ml	013/017	184	0.09	CD	E3	px
01	19:10:12	46.9970	-120.4153	-0.9*	1.2	Ml	015/019	111	0.58	DC	E3	px
01	22:10:01	46.1345	-120.3758	16.7	2.2	Ml	025/033	97	0.16	BB	E3	eq
03	23:02:05	46.4567	-121.2590	5.1	1.3	Ml	014/021	121	0.23	BC	C3	eq
05	04:42:37	46.8362	-119.2852	2.5	0.3	Ml	005/007	219	0.04	BD	E3	eq
06	16:09:26	46.4130	-119.2663	-0.3	0.7	Ml	008/008	200	0.11	BD	E3	eq
06	17:51:48	47.1143	-118.4598	-0.5*	1.6	Ml	013/015	191	0.66	DD	N3	px
06	22:20:34	46.1415	-119.2507	-0.2*	1.7	Ml	018/017	203	0.09	CD	E3	px
07	21:00:48	46.0897	-120.8947	6.8	1.1	Ml	016/023	80	0.33	CC	C3	eq
08	17:23:24	47.6550	-120.1682	4.0	0.6	Ml	007/010	88	0.09	AB	N3	eq
08	21:31:56	46.0455	-119.6717	-0.5*	0.8	Md	006/008	205	0.37	CD	E3	px
09	12:45:48	45.8125	-120.6295	13.0	1.4	Ml	014/017	111	0.13	AB	E3	eq
10	17:22:16	47.6837	-120.2210	-0.4*	0.6	Md	007/012	131	0.10	CC	N3	eq
13	21:20:25	45.7955	-120.0343	-0.5*	1.8	Ml	010/010	153	0.11	CC	E3	px
14	01:33:45	44.3008	-120.9130	-1.5*	2.0	Ml	008/009	194	0.08	CD	E3	px
16	05:49:57	46.1328	-120.3797	16.6	1.8	Ml	030/040	98	0.20	BB	E3	eq
16	11:53:58	47.5487	-120.2460	4.7	0.8	Md	007/012	113	0.08	AB	N3	eq
17	09:17:59	46.6237	-119.8133	7.1	1.0	Ml	017/025	83	0.08	AA	E3	eq
18	16:59:07	47.2755	-121.4313	8.0	1.6	Ml	020/027	67	0.10	AC	C3	eq
19	17:25:46	46.3808	-120.6273	16.2	1.5	Ml	007/007	193	0.06	AD	E3	eq
19	17:44:54	46.6163	-119.8455	6.4	1.0	Ml	016/020	89	0.07	AA	E3	eq
20	00:39:05	44.3105	-120.9367	-1.5*	1.7	Ml	011/012	219	0.18	CD	E3	px
22	00:41:26	44.3057	-120.9112	-1.4*	1.8	Ml	015/015	204	0.17	CD	E3	px
24	19:08:18	46.6040	-119.8658	6.2	1.1	Ml	012/020	96	0.07	AB	E3	eq
25	21:40:53	46.2782	-119.4185	-0.4*	1.6	Ml	015/018	126	0.19	CB	E3	px
March 2019												
01	13:48:36	48.1948	-120.7690	4.9	1.1	Ml	008/013	155	0.18	BC	C3	eq
01	19:59:29	46.2923	-119.7353	0.1*	0.7	Ml	006/006	293	0.07	CD	E3	eq
02	23:58:27	46.6115	-119.8670	6.2	0.1	Ml	003/005	278	0.01	BD	E3	eq
04	06:16:33	47.7900	-120.0637	5.1	0.8	Ml	010/014	102	0.11	AB	N3	eq
04	12:57:14	47.8150	-120.7335	-0.6*	1.7	Ml	009/006	115	0.38	CC	C3	px
05	00:34:13	47.6943	-120.3428	-0.5*	1.1	Ml	011/012	91	0.06	CB	N3	eq
05	08:37:45	46.7162	-119.5192	5.4	-0.1	Md	003/005	201	0.05	AD	E3	eq
06	05:57:52	47.4397	-120.1643	12.6	1.1	Ml	011/014	117	0.14	AB	N3	eq
06	20:10:05	46.9518	-119.4981	-0.5*	-5.0	Mh	001/000	0	0.00	AD	E3	px
06	22:17:02	47.9652	-117.3233	-0.6	2.3	Ml	008/012	178	0.17	BC	N3	eq
07	02:33:54	46.5960	-119.8638	7.0	0.4	Ml	006/007	266	0.02	AD	E3	eq
08	20:53:52	46.4768	-119.5832	14.2	0.1	Ml	013/015	72	0.07	AA	E3	eq
09	00:16:30	46.6152	-119.8438	6.8	1.1	Ml	013/020	89	0.08	AA	E3	eq
09	08:35:35	46.5425	-119.6095	20.2	1.5	Ml	030/042	40	0.10	AA	E3	eq
09	20:55:16	46.5425	-119.6100	19.0	0.1	Ml	015/019	54	0.11	AA	E3	eq
10	14:33:50	46.6853	-121.4663	5.2	1.3	Ml	023/030	157	0.12	AC	C3	eq

11	04:10:49	48.0205	-120.7122	0.9*	0.8	Md	006/007	148	0.13	CC	C3	eq
11	04:11:25	48.0238	-120.7150	0.8*	0.7	Md	005/005	150	0.09	CD	C3	eq
11	15:58:29	48.1493	-120.2107	-0.5*	1.8	Ml	015/017	162	0.09	CC	N3	eq
11	18:57:10	46.6032	-119.8522	6.7	1.0	Ml	015/019	89	0.07	AA	E3	eq
13	22:45:57	46.6170	-119.8448	6.8	0.6	Ml	008/012	266	0.04	AD	E3	eq
14	06:58:06	48.0250	-121.4950	11.3	1.2	Ml	010/011	170	0.10	BC	C3	eq
14	14:00:50	44.1182	-121.3408	3.5*	1.1	Ml	006/007	335	1.45	DD	C3	px
14	15:48:13	46.1460	-119.1867	-0.2*	2.1	Ml	016/022	160	0.12	CC	E3	px
14	23:45:39	44.3102	-120.8400	-1.4*	2.3	Ml	008/008	283	0.22	CD	E3	px
16	21:49:26	46.6043	-119.8352	6.5	0.6	Ml	007/010	154	0.08	AC	E3	eq
18	00:52:09	44.3722	-121.4265	12.4	1.4	Ml	011/014	177	0.24	BC	E3	eq
18	20:46:08	47.5133	-120.2917	-1.1*	0.7	Md	005/006	119	0.02	CC	N3	px
19	18:55:16	46.7572	-119.8492	13.1	0.7	Ml	005/010	155	0.06	AC	E3	eq
21	16:54:32	46.1583	-120.4398	14.4	1.5	Ml	019/026	76	0.28	BB	E3	eq
21	18:12:51	46.2502	-117.9460	-0.4	1.6	Ml	017/018	237	0.17	BD	E3	px
23	21:36:56	46.6075	-119.8438	6.8	0.6	Ml	015/021	88	0.07	AA	E3	eq
24	22:25:13	46.6140	-119.8465	6.5	0.5	Ml	011/018	175	0.07	AC	E3	eq
26	23:44:36	44.2988	-121.0550	-1.6*	1.6	Ml	009/009	212	0.51	DD	E3	px
28	12:26:04	46.6020	-119.8490	6.8	0.6	Ml	007/010	168	0.06	AC	E3	eq
28	19:47:02	47.5020	-117.0115	-0.7*	2.2	Ml	011/018	81	0.47	CD	N3	px
29	18:31:14	46.2818	-119.5422	-0.5*	1.7	Ml	013/017	187	0.09	CD	E3	px
April 2019												
02	13:00:29	46.7035	-121.0665	4.2	2.7	Ml	029/041	78	0.28	BC	C3	eq
04	16:55:16	46.2847	-119.5512	-0.5*	1.8	Ml	010/011	182	0.11	CD	E3	px
05	21:24:09	44.2568	-120.7657	-1.4*	2.2	Ml	012/013	233	0.27	CD	E3	px
11	23:27:40	47.5050	-120.2922	-1.2*	1.3	Ml	009/010	120	0.05	CC	N3	px
13	00:53:28	46.7070	-121.0620	8.8*	2.0	Ml	030/039	78	0.21	CC	C3	eq
15	22:43:21	47.3342	-118.5613	-0.5*	2.0	Ml	010/012	274	0.39	CD	N3	px
16	15:40:58	46.9102	-120.7162	5.0	1.6	Ml	023/032	78	0.42	CA	C3	eq
16	16:06:00	46.6777	-119.5770	9.5	0.3	Ml	006/008	121	0.11	AB	E3	eq
16	18:35:03	47.6822	-120.2395	1.9	1.2	Ml	007/010	131	0.08	BC	N3	eq
16	19:44:08	46.6177	-119.8423	7.1	0.5	Ml	003/005	265	0.01	BD	E3	eq
17	10:46:42	46.1637	-120.6552	15.1	1.2	Ml	011/012	197	0.34	CD	E3	eq
17	16:42:56	47.7475	-120.2283	0.1*	0.4	Md	007/011	78	0.11	CC	N3	eq
18	03:35:35	46.7150	-119.5247	-0.2*	0.3	Ml	007/011	86	0.14	CB	E3	px
18	18:40:21	47.0640	-120.8795	8.1	1.3	Ml	018/020	117	0.13	AC	C3	eq
19	22:59:41	46.6198	-119.8360	6.7	0.4	Ml	005/008	159	0.06	AC	E3	eq
20	10:38:44	46.6213	-119.8413	6.7	0.8	Ml	011/015	89	0.07	AA	E3	eq
22	20:57:02	46.1697	-119.4368	-0.4*	1.6	Ml	009/009	263	0.18	CD	E3	px
23	20:11:02	47.8080	-117.3503	-0.7*	1.8	Ml	006/008	218	0.43	CD	N3	px
23	22:09:06	44.0975	-121.3588	-1.6*	1.9	Ml	007/007	219	0.58	DD	N3	px
24	20:32:46	47.8310	-120.8948	-1.3*	1.2	Ml	007/009	213	0.15	CD	C3	px
25	16:32:50	47.0575	-118.7417	-0.4*	2.1	Md	005/004	250	0.00	CD	N3	px
26	10:21:18	46.7162	-119.5187	5.2	0.2	Ml	006/010	129	0.06	AB	E3	eq
28	04:39:02	46.7092	-119.4677	0.2*	0.4	Ml	008/011	80	0.06	CA	E3	eq
28	05:21:46	47.6975	-120.0893	5.1	0.9	Ml	011/013	58	0.14	AB	N3	eq
28	19:36:06	47.4337	-120.2733	8.8	1.6	Ml	017/020	86	0.11	AC	N3	eq
28	23:45:56	47.9442	-119.7847	11.0	0.8	Ml	010/015	122	0.07	AB	N3	eq
30	16:04:50	46.0332	-119.4027	-0.5*	1.1	Ml	009/012	212	0.17	CD	E3	px
30	18:13:01	45.9998	-119.4955	-0.3*	1.5	Ml	009/012	156	0.08	CC	E3	px
May 2019												
01	17:37:25	48.6285	-117.9193	-0.7*	1.4	Ml	006/010	229	0.34	CD	N3	px
02	11:06:46	47.6680	-120.3307	4.2	0.8	Ml	008/012	150	0.13	AC	N3	eq

02	21:22:23	46.7080	-119.5202	2.4	0.6	Ml	007/011	115	0.05	AB	E3	eq
03	18:53:34	46.2860	-119.2717	-0.2*	0.8	Ml	009/008	221	0.04	CD	E3	px
06	23:21:59	46.6033	-119.8015	8.1	0.4	Ml	006/011	210	0.05	AD	E3	eq
07	21:41:55	47.7045	-120.2542	-0.1*	0.1	Md	005/010	127	0.03	CC	N3	eq
08	11:13:38	46.5905	-119.7917	0.1*	0.1	Md	007/009	112	0.52	DB	E3	eq
09	20:23:29	47.4003	-117.7870	-0.5*	2.0	Ml	012/012	263	0.31	CD	N3	px
10	11:20:35	46.4572	-119.3503	14.4	1.6	Ml	038/052	43	0.13	AA	E3	eq
11	09:46:28	46.5672	-119.8427	7.7	0.8	Ml	015/024	91	0.08	AB	E3	eq
13	03:13:51	46.2230	-119.6505	14.9	0.8	Ml	010/014	198	0.05	AD	E3	eq
13	19:06:49	48.1782	-117.8710	-0.6*	1.8	Ml	013/018	157	0.90	DD	N3	px
13	20:57:27	46.6197	-119.8258	6.9	1.1	Ml	014/023	128	0.12	AB	E3	eq
15	18:04:37	45.9727	-119.7710	-0.5*	1.9	Ml	010/007	145	0.03	CC	E3	px
16	20:06:06	45.8085	-121.4835	-1.0*	1.6	Ml	009/012	166	0.41	CC	C3	px
17	22:33:19	45.2305	-118.1948	7.5*	2.1	Ml	006/010	125	0.37	CD	C3	eq
18	19:19:22	46.5308	-119.4215	22.0	2.4	Ml	039/043	39	0.10	AA	E3	eq
19	20:27:33	46.6000	-119.8702	6.4	0.9	Ml	010/014	196	0.06	AD	E3	eq
20	07:37:21	46.6252	-119.8107	7.1	0.7	Ml	008/013	140	0.06	AC	E3	eq
21	16:55:59	47.6640	-120.3063	-0.7*	0.3	Md	006/010	108	0.08	CB	N3	eq
22	11:43:44	47.7400	-120.6978	-0.6	1.7	Ml	017/016	72	0.12	AC	C3	eq
26	04:02:32	47.6408	-120.1458	3.2	1.0	Ml	009/011	90	0.05	AA	N3	eq
27	12:06:27	46.6055	-119.8405	6.5	0.6	Ml	008/012	160	0.07	AC	E3	eq
28	21:59:56	45.6887	-120.1700	-0.5*	2.3	Ml	009/010	120	0.07	CC	E3	px
30	04:05:23	46.2587	-119.5553	7.3	0.9	Ml	012/019	197	0.08	AD	E3	eq
30	04:32:13	46.2602	-119.5570	7.5	0.6	Ml	011/017	196	0.07	AD	E3	eq
30	19:37:47	46.7662	-117.1215	-0.8*	2.1	Ml	010/010	223	0.18	CD	E3	px
30	21:55:28	46.5830	-119.8170	8.6	0.5	Ml	007/009	184	0.03	AD	E3	eq
31	00:34:53	44.0223	-121.2505	-1.6*	2.2	Ml	015/013	146	0.11	CC	E3	px
June 2019												
01	00:26:29	46.5782	-119.8517	7.1	0.5	Ml	009/013	180	0.09	AC	E3	eq
01	00:26:47	46.5800	-119.8508	8.0	-0.0	Md	005/007	195	0.05	AD	E3	eq
03	21:50:23	46.5790	-119.3068	14.6	1.0	Ml	017/026	64	0.13	AA	E3	eq
04	09:24:09	46.5903	-119.8522	7.8	-0.1	Ml	004/006	245	0.05	AD	E3	eq
05	03:43:55	47.6745	-120.2835	-1.1	0.7	Md	005/009	143	0.10	AC	N3	eq
05	18:30:41	47.9233	-117.5208	-0.7*	2.1	Ml	007/009	185	0.33	CD	N3	px
06	02:11:00	46.5847	-119.8388	7.2	1.2	Ml	016/023	84	0.10	AA	E3	eq
06	02:43:15	46.6178	-119.8345	8.5	0.1	Md	004/006	311	0.03	AD	E3	eq
07	16:43:05	47.6773	-120.3322	0.5*	1.6	Ml	008/009	122	0.05	CB	N3	eq
10	19:35:21	46.1430	-119.1075	-0.3*	2.2	Ml	009/011	148	0.47	CC	E3	px
10	21:29:16	47.3692	-117.9487	-0.4*	2.3	Ml	012/014	276	0.30	CD	N3	px
11	17:09:43	47.8477	-117.3517	-0.5*	2.1	Ml	016/021	156	1.04	DD	N3	px
12	19:02:41	46.0305	-119.5477	-0.3*	0.8	Md	008/006	309	0.02	CD	E3	px
13	02:39:26	46.8163	-119.7150	0.4*	0.6	Ml	011/015	139	0.22	CC	E3	eq
14	17:00:43	46.4635	-119.7365	17.4	1.1	Ml	023/030	106	0.09	AB	E3	eq
15	03:22:14	46.7752	-120.9510	8.9	2.0	Ml	021/029	119	0.25	BB	C3	eq
15	04:09:06	47.6748	-120.3052	-0.4*	1.5	Ml	015/015	85	0.06	CB	N3	eq
15	11:09:56	46.5735	-119.7865	-0.3	0.7	Ml	011/017	110	0.32	CB	E3	eq
15	20:58:27	47.6953	-120.1340	5.3	0.5	Ml	006/010	103	0.04	AB	N3	eq
16	10:39:57	46.4200	-119.4497	18.5	1.1	Ml	009/009	101	0.07	AB	E3	eq
16	10:39:58	46.4317	-119.4517	16.4	1.3	Ml	012/017	84	0.10	AA	E3	eq
16	16:13:16	46.8295	-119.7363	2.1	3.2	Ml	052/047	43	0.12	AC	E3	eq
16	16:30:07	46.8327	-119.7370	2.5	0.8	Ml	014/018	135	0.11	AC	E3	eq
16	20:39:29	46.8362	-119.7342	4.6*	1.1	Ml	018/023	65	0.24	CC	E3	eq
18	19:46:40	47.7292	-119.9682	-0.9*	1.9	Ml	009/006	126	0.38	CC	N3	px

24	05:42:14	47.6940	-120.0045	3.7	1.2	Ml	010/011	109	0.05	AB	N3	eq
24	08:56:33	46.5753	-119.8498	9.7	0.4	Ml	007/011	226	0.09	AD	E3	eq
24	18:39:44	47.5653	-120.0298	-0.1*	0.6	Md	004/007	261	0.36	CD	N3	eq
24	23:07:36	46.5890	-119.8360	7.2	0.7	Ml	011/014	125	0.07	AB	E3	eq
24	23:09:21	46.5902	-119.8370	7.5	0.5	Ml	008/012	126	0.04	AB	E3	eq
25	06:29:37	46.5873	-119.8348	7.4	0.7	Ml	008/012	125	0.05	AB	E3	eq
26	20:19:05	46.6218	-119.8032	8.0	0.7	Ml	008/010	246	0.06	AD	E3	eq
27	19:53:09	45.4985	-118.0022	-1.1*	1.4	Ml	003/004	170	0.10	CD	E3	px
28	20:29:58	45.8802	-118.4042	-0.8*	1.8	Ml	006/008	140	0.60	DC	E3	px
30	11:01:40	46.5985	-119.8087	7.4	0.2	Md	006/008	263	0.07	BD	E3	eq
30	17:40:47	46.6188	-119.7982	7.3	0.4	Ml	006/012	241	0.06	AD	E3	eq
30	18:46:48	46.6190	-119.8265	7.0	1.5	Ml	026/033	86	0.07	AA	E3	eq
July 2019												
01	18:23:37	47.9362	-117.4747	-0.6*	2.2	Ml	014/015	189	0.42	CD	N3	px
02	11:23:18	47.7633	-117.6503	-0.6*	1.4	Ml	006/005	257	0.06	CD	N3	px
02	23:28:17	47.1412	-120.7900	-1.1*	1.4	Ml	013/011	184	0.25	CD	C3	px
03	18:38:45	46.1598	-119.2735	-0.3*	1.2	Ml	010/013	164	0.20	CC	E3	px
04	01:32:45	46.8260	-119.7515	0.2*	0.4	Ml	008/012	218	0.23	CD	E3	eq
04	13:04:22	46.9138	-120.7565	13.8	1.1	Ml	018/023	100	0.34	CB	C3	eq
05	16:48:36	46.3503	-120.3815	12.4	1.3	Ml	011/015	85	0.19	BB	E3	eq
05	17:09:17	46.7308	-119.9262	9.7	1.6	Ml	027/037	98	0.16	BB	E3	eq
05	18:01:32	46.6403	-119.8350	6.4	0.1	Md	003/006	288	0.07	AD	E3	eq
05	18:03:12	46.6243	-119.8240	6.6	0.2	Ml	005/008	257	0.03	AD	E3	eq
05	18:25:58	46.6182	-119.8202	6.7	0.4	Ml	007/010	252	0.03	AD	E3	eq
08	23:06:27	46.8365	-119.7293	3.2	1.3	Ml	015/016	107	0.12	AC	E3	eq
09	00:46:15	46.6195	-119.8418	6.4	1.1	Ml	017/024	89	0.08	AA	E3	eq
10	18:00:34	46.8307	-119.7357	0.0*	1.1	Ml	012/018	105	0.25	CC	E3	eq
10	21:36:48	48.2832	-119.5747	3.9	1.5	Ml	012/013	146	0.07	AC	N3	eq
11	00:00:57	47.4700	-120.6630	-1.1*	1.4	Ml	008/007	159	0.16	CC	C3	px
12	09:48:09	46.8107	-119.7390	5.2	0.4	Ml	003/006	156	0.04	AC	E3	eq
12	10:46:35	46.8295	-119.7348	3.2	2.5	Ml	036/036	61	0.10	AC	E3	eq
12	21:21:09	46.2247	-119.2242	-0.5*	1.2	Ml	007/009	306	0.50	DD	E3	px
13	03:48:50	46.1627	-120.4102	13.4	1.1	Ml	008/011	179	0.13	AC	E3	eq
13	10:28:20	46.5955	-119.8652	6.7	1.3	Ml	017/022	90	0.08	AA	E3	eq
13	10:31:21	46.6033	-119.8710	6.4	0.6	Ml	008/012	180	0.06	AC	E3	eq
13	17:52:13	48.2858	-121.3137	8.2	1.3	Ml	010/014	144	0.27	BC	C3	eq
15	06:30:52	46.6127	-119.7943	7.3	0.8	Ml	007/012	231	0.05	AD	E3	eq
15	07:30:58	46.6052	-119.3582	16.0	1.0	Ml	024/029	66	0.09	AA	E3	eq
15	17:03:42	46.5868	-119.8342	7.3	1.4	Ml	017/026	83	0.06	AA	E3	eq
15	20:58:06	44.4063	-121.0453	-1.4*	1.8	Ml	009/008	140	0.07	CC	E3	px
16	00:37:40	44.1090	-121.3368	-1.2*	1.9	Ml	014/017	137	0.38	CC	E3	px
16	18:41:03	46.4373	-119.0283	-0.1*	1.7	Ml	008/006	149	0.03	CC	E3	px
17	04:26:46	47.7440	-120.2958	2.4	0.7	Ml	006/010	90	0.05	BC	N3	eq
17	05:35:08	46.6092	-119.8493	6.8	1.5	Ml	021/026	89	0.07	AA	E3	eq
18	08:33:55	46.5233	-121.4220	-0.7	1.6	Ml	013/016	107	0.13	BC	C3	eq
19	17:00:27	47.6257	-120.2573	5.4	0.9	Md	004/006	155	0.05	BC	N3	eq
20	13:11:02	48.2400	-121.2328	9.2	1.0	Md	008/011	143	0.23	BC	C3	eq
22	22:49:05	47.7350	-119.4278	-0.9*	1.6	Ml	007/007	147	0.22	CC	N3	px
23	19:00:40	46.2435	-118.1270	-0.3*	2.0	Ml	010/011	257	0.17	CD	E3	px
23	21:41:28	46.8640	-119.5745	16.5	0.8	Ml	014/019	133	0.09	AB	E3	eq
26	01:41:35	47.4868	-120.6990	-1.2*	1.5	Ml	013/015	108	0.31	CC	C3	px
27	04:13:41	46.8315	-119.7377	2.1	0.6	Ml	010/014	105	0.07	AC	E3	eq
30	13:09:49	47.4153	-119.8612	11.2	0.9	Md	005/008	197	0.12	AD	N3	eq

30	22:48:52	44.2145	-120.2363	-1.6*	2.0	Ml	016/016	203	0.21	CD	N3	px
August 2019												
01	02:11:58	46.7138	-120.5452	15.1	1.1	Ml	011/015	104	0.17	BB	E3	eq
02	16:04:46	46.1745	-119.2510	-0.2*	1.2	Md	010/010	191	0.22	CD	E3	px
03	07:59:14	46.5917	-119.8615	6.6	0.3	Ml	008/010	185	0.04	AD	E3	eq
05	07:43:08	46.6010	-119.8080	7.8	1.0	Ml	016/025	83	0.08	AA	E3	eq
06	18:17:37	45.6968	-119.9223	16.7	1.6	Ml	010/013	135	0.16	BB	E3	eq
06	20:20:23	46.2490	-120.4295	-0.7	0.8	Ml	005/007	284	0.29	CD	E3	eq
09	18:47:10	47.0163	-118.8238	-0.4*	1.6	Ml	008/010	221	1.10	DD	N3	px
09	21:56:03	47.7228	-120.0415	4.7	2.0	Ml	017/016	64	0.07	AB	N3	eq
10	04:36:56	46.0798	-119.8548	-0.5*	1.2	Ml	010/013	138	0.10	CC	E3	px
10	08:39:41	47.7352	-120.0680	3.2	0.8	Md	007/011	81	0.06	AB	N3	eq
13	19:02:00	46.1738	-119.2697	-0.2*	1.2	Ml	012/013	158	0.12	CC	E3	px
14	14:05:19	46.6020	-119.8688	7.0	0.6	Ml	007/009	178	0.05	AC	E3	eq
14	23:52:36	46.6020	-119.8440	6.8	0.9	Ml	009/014	163	0.08	AC	E3	eq
15	14:14:41	48.0057	-120.6533	0.1*	1.2	Md	007/010	189	0.20	CD	C3	eq
17	12:48:18	47.7607	-120.2108	4.3	1.4	Ml	013/018	59	0.07	AC	N3	eq
18	03:12:52	45.4597	-117.3333	3.9*	1.3	Ml	004/008	170	0.47	DD	N3	eq
18	08:56:29	46.4202	-119.2718	0.2*	0.5	Ml	010/012	164	0.12	CC	E3	eq
24	00:10:47	44.0345	-121.3272	6.1	0.8	Ml	010/013	169	0.18	BC	E3	eq
24	05:47:23	46.8107	-119.7117	7.2	0.5	Ml	006/007	134	0.03	AB	E3	eq
26	04:07:16	44.0390	-121.3522	5.5	0.9	Ml	010/017	137	0.18	BC	E3	eq
26	20:00:49	46.1723	-119.2207	-0.3*	1.3	Ml	011/011	134	0.58	DC	E3	px
28	13:21:36	48.0050	-120.7883	17.1	1.0	Ml	012/015	116	0.18	BB	C3	eq
28	19:52:51	44.5758	-121.2498	-1.4*	1.8	Ml	013/013	99	0.31	CC	C3	px
30	18:22:11	46.6835	-120.6788	6.0	0.6	Ml	007/010	120	0.20	BC	E3	eq
September 2019												
05	08:35:15	46.3122	-119.5675	14.6	1.1	Ml	022/029	126	0.06	AB	E3	eq
05	22:12:18	47.6415	-119.8983	-1.0*	1.5	Md	009/011	174	0.30	CC	N3	px
11	05:46:47	47.6928	-120.0103	2.7	1.5	Md	009/013	100	0.08	AB	N3	eq
11	19:42:50	47.2347	-118.8562	-0.4*	1.3	Ml	009/010	163	0.29	CC	N3	px
12	00:02:19	47.4403	-117.8767	-0.5*	2.0	Ml	008/008	284	0.17	CD	N3	px
12	01:44:30	46.8407	-119.7257	3.3	2.0	Ml	037/046	43	0.17	BC	E3	eq
16	08:58:57	46.5277	-119.5733	18.6	1.8	Ml	036/041	38	0.10	AA	E3	eq
18	11:29:18	48.1480	-120.8203	8.8*	1.4	Ml	014/016	125	0.15	CC	C3	eq
20	02:42:56	46.6042	-119.8460	6.5	0.6	Ml	013/016	165	0.07	AC	E3	eq
20	21:10:08	46.1993	-119.2340	-0.2*	1.2	Ml	014/017	137	0.20	CC	E3	px
23	21:57:01	47.3653	-117.8900	-0.5*	2.1	Ml	010/016	194	0.70	DD	N3	px
24	01:46:17	48.0827	-120.4227	9.9	1.5	Ml	012/017	130	0.27	BB	C3	eq
25	14:35:42	47.6970	-120.1973	6.3	1.0	Ml	008/013	82	0.08	AB	N3	eq
26	07:10:21	46.6042	-119.8552	6.4	0.8	Ml	013/020	136	0.09	AC	E3	eq
27	11:14:32	48.3522	-120.4602	3.8	1.6	Md	009/013	233	0.24	BD	C3	eq
27	21:04:16	46.2535	-119.8203	-0.5*	1.2	Ml	015/023	142	0.26	CC	E3	px
29	01:07:51	46.5765	-119.8753	7.6	1.5	Ml	019/026	81	0.14	AA	E3	eq
29	01:15:22	46.5762	-119.8698	7.6	1.4	Ml	017/024	87	0.08	AA	E3	eq
29	15:17:42	46.6107	-119.8498	6.6	2.4	Ml	031/042	52	0.08	AA	E3	eq
29	15:20:59	46.6100	-119.8442	6.8	0.5	Ml	006/009	164	0.04	AC	E3	eq
29	15:21:52	46.6117	-119.8380	6.8	0.6	Ml	007/010	159	0.05	AC	E3	eq
29	16:07:32	46.6108	-119.8470	6.5	1.3	Ml	015/020	167	0.07	AC	E3	eq
29	16:40:38	46.6133	-119.8442	6.6	0.5	Ml	007/009	262	0.02	AD	E3	eq
29	17:39:25	46.6092	-119.8393	6.8	0.8	Ml	010/013	160	0.06	AC	E3	eq
29	23:58:13	46.6122	-119.8422	6.5	0.6	Ml	011/017	162	0.05	AC	E3	eq
30	02:14:53	46.6108	-119.8422	6.8	0.7	Ml	011/016	95	0.08	AB	E3	eq

30	15:40:17	46.2457	-119.5015	1.7	1.2	Ml	021/026	90	0.10	AB	E3	eq
30	20:34:49	46.7762	-120.8423	7.8	2.0	Ml	024/029	110	0.15	BB	C3	eq
30	20:35:28	46.7678	-120.8335	8.0	1.2	Md	008/010	203	0.19	BD	C3	eq

5.0 Discussion of Seismic Activity – FY 2019

5.1 Summary

During FY2019, seismic activity was relatively quiet throughout eastern Washington. 251 earthquakes were cataloged in the region, of which about 55% (139) took place on or in the immediate vicinity of the Hanford Site (Tables 5.1 and 5.2). Several earthquakes took place in the historically active area of Entiat and Chelan. Within the vicinity of the Hanford Site, there was typical swarm-type activity, most strongly observed in the Wye Swarm Area.

The depth distribution and geographic pattern of the earthquakes for the year are tabulated in Tables 5.1 and 5.2 and plotted on Figure 5.1.

Table 5.1. Depth Distribution of Eastern Washington Earthquakes for FY 2019

Category	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2019
Shallow (0-4 km deep)	22	18	18	17	75
Intermediate (4-9 km deep)	30	23	36	38	127
Deep (greater than 9 km deep)	20	14	11	14	49
Total	**62**	**55**	**65**	**69**	**251**
Felt	0	0	1	0	1
Probable Blast	26	28	29	25	108

Table 5.2. Earthquake Counts for FY 2019 for Earthquakes near the Hanford Site

Seismic Sources	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2019
Frenchman Hills	0	0	0	0	0
Saddle Mountains	1	2	0	1	4
Wahluke Slope	0	0	0	2	2
Coyote Rapids	1	1	4	0	6
Wye	6	3	1	1	11
Cold Creek	0	1	0	0	1
Rattlesnake Mountain	0	0	0	0	0
Horse Heaven Hills	0	0	0	0	0
Total for swarm areas	8	7	5	4	24
Random Events	23	19	37	36	115
Total For All Earthquakes	**31**	**26**	**42**	**40**	**139**

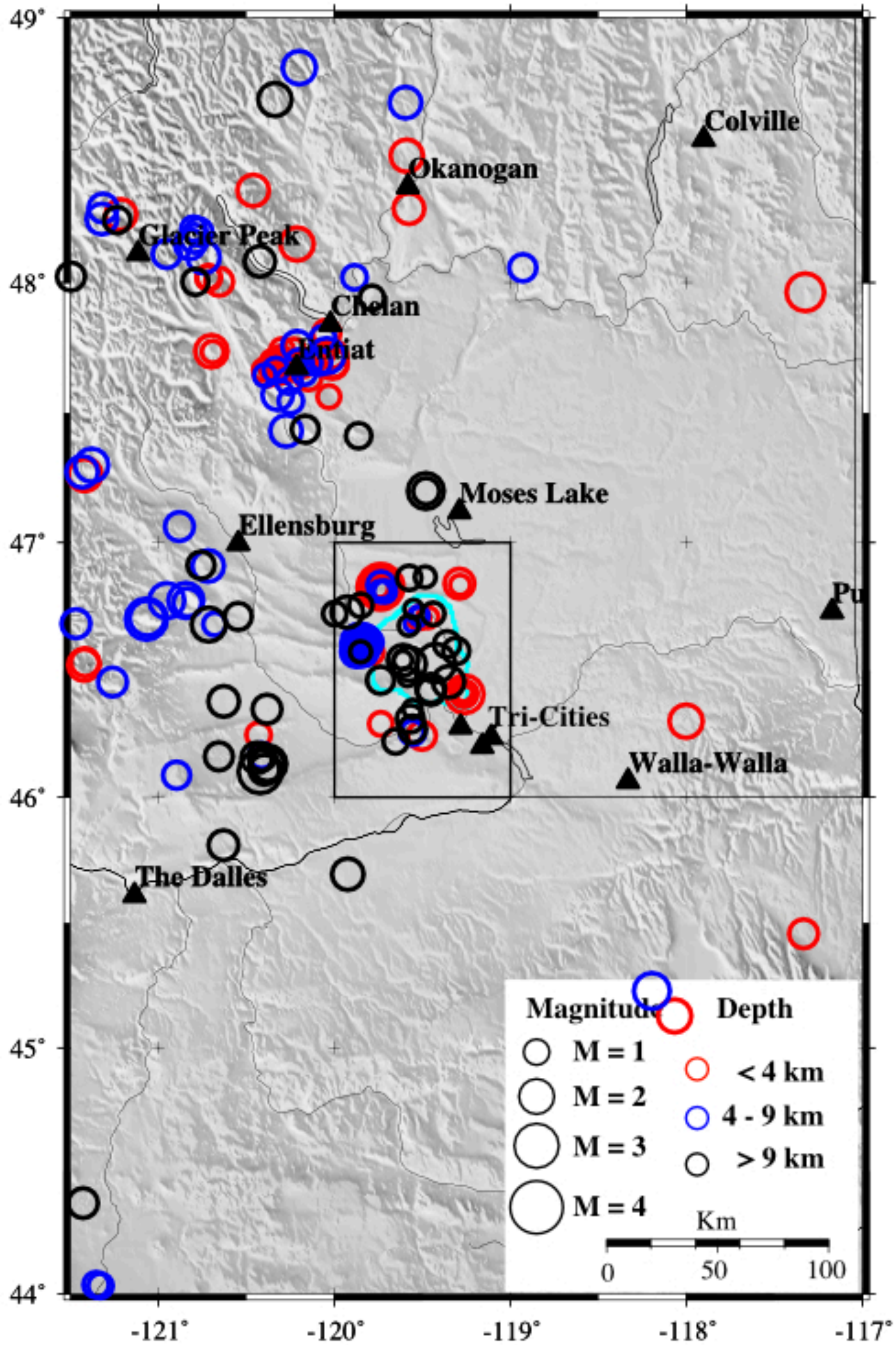

Figure 5.1. Hanford and Regional Epicenters of Earthquakes Recorded during FY 2019

Red circles stand for shallow earthquakes (0-4 km)
Blue circles for intermediate-depth earthquakes (4 9 km)
Black circles deep earthquakes (>9km).
Rectangle: area shown in Figure 5.2a

5.2 Example of a Notable Earthquake

The largest earthquake during the year near the Hanford Site was a shallow M3.2 earthquake on the north side of Saddle Mountain (see Figure 5.2a on June 16). While it was not a large earthquake, a score of people reported feeling it, and it was well recorded by the recently upgraded stations across the Hanford Nuclear Facility (HNF). As exemplified in Figure 5.2b, the modern stations permit a quantitative analysis of ground motion across the region and particularly on the Hanford Site. In addition to the spatial attenuation (decrease in shaking strength due to seismic propagation), we see the variability of ground motion between sites. Such information is valuable for studies of the hazard at specific sites on and near the HNF.

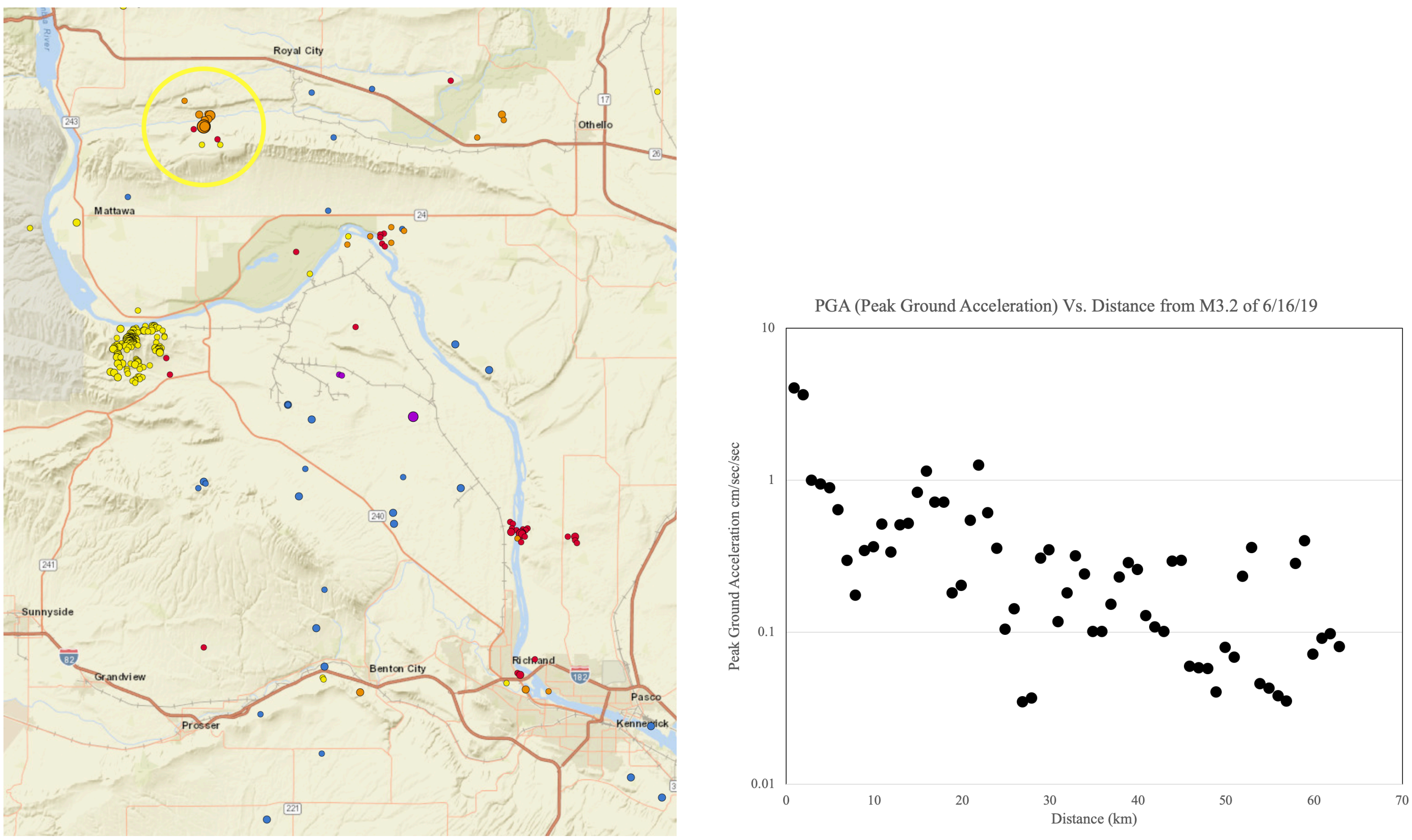

Figure 5.2. Location and Peak Horizontal Ground Accelerations for M3.2 Earthquake of 6/16/2019

a) left panel: map of epicenters of earthquakes located between 1 Oct 2017 and 1 Oct 2019 in the immediate vicinity of the Hanford Site. Epicenters are color coded by depth. Red: < 1 km, Orange: 1-5 km., Yellow 5-11 km,, and Blue: 11-21 km. The M3.2 of 6/16/2019 occurred in a persistent nest of seismicity indicated by the yellow circle within the Saddle Mountain swarm area. b) right panel: PGA (Peak Horizontal Ground Acceleration) as a function of distance from recordings of the earthquake on the HLSMP. Such quantitative granularity would not have been possible prior to the upgrades.

6.0 Status of Monitoring

Since the seismic monitoring network underwent significant enhancements during FY2017 and FY2018 the monitoring capabilities are strong. The annual report for FY2016 described an effort to upgrade as many network stations as possible with the aim of fire protection as well as enhanced seismic performance. About ½ of the regional stations have been upgraded, now.

Data from the newly upgraded stations illustrate the enhanced usefulness of the network (*i.e.,* section 5.2), but also underscore the robustness and high quality of the network products. Complementary network enhancements, not just to the monitoring stations themselves but also the necessary revisions to the digital telemetry architecture, were a “hidden” feature of the network upgrades. This has opened the potential to provide timely Earthquake Early Warnings (EEW) from the ShakeAlert EEW system that is being implemented on the west coast. Figure 6.1 illustrates how fast the delivery of data to the ShakeAlert system is. And the possibility to upgrade the rest of the network stations (see Figures 3.1 and 3.2) would add even more speed and precision and facilitate and improve the HLSMP mission.

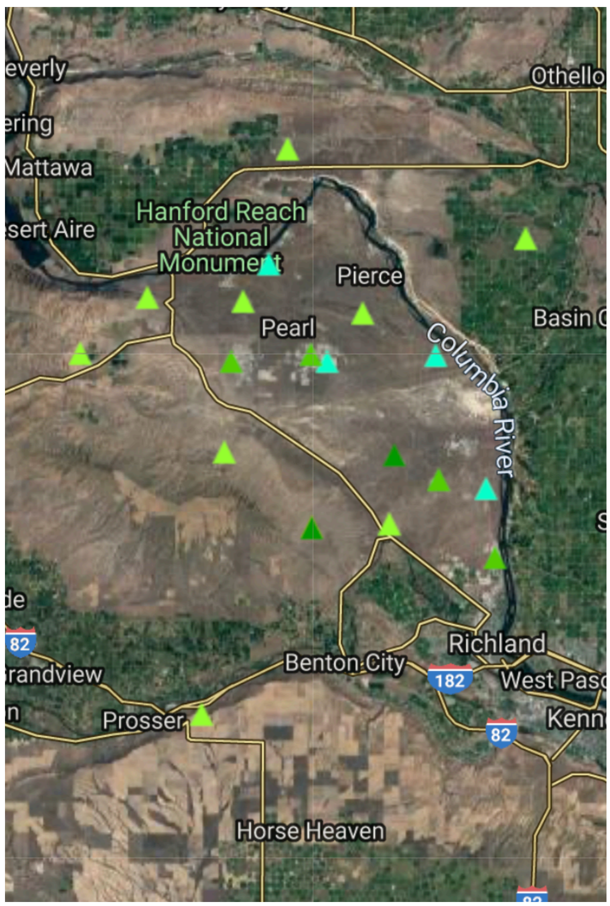

Figure 6.1. Illustration of Upgraded Station Data Latencies.

Stations recently upgraded in the vicinity of the Hanford Site are color coded by data latency (time interval between actual real time and availability of the data for processing). dark green = <0.5 sec., moderate green = 0.5 – 1 sec., light green = 1 – 1.5 sec., light blue = 1.5 – 2 sec.

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