Final Technical Report 2010-2014

Pacific Northwest Seismic Network – UW

USGS Cooperative Agreement G10AC00087

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I. Abstract

The Advanced National Seismic System (ANSS) provides major funding for the Pacific Northwest Seismic Network (PNSN) as the Tier 1 regional seismic network (RSN) in central Cascadia, comprised by the states of Washington and Oregon. PNSN has established, and is maintaining and further developing, an advanced infrastructure for seismic monitoring in the region. PNSN is centrally managed from the Seismo lab at the University of Washington Seattle campus. Elements of the operations of PNSN in the state of Oregon are carried out through a separate cooperative agreement with the University of Oregon (UO). This Final Technical Report is intended to consolidate the reporting for both the UO and the University of Washington (UW) cooperative agreements. The USGS Earthquake Program's Seattle office also provides valuable technical assistance. Thus PNSN is a truly collaborative enterprise internally, and is further coordinated with other RSNs through the ANSS. PNSN exchanges seismic data with surrounding networks, and provides enhanced services supported by additional sponsors, such as the Department of Energy and the Volcano Hazards Program, the state of Washington, and private scientific research foundations (*e.g.,* the Moore Foundation and the Murdock Trust). PNSN operates more than 360 seismic stations (~250 with ANSS support), and imports data from a further ~100 stations operated by contributing networks. PNSN uses the ANSS Quake Management System (AQMS) to acquire, process, locate, and catalog the region's seismicity (including explosions, tremor, sonic booms, etc.). Data from the PNSN are archived with low latency at the Incorporated Research Institutions in Seismology (IRIS) Data Management Center (DMC), providing millions of PNSN-acquired seismograms annually to researchers throughout the world.

II. Network Description

Robust, consistent, and responsive regional seismic monitoring in the Pacific Northwest (PNW) is critically important because the risks from earthquake hazards are so high. According to FEMA (2008) the annualized loss from earthquakes in the region exceeds 500 million dollars, the region at second highest risk in the nation just behind California (Figure 1). At the same time, the occurrence rate of smaller non-damaging earthquakes is not extremely high (Figure 2). The relative dearth of seismicity contributes to rather large uncertainties about the hazards and potential impacts of earthquakes here.

In the face of this somewhat self-contradictory threat, consistent seismic monitoring is key to:

- **establish and monitor a baseline** of "normal" or "background" seismicity both to understand the region's faulting processes and to help recognize when and if there is a change in seismic behavior,
- **rapidly characterize earthquake sources** in the region to answer the "where and how big" type of questions in the immediate aftermath of an earthquake for response and pubic information, and
- **directly measure ground motions** from damaging earthquakes that may impact the built environment and those from smaller earthquakes that provide information needed by scientists and engineers to properly characterize the inputs of their research and planning models as well as to validate their predictive outputs.

The next major earthquake to strike Portland or Eugene in Oregon, or anywhere within the Puget Sound metropolitan region in Washington, has the potential to seriously damage not only the local populace and economy, but to have deleterious impacts to the nation and even globally. This is because of the region's vital role in industrial production and transportation logistics.

The defining geological process within the PNW is the subduction of the Juan de Fuca (JDF) tectonic plate beneath North America (see Figure 2). In addition to the plate boundary megathrust fault that produces (geologically) frequent earthquakes as large as M9 (recurrence ~500 years, latest in 1700), damaging earthquakes are also produced within the subducting JDF plate (recurrence ~30 years, latest in 2001; $M\leq7$), and within the North American crust above the plate boundary (recurrence uncertain and spatially variable, latest in Seattle ~1100, latest in region 1892 east of the Cascade Range). The intraplate earthquakes are presumably driven by stresses not relieved by slip on the subduction megathrust. The region is also known as Cascadia because processes associated with subduction produces the Cascade Range and its active volcanoes, another geological threat monitored in part by the PNSN network. While Cascadian subduction, and hence the scientific rationale to define an RSN, extends to the northernmost portion of California and the southern half of Vancouver Island in Canada, political realities and historic inertia limit PNSN's authority to the states of Oregon and Washington. Therefore, another important aspect of an RSN is to coordinate with any surrounding RSNs and the national seismic monitoring system (the Advanced National Seismic System, or ANSS) to ensure and enhance the quality, accuracy, and robustness of its products.

The ANSS investment in the infrastructure and operation of the regional seismic monitoring for seismic hazards leverages funding from other clients who can build on the structure. It is also because of PNSN's strong collaborations with regional partners, other seismic networks, and the larger community of Earth Sciences.

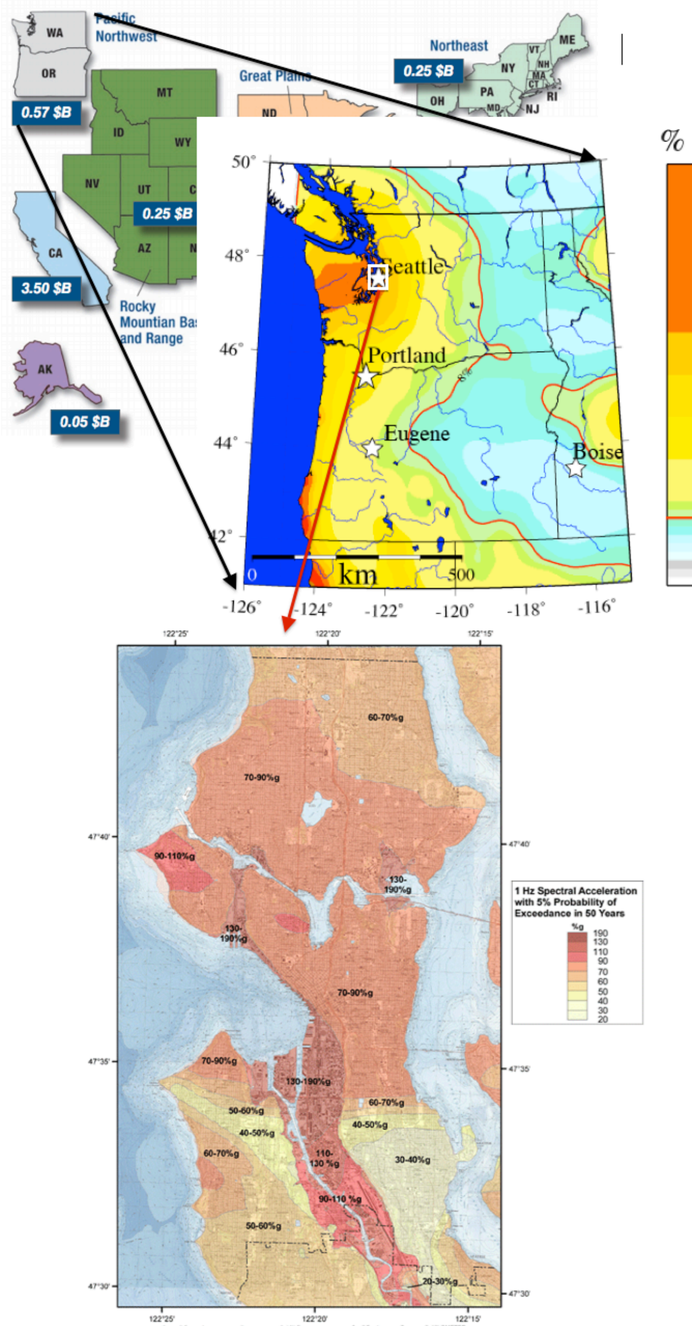

Figure 1. Earthquake Hazard and Risk in the Pacific Northwest. Oregon and Washington face 0.57B/yr expected losses from earthquakes (top, from FEMA, 2008). The hazard is highest in the west due to active subduction-related seismicity (middle panel shows 10% PE in 50 yr PGA from the 2002 national maps). Hazard in urbanized areas, such as Seattle (lower panel, showing 1-Hz Acceleration @ 5% PE in 50 yr, from USGS, 2012), is also influenced by topographic and geological features, as well as local crustal faults.

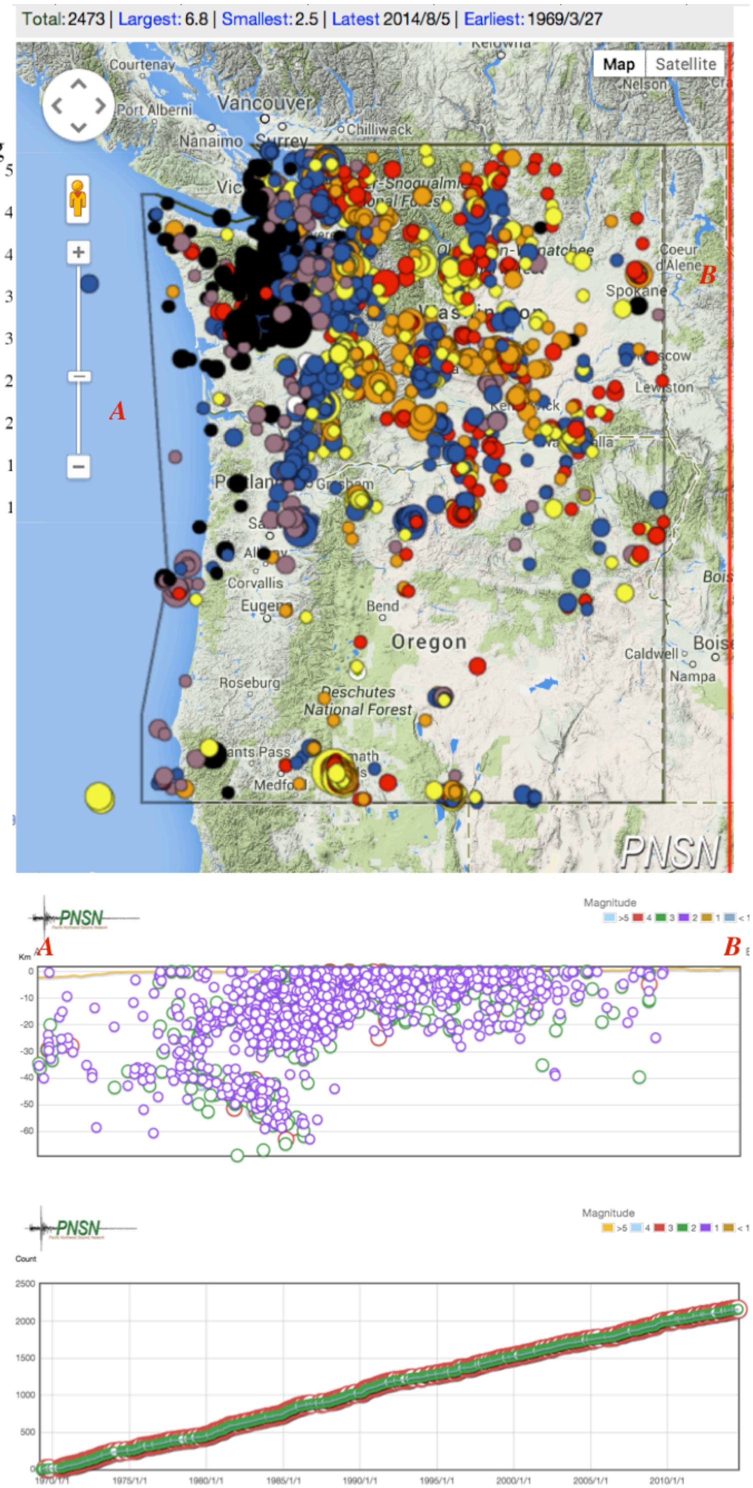

Figure 2. Magnitude ≥ 2.5 earthquakes (2473) in Cascadia since 1970 (from pnsn.org). Top panel: epicenters colored by depth (black=deepest, yellow=shallowest). Black box is PNSN authoritative region. Middle: depth cross-section from A – B revealing, amongst other interesting features, the subducting JDF slab in the lower left. Bottom: cumulative number of earthquakes showing fairly constant rate of seismicity since ~1980 (about 63 M ≥ 2.5 per year).

The ANSS supports the PNSN as the Tier 1 regional seismic network (RSN) in central Cascadia (as defined in the ANSS "Participation Policy" document). This support provides for:

- Operating more than 250 seismic stations in Washington and Oregon. An additional ~110 stations are operated by PNSN with support from other partners (chiefly USGS VHP and USDOE). PNSN is responsible for maintaining metadata from these >360 stations in the SIS system, at the IRIS DMC data archive, and in our AQMS system. We also archive data from these stations plus an additional ~36 CC network (USGS VHP-owned -and-operated) stations at the publicly-available IRIS DMC archive, generally within a minute of their arrival at the UW.
- Acquiring data from a further ~100 stations contributed by partner networks that operate stations in and surrounding the PNSN authoritative region. This includes stations in the TA, PB, CN, CI, BK, US, and CC networks. We also acquire triggered strong motion data automatically from about 30 NP network dial-up accelerographs. (Apart from the CC network stations, we are only responsible for maintaining metadata from the contributing stations in our AQMS database—not at the data archive.)
- Analysis of data from all of the above channels (>1200) using AQMS. Automatic detection/location/notification is followed by human review after any earthquake that triggers the system.
- Production and distribution of a suite of information products for disaster planners, emergency managers, policy makers, engineers and scientists, educators, and the public at large.
- Coordination of monitoring strategy, policies, procedures, and evolution with clients in the states of Oregon and Washington, with surrounding networks and, perhaps most critically, with ANSS partner networks and the ANSS system as a whole.

PNSN has established, and is maintaining and further developing, an advanced infrastructure for seismic monitoring in the region. However, because the national system has never been fully or adequately funded, we have rather woven together the current system by combining resources, and evolving a storied and now somewhat tired infrastructure, combining it with state-of-the-art components. To present what this looks like, particularly for the USGS EHP decision makers, we focus in the next section of this report on the network station distribution. An RSN's real value, of course, lies in its products: their quality, timeliness, accuracy, robustness, integrity, and completeness, and also in their importance. The station distribution and performance is at best a proxy for these.

One measure of the importance of a network is the extent to which its data are used by scientific and engineering researchers. According to IRIS DMC reporting in the past 15 months researchers worldwide have made more than 65,000 requests for data from just the UO and UW network codes, and downloaded more than 20 million seismograms, with an astounding 8.6 Terrabytes of data (see Table 1).

III. Seismic Stations Operated by PNSN

The counting of seismic stations operated by a large RSN can be somewhat fraught. This is in part because an RSN's job generally entails 3 different types of monitoring: short period high gain components (SP) in quiet settings to detect and accurately locate small "background" seismicity, broad-band (BB) stations to recover detailed ground motion for advanced studies and products, again from quiet settings, and strong motion accelerographs (SM) stations to record the strongest ground motions possible (at the expense of weaker motions from smaller earthquakes) and usually sited in urban settings or near structures of particular concern. Moreover, some types of SM are triggered, so whilst they may operate continuously, they only report sporadically.

Viewed this way, which focuses more on "use type", PNSN operates (under the UW and UO network codes) 46 BB sites, 150 SP sites, and 257 SM sites (162 continuous and 95 triggered NetQuakes types). This accounting may be most useful for comparing with the PNSN's station count in 1998, 10 BB sites, 129 SP sites, and 11 SM sites (USGS, 1999: Circular 1188). In 16 years, this is an increase of 305%. While we've not checked specifically, we think it unlikely that PNSN's ANSS funding level has seen an equivalent increase.

Table 1. Usage of UW & UO network seismic data, as provided by the IRIS DMC.

Dates	Net	# of Requests	# Kbytes	# of Seismograms
01/03/2014 to 04/03/2014	UW	2644	127986870	624171
01/03/2014 to 04/03/2014	UO	2191	7325948	81322
04/02/2014 to 07/02/2014	UW	4796	340657864	923947
04/02/2014 to 07/02/2014	UO	3283	265599617	1897153
07/01/2014 to 10/01/2014	UW	4294	1004846754	2325991
07/01/2014 to 10/01/2014	UO	3463	35343667	429166
10/01/2014 to 01/01/2015	UW	10197	3506062192	7042473
10/01/2014 to 01/01/2015	UO	3294	174156762	935950
01/01/2015 to 03/31/2015	UW	17074	2.96749e+09	5611809
01/01/2015 to 03/31/2015	UO	13951	1.76004e+08	853103
Total	-	65187	8605473674	20725085

A more "operational" view of the network focuses on the number of physical locations at which we operate sites (*i.e.,* FDSN station codes), because a single location may host more than one type of sensor. Accounted in this way we operate 4 types of stations (Figure 3). We operate 42 6-channel (BB+SM) sites, 29 4-channel sites (SP+SM), 186 3-channel SM (91 continuous and 95 triggered NetQuakes), and 121 SP sites (only a handful of which are 3-component). Of these 378 stations a subset is supported by the USGS VHP and a subset by the US Dept. of Energy (DOE) via a sub-contract with Mission Support Alliance LTD (MSA). Both of these PNSN clients provide funding basically to, within each of their sub-regions of enhanced concern, reduce the magnitude of completeness in the regional catalog, produce more accurate ground motions, and provide interpretative assistance. For the Volcano Program the sub-regions are the 9 highest-threat active Cascades volcanoes. For the DOE the sub-region is the Hanford Nuclear Reservation (HNR) and the faults in eastern Washington that might give rise to earthquakes that impact this very risky site. Historically in the PNW, PNSN volcano seismic monitoring has been supported with VHP-derived funds using the ANSS proposal process, and this is the first time they are being considered completely separately. The relationship with the DOE-supported sites is much more complicated, and can at most be just summarized here. For now, what matters is how to account for the costs and the value of these stations to the network. And that is a matter of some difficulty to assess because, of course, data from many stations supported by different entities can and do contribute to the products delivered to each and every client of PNSN data products.

For the VHP stations we have attempted a rather formal division wherein stations were divided into 3 categories: those almost or exclusively for detecting volcano earthquakes (32; 29 SP and 3 BB), those whose value is shared more-or-less equally between earthquake monitoring and volcano seismic monitoring (22; 16 SP, 1 3-channel SM, 1 4-channel SM+SP, and 5 6-channel BB), and those that are mostly useful for regional earthquake monitoring but might become critical under certain scenarios of volcanic unrest (19; 11 SP, 2 3-channel SM, 1 4-channel SM+SP, and 5 6-channel BB). To apportion these value-based estimates into a station-count type accounting we assign the Volcano-only sites a weight of 1, the shared category a weight of 0.5, and the emergency-only a weight of 0.25. Accounted for in this way, there are 49.25 "weighted" stations operated by PNSN for volcano monitoring (39.75 SP, 1 3-channel SM, 0.75 4-channel SM+SP, and 6.75 6-channel BB).

The DOE-supported stations are somewhat easier, since they have been independently funded for years. There are a total of 49 of those, of which 3 are 6-channel BB+SM, 5 are 3-channel SM, 38 are SP. As a fraction of total stations operated by PNSN, volcano monitoring and HNR monitoring then each comprise about 13.5% of the total effort. The stations of greatest interest of the EHP are about 73% of the PNSN operational effort.

This "split" of effort (we prefer to view this rather as a co-mingling of synergistic activities) cascades through the entire operations of PNSN, from station servicing and repair, through metadata maintenance, telemetry costs and real-estate agreements, instrument repair and testing in the lab, data processing, product generation, data review, status monitoring, and data archiving. We use the split as a proxy for effort required by the PNSN engineering staff. For staff further down the chain of data processing and analysis it may be a less accurate reflection of level of effort, particularly because there are additional (contributed) data streams to deal with, seismicity rates demanding different levels of attention in certain areas and at different times, and so forth. But it provides a starting place to approach the fundamentally impossible. One facet of network operations not explicitly accounted for in this station-focused approach is that PNSN imports data from a further 232 stations operated by cooperating institutions (100 SP, 51 SM, 81 BB) from within and surrounding the PNSN authoritative region (Figure 4). A not insignificant amount of effort goes into obtaining and using these data in our processing. However we cannot necessarily rely on them, as they are not operated by us, and we use their data at the pleasure of the cooperating colleagues.

All of the stations discussed above, including the imports, provide the data with which we continuously monitor for earthquakes and other seismic disturbances in the region, including the megathrust plate interface along the western edge of the region and at the region's dangerous volcanoes. The SP stations keep track of smaller background seismicity, the BB data characterize source properties and seismic wave propagation, and the SM stations are there to understand the impacts of high levels of ground motion from moderate to large earthquakes. The data all arrive at the "seismolab" at the UW via a broad variety of modes: analog FM radio, leased phone line, digital IP radio, through an analog-through-digital network (hosted by the Bonneville Power Administration), cell modem (Verizon and AT&T), VSAT, and Internet. What it lacks in ease of use is partially offset, we argue, by a type of robustness of diversity; it is difficult to envisage the disaster that takes out all telemetry modes (while it is easy to think of how a particular mode might be crippled).

IV. Routine Field and Data Center Operation

The routine work of PNSN is accomplished by teams. Each PNSN staff position is responsible for critical elements of the team, and hence important to overall network operations. The Management/Interpretation Team (Vidale/Bodin/Toomey) has overall responsibility for network work performance and presents scientific interpretations of network information products and report generation, and coordination with ANSS and other supporting projects. The UW Engineering Team (Hagel, Biundo, Gibbons, and Ling) provide support in the field and/or in the laboratory, designing, deploying, testing, repairing seismometers, data loggers, telemetry equipment (cell modems, digital IP radios, analog FM radios and antennas, solar and AC power systems), tuning and adjusting seismic and telemetry components, etc. The UW Data Processing Team (Bartlett, Hartog, Kress, Wright, and Connolly) is responsible for the many facets of work required to use the data in network operation. And each member of this team has specialties that range from physical and operating systems-level programming of the PNSN's computer servers, running the interconnected and multiply-redundant cluster of applications programs that comprise the seismic monitoring network and actually produce the information products, to maintaining the station and channel metadata (the information about each data channel needed to use the data in the network and to archive it properly), to analysts expert in reviewing the data—guiding the computer systems in the generation of accurate and trusted products. This team also is responsible for presentation of the network products on the PNSN website and delivering them to the ANSS, and satisfying ANSS and our customers with useful web-accessible information.

The PNSN field station maintenance is carried out by the Engineering Team. UW staff field engineers include positions at the UW Seattle campus (currently Hagel, Gibbons, Ling, and students), and a position located in Vancouver, WA (currently Biundo). We also coordinate fieldwork by our partners at UO (currently Fletcher) and, through a sub-contract to a DOE project for eastern Washington, a contract employee located in Richland, WA (currently Clayton) who occasionally helps service ANSS-supported stations. All engineers service all PNSN stations regardless of funding source (EHP, VHP, DOE, etc.) or station type (BB, SM, SP, etc.).

Our broader vision for the PNSN is to reduce our investment in the analog SP technologies that have formed the backbone of the networks, and gradually replace them with digital stations and telemetry. This cannot be accomplished overnight in part because the funding is not available, and in part because the requirements for digital stations are quite difficult to satisfy in the region. For example, the significantly greater power requirements of digital radios require larger solar panels at remote sites, which by creating a bigger station profile often makes permissions more difficult to obtain in the backcountry. It also requires the acquisition of radio pairs, more electrical power equipment, batteries, a datalogger of some sort, and perhaps more gear, as well as the investment in time and effort. Thus it is not inexpensive. We would like to analyze network performance in the absence of stations, and turn off those that we can without too badly impairing network performance. Eventually the technology will become unserviceable. (The fm radio technology we use is already becoming difficult to keep up, for example. The knowledge and skills base to maintain them is becoming rare). Meanwhile we plan to continue servicing the SP portion of the network that provides the data needed to track background seismicity adequately.

With funding from the American Recovery and Reinvestment Act (ARRA) we replaced 3 SP sub-nets with digital 4-channel (SM + SPZ) stations and have started investigation of some other strategies to test how digital upgrades might work in the region. These tests suggest that various strategies might be employed with the one that will work the best depending on the details on the ground. Another is the development of low-power field processors and EarthWorm data acquisition systems that we are testing. Our efforts in this have been collaborative with VHP and DOE-funded projects, and are showing signs of success. We are tracking similar efforts at Menlo Park, and planning to increase the communication between our groups. We hope this will turn into a major ANSS push—we feel it has the potential to make a great leap forward in ANSS RSN performance.

We have deployed about 96 NetQuakes accelerographs in the region (Figure 5). These have permitted us to add situational-awareness coverage in Portland and Spokane, and to significantly densify the strong motion network in the Puget Sound region. We have put new deployments on hold for the moment, however. The reason is that with recent changes in the USGS leadership of the NetQuakes program (chiefly the retirements of David Oppenheimer and Jim Luetgert) we are unsure of the longevity of this effort.

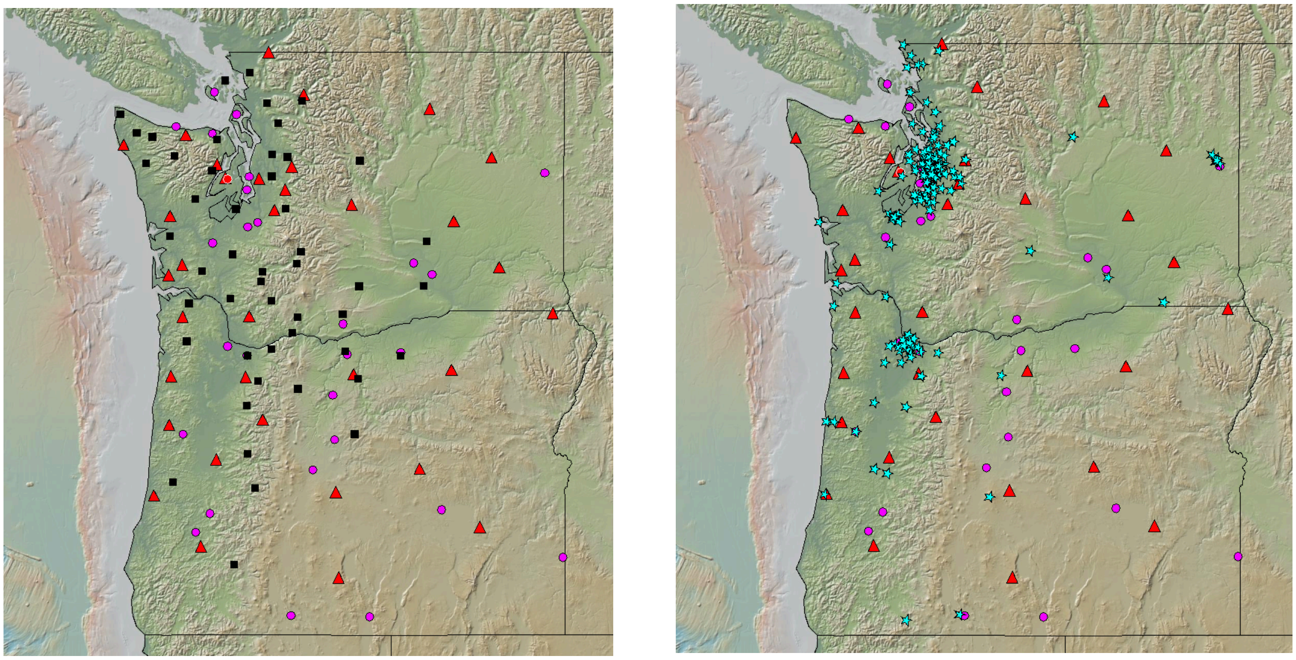

Figure 3. Seismic stations operated under this Cooperative Agreement during 2010-2015. Left Panel: High Gain channels, including analog short-period (black squares), Broadband (red triangles, and digital Short Periods (pink circles: these are the 4th channel of a KMI datalogger). Right Panel: Strong Motion channels, including 6-channel stations and the SM channels of 4-channel dataloggers (so the same red triangles and pink circles as are on the right panel). Blue stars are 3-channel Strong Motion accelerographs.

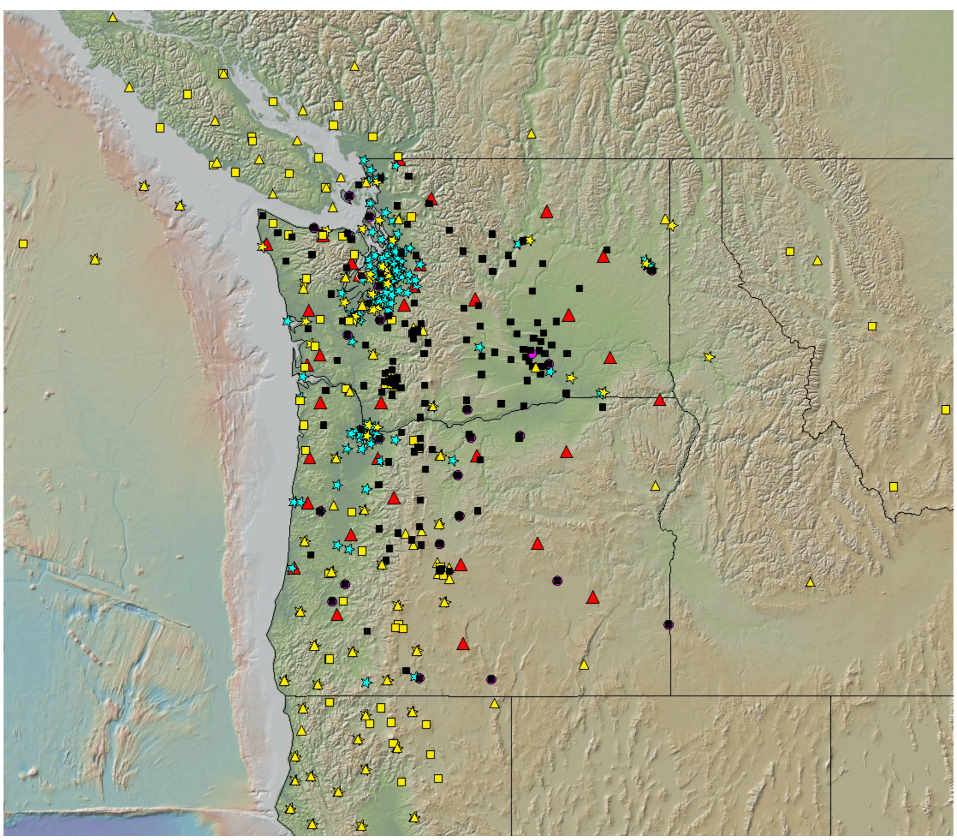

Figure 4. Locations of all stations used by PNSN to monitor regional earthquakes and ground motion. Color and shape coding same as in Figure 3. Except all yellow symbols are stations operated by other entities with data contributed in real time to PNSN. Also included as black symbols are stations operated by PNSN for the DOE/MSA and the USGS VHP at volcanoes.

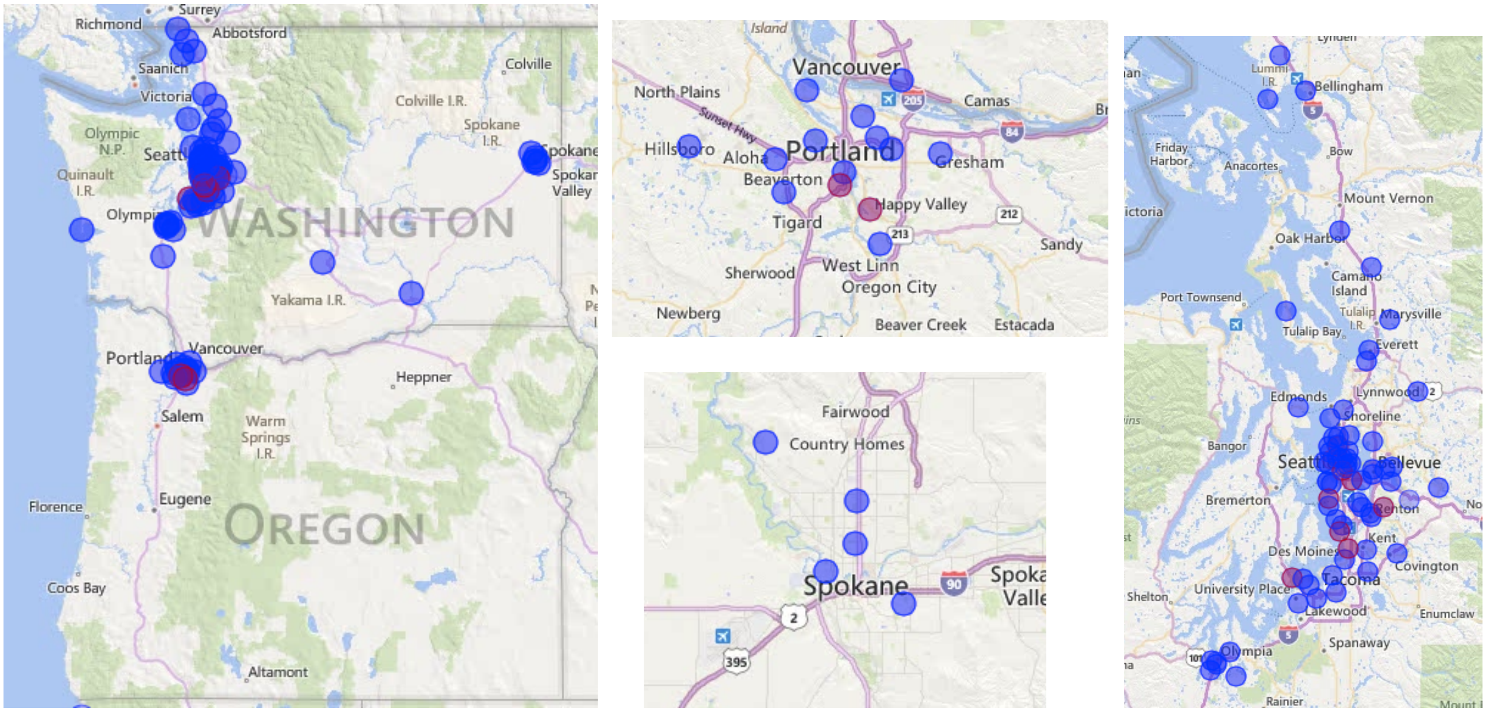

Figure 5. Locations of NetQuakes stations installed and operated by PNSN with assistance from Menlo Park.. Left panel reveals the overall deployments in the PNSN region. Top middle panel shows stations in Portland, OR, bottom middle panel shows stations in Spokane, WA. Right panel shows the distribution in the Puget Sound region. Stations are shown as blue circles, red circles are stations not reporting when the site was polled. (Thanks to the USGS Menlo Park for station maps at http://earthquake.usgs.gov/monitoring/netquakes/map/)

V. PNSN ANSS Regional Advisory Committee (RAC)

Amongst the nations' RSNS, PNSN has a specially active and helpful ANSS Regional Advisory Committee (RAC). Our RAC is comprised by leaders in the local and state disaster prevention and preparation communities, leaders in the engineering and geotechnical communities. Chaired by engineer C.B. Crouse, the PNSS ANSS RAC meets annually, and is consulted by email interrogatives about important regional seismic monitoring concerns. Details about the RAC, its composition, and meeting minutes are available online at: http://pnsn.org/network/anss/pacific-northwest-region-of-the-anss .

VI. PNSN Station Metadata and Earthquake Data Products

a. Station Inventory and Metadata

We are currently loading our station inventory information into the ANSS Station Information System (SIS) at CalTech. We have been involved in design and testing of SIS for use by RSNs and are moving forward with the anticipation of using it as our primary network inventory system, and to keep track of station metadata. We applaud the concept of a one-stop shop for both inventory and metadata purposes, and we think it is also important to use the same system for field installation data. Thus, we are developing the concepts of how to use SIS effectively within our network, not just as an additional burden on our metadata and inventory team, but as a truly useful – our only, if possible, metadata and inventory burden.

That said, there are still several issues that we are grappling with. One is the extent to which we at PNSN will become responsible for maintaining metadata for some of the hundreds of channels of contributed seismic data. This is compounded, of course, by the fact that we have operational metadata caches both in our AQMS system database, and in the IRIS DMC waveform archive (as dataless SEED). SIS is designed to be able to import and export metadata in formats these other clients need. However it raises concerns about policy and procedures for synchronizing the metadata between these various databases with the minimum amount of hands-on effort (and hence room for error). Another issue is getting as much metadata and inventory information into the SIS system for the historical PNSN network as well, which seems fairly necessary if SIS is to be truly a one-stop shop for this mission critical information.

We believe metadata for our current network stations to be complete and up-to-date. The PNSN dataless SEED is available from our data archive, the IRIS DMC. It is also available from the MDS in Golden, CO.

We currently produce "dataless" SEED via PDCC for all channels that are archived in near-real-time (all UW, UO, and also CC network SCNLs collected, basically) at the IRIS DMC. There are occasional discrepancies that we discover and repair, but we are really up to date with the current data.

Our channel response information is available from the IRIS DMC. It has not been a priority for us to keep a separate metadata cache. That said, we are following progress in the "station XML" development, and plan to be compliant with the agreed-upon standard.

Through the years we have been challenged to get our data into the NSMP/CDMG National Center for Engineering Strong Motion Data (NCESMD) "strongmotioncenter.org" website. In working with USGS staff, we determined that it was easier for them to obtain our station metadata (for strong motion stations only) from raw webpages on the UW website, and to manually enter it. This process was slow and effortful, but the goal was that for a strong motion event (PNSN's choice of threshold), the strong motion data center would connect to our waveservers and be able to generate and deliver data products of engineering interest quickly. Two years ago we were informed that strongmotioncenter.org has decided to now only accept V0 format data. This wipes out the efforts we had been making. Hence we have adopted a new strategy, which is to employ Northern California's code for producing V0 from AQMS data, and using that to supply the NCESMD data for events of interest.

b. Distribution of Earthquake Products

Currently, our Origin, Phase, and ShakeMap products are distributed into the USGS Product Distribution Layer (PDL). We modified Pete Lombard's code to produce QuakeML from the AQMS database so that it runs on our system.

c. ShakeMap

PNSN generates 3 different ShakeMap products. A standard resolution ShakeMap for regional purposes, and two large-scale high resolution ShakeMaps for the Puget lowlands and for the Hanford Nuclear Reservation. Both of the high resolutions versions use a very densely sampled geology for site corrections. We have consistently worked with Dave Wald and his ShakeMap group to work out how to distribute our special ShakeMap products, and that prospect seems recently to be getting closer. At the moment we serve these special products from our own website only. An example of an event that generated a Seattle Metro ShakeMap was a not-very-exciting M3.5 earthquake that took place on 28 July of last year (http://pnsn.org/shakemaps/60828527).

d. ShakeAlert/Tremor/Quickshake/"Families"

PNSN is working with USGS' ShakeAlert team (currently Wald and Appel) to implement a ShakeAlert for our sponsors in eastern Washington, the MSA. This ShakeAlert instance will provide coverage for a suite of hazardous sites on the Hanford Nuclear Reservation.

An earlier version of ShakeAlert fell into disrepair and disuse, and we are as of the writing of this report about two weeks out from what we plan to be a more sustainable instance.

We are also still hosting our popular tremor catalog feature (pnsn.org/tremor). We are working with the developer (former UW student Aaron Wech, now at the Alaska Volcano Observatory) to determine the most sustainable way to continue this work. We have also been negotiating with the AQMS schema development committee to consider whether no-volcanic tremor origins could or should be included in the AQMS schema.

A recent product we have developed, called "QuickShake" (pnsn.org/quickshake) is a real-time display of low-latency seismograms. This feature developed out of our Earthquake Early Warning (EEW) efforts and our monitoring of crowd motion at Seattle Seahawks NFL playoff games (pnsn.org/seahawks).

One of our lesser-known (though innovative and useful) products is a waveform-cross-correlation-based detector of earthquake "families" (http://www.kateallstadt.com/RCM/). This automatic system was developed by former UW student Kate Allstadt (currently with the Cascades Volcano Observatory, but moving soon to the landslide hazards group in Golden). It currently is a Matlab-based application that characterizes families of earthquakes (and glacier movements) at Mount Rainier. However, its range of potential application is much broader and we are in the process of evaluating its role within PNSN.

e. Real-time Distribution and Archiving of Waveform Data

PNSN exchanges waveforms in real time to Northern California (import/export), USNSN/NEIC (import/export), Montana (import/export), Canada (import/export), Cascades Volcano Observatory (import/export), both Tsunami warning centers (export only), and the IRIS DMC (import/export). These are the entities we permit to scoop data out of our Earthworm or Winston waveservers. All other waveform customers generally get PNSN waveforms from the IRIS archive. We recently started exporting our data to the DMC with a "ringserver" process, which made the transfer less gappy and reduced availabilities of our waveforms from the archive to be generally much less than a minute.

We were investigating the EDGE/CWB system of David Ketchum to make waveform data available, because it has many nice features. However, following discussions with Harley Benz we have decided to delay starting up yet another waveform delivery mechanism until it is well documented and not dependent on a single individual.

We are excited to begin exporting strong motion data to the *strongmotioncenter.org* folks. We have tried to instigate this several times over the past 5 years, but found it confounding and difficult to deal with the NSMP/CDMG strong motion data center. Recently we feel that a thaw has taken place and, moreover now that we are using AQMS, we should be able to convince them to distribute our strong motion event data.

f. IT Security

We recently renewed our IT interconnect agreements with the USGS as a part of our Cooperative Agreement.

g. Websites

Our *pnsn.org* webpage may present hypocenters from a number of sources (depending on the age and/or the location of the event). However for the most part we rely on the JSON feeds from Golden. That is, we send our origin information to NEIC, and hopefully they pass it back to us and we display it. While convoluted, this minimizes problems with duplicate postings, for example, by letting the ANSS "authoritative source" rules-matching ensure what the preferred origin is so all of our displays are consistent. One difficulty we have encountered is that the

Golden web team does not feed us back what we have asked for on numerous occasions: the event version number produced by us. Our work-around takes effort and is somewhat clumsy. While improving, the event-matching logic can get fooled by certain situations with poorly-located earthquakes on the periphery of the PNSN network (particularly off-shore events). We have tweaked our reporting to reduce this problem, and will continue to work with our system and the ANSS and other surrounding networks with the goal of eliminating it altogether. By the way, the Google API and its connection to the ANSS feeds and the AQMS database were developed here at PNSN by software engineer Jon Connolly and are in use by several RSNs.

The pnsn.org website also presents maps and lists of stations used in routine monitoring. These use the Google API noted above and each station on the lists and map also links to a set of day-long seismograms ("webicorders").

Each local event also links to an "event page" that presents the data about the event: origin information, waveforms, maps (including historical seismicity, CIIMs, ShakeMaps if they exist, etc.), and (for significant earthquakes) additional information about "notable" earthquakes (http://pnsn.org/earthquakes/notable).

Our webpages explain the nature of ANSS's network of RSNs and the nature of our collaborations with surrounding networks, including waveform exchanges. We also present the minutes and results from our regional ANSS advisory committee meetings (http://pnsn.org/outreach/anss). Our website also includes links to reports about network monitoring, earthquake products not generally available from ANSS (such as spectrograms and tremor catalog). We include multiple links to the ANSS webpages. Along with the operators of other ANSS RSNs we have tried with only limited success to influence the software engineers in Golden that are developing the ANSS web site to include correct links back to our event pages. Recently an ANSS working group has been meeting and a system-wide strategy seems to be developing, which we hope will yield a more mutually agreeable and sustainable policy.

One of the innovative features of *pnsn.org* is our extremely active social media presence with our Facebook (with about 6000 followers…https://www.facebook.com/thePNSN), Twitter, and Instagram pages. We strongly encourage other RSNs and the NEIC to consider using social media as an integral part of their missions for several important reasons. One is that it provides instant feedback as to how our messages of earthquake preparedness and the value of monitoring for reducing potential losses are faring. Another is that it provides an opportunity to involve the community in monitoring. While our seismic network has a global following, it is nevertheless predominantly a local audience and they actually help us by providing information (we know instantly when we have a problem with our website, for example!) and even operational support (hosting NetQuakes accelerographs, for example). Also we have noticed that having proactive feeds of information (tweeting information for example) about earthquakes actually reduces the load on our web servers. Increasingly people are not going to be sitting at their computers to actively retrieve information en masse when an earthquake occurs—but to the extent they do, it would load our presentation software and network. Pushing brief information bulletins through social media applications to (increasingly) mobile platforms provides folks what they want with a much smaller IT overhead. In short, social media present part of the solution to making our delivery of network products more resilient during future seismic (or volcanic) crises.

VII. Performance Standards

Perhaps the most important measure of performance of an RSN is really the extent to which the network meets the needs and expectations of its clients. The performance criteria and metrics criteria we designed in the ANSS Performance Standards V2.8 document provide very useful guides and targets, but really a baseline proxy for true performance as defined above. We strive to meet or exceed the ANSS Performance Standards and, for the most part believe that we succeed.

A couple of the metrics deserve special attention, however. Automatic Magnitude post time of 3 minutes for Hi-Risk Urban areas presents a challenge for AQMS, because in a large regional network, we wait for up to 4 minutes from the initial origin to be collecting waveforms for the Earthworm system to complete an origin solution. Deployment of the CISN ShakeAlert early warning system promises one path to help with this problem. However it is early days in our exploration of how to link the two (EEW and AQMS). A related performance criterion, the Reviewed origin post times for significant events (10 minutes) is a challenge because we find the Jiggle tool to review AQMS events can be very slow. We feel that this is an issue that ANSS should be taking the lead in solving. We feel quite sure that it is not anything we are doing wrong, *per se*, but rather the design of Jiggle/AQMS, and could be greatly sped up. We would love to be a part of this, but are not about to embark on an adventure of this scope on our own.

How do we assess and report on these criteria? We are addressing this in part with the approaches being discussed by the ANSS NIC. But at the same time we are reaching out to the IRIS DMC, our data archive. They have provided some support for PNSN to explore with them how to use the MUSTANG system to provide a number of data quality and timeliness measurements made on, and as, data arrive at the archive. MUSTANG is basically a database of waveform metrics tied to a webservices interface. The goal of our project is to develop and automate a system – a package of measures that an RSN would have running that gave up-to-the-minute status on waveform data quality and availability as well as provide useful reports for ANSS performance monitoring.

Appendix: Table of Stations Operated by PNSN for ANSS-EHP

R=Reftek; Q=Q330; G=CMG3; T=Trillium120; S=STS2; E=Episensor; C=Cell; V=VSAT; D=DSL; I=fiberswitch; F=Digital radio; M=llModem; B=KMI Basalt; K=K2; L=L4; x=S13.
Blue font = station maintenance shared equally with VHP. Green font = VHP contributes 25% to station maintenance.

6-Channel Stations (3sm,3sp)

Net	Sta	Lat	Lon	Equip.
UO	BUCK	44.20	-122.99	R,T,E,C
UO	DBO	43.12	-123.24	R,T,E,C
UO	PINE	43.79	-120.94	R,T,E,C
UW	BABR	44.62	-123.79	R,T,E,C
UW	BLO	44.68	-122.19	Q,G,E,C
UW	DOSE	47.72	-122.97	R,T,E,C
UW	FORK	47.95	-124.57	R,T,E,F
UW	GNW	47.56	-122.82	R,T,E,C
UW	HEBO	45.21	-123.76	R,T,E,M
UW	IRON	43.36	-118.47	Q,S,E,V
UW	IZEE	44.08	-119.50	Q,S,E,V
UW	JEDS	43.75	-124.05	R,T,E,C
UW	KENT	45.24	-120.64	Q,G,E,V
UW	LCCR	45.21	-122.48	Q,G,E,C
UW	LEBA	46.55	-123.56	Q,S,E,V
UW	LRIV	48.06	-123.50	R,T,E,C
UW	LTY	47.25	-120.67	R,T,E,D
UW	MRBL	48.52	-121.48	Q,G,E,C
UW	PASS	49.00	-122.09	Q,T,E,V
UW	RADR	46.42	-123.80	R,T,E,F
UW	RATT	47.43	-121.80	R,T,E,F
UW	SP2	47.56	-122.25	R,T,E,C
UW	STOR	47.19	-121.99	Q,T,E,C
UW	TOLT	47.69	-121.69	R,T,E,M
UW	TREE	42.73	-120.89	Q,S,E,V
UW	TUCA	46.51	-118.15	Q,S,E,V
UW	UMA	45.29	-118.96	Q,T,E,C
UW	WISH	47.12	-123.77	R,T,E,I
UW	WOL	47.06	-118.92	Q,S,E,C
UW	YACT	45.93	-122.42	Q,S,E,C
UW	BRAN	45.97	-117.23	Q,G,_,V
UW	DAV	47.80	-118.27	Q,G,_,V
UW	FISH	45.93	-123.56	Q,G,_,C
UW	OMA	48.36	-119.33	Q,G,_,C

4-Channel Stations (3sm,1sp)

UW	ALKI	47.58	-122.42	K,E,L,
UW	BEND	44.07	-121.33	B,E,x
UW	BURN	43.57	-119.13	K,E,x
UW	CPW	44.07	-121.33	B,E,L
UW	GHW	47.04	-122.27	B,E,L
UW	GLDO	45.84	-120.81	B,E,L
UW	GMO	44.44	-120.96	B,E,L
UW	GMW	47.55	-122.79	B,E,L
UW	HOG	42.24	-121.71	B,E,L,F
UW	HSO	43.53	-123.09	B,E,L,C
UW	IONE	45.50	-119.83	B,E,L,F
UW	JORV	42.98	-117.05	K,E,x,
UW	LKV	42.22	-120.36	K,E,L,
UW	MOR	45.47	-120.74	B,E,L
UW	MPO	44.50	-123.55	B,E.L
UW	PCFR	46.99	-122.44	K,E,x
UW	PGO	45.46	-122.45	B,E,L
UW	RRHS	46.80	-123.04	K,E,L,
UW	SFER	47.62	-117.37	K,E,L,
UW	SQM	48.07	-123.05	B,E,L
UW	STW	48.15	-123.67	B,E,L
UW	SVOH	48.29	-122.63	K,E,L,
UW	UMP	43.29	-123.33	K,E,L,
UW	UWF	48.55	-123.01	K,E,L,
UW	VCR	44.98	-120.99	B,E,L
UW	VVHS	47.42	-122.45	K,E,L,
UW	WPO	45.57	-122.79	B,E,L

Short Periods

UW	AUG	45.74	-121.68	
UW	BBO	42.89	-122.68	
UW	BHW	47.84	-122.03	
UW	BLN	48.01	-122.97	
UW	BOW	46.47	-123.23	
UW	BRO	44.27	-122.45	
UW	CDF	46.12	-122.05	
UW	CMW	48.42	-122.12	
UW	CRF	46.82	-119.39	
UO	FRIS	44.21	-122.10	
UW	GLK	46.56	-121.61	
UW	GSM	47.20	-121.80	
UW	GUL	45.92	-121.60	
UW	HBO	43.84	-122.32	
UW	HDW	47.65	-123.06	
UW	HTW	47.80	-121.77	
UO	HUO	44.12	-121.85	
UO	IRO	44.01	-122.26	
UW	JBO	45.46	-119.84	
UW	JCW	48.20	-121.93	
UW	KMO	45.64	-123.49	
UW	KOS	46.46	-122.20	D
UW	LCW	46.67	-122.70	
UW	MCW	48.68	-122.83	
UW	MEW	47.20	-122.65	
UW	NLO	46.09	-123.45	
UW	OBC	48.04	-124.08	
UW	OCP	48.30	-124.63	
UW	ON2	46.88	-123.78	
UW	OOW	47.73	-124.19	
UW	OSD	47.82	-123.71	
UW	OTR	48.09	-124.35	
UW	PGO	45.46	-122.45	

UW	PNLK	47.58	-122.03
UW	RDM	46.30	-119.44
UW	RNO	43.92	-123.72
UW	RPW	48.45	-121.51
UW	RVW	46.15	-122.74
UW	SBES	48.77	-122.42
UW	SLF	47.76	-120.53
UW	SMW	47.32	-123.34
UW	SSO	44.86	-122.46
UW	TDL	46.35	-122.22
UW	TRW	46.29	-120.54
UW	VBE	45.06	-121.59
UW	VG2	45.16	-122.27
UW	VGB	45.52	-120.78
UW	VIP	44.51	-120.62
UW	VLM	45.54	-122.04
UW	VTH	45.18	-120.56
UW	WPW	46.70	-121.54

Continuous Strong Motion

UW	ALCT	47.65	-122.04
UW	ALST	46.11	-123.03
UW	ALVY	44.00	-123.02
UW	BABE	47.61	-122.54
UW	BEVT	47.92	-122.27
UW	BRKS	47.76	-122.29
UW	BSFP	47.52	-122.30
UW	BULL	45.45	-122.16
UW	CDM	47.42	-121.76
UW	COLT	45.17	-122.44
UW	EARN	47.74	-122.04
UW	EGRN	47.07	-122.98
UW	ELW	47.49	-121.87
UW	ERW	48.45	-122.63
UW	EVCC	48.01	-122.20
UW	EVG	47.85	-122.15
UW	EYES	45.33	-123.06
UW	FINN	47.72	-122.23
UW	GTW	47.55	-122.32
UW	HART	47.58	-122.35
UW	HICC	47.39	-122.30
UW	HOLY	47.57	-122.38
UW	HUBA	45.63	-122.65
UW	KCA	47.54	-122.32
UW	KDK	47.60	-122.33
UW	KEEL	45.55	-122.90
UW	KFAL	42.26	-121.79
UW	KIMB	47.57	-122.30
UW	KIMR	47.50	-122.77
UW	KINR	47.75	-122.64
UW	KITP	47.68	-122.63
UW	KNEL	47.38	-122.25
UW	LANE	44.05	-123.23
UW	LAW	47.66	-122.39
UW	LEOT	47.77	-122.12
UW	LYNC	47.83	-122.29
UW	MAR	47.66	-122.12
UW	MAU	45.18	-121.08
UW	MBK	48.92	-122.14
UW	MBPA	47.90	-121.89
UW	MEA	47.62	-122.31
UW	MEG	46.27	-123.88
UW	MNW	47.57	-122.53
UW	MON	44.85	-123.24
UW	MPO	44.50	-123.55
UW	MRIN	44.80	-122.70
UW	NEW	44.62	-124.05
UW	NIHS	47.74	-122.22
UW	NNV	43.71	-121.28
UW	NOW	47.69	-122.25
UW	OHC	47.33	-123.16
UW	PAYL	47.19	-122.31
UW	PCEP	47.11	-122.29
UW	PERL	45.33	-122.78
UW	PGO	45.46	-122.45
UW	PGO	45.46	-122.45
UW	PIER	47.58	-122.34
UW	RAW	47.34	-121.93
UW	ROSS	45.66	-122.66
UW	SBES	48.77	-122.42
UW	SCC	47.75	-122.36
UW	SEA	47.65	-122.31
UW	SEAS	46.00	-123.93
UW	SLA	47.58	-122.33
UW	SMNR	47.20	-122.23
UW	SOUA	42.18	-122.70
UW	SP2	47.56	-122.25
UW	SSS1	47.58	-122.33
UW	SVTR	47.50	-121.78
UW	SWID	48.01	-122.41
UW	TAKO	43.74	-124.08
UW	TBPA	47.26	-122.37
UW	TKCO	47.54	-122.30
UW	TLW1	47.69	-121.69
UW	TOLO	44.62	-123.92
UW	UPS	47.26	-122.48
UW	WEL1	47.95	-119.86
UW	WEL2	47.95	-119.86
UW	WISC	47.61	-122.17

UW	WWH	46.05	-118.32

Triggered Strong Motion

UW	QAD	47.67	-122.39
UW	QAMI	45.53	-122.98
UW	QARB	47.64	-122.29
UW	QBGD	47.30	-122.38
UW	QBIT	47.72	-122.35
UW	QBOG	47.69	-122.36
UW	QBOV	47.62	-122.20
UW	QBRO	48.07	-122.12
UW	QBSH	47.53	-122.03
UW	QBUS	48.23	-122.20
UW	QCDG	48.10	-122.59
UW	QCEN	46.72	-122.96
UW	QCM	47.29	-122.51
UW	QCO	47.62	-122.33
UW	QCON	48.34	-122.34
UW	QCOR	47.66	-122.33
UW	QDA	45.44	-122.63
UW	QDJW	45.52	-122.59
UW	QDLP	47.51	-122.15
UW	QEGA	47.98	-122.21
UW	QEMI	47.64	-122.31
UW	QEMS	46.99	-122.81
UW	QESB	47.63	-122.11
UW	QEW	47.67	-117.44
UW	QFAL	47.57	-121.90
UW	QFFG	47.24	-122.36
UW	QFRG	47.38	-122.31
UW	QFRZ	47.03	-122.92
UW	QFTL	47.53	-122.39
UW	QFUG	45.57	-122.69
UW	QGBP	48.73	-122.67
UW	QGFY	47.61	-122.20
UW	QGLD	46.64	-120.58
UW	QGN	47.69	-122.40
UW	QHA	47.58	-122.38
UW	QHOP	47.06	-122.84
UW	QHRH	47.48	-122.20
UW	QHSH	48.76	-122.50
UW	QJBC	45.46	-122.79
UW	QJEA	47.38	-122.22
UW	QJLF	48.99	-122.74
UW	QKEV	47.31	-122.22
UW	QKRK	47.71	-122.19
UW	QKSO	47.27	-122.48
UW	QKTN	47.81	-122.53
UW	QLBR	47.47	-122.36
UW	QLIN	47.69	-122.35
UW	QLIZ	47.01	-122.92
UW	QLKR	47.51	-122.24
UW	QLUE	45.49	-122.68
UW	QMA	47.35	-122.32
UW	QMA	45.54	-122.61
UW	QMA	47.68	-122.31
UW	QMA	47.45	-122.33
UW	QMA	47.59	-122.29
UW	QMIN	47.59	-122.25
UW	QML	47.36	-122.09
UW	QNCH	45.61	-122.57
UW	QNKP	47.72	-122.37
UW	QNPB	47.43	-122.34
UW	QNW	47.64	-122.39
UW	QNZO	45.51	-122.81
UW	QOCL	47.03	-122.90
UW	QOCS	46.98	-124.17
UW	QOPE	47.05	-122.90
UW	QOUT	47.51	-122.39
UW	QPAL	47.66	-122.36
UW	QPBC	47.80	-122.33
UW	QPID	47.65	-117.37
UW	QPJE	47.71	-117.41
UW	QPLV	47.86	-121.99
UW	QPRK	47.64	-122.42
UW	QRCR	47.49	-122.21
UW	QRM	47.77	-122.39
UW	QRNR	47.52	-122.26
UW	QRW	48.87	-122.61
UW	QSAL	45.52	-122.50
UW	QSKF	47.68	-117.43
UW	QSKT	47.21	-122.53
UW	QSNL	47.72	-122.30
UW	QSNZ	47.63	-122.32
UW	QSRV	47.65	-122.31
UW	QTK	47.23	-122.45
UW	QTNB	47.29	-122.56
UW	QTVT	47.95	-122.22
UW	QUIN	47.03	-122.90
UW	QUIP	45.40	-122.61
UW	QVAS	47.58	-122.12
UW	QWA	45.57	-122.64
UW	QWE	47.68	-117.42
UW	QWL	45.60	-122.75
UW	QWS	46.33	-119.26
UW	QWZ	45.53	-122.73
UW	QXRD	47.62	-122.14
UW	QZOE	47.75	-117.50