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HANFORD SEISMIC REPORT FOR FISCAL YEAR 2020
(OCTOBER 2019-SEPTEMBER 2020)
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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

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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 (DOE) 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 FY2020, seismic activity was relatively quiet throughout eastern Washington. 333 earthquakes were cataloged in the region, of which about 31% (102) 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 near the Cold Creek 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
BWIP	Basalt Waste Isolation Project
CRBG	Columbia River Basalt Group
Dmin	Minimum distance (closest distance from an earthquake epicenter to a station)
DOE	U.S. Department of Energy
EEW	Earthquake early warnings
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
IRIS	Incorporated Research Institutions in Seismology
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
MSA	Mission Support Alliance
Mtyp	Magnitude type
NS/NP	Number of stations/number of phases
PNNL	Pacific Northwest National Laboratory
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
SHPS	Safety and Health Programs Support
SMA	Strong Motion Accelerometer (type of seismic station)
USGS	U.S. Geological Survey
UTC	Coordinated Universal Time
UW	University of Washington
WHC	Westinghouse Hanford Company
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) 2020 (October 2019 through September 2020). The MSA, Safety and Health Programs 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 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 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.

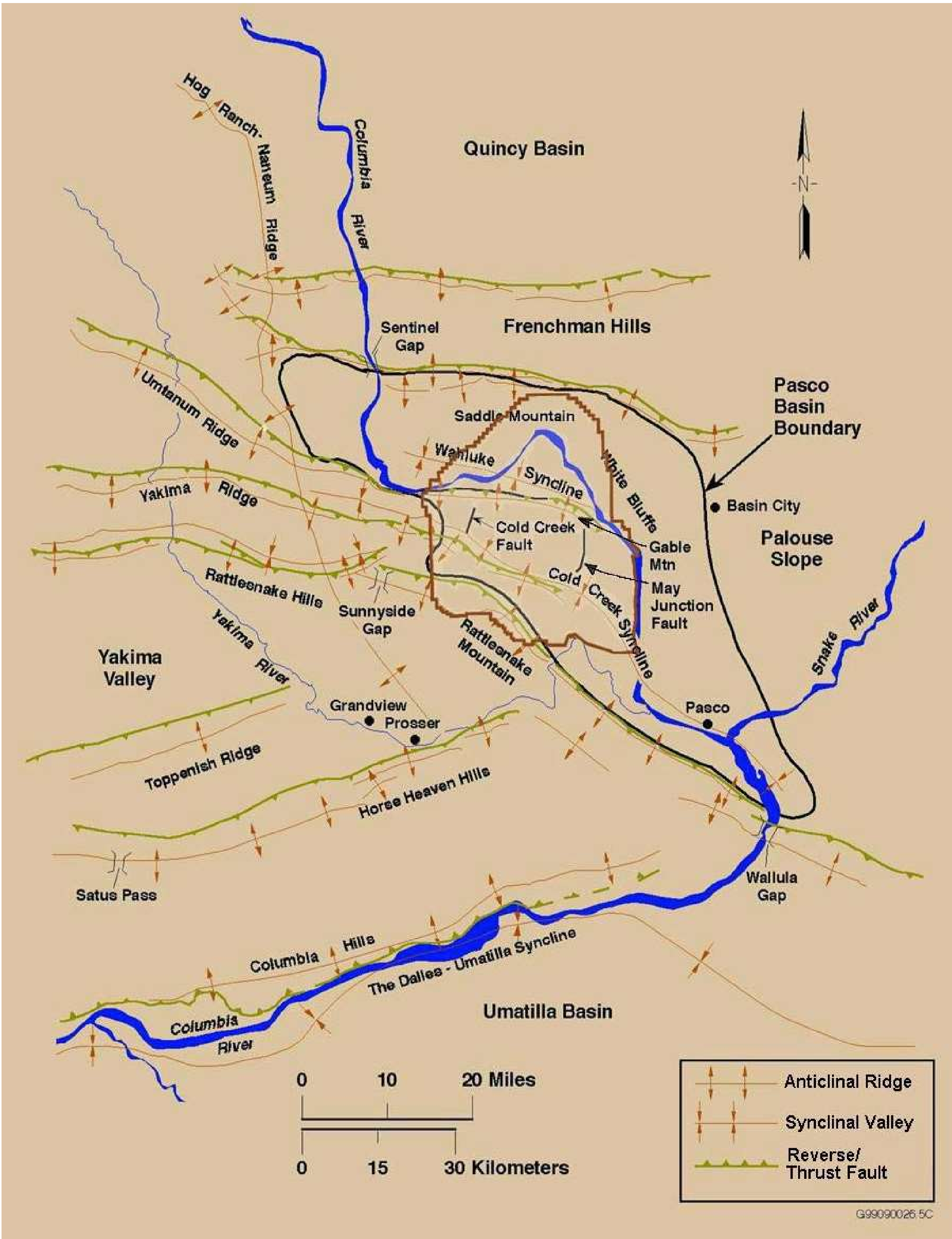

Figure 2.1. Tectonic Features of the Hanford Site within Eastern Washington

(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.

The seismic stations supported by MSA are further divided 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

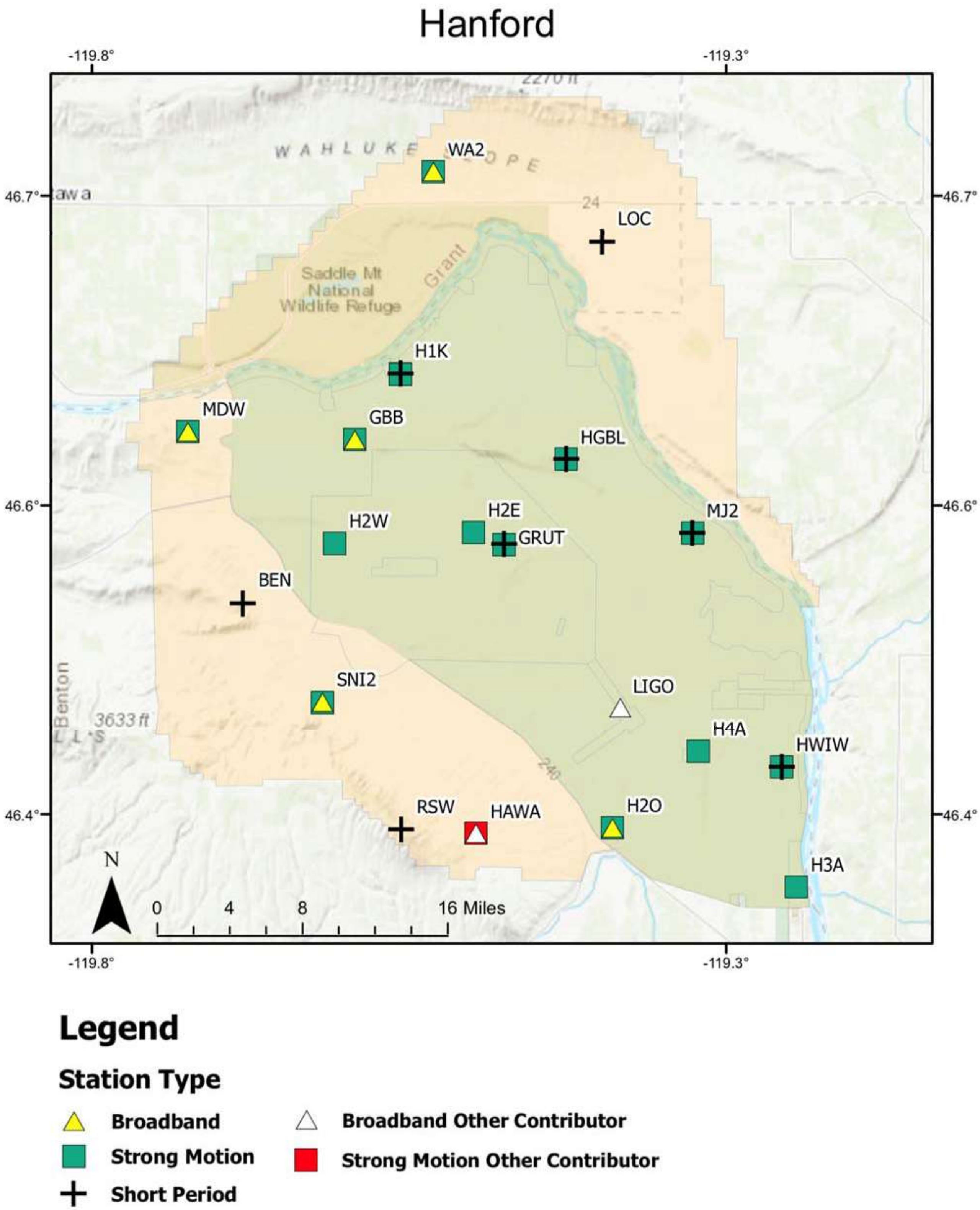

Figure 3.1. Hanford Seismic Network Onsite Stations

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

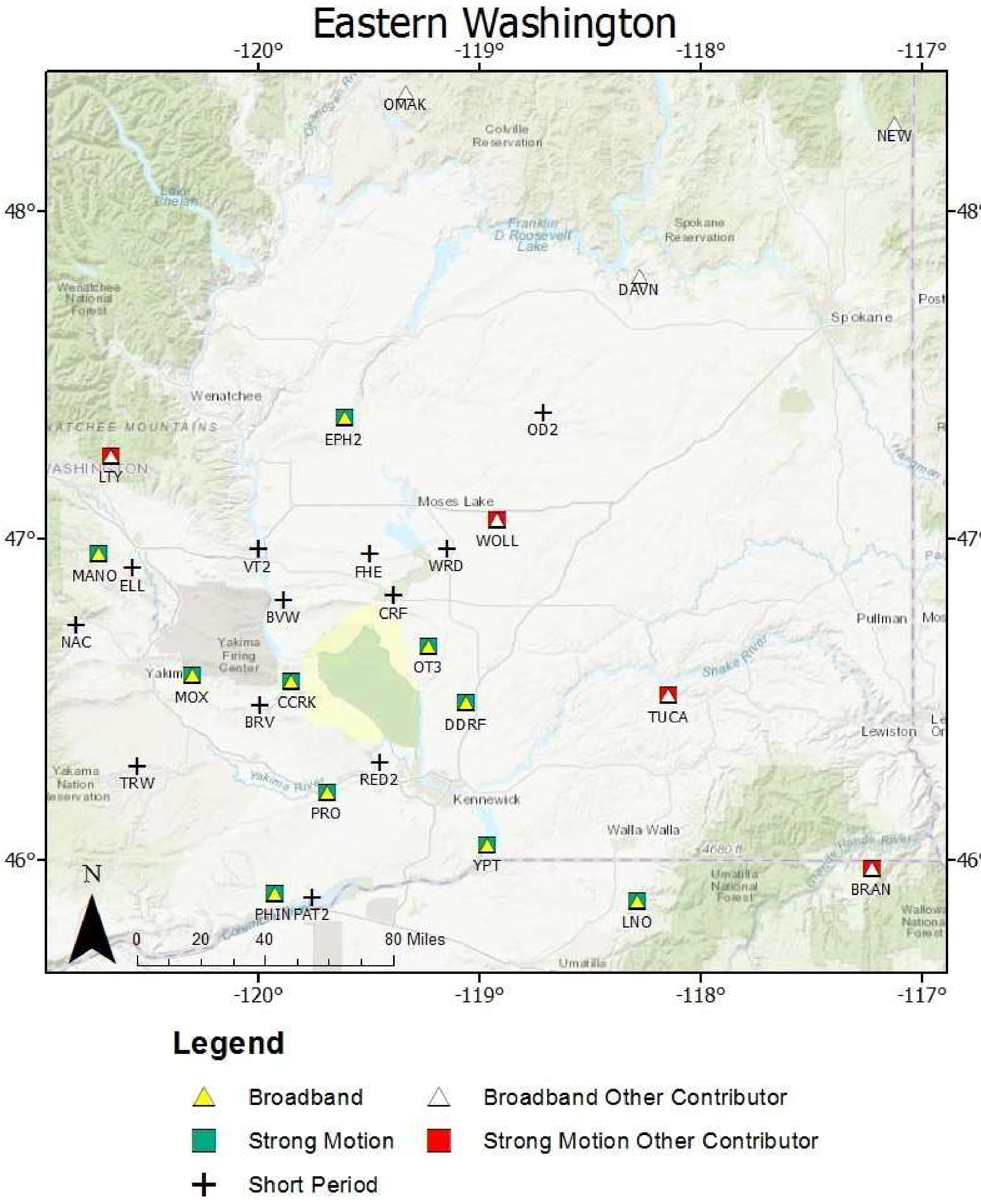

Figure 3.2. Hanford Seismic Network Stations of the Eastern Washington Region Sub-Network

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.

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 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 2020 Earthquake Catalog for Eastern Washington

Day	Time	Lat	Lon	Depth	Mag	Mtyp	NS/NP	Gap	Rms	Q	Mod	Type
October 2019												
01	03:40:10	46.6123	-119.8487	6.2	0.5	Ml	014/018	90	0.09	AA	E3	eq
01	16:29:59	47.6945	-120.3573	-0.1*	1.9	Md	008/011	94	0.10	CB	N3	eq
01	21:46:43	46.4270	-119.0305	-0.2*	1.2	Ml	013/016	149	0.08	CC	E3	px
02	07:48:42	46.6157	-119.8403	6.6	0.1	Ml	007/010	210	0.06	AD	E3	eq
02	22:48:21	47.3633	-117.8087	-0.4*	2.1	Ml	008/011	170	0.38	CD	N3	px
03	10:22:33	46.6003	-119.8525	6.8	0.7	Ml	010/012	172	0.05	AC	E3	eq
04	17:16:50	46.8305	-119.7367	2.1	1.1	Ml	018/026	153	0.13	AC	E3	eq
04	17:37:19	48.1098	-120.3212	7.8	1.1	Ml	013/020	135	0.09	AB	N3	eq
05	09:15:24	46.8422	-119.7390	5.5	0.8	Ml	006/009	163	0.13	AC	E3	eq
07	21:03:18	46.6078	-120.6823	-0.7*	1.5	Ml	012/014	87	0.73	DC	E3	px
08	03:21:35	46.6787	-119.5832	2.5	0.5	Ml	009/013	125	0.15	BB	E3	eq
08	19:06:36	47.8075	-117.3660	-0.6*	1.9	Ml	007/012	184	0.49	CD	N3	px
11	20:06:52	46.6045	-119.6618	13.1	0.3	Ml	011/016	105	0.09	AB	E3	eq
12	10:29:09	48.5720	-120.8753	8.9*	1.8	Ml	014/019	166	0.44	CC	C3	eq
14	09:15:55	46.0860	-120.3952	16.1	1.2	Ml	012/015	83	0.20	BB	E3	eq
14	15:19:00	46.8483	-119.7362	3.4	1.3	Ml	017/020	85	0.15	BC	E3	eq
15	03:43:50	46.2472	-119.5450	15.0	2.2	Ml	039/049	156	0.08	AC	E3	eq
15	19:03:14	46.9778	-119.1082	-0.3*	1.2	Ml	008/009	165	0.20	CC	E3	px
15	21:40:30	47.3645	-117.8947	-0.5*	2.0	Ml	011/013	201	0.09	CD	N3	px
21	04:54:16	46.6077	-119.8685	4.1	0.5	Ml	006/010	245	0.13	AD	E3	eq
22	01:00:04	46.6723	-119.5762	3.0	0.9	Ml	013/017	118	0.08	AB	E3	eq
25	01:07:25	46.6747	-120.6000	7.0	1.4	Ml	023/031	111	0.22	BC	E3	eq
25	17:29:10	46.6722	-120.6018	5.5	1.1	Ml	009/012	119	0.16	BC	E3	eq
27	19:01:11	46.5638	-119.8412	7.8	0.8	Ml	018/025	81	0.09	AA	E3	eq
27	21:27:27	46.6078	-119.8467	6.8	0.9	Ml	015/023	88	0.08	AA	E3	eq
29	00:00:46	46.6073	-119.7455	15.0	0.4	Ml	011/014	102	0.07	AB	E3	eq
30	20:41:33	47.6467	-120.1767	7.3	0.3	Md	007/011	127	0.04	AB	N3	eq
31	00:13:33	45.8622	-118.2508	-0.6*	2.0	Ml	012/013	216	0.54	DD	E3	px
November 2019												
01	15:06:34	47.6895	-120.2960	6.0	0.7	Ml	008/012	84	0.08	AB	N3	eq
01	18:31:54	46.7668	-117.0637	-0.3*	1.8	Ml	007/009	225	0.89	DD	E3	px
02	11:12:38	46.1488	-118.9405	9.8	1.1	Ml	016/024	104	0.24	BB	E3	eq
03	08:16:26	48.2445	-121.2343	7.6	2.0	Ml	018/022	130	0.19	BC	C3	eq
03	15:24:05	46.6000	-119.8622	6.6	1.3	Ml	023/032	91	0.07	AB	E3	eq
04	10:42:06	46.4677	-119.7265	13.9	1.1	Ml	025/031	81	0.08	AA	E3	eq
06	04:13:30	46.6153	-119.8482	7.4	0.5	Ml	010/011	99	0.09	AB	E3	eq
06	22:07:37	47.6285	-120.2142	-1.2*	1.5	Ml	009/011	123	0.15	CB	N3	px
08	20:47:24	45.8923	-119.3122	-0.3*	1.7	Ml	016/018	178	0.35	CC	E3	px
11	21:58:24	47.3448	-117.8705	-0.5*	2.2	Ml	009/013	205	0.55	DD	N3	px
14	06:43:45	45.5238	-120.1738	15.9	1.9	Ml	010/009	134	0.12	BB	E3	eq
14	16:31:27	46.6157	-119.8457	6.3	0.9	Ml	011/014	99	0.06	AB	E3	eq
15	07:41:22	46.2228	-120.2293	-0.7	0.7	Ml	004/006	180	0.77	DC	E3	eq
15	07:41:26	46.1995	-120.3272	8.0*	0.9	Ml	005/008	143	0.15	CC	E3	eq
15	20:13:35	47.7905	-117.3497	-0.6*	2.0	Ml	010/012	187	0.23	CD	N3	px
16	12:42:20	46.5807	-119.8655	7.4	0.9	Ml	014/020	109	0.09	AB	E3	eq
18	10:47:04	48.0583	-119.6597	16.7	1.6	Ml	014/024	123	0.23	BB	N3	eq
18	16:49:24	47.8245	-119.2733	5.9	3.5	Ml	019/024	142	0.16	BC	N3	eq
18	18:22:46	47.8163	-119.2483	0.4*	1.1	Md	011/015	101	0.51	DC	N3	eq
18	23:48:31	47.5390	-120.2685	-1.2*	1.4	Ml	011/010	172	0.20	CC	N3	px

19	13:48:58	48.7535	-120.1382	1.6*	1.8	Ml	008/013	180	0.68	DD	N3	eq
21	02:25:38	47.6483	-120.1708	-0.5*	1.1	Ml	011/013	95	0.12	CB	N3	eq
22	15:18:02	47.6957	-120.2967	4.5	0.7	Ml	007/010	97	0.05	AC	N3	eq
23	01:17:13	46.6063	-119.8540	-0.3*	0.5	Ml	012/017	126	0.14	CB	E3	px
25	03:49:14	47.6947	-120.1545	-0.4*	1.1	Ml	012/014	72	0.08	CB	N3	eq
25	21:57:19	46.6085	-119.8450	6.5	1.0	Ml	012/018	165	0.07	AC	E3	eq
26	10:20:54	47.6627	-120.2838	-1.1	0.2	Md	006/009	107	0.09	AB	N3	eq
28	06:09:29	46.5755	-119.8380	8.6	0.7	Ml	006/008	199	0.03	AD	E3	eq
28	06:43:46	46.5755	-119.8350	8.2	0.5	Ml	005/009	194	0.05	AD	E3	eq
December 2019												
01	06:03:09	46.5720	-119.8373	7.9	1.4	Ml	020/026	86	0.09	AA	E3	eq
01	09:11:17	46.5715	-119.8310	7.9	0.6	Ml	007/010	172	0.05	AC	E3	eq
01	20:31:38	46.5352	-121.4173	2.5	3.4	Ml	053/073	58	0.16	BC	C3	eq
02	15:40:39	47.6962	-121.4972	11.5	1.6	Ml	020/023	98	0.05	AB	C3	eq
03	06:22:16	46.3670	-119.3727	14.8	0.6	Ml	020/028	198	0.08	AD	E3	eq
03	22:50:39	46.6093	-119.8403	6.4	0.3	Ml	005/007	160	0.03	AC	E3	eq
04	00:24:02	45.7748	-118.5600	-0.7*	1.6	Ml	008/012	149	0.19	CC	E3	px
04	21:05:17	45.7120	-120.2103	18.2	1.7	Ml	015/019	132	0.21	BB	E3	eq
08	13:15:17	48.0383	-120.7285	5.7	1.2	Ml	009/013	133	0.22	BC	C3	eq
08	15:21:48	46.5282	-121.4137	2.5	1.1	Ml	018/027	114	0.16	BC	C3	eq
10	07:21:39	46.6477	-120.6275	6.5	0.7	Ml	006/008	133	0.07	AC	E3	eq
11	18:04:37	45.9087	-119.3020	-0.3*	1.7	Ml	015/022	174	0.26	CC	E3	px
12	22:24:45	46.9152	-120.4267	7.0	2.3	Ml	029/036	54	0.18	BB	E3	eq
13	00:58:35	46.5973	-119.8243	6.9	0.6	Ml	006/009	141	0.13	AC	E3	eq
13	08:46:09	47.8145	-120.7455	7.7	1.5	Md	011/013	121	0.25	BB	C3	eq
14	08:06:54	46.1192	-120.4605	14.1	1.4	Ml	021/030	154	0.14	AC	E3	eq
14	14:06:50	48.3165	-119.7342	0.4*	1.4	Ml	010/017	124	0.50	DC	N3	eq
16	10:36:25	46.7208	-120.0047	6.5	1.7	Ml	032/033	63	0.10	AC	E3	eq
17	02:18:38	47.8292	-119.2447	0.2*	0.9	Ml	011/016	98	0.25	CC	N3	eq
18	17:13:27	46.6125	-119.8432	6.6	1.6	Ml	026/032	65	0.09	AA	E3	eq
19	04:46:28	46.6083	-119.8377	6.5	0.4	Ml	008/012	158	0.08	AC	E3	eq
19	20:05:28	47.3072	-119.9547	-0.9*	1.4	Ml	013/014	93	0.37	CC	N3	px
19	22:18:36	47.3648	-117.9293	-0.4*	2.1	Ml	012/016	160	0.28	CD	N3	px
25	02:36:31	46.6080	-119.8467	6.9	0.3	Ml	006/010	166	0.03	AC	E3	eq
25	12:05:24	46.4653	-119.6173	17.5	0.3	Ml	016/022	102	0.07	AB	E3	eq
29	13:20:45	46.1493	-120.4625	21.8	1.0	Ml	008/009	198	0.08	AD	E3	eq
January 2020												
07	07:32:12	48.0932	-120.7620	5.3	1.5	Ml	011/014	146	0.13	AC	C3	eq
07	09:45:13	47.6658	-120.1335	-0.6*	1.1	Ml	013/012	79	0.21	CA	N3	eq
07	19:16:09	46.3783	-120.6327	7.3	1.1	Ml	006/009	196	0.38	CD	E3	eq
08	21:24:37	46.8558	-119.7293	4.8	0.7	Ml	007/011	236	0.23	BD	E3	eq
12	04:18:53	47.7378	-120.0343	2.3	0.9	Md	010/016	64	0.10	AB	N3	eq
12	23:36:53	46.8397	-119.7313	-0.0	1.1	Ml	011/016	156	0.20	BC	E3	eq
13	03:52:27	47.5757	-121.3788	9.1*	1.5	Ml	012/017	72	0.25	CC	C3	eq
13	11:37:28	47.7502	-120.0350	2.0	0.6	Md	005/008	120	0.07	AB	N3	eq
15	01:35:37	47.7542	-120.3152	4.4	1.1	Md	010/015	130	0.16	BC	N3	eq
15	18:01:19	46.6205	-119.8258	7.0	1.5	Ml	023/035	86	0.09	AA	E3	eq
17	20:14:08	46.5995	-119.8642	6.5	0.9	Ml	014/024	95	0.09	AB	E3	eq
19	07:07:34	47.6867	-120.3247	-0.3*	-0.1	Md	005/009	115	0.05	CB	N3	eq
20	03:40:40	46.8338	-119.7368	2.4	0.8	Ml	012/015	111	0.13	AC	E3	eq
21	20:33:36	46.7692	-120.8568	-0.8	0.6	Ml	008/011	125	0.38	CB	C3	eq
22	11:34:53	48.9625	-120.5085	9.4	1.9	Ml	012/019	111	0.56	DD	C3	eq
23	14:14:28	47.7498	-120.1017	4.5	0.6	Md	007/011	90	0.03	AB	N3	eq

23	23:00:18	44.1562	-121.3200	-1.3*	1.4	Ml	005/006	177	0.12	CC	N3	px
24	19:18:04	46.5910	-119.8610	7.0	1.0	Ml	010/018	96	0.06	AB	E3	eq
25	01:33:51	47.6678	-120.3385	4.2	0.3	Md	008/012	129	0.13	AB	N3	eq
28	11:25:18	46.4802	-119.4722	16.3	0.4	Ml	013/018	57	0.12	AA	E3	eq
28	11:44:42	46.4563	-120.7087	10.6	1.5	Ml	013/013	158	0.07	AC	C3	eq
February 2020												
01	17:27:18	47.6632	-120.1813	-0.4*	1.1	Md	005/008	152	0.04	CC	N3	eq
01	22:05:18	47.6632	-120.2508	-0.0*	0.2	Md	005/006	128	0.12	CC	N3	eq
02	02:02:07	47.9767	-119.8545	4.7	0.2	Md	004/007	153	0.05	AC	N3	eq
02	09:48:29	47.6725	-120.3187	0.5	1.6	Md	009/010	92	0.06	BB	N3	eq
03	10:21:33	47.7197	-120.0110	4.3	0.9	Md	007/010	97	0.04	AB	N3	eq
04	12:37:09	47.8188	-119.1238	14.2	1.2	Ml	008/009	160	0.13	BC	N3	eq
05	01:26:10	47.7140	-120.1823	5.7	1.6	Md	006/010	71	0.02	AC	N3	eq
05	15:32:10	48.2517	-121.3000	2.3*	0.4	Md	004/007	183	0.08	DD	C3	eq
08	09:41:41	48.2413	-121.3277	4.1	2.4	Ml	019/022	123	0.16	BC	C3	eq
08	09:49:04	48.2380	-121.3357	5.4	1.9	Ml	014/016	123	0.12	AC	C3	eq
08	12:56:28	47.6953	-120.1052	3.8	0.7	Ml	007/011	98	0.04	AB	N3	eq
09	07:33:20	47.7370	-120.2283	2.8	0.4	Md	006/009	73	0.06	BC	N3	eq
09	19:40:13	48.2425	-121.3140	5.8	1.1	Md	006/008	169	0.04	BC	C3	eq
10	05:18:10	47.6697	-120.1610	2.3	0.0	Md	004/007	149	0.06	BC	N3	eq
12	20:47:23	45.5518	-119.5818	-0.6	1.3	Ml	018/022	128	0.56	DC	E3	px
13	04:38:14	47.6662	-120.3192	5.0	0.1	Md	005/009	115	0.10	AB	N3	eq
13	07:16:15	47.6448	-120.1592	1.4	0.8	Ml	006/009	123	0.11	BB	N3	eq
13	20:42:47	46.9632	-119.4702	-0.4	2.0	Ml	020/020	85	0.19	BA	E3	px
14	00:23:44	47.6548	-120.1698	-0.3*	1.9	Md	009/013	89	0.14	CB	N3	eq
15	11:30:12	48.3047	-121.2487	21.7	0.7	Md	005/008	198	0.05	AD	C3	eq
15	20:24:04	46.6063	-119.8453	6.5	1.1	Ml	007/010	213	0.03	AD	E3	eq
18	00:57:07	45.8985	-119.3115	-0.3*	1.7	Ml	008/010	210	0.23	CD	E3	px
18	18:13:09	48.2198	-117.7073	-0.6*	1.2	Ml	004/005	165	0.11	CD	N3	px
19	03:31:36	46.6035	-119.8407	6.5	0.4	Ml	007/010	271	0.04	AD	E3	eq
20	03:00:11	47.8707	-119.2790	0.2*	1.2	Ml	011/015	99	0.31	CC	N3	eq
20	10:36:03	47.7332	-120.2628	-0.5*	1.1	Ml	009/013	72	0.04	CC	N3	eq
20	21:02:19	46.6583	-120.4703	-0.8*	1.0	Ml	006/006	138	0.16	CC	E3	px
21	00:08:38	45.5665	-119.5368	-0.5*	1.4	Ml	011/015	186	0.34	CD	E3	px
22	00:53:59	44.0225	-121.2493	-1.5*	2.0	Ml	014/013	146	0.18	CC	E3	px
23	04:05:43	47.1010	-121.3773	6.4	1.1	Ml	021/029	113	0.13	AC	C3	eq
25	14:51:40	47.5913	-120.2997	5.4	0.3	Md	007/012	102	0.06	AB	N3	eq
25	17:38:00	47.9758	-119.8525	4.3	0.4	Md	005/009	152	0.09	AC	N3	eq
25	18:47:31	47.9780	-119.8517	4.1	0.2	Md	004/007	154	0.08	AC	N3	eq
25	22:26:58	48.4957	-118.5655	-0.5*	1.8	Md	004/006	224	0.48	CD	N3	px
26	19:48:50	47.0182	-120.3860	-0.9*	1.1	Ml	012/013	130	0.25	CC	N3	px
28	21:01:00	45.7865	-118.1760	-0.7*	1.9	Ml	013/014	228	0.42	CD	E3	px
28	22:48:57	46.8643	-120.7663	19.3	0.7	Ml	007/009	171	0.15	BC	C3	eq
29	00:00:42	45.1635	-119.8635	-0.7*	2.1	Ml	010/011	285	0.72	DD	C3	px
29	23:50:48	46.7093	-121.0617	2.8	1.3	Ml	027/032	100	0.18	BC	C3	eq
March 2020												
01	01:14:16	46.7063	-121.0628	1.1	0.9	Ml	019/026	132	0.16	BC	C3	eq
01	05:44:50	46.0885	-118.8590	17.0	1.1	Ml	011/014	125	0.06	AB	E3	eq
02	01:36:28	46.0992	-118.8708	16.1	1.1	Ml	014/015	124	0.06	AB	E3	eq
02	04:33:20	47.9742	-119.8490	5.7	0.2	Md	004/007	149	0.07	AC	N3	eq
04	21:48:40	44.3805	-121.0290	-1.6*	1.9	Ml	013/016	132	0.14	CB	N3	px
05	10:34:58	47.6957	-120.0122	3.8	0.6	Md	007/010	135	0.05	AB	N3	eq
05	14:51:46	47.7590	-120.2852	0.2*	0.1	Md	006/008	80	0.04	CC	N3	eq

06	23:38:25	46.7662	-117.2107	-0.7*	1.8	Ml	011/013	179	0.67	DD	E3	px
07	00:59:35	44.0148	-121.2568	-1.5*	1.9	Ml	020/019	144	0.14	CC	E3	px
08	04:14:51	46.6027	-119.8635	6.6	0.8	Ml	013/021	94	0.14	AB	E3	eq
08	06:15:10	47.7358	-120.0140	5.5	0.8	Ml	007/009	106	0.04	AB	N3	eq
08	10:50:35	47.6657	-120.0990	6.7	0.3	Md	005/010	122	0.06	AB	N3	eq
09	03:52:40	47.7220	-120.2717	4.2	1.0	Ml	007/011	83	0.04	BC	N3	eq
10	19:42:36	44.3428	-120.7488	3.5*	2.3	Ml	014/013	285	0.27	CD	N3	px
10	21:05:41	46.9758	-119.0600	-0.4*	1.9	Ml	008/009	240	0.82	DD	E3	px
11	19:50:07	46.2900	-118.1752	-0.4*	1.9	Ml	015/017	148	0.21	CD	E3	px
13	00:25:53	47.5082	-120.3015	-1.2*	1.1	Ml	011/012	119	0.09	CC	N3	px
13	05:20:14	47.2572	-119.3008	5.2	0.7	Md	005/009	138	0.10	BC	N3	eq
16	12:47:42	46.6867	-120.9868	0.1*	0.8	Ml	011/014	161	0.15	CC	C3	eq
16	23:52:42	44.0098	-121.2950	-1.6*	1.6	Ml	009/010	162	0.33	CC	C3	px
17	00:30:28	46.6190	-119.8392	6.4	0.5	Ml	006/010	160	0.05	AC	E3	eq
17	02:08:41	48.0045	-119.9475	8.7	0.9	Md	010/013	173	0.07	AC	N3	eq
17	22:39:34	46.3968	-119.1860	2.6	1.1	Ml	015/020	199	0.09	AD	E3	eq
18	06:17:01	46.8092	-120.9323	7.4	1.1	Ml	015/018	113	0.25	BB	C3	eq
19	07:46:51	47.8455	-120.7513	8.1	0.7	Md	006/008	179	0.13	AC	C3	eq
20	20:28:44	46.1607	-119.1218	-0.2*	1.6	Ml	019/023	143	0.15	CC	E3	px
21	19:49:40	47.6433	-120.2163	2.0	0.9	Md	007/011	121	0.05	AB	N3	eq
21	20:21:46	47.6443	-120.1425	3.2	0.7	Md	006/009	112	0.03	AB	N3	eq
23	07:04:58	46.8218	-119.7508	2.7	1.4	Ml	019/021	133	0.18	BB	E3	eq
23	07:17:57	46.6172	-119.8363	6.9	0.6	Ml	006/009	158	0.04	AC	E3	eq
23	14:49:15	46.7608	-120.7093	3.0	0.9	Ml	007/009	119	0.38	CB	C3	eq
23	17:22:58	46.6183	-119.8432	6.5	1.5	Ml	025/033	75	0.08	AA	E3	eq
23	23:51:57	45.5170	-119.6043	7.9	1.5	Ml	016/021	148	0.13	AC	E3	eq
26	21:36:30	44.1015	-121.3473	-1.5*	1.9	Ml	012/013	135	0.41	CB	E3	px
27	10:44:41	47.6625	-120.3547	-0.5*	1.4	Ml	014/017	98	0.08	CB	N3	eq
28	00:20:39	44.3708	-121.0487	-1.6*	1.9	Ml	010/012	200	0.17	CD	N3	px
28	13:56:00	47.6850	-120.1123	1.4	0.6	Md	005/009	100	0.11	BB	N3	eq
30	01:38:40	46.6503	-119.5902	16.2	0.8	Ml	019/029	106	0.13	AB	E3	eq
31	03:10:31	47.9950	-119.1358	1.7*	0.7	Ml	007/009	173	0.33	CC	N3	eq
31	18:06:32	45.7227	-120.1700	-0.6*	2.1	Ml	007/008	276	0.11	CD	E3	px
31	23:19:07	47.3758	-117.8542	-0.5*	2.5	Ml	011/013	203	0.13	CD	N3	px
April 2020												
01	17:55:38	46.2848	-118.8122	-0.2*	1.2	Ml	011/015	210	0.19	CD	E3	px
03	05:32:40	47.7457	-120.2548	2.1	1.1	Ml	009/014	141	0.08	BC	N3	eq
03	18:32:34	45.7523	-120.0382	-0.4*	2.0	Ml	012/012	274	0.12	CD	E3	px
03	18:34:33	48.7768	-120.4350	0.9*	1.9	Md	004/005	308	0.22	DD	C3	eq
03	23:59:34	44.0563	-121.1543	-1.7*	2.1	Ml	007/008	261	0.14	CD	C3	px
04	06:25:47	47.6898	-120.3627	6.2	1.1	Md	008/011	137	0.10	AC	N3	eq
04	08:28:33	48.2545	-121.3038	11.3	0.9	Md	010/011	139	0.10	AC	C3	eq
05	09:13:34	47.7083	-120.1475	6.6	0.8	Ml	010/012	71	0.06	AB	N3	eq
05	15:55:35	46.6140	-119.8425	6.6	0.9	Ml	017/025	88	0.07	AA	E3	eq
06	15:38:38	46.7270	-120.8573	5.8	0.7	Ml	006/008	132	0.13	AB	C3	eq
07	14:50:59	48.3070	-118.8222	4.2*	1.4	Ml	008/010	118	0.74	DC	N3	eq
07	18:12:59	46.5563	-121.4498	2.6	1.6	Ml	036/053	83	0.16	BC	C3	eq
09	18:55:36	46.5588	-119.8467	8.7	0.5	Ml	008/014	135	0.09	AB	E3	eq
09	23:46:26	48.2650	-120.7393	13.6	1.1	Md	007/013	180	0.25	CC	C3	eq
10	00:57:36	44.9223	-121.2708	10.9	1.7	Ml	016/023	190	0.16	BD	C3	eq
14	00:00:32	44.0167	-121.2532	-1.5*	1.8	Ml	016/014	144	0.10	CC	C3	px
14	23:05:02	46.6205	-119.8448	6.6	0.5	Ml	006/009	267	0.03	AD	E3	eq
15	14:00:04	47.7305	-120.3132	7.1	2.3	Ml	018/018	68	0.11	AB	N3	eq

16	09:09:54	47.7477	-120.0750	4.0	1.1	Md	006/011	101	0.05	AB	N3	eq
16	15:29:55	47.5090	-120.2932	-1.2*	1.3	Md	008/009	120	0.06	CC	N3	px
18	09:29:05	48.0605	-119.7418	15.5	1.0	Md	009/011	129	0.17	BB	N3	eq
18	14:27:17	48.0735	-119.7465	14.9	0.9	Ml	010/017	149	0.18	BC	N3	eq
18	15:01:44	48.0538	-119.7385	16.8	0.8	Md	007/009	179	0.17	CC	N3	eq
19	09:09:10	46.4742	-119.7070	17.2	0.1	Ml	010/014	210	0.08	AD	E3	eq
20	21:49:43	47.8420	-120.9377	4.5	1.2	Md	008/009	173	0.07	AC	C3	eq
21	05:46:51	46.4542	-119.7928	9.7	0.2	Ml	008/011	216	0.10	AD	E3	eq
21	22:31:15	44.3983	-121.0310	-1.5*	1.9	Ml	011/013	156	0.61	DC	E3	px
21	22:52:00	45.3813	-117.0593	3.2*	1.9	Ml	004/005	210	0.03	CD	E3	eq
21	23:09:56	45.8817	-118.3968	-0.6*	2.3	Ml	011/008	117	0.15	CB	E3	px
22	22:28:46	47.4122	-117.9145	-0.5*	2.1	Ml	011/013	190	0.35	CD	N3	px
23	13:15:25	47.5710	-120.8408	7.8	1.2	Ml	011/017	132	0.16	BC	C3	eq
23	22:18:25	46.3507	-118.1378	-0.4*	1.3	Ml	009/010	194	0.16	CD	E3	px
23	22:51:25	45.5065	-118.0170	-1.1*	1.8	Ml	004/004	169	0.03	CD	E3	px
24	05:57:54	48.1432	-121.2402	12.2	1.3	Md	009/013	132	0.29	BB	C3	eq
24	07:25:01	46.6097	-119.9115	6.2	1.0	Ml	011/016	154	0.08	AC	E3	eq
24	08:19:46	46.5998	-119.8533	6.6	1.0	Ml	013/019	173	0.08	AC	E3	eq
25	22:39:00	46.5652	-119.8435	9.3	0.6	Ml	009/015	124	0.09	AB	E3	eq
26	01:28:29	46.7993	-121.0272	4.0	0.8	Ml	010/014	120	0.15	BC	C3	eq
28	01:37:40	46.6038	-119.8507	6.6	0.8	Ml	008/013	170	0.05	AC	E3	eq
30	01:24:07	44.9953	-121.0915	27.7	1.6	Ml	011/016	97	0.12	AB	E3	eq
30	21:01:56	47.4137	-121.4247	-1.8*	1.6	Md	008/008	320	0.45	DD	C3	px
May 2020												
01	00:06:51	47.7078	-120.3353	3.1	2.9	Ml	023/020	85	0.06	AC	N3	eq
01	00:45:15	47.7103	-120.3348	2.0	1.1	Ml	009/012	85	0.05	BC	N3	eq
01	02:46:37	47.7098	-120.3358	1.1*	0.7	Md	005/007	182	0.04	CD	N3	eq
02	13:55:17	47.6560	-120.2023	5.9	-0.1	Md	004/005	155	0.03	BD	N3	eq
02	14:37:52	46.6007	-119.8612	6.7	1.4	Ml	026/033	92	0.10	AB	E3	eq
02	15:13:15	46.6010	-119.8582	6.8	1.2	Ml	014/021	90	0.07	AA	E3	eq
02	17:39:17	46.6338	-120.8393	16.4	0.9	Ml	007/010	217	0.10	AD	C3	eq
02	18:23:31	46.6333	-120.8135	11.1	1.4	Ml	017/023	137	0.23	BC	C3	eq
04	15:49:47	46.6047	-119.8432	6.8	0.6	Ml	010/011	163	0.05	AC	E3	eq
04	18:05:33	46.2848	-120.1020	-0.5*	1.4	Ml	006/009	272	0.53	DD	E3	px
05	07:17:25	47.6857	-121.3985	8.9*	1.1	Ml	012/019	109	0.34	CC	C3	eq
07	19:32:48	47.1227	-120.7853	-1.0*	1.2	Ml	008/006	137	0.10	CC	C3	px
08	14:41:35	46.7355	-120.6242	8.8	0.4	Ml	003/005	258	0.12	CD	E3	eq
08	22:19:46	47.7102	-121.4043	8.9*	1.1	Ml	005/006	296	0.03	CD	C3	eq
08	22:57:54	46.5565	-121.4483	2.3	1.8	Ml	034/041	83	0.11	AC	C3	eq
10	06:51:53	45.8758	-120.2963	12.3	0.8	Ml	010/014	137	0.32	CC	E3	eq
10	07:50:51	45.8570	-120.2957	19.3	2.3	Ml	022/029	66	0.19	BA	E3	eq
10	15:59:09	47.6952	-120.1252	-0.7*	1.6	Ml	017/020	86	0.12	CB	N3	eq
11	11:19:32	46.6093	-119.8412	6.7	0.7	Ml	013/021	147	0.09	AC	E3	eq
11	12:03:01	46.6123	-119.8473	6.5	1.2	Ml	019/026	89	0.07	AA	E3	eq
11	18:53:19	47.3637	-117.8710	-0.5*	2.2	Ml	008/009	205	0.20	CD	N3	px
12	22:21:10	45.8602	-120.3123	16.2	2.2	Ml	014/017	116	0.14	AB	E3	eq
15	09:48:15	46.6193	-119.4638	15.8	0.6	Ml	017/028	64	0.08	AA	E3	eq
15	14:52:18	47.6238	-118.0378	-0.6*	1.5	Ml	003/005	200	0.39	CD	N3	px
15	21:50:42	47.8532	-117.2538	17.2	2.8	Ml	023/027	116	0.22	BC	N3	eq
15	22:08:14	44.3372	-121.1423	-1.4*	1.7	Ml	011/012	141	0.16	CC	N3	px
16	03:42:06	47.6688	-120.3242	-0.5*	0.6	Ml	006/011	110	0.08	CB	N3	eq
17	23:15:34	47.6885	-121.3897	9.4*	0.9	Ml	009/013	94	0.33	CC	C3	eq
18	04:00:41	47.6808	-121.4248	19.9	1.0	Ml	010/016	74	0.45	CB	C3	eq

20	00:51:19	46.6083	-119.8457	6.7	1.2	Ml	019/031	88	0.08	AA	E3	eq
20	19:31:52	47.3597	-117.9265	-0.5*	2.1	Ml	013/018	200	0.31	CD	N3	px
20	19:42:28	46.5975	-119.8627	6.8	0.9	Ml	013/021	95	0.07	AB	E3	eq
20	20:32:59	46.0325	-120.1767	-0.4*	2.4	Md	003/004	307	0.06	CD	E3	px
21	02:14:47	45.8830	-120.2873	16.3	1.7	Ml	016/017	198	0.19	BD	E3	eq
21	17:07:46	47.6648	-120.3807	-0.5*	0.8	Md	006/008	157	0.09	CC	N3	eq
21	21:12:28	45.8890	-119.3175	-0.3*	1.7	Ml	012/015	213	0.23	CD	E3	px
23	13:18:00	46.6028	-119.8665	6.4	1.6	Ml	026/039	54	0.11	AA	E3	eq
24	05:09:26	46.4488	-119.2018	0.4*	0.5	Md	003/004	185	0.10	DD	E3	eq
24	23:12:03	46.2045	-119.6603	8.7	0.2	Ml	007/010	240	0.09	AD	E3	eq
24	23:46:52	46.1967	-119.6227	7.5	0.4	Md	007/010	243	0.04	AD	E3	eq
25	12:01:52	46.7155	-121.0645	2.3	0.8	Ml	016/022	136	0.17	BC	C3	eq
25	21:58:27	48.2253	-121.3753	-0.1*	0.7	Md	004/007	145	0.17	CC	C3	eq
26	12:18:22	47.6768	-120.2768	-0.5*	0.5	Ml	007/012	91	0.10	CB	N3	eq
26	22:07:50	46.2700	-119.3980	-0.2*	1.9	Ml	024/023	168	0.09	CC	E3	px
28	22:00:43	46.7987	-117.4565	-1.1*	2.1	Ml	019/020	161	0.16	CD	E3	px
June 2020												
01	08:01:18	46.0178	-118.6172	5.3	1.9	Ml	019/025	139	0.11	AC	E3	eq
04	00:12:07	45.5415	-119.5423	-0.3	1.1	Ml	010/014	137	0.26	BC	E3	eq
06	13:06:11	47.6728	-120.3015	-0.5*	1.1	Ml	009/011	146	0.04	CC	N3	eq
09	18:20:48	47.7043	-120.3282	3.4	0.7	Ml	007/011	85	0.08	BC	N3	eq
09	23:37:37	46.5425	-119.5887	16.4	1.6	Ml	033/047	43	0.10	AA	E3	eq
09	23:38:09	46.5427	-119.5880	15.4	1.2	Ml	021/030	63	0.11	AA	E3	eq
10	00:47:16	45.1650	-118.0435	7.4*	0.8	Ml	003/005	162	0.18	CD	E3	eq
11	16:40:08	46.8603	-120.5688	16.5	1.3	Ml	016/019	121	0.25	BB	E3	eq
16	22:55:35	46.6108	-118.9475	-0.2*	1.4	Ml	021/023	198	0.21	CD	E3	px
17	13:33:27	46.6390	-119.7545	20.1	0.7	Ml	018/025	106	0.08	AB	E3	eq
19	22:37:14	45.6998	-119.1073	-0.6*	1.2	Ml	013/019	128	0.33	CC	E3	px
20	02:40:19	46.6878	-120.8227	11.7	0.5	Ml	009/010	156	0.19	BC	C3	eq
20	02:46:05	46.6293	-120.6453	16.4	0.4	Ml	007/009	143	0.07	AC	E3	eq
23	07:25:16	48.2002	-121.3643	4.1	0.8	Ml	007/011	152	0.11	AC	C3	eq
23	08:05:50	47.7372	-120.2007	1.0	1.1	Ml	009/014	125	0.07	BC	N3	eq
23	20:00:21	46.2522	-119.6437	-0.5*	1.7	Ml	012/014	142	0.16	CC	E3	px
24	04:01:23	46.5528	-119.7835	19.8	1.2	Ml	027/036	77	0.09	AA	E3	eq
25	12:27:03	47.6745	-120.0765	6.2	1.7	Ml	011/013	60	0.07	AB	N3	eq
25	21:41:56	46.1948	-118.8578	-0.4*	1.3	Md	007/009	191	0.40	CD	E3	px
27	00:48:42	48.1002	-121.3627	14.6	1.4	Ml	007/014	122	0.31	CB	C3	eq
29	15:06:43	46.6007	-119.8610	6.5	1.5	Ml	020/032	90	0.09	AA	E3	eq
29	18:14:51	46.6032	-119.8568	6.3	0.8	Ml	010/014	177	0.09	AC	E3	eq
30	21:49:52	44.5722	-121.2885	-1.3*	1.4	Ml	007/008	162	0.24	CC	E3	px
July 2020												
01	21:39:44	46.1565	-119.2760	-0.3*	1.3	Ml	015/015	166	0.13	CC	E3	px
02	03:17:19	46.6002	-119.8602	6.5	0.8	Ml	009/013	92	0.04	AB	E3	eq
02	17:39:39	47.0390	-120.6978	-0.9*	1.1	Ml	005/005	169	0.09	CD	C3	px
03	18:28:31	47.1798	-121.0627	9.1*	0.8	Ml	009/013	190	0.07	CD	C3	eq
04	12:34:52	46.6040	-119.8427	6.9	0.6	Ml	011/016	145	0.07	AC	E3	eq
04	12:41:57	46.6045	-119.8402	7.0	0.7	Ml	011/012	159	0.07	AC	E3	eq
05	10:28:07	47.1427	-121.3927	8.0*	0.8	Ml	016/025	181	0.09	CD	C3	eq
06	10:21:02	46.8022	-120.4280	14.3	1.2	Ml	021/025	61	0.23	BB	E3	eq
06	10:47:28	46.8148	-120.3992	7.9	1.3	Ml	023/028	57	0.26	BC	E3	eq
06	10:51:46	46.8140	-120.3995	12.0	0.7	Ml	007/012	183	0.32	CD	E3	eq
06	21:27:37	46.8173	-120.3882	7.7*	1.0	Ml	011/019	112	0.25	CC	E3	eq
07	19:38:53	46.8003	-120.4012	10.4	1.3	Ml	017/024	59	0.30	CB	E3	eq

08	06:20:17	47.7115	-120.1048	7.8	0.4	Md	007/010	101	0.07	AB	N3	eq
08	21:42:52	47.8357	-120.8627	-1.5*	1.4	Ml	013/015	131	0.16	CB	C3	px
09	09:05:02	47.7082	-120.0948	5.2	0.6	Ml	008/011	98	0.05	AB	N3	eq
09	21:42:23	47.3808	-117.9037	-0.4	2.0	Ml	016/016	131	0.18	BD	N3	px
12	05:30:38	47.4052	-120.5993	5.8	1.5	Ml	016/021	95	0.21	BC	C3	eq
15	17:54:30	47.6420	-120.2953	3.0	0.8	Ml	007/012	99	0.09	AB	N3	eq
15	18:53:13	46.1588	-119.2755	-0.3*	1.0	Md	012/010	202	0.12	CD	E3	px
16	13:54:13	46.1820	-119.0782	12.6	1.4	Ml	017/022	106	0.17	BB	E3	eq
16	21:43:18	47.6748	-120.3913	-0.3*	1.5	Ml	008/011	108	0.09	CB	N3	eq
16	22:04:02	48.1643	-119.5700	3.8	1.1	Ml	009/012	138	0.16	CC	N3	eq
17	17:35:03	47.6335	-120.2485	-1.1	0.8	Ml	009/016	119	0.12	AB	N3	eq
17	20:04:29	46.5742	-120.3198	8.5	1.1	Ml	006/006	143	0.06	AC	E3	eq
17	23:44:45	44.1188	-121.3420	-1.6*	1.7	Ml	013/017	138	0.28	CC	E3	px
19	09:51:12	46.7102	-120.9170	6.3	0.9	Md	004/007	286	0.13	BD	C3	eq
19	11:30:46	46.6753	-120.9617	6.5	0.5	Ml	009/012	150	0.12	AC	C3	eq
19	13:05:27	46.6832	-120.9503	4.1	0.5	Ml	007/009	234	0.13	AD	C3	eq
19	13:37:14	46.6732	-120.9590	8.4	1.5	Ml	029/042	77	0.24	BB	C3	eq
19	14:37:02	46.6653	-120.9697	7.5	0.9	Ml	014/019	78	0.18	BB	C3	eq
19	15:28:11	46.6907	-120.9352	5.0	0.5	Ml	006/008	257	0.04	AD	C3	eq
21	03:52:56	46.6842	-120.9637	7.7	0.7	Ml	012/016	143	0.17	BC	C3	eq
22	22:06:07	47.6767	-120.1362	-0.5*	1.0	Md	004/007	139	0.11	CC	N3	eq
24	02:34:19	48.4155	-119.9747	0.1*	1.3	Ml	011/018	124	0.18	CC	N3	eq
24	04:17:39	48.2762	-119.1343	6.6	1.2	Ml	008/011	257	0.32	CD	N3	eq
24	08:16:01	46.8005	-120.8433	11.9	0.6	Ml	012/016	98	0.21	BB	C3	eq
24	16:06:01	46.6137	-119.8448	6.6	1.3	Ml	017/020	89	0.08	AA	E3	eq
24	16:14:38	46.6138	-119.8398	6.7	0.6	Ml	008/011	161	0.09	AC	E3	eq
24	16:24:47	46.6088	-119.8440	6.8	1.3	Ml	020/021	58	0.10	AA	E3	eq
24	18:48:25	46.6128	-119.8437	6.8	1.5	Ml	022/027	53	0.08	AA	E3	eq
24	22:30:08	46.6132	-119.8430	6.9	2.0	Ml	024/030	52	0.07	AA	E3	eq
24	23:59:11	46.6117	-119.8427	6.8	1.0	Ml	015/023	88	0.09	AA	E3	eq
25	02:36:59	46.6090	-119.8417	6.7	0.6	Ml	010/014	93	0.06	AB	E3	eq
25	06:17:25	46.6810	-119.8913	0.4*	0.5	Ml	007/009	303	0.21	CD	E3	eq
27	06:22:51	46.5945	-119.8728	6.9	0.5	Ml	012/015	145	0.07	AC	E3	eq
27	06:27:55	46.6113	-119.8418	6.7	1.3	Ml	028/034	94	0.09	AB	E3	eq
27	18:25:55	47.8392	-117.4237	-0.7*	1.9	Ml	009/013	168	0.47	CD	N3	px
27	23:52:35	47.5582	-120.2852	-1.0*	1.4	Ml	011/014	94	0.17	CC	N3	px
28	15:11:49	47.7503	-120.0162	-0.4*	1.0	Ml	007/010	106	0.09	CB	N3	eq
29	18:27:01	46.1493	-119.2805	-0.3*	1.5	Ml	013/016	169	0.13	CC	E3	px
30	09:07:20	46.0480	-118.7358	17.5	2.0	Ml	024/027	79	0.09	AB	E3	eq
30	22:12:38	46.4495	-120.6868	12.5	0.8	Ml	008/009	195	0.26	BD	E3	eq
August 2020												
03	19:09:10	47.4118	-117.9858	-0.5*	1.8	Ml	009/010	186	0.39	CD	N3	px
05	05:14:10	46.6233	-120.5325	16.9	0.9	Ml	027/038	97	0.34	CB	E3	eq
05	18:18:49	46.9525	-119.0782	-0.3*	1.5	Ml	008/007	162	0.05	CC	E3	px
06	11:24:26	46.7535	-120.0225	10.7	1.2	Ml	024/028	54	0.10	AB	E3	eq
07	23:27:27	48.5093	-120.9958	12.7*	0.8	Md	005/007	238	0.12	CD	C3	eq
08	10:18:12	46.6922	-118.2217	11.9	1.4	Ml	013/021	188	0.31	CD	E3	eq
09	18:44:20	46.5960	-119.8322	5.1	0.2	Ml	010/014	227	0.10	AD	E3	eq
10	01:18:47	47.6463	-120.2648	-0.6	1.3	Ml	013/011	99	0.06	AB	N3	eq
11	01:08:12	47.3532	-120.2328	0.2*	0.8	Ml	010/014	106	0.38	CC	N3	eq
11	22:02:26	47.3650	-117.8635	-0.4*	2.3	Ml	011/015	165	0.29	CD	N3	px
14	16:23:47	47.1928	-120.7852	-0.9*	1.3	Ml	008/006	212	0.30	DD	C3	px
15	21:57:48	47.6820	-120.2910	-0.5*	0.5	Md	007/009	94	0.06	CC	N3	eq

16	00:38:12	48.1443	-119.2522	5.6	1.0	Ml	008/010	182	0.06	BD	N3	eq
17	01:30:26	48.3532	-119.7775	0.3*	1.3	Ml	011/016	192	0.17	CD	N3	eq
17	05:03:13	46.5027	-119.8463	5.5	0.3	Ml	006/008	233	0.09	AD	E3	eq
17	10:35:58	48.3475	-119.7695	0.2*	1.2	Ml	010/015	212	0.24	CD	N3	eq
17	21:26:23	48.6163	-118.6462	-0.6*	1.9	Ml	008/012	150	0.48	CD	N3	px
18	08:39:26	48.6137	-119.5645	0.3*	1.2	Ml	009/015	135	0.30	CC	N3	eq
18	16:42:00	47.7043	-120.0737	6.3	1.1	Ml	009/013	105	0.08	AB	N3	eq
18	18:40:59	48.1858	-121.3525	0.4*	1.5	Ml	007/009	139	0.20	CC	C3	eq
18	21:13:10	45.8895	-120.2522	-0.5*	1.5	Ml	013/013	244	0.20	CD	E3	px
18	22:53:20	44.4070	-121.0493	-1.5*	2.0	Ml	011/014	172	0.28	CC	E3	px
19	20:04:58	47.1122	-120.7223	-0.9*	0.9	Ml	005/007	183	0.46	CD	C3	px
20	17:03:32	47.7228	-120.3110	4.8	0.9	Md	007/010	119	0.06	AC	N3	eq
22	15:53:07	46.2208	-119.5330	6.4	0.7	Ml	010/015	233	0.06	AD	E3	eq
23	11:47:02	47.6895	-120.3558	-0.7*	1.3	Ml	011/012	109	0.04	CB	N3	eq
23	18:53:36	45.7003	-119.1578	8.4	1.1	Ml	013/016	140	0.06	AC	E3	eq
24	06:35:28	47.6993	-120.1227	2.9	0.8	Ml	009/014	99	0.08	AB	N3	eq
25	09:25:29	46.6040	-119.8480	7.0	0.4	Ml	009/013	225	0.09	AD	E3	eq
27	22:25:58	48.2330	-121.3413	8.5	1.3	Ml	012/014	149	0.14	AC	C3	eq
28	14:32:32	48.2402	-121.4530	8.8	0.2	Ml	009/011	131	0.07	AC	C3	eq
29	16:20:53	47.6443	-120.3222	-0.6*	0.6	Ml	009/012	97	0.08	CB	N3	eq
30	22:52:43	47.6657	-120.1195	3.8	0.5	Md	005/008	155	0.11	AC	N3	eq
31	13:44:46	47.7170	-120.0520	4.3	0.8	Ml	009/015	73	0.07	AB	N3	eq
31	20:30:19	44.6545	-121.1575	-1.0*	1.9	Ml	010/011	184	0.18	CD	N3	px
September 2020												
03	10:38:06	47.9108	-120.6188	9.2	0.6	Ml	006/008	191	0.17	BD	C3	eq
04	14:02:23	47.6653	-120.2215	-0.4*	0.5	Ml	007/009	105	0.04	CB	N3	eq
04	15:44:10	47.7297	-120.2780	6.0	0.0	Md	004/008	128	0.79	DC	N3	eq
04	22:33:37	47.7470	-120.2812	6.0	0.1	Md	005/009	137	0.07	BC	N3	eq
05	15:31:03	46.3380	-119.3338	16.0	0.9	Ml	022/028	186	0.09	AD	E3	eq
06	14:03:59	47.6770	-120.0457	5.3	0.4	Ml	005/007	150	0.04	AC	N3	eq
06	16:03:33	48.0680	-120.7060	1.1*	0.9	Ml	009/013	151	0.22	CC	C3	eq
07	03:44:42	46.5600	-119.7975	23.3	1.3	Ml	029/040	46	0.10	AA	E3	eq
07	04:06:03	47.5825	-121.3632	9.3	1.0	Ml	012/020	82	0.24	BC	C3	eq
07	08:25:51	48.8405	-119.8098	0.3*	2.1	Ml	012/016	132	0.43	CD	N3	eq
07	17:03:14	47.9157	-120.8048	7.2	0.9	Md	004/007	176	0.06	AC	C3	eq
08	17:48:13	47.7003	-120.0288	5.3	0.7	Ml	009/013	77	0.09	AC	N3	eq
10	12:54:11	47.9297	-120.6127	2.9	0.6	Md	006/010	198	0.33	CD	C3	eq
10	16:03:29	48.5195	-121.3933	4.9	-0.2	Md	004/006	279	0.03	BD	C3	eq
11	00:33:18	44.2613	-120.8632	-1.6*	2.0	Md	015/018	194	0.20	CD	C3	px
11	05:55:51	47.7425	-120.0100	3.6	0.3	Ml	005/008	106	0.05	AB	N3	eq
11	10:59:54	47.0955	-120.5912	9.1	1.3	Ml	027/036	50	0.20	BA	N3	eq
11	17:34:09	46.3985	-118.9775	-0.2*	1.4	Ml	009/010	171	0.22	CC	E3	px
12	16:41:57	46.6123	-119.8460	6.8	1.6	Ml	024/032	53	0.10	AA	E3	eq
13	19:52:44	46.6000	-119.8535	6.8	0.4	Ml	011/017	89	0.07	AA	E3	eq
13	20:59:26	48.2427	-121.3207	7.2	0.5	Ml	007/010	167	0.15	BC	C3	eq
14	05:41:33	47.0508	-121.0128	3.8	2.0	Ml	030/048	85	0.25	BC	C3	eq
14	18:18:22	47.6825	-120.1485	-0.6*	0.8	Ml	010/014	94	0.07	CB	N3	eq
16	08:09:52	46.8488	-119.5057	12.7	1.1	Ml	030/043	50	0.13	AA	E3	eq
16	14:57:34	46.6058	-119.8648	6.2	1.0	Ml	012/017	94	0.06	AB	E3	eq
16	21:51:28	47.3972	-117.8640	-0.5*	2.0	Ml	010/013	164	0.36	CD	N3	px
16	23:46:56	47.9482	-120.7335	1.1*	1.0	Md	005/008	209	0.27	CD	C3	eq
18	03:04:40	47.6997	-120.0280	-0.3*	0.0	Md	005/008	126	0.04	CB	N3	eq
19	05:50:15	46.4865	-119.7240	5.8	-0.1	Ml	007/010	214	0.07	AD	E3	eq

19	15:06:25	46.9415	-120.6972	7.1	1.5	Ml	032/035	79	0.30	CA	E3	eq
19	17:46:20	47.7413	-119.9908	5.5*	-0.2	Md	002/004	182	0.03	DD	N3	eq
19	17:50:56	47.6497	-120.1632	4.8	0.3	Ml	005/008	118	0.03	AB	N3	eq
20	04:27:51	47.6648	-120.2022	4.0	-0.2	Md	004/007	161	0.05	BC	N3	eq
22	01:13:21	46.6050	-119.8648	6.1	0.6	Ml	015/020	92	0.08	AB	E3	eq
22	17:01:08	45.8292	-118.3515	-0.3	2.0	Ml	012/015	132	0.29	BB	E3	eq
25	07:53:51	46.8212	-119.7372	0.1*	0.7	Ml	009/011	146	0.08	CC	E3	eq
25	18:11:33	48.3357	-117.8993	-0.6*	1.6	Ml	003/006	246	0.92	DD	N3	px
26	20:40:16	47.7330	-120.2017	-0.7*	1.1	Ml	009/014	124	0.15	CC	N3	eq
26	22:44:44	47.7355	-120.1987	1.0	0.7	Ml	006/010	139	0.05	BC	N3	eq
27	01:41:56	45.6995	-119.1455	10.2	1.4	Ml	020/025	241	0.15	BD	E3	eq
27	10:44:48	46.5583	-119.8442	8.7	0.6	Ml	012/020	139	0.09	AC	E3	eq
28	02:29:39	45.5533	-120.1392	17.4	1.5	Ml	015/021	202	0.20	BD	E3	eq
29	16:20:14	46.7458	-120.9553	7.2	1.1	Ml	016/021	124	0.11	AB	C3	eq
30	03:54:26	48.7097	-119.9725	2.9*	1.3	Ml	009/012	146	0.20	CD	N3	eq
30	23:49:25	46.0575	-188.7997	-0.4*	1.6	Ml	009/012	154	0.33	CC	E3	px

5.0 Discussion of Seismic Activity – FY 2020

5.1 Summary

During FY2020, seismic activity was relatively quiet throughout eastern Washington. 333 earthquakes were cataloged in the region, of which about 31% (102) 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 just northeast of the Cold Creek and the Saddle Mountain Swarm Areas.

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 2020

Category	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2020
Shallow (0-4 km deep)	15	31	19	33	98
Intermediate (4-9 km deep)	36	35	35	56	162
Deep (greater than 9 km deep)	14	10	29	20	73
Total	**65**	**76**	**83**	**109**	**333**
Felt	1	0	2	0	3
Probable Blast	18	25	26	23	92

Table 5.2. Earthquake Counts for FY 2020 for Earthquakes near the Hanford Site

Seismic Source Zones	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2020
Frenchman Hills	0	0	0	0	0
Saddle Mountains	1	1	0	1	3
Wahluke Slope	0	0	0	0	0
Coyote Rapids	2	1	0	0	3
Wye	0	0	0	0	0
Cold Creek	1	0	2	2	5
Rattlesnake Mountain	0	0	0	0	0
Horse Heaven Hills	0	0	1	0	1
Total for swarm areas	4	2	3	3	12
Random Events	27	14	24	25	90
Total For All Earthquakes	**31**	**16**	**27**	**28**	**102**

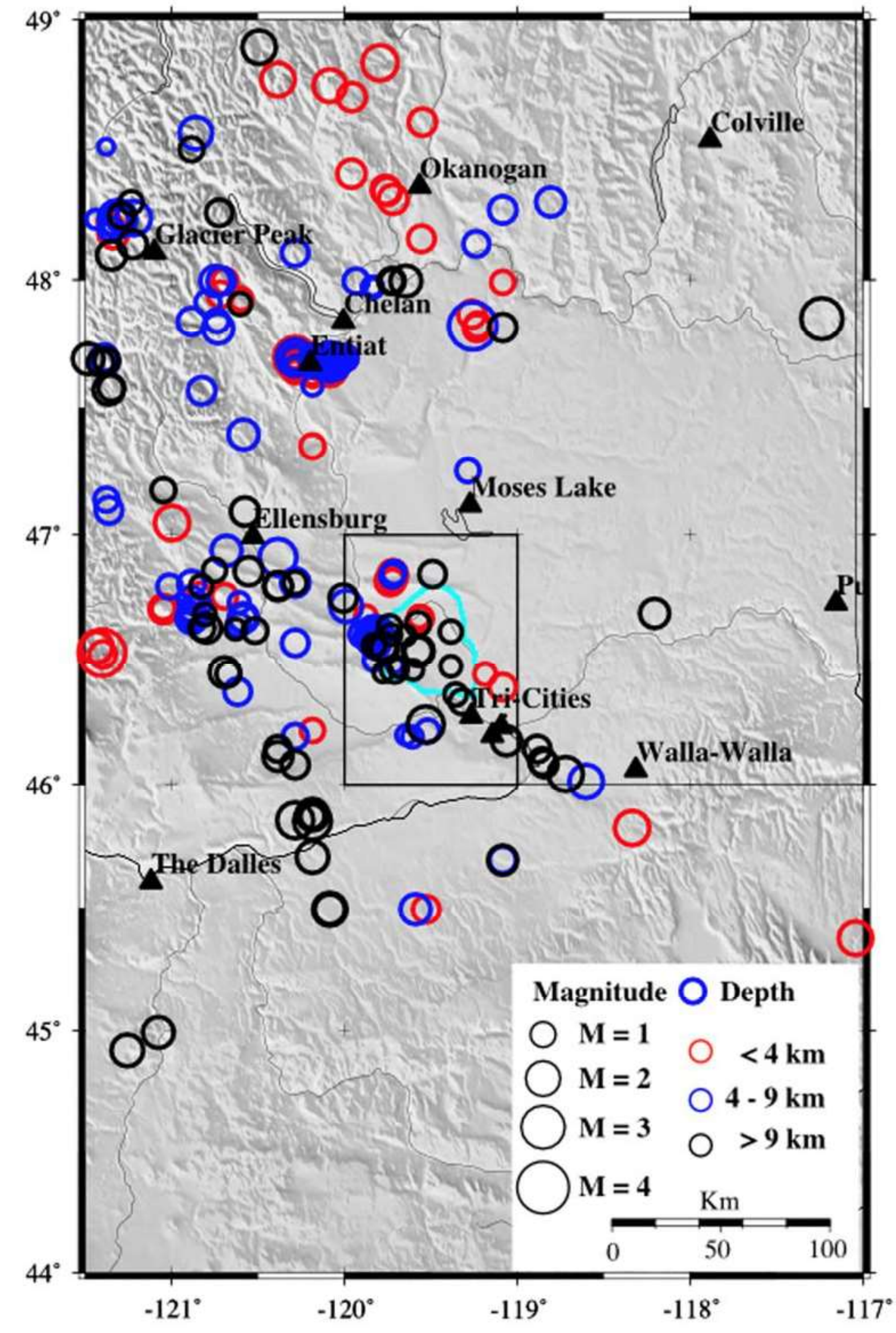

Figure 5.1. Hanford and Regional Epicenters of Earthquakes Recorded during FY 2020

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 FY2020 Seismicity Near HNR: Very Small and Very Slow

The largest earthquake during the year near the Hanford Site was an M2.2 event 15 km deep just to the west of Benton City and just south of the HNR (see Figure 5.2a). Only 2 people reported feeling it, but it was well recorded by the recently upgraded stations across the Hanford Nuclear Facility (HNF). As exemplified in Figure 5.2b and5.2c, the modern network stations are recording earthquakes as small as M0.5 at HNR. The microseismicity rate was slow and quite steady throughout the year. As is often the case, even this sparse seismicity is dominated by earthquakes in one or two local “swarms” that periodically show activity for a while, then calm down. This year continuing swarm activity in the northwest corner of the HNR (Midway), and a less active swarm under the northwest slope of the Wahluke ridge dominated the otherwise diffuse sprinkling of epicenters.

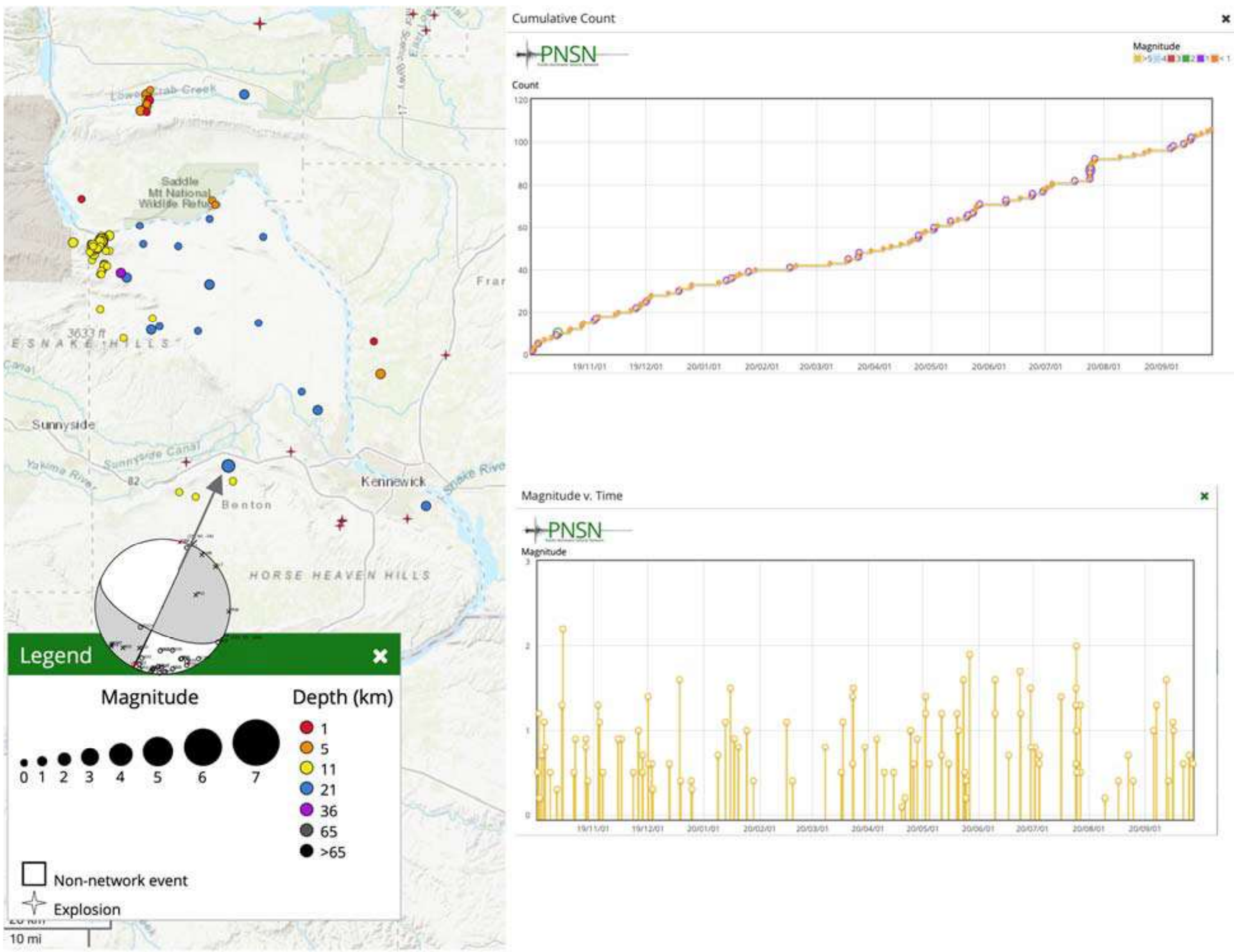

Figure 5.2. Locations and Occurrence Characteristics of Hanford Site Earthquakes in FY2020

a) left panel: map of epicenters of earthquakes located between 1 October 2019 and 30 September 2020 in the immediate vicinity of the Hanford Site. Epicenters are color coded by depth. The M2.2 earthquake discussed in the text is indicated by the arrow that shows the focal mechanism (revealing the 2 possible orientations of the fault and the associated direction of slip). b) upper right panel: cumulative count of earthquakes throughout FY2020. c) lower right panel: magnitude vs. time for all HNR FY2020 earthquakes.

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. FY2020, by contrast, has been a year marked by continuity in field activity, not station upgrades as in previous years. Network enhancements have been rather more focused on processing techniques and in-shop procedural advancements.

For example, in the last annual report, it was noted that data from the newly upgraded stations and complementary network telemetry enhancements has enabled PNSN to provide timely Earthquake Early Warnings (EEW) from the ShakeAlert EEW system that is being implemented on the west coast. Figure 6.1 illustrates that in order to drive down data delivery latency we have to develop new tools to test and track station telemetry performance. In this example we show how fast the delivery of data to the ShakeAlert system is over time. The visualization allows network engineering staff to detect patterns and mitigate potential problems before they degrade network performance. The obvious next step will be to study and to deploy machine learning techniques that may be able to recognize subtle but consequential patterns currently opaque to our visual and more intuitive methods.

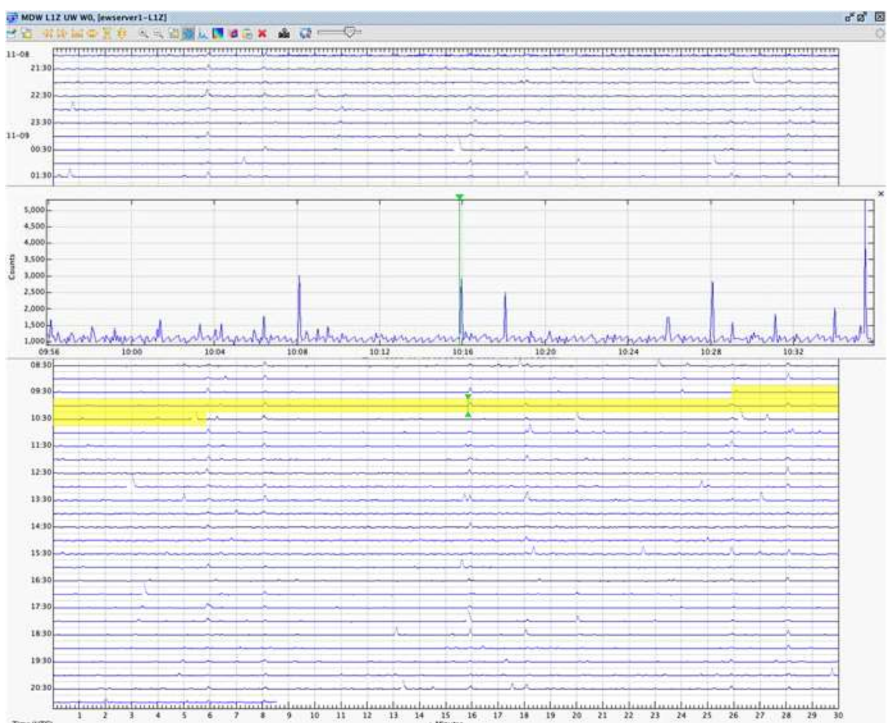

Figure 6.1. Illustration of Data Delivery Latency

This figure is a time series of latency…i.e., the time difference between when the ground moves at the station and when information about it is useable in PNSN's Seattle office. A one-day record is shown, each line covers 30 minutes and overall patterns of occasional periodic and random latency spikes can be seen. The inset is an expansion of the time period in yellow highlight and shows that the base latency is about a very healthy 1 second, and the larger periodic spikes are 2-3 seconds long and about 2-3 seconds in duration. This information is critical to tracking and fixing the source of the spikes.

7.0 References

Campbell NP. 1989. "Structural and Stratigraphic Interpretation of Rocks under the Yakima Fold Belt, Columbia Basin, Based on Recent Surface Mapping and Well Data." In *Volcanism and Tectonism in the Columbia River Flood-Basalt Province*, SP Reidel and PR Hooper (eds.), Special Paper 239, pp. 209–222. Geological Society of America, Boulder, Colorado.

Crosson RS. 1972. "Small Earthquakes, Structure, and Tectonics of the Puget Sound Region." *Bulletin of the Seismological Society of America* 62(5):1133–1171.

DOE. 1988. *Site Characterization Plan for the Reference Location, Hanford, Washington – Consultation Draft*. DOE/RW-0164, Vol. 1, U.S. Department of Energy, Washington, D.C.

DOE Order 420.1C, Chapter IV, Section 3.e. "Seismic Detection." U.S. Department of Energy, Washington, D.C.

DOE Order G 420.1-1A, Section 5.4.8. "Design for Emergency Preparedness and Emergency Communications." U.S. Department of Energy, Washington, D.C.

Fenneman NM. 1931. *Physiography of Western United States*. McGraw-Hill Book Company, Inc., New York.

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

Integrated Science Solutions, Inc., 2014. *Hanford Site Seismological Network Review and Recommendations for Network Reconfiguration.* ISSI. Walnut Creek, California.

Moore C and SP Reidel. 1996. *Hanford Site Seismic Monitoring Instrumentation Plan*. WHC-SD-GN-ER-30036, Westinghouse Hanford Company, Richland, Washington.

Reidel SP and KR Fecht. 1994a. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington*. Open File Report 94-8, Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia.

Reidel SP and KR Fecht. 1994b. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle*, *Washington*. Open File Report 94-13, Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia.

Reidel SP, KR Fecht, MC Hagood, and TL Tolan. 1989. "Geologic Development of the Central Columbia Plateau." In *Volcanism and Tectonism in the Columbia River Flood-Basalt Province*, SP Reidel and PR Hooper (eds.), Special Paper 239, pp. 247-264. Geological Society of America, Boulder, Colorado.

Reidel SP, NP Campbell, KR Fecht, and KA Lindsey. 1994. "Late Cenozoic Structure and Stratigraphy of South-Central Washington." In *Regional Geology of Washington State,* E Cheney and R Lasmanis (eds.), Bulletin 80, pp. 159-180. Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia.

Richter CF. 1958. *Elementary Seismology*. W. H. Freeman & Company, San Francisco, California.

Rohay AC, DW Glover, and SD Malone. 1985. *Time-Term Analysis of Upper Crustal Structure in the Columbia Basin, Washington*. RHO-BW-SA-435 P, Rockwell Hanford Operations, Richland, Washington.

Rohay AC, MD Sweeney, DC Hartshorn, RE Clayton, and JL Devary. 2010b. *Second Quarter Seismic Report for Fiscal Year 2010*. PNNL-19513, Pacific Northwest National Laboratory, Richland, Washington.