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Hanford Seismic Report for Fiscal Year 2022 (October 2021 - September 2022)

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Executive Summary

The Pacific Northwest Seismic Network (PNSN) and Hanford Mission Integration Solutions (HMIS) 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 FY 2022, seismic activity was relatively quiet throughout eastern Washington. 316 earthquakes were cataloged in the region, of which about 25% (78) 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 low to typical swarm-type activity, most strongly observed near the Horse Heaven and Wye Swarm Areas.

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
HMIS	Hanford Mission Integrated Solutions, LLC
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) 2022 (October 2021 through September 2022). Hanford Mission Integrated Solutions, LLC manages seismic monitoring for the Hanford Site with the monitoring work being performed by the PNSN under a sub-contract with the University of Washington (UW).

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, which 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 FY 2011, administration of the seismic monitoring networks was assumed by HLSMP and contracted to be operated by the PNSN, University of Washington.

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 are permanently archived at the Incorporated Research Institutions in Seismology (IRIS) seismic data archive in Seattle, with backup copies at IRIS facilities in Seattle and 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-wave-length 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 form 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.

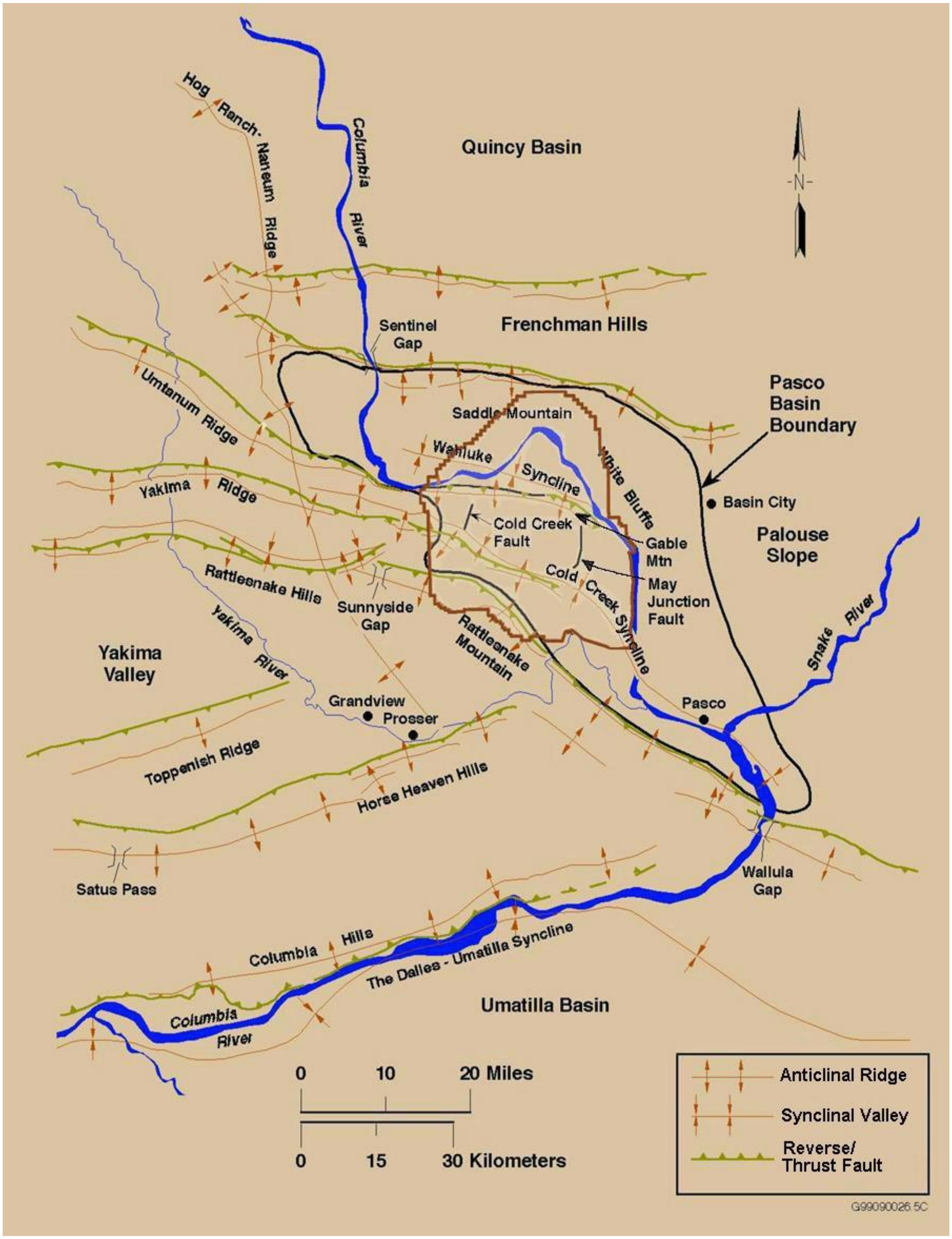

Figure 2.1. Tectonic Features of the Hanford Site within Eastern Washington

(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, one HLSMP short-period station records 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.

Five 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. An additional 16 sites record 6 channels of seismic data, three components of strong motion accelerometer data and three components of high-gain broadband data. 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 HMIS 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)
Strong motion and Broadband, 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
Strong motion and Short Period, 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
Broadband, 3-Channel Station				
LIGO	46.4617	-119.4177	158	LIGO Observatory
Short Period, Single Channel Analog				
BEN	46.5186	-119.7185	335	Benson Ranch
LOC	46.7169	-119.4320	210	Locke Island
RSW	46.3944	-119.5925	1045	Rattlesnake Mountain

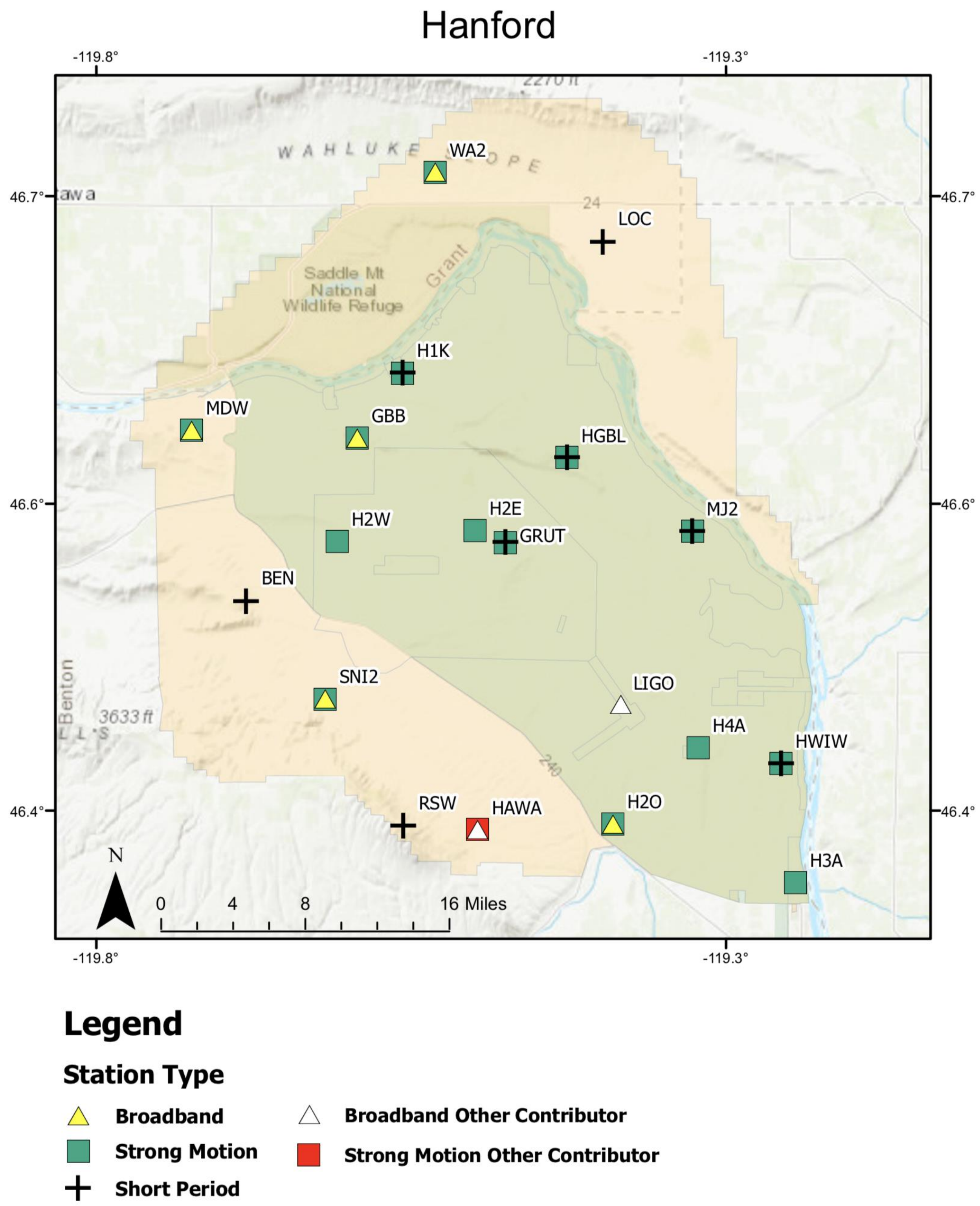

Figure 3.1. Hanford Seismic Network Onsite Stations

Table 3.2. Hanford Seismic Network Offsite Stations

Station	Latitude	Longitude	Elevation (m)	Station Name
Strong Motion and Broadband, 6-Channel Station				
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	Linction Mountain Oregon
MANO	46.9511	-120.7247	1200	Manatash Ridge Observatory
MOX	46.5772	-120.2993	501	Moxee City
OD2	47.388	-118.7108	553	Odessa 2
OT3	46.6689	-119.2341	322	Othello 3
PHIN	45.8950	-119.9280	227	Phinney Hill
PRO	46.2125	-119.6868	553	Prosser
YPT	46.0487	-118.9634	325	Yellepit
Short Period, Single-Channel Analog				
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
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
Short Period, 3-Channel Analog				
FHE	46.9518	-119.4981	455	Frenchman Hills East

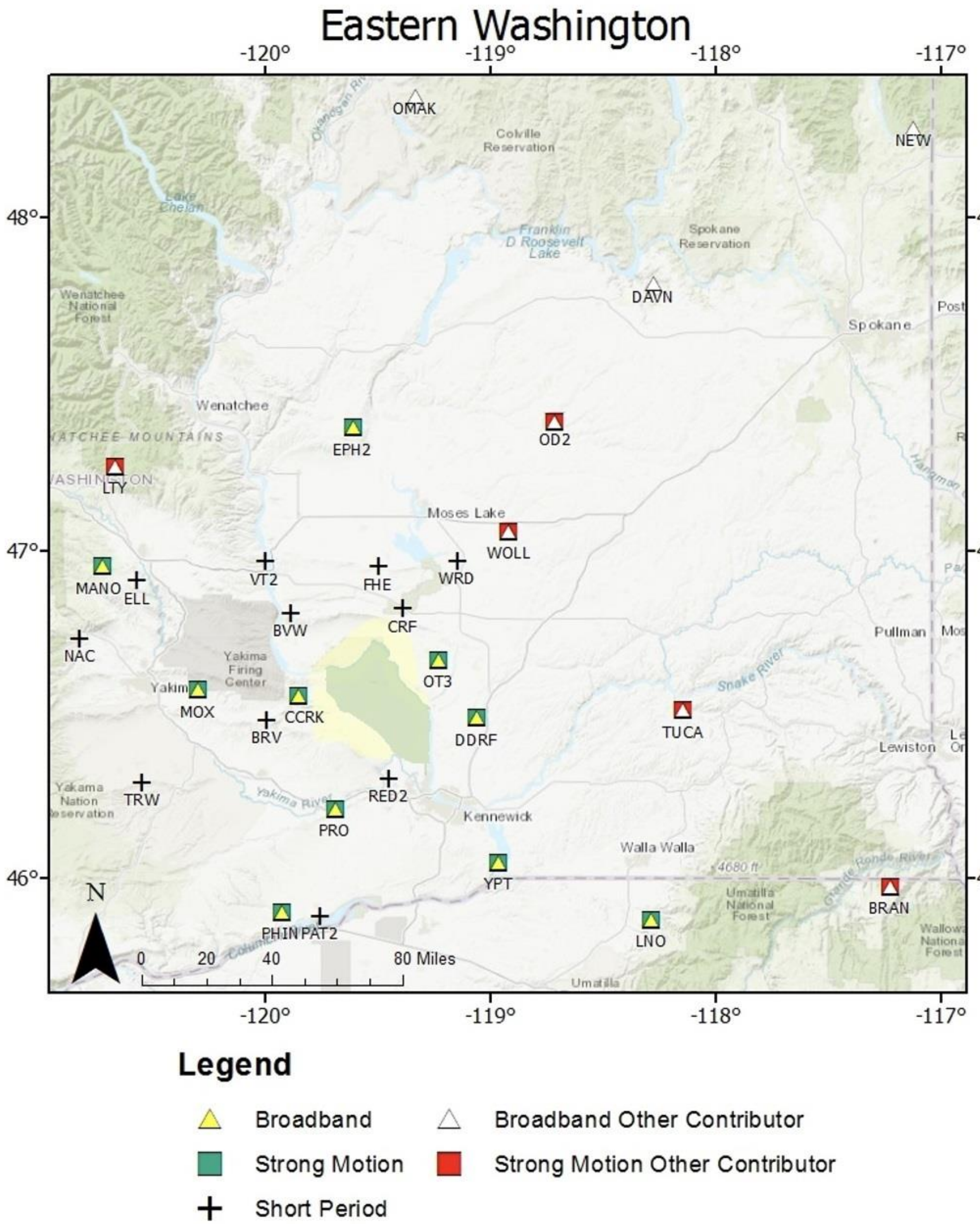

Figure 3.2. Hanford Seismic Network Stations of the Eastern Washington Region Sub-Network

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 145 combined data channels from: 14 single channel sites, 2 three-component seismometer sites (FHE and LIGO), 16 six-component sites (CCRK, DDRF, EPH2, GBB, H2O, LNO, MANO, MDW, MOX, OD2, OT3, PHIN, 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 three component sensors 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 15 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 conduits 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 (H3A, H4A, H2E, H2W) 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 Kinemetrics Basalts with 3 SMA channels that are supplemented by a high-gain vertical short-period sensor. Five sites have a broadband and strong-motion sensor packaged in a single casing that is deployed in a shallow posthole, Nanometrics Trillium Cascadia and a Centaur datalogger (GBB, H2O, MDW, SNI2, WA2).

A cell modem or digital radio 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 and 6-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. Acoustic signals are identified by their slower propagation across the network (soundwave speed) compared to seismic signals (elastic wave speed in rocks). All data are continuously telemetered, recorded, and 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 (Hartog et al., 2020). We currently run Earthworm version 7.10 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 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 (Hartog et al., 2020). 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 (44°-49° north latitude, 117°-121.5° west longitude) are reported in Table 4.2. 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 "wave speed model" (MOD), to solve for the most likely location for the earthquake source. AQMS divides the eastern Washington and Oregon region into 3 sub-regions. The wave speed 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 wave speed models to account for significant deviations in station elevations or stations situated on sedimentary layers. Station delays are determined empirically from accurately located earthquakes and blast events in the region.

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

Depth to Top of Layer (km)	Layer	Wave speed (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 three-component broadband stations. 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 2022 Earthquake Catalog for Eastern Washington

Table 4.2. Seismicity in the region 44° to 49° N latitude, -121.5° to -117° E longitude.

Day	Time	Lat	Lon	Depth	Mag	Mtype	NS/NP	Gap	Rms	Q	Mod	Type
October 2021												
02	14:37:12	47.7008	-120.2853	3.7	0.2	Ml	008/014	91	0.08	AB	N3	eq
04	20:52:45	47.6028	-120.3992	8.1	0.8	Md	007/013	121	0.20	BB	N3	eq
05	13:49:46	47.7130	-120.0273	7.0	0.9	Ml	015/025	63	0.10	AA	N3	eq
05	17:59:48	47.7893	-117.4145	-0.6*	2.0	Ml	009/014	108	0.18	CC	N3	px
06	04:10:26	48.5265	-119.7025	0.3*	1.6	Ml	012/013	121	0.16	CC	N3	eq
07	22:01:05	46.4550	-119.0477	-0.2*	1.3	Ml	008/008	225	0.14	CD	E3	px
07	23:26:13	47.2328	-118.1218	-0.4*	2.0	Ml	006/008	311	0.05	CD	N3	px
08	05:26:15	47.7273	-120.3053	3.2	0.4	Ml	010/016	94	0.05	AB	N3	eq
08	19:01:22	47.6685	-120.2902	3.9	0.1	Md	006/010	110	0.06	AB	N3	eq
08	20:55:13	47.1848	-118.2717	-0.5*	1.8	Ml	008/007	286	0.07	CD	N3	px
08	21:36:47	48.8793	-119.9158	0.8*	1.6	Ml	008/009	120	0.14	CC	N3	eq
11	23:00:46	46.7677	-118.2373	-0.3*	1.4	Ml	011/014	166	0.82	DC	E3	px
11	23:59:44	44.4042	-121.0550	-1.3*	1.9	Ml	009/008	132	0.23	CB	E3	px
14	19:03:30	47.3145	-121.1953	-1.0*	1.4	Ml	010/011	184	0.17	CD	C3	px
14	22:07:06	46.8950	-117.3555	-0.9*	2.1	Ml	009/013	132	0.67	DC	E3	px
15	20:21:12	48.9140	-121.1458	3.5	1.9	Ml	009/014	143	0.33	CC	C3	eq
16	11:05:05	47.6893	-120.3587	-0.3*	0.6	Ml	012/020	90	0.07	CB	N3	eq
16	22:27:56	47.6632	-120.2337	3.9	0.2	Md	006/011	111	0.05	AB	N3	eq
18	21:42:57	48.4108	-120.3573	-1.2	0.7	Md	007/010	191	0.13	BD	C3	eq
23	12:57:32	48.2887	-118.6950	1.9*	1.6	Ml	012/013	228	0.15	CD	N3	eq
31	07:39:32	47.7107	-120.2400	2.1	0.2	Ml	008/013	139	0.09	AC	N3	eq
31	17:48:34	47.7100	-120.2982	5.4	0.5	Ml	011/018	96	0.07	AB	N3	eq
November 2021												
02	04:49:10	46.7148	-119.1848	19.5	1.4	Ml	022/031	78	0.14	AB	E3	eq
03	11:11:16	46.6880	-120.9967	0.1*	1.0	Ml	010/015	130	0.12	CC	C3	eq
03	17:38:46	47.5737	-121.3793	8.8	1.3	Ml	026/034	59	0.20	BB	C3	eq
03	21:36:12	47.7363	-120.0247	3.5	1.0	Ml	009/016	66	0.11	AB	N3	eq
05	00:22:33	44.2538	-121.3240	-1.5*	1.0	Md	004/004	249	0.01	CD	N3	px
05	20:42:00	45.0807	-121.3333	-1.3*	0.9	Md	006/006	153	0.07	CC	N3	px
08	20:43:19	48.4615	-121.4742	9.1	1.6	Ml	015/018	134	0.13	AB	C3	eq
09	12:02:41	47.6787	-120.0172	3.2	0.7	Md	009/015	91	0.06	AB	N3	eq
11	20:47:56	45.6523	-120.3892	-0.6*	1.8	Ml	013/014	141	0.26	CC	E3	px
13	04:29:14	47.8727	-120.9310	3.6	1.5	Ml	018/020	78	0.09	AA	C3	eq
14	15:27:59	46.8202	-119.8842	22.5	2.1	Ml	039/045	45	0.13	AA	E3	eq
15	02:21:51	47.7177	-120.3267	3.3	1.5	Md	012/018	81	0.06	AB	N3	eq
19	16:56:18	47.7533	-120.4888	3.2	1.2	Ml	010/012	97	0.11	AB	N3	eq
21	20:21:07	47.6605	-120.1938	3.1	1.3	Ml	017/022	93	0.05	AB	N3	eq
22	07:09:38	47.8850	-120.8530	4.8	0.9	Ml	010/011	96	0.06	AB	C3	eq
22	10:32:40	46.4033	-121.3028	6.5	1.4	Ml	010/011	221	0.09	BD	C3	eq
24	07:45:48	47.6647	-120.3260	0.9	0.3	Ml	007/011	202	0.05	BD	N3	eq
29	16:55:15	47.7238	-120.3057	4.3	0.4	Ml	008/014	95	0.11	AB	N3	eq
29	21:00:52	46.9647	-119.1157	-0.3*	1.9	Ml	006/007	141	0.27	CC	E3	px
30	09:15:59	47.7457	-120.1198	6.1	-0.2	Md	004/006	177	0.07	AC	N3	eq
December 2021												
01	12:18:14	48.7538	-120.9978	-0.1	1.8	Ml	017/023	139	0.26	BD	C3	eq
01	19:58:28	47.3610	-117.8690	-0.5*	1.9	Ml	007/008	295	0.49	DD	N3	px
02	21:17:14	46.7617	-117.9032	-0.3*	1.8	Ml	013/015	228	0.40	CD	E3	px
03	18:10:03	45.6212	-120.9855	-1.3*	1.8	Ml	009/010	291	0.11	CD	C3	px
05	04:38:09	48.6965	-119.4937	0.3*	1.6	Ml	009/011	169	0.15	CC	N3	eq

05	08:11:56	48.7017	-119.4882	-0.6	1.6	Ml	010/013	166	0.16	BC	N3	eq
05	17:53:33	48.7493	-120.9840	-0.3	1.7	Ml	013/017	193	0.31	CD	C3	eq
05	21:21:29	48.6987	-120.2362	9.6	3.1	Ml	028/037	87	0.27	BC	C3	eq
05	22:27:54	48.7552	-121.0028	-0.0	1.2	Ml	014/016	193	0.28	BD	C3	eq
05	23:13:12	47.9082	-120.7603	0.2	1.0	Md	008/013	108	0.09	CB	C3	eq
06	00:07:24	48.7157	-119.4850	0.4*	1.3	Ml	009/013	172	0.27	CC	N3	eq
06	00:09:13	47.9077	-120.7600	0.4	1.1	Md	009/013	108	0.11	CB	C3	eq
06	04:45:02	48.7027	-119.4775	0.2*	2.4	Ml	016/018	172	0.09	CC	N3	eq
06	07:15:23	48.7043	-119.4755	0.3*	2.2	Ml	011/012	173	0.09	CC	N3	eq
06	08:55:30	48.7017	-119.4922	0.1*	2.4	Ml	013/017	169	0.12	CC	N3	eq
06	10:47:07	48.7020	-119.4903	0.7*	1.6	Ml	012/014	171	0.16	CC	N3	eq
06	10:58:25	47.6940	-120.3425	-1.1	0.5	Ml	008/012	123	0.06	AB	N3	eq
10	00:00:05	45.9198	-119.3002	-0.3*	1.8	Ml	014/019	203	0.31	CD	E3	px
10	17:13:30	47.8605	-120.7855	16.0	1.5	Md	005/007	138	0.07	BC	C3	eq
10	19:18:07	46.4360	-119.0205	-0.2*	1.3	Ml	012/014	152	0.14	CC	E3	px
13	05:21:43	48.1892	-120.8035	4.2	1.5	Ml	012/018	165	0.17	BC	C3	eq
13	10:08:23	48.1983	-120.8203	5.5	1.2	Ml	011/015	122	0.15	BC	C3	eq
14	08:16:23	48.7602	-120.9955	9.4*	1.9	Ml	019/027	80	0.41	CD	C3	eq
14	09:55:30	47.6822	-120.4452	8.9	2.0	Ml	026/028	109	0.15	BB	N3	eq
14	12:31:33	48.7580	-120.9803	0.2	1.6	Md	015/018	141	0.33	CD	C3	eq
15	04:51:09	45.1353	-120.9360	14.8	1.1	Ml	005/008	130	0.20	BB	C3	eq
15	08:44:26	48.1930	-120.8040	1.9	1.0	Md	007/011	167	0.16	BC	C3	eq
16	09:16:14	47.6862	-120.3320	-0.0*	0.3	Ml	006/008	209	0.06	CD	N3	eq
16	19:35:05	46.2447	-119.4747	-0.3*	2.2	Md	012/014	140	0.13	CC	E3	px
17	12:40:17	47.4223	-120.5038	1.2	1.8	Ml	024/032	72	0.26	BC	N3	eq
18	16:29:31	47.5953	-120.2313	7.1	0.6	Md	007/012	161	0.05	AC	N3	eq
18	19:10:59	47.6988	-120.0152	2.9	0.3	Ml	006/009	131	0.06	AB	N3	eq
19	03:16:59	47.6277	-120.2893	5.0	0.5	Ml	006/010	139	0.08	AC	N3	eq
23	22:21:32	48.6515	-119.8960	0.1*	1.7	Ml	009/012	136	0.16	CC	N3	eq
25	05:47:17	44.5538	-120.2630	7.2*	2.0	Ml	022/029	201	0.40	CD	N3	eq
29	08:09:50	46.6055	-119.7993	7.6	0.9	Ml	018/026	75	0.12	AA	E3	eq
30	06:41:24	48.1188	-120.6542	-0.7	1.8	Ml	022/031	105	0.25	BC	C3	eq
30	12:03:14	47.6805	-120.3212	2.2	1.3	Ml	014/021	110	0.07	AB	N3	eq
30	17:06:26	48.1112	-120.6578	7.0	1.2	Ml	012/022	104	0.20	BC	C3	eq
31	03:46:50	47.7205	-120.3175	5.4	2.1	Ml	022/029	78	0.10	AB	N3	eq
January 2022												
05	03:02:58	47.5618	-117.2928	0.1*	1.9	Ml	014/008	157	0.09	CC	N3	eq
06	23:26:14	46.6235	-120.6698	-0.7*	1.7	Ml	013/014	151	0.80	DC	E3	px
08	20:06:47	46.2550	-119.5487	7.2	0.7	Ml	011/019	195	0.06	AD	E3	eq
08	20:12:11	46.2512	-119.5512	8.2	0.4	Ml	008/013	197	0.07	AD	E3	eq
08	22:14:50	46.2560	-119.5477	6.8	0.7	Ml	011/019	193	0.08	AD	E3	eq
08	23:34:28	46.2533	-119.5477	6.8	0.4	Ml	009/012	197	0.04	AD	E3	eq
10	00:33:38	45.5358	-119.5757	5.8	1.4	Ml	015/020	130	0.31	CC	E3	eq
10	13:20:37	48.2282	-121.3280	8.2	1.9	Ml	017/026	104	0.34	CC	C3	eq
11	20:57:26	45.8875	-119.3002	-0.3*	1.5	Ml	009/014	215	0.17	CD	E3	px
13	04:31:54	46.9482	-119.1305	12.1	1.0	Ml	018/027	109	0.21	BB	E3	eq
14	03:24:59	46.1460	-119.8475	23.5	1.1	Ml	020/031	107	0.11	AB	E3	eq
14	10:01:34	46.1423	-119.8402	21.8	1.3	Ml	018/027	69	0.13	AA	E3	eq
18	13:52:40	47.6820	-120.2528	3.8	0.2	Md	006/011	137	0.04	AC	N3	eq
18	20:37:43	46.1040	-118.7713	-0.3*	1.6	Ml	008/005	158	0.09	CD	E3	px
18	22:49:27	46.5592	-117.7548	-0.6*	1.6	Ml	012/013	111	0.25	CC	E3	px
18	23:03:35	46.5902	-117.7800	-0.2*	2.2	Ml	013/016	319	0.47	CD	E3	px
18	23:15:45	44.6587	-121.1747	-1.1*	1.3	Ml	008/008	179	0.09	CC	E3	px
19	04:44:26	46.6927	-121.0792	13.9	0.7	Ml	016/022	138	0.11	AC	C3	eq

19	05:21:16	46.6937	-121.0777	12.8	0.8	Ml	019/026	138	0.14	BC	C3	eq
19	22:59:32	46.2658	-119.3985	-0.3*	1.9	Ml	024/025	168	0.12	CC	E3	px
22	23:41:45	47.7738	-120.7950	2.6	1.4	Ml	018/029	59	0.25	BC	C3	eq
25	00:27:16	46.6487	-119.8133	0.2*	0.6	Ml	008/008	132	0.04	CB	E3	eq
26	09:17:45	47.7138	-120.3108	1.9	1.3	Ml	014/022	84	0.06	AB	N3	eq
26	18:59:15	47.6557	-118.1255	3.6	1.8	Ml	009/009	144	0.09	AD	N3	eq
February 2022												
02	21:06:44	45.8925	-119.3028	-0.3*	1.3	Ml	007/007	178	0.24	CC	E3	px
03	08:35:53	46.6078	-119.8430	6.5	1.1	Ml	013/018	129	0.07	AB	E3	eq
04	01:39:05	47.7377	-120.0245	4.2	1.2	Ml	011/017	91	0.06	AB	N3	eq
04	19:01:11	44.0177	-121.2373	-1.6*	1.9	Ml	011/009	148	0.06	CC	N3	px
04	20:55:01	44.3818	-121.0652	-1.4*	1.7	Ml	006/006	197	0.07	CD	N3	px
07	03:57:03	47.7078	-120.2535	3.2	0.4	Ml	011/019	78	0.06	AA	N3	eq
08	14:35:02	48.2475	-120.8822	8.9*	1.6	Md	007/013	131	0.30	CC	C3	eq
09	09:46:05	47.6813	-120.2513	2.4	0.4	Ml	007/012	84	0.04	AA	N3	eq
09	19:36:49	47.6695	-120.1613	1.9	0.4	Ml	006/011	126	0.07	AB	N3	eq
10	10:15:38	47.6382	-120.2948	5.2	0.4	Md	009/009	114	0.03	AB	N3	eq
11	16:53:35	46.2633	-119.5377	5.5	0.6	Ml	006/009	285	0.05	AD	E3	eq
11	19:54:14	46.2763	-119.4970	9.6	0.6	Ml	005/008	285	0.06	BD	E3	eq
12	00:46:43	44.0190	-120.9052	-1.7*	2.0	Ml	008/007	307	0.12	CD	E3	px
12	01:54:42	46.2623	-119.5375	6.1	0.5	Ml	007/012	192	0.05	AD	E3	eq
12	06:19:40	45.9950	-118.6427	8.0	1.8	Ml	021/029	86	0.17	BA	E3	eq
12	12:52:20	46.2822	-119.4843	9.7	0.0	Md	004/006	284	0.02	CD	E3	eq
13	15:00:23	47.6447	-120.1442	3.1	0.1	Ml	006/009	117	0.07	AB	N3	eq
14	00:29:36	47.7113	-120.4118	2.7	0.3	Md	005/008	149	0.03	BC	N3	eq
15	21:05:05	46.2512	-119.6518	-0.5*	1.9	Ml	008/011	145	0.04	CC	E3	px
17	08:39:05	48.1928	-121.2907	9.6	1.0	Md	005/008	157	0.05	AC	C3	eq
18	19:58:12	46.2838	-117.9523	-0.4*	1.9	Ml	021/024	234	0.22	CD	E3	px
19	02:37:37	48.7523	-120.9995	8.9*	1.2	Ml	012/015	139	0.23	CD	C3	eq
19	05:36:39	46.9175	-120.5600	-0.7	1.1	Ml	017/025	108	0.65	DB	E3	eq
19	19:20:42	46.5990	-119.8685	6.7	2.2	Ml	031/046	51	0.11	AA	E3	eq
19	19:37:29	46.5997	-119.8653	6.6	1.9	Ml	029/036	51	0.09	AA	E3	eq
24	22:02:21	46.0917	-119.5227	-0.4*	1.6	Ml	008/011	207	0.07	CD	E3	px
25	00:37:08	47.2890	-117.8605	-0.6*	2.2	Ml	008/008	176	0.23	CC	N3	px
25	07:48:25	46.8170	-119.4253	0.1*	0.5	Ml	010/017	102	0.09	CB	E3	eq
25	10:44:47	47.7032	-120.2993	-0.5*	1.5	Ml	019/028	81	0.07	CB	N3	eq
26	13:25:47	47.8920	-120.3778	2.3	1.0	Ml	011/018	91	0.09	BC	N3	eq
March 2022												
02	16:16:02	47.6432	-120.2163	6.4	0.4	Md	007/010	136	0.02	AC	N3	eq
04	08:44:57	47.7323	-120.2702	2.0	0.5	Ml	010/018	81	0.06	AB	N3	eq
04	17:56:57	46.9937	-120.3618	-0.9*	1.7	Ml	017/017	92	0.33	CC	E3	px
07	01:06:09	46.8455	-120.6368	11.0	1.3	Ml	016/018	84	0.37	CA	E3	eq
07	07:29:52	47.7123	-120.1092	5.5	0.5	Ml	010/016	99	0.09	AB	N3	eq
10	00:49:37	46.2643	-119.5397	5.9	0.8	Ml	008/013	189	0.07	AD	E3	eq
10	00:53:42	46.2765	-119.4987	9.3	0.0	Ml	005/007	284	0.02	CD	E3	eq
10	19:45:53	47.3717	-117.8997	-0.6*	2.0	Ml	008/009	202	0.23	CD	N3	px
11	05:01:49	46.5713	-119.8112	6.3	0.9	Ml	010/016	152	0.09	AC	E3	eq
11	14:29:27	46.2230	-119.5528	4.3*	0.3	Ml	004/007	311	0.31	DD	E3	eq
13	01:12:11	46.6165	-119.8492	6.3	1.2	Ml	017/023	143	0.08	AC	E3	eq
13	08:10:55	46.6090	-119.8397	6.5	0.7	Ml	010/016	117	0.07	AB	E3	eq
13	08:13:51	46.6120	-119.8497	6.7	1.8	Ml	029/036	89	0.08	AA	E3	eq
14	20:34:34	45.6395	-118.7773	12.9	1.3	Ml	005/006	146	0.24	BC	E3	eq
15	07:00:42	46.8442	-120.9588	0.1*	0.8	Ml	014/017	98	0.28	CC	C3	eq
16	04:41:06	46.8523	-119.3923	15.2	0.6	Ml	011/015	119	0.17	BB	E3	eq

16	20:13:16	45.8665	-119.3385	-0.3*	1.8	Ml	012/016	237	0.17	CD	E3	px
18	14:58:06	47.7650	-120.0098	1.7	1.1	Ml	011/016	64	0.07	AA	N3	eq
19	12:56:56	46.2672	-119.5282	7.7	0.2	Ml	007/009	191	0.04	AD	E3	eq
19	13:58:07	47.7072	-120.0315	2.9	0.8	Ml	015/023	64	0.08	AB	N3	eq
20	03:35:50	47.8692	-120.6985	8.6	1.4	Ml	009/013	157	0.15	BC	C3	eq
21	06:17:05	46.3750	-119.4062	3.7	0.7	Ml	009/012	149	0.09	AC	E3	eq
22	06:07:36	48.1508	-120.7650	6.9	0.7	Md	006/010	163	0.21	BC	C3	eq
23	04:28:57	47.7260	-120.1658	2.8	0.4	Ml	008/013	64	0.05	AB	N3	eq
23	06:13:35	46.4065	-119.2673	2.2	1.2	Ml	018/025	131	0.09	AB	E3	eq
23	16:37:56	47.6010	-120.2312	5.5	0.8	Ml	006/010	198	0.09	AD	N3	eq
24	22:47:52	46.7223	-121.0683	2.3	0.9	Ml	018/022	128	0.22	BC	C3	eq
25	02:50:25	47.6883	-120.0910	4.9	0.6	Ml	010/014	60	0.06	AB	N3	eq
25	10:26:51	46.7360	-121.0587	0.1*	0.7	Ml	013/019	153	0.21	CC	C3	eq
26	07:44:04	48.1712	-121.2595	9.9	0.8	Ml	011/017	100	0.25	BB	C3	eq
26	15:27:24	47.6815	-120.2895	-0.5*	1.5	Ml	021/029	85	0.11	CA	N3	eq
27	00:14:49	46.7248	-121.0642	0.1*	0.9	Ml	016/024	137	0.20	CC	C3	eq
27	00:15:32	46.7220	-121.0650	0.3*	1.0	Ml	020/027	129	0.22	CC	C3	eq
27	06:11:01	46.6838	-121.0827	12.1	0.8	Ml	023/034	117	0.16	BC	C3	eq
27	19:06:25	46.6930	-121.0785	10.2	1.0	Ml	023/035	102	0.18	BC	C3	eq
28	14:32:01	47.5347	-120.1400	8.4	0.5	Ml	006/011	185	0.13	AD	N3	eq
April 2022												
01	07:54:34	46.2670	-119.5313	6.2	0.2	Ml	008/012	283	0.06	AD	E3	eq
01	08:07:50	46.2728	-119.5295	6.4	0.1	Ml	006/009	278	0.03	AD	E3	eq
02	00:41:48	46.6947	-120.5705	10.6	2.0	Ml	032/042	86	0.17	BB	E3	eq
03	18:41:01	46.6077	-119.8497	6.9	2.2	Ml	034/047	53	0.08	AA	E3	eq
04	00:25:53	46.6062	-119.8475	6.8	1.6	Ml	026/036	53	0.10	AA	E3	eq
04	02:24:54	47.7270	-120.1673	2.8	0.6	Ml	012/016	72	0.06	AB	N3	eq
04	12:02:48	46.2548	-119.5493	7.1	0.6	Ml	006/009	195	0.07	AD	E3	eq
04	13:56:16	46.2523	-119.5448	7.1	1.4	Ml	015/020	199	0.06	AD	E3	eq
04	14:12:48	46.2523	-119.5455	7.0	1.0	Ml	010/015	198	0.07	AD	E3	eq
04	14:20:18	46.2468	-119.5472	8.3	1.4	Ml	012/017	203	0.09	AD	E3	eq
04	19:50:41	46.6208	-120.4988	-0.7*	1.7	Ml	008/010	103	0.32	CC	E3	px
05	00:28:24	46.2557	-119.5512	7.0	1.0	Ml	013/018	193	0.08	AD	E3	eq
05	17:59:06	47.0667	-120.7235	-1.0*	1.7	Ml	011/011	86	0.30	CB	C3	px
07	21:47:00	46.6180	-119.8213	6.9	1.0	Ml	014/021	84	0.05	AA	E3	eq
07	22:20:32	46.6198	-119.8227	6.9	1.0	Ml	017/025	85	0.06	AA	E3	eq
07	22:21:58	46.6203	-119.8233	7.0	1.1	Ml	018/024	85	0.05	AA	E3	eq
07	22:22:54	46.6185	-119.8218	7.0	1.6	Ml	023/029	57	0.06	AA	E3	eq
07	22:24:02	46.6182	-119.8215	7.4	1.3	Ml	016/024	126	0.08	AB	E3	eq
08	18:51:57	46.9133	-120.5757	-0.9*	1.6	Ml	010/010	114	0.93	DB	E3	px
10	18:49:34	46.2525	-119.5447	7.0	0.8	Ml	013/020	199	0.08	AD	E3	eq
10	23:18:38	46.2513	-119.5438	7.2	1.6	Ml	023/029	200	0.07	AD	E3	eq
10	23:54:26	46.2450	-119.5323	7.2	1.9	Ml	026/036	198	0.08	AD	E3	eq
11	11:33:41	46.2627	-119.5402	7.4	0.2	Md	009/013	281	0.05	AD	E3	eq
11	19:11:48	46.1623	-119.1353	4.8*	1.6	Ml	009/012	171	0.22	CC	E3	px
12	18:00:35	47.5395	-120.2580	-1.2*	1.2	Ml	007/012	173	0.43	CC	N3	px
12	18:07:56	46.2522	-119.5448	7.2	1.1	Ml	014/023	199	0.07	AD	E3	eq
16	10:18:29	47.6467	-120.1463	3.4	1.1	Ml	015/020	83	0.06	AA	N3	eq
17	13:30:46	47.7107	-120.2278	-0.4*	0.2	Ml	007/011	135	0.10	CB	N3	eq
19	04:12:56	47.6867	-120.0565	4.0	0.2	Ml	004/008	167	0.07	AC	N3	eq
20	22:24:24	47.5530	-120.2797	-1.2*	1.1	Ml	006/007	164	0.10	CC	N3	px
22	08:19:34	47.6812	-120.0708	6.3	1.4	Ml	013/019	92	0.07	AB	N3	eq
22	17:42:59	46.0620	-119.3603	-0.3*	1.5	Ml	014/014	145	0.15	CC	E3	px
23	23:26:58	47.6627	-120.1142	2.7	0.2	Ml	007/010	110	0.06	AB	N3	eq

24	10:58:32	47.6413	-120.4005	-0.1*	0.2	Md	006/009	196	0.09	CD	N3	eq
25	18:12:43	47.4108	-117.8923	-0.6*	2.1	Ml	009/011	103	0.41	CC	N3	px
27	15:26:59	46.6428	-119.8707	5.4	1.3	Ml	017/029	64	0.12	AB	E3	eq
28	08:17:20	46.6407	-119.8675	5.0	0.7	Ml	012/015	98	0.05	AB	E3	eq
28	15:26:49	46.7628	-121.0370	0.1*	0.8	Ml	013/021	146	0.19	CC	C3	eq
29	06:34:02	47.6412	-120.1902	6.0	0.4	Ml	005/009	138	0.03	AC	N3	eq
29	06:37:14	47.7530	-120.3248	1.8	0.6	Ml	007/011	92	0.04	BC	N3	eq
29	11:27:23	46.1718	-119.8262	25.4	1.0	Ml	018/025	170	0.07	AC	E3	eq
May 2022												
01	17:45:18	46.5998	-119.8622	6.7	1.1	Ml	022/029	55	0.10	AA	E3	eq
03	13:02:20	46.2637	-119.5712	7.0	0.1	Ml	010/014	175	0.07	AC	E3	eq
04	22:41:20	44.0198	-121.2653	-1.5*	0.9	Ml	010/008	186	0.10	CD	E3	px
05	01:02:44	48.1602	-119.2113	0.5*	1.1	Ml	011/013	178	0.18	CC	N3	eq
05	01:04:18	44.2560	-120.8947	-1.6*	2.3	Ml	009/011	190	0.16	CD	N3	px
05	23:09:29	46.6078	-119.8445	6.6	0.7	Ml	009/014	164	0.07	AC	E3	eq
06	03:30:24	44.4028	-117.0307	7.4*	1.9	Ml	006/008	92	0.44	CD	E3	eq
06	06:38:47	48.4233	-120.4423	8.9*	1.4	Md	009/014	166	0.27	CC	C3	eq
08	00:38:51	46.4858	-119.7240	6.2	0.6	Ml	008/012	174	0.06	AC	E3	eq
08	12:52:59	46.1978	-119.2602	5.9	1.2	Ml	013/019	148	0.14	AC	E3	eq
09	07:42:51	46.5422	-119.0937	11.4	1.0	Ml	007/008	115	0.08	AB	E3	eq
09	07:43:39	46.5425	-119.0950	10.7	1.1	Ml	013/016	115	0.08	AB	E3	eq
09	08:09:39	46.5428	-119.0833	12.8	1.1	Ml	013/018	85	0.12	AA	E3	eq
09	19:12:53	46.4720	-120.9043	0.6*	1.1	Ml	006/008	246	0.63	DD	C3	eq
10	13:18:38	48.1250	-121.4003	11.5	0.8	Ml	006/012	155	0.20	BC	C3	eq
13	07:15:00	47.6978	-120.3242	1.3	0.8	Ml	013/021	87	0.05	AB	N3	eq
14	00:58:49	46.1415	-119.1977	-0.2*	2.0	Ml	019/023	163	0.16	CC	E3	px
15	07:44:39	46.6103	-119.8495	6.5	1.3	Ml	025/034	80	0.10	AA	E3	eq
17	17:56:21	47.4298	-117.8625	-0.6*	1.8	Ml	007/007	171	0.37	CC	N3	px
17	22:50:06	44.0242	-121.2673	-1.8*	1.2	Ml	009/009	171	0.18	CC	N3	px
19	20:53:21	46.1357	-119.2753	-0.3*	1.9	Ml	017/020	175	0.24	CC	E3	px
23	17:02:28	45.5953	-121.1063	-1.3*	1.9	Ml	007/008	279	0.09	CD	C3	px
23	21:41:07	44.5388	-118.2272	8.1*	1.6	Ml	005/008	125	0.52	DD	C3	eq
24	23:49:58	46.1958	-120.3372	7.9*	1.2	Ml	005/005	180	0.03	CD	E3	eq
25	20:02:14	46.6758	-119.3458	0.8*	-0.2	Md	002/004	281	0.27	CD	E3	eq
25	20:22:35	47.3870	-117.9338	-0.6*	2.1	Ml	010/012	198	0.17	CD	N3	px
26	07:16:24	46.7245	-120.7513	9.0	0.7	Ml	013/017	96	0.27	BB	C3	eq
26	08:06:49	46.8228	-119.7390	0.1*	0.4	Ml	007/011	147	0.22	CC	E3	eq
28	17:12:47	45.5693	-120.0843	18.9	1.5	Ml	012/017	198	0.07	AD	E3	eq
28	19:08:11	48.8078	-120.8225	-0.1	3.2	Ml	016/022	159	0.37	CD	C3	eq
30	16:08:08	48.8235	-120.8190	-0.5	1.7	Ml	010/014	213	0.55	DD	C3	eq
31	10:53:30	46.9535	-120.1067	6.2	1.5	Ml	025/025	89	0.13	AB	E3	eq
31	19:36:52	48.8068	-120.8380	9.4*	2.1	Ml	012/015	146	0.31	CD	C3	eq
June 2022												
01	06:56:18	46.4855	-119.7247	6.6	0.5	Ml	010/014	176	0.08	AC	E3	eq
01	21:12:39	46.9175	-120.1137	3.7	1.0	Ml	013/012	92	0.20	BB	E3	eq
02	19:22:01	46.7343	-120.8262	-1.0*	1.4	Ml	007/009	123	0.96	DB	C3	px
02	21:10:53	44.7203	-117.7563	9.6*	1.7	Ml	003/004	225	0.01	CD	C3	eq
04	06:41:25	47.6530	-120.3780	3.3	1.1	Ml	016/020	95	0.07	AB	N3	eq
04	12:01:31	46.2197	-119.0602	13.6	1.0	Ml	017/029	146	0.26	BC	E3	eq
08	04:33:04	47.6513	-120.2595	5.4	0.3	Md	006/011	120	0.06	AB	N3	eq
08	05:59:06	46.2557	-119.5485	6.9	0.7	Ml	011/017	193	0.09	AD	E3	eq
08	23:16:13	48.2815	-118.6855	1.8*	1.5	Ml	009/010	168	0.21	CC	N3	eq
10	17:15:14	45.8413	-118.2250	-0.6*	2.1	Ml	008/008	236	0.99	DD	E3	px
11	00:03:39	46.1892	-120.3543	12.5	2.4	Ml	036/042	93	0.13	AB	E3	eq

11	17:40:45	46.1873	-120.3585	12.4	1.4	Ml	019/026	136	0.12	AC	E3	eq
11	19:26:36	46.6643	-120.9203	4.6	1.8	Ml	018/025	118	0.23	BC	C3	eq
13	00:07:17	45.6998	-119.1645	7.9	1.1	Ml	014/014	151	0.08	AC	E3	eq
15	21:41:49	44.4102	-121.0518	-1.5*	2.0	Ml	009/008	172	0.09	CC	E3	px
16	01:23:17	45.7023	-119.1903	8.9	1.1	Ml	017/019	133	0.22	BC	E3	eq
16	14:15:57	47.3698	-120.4493	4.5	1.1	Ml	015/023	120	0.29	BC	N3	eq
19	05:00:14	46.8543	-120.6838	11.9	1.0	Ml	009/013	125	0.44	CB	E3	eq
22	18:38:47	47.8007	-117.3628	-0.7*	2.4	Md	010/015	77	0.66	DC	N3	px
23	02:48:24	44.8527	-117.0427	6.7*	2.2	Ml	004/007	123	0.37	CC	N3	eq
24	22:41:32	48.2632	-120.7265	8.8*	1.7	Ml	012/022	109	0.26	CC	C3	eq
24	23:12:50	46.6598	-120.4875	-0.5*	1.7	Ml	013/017	74	0.45	CC	E3	px
25	02:11:58	47.6635	-120.2860	3.5	1.0	Ml	010/016	86	0.07	AA	N3	eq
26	02:33:03	48.3045	-120.5757	6.5	0.9	Md	005/009	178	0.08	AC	C3	eq
27	10:01:03	48.2477	-120.7112	8.7*	0.9	Ml	007/013	175	0.15	CC	C3	eq
27	13:40:02	48.2053	-121.3802	-0.7	1.1	Md	009/012	133	0.12	AC	C3	eq
28	06:59:10	45.8715	-120.1658	16.8	2.4	Ml	021/029	121	0.15	BB	E3	eq
30	09:52:35	45.0083	-121.3143	7.0*	1.5	Ml	016/021	86	0.20	CC	E3	eq
30	11:37:56	46.4132	-119.2773	0.3*	1.1	Ml	018/027	87	0.13	CA	E3	eq
July 2022												
01	11:57:32	48.1787	-120.1433	1.2	0.7	Ml	007/011	130	0.04	BC	N3	eq
03	06:16:56	48.3187	-120.4433	7.4	0.8	Ml	007/010	169	0.10	AC	C3	eq
03	10:14:29	46.5957	-119.8585	6.6	0.7	Ml	011/018	136	0.08	AC	E3	eq
05	18:02:00	46.6078	-119.8590	6.5	-0.4	Md	003/005	269	0.00	BD	E3	eq
06	09:58:04	47.6690	-120.0883	6.9	0.5	Ml	010/019	67	0.09	AA	N3	eq
07	20:22:52	46.6703	-120.5093	-0.8*	1.4	Ml	017/018	80	0.42	CC	E3	px
09	12:51:33	47.9238	-120.3847	-0.3*	1.8	Ml	020/028	66	0.09	CC	N3	eq
12	17:11:41	46.6397	-120.4863	-0.6*	1.5	Ml	012/011	96	0.19	CC	E3	px
13	18:47:44	46.0955	-119.3158	-0.3*	0.6	Ml	007/009	166	0.21	CC	E3	px
15	02:25:04	47.0432	-120.9427	14.5	2.0	Ml	037/052	58	0.27	BA	C3	eq
15	11:04:56	46.6508	-120.9238	0.0	1.4	Ml	018/026	121	0.29	BC	C3	eq
18	11:05:52	48.2103	-119.5923	1.7*	0.7	Ml	004/006	116	0.11	CC	N3	eq
19	01:32:09	45.7798	-118.9653	-0.6*	1.4	Ml	011/012	102	0.32	CC	E3	px
20	15:28:43	46.5582	-119.5552	14.1	0.6	Ml	012/018	77	0.07	AA	E3	eq
20	20:21:21	44.5688	-117.4108	-1.1	1.6	Ml	006/006	120	0.18	BC	E3	eq
20	20:41:14	47.3840	-117.8662	-0.6*	2.1	Ml	007/008	133	0.51	DC	N3	px
21	22:33:17	46.3552	-119.2898	13.8	1.3	Ml	020/026	100	0.15	BB	E3	eq
22	00:45:45	46.2925	-118.0260	-0.3*	1.8	Ml	015/015	224	0.34	CD	E3	px
22	05:10:16	47.6582	-120.1942	3.0	0.7	Ml	008/013	116	0.06	AB	N3	eq
22	14:11:23	47.0587	-118.7158	9.6	2.1	Ml	021/032	123	0.48	CB	N3	eq
22	18:01:57	48.2285	-117.8762	-0.7*	1.8	Ml	008/011	166	0.52	DC	N3	px
23	16:34:36	48.5782	-121.3070	-0.4	0.9	Ml	006/007	139	0.12	BC	C3	eq
24	08:48:35	46.2190	-119.4387	9.3	0.2	Ml	009/014	259	0.08	AD	E3	eq
27	21:53:38	45.9267	-119.2927	-0.3*	1.5	Ml	012/012	176	0.13	CC	E3	px
28	21:29:42	46.7562	-121.0270	0.3*	0.9	Ml	015/018	165	0.11	CC	C3	eq
29	13:32:25	46.9390	-119.2743	7.8	0.7	Ml	007/010	104	0.26	BB	E3	eq
29	16:35:53	44.0148	-121.2575	-1.7*	2.0	Ml	018/016	173	0.06	CC	E3	px
29	18:06:02	47.6308	-120.2148	-1.1*	1.5	Ml	010/010	130	0.06	CB	N3	px
29	19:51:29	47.3918	-117.8592	-0.7*	2.4	Ml	009/008	163	0.12	CC	N3	px
31	21:38:16	47.7043	-120.3220	2.1	0.7	Ml	006/011	120	0.07	AB	N3	eq
August 2022												
01	00:30:14	47.6463	-120.1252	7.7	0.6	Ml	009/014	60	0.10	AA	N3	eq
01	09:10:54	47.7275	-120.4340	12.7	0.5	Ml	013/018	95	0.09	AB	N3	eq
01	18:06:44	47.7618	-120.1520	4.4	1.8	Ml	017/029	52	0.13	AB	N3	eq
01	18:26:45	46.7537	-121.0355	0.6*	1.1	Ml	023/029	119	0.18	CC	C3	eq

01	20:40:38	46.5805	-120.8537	7.0	0.9	Ml	005/007	224	0.07	BD	C3	eq
02	14:58:15	47.6533	-120.3762	3.8	2.0	Ml	017/025	101	0.07	AB	N3	eq
03	12:37:07	47.6297	-121.3887	10.9	1.2	Ml	018/023	83	0.15	BA	C3	eq
03	14:56:25	48.3770	-120.2588	1.2	1.2	Ml	009/012	160	0.12	BC	N3	eq
03	18:40:34	46.7228	-121.0400	0.8*	0.8	Ml	014/019	106	0.17	CC	C3	eq
04	08:29:57	47.6077	-121.3813	8.6	1.3	Ml	019/027	108	0.17	BB	C3	eq
04	16:19:37	46.7578	-120.9693	6.2	0.8	Ml	017/026	98	0.16	BB	C3	eq
04	16:22:10	48.6455	-118.0192	-0.8*	1.5	Md	005/004	300	0.04	CD	N3	px
04	21:53:36	46.5498	-119.3833	17.4	1.1	Ml	017/026	96	0.08	AB	E3	eq
05	22:32:02	46.7467	-121.0320	4.0	0.8	Ml	016/019	131	0.19	BC	C3	eq
06	06:39:28	47.0423	-120.9540	11.6	1.4	Ml	012/011	132	0.19	BB	C3	eq
07	07:45:02	47.5982	-120.2473	6.6	0.1	Ml	005/007	201	0.03	AD	N3	eq
08	21:21:30	46.6183	-120.7453	8.3	0.9	Ml	012/016	114	0.18	BB	C3	eq
09	17:09:18	46.1688	-121.2792	6.2	1.3	Ml	011/017	104	0.12	AC	C3	eq
11	16:04:19	47.6258	-117.3603	-0.8*	1.6	Md	004/005	216	0.41	CD	N3	px
12	04:38:24	47.6473	-120.2440	1.5	0.4	Ml	006/010	128	0.07	AB	N3	eq
13	13:31:50	46.1315	-120.5017	12.3	3.0	Ml	040/054	62	0.18	BB	E3	eq
13	18:14:29	46.1457	-120.4655	7.3	0.7	Ml	007/008	200	0.05	BD	E3	eq
13	23:37:50	47.6265	-120.0498	8.8	0.2	Md	005/008	132	0.08	AB	N3	eq
17	02:07:06	46.6098	-119.8503	6.6	1.2	Ml	020/027	46	0.06	AA	E3	eq
17	04:26:16	47.6680	-120.2905	2.1	0.2	Ml	006/010	95	0.05	AB	N3	eq
17	06:30:48	46.7563	-121.0363	3.4	0.9	Ml	020/025	118	0.16	BC	C3	eq
17	15:57:35	47.7235	-120.0110	5.5	0.8	Ml	012/017	81	0.08	AB	N3	eq
17	17:22:39	47.6512	-120.1330	5.5	0.2	Ml	006/009	123	0.04	AB	N3	eq
17	17:26:38	47.6513	-120.1350	5.7	0.0	Ml	005/009	134	0.05	AB	N3	eq
19	04:03:19	47.0530	-120.9737	6.9	0.9	Ml	021/033	132	0.29	BC	C3	eq
19	06:53:50	46.7388	-121.0388	3.4	1.3	Ml	032/048	102	0.27	BC	C3	eq
19	13:47:08	47.7315	-120.3148	3.0	0.6	Ml	008/013	96	0.06	BC	N3	eq
20	10:35:02	48.9987	-119.0930	11.5	2.2	Ml	013/017	164	0.30	CC	N3	eq
20	11:05:59	48.9313	-119.0912	15.9	1.1	Ml	005/007	260	0.10	BD	N3	eq
20	21:54:06	48.7213	-120.3255	9.8*	1.5	Ml	012/018	118	0.35	CC	C3	eq
20	21:57:06	47.7125	-120.0863	3.5	1.5	Ml	022/023	54	0.06	AB	N3	eq
20	22:25:04	46.2973	-119.6310	0.0*	0.3	Ml	006/008	170	0.03	CC	E3	eq
21	23:49:42	48.7437	-120.0498	10.8	2.2	Ml	014/018	131	0.18	BC	N3	eq
22	00:56:52	48.2290	-119.2665	8.3	1.7	Ml	013/016	68	0.12	AB	N3	eq
22	04:47:54	47.5735	-120.1640	7.0	0.5	Ml	007/010	168	0.05	AC	N3	eq
22	07:52:24	46.7495	-121.0317	0.2*	0.7	Ml	019/025	121	0.14	CC	C3	eq
22	21:18:02	45.8838	-119.3163	-0.3*	1.5	Ml	008/010	215	0.15	CD	E3	px
23	09:32:31	46.7478	-121.0307	3.6	1.6	Ml	036/046	98	0.19	BC	C3	eq
23	11:36:57	47.6972	-120.2945	2.0	1.6	Ml	020/023	82	0.06	AB	N3	eq
24	14:58:13	47.1742	-121.1085	10.8	1.1	Ml	017/026	135	0.32	CB	C3	eq
24	17:38:56	45.9125	-119.3030	-0.3*	1.5	Ml	007/010	205	0.24	CD	E3	px
25	00:34:49	47.6182	-120.2680	1.5	0.7	Ml	005/008	165	0.04	AC	N3	eq
26	20:50:06	46.7457	-117.1062	-0.7*	2.4	Md	007/008	244	0.56	DD	E3	px
26	22:02:32	48.7537	-121.0008	10.1*	1.1	Ml	007/012	193	0.31	CD	C3	eq
28	06:00:49	47.6580	-120.1852	1.5	0.5	Ml	006/008	99	0.07	AB	N3	eq
29	00:24:30	48.3812	-120.2702	2.8	1.1	Ml	009/013	138	0.15	BC	N3	eq
29	19:28:21	48.5895	-117.9660	-0.9*	1.4	Ml	006/007	199	0.16	CD	N3	px
30	03:55:37	47.6462	-120.1427	2.8	0.6	Ml	010/015	80	0.07	AA	N3	eq
30	04:25:32	47.7147	-120.0418	6.2	0.5	Ml	009/011	117	0.07	AB	N3	eq
30	15:19:16	47.6662	-120.3067	4.3	0.4	Ml	007/009	104	0.07	AB	N3	eq
30	16:32:10	47.6663	-120.3042	4.3	0.4	Ml	005/008	109	0.08	AB	N3	eq
30	17:37:10	47.6602	-119.7243	12.0	0.6	Ml	008/012	97	0.08	AC	N3	eq
30	19:56:20	46.1893	-120.3537	13.7	1.4	Ml	014/018	125	0.12	AB	E3	eq

30	23:25:32	47.6615	-119.7237	12.1	1.1	Ml	012/018	73	0.09	AC	N3	eq
31	06:52:00	47.6582	-119.7277	11.3	0.2	Ml	008/014	98	0.09	AC	N3	eq
31	07:13:08	47.6598	-119.7242	11.0	0.3	Ml	007/012	97	0.08	AC	N3	eq
31	11:11:32	44.0163	-120.6177	10.0*	1.6	Ml	012/019	321	0.23	CD	N3	eq
31	21:22:01	45.8988	-119.3075	-0.3*	1.6	Ml	011/014	211	0.13	CD	E3	px
September 2022												
01	08:03:18	47.6188	-120.2688	0.9	0.4	Ml	004/008	163	0.09	BC	N3	eq
01	22:13:09	45.8962	-119.3087	-0.3*	1.7	Ml	015/019	177	0.16	CC	E3	px
02	17:42:14	48.1448	-117.8667	-0.9*	1.5	Ml	005/007	187	0.08	CD	N3	px
03	11:52:39	45.7238	-118.5525	8.3*	1.0	Ml	004/006	163	0.15	CC	E3	eq
04	12:44:19	46.7477	-121.0390	6.9	0.9	Ml	020/031	101	0.23	BC	C3	eq
05	03:32:18	47.6205	-120.2653	0.4	0.9	Ml	010/016	64	0.09	BA	N3	eq
05	21:22:49	47.6545	-120.2162	2.8	0.3	Ml	005/010	122	0.05	AB	N3	eq
10	10:47:23	46.7367	-121.0368	4.9	0.7	Ml	019/026	125	0.27	BC	C3	eq
13	01:49:14	47.7215	-120.2975	4.4	0.4	Ml	007/013	93	0.07	AB	N3	eq
15	00:04:46	44.2112	-121.1610	-1.7*	1.0	Ml	007/007	296	0.46	DD	N3	px
16	18:26:01	47.7197	-120.0193	4.7	0.3	Ml	004/006	182	0.04	AD	N3	eq
17	13:22:53	47.6960	-120.3245	2.5	0.2	Ml	006/011	112	0.07	AB	N3	eq
20	06:07:51	47.6413	-120.1192	4.2	0.8	Ml	010/016	87	0.08	AA	N3	eq
20	20:03:44	46.1440	-119.2815	-0.2*	1.3	Ml	011/017	208	0.13	CD	E3	px
21	06:25:15	47.9477	-120.7167	4.5	0.5	Ml	011/017	95	0.20	BC	C3	eq
22	18:53:59	47.8450	-117.5782	-0.7*	1.0	Md	006/007	124	0.06	CC	N3	px
22	19:28:51	47.5060	-120.2943	-1.2*	1.2	Ml	010/009	120	0.04	CC	N3	px
23	22:55:26	48.9583	-119.0842	14.6	1.2	Ml	007/011	183	0.20	BD	N3	eq
25	00:53:33	46.0367	-118.6848	16.2	1.4	Ml	011/013	154	0.10	AC	E3	eq
25	16:04:15	46.7577	-121.0315	3.7	0.7	Ml	016/024	131	0.14	AC	C3	eq
25	16:41:32	47.6575	-120.1787	2.4	0.4	Ml	008/013	91	0.06	AB	N3	eq
25	22:20:24	47.6762	-120.1165	3.4	0.6	Ml	009/012	113	0.05	AB	N3	eq
26	17:20:36	46.4888	-120.8153	1.6*	1.2	Ml	007/008	152	0.62	DC	C3	eq
26	20:33:20	45.0868	-121.3442	-1.2*	1.1	Ml	007/007	150	0.04	CC	C3	px
27	23:06:47	44.3250	-121.0787	-1.6*	1.8	Ml	009/011	254	0.41	CD	C3	px
28	14:26:21	47.6513	-120.1963	3.0	0.5	Ml	006/011	125	0.10	AB	N3	eq
28	21:02:52	46.2458	-119.4793	-0.3*	1.2	Ml	006/007	241	0.03	CD	E3	px
29	08:01:53	46.0147	-119.2235	12.9*	1.6	Ml	020/025	123	0.25	CC	E3	eq
29	15:53:04	47.6152	-120.2450	3.4	0.6	Ml	004/008	174	0.06	AC	N3	eq
29	22:13:55	46.5988	-119.7947	7.6	0.5	Ml	010/015	191	0.07	AD	E3	eq
30	21:09:20	44.1138	-121.3732	-1.6*	2.0	Ml	011/010	193	0.68	DD	E3	px
30	21:23:59	46.7538	-121.0233	0.3*	0.6	Ml	008/012	138	0.11	CC	C3	eq
30	22:31:59	47.7922	-117.6787	0.3*	1.6	Md	009/013	98	0.11	CC	N3	eq

5.0 Discussion of Seismic Activity – FY 2022

5.1 Summary

During FY 2022, seismic activity was relatively quiet throughout eastern Washington. 316 earthquakes were cataloged in the region, of which 25% (78) 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 low to typical swarm-type activity, most strongly observed in the Horse Heaven and the Wye 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 2022

Category	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2022
Shallow (0-4 km deep)	40	27	20	40	127
Intermediate (4-9 km deep)	17	30	48	33	128
Deep (greater than 9 km deep)	7	15	14	25	61
Total	**64**	**72**	**82**	**98**	**316**
Felt	1	0	0	1	2
Probable Blast	18	18	21	28	85

Table 5.2. Earthquake Counts for FY 2022 for Earthquakes near the Hanford Site

Seismic Source Zones	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2022
Frenchman Hills	0	0	0	1	1
Saddle Mountains	0	1	0	0	1
Wahluke Slope	0	0	0	0	0
Coyote Rapids	0	0	0	0	0
Wye	0	1	1	1	3
Cold Creek	0	0	2	0	2
Rattlesnake Mountain	0	0	0	1	1
Horse Heaven Hills	0	2	1	0	3
Total for swarm areas	0	4	4	3	11
Random Events	3	23	33	8	67
Total For All Earthquakes	**3**	**27**	**37**	**11**	**78**

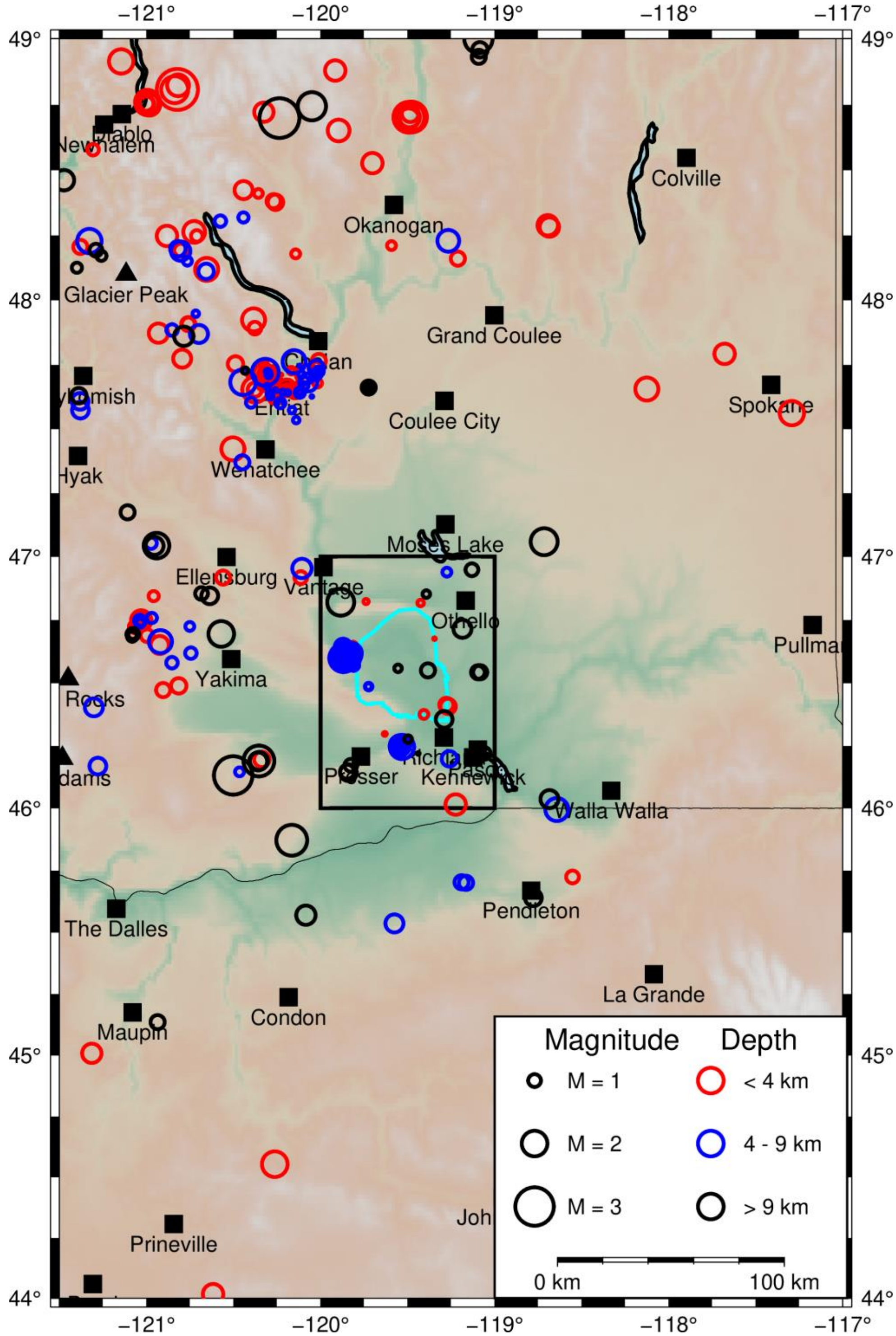

Figure 5.1. Hanford and Regional Epicenters of Earthquakes Recorded during FY 2022. Background color indicates elevation.

Red circles stand for shallow earthquakes (0-4 km). Blue circles for intermediate-depth earthquakes (4-9 km).

6.0 Status of Monitoring

In addition to the significant enhancements of the seismic monitoring network made during FY 2017 and FY 2018, the PNSN has added additional monitoring stations in eastern WA using funding from the USGS ShakeAlert^{TM} project. Therefore, overall monitoring capability of seismicity in the region surrounding the Hanford Site has improved. In addition, during FY 2022, using funding from the USGS, PNSN replaced old-fashioned analog equipment at site OD2 (Odessa, WA) to create another six-channel broadband and strong-motion station. A failing Q330 data logger at DDRF has been replaced by a new Q330S+, on loan from the USGS.

As of May 4th, 2021, ShakeAlert^{TM} powered Earthquake Early Warnings are available to individuals in WA state with smart phones, through the federal Wireless Emergency Alert (WEA) system, the Android operating system, or by downloading a phone app named MyShake. Additional cell phone apps are expected to become available in the future. Data from twenty-six stations operated and maintained under the current contract are of sufficient quality and low-latency that they are forwarded by the PNSN to contribute to the ShakeAlert^{TM} system, resulting in a higher probability of timely, useful, warnings for personnel at the Hanford Site. Likewise, improvements made to ShakeMap (which are maps of observed shaking produced after an earthquake) benefit Hanford Site operations. In previous reports, it was noted that PNSN has adopted new methods to monitor the quality and data latency of their growing network. These improvements benefit the HSN and EWRSN as well.

Looking ahead, PNSN would like to make further upgrades to the network. Several instruments of the HSN and EWRSN are reaching end-of-life and exhibit (intermittent) issues. The five Kinemetrics Basalt dataloggers with internal Episensor ES-T accelerometers were purchased in 2012 and are now 10 years old. The equipment purchased from IRIS in 2008 is 14+ years old; we had to replace the Q330 at DDRF, station PHIN still has all the original IRIS equipment. CCRK was rebuilt after it was destroyed by wildfire and has new FY 2017 equipment. The PNSN is phasing out operating analog-telemetry stations due to the inability to purchase new analog radios, and lack of staff trained in this old-fashioned technology. On the Hanford Site, three old-fashioned analog stations remain, BEN, LOC, and RSW. Given the density of digital stations on the site, we may be able to discontinue these three sites without losing significant monitoring capability. In the wider EWRSN, another eleven analog stations remain. In the next year, PNSN plans to analyze the contribution of each analog site to the monitoring capability and propose which locations need to be retained, and which can be decommissioned.

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.

Hartog, JR, PA Friberg, VC Kress, P Bodin, R Bhadha, 2020 *Open-Source ANSS Quake Monitoring System Software*, Seism. Res. Lett., https://doi.org/10.1785/0220190219

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

Klein, Fred W., 2002, *User's Guide to HYPOINVERSE–2000, a Fortran Program to Solve for Earthquake Locations and Magnitudes: U.S. Geological Survey Open-File Report 02-171*, 123 pp., *https://pubs.usgs.gov/of/2002/0171/*.

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.

Executive Summary

The Pacific Northwest Seismic Network (PNSN) and Hanford Mission Integration Solutions (HMIS) 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 FY 2022, seismic activity was relatively quiet throughout eastern Washington. 316 earthquakes were cataloged in the region, of which about 25% (78) 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 low to typical swarm-type activity, most strongly observed near the Horse Heaven and Wye Swarm Areas.

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
HMIS	Hanford Mission Integrated Solutions, LLC
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) 2022 (October 2021 through September 2022). Hanford Mission Integrated Solutions, LLC manages seismic monitoring for the Hanford Site with the monitoring work being performed by the PNSN under a sub-contract with the University of Washington (UW).

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, which 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 FY 2011, administration of the seismic monitoring networks was assumed by HLSMP and contracted to be operated by the PNSN, University of Washington.

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 are permanently archived at the Incorporated Research Institutions in Seismology (IRIS) seismic data archive in Seattle, with backup copies at IRIS facilities in Seattle and 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-wave-length 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 form 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.

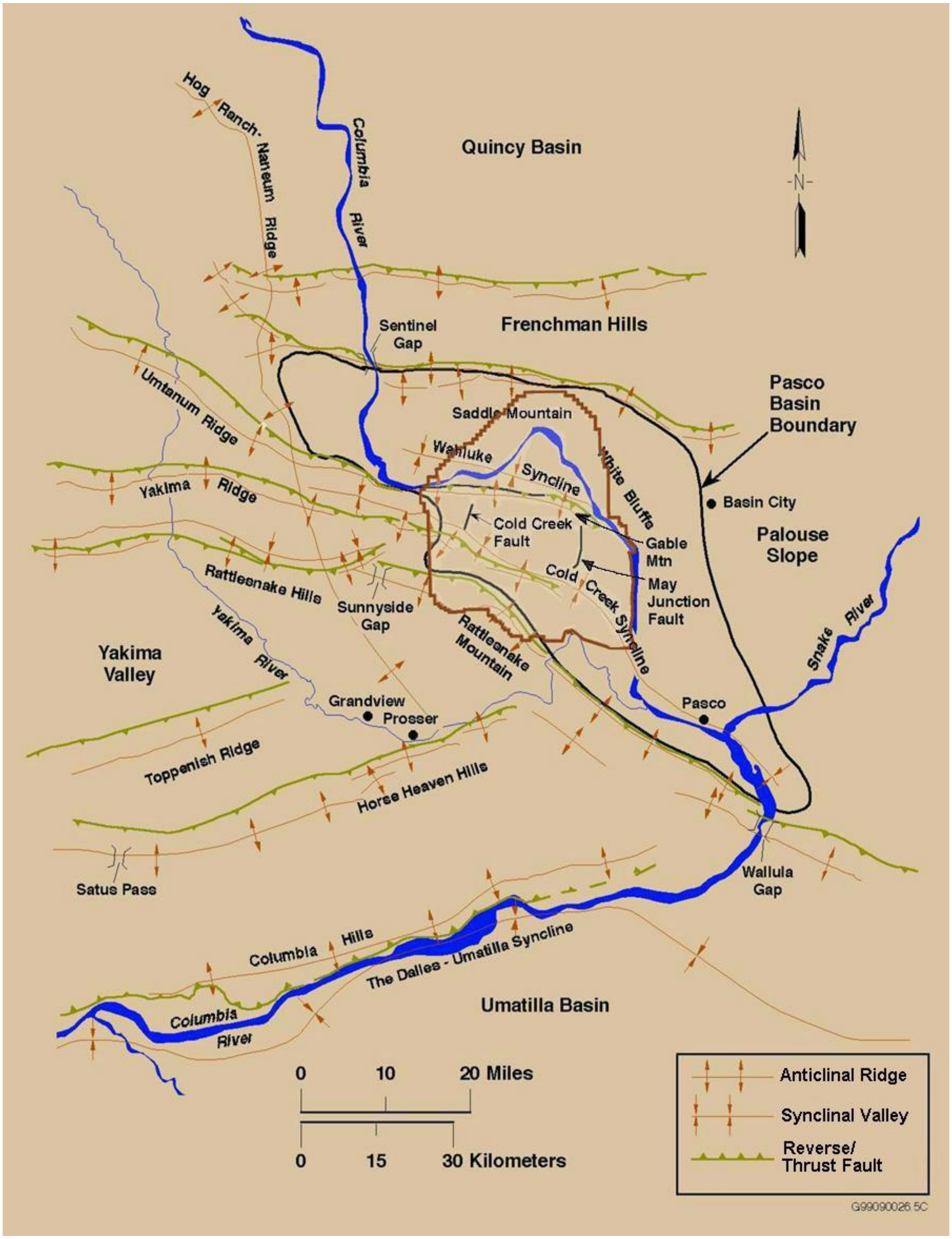

Figure 2.1. Tectonic Features of the Hanford Site within Eastern Washington

(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, one HLSMP short-period station records 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.

Five 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. An additional 16 sites record 6 channels of seismic data, three components of strong motion accelerometer data and three components of high-gain broadband data. 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 HMIS 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)
Strong motion and Broadband, 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
Strong motion and Short Period, 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
Broadband, 3-Channel Station				
LIGO	46.4617	-119.4177	158	LIGO Observatory
Short Period, Single Channel Analog				
BEN	46.5186	-119.7185	335	Benson Ranch
LOC	46.7169	-119.4320	210	Locke Island
RSW	46.3944	-119.5925	1045	Rattlesnake Mountain

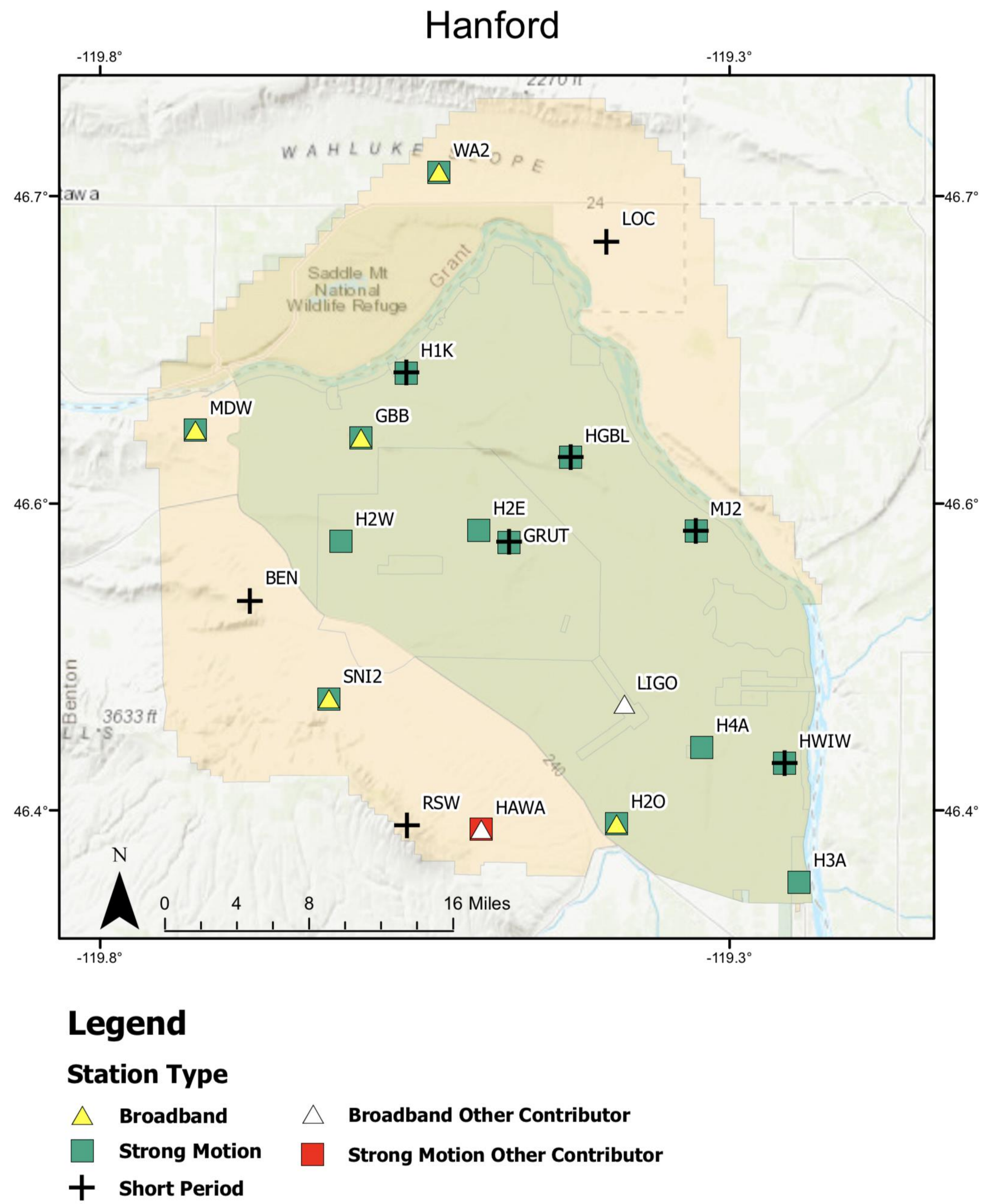

Figure 3.1. Hanford Seismic Network Onsite Stations

Table 3.2. Hanford Seismic Network Offsite Stations

Station	Latitude	Longitude	Elevation (m)	Station Name
Strong Motion and Broadband, 6-Channel Station				
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
OD2	47.388	-118.7108	553	Odessa 2
OT3	46.6689	-119.2341	322	Othello 3
PHIN	45.8950	-119.9280	227	Phinney Hill
PRO	46.2125	-119.6868	553	Prosser
YPT	46.0487	-118.9634	325	Yellepit
Short Period, Single-Channel Analog				
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
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
Short Period, 3-Channel Analog				
FHE	46.9518	-119.4981	455	Frenchman Hills East

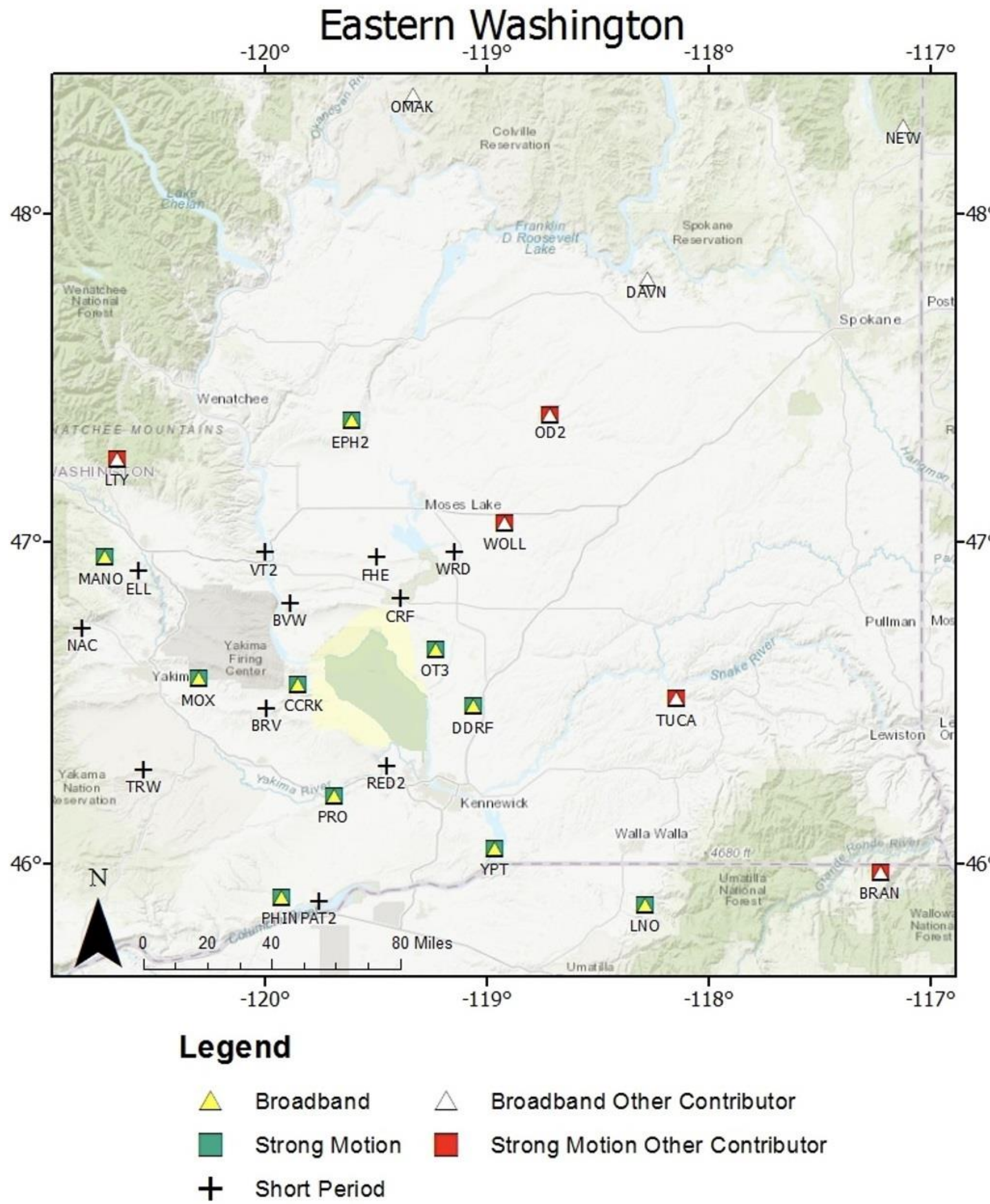

Figure 3.2. Hanford Seismic Network Stations of the Eastern Washington Region Sub-Network

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 145 combined data channels from: 14 single channel sites, 2 three-component seismometer sites (FHE and LIGO), 16 six-component sites (CCRK, DDRF, EPH2, GBB, H2O, LNO, MANO, MDW, MOX, OD2, OT3, PHIN, 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 three component sensors 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 15 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 conduits 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 (H3A, H4A, H2E, H2W) 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 Kinemetrics Basalts with 3 SMA channels that are supplemented by a high-gain vertical short-period sensor. Five sites have a broadband and strong-motion sensor packaged in a single casing that is deployed in a shallow posthole, Nanometrics Trillium Cascadia and a Centaur datalogger (GBB, H2O, MDW, SNI2, WA2).

A cell modem or digital radio 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 and 6-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. Acoustic signals are identified by their slower propagation across the network (soundwave speed) compared to seismic signals (elastic wave speed in rocks). All data are continuously telemetered, recorded, and 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 (Hartog et al., 2020). We currently run Earthworm version 7.10 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 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 (Hartog et al., 2020). 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 (44°-49° north latitude, 117°-121.5° west longitude) are reported in Table 4.2. 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 "wave speed model" (MOD), to solve for the most likely location for the earthquake source. AQMS divides the eastern Washington and Oregon region into 3 sub-regions. The wave speed 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 wave speed models to account for significant deviations in station elevations or stations situated on sedimentary layers. Station delays are determined empirically from accurately located earthquakes and blast events in the region.

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

Depth to Top of Layer (km)	Layer	Wave speed (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 three-component broadband stations. 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 2022 Earthquake Catalog for Eastern Washington

Table 4.2. Seismicity in the region 44° to 49° N latitude, -121.5° to -117° E longitude.

Day	Time	Lat	Lon	Depth	Mag	Mtype	NS/NP	Gap	Rms	Q	Mod	Type
October 2021												
02	14:37:12	47.7008	-120.2853	3.7	0.2	Ml	008/014	91	0.08	AB	N3	eq
04	20:52:45	47.6028	-120.3992	8.1	0.8	Md	007/013	121	0.20	BB	N3	eq
05	13:49:46	47.7130	-120.0273	7.0	0.9	Ml	015/025	63	0.10	AA	N3	eq
05	17:59:48	47.7893	-117.4145	-0.6*	2.0	Ml	009/014	108	0.18	CC	N3	px
06	04:10:26	48.5265	-119.7025	0.3*	1.6	Ml	012/013	121	0.16	CC	N3	eq
07	22:01:05	46.4550	-119.0477	-0.2*	1.3	Ml	008/008	225	0.14	CD	E3	px
07	23:26:13	47.2328	-118.1218	-0.4*	2.0	Ml	006/008	311	0.05	CD	N3	px
08	05:26:15	47.7273	-120.3053	3.2	0.4	Ml	010/016	94	0.05	AB	N3	eq
08	19:01:22	47.6685	-120.2902	3.9	0.1	Md	006/010	110	0.06	AB	N3	eq
08	20:55:13	47.1848	-118.2717	-0.5*	1.8	Ml	008/007	286	0.07	CD	N3	px
08	21:36:47	48.8793	-119.9158	0.8*	1.6	Ml	008/009	120	0.14	CC	N3	eq
11	23:00:46	46.7677	-118.2373	-0.3*	1.4	Ml	011/014	166	0.82	DC	E3	px
11	23:59:44	44.4042	-121.0550	-1.3*	1.9	Ml	009/008	132	0.23	CB	E3	px
14	19:03:30	47.3145	-121.1953	-1.0*	1.4	Ml	010/011	184	0.17	CD	C3	px
14	22:07:06	46.8950	-117.3555	-0.9*	2.1	Ml	009/013	132	0.67	DC	E3	px
15	20:21:12	48.9140	-121.1458	3.5	1.9	Ml	009/014	143	0.33	CC	C3	eq
16	11:05:05	47.6893	-120.3587	-0.3*	0.6	Ml	012/020	90	0.07	CB	N3	eq
16	22:27:56	47.6632	-120.2337	3.9	0.2	Md	006/011	111	0.05	AB	N3	eq
18	21:42:57	48.4108	-120.3573	-1.2	0.7	Md	007/010	191	0.13	BD	C3	eq
23	12:57:32	48.2887	-118.6950	1.9*	1.6	Ml	012/013	228	0.15	CD	N3	eq
31	07:39:32	47.7107	-120.2400	2.1	0.2	Ml	008/013	139	0.09	AC	N3	eq
31	17:48:34	47.7100	-120.2982	5.4	0.5	Ml	011/018	96	0.07	AB	N3	eq
November 2021												
02	04:49:10	46.7148	-119.1848	19.5	1.4	Ml	022/031	78	0.14	AB	E3	eq
03	11:11:16	46.6880	-120.9967	0.1*	1.0	Ml	010/015	130	0.12	CC	C3	eq
03	17:38:46	47.5737	-121.3793	8.8	1.3	Ml	026/034	59	0.20	BB	C3	eq
03	21:36:12	47.7363	-120.0247	3.5	1.0	Ml	009/016	66	0.11	AB	N3	eq
05	00:22:33	44.2538	-121.3240	-1.5*	1.0	Md	004/004	249	0.01	CD	N3	px
05	20:42:00	45.0807	-121.3333	-1.3*	0.9	Md	006/006	153	0.07	CC	N3	px
08	20:43:19	48.4615	-121.4742	9.1	1.6	Ml	015/018	134	0.13	AB	C3	eq
09	12:02:41	47.6787	-120.0172	3.2	0.7	Md	009/015	91	0.06	AB	N3	eq
11	20:47:56	45.6523	-120.3892	-0.6*	1.8	Ml	013/014	141	0.26	CC	E3	px
13	04:29:14	47.8727	-120.9310	3.6	1.5	Ml	018/020	78	0.09	AA	C3	eq
14	15:27:59	46.8202	-119.8842	22.5	2.1	Ml	039/045	45	0.13	AA	E3	eq
15	02:21:51	47.7177	-120.3267	3.3	1.5	Md	012/018	81	0.06	AB	N3	eq
19	16:56:18	47.7533	-120.4888	3.2	1.2	Ml	010/012	97	0.11	AB	N3	eq
21	20:21:07	47.6605	-120.1938	3.1	1.3	Ml	017/022	93	0.05	AB	N3	eq
22	07:09:38	47.8850	-120.8530	4.8	0.9	Ml	010/011	96	0.06	AB	C3	eq
22	10:32:40	46.4033	-121.3028	6.5	1.4	Ml	010/011	221	0.09	BD	C3	eq
24	07:45:48	47.6647	-120.3260	0.9	0.3	Ml	007/011	202	0.05	BD	N3	eq
29	16:55:15	47.7238	-120.3057	4.3	0.4	Ml	008/014	95	0.11	AB	N3	eq
29	21:00:52	46.9647	-119.1157	-0.3*	1.9	Ml	006/007	141	0.27	CC	E3	px
30	09:15:59	47.7457	-120.1198	6.1	-0.2	Md	004/006	177	0.07	AC	N3	eq
December 2021												
01	12:18:14	48.7538	-120.9978	-0.1	1.8	Ml	017/023	139	0.26	BD	C3	eq
01	19:58:28	47.3610	-117.8690	-0.5*	1.9	Ml	007/008	295	0.49	DD	N3	px
02	21:17:14	46.7617	-117.9032	-0.3*	1.8	Ml	013/015	228	0.40	CD	E3	px
03	18:10:03	45.6212	-120.9855	-1.3*	1.8	Ml	009/010	291	0.11	CD	C3	px
05	04:38:09	48.6965	-119.4937	0.3*	1.6	Ml	009/011	169	0.15	CC	N3	eq

05	08:11:56	48.7017	-119.4882	-0.6	1.6	Ml	010/013	166	0.16	BC	N3	eq
05	17:53:33	48.7493	-120.9840	-0.3	1.7	Ml	013/017	193	0.31	CD	C3	eq
05	21:21:29	48.6987	-120.2362	9.6	3.1	Ml	028/037	87	0.27	BC	C3	eq
05	22:27:54	48.7552	-121.0028	-0.0	1.2	Ml	014/016	193	0.28	BD	C3	eq
05	23:13:12	47.9082	-120.7603	0.2	1.0	Md	008/013	108	0.09	CB	C3	eq
06	00:07:24	48.7157	-119.4850	0.4*	1.3	Ml	009/013	172	0.27	CC	N3	eq
06	00:09:13	47.9077	-120.7600	0.4	1.1	Md	009/013	108	0.11	CB	C3	eq
06	04:45:02	48.7027	-119.4775	0.2*	2.4	Ml	016/018	172	0.09	CC	N3	eq
06	07:15:23	48.7043	-119.4755	0.3*	2.2	Ml	011/012	173	0.09	CC	N3	eq
06	08:55:30	48.7017	-119.4922	0.1*	2.4	Ml	013/017	169	0.12	CC	N3	eq
06	10:47:07	48.7020	-119.4903	0.7*	1.6	Ml	012/014	171	0.16	CC	N3	eq
06	10:58:25	47.6940	-120.3425	-1.1	0.5	Ml	008/012	123	0.06	AB	N3	eq
10	00:00:05	45.9198	-119.3002	-0.3*	1.8	Ml	014/019	203	0.31	CD	E3	px
10	17:13:30	47.8605	-120.7855	16.0	1.5	Md	005/007	138	0.07	BC	C3	eq
10	19:18:07	46.4360	-119.0205	-0.2*	1.3	Ml	012/014	152	0.14	CC	E3	px
13	05:21:43	48.1892	-120.8035	4.2	1.5	Ml	012/018	165	0.17	BC	C3	eq
13	10:08:23	48.1983	-120.8203	5.5	1.2	Ml	011/015	122	0.15	BC	C3	eq
14	08:16:23	48.7602	-120.9955	9.4*	1.9	Ml	019/027	80	0.41	CD	C3	eq
14	09:55:30	47.6822	-120.4452	8.9	2.0	Ml	026/028	109	0.15	BB	N3	eq
14	12:31:33	48.7580	-120.9803	0.2	1.6	Md	015/018	141	0.33	CD	C3	eq
15	04:51:09	45.1353	-120.9360	14.8	1.1	Ml	005/008	130	0.20	BB	C3	eq
15	08:44:26	48.1930	-120.8040	1.9	1.0	Md	007/011	167	0.16	BC	C3	eq
16	09:16:14	47.6862	-120.3320	-0.0*	0.3	Ml	006/008	209	0.06	CD	N3	eq
16	19:35:05	46.2447	-119.4747	-0.3*	2.2	Md	012/014	140	0.13	CC	E3	px
17	12:40:17	47.4223	-120.5038	1.2	1.8	Ml	024/032	72	0.26	BC	N3	eq
18	16:29:31	47.5953	-120.2313	7.1	0.6	Md	007/012	161	0.05	AC	N3	eq
18	19:10:59	47.6988	-120.0152	2.9	0.3	Ml	006/009	131	0.06	AB	N3	eq
19	03:16:59	47.6277	-120.2893	5.0	0.5	Ml	006/010	139	0.08	AC	N3	eq
23	22:21:32	48.6515	-119.8960	0.1*	1.7	Ml	009/012	136	0.16	CC	N3	eq
25	05:47:17	44.5538	-120.2630	7.2*	2.0	Ml	022/029	201	0.40	CD	N3	eq
29	08:09:50	46.6055	-119.7993	7.6	0.9	Ml	018/026	75	0.12	AA	E3	eq
30	06:41:24	48.1188	-120.6542	-0.7	1.8	Ml	022/031	105	0.25	BC	C3	eq
30	12:03:14	47.6805	-120.3212	2.2	1.3	Ml	014/021	110	0.07	AB	N3	eq
30	17:06:26	48.1112	-120.6578	7.0	1.2	Ml	012/022	104	0.20	BC	C3	eq
31	03:46:50	47.7205	-120.3175	5.4	2.1	Ml	022/029	78	0.10	AB	N3	eq
January 2022												
05	03:02:58	47.5618	-117.2928	0.1*	1.9	Ml	014/008	157	0.09	CC	N3	eq
06	23:26:14	46.6235	-120.6698	-0.7*	1.7	Ml	013/014	151	0.80	DC	E3	px
08	20:06:47	46.2550	-119.5487	7.2	0.7	Ml	011/019	195	0.06	AD	E3	eq
08	20:12:11	46.2512	-119.5512	8.2	0.4	Ml	008/013	197	0.07	AD	E3	eq
08	22:14:50	46.2560	-119.5477	6.8	0.7	Ml	011/019	193	0.08	AD	E3	eq
08	23:34:28	46.2533	-119.5477	6.8	0.4	Ml	009/012	197	0.04	AD	E3	eq
10	00:33:38	45.5358	-119.5757	5.8	1.4	Ml	015/020	130	0.31	CC	E3	eq
10	13:20:37	48.2282	-121.3280	8.2	1.9	Ml	017/026	104	0.34	CC	C3	eq
11	20:57:26	45.8875	-119.3002	-0.3*	1.5	Ml	009/014	215	0.17	CD	E3	px
13	04:31:54	46.9482	-119.1305	12.1	1.0	Ml	018/027	109	0.21	BB	E3	eq
14	03:24:59	46.1460	-119.8475	23.5	1.1	Ml	020/031	107	0.11	AB	E3	eq
14	10:01:34	46.1423	-119.8402	21.8	1.3	Ml	018/027	69	0.13	AA	E3	eq
18	13:52:40	47.6820	-120.2528	3.8	0.2	Md	006/011	137	0.04	AC	N3	eq
18	20:37:43	46.1040	-118.7713	-0.3*	1.6	Ml	008/005	158	0.09	CD	E3	px
18	22:49:27	46.5592	-117.7548	-0.6*	1.6	Ml	012/013	111	0.25	CC	E3	px
18	23:03:35	46.5902	-117.7800	-0.2*	2.2	Ml	013/016	319	0.47	CD	E3	px
18	23:15:45	44.6587	-121.1747	-1.1*	1.3	Ml	008/008	179	0.09	CC	E3	px
19	04:44:26	46.6927	-121.0792	13.9	0.7	Ml	016/022	138	0.11	AC	C3	eq

19	05:21:16	46.6937	-121.0777	12.8	0.8	Ml	019/026	138	0.14	BC	C3	eq
19	22:59:32	46.2658	-119.3985	-0.3*	1.9	Ml	024/025	168	0.12	CC	E3	px
22	23:41:45	47.7738	-120.7950	2.6	1.4	Ml	018/029	59	0.25	BC	C3	eq
25	00:27:16	46.6487	-119.8133	0.2*	0.6	Ml	008/008	132	0.04	CB	E3	eq
26	09:17:45	47.7138	-120.3108	1.9	1.3	Ml	014/022	84	0.06	AB	N3	eq
26	18:59:15	47.6557	-118.1255	3.6	1.8	Ml	009/009	144	0.09	AD	N3	eq
February 2022												
02	21:06:44	45.8925	-119.3028	-0.3*	1.3	Ml	007/007	178	0.24	CC	E3	px
03	08:35:53	46.6078	-119.8430	6.5	1.1	Ml	013/018	129	0.07	AB	E3	eq
04	01:39:05	47.7377	-120.0245	4.2	1.2	Ml	011/017	91	0.06	AB	N3	eq
04	19:01:11	44.0177	-121.2373	-1.6*	1.9	Ml	011/009	148	0.06	CC	N3	px
04	20:55:01	44.3818	-121.0652	-1.4*	1.7	Ml	006/006	197	0.07	CD	N3	px
07	03:57:03	47.7078	-120.2535	3.2	0.4	Ml	011/019	78	0.06	AA	N3	eq
08	14:35:02	48.2475	-120.8822	8.9*	1.6	Md	007/013	131	0.30	CC	C3	eq
09	09:46:05	47.6813	-120.2513	2.4	0.4	Ml	007/012	84	0.04	AA	N3	eq
09	19:36:49	47.6695	-120.1613	1.9	0.4	Ml	006/011	126	0.07	AB	N3	eq
10	10:15:38	47.6382	-120.2948	5.2	0.4	Md	009/009	114	0.03	AB	N3	eq
11	16:53:35	46.2633	-119.5377	5.5	0.6	Ml	006/009	285	0.05	AD	E3	eq
11	19:54:14	46.2763	-119.4970	9.6	0.6	Ml	005/008	285	0.06	BD	E3	eq
12	00:46:43	44.0190	-120.9052	-1.7*	2.0	Ml	008/007	307	0.12	CD	E3	px
12	01:54:42	46.2623	-119.5375	6.1	0.5	Ml	007/012	192	0.05	AD	E3	eq
12	06:19:40	45.9950	-118.6427	8.0	1.8	Ml	021/029	86	0.17	BA	E3	eq
12	12:52:20	46.2822	-119.4843	9.7	0.0	Md	004/006	284	0.02	CD	E3	eq
13	15:00:23	47.6447	-120.1442	3.1	0.1	Ml	006/009	117	0.07	AB	N3	eq
14	00:29:36	47.7113	-120.4118	2.7	0.3	Md	005/008	149	0.03	BC	N3	eq
15	21:05:05	46.2512	-119.6518	-0.5*	1.9	Ml	008/011	145	0.04	CC	E3	px
17	08:39:05	48.1928	-121.2907	9.6	1.0	Md	005/008	157	0.05	AC	C3	eq
18	19:58:12	46.2838	-117.9523	-0.4*	1.9	Ml	021/024	234	0.22	CD	E3	px
19	02:37:37	48.7523	-120.9995	8.9*	1.2	Ml	012/015	139	0.23	CD	C3	eq
19	05:36:39	46.9175	-120.5600	-0.7	1.1	Ml	017/025	108	0.65	DB	E3	eq
19	19:20:42	46.5990	-119.8685	6.7	2.2	Ml	031/046	51	0.11	AA	E3	eq
19	19:37:29	46.5997	-119.8653	6.6	1.9	Ml	029/036	51	0.09	AA	E3	eq
24	22:02:21	46.0917	-119.5227	-0.4*	1.6	Ml	008/011	207	0.07	CD	E3	px
25	00:37:08	47.2890	-117.8605	-0.6*	2.2	Ml	008/008	176	0.23	CC	N3	px
25	07:48:25	46.8170	-119.4253	0.1*	0.5	Ml	010/017	102	0.09	CB	E3	eq
25	10:44:47	47.7032	-120.2993	-0.5*	1.5	Ml	019/028	81	0.07	CB	N3	eq
26	13:25:47	47.8920	-120.3778	2.3	1.0	Ml	011/018	91	0.09	BC	N3	eq
March 2022												
02	16:16:02	47.6432	-120.2163	6.4	0.4	Md	007/010	136	0.02	AC	N3	eq
04	08:44:57	47.7323	-120.2702	2.0	0.5	Ml	010/018	81	0.06	AB	N3	eq
04	17:56:57	46.9937	-120.3618	-0.9*	1.7	Ml	017/017	92	0.33	CC	E3	px
07	01:06:09	46.8455	-120.6368	11.0	1.3	Ml	016/018	84	0.37	CA	E3	eq
07	07:29:52	47.7123	-120.1092	5.5	0.5	Ml	010/016	99	0.09	AB	N3	eq
10	00:49:37	46.2643	-119.5397	5.9	0.8	Ml	008/013	189	0.07	AD	E3	eq
10	00:53:42	46.2765	-119.4987	9.3	0.0	Ml	005/007	284	0.02	CD	E3	eq
10	19:45:53	47.3717	-117.8997	-0.6*	2.0	Ml	008/009	202	0.23	CD	N3	px
11	05:01:49	46.5713	-119.8112	6.3	0.9	Ml	010/016	152	0.09	AC	E3	eq
11	14:29:27	46.2230	-119.5528	4.3*	0.3	Ml	004/007	311	0.31	DD	E3	eq
13	01:12:11	46.6165	-119.8492	6.3	1.2	Ml	017/023	143	0.08	AC	E3	eq
13	08:10:55	46.6090	-119.8397	6.5	0.7	Ml	010/016	117	0.07	AB	E3	eq
13	08:13:51	46.6120	-119.8497	6.7	1.8	Ml	029/036	89	0.08	AA	E3	eq
14	20:34:34	45.6395	-118.7773	12.9	1.3	Ml	005/006	146	0.24	BC	E3	eq
15	07:00:42	46.8442	-120.9588	0.1*	0.8	Ml	014/017	98	0.28	CC	C3	eq
16	04:41:06	46.8523	-119.3923	15.2	0.6	Ml	011/015	119	0.17	BB	E3	eq

16	20:13:16	45.8665	-119.3385	-0.3*	1.8	Ml	012/016	237	0.17	CD	E3	px
18	14:58:06	47.7650	-120.0098	1.7	1.1	Ml	011/016	64	0.07	AA	N3	eq
19	12:56:56	46.2672	-119.5282	7.7	0.2	Ml	007/009	191	0.04	AD	E3	eq
19	13:58:07	47.7072	-120.0315	2.9	0.8	Ml	015/023	64	0.08	AB	N3	eq
20	03:35:50	47.8692	-120.6985	8.6	1.4	Ml	009/013	157	0.15	BC	C3	eq
21	06:17:05	46.3750	-119.4062	3.7	0.7	Ml	009/012	149	0.09	AC	E3	eq
22	06:07:36	48.1508	-120.7650	6.9	0.7	Md	006/010	163	0.21	BC	C3	eq
23	04:28:57	47.7260	-120.1658	2.8	0.4	Ml	008/013	64	0.05	AB	N3	eq
23	06:13:35	46.4065	-119.2673	2.2	1.2	Ml	018/025	131	0.09	AB	E3	eq
23	16:37:56	47.6010	-120.2312	5.5	0.8	Ml	006/010	198	0.09	AD	N3	eq
24	22:47:52	46.7223	-121.0683	2.3	0.9	Ml	018/022	128	0.22	BC	C3	eq
25	02:50:25	47.6883	-120.0910	4.9	0.6	Ml	010/014	60	0.06	AB	N3	eq
25	10:26:51	46.7360	-121.0587	0.1*	0.7	Ml	013/019	153	0.21	CC	C3	eq
26	07:44:04	48.1712	-121.2595	9.9	0.8	Ml	011/017	100	0.25	BB	C3	eq
26	15:27:24	47.6815	-120.2895	-0.5*	1.5	Ml	021/029	85	0.11	CA	N3	eq
27	00:14:49	46.7248	-121.0642	0.1*	0.9	Ml	016/024	137	0.20	CC	C3	eq
27	00:15:32	46.7220	-121.0650	0.3*	1.0	Ml	020/027	129	0.22	CC	C3	eq
27	06:11:01	46.6838	-121.0827	12.1	0.8	Ml	023/034	117	0.16	BC	C3	eq
27	19:06:25	46.6930	-121.0785	10.2	1.0	Ml	023/035	102	0.18	BC	C3	eq
28	14:32:01	47.5347	-120.1400	8.4	0.5	Ml	006/011	185	0.13	AD	N3	eq
April 2022												
01	07:54:34	46.2670	-119.5313	6.2	0.2	Ml	008/012	283	0.06	AD	E3	eq
01	08:07:50	46.2728	-119.5295	6.4	0.1	Ml	006/009	278	0.03	AD	E3	eq
02	00:41:48	46.6947	-120.5705	10.6	2.0	Ml	032/042	86	0.17	BB	E3	eq
03	18:41:01	46.6077	-119.8497	6.9	2.2	Ml	034/047	53	0.08	AA	E3	eq
04	00:25:53	46.6062	-119.8475	6.8	1.6	Ml	026/036	53	0.10	AA	E3	eq
04	02:24:54	47.7270	-120.1673	2.8	0.6	Ml	012/016	72	0.06	AB	N3	eq
04	12:02:48	46.2548	-119.5493	7.1	0.6	Ml	006/009	195	0.07	AD	E3	eq
04	13:56:16	46.2523	-119.5448	7.1	1.4	Ml	015/020	199	0.06	AD	E3	eq
04	14:12:48	46.2523	-119.5455	7.0	1.0	Ml	010/015	198	0.07	AD	E3	eq
04	14:20:18	46.2468	-119.5472	8.3	1.4	Ml	012/017	203	0.09	AD	E3	eq
04	19:50:41	46.6208	-120.4988	-0.7*	1.7	Ml	008/010	103	0.32	CC	E3	px
05	00:28:24	46.2557	-119.5512	7.0	1.0	Ml	013/018	193	0.08	AD	E3	eq
05	17:59:06	47.0667	-120.7235	-1.0*	1.7	Ml	011/011	86	0.30	CB	C3	px
07	21:47:00	46.6180	-119.8213	6.9	1.0	Ml	014/021	84	0.05	AA	E3	eq
07	22:20:32	46.6198	-119.8227	6.9	1.0	Ml	017/025	85	0.06	AA	E3	eq
07	22:21:58	46.6203	-119.8233	7.0	1.1	Ml	018/024	85	0.05	AA	E3	eq
07	22:22:54	46.6185	-119.8218	7.0	1.6	Ml	023/029	57	0.06	AA	E3	eq
07	22:24:02	46.6182	-119.8215	7.4	1.3	Ml	016/024	126	0.08	AB	E3	eq
08	18:51:57	46.9133	-120.5757	-0.9*	1.6	Ml	010/010	114	0.93	DB	E3	px
10	18:49:34	46.2525	-119.5447	7.0	0.8	Ml	013/020	199	0.08	AD	E3	eq
10	23:18:38	46.2513	-119.5438	7.2	1.6	Ml	023/029	200	0.07	AD	E3	eq
10	23:54:26	46.2450	-119.5323	7.2	1.9	Ml	026/036	198	0.08	AD	E3	eq
11	11:33:41	46.2627	-119.5402	7.4	0.2	Md	009/013	281	0.05	AD	E3	eq
11	19:11:48	46.1623	-119.1353	4.8*	1.6	Ml	009/012	171	0.22	CC	E3	px
12	18:00:35	47.5395	-120.2580	-1.2*	1.2	Ml	007/012	173	0.43	CC	N3	px
12	18:07:56	46.2522	-119.5448	7.2	1.1	Ml	014/023	199	0.07	AD	E3	eq
16	10:18:29	47.6467	-120.1463	3.4	1.1	Ml	015/020	83	0.06	AA	N3	eq
17	13:30:46	47.7107	-120.2278	-0.4*	0.2	Ml	007/011	135	0.10	CB	N3	eq
19	04:12:56	47.6867	-120.0565	4.0	0.2	Ml	004/008	167	0.07	AC	N3	eq
20	22:24:24	47.5530	-120.2797	-1.2*	1.1	Ml	006/007	164	0.10	CC	N3	px
22	08:19:34	47.6812	-120.0708	6.3	1.4	Ml	013/019	92	0.07	AB	N3	eq
22	17:42:59	46.0620	-119.3603	-0.3*	1.5	Ml	014/014	145	0.15	CC	E3	px
23	23:26:58	47.6627	-120.1142	2.7	0.2	Ml	007/010	110	0.06	AB	N3	eq

24	10:58:32	47.6413	-120.4005	-0.1*	0.2	Md	006/009	196	0.09	CD	N3	eq
25	18:12:43	47.4108	-117.8923	-0.6*	2.1	Ml	009/011	103	0.41	CC	N3	px
27	15:26:59	46.6428	-119.8707	5.4	1.3	Ml	017/029	64	0.12	AB	E3	eq
28	08:17:20	46.6407	-119.8675	5.0	0.7	Ml	012/015	98	0.05	AB	E3	eq
28	15:26:49	46.7628	-121.0370	0.1*	0.8	Ml	013/021	146	0.19	CC	C3	eq
29	06:34:02	47.6412	-120.1902	6.0	0.4	Ml	005/009	138	0.03	AC	N3	eq
29	06:37:14	47.7530	-120.3248	1.8	0.6	Ml	007/011	92	0.04	BC	N3	eq
29	11:27:23	46.1718	-119.8262	25.4	1.0	Ml	018/025	170	0.07	AC	E3	eq
May 2022												
01	17:45:18	46.5998	-119.8622	6.7	1.1	Ml	022/029	55	0.10	AA	E3	eq
03	13:02:20	46.2637	-119.5712	7.0	0.1	Ml	010/014	175	0.07	AC	E3	eq
04	22:41:20	44.0198	-121.2653	-1.5*	0.9	Ml	010/008	186	0.10	CD	E3	px
05	01:02:44	48.1602	-119.2113	0.5*	1.1	Ml	011/013	178	0.18	CC	N3	eq
05	01:04:18	44.2560	-120.8947	-1.6*	2.3	Ml	009/011	190	0.16	CD	N3	px
05	23:09:29	46.6078	-119.8445	6.6	0.7	Ml	009/014	164	0.07	AC	E3	eq
06	03:30:24	44.4028	-117.0307	7.4*	1.9	Ml	006/008	92	0.44	CD	E3	eq
06	06:38:47	48.4233	-120.4423	8.9*	1.4	Md	009/014	166	0.27	CC	C3	eq
08	00:38:51	46.4858	-119.7240	6.2	0.6	Ml	008/012	174	0.06	AC	E3	eq
08	12:52:59	46.1978	-119.2602	5.9	1.2	Ml	013/019	148	0.14	AC	E3	eq
09	07:42:51	46.5422	-119.0937	11.4	1.0	Ml	007/008	115	0.08	AB	E3	eq
09	07:43:39	46.5425	-119.0950	10.7	1.1	Ml	013/016	115	0.08	AB	E3	eq
09	08:09:39	46.5428	-119.0833	12.8	1.1	Ml	013/018	85	0.12	AA	E3	eq
09	19:12:53	46.4720	-120.9043	0.6*	1.1	Ml	006/008	246	0.63	DD	C3	eq
10	13:18:38	48.1250	-121.4003	11.5	0.8	Ml	006/012	155	0.20	BC	C3	eq
13	07:15:00	47.6978	-120.3242	1.3	0.8	Ml	013/021	87	0.05	AB	N3	eq
14	00:58:49	46.1415	-119.1977	-0.2*	2.0	Ml	019/023	163	0.16	CC	E3	px
15	07:44:39	46.6103	-119.8495	6.5	1.3	Ml	025/034	80	0.10	AA	E3	eq
17	17:56:21	47.4298	-117.8625	-0.6*	1.8	Ml	007/007	171	0.37	CC	N3	px
17	22:50:06	44.0242	-121.2673	-1.8*	1.2	Ml	009/009	171	0.18	CC	N3	px
19	20:53:21	46.1357	-119.2753	-0.3*	1.9	Ml	017/020	175	0.24	CC	E3	px
23	17:02:28	45.5953	-121.1063	-1.3*	1.9	Ml	007/008	279	0.09	CD	C3	px
23	21:41:07	44.5388	-118.2272	8.1*	1.6	Ml	005/008	125	0.52	DD	C3	eq
24	23:49:58	46.1958	-120.3372	7.9*	1.2	Ml	005/005	180	0.03	CD	E3	eq
25	20:02:14	46.6758	-119.3458	0.8*	-0.2	Md	002/004	281	0.27	CD	E3	eq
25	20:22:35	47.3870	-117.9338	-0.6*	2.1	Ml	010/012	198	0.17	CD	N3	px
26	07:16:24	46.7245	-120.7513	9.0	0.7	Ml	013/017	96	0.27	BB	C3	eq
26	08:06:49	46.8228	-119.7390	0.1*	0.4	Ml	007/011	147	0.22	CC	E3	eq
28	17:12:47	45.5693	-120.0843	18.9	1.5	Ml	012/017	198	0.07	AD	E3	eq
28	19:08:11	48.8078	-120.8225	-0.1	3.2	Ml	016/022	159	0.37	CD	C3	eq
30	16:08:08	48.8235	-120.8190	-0.5	1.7	Ml	010/014	213	0.55	DD	C3	eq
31	10:53:30	46.9535	-120.1067	6.2	1.5	Ml	025/025	89	0.13	AB	E3	eq
31	19:36:52	48.8068	-120.8380	9.4*	2.1	Ml	012/015	146	0.31	CD	C3	eq
June 2022												
01	06:56:18	46.4855	-119.7247	6.6	0.5	Ml	010/014	176	0.08	AC	E3	eq
01	21:12:39	46.9175	-120.1137	3.7	1.0	Ml	013/012	92	0.20	BB	E3	eq
02	19:22:01	46.7343	-120.8262	-1.0*	1.4	Ml	007/009	123	0.96	DB	C3	px
02	21:10:53	44.7203	-117.7563	9.6*	1.7	Ml	003/004	225	0.01	CD	C3	eq
04	06:41:25	47.6530	-120.3780	3.3	1.1	Ml	016/020	95	0.07	AB	N3	eq
04	12:01:31	46.2197	-119.0602	13.6	1.0	Ml	017/029	146	0.26	BC	E3	eq
08	04:33:04	47.6513	-120.2595	5.4	0.3	Md	006/011	120	0.06	AB	N3	eq
08	05:59:06	46.2557	-119.5485	6.9	0.7	Ml	011/017	193	0.09	AD	E3	eq
08	23:16:13	48.2815	-118.6855	1.8*	1.5	Ml	009/010	168	0.21	CC	N3	eq
10	17:15:14	45.8413	-118.2250	-0.6*	2.1	Ml	008/008	236	0.99	DD	E3	px
11	00:03:39	46.1892	-120.3543	12.5	2.4	Ml	036/042	93	0.13	AB	E3	eq

11	17:40:45	46.1873	-120.3585	12.4	1.4	Ml	019/026	136	0.12	AC	E3	eq
11	19:26:36	46.6643	-120.9203	4.6	1.8	Ml	018/025	118	0.23	BC	C3	eq
13	00:07:17	45.6998	-119.1645	7.9	1.1	Ml	014/014	151	0.08	AC	E3	eq
15	21:41:49	44.4102	-121.0518	-1.5*	2.0	Ml	009/008	172	0.09	CC	E3	px
16	01:23:17	45.7023	-119.1903	8.9	1.1	Ml	017/019	133	0.22	BC	E3	eq
16	14:15:57	47.3698	-120.4493	4.5	1.1	Ml	015/023	120	0.29	BC	N3	eq
19	05:00:14	46.8543	-120.6838	11.9	1.0	Ml	009/013	125	0.44	CB	E3	eq
22	18:38:47	47.8007	-117.3628	-0.7*	2.4	Md	010/015	77	0.66	DC	N3	px
23	02:48:24	44.8527	-117.0427	6.7*	2.2	Ml	004/007	123	0.37	CC	N3	eq
24	22:41:32	48.2632	-120.7265	8.8*	1.7	Ml	012/022	109	0.26	CC	C3	eq
24	23:12:50	46.6598	-120.4875	-0.5*	1.7	Ml	013/017	74	0.45	CC	E3	px
25	02:11:58	47.6635	-120.2860	3.5	1.0	Ml	010/016	86	0.07	AA	N3	eq
26	02:33:03	48.3045	-120.5757	6.5	0.9	Md	005/009	178	0.08	AC	C3	eq
27	10:01:03	48.2477	-120.7112	8.7*	0.9	Ml	007/013	175	0.15	CC	C3	eq
27	13:40:02	48.2053	-121.3802	-0.7	1.1	Md	009/012	133	0.12	AC	C3	eq
28	06:59:10	45.8715	-120.1658	16.8	2.4	Ml	021/029	121	0.15	BB	E3	eq
30	09:52:35	45.0083	-121.3143	7.0*	1.5	Ml	016/021	86	0.20	CC	E3	eq
30	11:37:56	46.4132	-119.2773	0.3*	1.1	Ml	018/027	87	0.13	CA	E3	eq
July 2022												
01	11:57:32	48.1787	-120.1433	1.2	0.7	Ml	007/011	130	0.04	BC	N3	eq
03	06:16:56	48.3187	-120.4433	7.4	0.8	Ml	007/010	169	0.10	AC	C3	eq
03	10:14:29	46.5957	-119.8585	6.6	0.7	Ml	011/018	136	0.08	AC	E3	eq
05	18:02:00	46.6078	-119.8590	6.5	-0.4	Md	003/005	269	0.00	BD	E3	eq
06	09:58:04	47.6690	-120.0883	6.9	0.5	Ml	010/019	67	0.09	AA	N3	eq
07	20:22:52	46.6703	-120.5093	-0.8*	1.4	Ml	017/018	80	0.42	CC	E3	px
09	12:51:33	47.9238	-120.3847	-0.3*	1.8	Ml	020/028	66	0.09	CC	N3	eq
12	17:11:41	46.6397	-120.4863	-0.6*	1.5	Ml	012/011	96	0.19	CC	E3	px
13	18:47:44	46.0955	-119.3158	-0.3*	0.6	Ml	007/009	166	0.21	CC	E3	px
15	02:25:04	47.0432	-120.9427	14.5	2.0	Ml	037/052	58	0.27	BA	C3	eq
15	11:04:56	46.6508	-120.9238	0.0	1.4	Ml	018/026	121	0.29	BC	C3	eq
18	11:05:52	48.2103	-119.5923	1.7*	0.7	Ml	004/006	116	0.11	CC	N3	eq
19	01:32:09	45.7798	-118.9653	-0.6*	1.4	Ml	011/012	102	0.32	CC	E3	px
20	15:28:43	46.5582	-119.5552	14.1	0.6	Ml	012/018	77	0.07	AA	E3	eq
20	20:21:21	44.5688	-117.4108	-1.1	1.6	Ml	006/006	120	0.18	BC	E3	eq
20	20:41:14	47.3840	-117.8662	-0.6*	2.1	Ml	007/008	133	0.51	DC	N3	px
21	22:33:17	46.3552	-119.2898	13.8	1.3	Ml	020/026	100	0.15	BB	E3	eq
22	00:45:45	46.2925	-118.0260	-0.3*	1.8	Ml	015/015	224	0.34	CD	E3	px
22	05:10:16	47.6582	-120.1942	3.0	0.7	Ml	008/013	116	0.06	AB	N3	eq
22	14:11:23	47.0587	-118.7158	9.6	2.1	Ml	021/032	123	0.48	CB	N3	eq
22	18:01:57	48.2285	-117.8762	-0.7*	1.8	Ml	008/011	166	0.52	DC	N3	px
23	16:34:36	48.5782	-121.3070	-0.4	0.9	Ml	006/007	139	0.12	BC	C3	eq
24	08:48:35	46.2190	-119.4387	9.3	0.2	Ml	009/014	259	0.08	AD	E3	eq
27	21:53:38	45.9267	-119.2927	-0.3*	1.5	Ml	012/012	176	0.13	CC	E3	px
28	21:29:42	46.7562	-121.0270	0.3*	0.9	Ml	015/018	165	0.11	CC	C3	eq
29	13:32:25	46.9390	-119.2743	7.8	0.7	Ml	007/010	104	0.26	BB	E3	eq
29	16:35:53	44.0148	-121.2575	-1.7*	2.0	Ml	018/016	173	0.06	CC	E3	px
29	18:06:02	47.6308	-120.2148	-1.1*	1.5	Ml	010/010	130	0.06	CB	N3	px
29	19:51:29	47.3918	-117.8592	-0.7*	2.4	Ml	009/008	163	0.12	CC	N3	px
31	21:38:16	47.7043	-120.3220	2.1	0.7	Ml	006/011	120	0.07	AB	N3	eq
August 2022												
01	00:30:14	47.6463	-120.1252	7.7	0.6	Ml	009/014	60	0.10	AA	N3	eq
01	09:10:54	47.7275	-120.4340	12.7	0.5	Ml	013/018	95	0.09	AB	N3	eq
01	18:06:44	47.7618	-120.1520	4.4	1.8	Ml	017/029	52	0.13	AB	N3	eq
01	18:26:45	46.7537	-121.0355	0.6*	1.1	Ml	023/029	119	0.18	CC	C3	eq

01	20:40:38	46.5805	-120.8537	7.0	0.9	Ml	005/007	224	0.07	BD	C3	eq
02	14:58:15	47.6533	-120.3762	3.8	2.0	Ml	017/025	101	0.07	AB	N3	eq
03	12:37:07	47.6297	-121.3887	10.9	1.2	Ml	018/023	83	0.15	BA	C3	eq
03	14:56:25	48.3770	-120.2588	1.2	1.2	Ml	009/012	160	0.12	BC	N3	eq
03	18:40:34	46.7228	-121.0400	0.8*	0.8	Ml	014/019	106	0.17	CC	C3	eq
04	08:29:57	47.6077	-121.3813	8.6	1.3	Ml	019/027	108	0.17	BB	C3	eq
04	16:19:37	46.7578	-120.9693	6.2	0.8	Ml	017/026	98	0.16	BB	C3	eq
04	16:22:10	48.6455	-118.0192	-0.8*	1.5	Md	005/004	300	0.04	CD	N3	px
04	21:53:36	46.5498	-119.3833	17.4	1.1	Ml	017/026	96	0.08	AB	E3	eq
05	22:32:02	46.7467	-121.0320	4.0	0.8	Ml	016/019	131	0.19	BC	C3	eq
06	06:39:28	47.0423	-120.9540	11.6	1.4	Ml	012/011	132	0.19	BB	C3	eq
07	07:45:02	47.5982	-120.2473	6.6	0.1	Ml	005/007	201	0.03	AD	N3	eq
08	21:21:30	46.6183	-120.7453	8.3	0.9	Ml	012/016	114	0.18	BB	C3	eq
09	17:09:18	46.1688	-121.2792	6.2	1.3	Ml	011/017	104	0.12	AC	C3	eq
11	16:04:19	47.6258	-117.3603	-0.8*	1.6	Md	004/005	216	0.41	CD	N3	px
12	04:38:24	47.6473	-120.2440	1.5	0.4	Ml	006/010	128	0.07	AB	N3	eq
13	13:31:50	46.1315	-120.5017	12.3	3.0	Ml	040/054	62	0.18	BB	E3	eq
13	18:14:29	46.1457	-120.4655	7.3	0.7	Ml	007/008	200	0.05	BD	E3	eq
13	23:37:50	47.6265	-120.0498	8.8	0.2	Md	005/008	132	0.08	AB	N3	eq
17	02:07:06	46.6098	-119.8503	6.6	1.2	Ml	020/027	46	0.06	AA	E3	eq
17	04:26:16	47.6680	-120.2905	2.1	0.2	Ml	006/010	95	0.05	AB	N3	eq
17	06:30:48	46.7563	-121.0363	3.4	0.9	Ml	020/025	118	0.16	BC	C3	eq
17	15:57:35	47.7235	-120.0110	5.5	0.8	Ml	012/017	81	0.08	AB	N3	eq
17	17:22:39	47.6512	-120.1330	5.5	0.2	Ml	006/009	123	0.04	AB	N3	eq
17	17:26:38	47.6513	-120.1350	5.7	0.0	Ml	005/009	134	0.05	AB	N3	eq
19	04:03:19	47.0530	-120.9737	6.9	0.9	Ml	021/033	132	0.29	BC	C3	eq
19	06:53:50	46.7388	-121.0388	3.4	1.3	Ml	032/048	102	0.27	BC	C3	eq
19	13:47:08	47.7315	-120.3148	3.0	0.6	Ml	008/013	96	0.06	BC	N3	eq
20	10:35:02	48.9987	-119.0930	11.5	2.2	Ml	013/017	164	0.30	CC	N3	eq
20	11:05:59	48.9313	-119.0912	15.9	1.1	Ml	005/007	260	0.10	BD	N3	eq
20	21:54:06	48.7213	-120.3255	9.8*	1.5	Ml	012/018	118	0.35	CC	C3	eq
20	21:57:06	47.7125	-120.0863	3.5	1.5	Ml	022/023	54	0.06	AB	N3	eq
20	22:25:04	46.2973	-119.6310	0.0*	0.3	Ml	006/008	170	0.03	CC	E3	eq
21	23:49:42	48.7437	-120.0498	10.8	2.2	Ml	014/018	131	0.18	BC	N3	eq
22	00:56:52	48.2290	-119.2665	8.3	1.7	Ml	013/016	68	0.12	AB	N3	eq
22	04:47:54	47.5735	-120.1640	7.0	0.5	Ml	007/010	168	0.05	AC	N3	eq
22	07:52:24	46.7495	-121.0317	0.2*	0.7	Ml	019/025	121	0.14	CC	C3	eq
22	21:18:02	45.8838	-119.3163	-0.3*	1.5	Ml	008/010	215	0.15	CD	E3	px
23	09:32:31	46.7478	-121.0307	3.6	1.6	Ml	036/046	98	0.19	BC	C3	eq
23	11:36:57	47.6972	-120.2945	2.0	1.6	Ml	020/023	82	0.06	AB	N3	eq
24	14:58:13	47.1742	-121.1085	10.8	1.1	Ml	017/026	135	0.32	CB	C3	eq
24	17:38:56	45.9125	-119.3030	-0.3*	1.5	Ml	007/010	205	0.24	CD	E3	px
25	00:34:49	47.6182	-120.2680	1.5	0.7	Ml	005/008	165	0.04	AC	N3	eq
26	20:50:06	46.7457	-117.1062	-0.7*	2.4	Md	007/008	244	0.56	DD	E3	px
26	22:02:32	48.7537	-121.0008	10.1*	1.1	Ml	007/012	193	0.31	CD	C3	eq
28	06:00:49	47.6580	-120.1852	1.5	0.5	Ml	006/008	99	0.07	AB	N3	eq
29	00:24:30	48.3812	-120.2702	2.8	1.1	Ml	009/013	138	0.15	BC	N3	eq
29	19:28:21	48.5895	-117.9660	-0.9*	1.4	Ml	006/007	199	0.16	CD	N3	px
30	03:55:37	47.6462	-120.1427	2.8	0.6	Ml	010/015	80	0.07	AA	N3	eq
30	04:25:32	47.7147	-120.0418	6.2	0.5	Ml	009/011	117	0.07	AB	N3	eq
30	15:19:16	47.6662	-120.3067	4.3	0.4	Ml	007/009	104	0.07	AB	N3	eq
30	16:32:10	47.6663	-120.3042	4.3	0.4	Ml	005/008	109	0.08	AB	N3	eq
30	17:37:10	47.6602	-119.7243	12.0	0.6	Ml	008/012	97	0.08	AC	N3	eq
30	19:56:20	46.1893	-120.3537	13.7	1.4	Ml	014/018	125	0.12	AB	E3	eq

30	23:25:32	47.6615	-119.7237	12.1	1.1	Ml	012/018	73	0.09	AC	N3	eq
31	06:52:00	47.6582	-119.7277	11.3	0.2	Ml	008/014	98	0.09	AC	N3	eq
31	07:13:08	47.6598	-119.7242	11.0	0.3	Ml	007/012	97	0.08	AC	N3	eq
31	11:11:32	44.0163	-120.6177	10.0*	1.6	Ml	012/019	321	0.23	CD	N3	eq
31	21:22:01	45.8988	-119.3075	-0.3*	1.6	Ml	011/014	211	0.13	CD	E3	px
September 2022												
01	08:03:18	47.6188	-120.2688	0.9	0.4	Ml	004/008	163	0.09	BC	N3	eq
01	22:13:09	45.8962	-119.3087	-0.3*	1.7	Ml	015/019	177	0.16	CC	E3	px
02	17:42:14	48.1448	-117.8667	-0.9*	1.5	Ml	005/007	187	0.08	CD	N3	px
03	11:52:39	45.7238	-118.5525	8.3*	1.0	Ml	004/006	163	0.15	CC	E3	eq
04	12:44:19	46.7477	-121.0390	6.9	0.9	Ml	020/031	101	0.23	BC	C3	eq
05	03:32:18	47.6205	-120.2653	0.4	0.9	Ml	010/016	64	0.09	BA	N3	eq
05	21:22:49	47.6545	-120.2162	2.8	0.3	Ml	005/010	122	0.05	AB	N3	eq
10	10:47:23	46.7367	-121.0368	4.9	0.7	Ml	019/026	125	0.27	BC	C3	eq
13	01:49:14	47.7215	-120.2975	4.4	0.4	Ml	007/013	93	0.07	AB	N3	eq
15	00:04:46	44.2112	-121.1610	-1.7*	1.0	Ml	007/007	296	0.46	DD	N3	px
16	18:26:01	47.7197	-120.0193	4.7	0.3	Ml	004/006	182	0.04	AD	N3	eq
17	13:22:53	47.6960	-120.3245	2.5	0.2	Ml	006/011	112	0.07	AB	N3	eq
20	06:07:51	47.6413	-120.1192	4.2	0.8	Ml	010/016	87	0.08	AA	N3	eq
20	20:03:44	46.1440	-119.2815	-0.2*	1.3	Ml	011/017	208	0.13	CD	E3	px
21	06:25:15	47.9477	-120.7167	4.5	0.5	Ml	011/017	95	0.20	BC	C3	eq
22	18:53:59	47.8450	-117.5782	-0.7*	1.0	Md	006/007	124	0.06	CC	N3	px
22	19:28:51	47.5060	-120.2943	-1.2*	1.2	Ml	010/009	120	0.04	CC	N3	px
23	22:55:26	48.9583	-119.0842	14.6	1.2	Ml	007/011	183	0.20	BD	N3	eq
25	00:53:33	46.0367	-118.6848	16.2	1.4	Ml	011/013	154	0.10	AC	E3	eq
25	16:04:15	46.7577	-121.0315	3.7	0.7	Ml	016/024	131	0.14	AC	C3	eq
25	16:41:32	47.6575	-120.1787	2.4	0.4	Ml	008/013	91	0.06	AB	N3	eq
25	22:20:24	47.6762	-120.1165	3.4	0.6	Ml	009/012	113	0.05	AB	N3	eq
26	17:20:36	46.4888	-120.8153	1.6*	1.2	Ml	007/008	152	0.62	DC	C3	eq
26	20:33:20	45.0868	-121.3442	-1.2*	1.1	Ml	007/007	150	0.04	CC	C3	px
27	23:06:47	44.3250	-121.0787	-1.6*	1.8	Ml	009/011	254	0.41	CD	C3	px
28	14:26:21	47.6513	-120.1963	3.0	0.5	Ml	006/011	125	0.10	AB	N3	eq
28	21:02:52	46.2458	-119.4793	-0.3*	1.2	Ml	006/007	241	0.03	CD	E3	px
29	08:01:53	46.0147	-119.2235	12.9*	1.6	Ml	020/025	123	0.25	CC	E3	eq
29	15:53:04	47.6152	-120.2450	3.4	0.6	Ml	004/008	174	0.06	AC	N3	eq
29	22:13:55	46.5988	-119.7947	7.6	0.5	Ml	010/015	191	0.07	AD	E3	eq
30	21:09:20	44.1138	-121.3732	-1.6*	2.0	Ml	011/010	193	0.68	DD	E3	px
30	21:23:59	46.7538	-121.0233	0.3*	0.6	Ml	008/012	138	0.11	CC	C3	eq
30	22:31:59	47.7922	-117.6787	0.3*	1.6	Md	009/013	98	0.11	CC	N3	eq

5.0 Discussion of Seismic Activity – FY 2022

5.1 Summary

During FY 2022, seismic activity was relatively quiet throughout eastern Washington. 316 earthquakes were cataloged in the region, of which 25% (78) 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 low to typical swarm-type activity, most strongly observed in the Horse Heaven and the Wye 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 2022

Category	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2022
Shallow (0-4 km deep)	40	27	20	40	127
Intermediate (4-9 km deep)	17	30	48	33	128
Deep (greater than 9 km deep)	7	15	14	25	61
Total	**64**	**72**	**82**	**98**	**316**
Felt	1	0	0	1	2
Probable Blast	18	18	21	28	85

Table 5.2. Earthquake Counts for FY 2022 for Earthquakes near the Hanford Site

Seismic Source Zones	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	FY 2022
Frenchman Hills	0	0	0	1	1
Saddle Mountains	0	1	0	0	1
Wahluke Slope	0	0	0	0	0
Coyote Rapids	0	0	0	0	0
Wye	0	1	1	1	3
Cold Creek	0	0	2	0	2
Rattlesnake Mountain	0	0	0	1	1
Horse Heaven Hills	0	2	1	0	3
Total for swarm areas	0	4	4	3	11
Random Events	3	23	33	8	67
Total For All Earthquakes	**3**	**27**	**37**	**11**	**78**

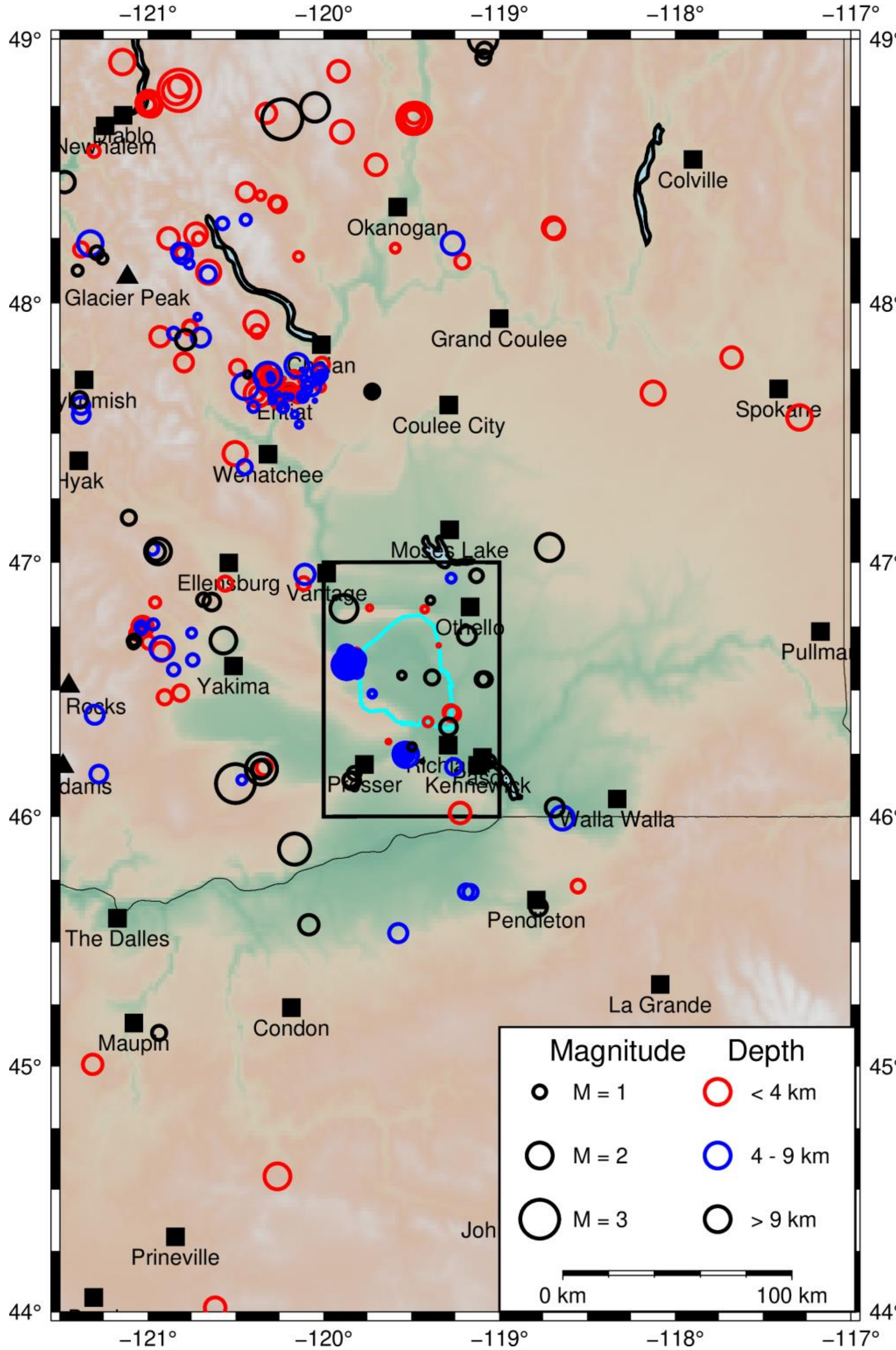

Figure 5.1. Hanford and Regional Epicenters of Earthquakes Recorded during FY 2022. Background color indicates elevation.

Red circles stand for shallow earthquakes (0-4 km). Blue circles for intermediate-depth earthquakes (4-9 km).

6.0 Status of Monitoring

In addition to the significant enhancements of the seismic monitoring network made during FY 2017 and FY 2018, the PNSN has added additional monitoring stations in eastern WA using funding from the USGS ShakeAlert^{TM} project. Therefore, overall monitoring capability of seismicity in the region surrounding the Hanford Site has improved. In addition, during FY 2022, using funding from the USGS, PNSN replaced old-fashioned analog equipment at site OD2 (Odessa, WA) to create another six-channel broadband and strong-motion station. A failing Q330 data logger at DDRF has been replaced by a new Q330S+, on loan from the USGS.

As of May 4th, 2021, ShakeAlert^{TM} powered Earthquake Early Warnings are available to individuals in WA state with smart phones, through the federal Wireless Emergency Alert (WEA) system, the Android operating system, or by downloading a phone app named MyShake. Additional cell phone apps are expected to become available in the future. Data from twenty-six stations operated and maintained under the current contract are of sufficient quality and low-latency that they are forwarded by the PNSN to contribute to the ShakeAlert^{TM} system, resulting in a higher probability of timely, useful, warnings for personnel at the Hanford Site. Likewise, improvements made to ShakeMap (which are maps of observed shaking produced after an earthquake) benefit Hanford Site operations. In previous reports, it was noted that PNSN has adopted new methods to monitor the quality and data latency of their growing network. These improvements benefit the HSN and EWRSN as well.

Looking ahead, PNSN would like to make further upgrades to the network. Several instruments of the HSN and EWRSN are reaching end-of-life and exhibit (intermittent) issues. The five Kinemetrics Basalt dataloggers with internal Episensor ES-T accelerometers were purchased in 2012 and are now 10 years old. The equipment purchased from IRIS in 2008 is 14+ years old; we had to replace the Q330 at DDRF, station PHIN still has all the original IRIS equipment. CCRK was rebuilt after it was destroyed by wildfire and has new FY 2017 equipment. The PNSN is phasing out operating analog-telemetry stations due to the inability to purchase new analog radios, and lack of staff trained in this old-fashioned technology. On the Hanford Site, three old-fashioned analog stations remain, BEN, LOC, and RSW. Given the density of digital stations on the site, we may be able to discontinue these three sites without losing significant monitoring capability. In the wider EWRSN, another eleven analog stations remain. In the next year, PNSN plans to analyze the contribution of each analog site to the monitoring capability and propose which locations need to be retained, and which can be decommissioned.

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.

Hartog, JR, PA Friberg, VC Kress, P Bodin, R Bhadha, 2020 *Open-Source ANSS Quake Monitoring System Software*, Seism. Res. Lett., https://doi.org/10.1785/0220190219

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

Klein, Fred W., 2002, *User's Guide to HYPOINVERSE–2000, a Fortran Program to Solve for Earthquake Locations and Magnitudes: U.S. Geological Survey Open-File Report 02-171*, 123 pp., *https://pubs.usgs.gov/of/2002/0171/*.

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.