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Technical Memorandum No. 86-68330-2011-16

2010 Annual Report
Paradox Valley Seismic Network
Paradox Valley Project, Colorado

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center

May 2011

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Prepared by

Lisa Block
Chris Wood

U.S. Department of the Interior
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Denver, Colorado

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Prepared By

Lisa Block
Geophysicist

5/25/2011
Date

Chris Wood
Geophysicist

5/25/11
Date

Peer Review

Dan Levish
Manager, Seismotectonics and Geophysics Group

5/25/11
Date

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1.0 INTRODUCTION

The Paradox Valley Seismic Network (PVSN) monitors earthquakes induced by injection operations at the Bureau of Reclamation's Paradox Valley Unit (PVU) deep disposal well, as well as local naturally-occurring earthquakes. This report summarizes PVSN operations and the data recorded during calendar year 2010. Project background information is included in section 2.0, including the history of PVU injection operations and details of the seismic network. In section 3.0, PVSN project operations during 2010 are presented, including discussion of maintenance and upgrades of seismic stations and data acquisition systems, network performance, and data management activities. The earthquake data recorded during 2010 are presented in section 4.0 and compared to historical seismicity trends.

2.0 PROJECT BACKGROUND

2.1 Paradox Valley Unit

Reclamation's Paradox Valley Unit (PVU), a component of the Colorado River Basin Salinity Control Project, diverts salt brine that would otherwise flow into the Dolores River, a tributary of the Colorado River. PVU is located in western Montrose County approximately 90 km southwest of Grand Junction, CO and 16 km east of the Colorado-Utah border (**Figure 2-1**). The brine is pumped from 9 extraction wells located within Paradox Valley near the Dolores River, which flows from southwest to northeast across the valley (**Figure 2-2**). The diverted brine is injected at high pressure into a deep disposal well, designated as PVU Salinity Control Well No. 1. The disposal well is located approximately 1.5 km southwest of Paradox Valley, near the town of Bedrock (**Figure 2-2**).

PVU Salinity Control Well No. 1 was completed in 1987 at a total depth (t.d.) of 4.88 km (approximately 16,000 ft). The well was built to Environmental Protection Agency (EPA) Underground Injection Code (UIC) Class I standards ("Isolate hazardous, industrial and municipal wastes through deep injection"), but was permitted in 1995 by EPA as a Class V disposal well ("Manage the shallow injection of non-hazardous fluids"). The well penetrates Triassic rock at the surface through Precambrian rock at t.d. and has a minor drift to the east and slightly to the north. Based on interpretation of regional core and log data, the Mississippian Leadville carbonate was selected as the primary injection zone with the upper Precambrian as a secondary zone (Bremkamp and Harr, 1988). The well casing of PVU No. 1 (constructed of Hastelloy C-276, a nickel-molybdenum-chromium alloy) was perforated at about 20 perforations/m in two major intervals between 4.3 km and 4.8 km depth. Plan and vertical views of the wellbore, with near-wellbore stratigraphy and the perforation intervals, are shown in **Figure 2-3**.

2.2 PVU Injection Operations

Between 1991 and 1995, PVU conducted a series of 7 injection tests, an acid stimulation test, and a reservoir integrity test. The purpose of these tests was to qualify for a Class V permit for deep disposal from the EPA. Continuous injection of brine began in July, 1996, after EPA granted the permit. Since continuous injection began, PVU has instituted and maintained three major changes in injection operations. Each change was invoked to mitigate the potential for unacceptable seismicity or to improve injection economics. Each change was maintained for a sufficient period to be considered a sustained injection "*phase*". These injection phases are described below.

2.2.1 Phase I (July 22, 1996 - July 25, 1999)

During this initial phase of continuous injection, PVU injected at a maximum flow rate of 345 gpm (~1306 l/min), at about 4,900 psi (~33.8 MPa) surface pressure. This corresponds to ~11,600 psi (~80 MPa) downhole pressure at 4.3 km depth. To maintain this rate, 3 constant-rate pumps were used with each operating at 115 gpm. The surface pressure on occasion approached the wellhead pressure safety limit of 5,000 psi. At these times PVU would shut down one injection pump and sometimes two pumps, reducing injection rate, and letting pressure drop a few hundred psi before returning to a 3-pump injection. These shutdowns occurred frequently and lasted for minutes, hours, or a few days. Maintenance shutdowns lasted for one to two weeks and,

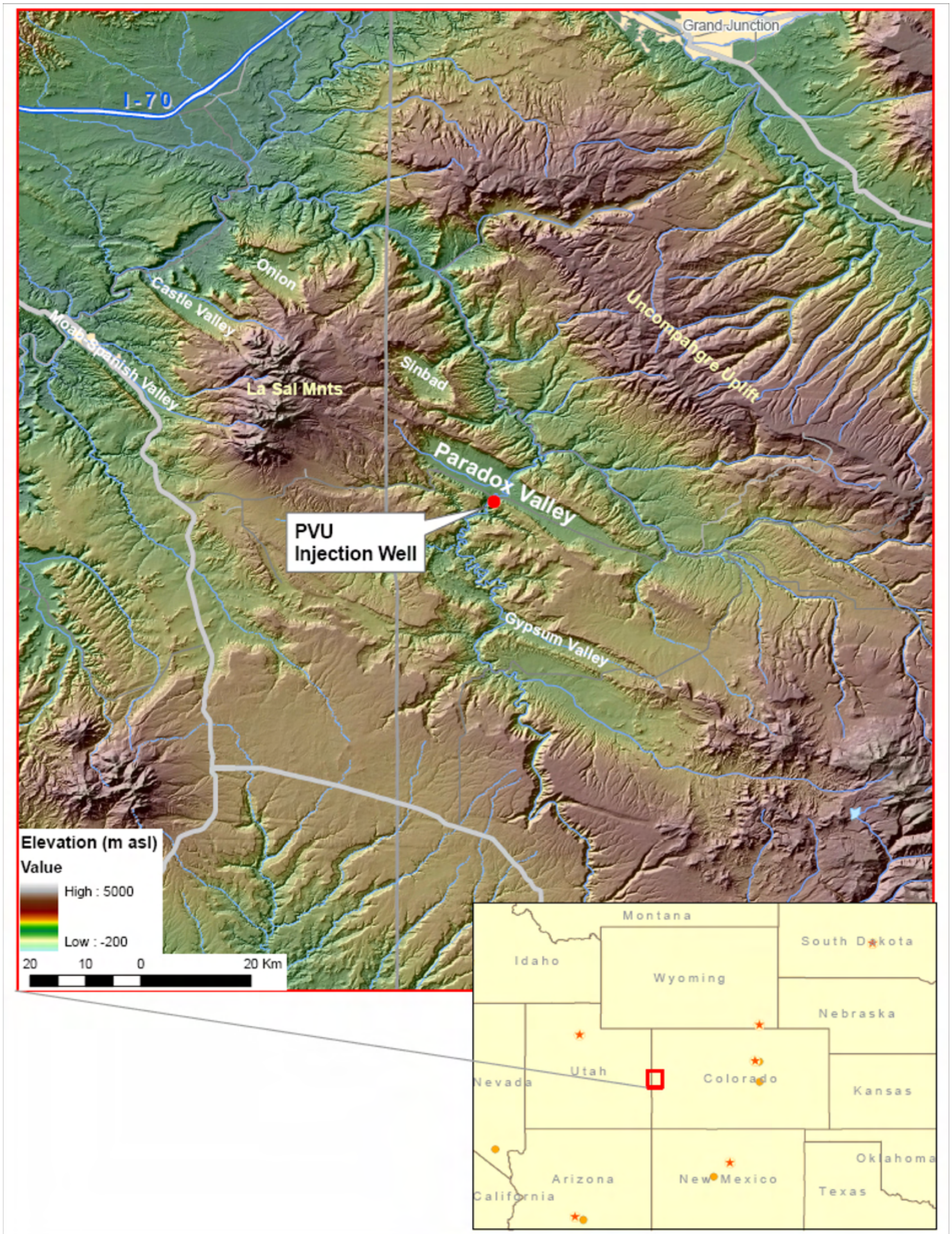

Figure 2-1 Location of the deep injection well at Reclamation's Paradox Valley Unit in western Colorado.

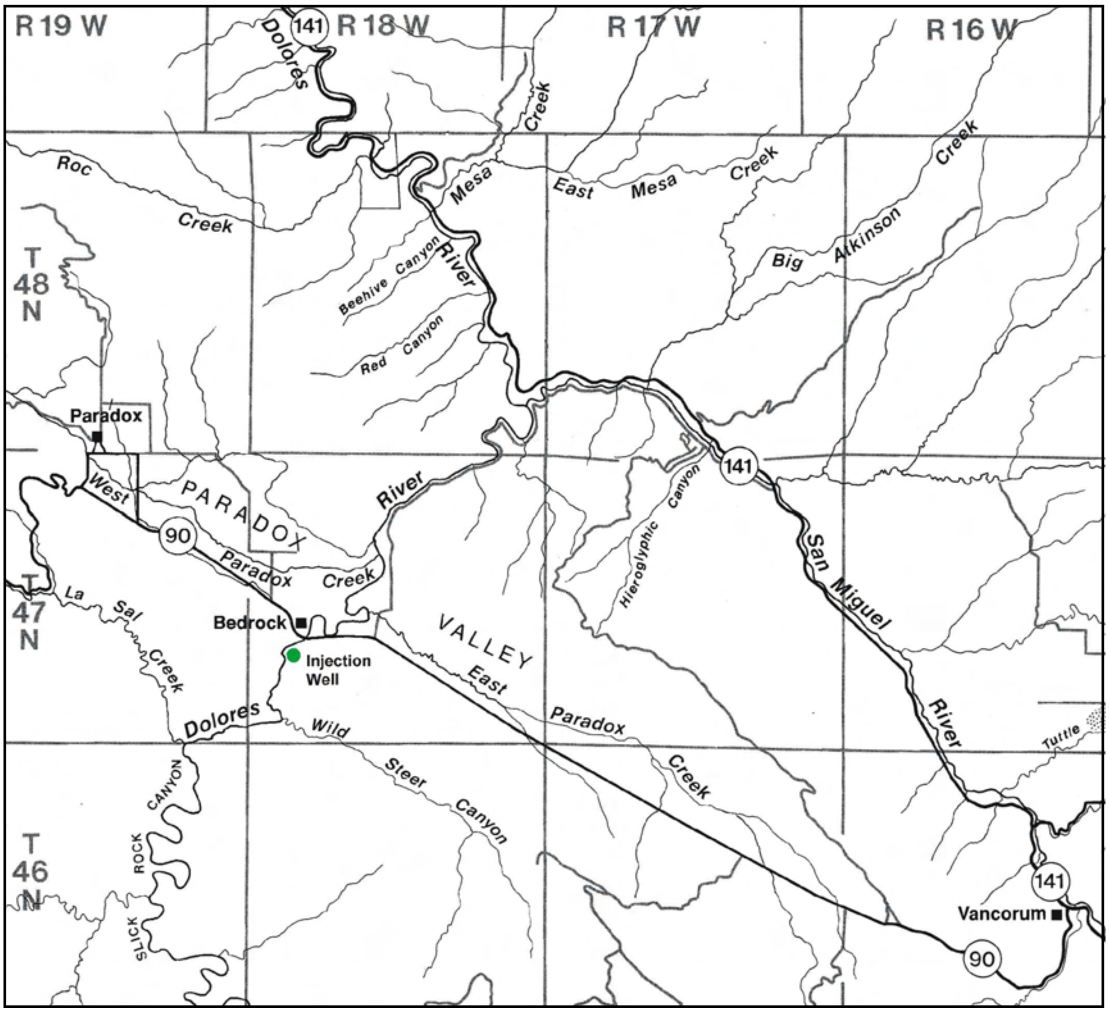

Figure 2-2 Location of the Paradox Valley Unit injection well (green dot) and local geography. Figure is adapted from Parker (1992). Each square is approximately 10 km by 10 km.

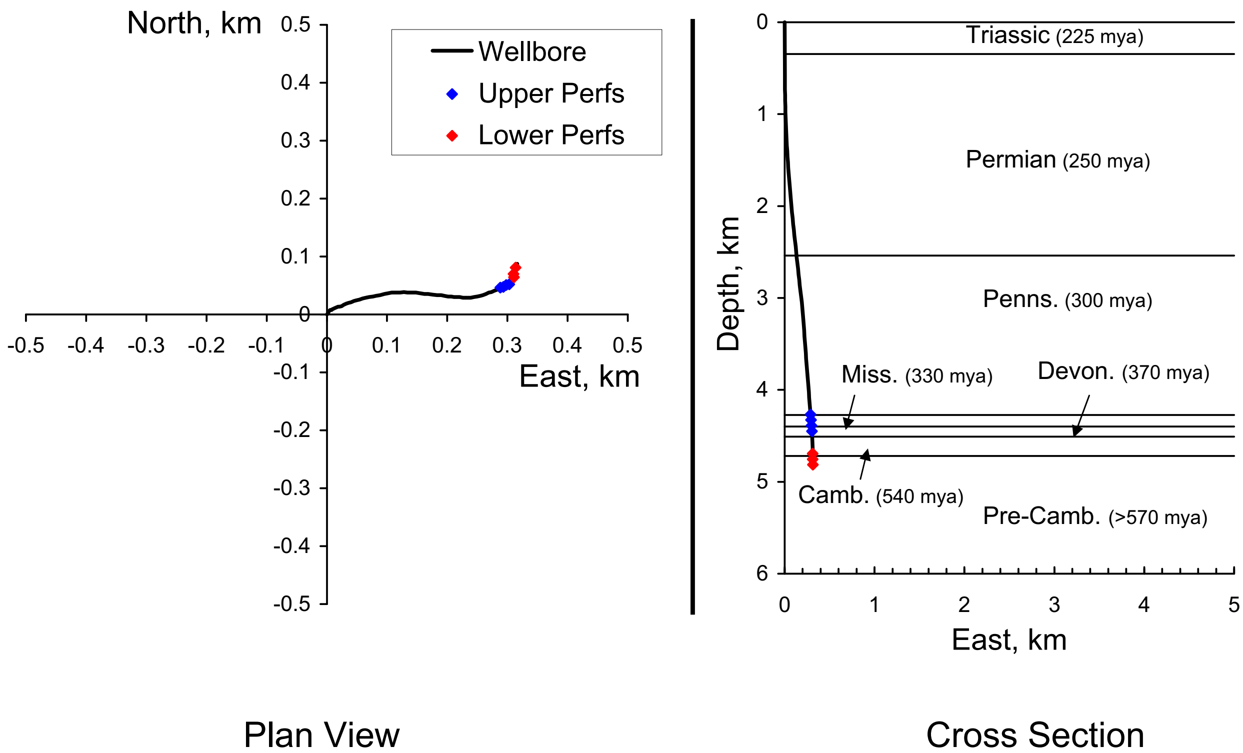

Figure 2-3 PVU injection well in plan view (left) and north-viewing vertical cross section (right). Figures include the near-wellbore stratigraphy and locations of the upper and lower casing perforations.

in mid-1997, a 71-day shutdown was needed to replace operations and maintenance contractors. The shutdowns resulted in an overall average injection rate for *phase I* of ~300 gpm (1136 l/min). The injectate during *phase I* was 70% Paradox Valley Brine (PVB) and 30% fresh water.

2.2.2 Phase II (July 26, 1999 - June 22, 2000)

Following two magnitude **M** 3.5 events in June and July, 1999, PVU augmented injection to include a 20-day shutdown (i.e., a "shut-in") every six months. Prior to these events, it was noted that the rate of seismicity in the near-wellbore region (i.e., within about a 2-km radius from the wellbore) decreased during and following unscheduled maintenance shutdowns and during the shutdowns following the injection tests of 1991 through 1995. It was hoped that the biannual shutdowns would reduce the potential for inducing large-magnitude earthquakes by allowing extra time for the injectate to diffuse from the pressurized fractures and faults into the formation rock matrix. When injecting during this phase, the injection pressure and flow rate were the same as during *Phase I*.

2.2.3 Phase III (June 23, 2000 - January 6, 2002)

Immediately following a **M** 4.3 earthquake on May 27, 2000, PVU shut down for 28 days. During this shutdown period, PVU evaluated the existing injection strategy and its relationship to induced seismicity. PVU decided to reduce the injection flow rate in order to reduce the potential for inducing large-magnitude earthquakes. On June 23, 2000, PVU resumed injection using two pumps rather than three. This change decreased the injection flow rate by 33% compared to earlier phases, to 230 gpm (~871 l/min). The 70:30 ratio of brine to fresh water and the biannual 20-day shutdowns were maintained.

2.2.4 Phase IV (January 7, 2002 - present)

Beginning with continuous operations in 1996, PVU diluted the injectate to 70% PVB and 30% Dolores River fresh water. A geochemical study had predicted that if 100% PVB were injected, it would interact with connate fluids and the dolomitized Leadville Limestone at downhole (initial) temperatures and pressures, and that PVB would then precipitate calcium sulfate, which in turn would lead to restricted permeability (Kharaka, 1997). During October 2001, with the decreased injection volume discussed above, the injectate concentration question was reconsidered. Temperature logging in the injection interval recorded substantial near-wellbore cooling, indicating that if precipitation occurred, it would not be near the wellbore perforations where clogging would be a concern. Further discussions indicated that, if precipitation occurs, its maximum expected rate is ~8 tons of calcium sulfate per day. To put this amount into perspective, injecting at ~230 gpm, assuming a density of 8.33 lbs/gal, results in a daily injection of ~1380 tons. The maximum expected precipitate is ~0.6% of the daily injection mass.

After considering this new information, the decision was made to begin injecting 100% PVB, in order to increase the amount of salt disposed of with the reduced injection rate initialized in *phase III*. Injecting 100% PVB began on January 7, 2002, following the December-January 20-day shutdown, and has been maintained since. The same reduced injection rate as in *phase III* (230 gpm) and biannual 20-day shutdowns have been maintained. The only noticeable affect of the change to 100% PVB injectate has been increasing bottom hole pressure because of the increased density of 100% PVB (by about 5%) over the 70% PVB : 30% fresh water mix. No affect on the induced seismicity has been detected.

2.3 Seismic Monitoring

2.3.1 Paradox Valley Seismic Network

During planning for PVU it was recognized that earthquakes could be induced by the high-pressure, deep-well injection of brine. This was based on comparison to other deep-well injection projects in Colorado, including the Rocky Mountain Arsenal, near Denver, and oil and gas extraction projects near Rangley. In 1983, eight years before the first injection at PVU, Reclamation commissioned a seismic monitoring network to characterize the pre-injection, naturally-occurring seismicity in the Paradox Valley region, and to monitor earthquakes that might be induced once injection operations began. The Paradox Valley Seismic Network (PVSN) was the product of these efforts. Field equipment for an initial 10-station network was acquired and installed in 1983 by the U.S. Geological Survey (USGS), under a Memorandum of Agreement with Reclamation. For the first six years of monitoring, seismic data from this network were acquired and processed by USGS at their facilities in Golden, Colorado. In 1990, responsibility for data acquisition and analysis was assumed by Reclamation. USGS has continued to assist Reclamation with the design and maintenance of the field instrumentation and telemetry.

Over the years, the original 10-station continuously telemetered, high-gain seismic network has been upgraded and expanded. Four stations (PV11-PV14) were added to this array in 1989, and two more were added in 1999 (PV16) and 2005 (PV17), bringing the total number of stations to its current compliment of 16. Station PV15 was installed in 1995 to replace PV06, which had been repeatedly vandalized and was finally removed the year before. Station PV08 was removed in October, 2003 to accommodate nearby construction activities, but was reinstalled in October, 2007.

Recent upgrades to the high-gain seismic network have focused on replacing the original analog short-period seismic equipment, which is becoming increasingly difficult to maintain, with modern digital broadband instrumentation. In November, 2005, a new digitally-telemetered station (PV17) was installed that employs a broadband triaxial seismometer. Twelve existing stations have been converted from analog short-period to digital broad-band instrumentation since 2005: PV12 in November, 2005, PV04 in May, 2007, PV14 in June 2007, PV02, PV03, PV10, and PV11 in October, 2008, and PV01, PV05, PV07, PV13, and PV16 in May, 2010.

In addition to the continuously telemetered high-gain seismic array, three event-triggered strong motion instruments have been added to PVSN. The first strong motion instrument (station name PVPP) was installed near the injection well-head in 1997. A second strong-motion instrument was installed near the extraction facilities (PVEF) in 2003, and the third was installed in the nearby community of Paradox, Colorado (PVCC) in 2005. The strong-motion array is designed to measure ground motions from events that are large enough to be felt or cause damage, and which would completely saturate the high-gain array.

The locations of the PVSN seismograph stations are shown in **Figure 2-4**. More detailed information about the stations is provided in **Table 2-1,** including installation date, station type, and number of components. **Table 2-2** lists descriptive information about the telemetered stations, including a legal descriptions of the station locations.

2.3.2 Monitoring Operations

Current PVSN monitoring operations include: (1) acquiring continuous ground motion data originating in and around Paradox Valley and the surrounding region; (2) sending this data in real time to processing facilities located at Reclamation’s Technical Service Center in Lakewood, CO; (3) identifying local seismic events within these data; (4) determining the location, origin time, and magnitude of each seismic event; (5) determining the individual and cumulative characteristics of the events; (6) identifying and evaluating relationships between seismicity, geology, subsurface brine and connate water/pressure movements and locations, and injection parameters; (7) maintaining a database of both events and injection parameters; and (8) documenting findings.

Natural seismicity rates in the Paradox Valley area are low. During pre-injection monitoring, only a single local earthquake was recorded, located 18 km north of the injection well. Upon initiation

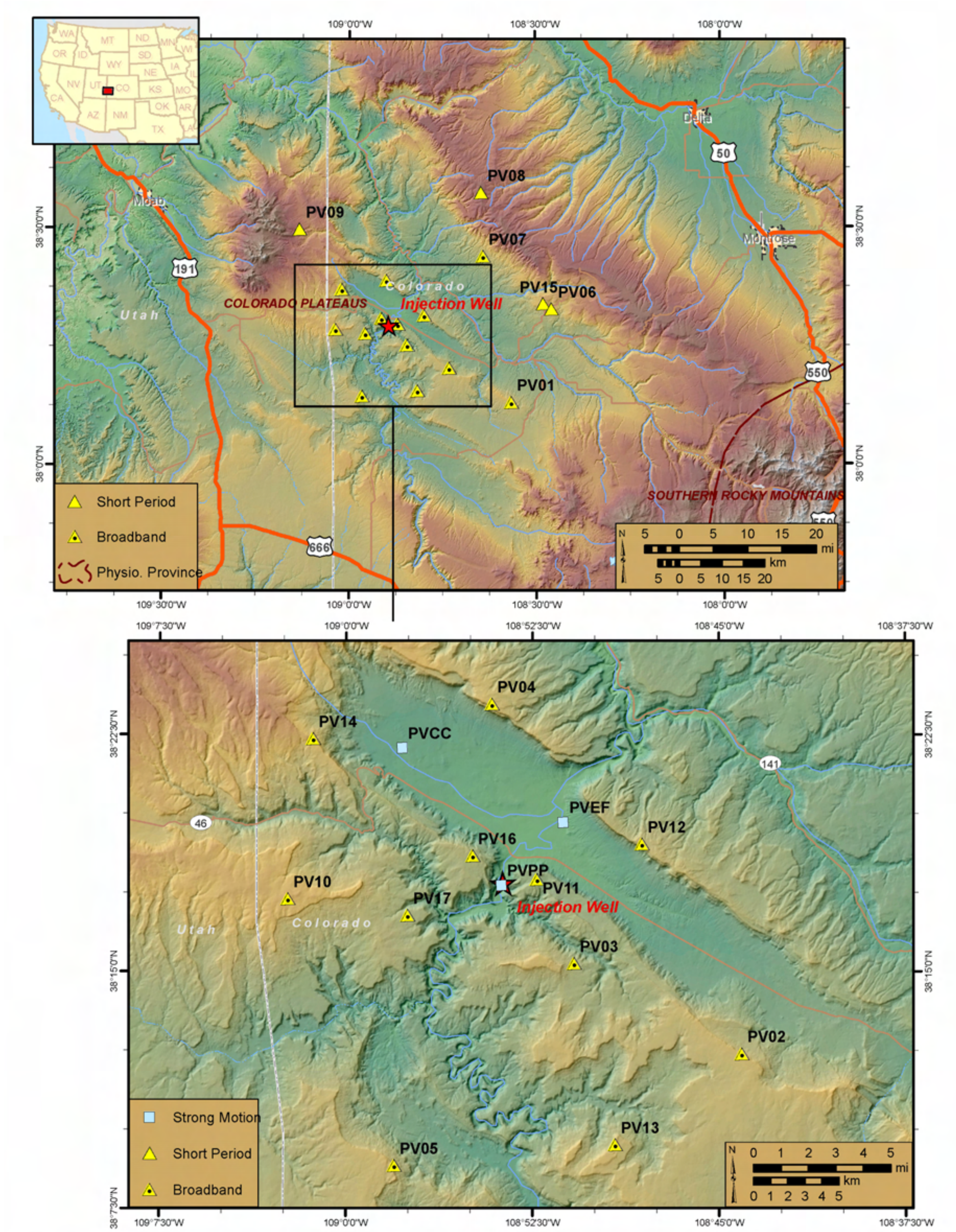

Figure 2-4 Locations of the Paradox Valley Seismic Network stations and the Paradox Valley Unit injection well. PVCC, PVEF & PVPP are the strong motion stations. Station PV06 was replaced by PV15. Physiographic provinces from Fenneman and Johnson (1946).

of injection, numerous induced earthquakes were detected in the immediate vicinity of the injection well. By the end of 1998, the region of induced seismicity had expanded to a maximum distance of 8.5 km from the well. The induced seismicity at that time occurred in two distinct zones: a primary zone immediately surrounding the well and extending to a radial distance of about 3.5 km, and a secondary zone centered approximated 7.5 km northwest of the well. In January, 1999, the frequency of recorded induced seismicity reached its peak value of over 150 events per month.

While the vast majority of seismicity induced by injection operations has been below the threshold of human detection, approximately 70 events large enough to potentially be felt (**M** >= 2.5) occurred between 1991 and 2010. As discussed in section 2.2, injection operations have been adjusted twice in an attempt to minimize the potential for generating felt earthquakes. In response to two **M** 3.5 events that occurred in mid-1999, the operation of the injection well was altered to require a minimum of two shut down periods per year,of at least 20 days each. In response to an **M** 4.3 earthquake that occurred on May 27, 2000, operations were modified to reduce the nominal injection flow rate from 345 gpm to 230 gpm. Partially as a result of these changes in injection operations, the frequency of seismic activity generally declined from its peak value in January 1999 until late 2000.

Since late 2000, the frequency of seismic activity has fluctuated slightly in response to injection operations, but has remained low compared to pre-2000 levels. Although the rate of induced seismic activity continues to be low, induced seismic events have been detected in several new locations since 2009. Earthquakes believed to be induced by fluid injection are now being detected at distances up to 9 km from the injection well in several directions. In addition to these clearly-induced earthquakes, more than 600 local earthquakes have been detected in the Paradox Valley area at distances greater than 9 km from the well since injection began, mostly near the northern end of the valley. The potential relationship of these events to injection operations is not clear.

More than 4800 seismic events located within 9 km of the injection well have been recorded by PVSN since injection operations began in 1991 (through 2010). Computed event focal depths indicate that the vast majority of the induced earthquakes follow the targeted injection horizons, suggesting that the injected brine is remaining below the confining layers as anticipated.

Table 2-1 PVSN Station Locations and Characteristics

Station Name	Latitude deg., N	Longitude deg., W	Elev. m	Dates of Operation	Station Type	Sensor Direction
PV01	38.13	108.57	2191	5/83-present 5/10-present	short-period broad-band	vertical triaxial
PV02	38.21	108.74	2177	5/83-present 10/08-present	short-period broad-band	vertical triaxial
PV03	38.25	108.85	1972	5/83-present 10/08-present	short-period broad-band	vertical triaxial
PV04	38.39	108.90	2176	5/83-6/06 5/07-present	short-period broad-band	vertical triaxial
PV05	38.15	108.97	2142	5/83-present 5/10-present	short-period broad-band	vertical triaxial
PV06	38.33	108.46	2243	5/83-8/94	short-period	vertical
PV07	38.44	108.64	2040	6/83-present 5/10-present	short-period- broad-band	vertical triaxial
PV08	38.58	108.65	2950	6/83-9/89 9/89-10/03 10/07-present	short-period short-period short-period	triaxial vertical triaxial
PV09	38.50	109.13	2662	6/83-present	short-period	vertical
PV10	38.29	109.04	2266	6/83-present 10/08-present	short-period broad-band	vertical triaxial
PV11	38.30	108.87	1882	12/89-present 10/08-present	short-period broad-band	triaxial triaxial
PV12	38.32	108.80	2092	12/89-7/05 11/05-present	short-period broad-band	vertical triaxial
PV13	38.16	108.82	2158	12/89-present 5/10-present	short-period broad-band	vertical triaxial
PV14	38.37	109.02	2234	12/89-4/02 6/07-present	short-period broad-band	vertical triaxial
PV15	38.34	108.48	2234	6/95-present	short-period	vertical
PV16	38.31	108.92	2025	7/99-present 5/10-present	short-period broad-band	triaxial triaxial
PV17	38.28	108.96	1991	11/05-present	broad-band	triaxial

Table 2-1 PVSN Station Locations and Characteristics

Station Name	Latitude deg., N	Longitude deg., W	Elev. m	Dates of Operation	Station Type	Sensor Direction
PVPP	38.30	108.90	1524	12/97-present	strong motion	triaxial
PVEF	38.33	108.85	1513	10/03-present	strong motion	triaxial
PVCC	38.37	108.96	1617	6/05-present	strong motion	triaxial

Notes: Table lists network configuration as of 12/31/2010. Elevations are relative to mean sea level (msl), the surface elevation of the injection well is 1540 m above msl. Stations with vertical sensor direction are single-component; triaxial are 3-component (vertical, north, and east).

Table 2-2 Current PVSN Telemetered Sites - Legal Descriptions

Station Desig.	Station Name	Legal Description
PV01	The Burn	T45N R15W S19 C,NM
PV02	Monogram Mesa	T46N R17W S27 C,NM
PV03	Wild Steer	T46N R18W S10 C,NM
PV04	Carpenter Flats	T48N R18W S30 C,NM
PV05	E. Island Mesa	T45N R19W S16 C,NM
PV07	Long Mesa	T48N R16W S9 C,NM
PV08	Uncompahgre Butte	T50N R16W S22 C,NM
PV09	North LaSalle	T26S R25E S35 U,SLC
PV10	Wray Mesa	T47N R20W S35 C,NM
PV11	Davis Mesa	T47N R18W S29 C,NM
PV12	Saucer Basin	T47N R18W S24 C,NM
PV13	Radium Mtn	T45N R18W S14 C,NM
PV14	Lion Creek	T48N R20W S36 C,NM
PV15	Pinto Mesa	T47N R15W S11 C,NM
PV16	Nyswonger Mesa	T47N R19W S24 C,NM
PV17	Wray Mesa East	T47N R19W S34 C,NM

3.0 PVSN OPERATIONS IN 2010

3.1 Network Maintenance and Upgrades

3.1.1 Seismic Stations

During 2009, new broadband digital seismic stations were installed at five existing sites: PV01, PV05, PV07, PV13, and PV16. All necessary equipment other than the seismometers were installed in 2009. However, because of delays in receiving the new digital seismometers from the vendor, these stations could not be brought online before the end of the 2009 field season. The seismometers were installed and these five digital stations brought online in May, 2010. This installation brought the number of PVSN digital broad-band seismometers to it's current number, 13.

Maintenance, repairs, and minor upgrades were performed at several existing seismic stations and at Hopkins Field Airport during five site visits in 2010. Tasks performed during these trips include: replacing batteries, upgrading cabling, re-orienting seismometers with a precision laser tool, thermally insulating seismometer vaults, replacing a defective digital seismometer at station PV03, replacing a failed radio at digital station PV11, replacing GPS antennas at station PV16 and at Hopkins Field, replacing router fans at Hopkins Field, replacing an analog transmitter at analog station PV15, and building a new tower base for station PV04 (after the tower was toppled by winds in March, 2010). Further details of the work performed at the seismic stations during 2010 are included in the attached site visit reports (Appendix C).

Reconnaissance of potential new sites for digital seismograph stations to replace analog stations PV08 and PV09 (because the current locations of these stations are not optimal), as well as for a few additional stations to improve monitoring coverage of some critical areas, was performed during several trips in the fall of 2009. In early 2010, applications were submitted to the U.S. Dept. of Agriculture Forest Service (USFS) and the Dept. of Interior Bureau of Land Management (BLM) to obtain rights-of-way for the selected sites. In June, 2010, cultural and environmental resource site surveys were conducted by Reclamation specialists in compliance with National Environmental Policy Act (NEPA) policies. During these site visits, the precise locations of the seismometer vaults and tower bases were also determined and radio communication checks were performed. Reclamation has obtained rights-of-way for all requested BLM sites and begun construction of the new seismograph stations. (Permits have not yet been obtained from the USFS.)

3.1.2 Data Acquisition System

In early August, 2010, an improved data acquisition event detection procedure was implemented. This procedure allows the waveform data from the broadband digital stations to be filtered prior to running the event detection algorithm. Very small earthquakes normally produce relatively high-frequency but low-amplitude signals. At the broadband stations, these signals are often superimposed on much lower-frequency but higher-amplitude background noise. With the improved triggering procedure, this low-frequency background noise is removed prior to event detection. The result is more robust detection of very small earthquakes. Since the analog short-period seismometers are not sensitive to the very low-frequency background noise, this is not an important issue with event detection from short-period waveform data. This improved event detection procedure has been running in parallel with the previous procedure since early August, 2010. During an initial two-month testing period, the new procedure detected all of the induced earthquakes detected by the previous procedure, plus additional events with magnitudes less than **M** 0.5. Hence, the previous triggering procedure, which has been in use since Nov. 2007, appears to detect all events with magnitude >= **M** 0.5. The new procedure has resulted in better detection of events below that previous threshold.

3.2 Network Performance

PVSN performed well during 2010. The annual network performance can be characterized by two aspects: performance of individual seismic stations (how well individual stations functioned throughout the year) and performance of network data acquisition (the continuity of data acquisition and recording).

Figure 3-1 indicates the performance of the individual seismic stations during 2010. Each horizontal line across the plot represents one seismic data channel, as indicated on the left side of the plot. Each data channel name consists of the station name (e.g., PV01), the component identifier (V = vertical; E - east-west; N = north-south), and a label indicating whether it is an analog (a) or digital (d) station. Thick blue lines indicate that the data channel was installed and functioning normally. Thin red lines indicate that the data channel was offline and therefore no data from that channel were being recorded. Intermediate-thickness green lines indicate either that the data channel was offline intermittently or that there was some problem with data quality. The chart in **Figure 3-1** only indicates whether the individual seismic data channels were functioning properly and not whether they were being recorded by the acquisition system. The reasons for problems with individual station performance are variable. Details of the performance of the digital seismic stations are given in **Table 3-1**, while the performance of the analog stations is summarized in **Table 3-2**. None of the station performance issues significantly degraded the performance of the seismic network.

The performance of PVSN data acquisition during 2010 is represented by the graph shown in **Figure 3-2**. This graph plots the performance of data acquisition and recording as a function of time. A performance rating of 100% indicates that the data acquisition system, including the servers located at Hopkins Field in Nucla, the dedicated telephone line from Nucla to Denver, and the data acquisition and recording system in Denver were all operating properly. Hence, during these times, all seismic events above the detection threshold were being identified and the corresponding seismic data streams were being saved for analysis. A performance rating of 0% indicates that some component of the data acquisition system was offline and that no seismic data were being saved during that time period. (Because this graph represents daily values, periodic shut-downs for routine equipment maintenance lasting less than two hours are ignored in this performance rating.) The backup data acquisition system at Hopkins Field in Nucla, Colorado performed exceptionally well throughout 2010 and, as a result, there were no days when the network was offline. Hence, the PVSN uptime for 2010 is 100%. PVSN uptime for 2010 is compared to that for previous years in **Table 3-3**.

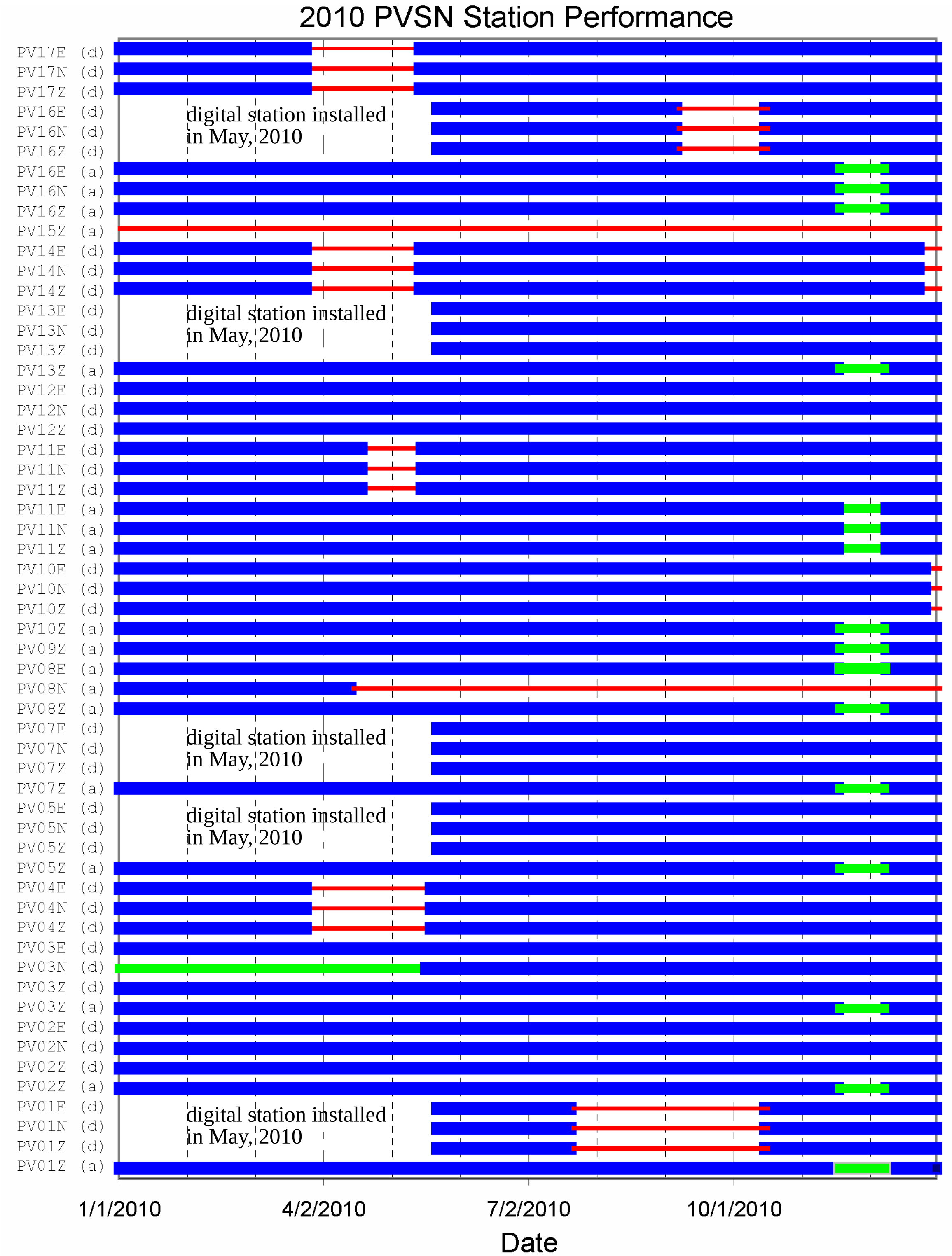

Figure 3-1 Performance of PVSN seismic data channels during 2010. The letter in parentheses indicates whether the data channel is analog (a) or digital (d). Thick blue lines indicate that the channel was installed and functioning well. Thin red lines indicate that the channel was offline. Intermediate-thickness green lines indicate that the channel was online but experiencing some type of problem; see text for explanations.

Table 3-1 Performance of digital seismic stations during 2010

Station	Performance
PV01	New station brought online on May 23, 2010; offline from July 22 to October 14, due to failed radio.
PV02	Online and functioning normally throughout 2010
PV03	Malfunctioning North component from January to May 17; other components functioning normally throughout 2010
PV04	Station was toppled by wind loading on March 26; down until May 19
PV05	New station brought online on May 23, 2010; online and functioning normally through rest of 2010
PV07	New station brought online on May 23 2010; online and functioning normally through rest of 2010
PV10	Online and functioning normally throughout nearly all of 2010; went offline on Dec. 27, possibly due to defective low-voltage disconnect circuits
PV11	Offline April 20 - May 15, due to a failed radio
PV12	Online and functioning normally throughout 2010
PV13	New station brought online on May 23, 2010; online and functioning normally through rest of 2010
PV14	Because data from PV14 is relayed through PV04, PV14 went offline on March 26 when station PV04 was toppled by wind; PV14 brought back online on May 14; went offline on Dec. 24, possibly due to defective low-voltage disconnect circuits
PV16	New station brought online on May 23, 2010; lost time synchronization on September 7; timing restored on October 15.
PV17	Because data from PV17 is relayed through PV04, PV17 went offline on March 26 when station PV04 was toppled by wind; PV17 brought back online on May 14.

Table 3-2 Performance of analog seismic stations during 2010

Station	Performance
PV01	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV02	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV03	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV05	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV07	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV08	North component failed on April 15. Other components functioned normally throughout 2010
PV09	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV10	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV11	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV13	Online and functioning normally except for timing problem from Nov. 18 - Dec. 8 (see below)
PV15	Offline throughout 2010, due to deterioration of old analog equipment
PV16	Occasional drop-outs of analog telemetry throughout year; timing problem from Nov. 18 - Dec. 8 (see below)
all analog stations	Lost timing from November 18 to December 8, due to failed GPS antenna at Hopkins Field in Nucla, CO

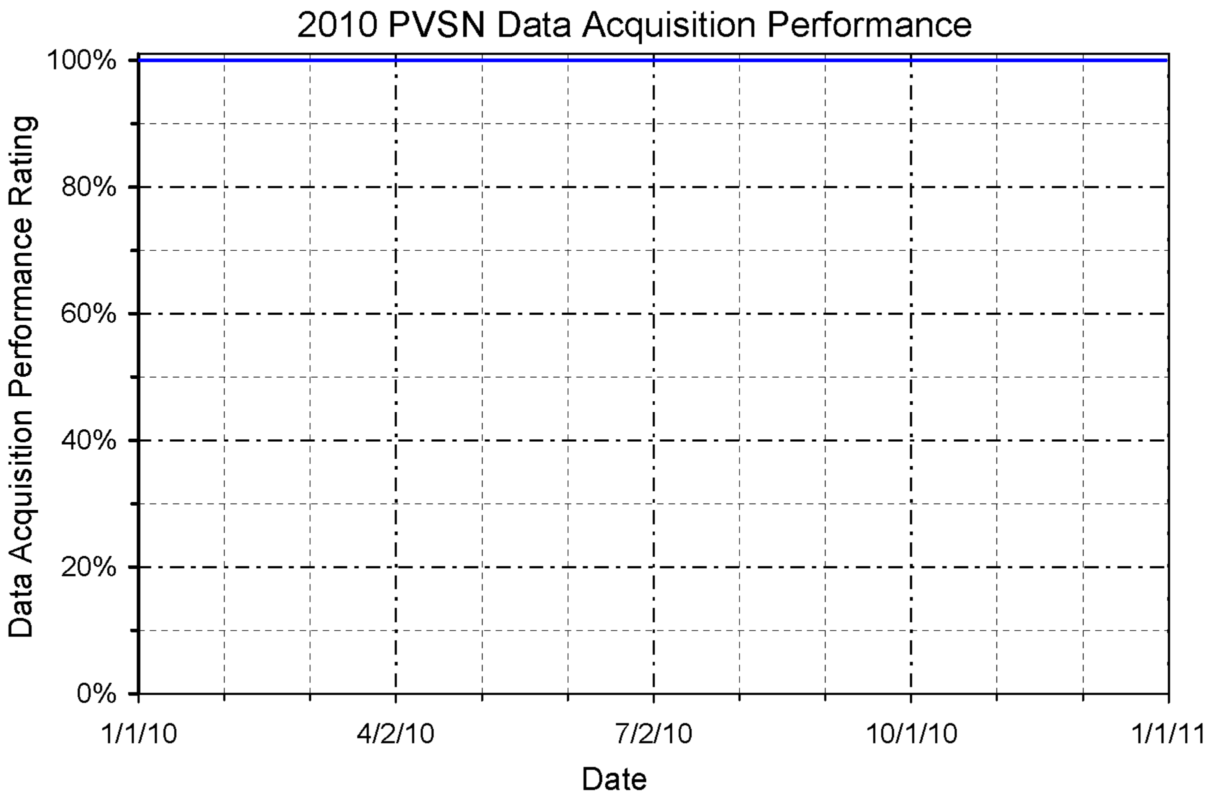

Figure 3-2 Performance of PVSN data acquisition during 2010. A rating of 100% indicates that PVSN was continuously triggering on seismic events above the detection threshold and properly recording the seismic datafiles. A rating of 0% indicates that some part of the data acquisition, transmission, or recording system was down and no data were recorded. See text for further explanations.

3.3 Recalculation of Magnitudes

Magnitudes for all previously recorded local earthquakes were recalculated in 2010 as part of a review of historical seismic network data, and new automated methods for determining magnitudes was developed and put into production use. The purpose of this effort was to establish a consistent magnitude scale for all PVSN local earthquakes. Earlier magnitude calculations relied on manual measurement methods that could yield different results depending on the analyst, and which often did not make use of all available data.

PVSN uses a duration magnitude scale that is based on the signal durations measured from seismograms for each station. Durations are defined as the time, in seconds, between the P-wave arrival and the point where the seismogram has decayed to approximately the pre-event noise level. Historically, PVSN durations have been determined by visual examination of the traces, often using just a small subset of the available stations. This sometimes led to highly variable estimates of average duration and magnitude, especially in cases where few traces were used, or if the data were processed by different analysts.

Table 3-3 Annual PVSN Uptime

Year	Annual Number of Down Days	Percent Uptime
2000	24	93.4%
2001	**	**
2002	5	98.6%
2003	14.5	96.0%
2004	16	95.6%
2005	34	90.7%
2006	47	87.1%
2007	37	89.9%
2008	10	97.2%
2009	6.5	98.2%
2010	0	100%
**not tabulated in 2001		

For the 2010 magnitude recalculation, new automated procedures were developed that were designed to minimize analyst bias, and to use all available data. In order to maintain consistency with past analyses, the automated procedures were tuned to preserve the average magnitude previously determined for the entire dataset of local PVSN earthquakes recorded through November, 2010. The new procedures were implemented in all software applications used for processing PVSN earthquakes. Magnitudes for local PVSN earthquakes recorded since November, 2010 are being determined using these new procedures. Details of the magnitude calculation procedure, and a comparison of magnitudes determined form the old and new procedures, are provided in Appendix B.

4.0 SEISMIC DATA RECORDED IN 2010

4.1 Annual Summary

714 earthquakes were recorded within or near the perimeter of the Paradox Valley Seismic Network during 2010. The map in **Figure 4-1** shows the epicenters of these events (colored circles), as well as the epicenters of all earthquakes recorded in previous years (gray circles). The local earthquakes recorded during 2010 are plotted as a function of date and earthquake magnitude in **Figure 4-2.** The dates and times of occurrence, latitudes, longitudes, elevations, depths, and computed duration magnitudes of these earthquakes are listed in Appendix A.

During most of PVU's injection history (1991-2009), the seismicity interpreted to be induced by injection operations occurred in two distinct regions: the primary near-well region, surrounding the well to a radial distance of approximately 4 km, and a secondary region centered approximately 7.5 km northwest of the injection well and referred to as the northwest (NW) cluster. The induced earthquakes that occurred during 2010 in the near-well region are indicated by magenta circles on the map in **Figure 4-1**, and the 2010 events located in or near the NW cluster are indicated by blue circles. Outside these two zones of induced seismicity, there has historically been relatively little seismic activity in the Paradox Valley area. A few earthquakes have occasionally occurred around the edges of the valley, especially at the northern end of Paradox Valley.

During 2010, local earthquakes were detected in two previously aseismic areas in and near Paradox Valley. In June, a magnitude **M** 0.1 earthquake occurred approximately 8 km west of the injection well (white circle in **Figure 4-1**). In mid-July, an **M** 0.9 earthquake occurred in north-central Paradox Valley, approximately 9 km north-northwest of the injection well and about 2 km east of the town of Paradox. In early August, two more earthquakes (**M** 0.6 and **M** 0.2) occurred in approximately the same location. The epicenters of these north-central valley events are represented by the purple circles in **Figure 4-1.**

Seismic activity increased during 2010 in two areas that had previously experienced a much lower rate of seismic activity. Eleven earthquakes occurred in a tight cluster located about 6 km southeast of the injection well, now referred to as the southeast (SE) cluster (green circles, **Figure 4-1).** These earthquakes occurred over several months (in March, April, July, September, and October; see **Figure 4-2**), usually as single events. Duration magnitudes of these events range from **M** -0.7 to **M** 1.9. Only 3 events were detected at this location prior to 2010 (in November 2004, May 2008, and November 2009). Hence, the seismicity rate of this small cluster increased substantially in 2010 compared to prior years. To put the seismicity rate in perspective, the SE cluster, with 11 recorded earthquakes in 2010, was almost as active as the NW cluster, which produced 13 earthquakes during 2010.

The other area that experienced a significant increase in seismic activity in 2010 is along the northern edge of Paradox Valley. Earthquakes have been detected in this region every year since 2000. From 2000 to 2009, the annual number of earthquakes detected in this region ranged from 2 to 33. In contrast, 557 northern valley earthquakes were recorded during 2010 (yellow circles, **Figure 4-1).** The majority of these earthquakes (545), occurred in a swarm of activity lasting just

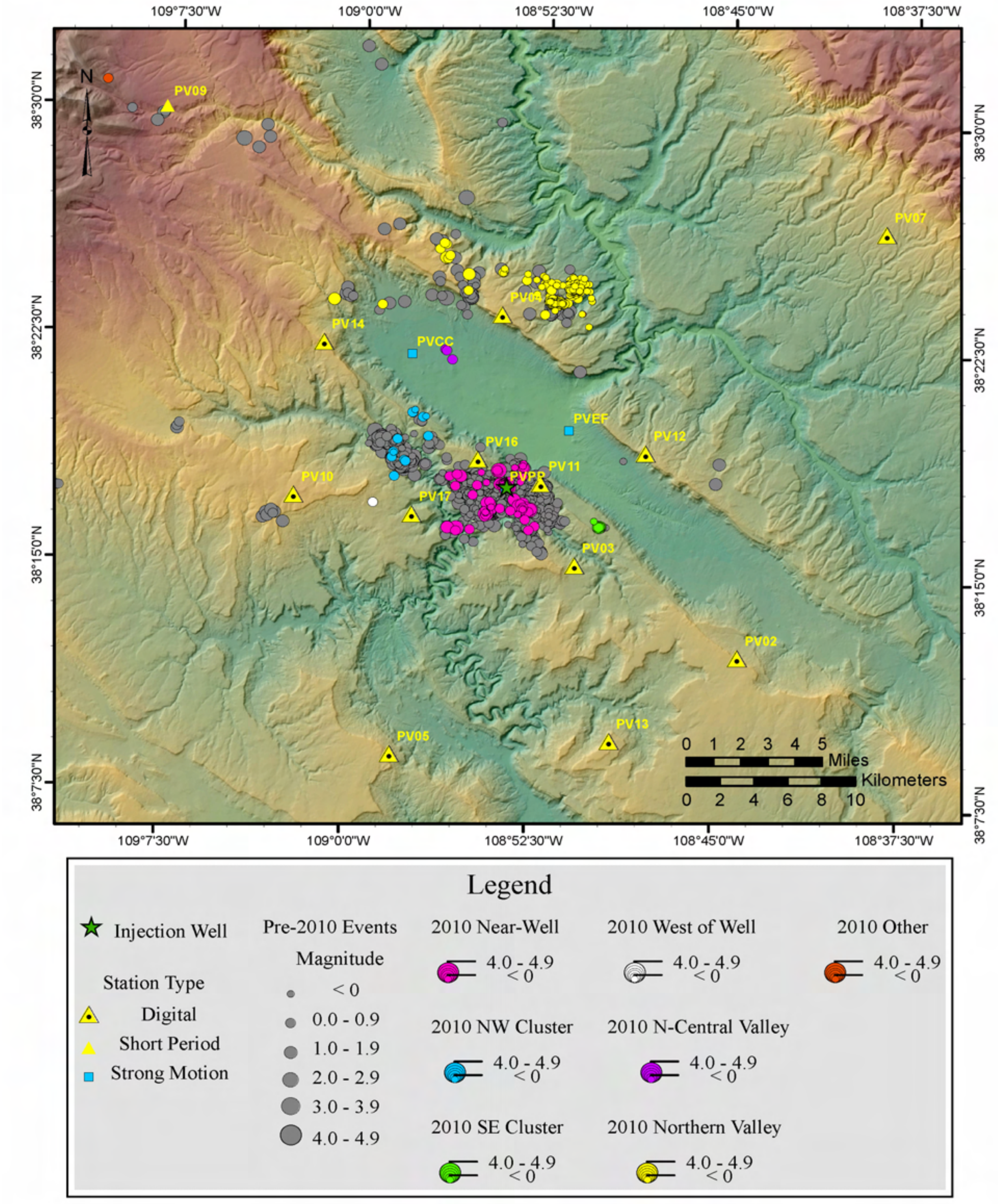

Figure 4-1 Locations of local earthquakes recorded by PVSN during 2010 (colored circles) and previous years (gray circles).

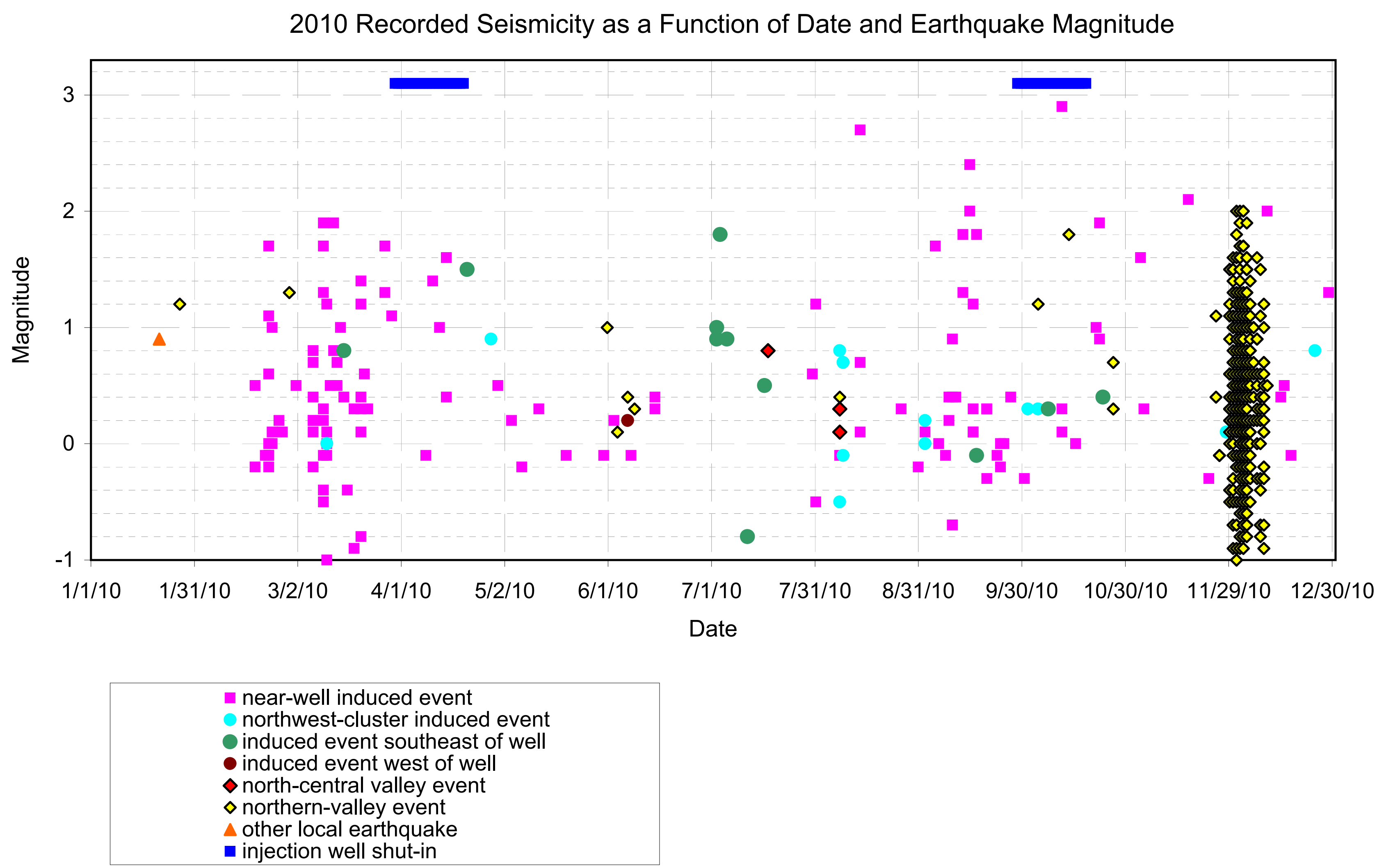

Figure 4-2 Earthquakes recorded by PVSN during 2010, plotted as a function of date, magnitude, and event location category. The dates of injection well shut-ins are included as indicated by the legend.

16 days, from November 26 to December 11 (**Figure 4-2**). These swarm earthquakes are located about 4 km east of station PV04. The magnitudes of the earthquakes that occurred during the November-December swarm range from **M** -1.1 to **M** 2.0. The magnitudes of the 12 other northern valley events that occurred during 2010 range from **M** 0.0 to **M** 1.6.

The 2010 earthquakes that occurred in the SE cluster, north-central Paradox Valley, and 8 km west of the injection well locate at depths ranging from 3.6 to 5.7 km (relative to the ground surface elevation at the injection wellhead, 1.524 km). This is the same depth range as the majority of events occurring in the near-well and NW cluster areas of induced seismicity. This consistency in depth is shown on the map presented in **Figure 4-3**, which includes all local earthquakes recorded by PVSN color-coded by depth range. Excluding earthquakes with magnitude less than **M** 0 (which generally have poorly-constrained locations), estimated depths of the northern valley events that occurred during 2010 range from 2.5 to 7.9 km. The northern valley events that occurred during the Nov.-Dec. 2010 swarm east of station PV04 locate shallower than 6.0 km.

The numbers and magnitudes of the events recorded by PVSN during 2010 for each of the location categories discussed above are summarized in **Table 4-1**, and the average daily seismicity rates are listed in **Table 4-2**.

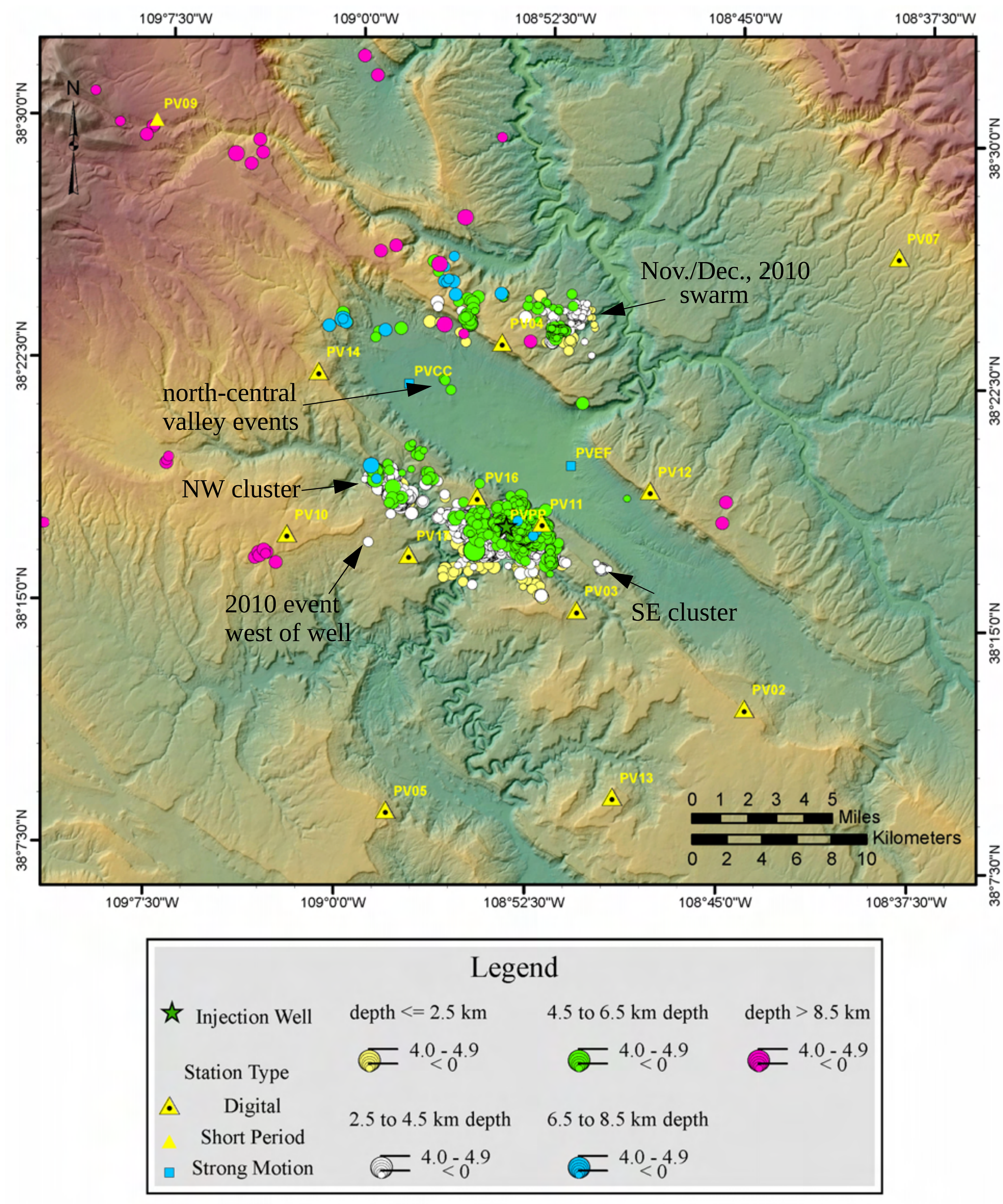

Figure 4-3 All local earthquakes recorded by PVSN (from 1985 through 2010), color-coded by event depth range. Depths are relative to the ground surface elevation at the injection wellhead (1.524 km).

Table 4-1 Summary of events recorded during 2010 by location category

Location Category[1]	Number of Earthquakes	Magnitude Range	Median Magnitude
near-well	128	-1.5 - 2.6	0.25
NW cluster	13	-0.6 - 0.8	0.2
SE cluster	11	-0.7 - 1.9	0.5
west of well	1	0.1	0.1
north-central valley	3	0.2 - 0.9	0.6
northern valley	557	-1.1 - 2.0	0.3
other	1	0.7	0.7
TOTAL	714	-1.5 - 2.6	0.3

Table 4-2 Average daily seismicity rates of local earthquakes recorded by PVSN during 2010. These rates were computed using the number of days the network was operational, 365, as discussed in section 3.

Earthquake Group	All Magnitudes		Magnitude >= **M** 0.5	
	Number of Events Recorded	Average Daily Rate	Number of Events Recorded	Average Daily Rate
near-well	128	0.351	44	0.121
NW-cluster	13	0.036	3	0.008
SE cluster	11	0.030	6	0.016
west of well	1	0.003	0	0
north-central valley	3	0.008	2	0.005
northern valley events	557	1.526	239	0.655
other	1	0.003	1	0.003
TOTAL	714	1.956	295	0.808

4.2 Injection-Induced Earthquakes

4.2.1 2010 Seismicity

The seismicity recorded during 2010 indicates that the zone of influence of the injection well is expanding. We interpret the earthquakes that occurred in the SE cluster, in north-central Paradox Valley, and 8 km west of the injection well to be due to fluid injection. These locations are indicated by the yellow dashed circles on the map shown in **Figure 4-4.** The earthquake hypocenters are also seen in the vertical cross sections presented in **Figure 4-5.** In these figures, the earthquakes that occurred during 2010 and those that occurred in previous years are each separated into two categories based on how precise the computed hypocenters are relative to the other events. However, even the events with the “poorer locations” are fairly well-located. (The earthquakes with the “best locations” meet the following criteria in the event *relative* location: number of stations with cross-correlation time differences >= 6; maximum azimuthal gap in ray coverage <= 100 degrees, and the horizontal distance from the earthquake epicenter to the closest station with observed time differences divided by the earthquake (focal) depth is <= 1.0.)

Our interpretation that the earthquakes in these new areas are related to fluid injection is based on the following observations. First, no pre-injection seismicity was observed in any of these three locations. In fact, no seismicity was observed in north-central Paradox Valley or at the location 8 km west of the injection well prior to 2010, despite 25 years of near-continuous seismic monitoring. No seismicity was observed in the area of the SE cluster prior to 2004. Second, these earthquakes locate at the same depths (~ 3 to 6 km) as the induced seismicity in the near-well and NW cluster regions. Naturally-occurring earthquakes in this geologic province tend to occur deeper than about 7 km. Finally, the near-simultaneous occurrence of seismicity 6 to 9 km from the injection well in three different azimuths suggests that these events are due to an expansion of the zone of influence of the injectate. This interpretation does not require that injectate is migrating to these distances. Rather, the increasing volume of injectate in the subsurface formations and the increasing pore pressures in these rocks are affecting the stress field in the surrounding area. Depending on the in-situ stress conditions across pre-existing fractures, even small changes in the local stress field can induce earthquakes.

Some anomalous seismic activity, compared to historical trends (1991-2009), also occurred within the near-well region and NW cluster during 2010. A few of the earthquakes that have been classified as NW cluster events actually locate about 2.5 km northeast of the majority of historical NW cluster earthquakes. These events are indicated by the black dashed circle on the map in **Figure 4-4.** As can be seen, these events locate between the center of the historical NW cluster seismicity and the recent north-central valley earthquakes. In the near-well region, a cluster of a few earthquakes (including one of the largest earthquakes induced in 2010, an **M** 2.6 event) occurred approximately 1 km north-northwest of the injection well, in an area that has been historically aseismic. Another group of earthquakes occurred about 4 km southwest of the well, at the far edge of the near-well region. These two areas are indicated by the white dashed circles in **Figure 4-4**. The group of earthquakes 4 km southwest of the well also locate anomalously shallow, at a depth of slightly less than 2 km (**Figure 4-5).** A few earthquakes have located at shallow depths in this area in recent years, but they have been small in magnitude and therefore have had poorly-constrained hypocenters. A magnitude **M** 2.0 earthquake with a well-

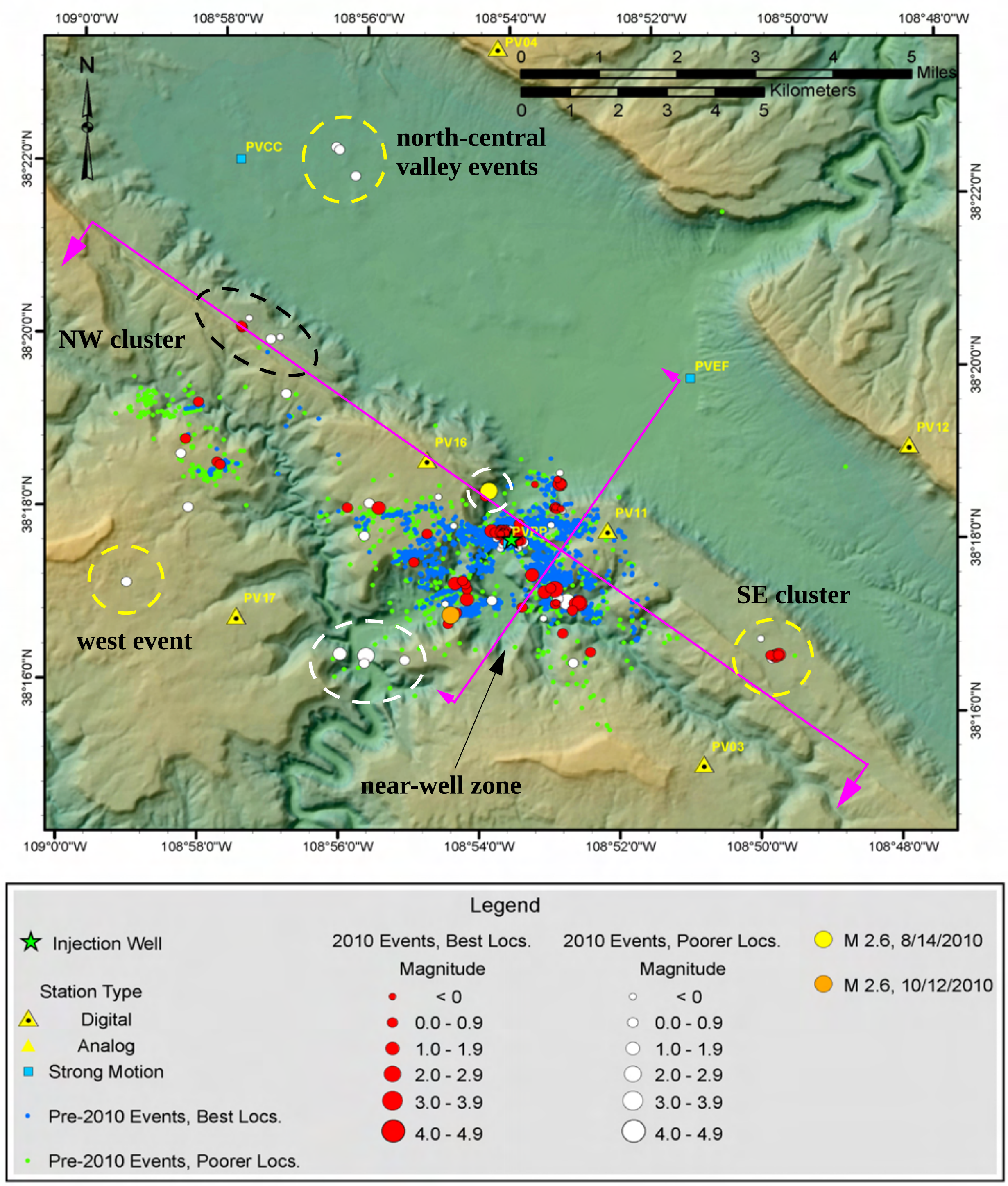

Figure 4-4 Map showing the locations of induced earthquakes recorded in 2010, compared to the locations of previously-induced events. The dashed circles indicate areas of recent seismic activity that is anomalous compared to historical trends. The magenta lines indicate the orientations of the cross sections presented in Figure 4-5.

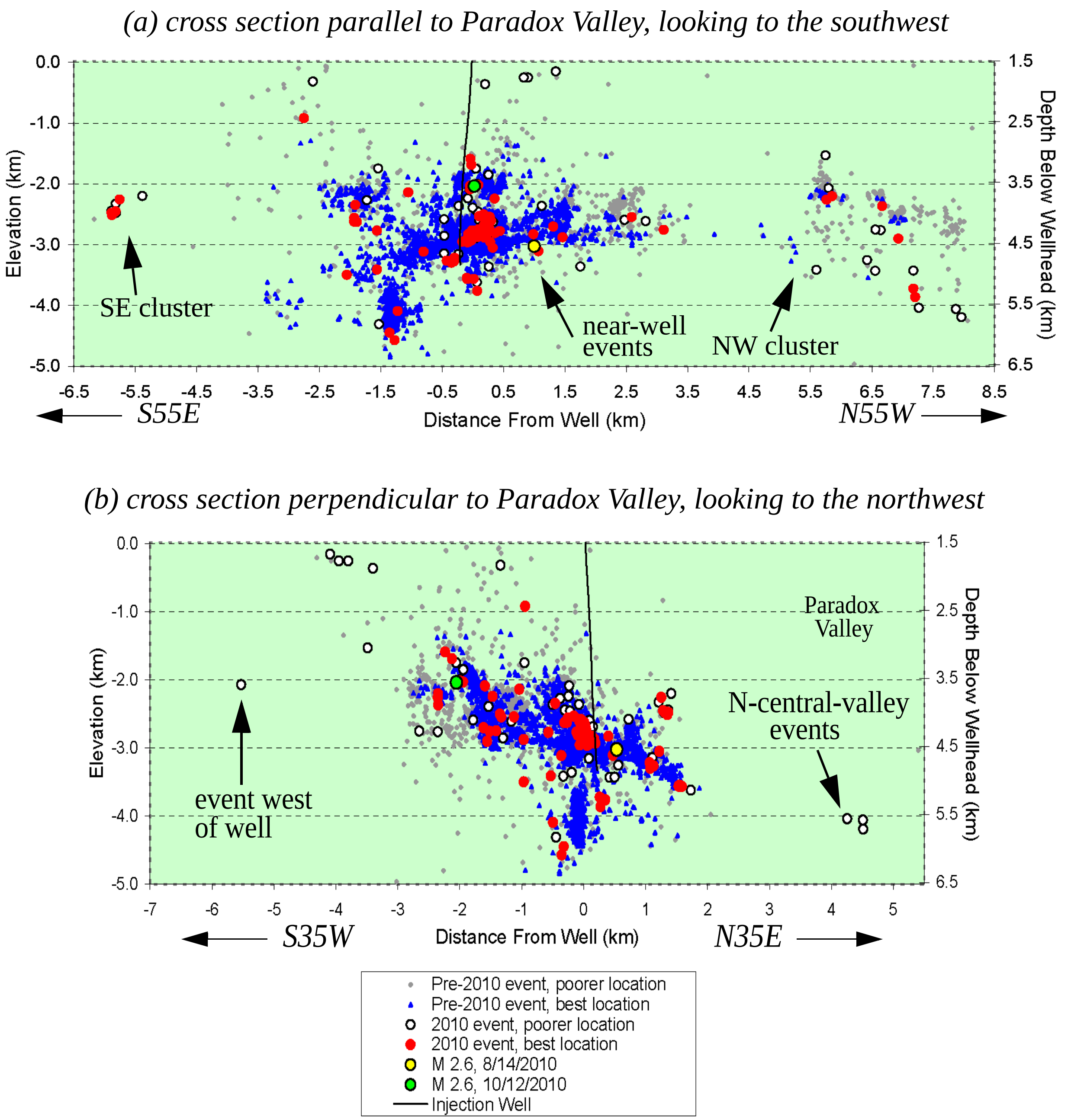

Figure 4-5 Vertical cross sections showing the locations of induced earthquakes recorded in 2010, compared to the locations of previously-induced events: (a) section parallel to Paradox Valley (b) section perpendicular to Paradox Valley. The orientations of the cross sections are indicated by the magenta lines in Figure 4-4.

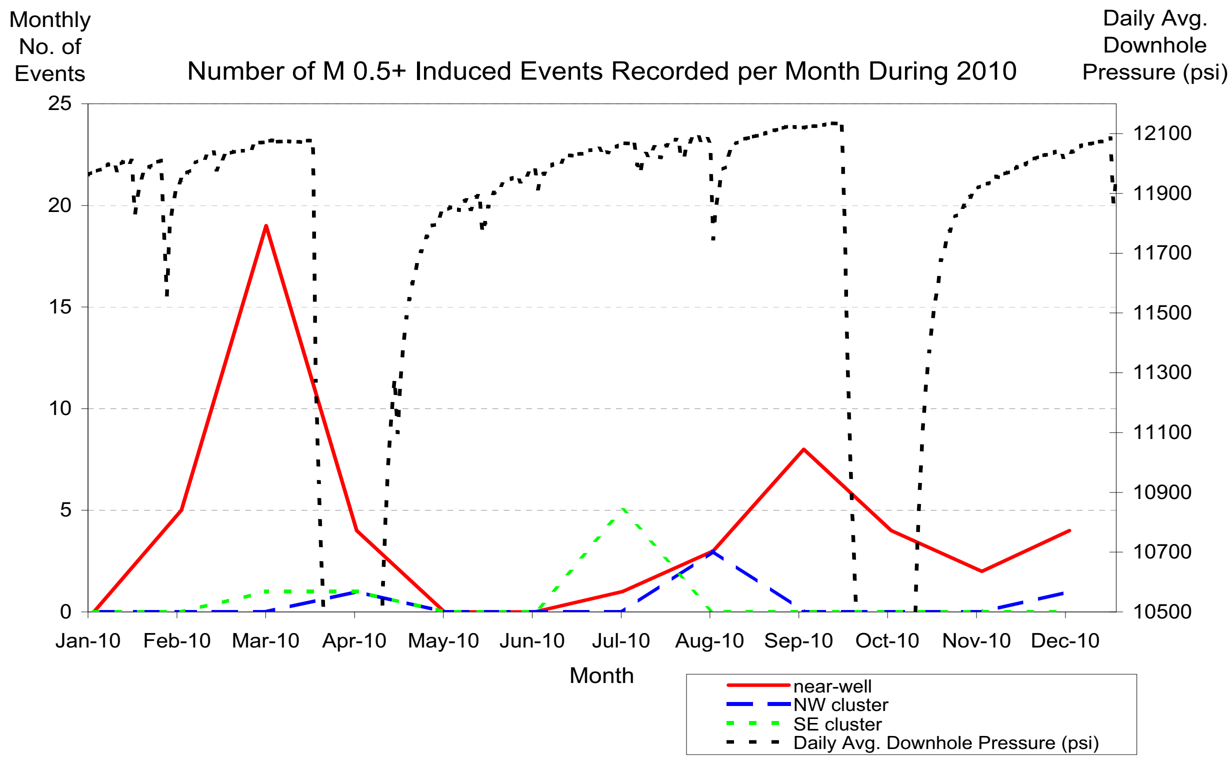

Figure 4-6 Number of earthquakes detected in the near-well (solid red line), NW-cluster (long dashed blue line), and SE-cluster (short dashed green line) regions per month during 2010. The dashed black curve shows the daily average downhole pressure in the injection well.

constrained hypocenter occurred in this area in 2010. It locates at a depth of 1.8 km, relative to the elevation of the injection wellhead. An additional seismic station southwest of the injection well, which is scheduled to come online by the fall of 2011, will provide additional coverage and increased confidence in the computed locations of earthquakes occurring in this area.

Figure 4-6 shows that the seismic activity in the three main zones of induced seismicity, the near-well region, NW cluster, and SE cluster, was sporadic during 2010. During some months, the seismicity rate was relatively high. During other months, the seismicity rate was very low. The rate of induced seismicity was higher in the near-well region than in NW or SE clusters during all months except July, when the SE cluster was the most active of the three areas. A significant fraction of the near-well events that occurred during the two months with the highest rates of near-well seismicity, March and September, locate within 500 m of the injection well. These months correspond to times immediately prior to the two 20-day injection well shutdown periods, which began on March 31 and Sept. 29. The injection pressure generally increases during each 6-month injection cycle, and the pressure at the end of a given cycle is usually higher than it was at the end of the previous cycle (black dashed curve, **Figure 4-6).** The occurrence of increased seismic activity within 500 m of the well at the ends of the 6-month injection cycles, when the injection pressure is at or close to a new maximum, suggests that these high pressures are causing the observed relative high seismicity rates.

Table 4-2 Peak ground motion accelerations recorded for a large-magnitude induced earthquake that occurred in August, 2010.

Date	UTC Time	Event Duration Magnitude	Strong Motion Station	Component	Peak Acceleration (g)
8/14/2010	8:57:44	2.6	PVEF	Vertical	0.03
				North	0.03
				East	0.05

[1] The locations of the strong motion stations are shown on the map in Figure 4-1.

Two induced earthquakes with magnitude greater than or equal to **M** 2.5 (**M** 2.5+) were recorded during 2010, both in the near-well region (< 5 km radial distance from the injection well). This magnitude threshold is significant because it represents the approximate threshold for human detection in the nearby communities of Paradox and Bedrock. An **M** 2.6 earthquake occurred on August 14, approximately 1 km north-northwest of the injection well, and another **M** 2.6 earthquake occurred on October 12, about 2 km southwest of the well. The earthquake locations are shown in **Figures 4-4** and **4-5**. The August event triggered a strong motion instrument located at the brine extraction field. Ground motion accelerations recorded for this event are listed in **Table 4-2**.

4.2.2 Comparison to 2009 Seismicity

The recorded seismicity induced by PVU operations during 2010 increased in rate but decreased in magnitude compared to the previous year. Only a small portion of this difference is due to increased event detection capabilities beginning in August, 2010 (see section 3.1.2). The numbers of induced earthquakes recorded during 2010 and 2009 are plotted as a function of magnitude in **Figure 4-7.** Individual histograms are shown for earthquakes induced in the near-well region, for those induced at distances greater than 5 km from the well (including events in the NW and SE clusters, north-central Paradox Valley, and the event 8 km west of the well), and for all induced events. Cumulative magnitude-frequency plots of the same data are presented in **Figure 4-8**

The number of earthquakes recorded in the near-well region increased from 97 in 2009 to 128 in 2010. The number of events with magnitude greater than 0.5 decreased; the increase in near-well seismicity in 2010 compared to 2009 is only for events with magnitude < **M** 0.5 (**Figure 4-7**, top). Hence, the number of larger-magnitude near-well events as a fraction of the total number of near-well events decreased substantially in 2010, compared to 2009. In 2009, 41% of the near-well events had magnitude > **M** 1.0, whereas in 2010, only 21% of the near-well events had magnitude > **M** 1.0 (**Figure 4-8**, top). The largest near-well earthquake induced during 2009 had a magnitude of **M** 2.9. The largest near-well earthquake recorded during 2010 had a magnitude of **M** 2.6. Two **M** 2.5+ earthquakes occurred in the near-well region during 2010, compared to three in 2009.

The number of induced earthquakes recorded at distances from the well greater than 5 km (in the NW and SE clusters, north-central valley, and west of the well) increased from 23 in 2009 to 28 in

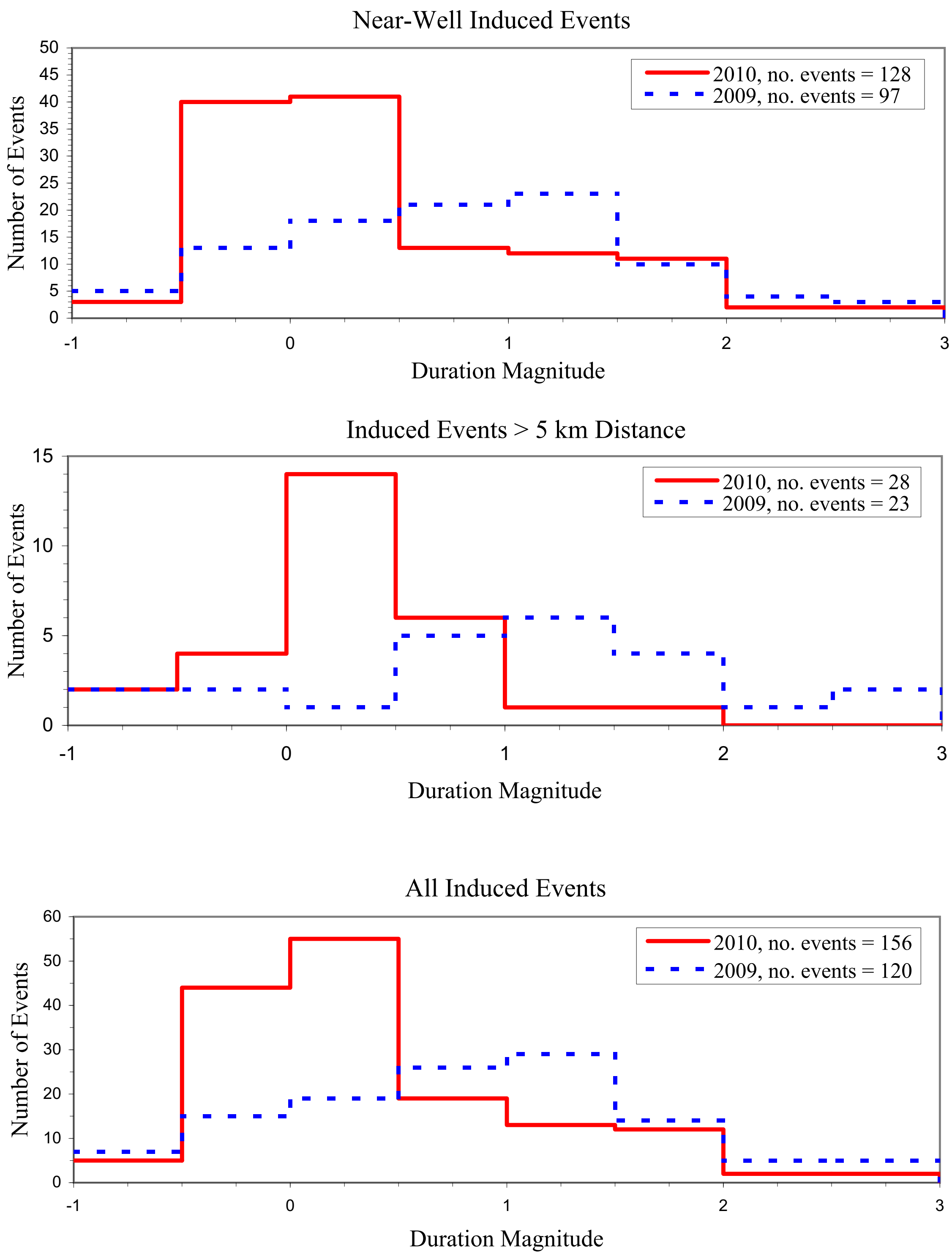

Figure 4-7 Magnitude histograms of induced events recorded in the near-well region (top), at distances greater than 5 km from the well (middle), and in all areas (bottom) during 2010 (solid red lines) and 2009 (dashed blue lines).

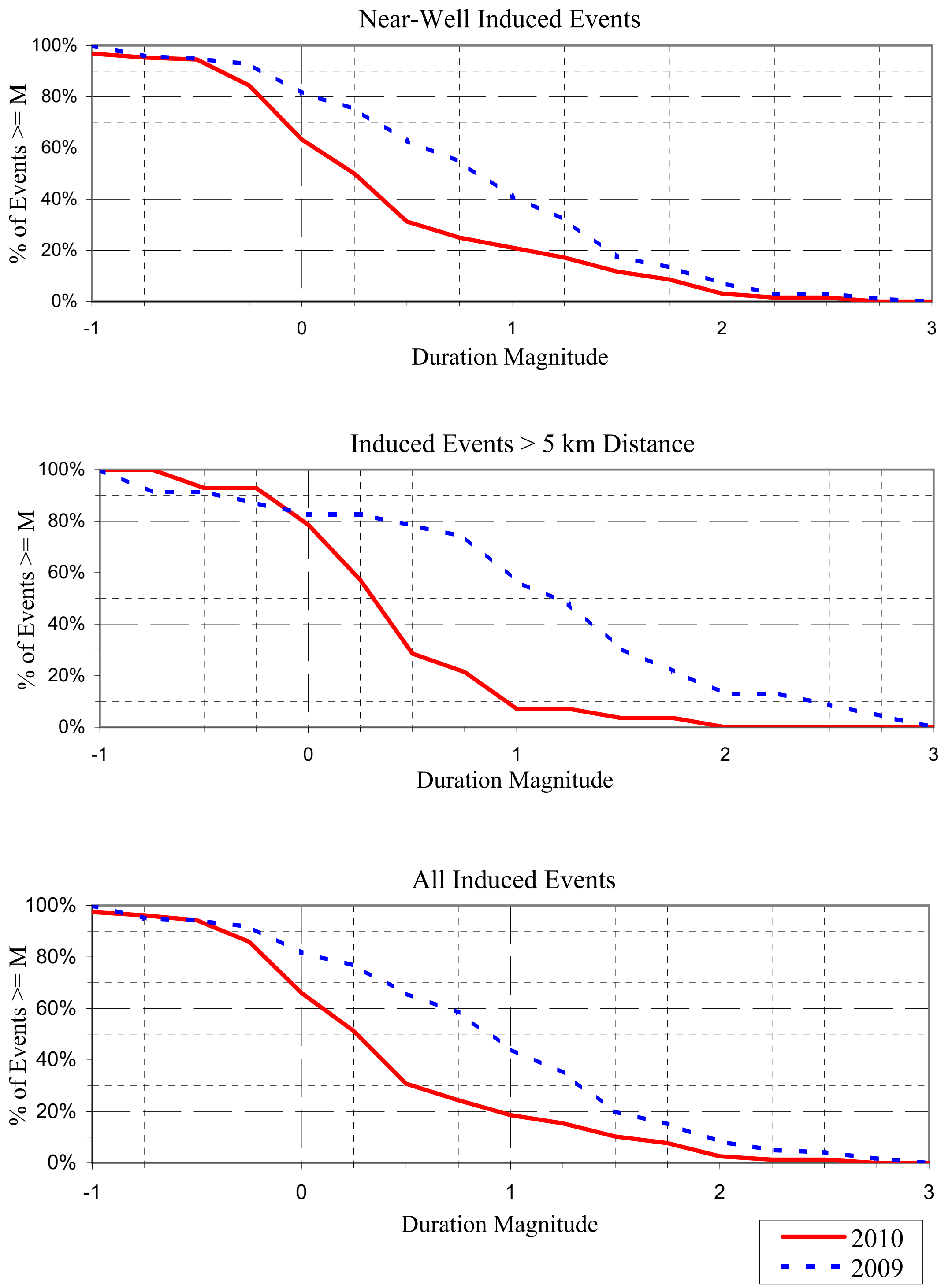

Figure 4-8 Cumulative magnitude-frequency plots of induced events recorded in the near-well region (top), at distances greater than 5 km from the well (middle), and in all areas (bottom) during 2010 (solid red lines) and 2009 (dashed blue lines).

2010. However, this overall increase is due solely to an increase in the seismicity rate of events with magnitude < **M** 1.0 (**Figure 4-7**, middle). For events with magnitude > **M** 1.0, both the absolute number of events and the number of events as a fraction of the total decreased in 2010 compared to 2009. In 2010, only 7% of the induced earthquakes in these areas had a magnitude > **M** 1.0, compared to 57% in 2009 **(Figure 4-8**, middle). No earthquakes with magnitude >= **M** 2.5 occurred in this region during 2010; two such events were recorded during 2009. The largest event recorded during 2010 had a magnitude of **M** 1.9 (in the SE cluster), whereas the largest event recorded during 2009 had a magnitude of **M** 2.9 (in the NW cluster).

4.2.3 Historical Seismicity Trends

The bubble plots in **Figure 4-9** show the occurrence of induced earthquakes in the near-well region (< 5 km radial distance from the injection well) and the occurrence of induced earthquakes in the NW and SE clusters, north-central Paradox Valley, and 8 km west of the well (5 to 10 km radial distance), as a function of date and magnitude. The area of each circle in these plots is scaled by the number of earthquakes occurring in a given quarter-year and magnitude range. The downhole injection pressures, averaged over varying lengths of time, are included in **Figure 4-9** for reference.

The near-well seismicity recorded during continuous injection operations is characterized by three periods of relatively high activity (1997-2000, 2003-2005, and mid-2008-present), separated by two distinctly quieter periods that have lower seismicity rates and a lack of events with magnitudes of **M** 2.5 or greater (2001-2002 and 2006-mid-2008). Although the near-well seismicity in the first half of 2010 lacks events with magnitudes greater than **M** 2.0, seismicity rates of smaller-magnitude events remained high during the first quarter (**Figure 4-9**, middle). Earthquakes with magnitudes in the **M** 2.0 to **M** 3.0 range occurred during the second half of 2010. We consider the 2010 near-well seismicity to be a continuation of the third period of relatively high near-well seismic activity, consistent with high averaged injection pressures (**Figure 4-9**, top).

The induced seismicity occurring at distances greater than 5 km from the injection well shows no distinct variation over time (**Figure 4-9**, bottom). No earthquakes with magnitudes > **M** 2.0 occurred in this distance range during 2010. One-year gaps in the occurrence of **M** 2.0+ events at these distances are not unusual, as they have occurred a few times since continuous injection operations began.

4.3 Northern-Valley Earthquakes

PVSN has recorded earthquakes occurring around the edges of northern Paradox Valley every year since 2000. (Only one earthquake in this general area was detected by PVSN from 1985 to 1999, and it locates more than 2 km north of the closest post-1999 seismic activity.) The map in **Figure 4-10** shows the locations of the earthquakes that we classify as “northern valley” events (color-coded by year of occurrence), and the bubble plot in **Figure 4-11** shows the occurrence of these events as a function of date and magnitude range. The area of each circle in the bubble plot is scaled by the number of events occurring in a given quarter-year and magnitude range.

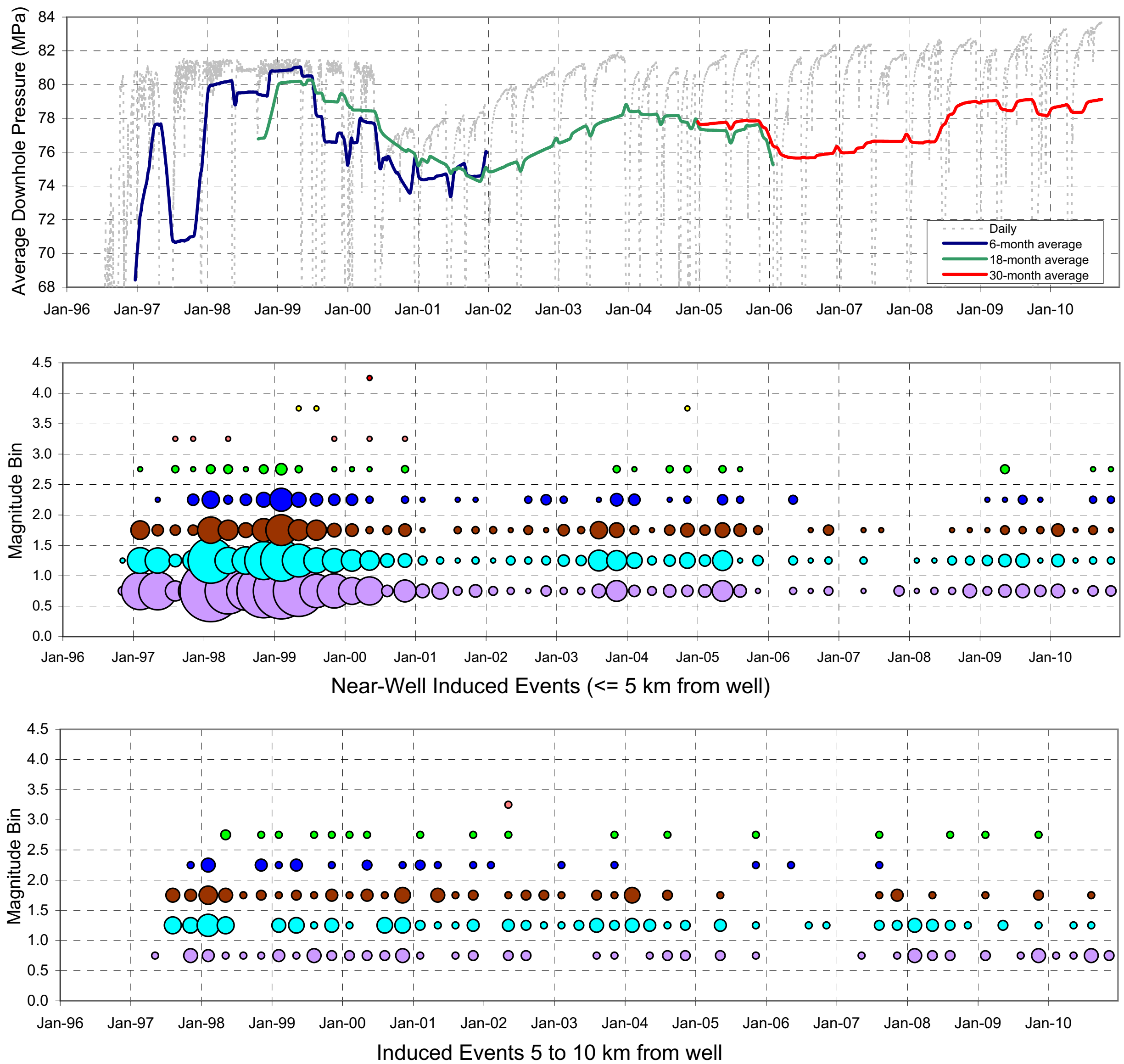

Figure 4-9 Injection well downhole pressure data averaged over daily, 6-month, 18-month, and 30-month time periods (top) and occurrence of induced seismicity as a function of date in the near-well region (middle) and at distances of 5 to 10 km from the well (bottom). In the seismicity plots, the quarterly rate of seismicity is shown as a function of magnitude. The area of each circle is scaled by the number of earthquakes occurring in that quarter-year and magnitude range. Data recorded during continuous PVU injection operations from 1996 through 2010 are included.

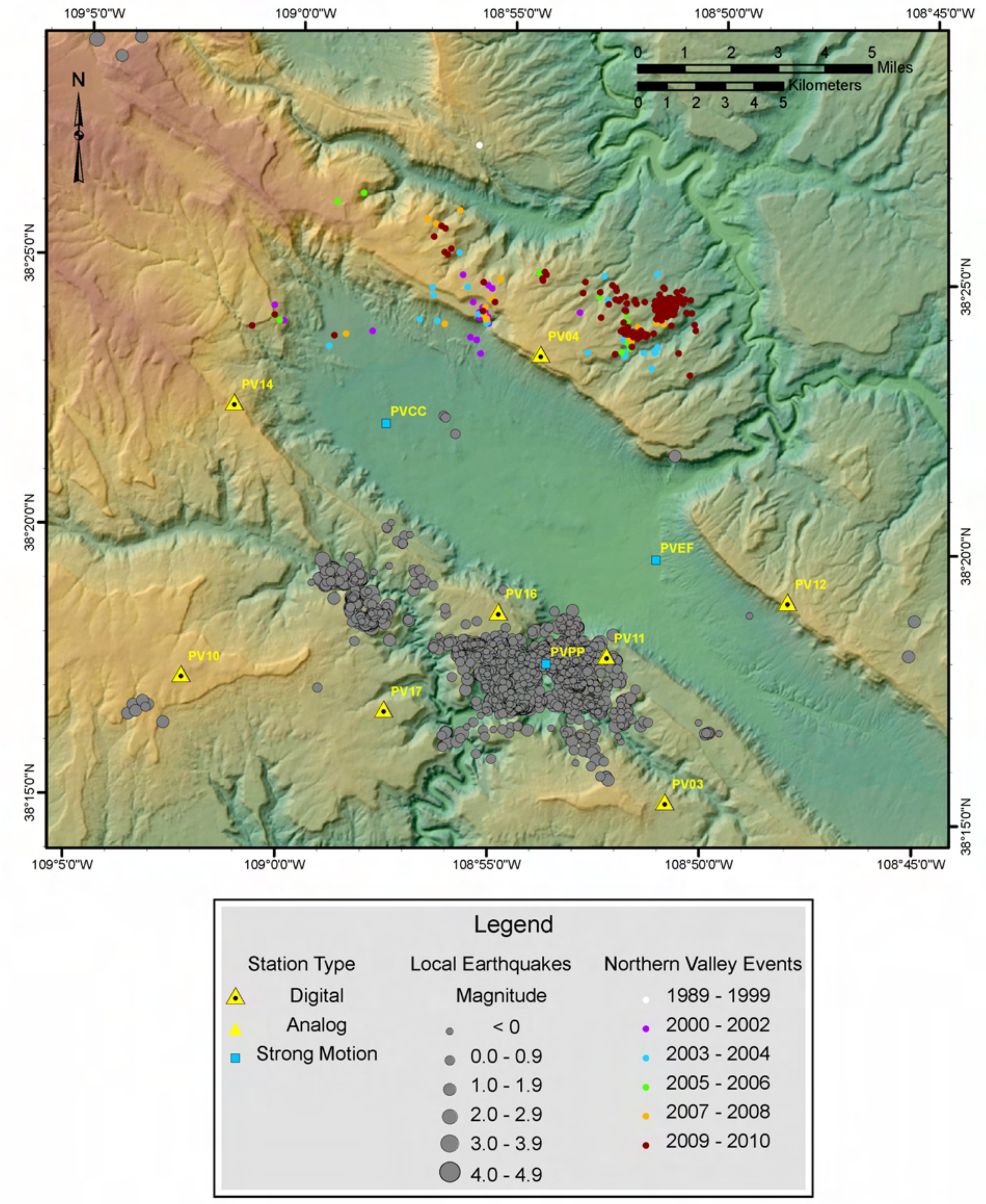

Figure 4-10 Epicenters of northern valley earthquakes color-coded by year of occurrence. The single event that was detected prior to 2000 (white circle) was recorded in 1989 and had a magnitude of ***M*** *2.9.*

In 2010, PVSN recorded a level of northern valley seismic activity that is unprecedented in the history of the network. 557 northern valley earthquakes were recorded during 2010**.** For comparison, the maximum number of northern valley earthquakes detected in any prior calendar year is 33 (in 2003), and the median annual number of northern valley events detected in 2000 through 2009 is 7. 102 northern valley earthquakes with magnitude >= **M** 1.0 were recorded during 2010, more than twice the number of **M** 1.0+ northern valley events (50) recorded in the previous 10 years combined.

The majority of the northern valley earthquakes recorded during 2010 (545 events) occurred in a swarm of activity lasting just 16 days, from November 26 to December 11 (**Figure 4-2**). These swarm earthquakes are located about 4 km east of station PV04 (**Figure 4-1**). Seismic activity has only been detected in this particular location since 2002. Seismic swarms have been detected at this location twice in the past: 23 earthquakes were recorded over a span of 6 days in September, 2003 and 10 earthquakes were recorded during 3 days in October, 2005. Even accounting for improved event detection capabilities over time, the seismic activity observed during the most recent swarm surpasses all previous observations for this area. For example, 99 earthquakes with magnitude >= **M** 1.0 were recorded during the 2010 swarm, compared to only 10 during the 2003 swarm and 8 during the 2005 swarm, although the ability to detect events in this magnitude range has not changed significantly over these years. The greater number of events recorded during the 2010 swarm compared to the earlier swarms is due not only to the longer duration of the swarm activity (16 days in 2010, compared to 6 days in 2003 and 3 days in 2005), but also to a higher rate of seismicity. For example, the 99 **M** 1.0+ earthquakes recorded during the 16-day 2010 swarm yield an average rate of 6.2 **M** 1.0+ events per day, compared to rates of 1.7 for 2003 and 2.7 for 2005.

The 12 northern valley earthquakes that occurred during 2010 but were not part of the November-December swarm activity occurred throughout the year (**Figure 4-2**) and in nearly every previously-active northern valley region (**Figure 4-1**). Hence, even disregarding the November-December swarm activity, the seismic activity in the northern valley area was relatively high, especially compared to the previous year (2009) when only 2 northern valley events were recorded.

The magnitudes of the northern valley earthquakes recorded during 2010 are comparable to the magnitudes of northern valley events recorded in the previous 10 years. Magnitudes of the 90 northern valley earthquakes recorded from 2000 through 2009 range from **M** -0.7 to **M** 2.9, with all but one event having magnitude <= **M** 2.3. Magnitudes of the 545 earthquakes that occurred during the November-December 2010 swarm range from **M** -1.1 to **M** 2.0. The magnitudes of the 12 other northern valley events that occurred during 2010 range from **M** 0.0 to **M** 1.6.

Whether the northern valley seismicity is related to PVU fluid injection remains uncertain, but there is some evidence that it may be. The onset of northern valley seismicity after about 4 years of continuous injection operations and the almost total lack of seismicity in the 15 years of seismic monitoring prior to this (which only became clear after comprehensive data review and re-classification was performed in 2008-2009) suggests a relationship between fluid injection and northern valley seismicity. Improvements in data acquisition and transmission over the years have resulted in better detection capabilities, but these improvements are unlikely to account for the

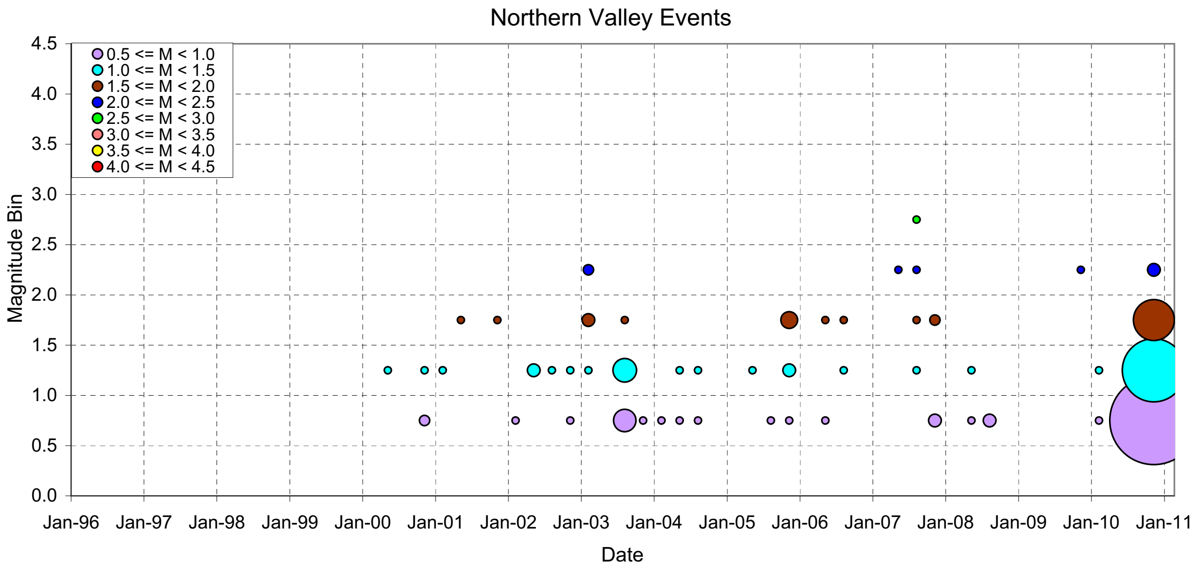

Figure 4-11 Occurrence of northern valley seismicity as a function of date and magnitude. The area of each circle is scaled by the number of earthquakes occurring in a given quarter-year and magnitude range. Data recorded during continuous PVU injection operations from 1996 through 2010 are included.

abrupt onset of northern valley seismicity in 2000 and cannot account for the recent increase in northern valley seismicity rates. Events with magnitudes greater than approximately **M** 1.0 should have been detected fairly reliably during nearly all of PVSN's history. Yet **M** 1.0+ northern valley earthquakes only began being detected in 2000 (other than a single 1989 event located further north), have been detected every year since 2000, and have recently greatly increased in rate of occurrence.

Many of the northern valley earthquakes also locate shallower than most naturally-occurring earthquakes in this region. Estimated depths of these earthquakes generally range from about 3 to 8 km (relative to the ground surface elevation at the injection wellhead), with the shallower earthquakes occurring toward the east, in the vicinity of station PV04 (**Figure 4-3**). However, because of a large gap in station coverage to the north, the depth estimates for these events are not as accurate as those for earthquakes occurring near the center of the seismic network (such as those close to the injection well). The relatively poor station coverage in this area also makes it difficult to compute a good velocity model with which to locate the earthquakes. Several new stations are in the process of being installed to improve coverage for the northern valley earthquakes. These stations should come online by the fall of 2011. It will likely take another one to two years (depending on seismicity rates) to acquire enough data to compute a better velocity model for this area and improve the depth estimates for the northern valley events. Until these steps are completed, it will likely remain difficult to further evaluate whether the earthquakes occurring around the northern edges of Paradox Valley are being induced by PVU fluid injection.

4.4 Other Local Earthquakes

One local earthquake, believed to be a naturally occurring earthquake and not associated with the other areas of seismicity discussed above, was detected by PVSN during 2010. It locates just northwest of station PV09 at an estimated depth of about 19 km (**Figure 4-1**). It's duration magnitude is **M** 0.7.

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APPENDIX A
PVSN 2010 LOCAL EARTHQUAKE CATALOG

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
1/21/2010	9:09:06	38.5132	-109.1763	-17.4	18.9	0.7	other
1/27/2010	20:44:58	38.4038	-108.926	-4.4	5.9	0.7	northern valley
2/18/2010	17:31:05	38.2977	-108.8979	-2.6	4.1	0.4	near-well
2/18/2010	17:31:31	38.2975	-108.8976	-2.6	4.1	-0.4	near-well
2/21/2010	21:21:32	38.2978	-108.8971	-2.7	4.2	0.4	near-well
2/22/2010	4:24:42	38.2979	-108.8973	-2.6	4.2	1.8	near-well
2/22/2010	4:26:31	38.2979	-108.8972	-2.7	4.2	-0.1	near-well
2/22/2010	9:36:21	38.2977	-108.8971	-2.7	4.2	-0.1	near-well
2/22/2010	10:01:46	38.2978	-108.8969	-2.7	4.2	0.4	near-well
2/22/2010	21:43:22	38.2979	-108.8973	-2.6	4.1	1.1	near-well
2/22/2010	21:49:01	38.2977	-108.8971	-2.6	4.2	0.3	near-well
2/22/2010	23:54:01	38.2981	-108.8965	-2.7	4.2	-0.3	near-well
2/23/2010	21:34:27	38.2972	-108.8948	-2.9	4.4	1.2	near-well
2/23/2010	21:38:53	38.3023	-108.8833	-3.1	4.7	-0.3	near-well
2/23/2010	21:39:07	38.3027	-108.8836	-3.3	4.8	-0.3	near-well
2/25/2010	2:28:45	38.2976	-108.8953	-2.9	4.4	0.3	near-well
2/26/2010	21:06:38	38.2977	-108.899	-2.8	4.3	0.1	near-well
2/28/2010	4:24:48	38.4128	-108.9262	-3.2	4.7	1.4	northern valley
3/2/2010	20:06:37	38.298	-108.8971	-2.7	4.2	0.6	near-well
3/7/2010	19:16:00	38.3029	-108.8852	-3.2	4.7	0.5	near-well
3/7/2010	19:16:31	38.3029	-108.8845	-3.3	4.8	-0.1	near-well
3/7/2010	19:17:08	38.3027	-108.8847	-3.3	4.8	0.1	near-well
3/7/2010	19:17:48	38.3084	-108.8847	-3.6	5.1	-0.4	near-well
3/7/2010	19:18:25	38.2995	-108.8858	-2.6	4.1	-0.3	near-well
3/7/2010	19:19:30	38.303	-108.885	-3.3	4.8	-0.2	near-well
3/7/2010	19:19:30	38.303	-108.885	-3.3	4.8	0.2	near-well
3/10/2010	4:02:17	38.2943	-108.8958	-2.2	3.8	-1.5	near-well
3/10/2010	4:02:21	38.2977	-108.8964	-2.7	4.2	-0.1	near-well
3/10/2010	4:57:59	38.2981	-108.897	-2.7	4.3	0.1	near-well
3/10/2010	4:58:20	38.2979	-108.8976	-2.7	4.2	1.9	near-well
3/10/2010	4:58:30	38.2946	-108.8976	-2.4	4	-0.4	near-well
3/10/2010	5:01:17	38.2979	-108.8972	-2.6	4.2	1.5	near-well
3/10/2010	7:06:58	38.2978	-108.8978	-2.8	4.3	0	near-well
3/10/2010	7:50:03	38.298	-108.8969	-2.7	4.2	1.3	near-well
3/11/2010	10:58:02	38.2979	-108.8961	-2.9	4.4	0.1	near-well
3/11/2010	13:10:53	38.298	-108.8966	-2.9	4.4	1.1	near-well
3/11/2010	13:40:33	38.3089	-108.9644	-2.3	3.8	0	NW cluster
3/11/2010	15:35:32	38.2973	-108.8975	-2.6	4.2	-0.2	near-well
3/11/2010	15:36:36	38.2965	-108.8987	-3.4	4.9	-1	near-well
3/11/2010	21:29:40	38.2976	-108.8967	-2.8	4.3	1.4	near-well
3/12/2010	16:28:09	38.2978	-108.8967	-2.8	4.4	0.4	near-well
3/13/2010	19:17:58	38.2975	-108.8981	-3	4.5	1.8	near-well
3/13/2010	19:44:10	38.2978	-108.8966	-2.9	4.4	0.8	near-well
3/14/2010	21:43:31	38.2976	-108.8982	-2.6	4.1	0.7	near-well
3/14/2010	23:58:42	38.2978	-108.8935	-2.9	4.5	0	near-well
3/15/2010	20:48:02	38.2973	-108.8933	-2.9	4.4	0.7	near-well
3/16/2010	11:33:58	38.2977	-108.8973	-2.8	4.3	0.3	near-well
3/16/2010	18:39:00	38.2762	-108.8309	-2.4	4	0.5	SE cluster
3/17/2010	19:11:35	38.2978	-108.8976	-2.7	4.2	-0.4	near-well
3/19/2010	4:18:10	38.2976	-108.8951	-2.9	4.4	0.7	near-well
3/19/2010	17:22:52	38.2948	-108.8933	-2.4	3.9	-0.8	near-well
3/21/2010	6:14:00	38.2978	-108.8974	-2.6	4.2	1.7	near-well
3/21/2010	6:15:06	38.2945	-108.896	-2.1	3.6	-1.5	near-well
3/21/2010	6:15:09	38.2954	-108.8972	-2.5	4	-1	near-well
3/21/2010	6:20:56	38.2978	-108.8969	-2.7	4.2	0	near-well

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
3/21/2010	6:28:49	38.2977	-108.8967	-2.7	4.2	0.3	near-well
3/21/2010	20:04:42	38.2975	-108.8959	-2.8	4.3	0.6	near-well
3/22/2010	15:51:21	38.2977	-108.8973	-2.8	4.3	0.4	near-well
3/23/2010	14:14:22	38.298	-108.8973	-2.8	4.4	-0.2	near-well
3/28/2010	9:58:54	38.3075	-108.8842	-3.6	5.1	1	near-well
3/28/2010	10:05:40	38.3074	-108.884	-3.6	5.1	1.7	near-well
3/30/2010	23:49:33	38.2977	-108.8956	-2.9	4.4	0.1	near-well
Injection well was shut in on March 31 (pressure: 4,930 psi).							
4/9/2010	17:49:13	38.3025	-108.929	-2.6	4.1	0.1	near-well
4/11/2010	6:21:01	38.3016	-108.9266	-2.5	4.1	1.4	near-well
4/13/2010	23:25:14	38.2914	-108.9179	-2.7	4.2	0.6	near-well
4/15/2010	10:37:53	38.2897	-108.8899	-3.1	4.6	1.6	near-well
4/15/2010	10:40:47	38.2835	-108.892	-2.1	3.7	0.2	near-well
4/21/2010	9:05:48	38.2762	-108.8309	-2.5	4	1.3	SE cluster
Injection resumed on April 21 (pressure: 1,298 psi).							
4/28/2010	1:42:54	38.3005	-108.9717	-1.5	3.1	0.6	NW cluster
4/30/2010	16:35:21	38.297	-108.915	-2.9	4.4	0.3	near-well
5/4/2010	2:41:59	38.3075	-108.8839	-3.5	5.1	0.2	near-well
5/7/2010	18:24:48	38.2987	-108.9088	-2.4	3.9	-0.2	near-well
5/12/2010	16:11:06	38.3097	-108.8843	-3.6	5.1	-0.1	near-well
5/20/2010	9:56:14	38.3073	-108.89	-3	4.6	-0.4	near-well
5/31/2010	19:44:29	38.2732	-108.8794	-0.3	1.8	0	near-well
6/1/2010	2:35:40	38.4228	-108.9393	-6.4	7.9	0.6	northern valley
6/3/2010	22:38:34	38.2843	-108.8841	-2.8	4.3	0.1	near-well
6/4/2010	19:07:48	38.4297	-108.9435	-5	6.5	0	northern valley
6/7/2010	0:34:08	38.421	-108.9407	-5.8	7.3	0.9	northern valley
6/7/2010	18:10:47	38.2857	-108.9855	-2.1	3.6	0.1	west of well
6/8/2010	8:35:31	38.2835	-108.9101	-1.8	3.4	-0.1	near-well
6/9/2010	12:40:12	38.429	-108.942	-5	6.6	0.2	northern valley
6/15/2010	0:29:32	38.2725	-108.9192	-0.4	1.9	0.1	near-well
6/15/2010	5:35:40	38.2854	-108.8836	-4.3	5.8	0.2	near-well
7/3/2010	16:42:04	38.2759	-108.8317	-2.5	4	1	SE cluster
7/3/2010	16:42:34	38.2759	-108.832	-2.5	4	0.4	SE cluster
7/4/2010	0:39:34	38.276	-108.8317	-2.5	4	1.9	SE cluster
7/6/2010	2:58:54	38.2759	-108.8321	-2.5	4	0.9	SE cluster
7/12/2010	19:17:33	38.2792	-108.8353	-2.2	3.7	-0.7	SE cluster
7/17/2010	23:07:18	38.2761	-108.8329	-2.3	3.8	0.4	SE cluster
7/18/2010	11:18:54	38.3655	-108.9352	-4	5.6	0.9	N-central valley
7/31/2010	7:21:51	38.2874	-108.8854	-4.6	6.1	0.4	near-well
8/1/2010	4:41:09	38.2866	-108.8868	-4.1	5.6	1.1	near-well
8/1/2010	15:37:19	38.2846	-108.8839	-3.4	4.9	-0.6	near-well
8/8/2010	3:41:04	38.3335	-108.9537	-3.4	5	0.3	NW cluster
8/8/2010	3:41:21	38.3339	-108.9515	-3.3	4.8	-0.6	NW cluster
8/8/2010	16:00:35	38.4263	-108.9463	-4.7	6.2	0.3	northern valley
8/8/2010	16:43:23	38.371	-108.94	-4.2	5.7	0.6	N-central valley
8/8/2010	17:55:23	38.3705	-108.9392	-4.1	5.6	0.2	N-central valley
8/8/2010	18:56:39	38.2816	-108.8868	-1.7	3.3	-0.2	near-well
8/9/2010	10:28:20	38.3355	-108.9605	-3.7	5.2	0.5	NW cluster
8/9/2010	10:28:34	38.3358	-108.9607	-3.9	5.4	0.1	NW cluster
8/9/2010	10:30:08	38.3373	-108.959	-3.4	5	-0.1	NW cluster
8/14/2010	8:57:44	38.3057	-108.9008	-3	4.5	2.6	near-well
8/14/2010	9:55:42	38.3046	-108.9016	-2.8	4.4	0.3	near-well
8/14/2010	10:15:51	38.3056	-108.9019	-3.1	4.6	0	near-well
8/26/2010	1:24:41	38.2788	-108.8821	-3.5	5	0.2	near-well
8/31/2010	15:05:11	38.2959	-108.8969	-2.5	4.1	-0.1	near-well
9/2/2010	7:41:54	38.2985	-108.8979	-2.6	4.2	-0.1	near-well
9/2/2010	12:02:45	38.3137	-108.9729	-2.4	3.9	0.3	NW cluster
9/2/2010	12:03:02	38.3135	-108.9727	-2.8	4.3	-0.2	NW cluster

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
9/5/2010	5:29:16	38.2971	-108.8945	-2.8	4.4	1.5	near-well
9/6/2010	15:41:18	38.2962	-108.8936	-2.9	4.5	0	near-well
9/8/2010	19:42:15	38.297	-108.8936	-2.8	4.4	-0.2	near-well
9/9/2010	6:21:24	38.2963	-108.8929	-3	4.5	0.3	near-well
9/9/2010	12:23:28	38.2975	-108.8933	-2.9	4.4	0.3	near-well
9/10/2010	2:48:56	38.2733	-108.9345	-0.2	1.7	1.1	near-well
9/10/2010	17:01:39	38.2956	-108.8957	-2.8	4.3	-0.4	near-well
9/10/2010	17:02:48	38.2978	-108.8953	-2.6	4.1	-0.8	near-well
9/10/2010	21:40:10	38.2962	-108.9298	-2.6	4.1	0.5	near-well
9/11/2010	23:02:27	38.2972	-108.894	-2.9	4.4	0.2	near-well
9/13/2010	18:37:46	38.2754	-108.8754	-0.9	2.4	0.9	near-well
9/13/2010	23:54:42	38.2847	-108.8786	-2.6	4.1	1.7	near-well
9/15/2010	22:45:12	38.2848	-108.8813	-2.3	3.8	2	near-well
9/15/2010	23:20:31	38.2846	-108.8786	-2.6	4.1	2.2	near-well
9/16/2010	6:48:55	38.2966	-108.894	-3	4.5	0.3	near-well
9/16/2010	6:50:15	38.2965	-108.8938	-3	4.5	0.3	near-well
9/16/2010	6:59:25	38.2977	-108.8936	-2.9	4.4	0.7	near-well
9/16/2010	7:16:29	38.2972	-108.8936	-2.8	4.4	0.9	near-well
9/17/2010	11:38:24	38.2845	-108.8794	-2.6	4.1	1.9	near-well
9/17/2010	19:28:32	38.2761	-108.8321	-2.5	4	0	SE cluster
9/20/2010	1:39:48	38.2866	-108.9051	-2.7	4.3	0.3	near-well
9/20/2010	1:40:22	38.2852	-108.905	-2.4	3.9	-0.3	near-well
9/20/2010	1:41:07	38.2882	-108.9063	-2.5	4.1	0.2	near-well
9/20/2010	1:41:07	38.2875	-108.9055	-2.5	4	0.3	near-well
9/23/2010	1:31:08	38.298	-108.8943	-2.9	4.4	-0.2	near-well
9/24/2010	2:29:36	38.2962	-108.8947	-2.9	4.4	-0.2	near-well
9/24/2010	17:14:58	38.2979	-108.8947	-2.8	4.4	-0.2	near-well
9/25/2010	5:55:42	38.2995	-108.8934	-3.8	5.3	0.1	near-well
9/27/2010	19:46:57	38.296	-108.8923	-3.2	4.7	0.1	near-well
Injection well was shut in on Sept. 29 (pressure: 4, 990 psi).							
10/1/2010	3:59:22	38.2985	-108.8954	-2.7	4.2	-0.3	near-well
10/2/2010	4:23:00	38.3094	-108.9652	-2.2	3.7	0.3	NW cluster
10/5/2010	4:59:36	38.4217	-108.9418	-6.4	7.9	1.1	northern valley
10/5/2010	22:08:44	38.3108	-108.9738	-2.8	4.3	0.2	NW cluster
10/8/2010	3:53:27	38.2754	-108.8326	-2.3	3.8	0.5	SE cluster
10/12/2010	4:40:38	38.2815	-108.9087	-2	3.6	2.6	near-well
10/12/2010	11:56:41	38.2816	-108.9089	-1.7	3.3	0	near-well
10/12/2010	16:30:47	38.2822	-108.9087	-2	3.5	-0.1	near-well
10/14/2010	19:59:23	38.3967	-109.0167	-5.7	7.3	1.6	northern valley
10/16/2010	8:19:52	38.2807	-108.9087	-1.7	3.2	0	near-well
Injection resumed on Oct. 20 (pressure: 1, 369 psi).							
10/22/2010	21:11:18	38.2833	-108.8801	-2.3	3.9	0.8	near-well
10/23/2010	1:06:52	38.282	-108.9073	-2	3.6	0.5	near-well
10/23/2010	16:39:22	38.2846	-108.905	-2.1	3.6	1.8	near-well
10/24/2010	23:04:12	38.2761	-108.8311	-2.5	4	0.2	SE cluster
10/27/2010	0:05:30	38.3985	-108.8633	-3.9	5.4	0.1	northern valley
10/27/2010	7:52:33	38.3947	-108.984	-4.9	6.4	0.8	northern valley
11/4/2010	14:00:05	38.2875	-108.908	-2.2	3.8	1.4	near-well
11/5/2010	13:08:32	38.2799	-108.9093	-1.6	3.1	0.3	near-well
11/18/2010	4:39:49	38.2872	-108.8844	-4.4	6	2.1	near-well
11/24/2010	16:05:32	38.3042	-108.9127	-3.4	4.9	-0.3	near-well
11/26/2010	10:43:13	38.403	-108.8555	-2	3.5	0.4	northern valley
11/26/2010	10:43:13	38.3983	-108.8654	-3.8	5.3	1.1	northern valley
11/27/2010	1:52:01	38.3984	-108.865	-3.9	5.4	1.3	northern valley
11/27/2010	1:52:42	38.4078	-108.8538	-2.3	3.9	-0.5	northern valley
11/27/2010	1:52:42	38.4092	-108.8508	-1.8	3.3	-0.2	northern valley
11/27/2010	1:52:50	38.4102	-108.8483	-1.2	2.7	-0.2	northern valley
11/27/2010	1:53:30	38.4093	-108.8513	-2	3.5	-0.5	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
11/27/2010	1:54:14	38.4082	-108.8528	-2.2	3.8	-0.5	northern valley
11/27/2010	2:14:20	38.3985	-108.8645	-3.9	5.4	-0.1	northern valley
11/27/2010	2:20:47	38.3986	-108.865	-3.9	5.4	-0.1	northern valley
11/29/2010	3:09:26	38.3209	-108.9701	-2.9	4.4	0.1	NW cluster
11/29/2010	23:52:48	38.3985	-108.8647	-3.9	5.4	0.3	northern valley
11/30/2010	0:01:58	38.3985	-108.8649	-3.9	5.4	0.3	northern valley
11/30/2010	2:18:46	38.3985	-108.8653	-3.9	5.4	0.1	northern valley
11/30/2010	2:29:35	38.3985	-108.8659	-3.9	5.4	0.3	northern valley
11/30/2010	2:45:34	38.3985	-108.8659	-3.9	5.4	0.1	northern valley
11/30/2010	3:44:31	38.3984	-108.8661	-3.9	5.4	0.3	northern valley
11/30/2010	4:04:00	38.3985	-108.8658	-3.8	5.4	1.2	northern valley
11/30/2010	4:04:13	38.3985	-108.8651	-3.9	5.4	0.6	northern valley
11/30/2010	4:17:04	38.3985	-108.8658	-3.9	5.4	0.1	northern valley
11/30/2010	5:02:45	38.3982	-108.8647	-3.8	5.3	1.1	northern valley
11/30/2010	5:08:11	38.3985	-108.8659	-3.9	5.4	0.2	northern valley
11/30/2010	6:36:23	38.3986	-108.8662	-3.8	5.3	1.5	northern valley
11/30/2010	6:39:45	38.3985	-108.8665	-3.8	5.3	0.4	northern valley
11/30/2010	7:10:08	38.3985	-108.8668	-3.8	5.3	0.3	northern valley
11/30/2010	7:11:35	38.3984	-108.8641	-3.9	5.5	0	northern valley
11/30/2010	8:33:36	38.3988	-108.865	-3.8	5.4	0.2	northern valley
11/30/2010	8:35:09	38.4072	-108.8558	-2.5	4	-0.4	northern valley
11/30/2010	8:49:57	38.3985	-108.8658	-3.8	5.3	0.4	northern valley
11/30/2010	10:23:48	38.3985	-108.8644	-4	5.5	0.3	northern valley
11/30/2010	10:33:28	38.3985	-108.8653	-3.9	5.4	1.5	northern valley
11/30/2010	12:19:16	38.3985	-108.8648	-3.9	5.4	0.2	northern valley
11/30/2010	12:54:41	38.3985	-108.8657	-3.9	5.4	0.1	northern valley
11/30/2010	13:48:11	38.3982	-108.8649	-3.9	5.4	1.1	northern valley
11/30/2010	13:50:16	38.4072	-108.8522	-2.2	3.7	-0.5	northern valley
11/30/2010	14:43:28	38.3986	-108.8643	-3.9	5.4	1.5	northern valley
11/30/2010	14:45:00	38.407	-108.8537	-2.4	3.9	0.3	northern valley
11/30/2010	14:47:30	38.3986	-108.8649	-3.8	5.4	0.6	northern valley
11/30/2010	15:33:43	38.3985	-108.8638	-3.9	5.4	0.6	northern valley
11/30/2010	20:32:51	38.3984	-108.864	-3.9	5.4	0.4	northern valley
11/30/2010	20:35:07	38.4095	-108.8443	1.7	-0.1	-0.4	northern valley
11/30/2010	20:48:57	38.3985	-108.8641	-3.9	5.5	0.6	northern valley
11/30/2010	21:02:24	38.3985	-108.8637	-4	5.5	0.9	northern valley
12/1/2010	3:19:09	38.3985	-108.8642	-4	5.5	0.2	northern valley
12/1/2010	3:21:34	38.3987	-108.8644	-3.9	5.5	0.4	northern valley
12/1/2010	3:22:41	38.4055	-108.8518	-2.4	3.9	-0.5	northern valley
12/1/2010	3:36:10	38.3985	-108.8641	-3.9	5.5	0.7	northern valley
12/1/2010	3:36:37	38.4063	-108.8507	-1.8	3.3	-0.7	northern valley
12/1/2010	3:37:13	38.3985	-108.864	-3.9	5.4	0.1	northern valley
12/1/2010	3:40:40	38.3983	-108.8665	-3.8	5.4	0.5	northern valley
12/1/2010	5:54:16	38.4058	-108.8542	-2.1	3.6	-0.9	northern valley
12/1/2010	5:54:17	38.3985	-108.8661	-3.8	5.3	1.6	northern valley
12/1/2010	10:25:57	38.3986	-108.8649	-3.9	5.4	1.4	northern valley
12/1/2010	10:44:21	38.3975	-108.8664	-4	5.5	0.5	northern valley
12/1/2010	10:46:01	38.3985	-108.8652	-3.9	5.4	1	northern valley
12/1/2010	10:46:32	38.3985	-108.8655	-3.9	5.4	0.5	northern valley
12/1/2010	10:47:48	38.4073	-108.8552	-2.3	3.8	-0.4	northern valley
12/1/2010	11:01:10	38.3984	-108.866	-3.8	5.4	0.7	northern valley
12/1/2010	11:01:42	38.4075	-108.8545	-2.2	3.8	-0.5	northern valley
12/1/2010	11:02:14	38.4085	-108.8542	-2.2	3.7	-0.1	northern valley
12/1/2010	14:45:43	38.3985	-108.8669	-3.8	5.3	0.4	northern valley
12/1/2010	17:13:51	38.3985	-108.8668	-3.8	5.3	1	northern valley
12/1/2010	17:31:01	38.3985	-108.8669	-3.8	5.3	1.1	northern valley
12/1/2010	18:59:48	38.3985	-108.8671	-3.8	5.3	1.5	northern valley
12/1/2010	19:08:16	38.4097	-108.8507	-1.3	2.8	-0.7	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/1/2010	19:18:45	38.3984	-108.8674	-3.8	5.3	0.8	northern valley
12/1/2010	19:20:26	38.3985	-108.8671	-3.8	5.3	1.3	northern valley
12/1/2010	19:41:00	38.3985	-108.8671	-3.8	5.3	0.7	northern valley
12/1/2010	19:41:58	38.4072	-108.8533	-2	3.6	0	northern valley
12/1/2010	20:43:23	38.3985	-108.8649	-3.9	5.5	0.2	northern valley
12/1/2010	21:05:21	38.3984	-108.8673	-3.8	5.3	0.3	northern valley
12/1/2010	21:06:56	38.4072	-108.8553	-2.1	3.7	-0.3	northern valley
12/1/2010	21:09:40	38.4078	-108.8537	-2	3.5	-0.1	northern valley
12/1/2010	22:18:59	38.3983	-108.8666	-3.9	5.4	0.6	northern valley
12/1/2010	22:31:18	38.3984	-108.8672	-3.8	5.3	1.5	northern valley
12/2/2010	0:10:06	38.4075	-108.8553	-2.4	3.9	-0.9	northern valley
12/2/2010	0:10:08	38.3985	-108.8668	-3.9	5.4	0.4	northern valley
12/2/2010	1:25:57	38.3984	-108.8668	-3.8	5.4	0.5	northern valley
12/2/2010	1:27:32	38.405	-108.8557	-2.2	3.7	-0.7	northern valley
12/2/2010	1:54:15	38.3985	-108.8668	-3.9	5.4	1.3	northern valley
12/2/2010	8:20:34	38.3985	-108.8666	-3.9	5.4	1	northern valley
12/2/2010	9:11:06	38.3985	-108.8664	-3.8	5.3	0.1	northern valley
12/2/2010	9:55:07	38.3986	-108.8667	-3.8	5.3	0.1	northern valley
12/2/2010	9:55:56	38.4055	-108.8528	-2.1	3.7	-1.1	northern valley
12/2/2010	11:02:37	38.3984	-108.867	-3.9	5.4	0.2	northern valley
12/2/2010	14:46:14	38.3985	-108.8667	-3.9	5.4	0.5	northern valley
12/2/2010	14:47:36	38.3985	-108.8663	-3.9	5.4	1.8	northern valley
12/2/2010	14:48:25	38.3985	-108.8664	-3.9	5.4	0.4	northern valley
12/2/2010	14:48:50	38.3985	-108.8665	-3.9	5.4	1.3	northern valley
12/2/2010	14:50:01	38.3981	-108.8665	-3.8	5.3	1.2	northern valley
12/2/2010	15:20:30	38.3984	-108.8666	-3.9	5.4	0.3	northern valley
12/2/2010	15:22:48	38.4083	-108.8527	-2	3.5	-0.7	northern valley
12/2/2010	15:59:32	38.3986	-108.8664	-3.8	5.4	0.6	northern valley
12/2/2010	16:32:55	38.405	-108.8562	-2.6	4.1	-0.1	northern valley
12/2/2010	16:46:53	38.4053	-108.8523	-1.8	3.4	-0.5	northern valley
12/2/2010	16:53:27	38.3985	-108.8663	-3.9	5.4	0.2	northern valley
12/2/2010	16:53:51	38.3985	-108.8661	-3.9	5.4	-0.2	northern valley
12/2/2010	16:56:36	38.3985	-108.8665	-3.9	5.4	0.1	northern valley
12/2/2010	16:56:47	38.3984	-108.8667	-3.9	5.4	0.9	northern valley
12/2/2010	17:04:24	38.4063	-108.8553	-2.5	4	-1	northern valley
12/2/2010	17:07:26	38.3986	-108.8661	-3.8	5.3	1.2	northern valley
12/2/2010	17:32:37	38.3988	-108.8666	-3.9	5.4	1.2	northern valley
12/2/2010	17:36:30	38.4085	-108.8663	-3.3	4.9	-1	northern valley
12/2/2010	17:45:05	38.3985	-108.8669	-3.9	5.4	1.2	northern valley
12/2/2010	17:51:41	38.3984	-108.8667	-3.8	5.4	1.1	northern valley
12/2/2010	17:51:54	38.3984	-108.8664	-3.9	5.4	0.1	northern valley
12/2/2010	18:13:08	38.3985	-108.8672	-3.8	5.3	0.7	northern valley
12/2/2010	19:01:42	38.3985	-108.8659	-3.9	5.5	1	northern valley
12/2/2010	19:03:57	38.3986	-108.8664	-3.9	5.5	1.6	northern valley
12/2/2010	19:04:14	38.3985	-108.8665	-3.9	5.4	0.8	northern valley
12/2/2010	19:12:58	38.3983	-108.8662	-3.9	5.4	0.5	northern valley
12/2/2010	19:13:36	38.3986	-108.8659	-3.9	5.4	0.3	northern valley
12/2/2010	19:28:28	38.3986	-108.8662	-3.9	5.5	0.3	northern valley
12/2/2010	20:13:11	38.3986	-108.8659	-3.9	5.4	1.2	northern valley
12/2/2010	20:17:06	38.3986	-108.8661	-3.9	5.4	0.9	northern valley
12/2/2010	21:43:26	38.399	-108.8666	-4	5.5	2	northern valley
12/2/2010	21:58:07	38.3986	-108.8673	-3.8	5.4	0.5	northern valley
12/2/2010	21:58:32	38.3985	-108.8656	-3.9	5.5	1.1	northern valley
12/2/2010	22:06:44	38.3984	-108.8674	-3.8	5.3	1	northern valley
12/2/2010	22:07:23	38.3985	-108.8674	-3.8	5.3	-0.2	northern valley
12/2/2010	22:38:28	38.3985	-108.8657	-3.8	5.4	1.2	northern valley
12/2/2010	22:40:26	38.3985	-108.8652	-3.8	5.4	0.1	northern valley
12/2/2010	23:24:21	38.3985	-108.8646	-3.9	5.4	0.5	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/2/2010	23:25:43	38.3985	-108.8646	-3.9	5.5	0.4	northern valley
12/3/2010	0:29:06	38.3984	-108.8674	-3.8	5.3	1	northern valley
12/3/2010	0:30:32	38.3985	-108.8672	-3.8	5.3	1.9	northern valley
12/3/2010	0:55:31	38.3986	-108.8655	-3.9	5.5	0.8	northern valley
12/3/2010	2:34:09	38.3984	-108.8668	-3.9	5.4	0.8	northern valley
12/3/2010	2:35:42	38.3985	-108.8664	-3.9	5.4	0.1	northern valley
12/3/2010	2:38:55	38.3985	-108.8667	-3.9	5.4	0.8	northern valley
12/3/2010	2:39:14	38.4073	-108.854	-2.1	3.6	-0.1	northern valley
12/3/2010	2:39:48	38.3983	-108.8669	-3.8	5.3	-0.3	northern valley
12/3/2010	2:40:20	38.4037	-108.8558	-2.5	4	-0.1	northern valley
12/3/2010	2:58:10	38.3986	-108.8664	-3.9	5.5	0.3	northern valley
12/3/2010	2:59:39	38.4052	-108.8545	-2.2	3.7	0.1	northern valley
12/3/2010	3:16:25	38.3986	-108.8665	-3.9	5.4	1.3	northern valley
12/3/2010	3:30:55	38.3986	-108.8676	-3.9	5.4	0.1	northern valley
12/3/2010	3:34:39	38.3984	-108.8669	-3.9	5.4	0.4	northern valley
12/3/2010	3:39:05	38.3984	-108.8665	-3.9	5.4	0.9	northern valley
12/3/2010	5:14:56	38.3985	-108.8664	-3.9	5.4	1.6	northern valley
12/3/2010	5:15:36	38.3985	-108.8662	-3.9	5.4	0.1	northern valley
12/3/2010	6:42:47	38.3985	-108.8662	-3.9	5.4	0.1	northern valley
12/3/2010	7:59:06	38.3984	-108.8677	-3.8	5.3	0.7	northern valley
12/3/2010	8:20:58	38.3985	-108.8673	-3.8	5.3	1.2	northern valley
12/3/2010	10:40:26	38.3986	-108.8649	-4	5.5	1.1	northern valley
12/3/2010	11:08:30	38.3985	-108.8679	-3.8	5.4	0.6	northern valley
12/3/2010	11:48:55	38.4133	-108.8753	-3.6	5.1	-0.8	northern valley
12/3/2010	12:41:27	38.41	-108.87	-3.5	5	-0.2	northern valley
12/3/2010	13:16:15	38.4063	-108.854	-2.6	4.1	-0.5	northern valley
12/3/2010	13:24:24	38.3985	-108.8648	-3.9	5.5	0.2	northern valley
12/3/2010	13:24:24	38.4058	-108.8528	-2.3	3.8	-0.2	northern valley
12/3/2010	13:30:51	38.3985	-108.8673	-3.8	5.3	1.3	northern valley
12/3/2010	13:32:26	38.4105	-108.8867	-3.8	5.3	0.4	northern valley
12/3/2010	13:48:53	38.3985	-108.8679	-3.8	5.4	0.2	northern valley
12/3/2010	13:49:27	38.3985	-108.8679	-3.8	5.3	0.5	northern valley
12/3/2010	14:34:34	38.3985	-108.8656	-4	5.5	0.1	northern valley
12/3/2010	14:39:01	38.3983	-108.868	-3.8	5.4	0.4	northern valley
12/3/2010	15:22:38	38.3985	-108.8655	-4	5.5	1.4	northern valley
12/3/2010	15:32:40	38.3987	-108.8651	-4	5.5	0.3	northern valley
12/3/2010	15:51:22	38.3985	-108.8655	-3.9	5.4	0	northern valley
12/3/2010	16:28:19	38.3986	-108.8654	-4	5.5	1.2	northern valley
12/3/2010	16:42:28	38.3985	-108.8648	-3.9	5.4	0.4	northern valley
12/3/2010	16:59:41	38.3985	-108.8655	-3.9	5.4	0	northern valley
12/3/2010	17:15:35	38.3984	-108.8678	-3.9	5.4	0.9	northern valley
12/3/2010	17:16:24	38.3985	-108.8653	-4	5.5	1.2	northern valley
12/3/2010	17:19:47	38.3986	-108.8649	-4	5.5	0.9	northern valley
12/3/2010	17:19:47	38.3986	-108.8649	-4	5.5	0.5	northern valley
12/3/2010	17:20:46	38.3985	-108.868	-3.8	5.4	-0.2	northern valley
12/3/2010	17:20:46	38.3985	-108.868	-3.8	5.3	-0.4	northern valley
12/3/2010	17:21:31	38.407	-108.853	-2.4	4	-0.7	northern valley
12/3/2010	17:24:59	38.4058	-108.8538	-2.4	3.9	0.3	northern valley
12/3/2010	17:58:43	38.3985	-108.8651	-4	5.5	0.9	northern valley
12/3/2010	18:02:19	38.4125	-108.874	-3.5	5	-0.9	northern valley
12/3/2010	18:17:20	38.3986	-108.8655	-3.9	5.5	0.3	northern valley
12/3/2010	18:38:29	38.3985	-108.8649	-4	5.5	0.7	northern valley
12/3/2010	18:42:13	38.3985	-108.8662	-3.8	5.3	0.9	northern valley
12/3/2010	18:42:31	38.4082	-108.8543	-2.3	3.8	-0.1	northern valley
12/3/2010	18:49:01	38.3985	-108.866	-3.9	5.4	1.2	northern valley
12/3/2010	18:49:28	38.3983	-108.8662	-3.9	5.4	0	northern valley
12/3/2010	18:50:33	38.4042	-108.8535	-2.3	3.8	0	northern valley
12/3/2010	19:24:59	38.3986	-108.8651	-3.9	5.4	1.6	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/3/2010	19:26:45	38.3986	-108.8652	-3.9	5.4	0.2	northern valley
12/3/2010	19:32:45	38.3985	-108.8644	-4	5.5	0.1	northern valley
12/3/2010	19:38:07	38.3986	-108.8641	-4	5.5	0.3	northern valley
12/3/2010	19:40:07	38.3985	-108.8636	-4	5.5	-0.1	northern valley
12/3/2010	19:52:18	38.3984	-108.868	-3.8	5.3	0.2	northern valley
12/3/2010	20:06:26	38.4058	-108.8533	-2.5	4	-0.4	northern valley
12/3/2010	20:48:28	38.3985	-108.8652	-4	5.5	1.7	northern valley
12/3/2010	21:03:37	38.3986	-108.8657	-3.9	5.4	1.5	northern valley
12/3/2010	21:05:25	38.3985	-108.8647	-4	5.5	0	northern valley
12/3/2010	21:09:57	38.3985	-108.8637	-4	5.5	0.2	northern valley
12/3/2010	21:16:54	38.3985	-108.866	-3.9	5.4	0.4	northern valley
12/3/2010	21:28:09	38.3985	-108.8636	-4	5.5	0.3	northern valley
12/3/2010	21:56:50	38.3985	-108.8635	-4	5.5	0.4	northern valley
12/3/2010	22:08:21	38.3985	-108.864	-3.9	5.5	0.4	northern valley
12/3/2010	22:12:34	38.3985	-108.8647	-4	5.5	1	northern valley
12/3/2010	22:13:33	38.4015	-108.8517	-1.1	2.6	0.6	northern valley
12/3/2010	22:22:47	38.3986	-108.8639	-4	5.5	0.9	northern valley
12/3/2010	22:38:32	38.3945	-108.8668	-3.8	5.3	-0.2	northern valley
12/3/2010	22:58:51	38.3986	-108.8648	-4	5.5	0	northern valley
12/3/2010	23:01:57	38.3984	-108.8633	-4	5.6	0.2	northern valley
12/3/2010	23:08:33	38.3985	-108.8657	-3.9	5.5	2	northern valley
12/3/2010	23:13:36	38.3986	-108.8643	-4	5.5	0.3	northern valley
12/3/2010	23:13:36	38.3986	-108.8643	-4	5.5	0.5	northern valley
12/3/2010	23:13:36	38.3986	-108.8644	-4	5.5	0	northern valley
12/3/2010	23:13:49	38.3985	-108.8666	-3.9	5.4	0.7	northern valley
12/3/2010	23:13:49	38.3984	-108.8668	-3.9	5.4	-0.1	northern valley
12/3/2010	23:14:01	38.4058	-108.8573	-2.7	4.2	-0.9	northern valley
12/3/2010	23:17:52	38.3984	-108.8669	-3.8	5.4	-0.5	northern valley
12/3/2010	23:18:59	38.4057	-108.8567	-2.5	4	0.5	northern valley
12/3/2010	23:18:59	38.4057	-108.856	-2.4	3.9	0.5	northern valley
12/3/2010	23:18:59	38.404	-108.8557	-2.3	3.8	0.6	northern valley
12/3/2010	23:19:31	38.3983	-108.8632	-4	5.5	-0.6	northern valley
12/3/2010	23:19:31	38.3983	-108.8632	-4	5.5	0	northern valley
12/3/2010	23:30:26	38.3984	-108.8668	-3.8	5.3	0.1	northern valley
12/4/2010	1:02:31	38.3985	-108.8643	-4	5.5	0.5	northern valley
12/4/2010	1:04:44	38.4145	-108.903	-4	5.5	0.1	northern valley
12/4/2010	1:37:22	38.3985	-108.8681	-3.9	5.4	1.3	northern valley
12/4/2010	1:44:46	38.3986	-108.8659	-3.9	5.4	0.4	northern valley
12/4/2010	1:45:32	38.3986	-108.866	-3.9	5.4	1.4	northern valley
12/4/2010	1:45:32	38.3986	-108.866	-3.9	5.4	1.3	northern valley
12/4/2010	1:46:31	38.3986	-108.8657	-3.9	5.5	-0.2	northern valley
12/4/2010	1:46:31	38.3986	-108.8657	-3.9	5.5	-0.3	northern valley
12/4/2010	1:49:59	38.3986	-108.8642	-4	5.5	0.8	northern valley
12/4/2010	1:59:15	38.3985	-108.8638	-4	5.6	0.3	northern valley
12/4/2010	1:59:15	38.3985	-108.8638	-4	5.6	1.2	northern valley
12/4/2010	2:08:41	38.4158	-108.9015	-3.9	5.4	-0.3	northern valley
12/4/2010	2:10:24	38.3986	-108.8678	-3.9	5.4	0.5	northern valley
12/4/2010	2:16:54	38.3986	-108.8671	-3.9	5.5	0.1	northern valley
12/4/2010	2:27:06	38.3985	-108.8649	-3.9	5.4	0.8	northern valley
12/4/2010	2:37:04	38.3985	-108.8645	-3.9	5.4	0.8	northern valley
12/4/2010	2:38:36	38.3985	-108.8641	-4	5.5	0.2	northern valley
12/4/2010	2:38:51	38.3985	-108.8642	-3.9	5.4	0.2	northern valley
12/4/2010	2:38:57	38.3985	-108.8647	-3.9	5.4	0.1	northern valley
12/4/2010	2:47:18	38.3985	-108.8649	-3.8	5.4	0.4	northern valley
12/4/2010	2:50:45	38.3986	-108.8654	-3.8	5.4	1	northern valley
12/4/2010	2:51:27	38.4058	-108.852	-1.8	3.4	-0.5	northern valley
12/4/2010	3:26:21	38.3971	-108.8648	-3.9	5.4	0.2	northern valley
12/4/2010	3:28:20	38.3992	-108.8632	-3.8	5.3	0.2	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/4/2010	3:35:50	38.3992	-108.8708	-3.8	5.3	0.3	northern valley
12/4/2010	4:11:10	38.3985	-108.8645	-4	5.5	0.4	northern valley
12/4/2010	5:31:34	38.4067	-108.8528	-1.8	3.3	-0.1	northern valley
12/4/2010	6:30:37	38.3985	-108.8645	-4	5.5	0.7	northern valley
12/4/2010	6:48:59	38.3986	-108.8642	-4	5.5	0.5	northern valley
12/4/2010	7:26:55	38.3985	-108.8664	-3.9	5.4	0.5	northern valley
12/4/2010	7:28:27	38.3985	-108.8661	-3.8	5.4	-0.2	northern valley
12/4/2010	8:12:44	38.3985	-108.8679	-3.8	5.3	0.5	northern valley
12/4/2010	8:17:36	38.3985	-108.8679	-3.8	5.4	0.3	northern valley
12/4/2010	8:24:59	38.3985	-108.8682	-3.9	5.4	0.4	northern valley
12/4/2010	8:25:50	38.4072	-108.8538	-2	3.5	-0.6	northern valley
12/4/2010	8:43:24	38.3984	-108.868	-3.8	5.4	0.4	northern valley
12/4/2010	9:04:47	38.3985	-108.8676	-3.9	5.4	0.4	northern valley
12/4/2010	9:11:20	38.4067	-108.8535	-2.5	4	-0.5	northern valley
12/4/2010	9:11:42	38.4068	-108.8557	-2.4	3.9	-0.5	northern valley
12/4/2010	9:11:58	38.4033	-108.8575	-2.6	4.1	-0.2	northern valley
12/4/2010	9:20:02	38.3986	-108.8675	-3.9	5.4	0.3	northern valley
12/4/2010	9:31:26	38.3985	-108.863	-4	5.6	0.3	northern valley
12/4/2010	9:31:53	38.4053	-108.8508	-2.2	3.7	-0.5	northern valley
12/4/2010	9:32:41	38.4048	-108.851	-2.2	3.7	-0.4	northern valley
12/4/2010	10:11:56	38.3985	-108.868	-3.8	5.4	0.5	northern valley
12/4/2010	10:13:03	38.3985	-108.8676	-3.9	5.4	0.8	northern valley
12/4/2010	10:13:03	38.3985	-108.8676	-3.9	5.4	0.6	northern valley
12/4/2010	10:15:15	38.4075	-108.8567	-2.6	4.1	-0.7	northern valley
12/4/2010	10:15:15	38.4053	-108.8547	-2.1	3.6	-0.7	northern valley
12/4/2010	10:28:12	38.4042	-108.8552	-2.1	3.6	-0.1	northern valley
12/4/2010	10:47:19	38.4057	-108.8702	-2.4	3.9	0.9	northern valley
12/4/2010	10:50:39	38.3992	-108.8702	-3.8	5.3	-0.7	northern valley
12/4/2010	10:50:44	38.4073	-108.8765	-2.9	4.4	-0.5	northern valley
12/4/2010	10:50:55	38.3985	-108.8683	-3.8	5.3	0.5	northern valley
12/4/2010	11:00:08	38.3984	-108.8676	-3.8	5.3	1.1	northern valley
12/4/2010	12:19:20	38.3987	-108.8674	-3.9	5.5	0	northern valley
12/4/2010	12:40:01	38.3986	-108.8675	-3.9	5.5	1.2	northern valley
12/4/2010	12:51:11	38.3986	-108.8671	-3.9	5.5	0.6	northern valley
12/4/2010	12:54:39	38.3985	-108.8642	-4	5.5	0	northern valley
12/4/2010	12:54:39	38.3985	-108.8642	-4	5.5	0.4	northern valley
12/4/2010	13:10:45	38.3985	-108.8681	-3.9	5.4	0.9	northern valley
12/4/2010	14:15:32	38.409	-108.872	-2.9	4.4	0.2	northern valley
12/4/2010	14:19:04	38.4088	-108.874	-2.9	4.4	0.5	northern valley
12/4/2010	14:20:13	38.4085	-108.8727	-2.7	4.2	0.4	northern valley
12/4/2010	14:20:59	38.4055	-108.8697	-2.2	3.7	0.2	northern valley
12/4/2010	14:21:08	38.4067	-108.8528	-2.4	4	-0.7	northern valley
12/4/2010	14:21:24	38.4088	-108.8583	-2.7	4.3	-0.6	northern valley
12/4/2010	14:22:07	38.3862	-108.8435	-1.8	3.3	-0.8	northern valley
12/4/2010	14:22:16	38.414	-108.886	-3.5	5	-0.9	northern valley
12/4/2010	14:23:00	38.411	-108.88	-3.3	4.8	-0.2	northern valley
12/4/2010	14:27:19	38.4097	-108.8553	-2.4	3.9	0.2	northern valley
12/4/2010	14:45:08	38.3986	-108.866	-3.8	5.3	0.5	northern valley
12/4/2010	15:08:15	38.4167	-108.9022	-4	5.5	-0.8	northern valley
12/4/2010	15:17:01	38.3986	-108.8675	-3.9	5.5	0	northern valley
12/4/2010	15:17:30	38.41	-108.8523	-2.1	3.6	-0.6	northern valley
12/4/2010	15:18:25	38.4083	-108.854	-2.3	3.8	-1	northern valley
12/4/2010	15:18:34	38.4128	-108.8548	-2.6	4.1	-0.5	northern valley
12/4/2010	15:22:10	38.4047	-108.8528	-2.4	4	-0.4	northern valley
12/4/2010	15:24:25	38.3986	-108.8672	-3.9	5.5	0.6	northern valley
12/4/2010	15:25:41	38.4067	-108.8555	-2.2	3.8	-0.5	northern valley
12/4/2010	15:30:11	38.3985	-108.8634	-4	5.5	1	northern valley
12/4/2010	15:32:46	38.3985	-108.8637	-4	5.5	0.5	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/4/2010	15:37:09	38.3985	-108.8633	-4	5.5	1.2	northern valley
12/4/2010	16:28:50	38.3986	-108.8649	-4	5.5	1.7	northern valley
12/4/2010	16:38:05	38.3985	-108.8655	-4	5.5	2	northern valley
12/4/2010	18:27:37	38.4068	-108.8513	-2	3.6	0.5	northern valley
12/4/2010	19:36:34	38.3985	-108.8632	-3.9	5.4	1.1	northern valley
12/4/2010	19:55:56	38.3984	-108.8683	-3.8	5.3	0.4	northern valley
12/4/2010	20:14:10	38.3985	-108.8656	-4	5.5	0.4	northern valley
12/4/2010	21:00:34	38.3988	-108.8698	-3.9	5.4	0.3	northern valley
12/4/2010	21:05:14	38.3985	-108.8674	-3.8	5.3	0.2	northern valley
12/4/2010	21:15:26	38.3985	-108.867	-3.8	5.3	1.7	northern valley
12/4/2010	21:17:02	38.3987	-108.8697	-3.9	5.4	-0.1	northern valley
12/4/2010	21:17:23	38.3988	-108.8699	-3.8	5.3	0.6	northern valley
12/4/2010	21:18:38	38.3984	-108.8674	-3.8	5.3	-0.2	northern valley
12/4/2010	21:20:29	38.3995	-108.8699	-3.8	5.3	0.6	northern valley
12/4/2010	21:20:29	38.3988	-108.8585	-1	2.5	0.5	northern valley
12/4/2010	21:20:53	38.3985	-108.8699	-3.9	5.5	-0.1	northern valley
12/4/2010	21:20:53	38.3985	-108.8699	-3.8	5.3	-0.2	northern valley
12/4/2010	21:25:13	38.3989	-108.8697	-3.7	5.2	0.4	northern valley
12/4/2010	21:27:23	38.4117	-108.8737	-3.4	5	-0.7	northern valley
12/4/2010	21:34:22	38.3988	-108.8697	-3.7	5.2	0.2	northern valley
12/4/2010	21:59:55	38.3987	-108.8699	-3.9	5.4	0.4	northern valley
12/4/2010	22:02:39	38.3987	-108.8696	-3.8	5.3	0.3	northern valley
12/4/2010	22:02:39	38.3987	-108.8696	-3.7	5.3	0.5	northern valley
12/4/2010	22:02:39	38.3987	-108.8696	-3.7	5.3	0.3	northern valley
12/4/2010	22:04:41	38.3985	-108.8695	-3.8	5.3	0.1	northern valley
12/4/2010	22:04:41	38.3985	-108.8696	-3.8	5.3	0	northern valley
12/4/2010	22:07:16	38.3986	-108.8697	-3.8	5.3	0	northern valley
12/4/2010	22:07:30	38.3983	-108.8692	-3.7	5.2	0	northern valley
12/4/2010	22:07:43	38.3993	-108.8701	-3.8	5.3	0.2	northern valley
12/4/2010	22:09:18	38.3985	-108.8675	-3.7	5.3	0.5	northern valley
12/4/2010	23:16:13	38.3986	-108.868	-3.8	5.4	-0.1	northern valley
12/4/2010	23:16:36	38.3985	-108.8679	-3.8	5.3	0.3	northern valley
12/4/2010	23:17:17	38.414	-108.9028	-3.8	5.3	-0.7	northern valley
12/4/2010	23:20:45	38.3985	-108.8679	-3.8	5.3	0	northern valley
12/4/2010	23:34:28	38.3985	-108.8682	-3.9	5.4	1.1	northern valley
12/4/2010	23:35:48	38.4073	-108.8558	-2.4	3.9	0.1	northern valley
12/4/2010	23:49:21	38.3986	-108.8639	-4	5.5	0.5	northern valley
12/5/2010	1:14:20	38.3982	-108.8659	-3.9	5.4	1	northern valley
12/5/2010	1:15:25	38.3984	-108.8655	-3.9	5.4	-0.2	northern valley
12/5/2010	1:16:22	38.3989	-108.8657	-3.9	5.4	0.2	northern valley
12/5/2010	1:17:38	38.3985	-108.8655	-3.9	5.4	0.6	northern valley
12/5/2010	1:18:24	38.3986	-108.8648	-3.9	5.4	1.9	northern valley
12/5/2010	1:39:53	38.4068	-108.8535	-2.2	3.8	0	northern valley
12/5/2010	1:40:07	38.3985	-108.8657	-3.8	5.4	1.5	northern valley
12/5/2010	1:41:44	38.3985	-108.8662	-3.8	5.3	0.2	northern valley
12/5/2010	2:23:15	38.4078	-108.8695	-2.5	4	0.5	northern valley
12/5/2010	2:23:16	38.4018	-108.8703	-1.4	2.9	0.6	northern valley
12/5/2010	2:25:31	38.3997	-108.8706	-3.9	5.4	0.1	northern valley
12/5/2010	3:24:20	38.3995	-108.8635	-2.8	4.3	0.1	northern valley
12/5/2010	3:24:35	38.3986	-108.8696	-3.8	5.3	-0.1	northern valley
12/5/2010	3:25:14	38.3985	-108.8681	-3.8	5.4	-0.3	northern valley
12/5/2010	3:25:24	38.4032	-108.8793	-3.9	5.5	-0.6	northern valley
12/5/2010	3:25:45	38.4002	-108.8418	-0.5	2	-0.6	northern valley
12/5/2010	3:26:14	38.4132	-108.8553	-3	4.5	-0.4	northern valley
12/5/2010	3:40:06	38.3985	-108.8674	-3.8	5.4	1.1	northern valley
12/5/2010	3:42:21	38.4072	-108.8543	-1.9	3.4	-0.2	northern valley
12/5/2010	3:47:13	38.3985	-108.8667	-3.9	5.4	1.2	northern valley
12/5/2010	3:47:34	38.3985	-108.8666	-3.8	5.4	-0.1	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/5/2010	3:47:45	38.4053	-108.8557	-2.6	4.1	-0.2	northern valley
12/5/2010	3:48:06	38.3985	-108.8668	-4	5.5	0.2	northern valley
12/5/2010	3:48:23	38.3985	-108.8666	-4	5.5	0.2	northern valley
12/5/2010	3:48:39	38.3985	-108.8662	-3.9	5.5	0.5	northern valley
12/5/2010	3:50:04	38.3985	-108.8661	-3.9	5.4	0.6	northern valley
12/5/2010	5:02:55	38.392	-108.8733	-0.2	1.7	0	northern valley
12/5/2010	5:03:06	38.4057	-108.8458	-0.1	1.7	-0.3	northern valley
12/5/2010	5:16:59	38.3985	-108.8653	-4	5.5	1.5	northern valley
12/5/2010	5:24:40	38.3986	-108.868	-3.9	5.5	0.3	northern valley
12/5/2010	5:47:23	38.3985	-108.8686	-3.9	5.4	1.3	northern valley
12/5/2010	5:48:32	38.3986	-108.8675	-4	5.5	0.7	northern valley
12/5/2010	6:11:34	38.3986	-108.8677	-3.9	5.5	1.5	northern valley
12/5/2010	6:12:12	38.3986	-108.8678	-3.9	5.4	0.2	northern valley
12/5/2010	6:20:11	38.3986	-108.8671	-3.9	5.5	1	northern valley
12/5/2010	7:43:05	38.3985	-108.8687	-3.9	5.4	0.7	northern valley
12/5/2010	7:54:21	38.3986	-108.8682	-3.9	5.4	0.2	northern valley
12/5/2010	7:56:57	38.3985	-108.8683	-3.9	5.4	0.8	northern valley
12/5/2010	7:56:57	38.3985	-108.8683	-3.9	5.4	0.7	northern valley
12/5/2010	7:57:55	38.3986	-108.8677	-3.9	5.4	1.6	northern valley
12/5/2010	7:57:55	38.3986	-108.8677	-3.9	5.4	1.6	northern valley
12/5/2010	7:58:58	38.3985	-108.8684	-3.8	5.4	-0.2	northern valley
12/5/2010	7:58:58	38.3984	-108.8683	-3.8	5.3	0.2	northern valley
12/5/2010	7:59:58	38.41	-108.8532	-2	3.6	-0.5	northern valley
12/5/2010	7:59:58	38.4087	-108.8532	-2	3.5	-0.5	northern valley
12/5/2010	8:00:05	38.4068	-108.8557	-2.4	3.9	-0.3	northern valley
12/5/2010	8:18:43	38.4067	-108.8535	-1.9	3.4	-0.4	northern valley
12/5/2010	8:18:50	38.3985	-108.8686	-3.9	5.4	0.3	northern valley
12/5/2010	9:47:27	38.3987	-108.8678	-3.9	5.4	0.6	northern valley
12/5/2010	10:13:38	38.4058	-108.8523	-1.8	3.3	0.1	northern valley
12/5/2010	10:13:52	38.3985	-108.8675	-3.8	5.3	1.5	northern valley
12/5/2010	10:57:24	38.3985	-108.8672	-3.8	5.3	0.4	northern valley
12/5/2010	10:59:45	38.3985	-108.8685	-3.9	5.4	0.8	northern valley
12/5/2010	10:59:45	38.3985	-108.8685	-3.9	5.4	1.3	northern valley
12/5/2010	10:59:45	38.3985	-108.8685	-3.9	5.4	1.3	northern valley
12/5/2010	11:00:30	38.4065	-108.8538	-2.2	3.7	-0.4	northern valley
12/5/2010	11:01:41	38.4082	-108.856	-2.3	3.9	0	northern valley
12/5/2010	11:01:41	38.4072	-108.856	-2.3	3.8	0	northern valley
12/5/2010	11:20:52	38.407	-108.8515	-2	3.5	-0.7	northern valley
12/5/2010	11:21:02	38.4092	-108.857	-2.6	4.2	0.1	northern valley
12/5/2010	11:21:20	38.3993	-108.8703	-3.8	5.3	-0.7	northern valley
12/5/2010	11:21:28	38.393	-108.8483	-2.2	3.7	-0.4	northern valley
12/5/2010	11:22:02	38.3986	-108.8679	-3.9	5.4	0	northern valley
12/5/2010	11:23:46	38.3984	-108.8679	-3.9	5.5	0.4	northern valley
12/5/2010	11:25:49	38.3986	-108.8674	-3.9	5.4	0.7	northern valley
12/5/2010	11:26:31	38.3993	-108.8713	-3.7	5.3	-0.2	northern valley
12/5/2010	11:26:45	38.4055	-108.8548	-2	3.5	-0.8	northern valley
12/5/2010	11:27:38	38.4045	-108.8568	-2.4	3.9	-0.3	northern valley
12/5/2010	11:28:18	38.3989	-108.8698	-3.7	5.3	0.1	northern valley
12/5/2010	11:31:34	38.3985	-108.8682	-3.9	5.5	0.3	northern valley
12/5/2010	11:38:16	38.3996	-108.8707	-3.9	5.4	0.8	northern valley
12/5/2010	11:39:14	38.4065	-108.8575	-2.1	3.6	0.2	northern valley
12/5/2010	11:40:22	38.4093	-108.8565	-2.7	4.2	0.1	northern valley
12/5/2010	11:48:30	38.3985	-108.8626	-4	5.5	0.2	northern valley
12/5/2010	11:52:45	38.3985	-108.8682	-3.9	5.4	1.5	northern valley
12/5/2010	11:54:50	38.405	-108.8532	-1.8	3.3	-0.1	northern valley
12/5/2010	11:55:15	38.3985	-108.8679	-3.8	5.3	0	northern valley
12/5/2010	12:19:06	38.3985	-108.8683	-3.8	5.3	0.8	northern valley
12/5/2010	12:22:47	38.3985	-108.8686	-4	5.5	0.6	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/5/2010	12:41:24	38.3986	-108.8682	-3.8	5.3	0.7	northern valley
12/5/2010	13:21:25	38.3986	-108.8681	-4	5.5	0.5	northern valley
12/5/2010	15:22:56	38.3986	-108.8682	-4	5.5	0.8	northern valley
12/5/2010	15:31:56	38.3985	-108.8682	-3.9	5.5	0.7	northern valley
12/5/2010	16:26:39	38.3985	-108.864	-3.9	5.5	0.6	northern valley
12/5/2010	16:27:31	38.4118	-108.85	-2	3.5	0	northern valley
12/5/2010	16:29:08	38.3985	-108.8684	-4	5.5	0.2	northern valley
12/5/2010	16:31:59	38.3985	-108.8642	-3.9	5.5	1.1	northern valley
12/5/2010	16:33:40	38.406	-108.8515	-2	3.6	0	northern valley
12/5/2010	16:38:50	38.3984	-108.8626	-4	5.6	1	northern valley
12/5/2010	16:44:50	38.3986	-108.8642	-4	5.5	1.5	northern valley
12/5/2010	16:45:44	38.3978	-108.8615	-4.2	5.7	0.1	northern valley
12/5/2010	16:51:15	38.3986	-108.8646	-4	5.5	0.5	northern valley
12/5/2010	17:12:30	38.3985	-108.8644	-3.9	5.5	0.3	northern valley
12/5/2010	17:49:41	38.3985	-108.8686	-3.9	5.4	-0.4	northern valley
12/5/2010	17:49:52	38.3989	-108.8685	-4	5.5	0.6	northern valley
12/5/2010	18:00:58	38.3985	-108.8682	-3.9	5.4	0.4	northern valley
12/5/2010	18:01:25	38.3984	-108.8625	-4	5.6	0	northern valley
12/5/2010	18:03:12	38.3983	-108.8626	-4	5.5	0.1	northern valley
12/5/2010	18:42:56	38.3985	-108.8638	-4	5.6	1.6	northern valley
12/5/2010	18:51:48	38.3985	-108.8686	-3.9	5.4	0.5	northern valley
12/5/2010	18:53:35	38.3985	-108.8684	-3.9	5.4	0.8	northern valley
12/5/2010	18:53:35	38.3985	-108.8684	-3.9	5.4	0.7	northern valley
12/5/2010	18:53:51	38.4062	-108.8582	-2.7	4.2	-0.2	northern valley
12/5/2010	18:54:07	38.4093	-108.8555	-2.3	3.8	-0.5	northern valley
12/5/2010	18:56:12	38.3985	-108.8641	-4	5.5	1.3	northern valley
12/5/2010	18:56:12	38.3985	-108.8641	-4	5.5	1.2	northern valley
12/5/2010	19:00:30	38.3984	-108.8633	-4.1	5.6	1	northern valley
12/5/2010	19:27:03	38.3985	-108.8683	-3.9	5.5	0.6	northern valley
12/5/2010	19:27:52	38.4082	-108.8548	-2.4	3.9	-0.7	northern valley
12/5/2010	19:28:25	38.406	-108.8558	-2.4	3.9	-0.5	northern valley
12/5/2010	19:39:59	38.3985	-108.8681	-4	5.5	0.3	northern valley
12/5/2010	19:42:33	38.3986	-108.8678	-3.9	5.5	-0.2	northern valley
12/5/2010	19:49:15	38.3986	-108.8675	-3.9	5.5	1.6	northern valley
12/5/2010	19:57:41	38.409	-108.8663	-3.5	5	0.1	northern valley
12/5/2010	19:58:33	38.3984	-108.862	-4	5.5	-0.6	northern valley
12/5/2010	20:03:55	38.3986	-108.8671	-3.9	5.5	0.4	northern valley
12/5/2010	20:04:09	38.3985	-108.8624	-4.1	5.6	0.5	northern valley
12/5/2010	20:05:04	38.4078	-108.8657	-3.1	4.6	-0.3	northern valley
12/5/2010	20:43:03	38.3984	-108.8629	-4	5.5	0.2	northern valley
12/5/2010	21:02:44	38.3985	-108.8621	-4.1	5.6	1.3	northern valley
12/5/2010	22:12:34	38.3985	-108.8628	-4	5.5	0.6	northern valley
12/6/2010	1:25:54	38.3984	-108.8668	-3.8	5.3	0.9	northern valley
12/6/2010	1:39:46	38.4005	-108.8687	-4	5.6	0.1	northern valley
12/6/2010	2:06:45	38.3986	-108.863	-4	5.5	0.5	northern valley
12/6/2010	6:16:16	38.3984	-108.8629	-4	5.6	1.2	northern valley
12/6/2010	6:18:49	38.4083	-108.8473	-1.3	2.8	-0.1	northern valley
12/6/2010	6:31:53	38.3985	-108.8637	-4	5.5	0.9	northern valley
12/6/2010	6:33:01	38.3985	-108.8634	-4	5.5	1.4	northern valley
12/6/2010	6:40:14	38.3985	-108.8629	-4	5.5	1.1	northern valley
12/6/2010	8:27:50	38.3986	-108.8651	-3.9	5.5	0.7	northern valley
12/6/2010	8:39:46	38.3985	-108.8653	-3.9	5.4	0.9	northern valley
12/6/2010	8:49:19	38.3985	-108.8649	-3.9	5.4	0.9	northern valley
12/6/2010	9:11:11	38.3986	-108.8641	-4	5.5	1	northern valley
12/6/2010	9:12:27	38.3985	-108.8683	-3.8	5.4	0.6	northern valley
12/6/2010	9:25:58	38.3985	-108.8649	-4	5.5	1	northern valley
12/6/2010	9:27:19	38.3985	-108.8648	-4	5.5	-0.3	northern valley
12/6/2010	9:40:02	38.4072	-108.85	-2	3.5	0.1	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/6/2010	9:44:40	38.3982	-108.8629	-3.9	5.5	0.1	northern valley
12/6/2010	13:23:42	38.3985	-108.8622	-4	5.6	0.8	northern valley
12/6/2010	14:01:57	38.3985	-108.8682	-4	5.5	0.9	northern valley
12/6/2010	14:25:27	38.3985	-108.8622	-4	5.6	0.4	northern valley
12/6/2010	14:25:53	38.3985	-108.8695	-3.7	5.2	0	northern valley
12/6/2010	14:26:01	38.3986	-108.8624	-4	5.6	0.8	northern valley
12/6/2010	15:25:45	38.3984	-108.863	-4	5.5	0.8	northern valley
12/6/2010	15:25:45	38.3984	-108.863	-4	5.5	0.8	northern valley
12/6/2010	17:18:57	38.3983	-108.8615	-4	5.6	0.5	northern valley
12/6/2010	17:19:57	38.4062	-108.8505	-2.3	3.8	-0.5	northern valley
12/6/2010	17:24:57	38.4097	-108.8465	-1	2.5	-0.5	northern valley
12/6/2010	18:20:42	38.3985	-108.8632	-3.9	5.5	0.7	northern valley
12/6/2010	18:21:21	38.3984	-108.8632	-3.9	5.4	0.6	northern valley
12/6/2010	18:49:56	38.3985	-108.8639	-3.9	5.4	0.2	northern valley
12/6/2010	21:36:53	38.3984	-108.863	-4	5.5	1.1	northern valley
12/6/2010	21:54:19	38.3984	-108.8672	-3.8	5.3	0.5	northern valley
12/6/2010	22:37:46	38.3981	-108.8662	-3.8	5.3	0.5	northern valley
12/6/2010	23:38:31	38.3986	-108.866	-3.8	5.3	0.9	northern valley
12/6/2010	0:00:07	38.4062	-108.853	-1.9	3.4	-0.2	northern valley
12/7/2010	0:06:05	38.3979	-108.8635	-3.9	5.4	0.7	northern valley
12/7/2010	1:43:50	38.3985	-108.8637	-4	5.5	1	northern valley
12/7/2010	1:50:08	38.3985	-108.8639	-3.9	5.5	0.6	northern valley
12/7/2010	2:47:11	38.4092	-108.85	-2	3.6	0.4	northern valley
12/7/2010	3:46:21	38.3015	-108.9341	-2.8	4.3	0.6	near-well
12/7/2010	7:23:15	38.3985	-108.8627	-4	5.6	1	northern valley
12/7/2010	7:24:46	38.3984	-108.8627	-4.1	5.6	0.2	northern valley
12/8/2010	7:38:38	38.3985	-108.8656	-3.9	5.5	0.5	northern valley
12/8/2010	9:08:37	38.3984	-108.8615	-4.1	5.6	0.9	northern valley
12/8/2010	9:13:21	38.3984	-108.8625	-4	5.5	0.9	northern valley
12/8/2010	15:18:13	38.3986	-108.8649	-3.9	5.4	0.9	northern valley
12/8/2010	15:20:01	38.3985	-108.8645	-3.9	5.4	0.6	northern valley
12/8/2010	16:17:18	38.3984	-108.8644	-3.9	5.4	0.5	northern valley
12/8/2010	16:17:38	38.3985	-108.8642	-3.9	5.5	0	northern valley
12/8/2010	16:31:34	38.3985	-108.8641	-3.9	5.4	0.6	northern valley
12/8/2010	23:13:40	38.3984	-108.8674	-3.8	5.3	0.3	northern valley
12/8/2010	23:14:41	38.4075	-108.8585	-2.7	4.2	-0.3	northern valley
12/8/2010	23:43:15	38.3985	-108.8673	-3.8	5.3	0.5	northern valley
12/8/2010	23:44:45	38.3985	-108.867	-3.8	5.3	1.6	northern valley
12/8/2010	23:45:41	38.3985	-108.8675	-3.7	5.3	0.2	northern valley
12/9/2010	0:10:33	38.3985	-108.8667	-3.8	5.3	0.2	northern valley
12/9/2010	7:34:48	38.3985	-108.8633	-4	5.5	1.1	northern valley
12/9/2010	7:36:20	38.4065	-108.8522	-2.2	3.7	-0.3	northern valley
12/9/2010	7:36:38	38.4078	-108.85	-2.1	3.6	-0.8	northern valley
12/9/2010	8:21:02	38.3985	-108.8639	-3.9	5.5	0.4	northern valley
12/9/2010	9:05:01	38.4085	-108.8623	-2.3	3.8	-0.7	northern valley
12/9/2010	9:05:11	38.402	-108.8425	-0.8	2.4	-0.7	northern valley
12/9/2010	16:10:40	38.4095	-108.8492	-1.5	3	-0.4	northern valley
12/9/2010	16:33:10	38.4055	-108.8513	-2.6	4.1	-0.7	northern valley
12/9/2010	17:57:16	38.3985	-108.8655	-3.8	5.3	0.4	northern valley
12/9/2010	17:57:37	38.4048	-108.8523	-2	3.5	0.3	northern valley
12/9/2010	18:30:50	38.3984	-108.8624	-4	5.5	0.4	northern valley
12/9/2010	22:54:41	38.3985	-108.8616	-4.1	5.6	0.6	northern valley
12/9/2010	22:56:25	38.4052	-108.8505	-2.3	3.8	0	northern valley
12/9/2010	23:49:03	38.3985	-108.8623	-4	5.5	1.5	northern valley
12/10/2010	0:03:42	38.3984	-108.862	-4.1	5.6	0.6	northern valley
12/10/2010	0:03:57	38.3985	-108.8624	-4	5.6	-0.2	northern valley
12/10/2010	0:07:59	38.3985	-108.8624	-4.1	5.6	0.2	northern valley
12/10/2010	0:08:17	38.4055	-108.8437	-0.6	2.1	-0.2	northern valley

Table A-1 Local earthquakes recorded by PVSN during 2010. The earthquake shaded in color is a large-magnitude event that triggered PVSN strong motion instruments.

Date	Time[1]	Latitude (deg.)	Longitude (deg.)	Elevation[2] (km)	Depth[3] (km)	Duration Magnitude	Location Category[4]
12/10/2010	0:32:44	38.4057	-108.8507	-2.3	3.8	-0.9	northern valley
12/10/2010	0:41:55	38.3984	-108.8628	-4	5.5	0.1	northern valley
12/10/2010	1:46:27	38.3985	-108.8642	-3.9	5.5	0.4	northern valley
12/10/2010	11:14:33	38.3983	-108.8608	-4	5.6	0.1	northern valley
12/10/2010	17:24:14	38.3985	-108.863	-4	5.5	0.7	northern valley
12/10/2010	17:32:31	38.3985	-108.8628	-4	5.5	1.2	northern valley
12/10/2010	18:31:51	38.3985	-108.8678	-3.8	5.3	0.5	northern valley
12/10/2010	18:37:41	38.3985	-108.8681	-3.8	5.3	0.3	northern valley
12/10/2010	18:41:39	38.3985	-108.8645	-3.9	5.4	0.7	northern valley
12/10/2010	18:52:24	38.4105	-108.8488	-1.5	3.1	-0.7	northern valley
12/10/2010	23:32:13	38.4087	-108.8517	-2.3	3.8	-0.3	northern valley
12/10/2010	23:38:03	38.3986	-108.8644	-3.9	5.5	0.1	northern valley
12/10/2010	23:45:57	38.3986	-108.8639	-4	5.5	1	northern valley
12/10/2010	23:53:48	38.3984	-108.8633	-4	5.5	0.4	northern valley
12/11/2010	0:04:50	38.411	-108.8567	-4.4	5.9	0.5	northern valley
12/11/2010	0:04:51	38.4053	-108.8528	-2.4	4	0.2	northern valley
12/11/2010	0:05:34	38.4125	-108.8477	-1.7	3.3	-0.7	northern valley
12/11/2010	0:11:21	38.3984	-108.8634	-4.1	5.6	0.2	northern valley
12/11/2010	11:48:24	38.2732	-108.9283	-0.3	1.8	2	near-well
12/15/2010	16:22:42	38.2845	-108.8992	-2.9	4.4	0.4	near-well
12/16/2010	17:58:30	38.2717	-108.9287	-0.3	1.8	0.5	near-well
12/18/2010	8:30:44	38.2822	-108.909	-2	3.5	-0.1	near-well
12/23/2010	12:01:56	38.3985	-108.8646	-3.9	5.5	0.7	northern valley
12/25/2010	20:31:43	38.3231	-108.9496	-3.4	4.9	0.8	NW cluster
12/29/2010	12:16:52	38.298	-108.8998	-2.8	4.3	1.3	near-well

[1] Time listed is Coordinated Universal Time, UTC (Mountain Standard Time = UTC – 7 hours)
[2] Elevation is given with respect to mean sea level.
[3] Depth is referenced to the surveyed elevation of the injection wellhead, 1.524 km.
[4] Earthquake location categories:

near-well: located within 5 km of the injection well (induced by fluid injection)

NW cluster: located within the zone of induced seismicity that is centered approximately 7.5 km northwest of the injection well (induced by fluid injection)

SE cluster: located within a zone of induced seismicity that is centered approximately 6 km southeast of the injection well (induced by fluid injection)

west of well: located about 8 km west of the injection well (induced by fluid injection) - currently this is an isolated event

north (N.)-central valley: located beneath north-central Paradox Valley, approximately 9 km north-northwest of the injection well (very likely related to injection)

northern valley: located in or very near areas of recurring seismicity along the northern edge of Paradox Valley (relation to injection uncertain)

other: local earthquake not associated with any of the other location categories (likely naturally-occurring earthquake)

Appendix B
Recalculation of Earthquake Magnitudes

B.1 Method

PVSN uses a duration magnitude scale that is based on the signal durations measured from seismograms for each station. Durations are defined as the time, in seconds, between the P-wave arrival and the point where the seismogram has decayed to approximately the pre-event noise level. For each local earthquake, a duration magnitude is computed from the average of the measured station durations according to the equation $M_D = -3.13 + 2.74 \times \log(\overline{duration})$, where the logarithm is base 10. Durations are typically measured from the vertical-component trace, which has been band-passed filtered between frequencies of 1.2 and 20 Hz.

In 2010, new automatic procedures for calculating duration were developed, based on fitting a pre-defined envelope curve to the seismic coda. Because the actual seismic waveform is highly oscillatory, a smoothed representation called the scan curve is first calculated using a 3-second moving average of the absolute value of the waveform with mean removed. For envelope curves, we examined both exponential and power-law functions, but found that the exponential form provides results that are more consistent with previous visual fitting procedures.

Calculated durations were found to be strongly dependent on the selection of the start and end times chosen for fitting the envelope curve, so a procedure was developed to minimize this dependency over a wide range of magnitudes and data types (e.g., 24-bit broadband vs. 12-bit short-period). In this procedure, initial values for the start and end times are determined by examining that part of the coda lying between 50 and 0.5 percent of the maximum scan-curve value, following the S-wave arrival. Adjustments are then made for clipped or noisy data, or for traces that do not consistently decrease in amplitude with time. This procedure results in start and end times that are consistent with visual fitting procedures.

A least-squares fit to the envelope function is computed using the values of the scan curve between the automatically-determined start and end times. Durations are then calculated by extrapolating the envelope function to the time at which it decreases to a specified target value. Because durations are calculated by extrapolating the fitted envelope function rather than by directly observing the decay point of the seismogram, the calculated durations may occasionally extend beyond the end of the recorded data. This characteristic allows durations to be estimated for events for which recording ceased before the seismogram had been fully recorded, which would not be possible using visual fitting procedures alone. However, in such cases, the reliability of the extrapolation may be difficult to verify.

Calculated durations are strongly dependent on the choice of the target value for the envelope function. We examined candidate target values derived from: (1) the pre-event noise level, which makes the calculated duration dependent on the noise characteristics of the station at the time of each earthquake; and, (2) pre-defined absolute amplitudes, which makes the calculated duration independent of changes in noise levels over time. Intuitively, durations that are independent of noise level could be expected to provide more robust results. In practice, we found that target levels based on the pre-event noise levels provided greater consistency to a set of carefully-measured durations determined from manual procedures.

Tuning parameters in the software allow for scaling of the target level to be based on the noise level, and to provide for a noise floor, which helps to dampen some of the dependence on noise. Adjustment of these tuning parameters allows for systematic adjustment of the calculated durations, and therefore provides control over the distribution of final magnitude values. Using all 5009 local PVSN earthquakes recorded through November, 2010, tuning parameters were adjusted by comparing the probability distribution of the old and new magnitudes through a trial-and-error process to match the means of the magnitude distributions. Satisfactory results were obtained after two iterations of recalculating magnitudes for this set of local earthquakes.

B.2 Analysis

Exploratory data analysis methods were used to examine the dependence of magnitude on various parameters such as date of occurrence and focal depth, and to examine the distribution of magnitudes determined from the new and old procedures, as well as the magnitude differences (defined as the new minus old magnitude for each local earthquake). Each earthquake provides a paired sample for any two of these parameters, so first-order correlations can be visualized with a matrix of scatterplots for each possible pair of parameters. **Figure B-1** shows the scatterplot matrix for the following parameters: date of earthquake occurrence, focal depth, old and new magnitudes, and the difference between the old and new magnitudes. Several characteristics are apparent from this plot. First, focal depth appears to be uncorrelated with either time or magnitude, with most focal depths clustering near the ~4.5 km depth of the perforation zone of the injection well (corresponding to an elevation of about -3000 m). Second, the distribution of magnitudes is dependent on time in the sense that there are periods of no earthquakes, and that there is a variation in the numbers of small magnitude earthquakes over time. Third, there is a positive correlation between magnitudes determined using the old and new procedures.

The distribution of magnitude (either “old” or “new”) over time indicates significant variations. **Figure B-2** is a detailed scatterplot of new magnitude versus time which illustrates the following characteristics: (1) during the pre-injection phase, little seismicity was recorded; (2) significant levels of seismicity were detected beginning with the well tests; (3) the greatest numbers of earthquakes were recorded during the initial production phase, when 3 continuous-volume pumps were in operation; (4) fewer earthquakes have been recorded since injection was limited to two pumps, and regular shut-ins implemented (which continues to the present); and (5) increased numbers of small-magnitude earthquakes have been recorded following the initiation of seismic network upgrades. These observations can also be seen by locally smoothing the scatterplot values. The solid red line in the figure indicates a locally-weighted scatterplot-smoother (LOESS) regression that takes a weighted average of the nearest 400 earthquakes in time and does a regression to a degree-one polynomial. The LOESS model provides an estimate of the mean magnitude as it varies over time, based on averaging over a small number of neighboring magnitudes.

A strong, positive correlation exists between the old and new magnitudes (correlation coefficient of 0.896), which is apparent in the detailed scatterplot shown in **Figure B-3**. For illustration

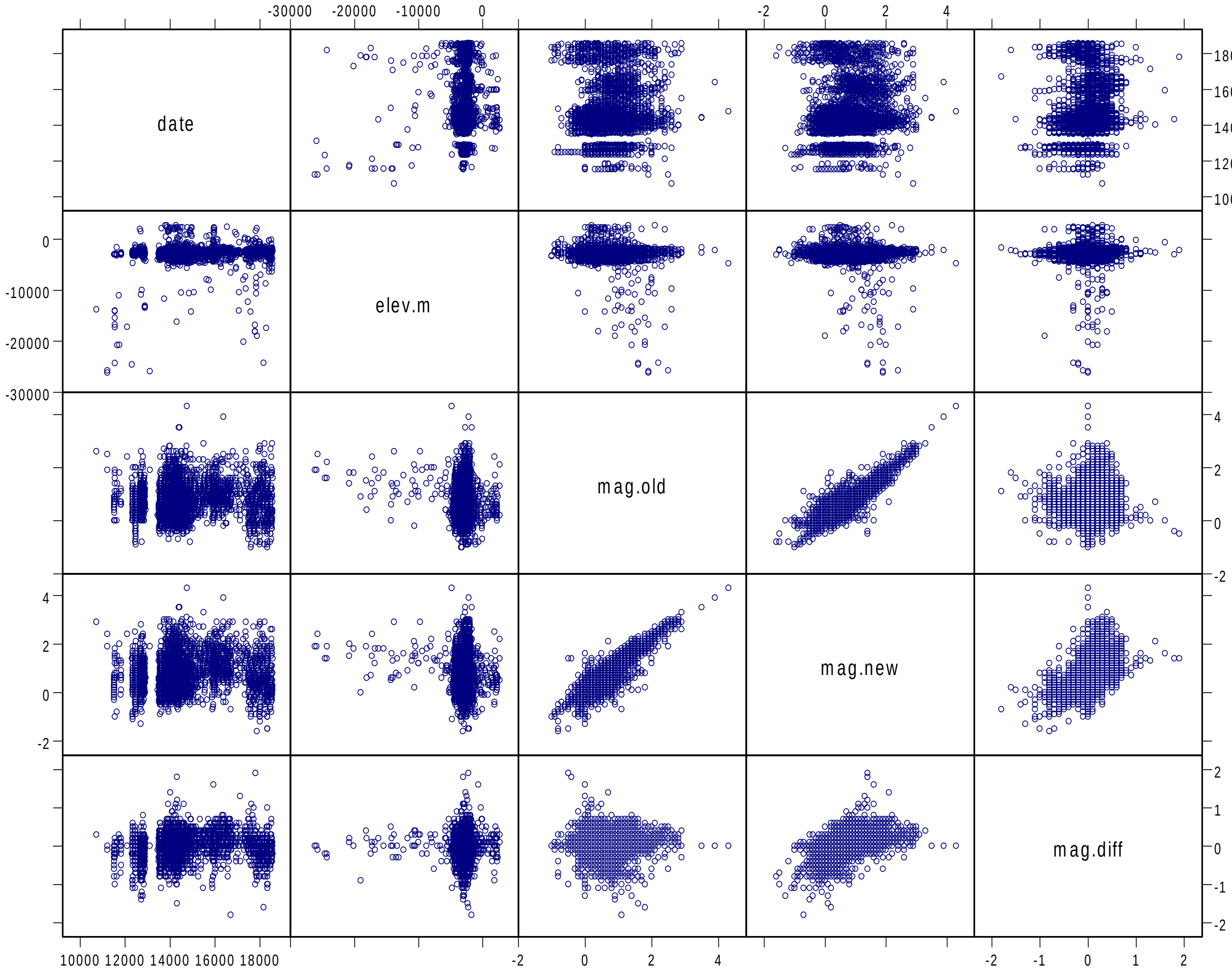

Figure B-1 Scatterplot matrix for all local PVSN earthquakes recorded through November, 2010. Data from over 5,000 earthquakes are shown. Each scatterplot shows the correlations between pairs of variables recorded for every earthquake. Variables considered for this analysis include date (as the number of days from an arbitrary origin), focal depth (as elevation, in m), old and new magnitudes, and magnitude difference.

purposes, a robust linear regression treating the new magnitude as the dependent variable indicates a slope of near unity, and zero intercept. This regression is qualitative since formally, neither magnitude measure can be considered strictly dependent.

The distribution of recorded magnitudes is likely to be a complicated function representing several competing effects. At sufficiently small magnitudes, seismic phases will be undetectable at most stations because of noise and finite dynamic range of the instrumentation, and the earthquakes therefore will not be recorded. This effect will be apparent in the probability density of observed magnitudes by a substantial decrease in recorded earthquakes below a threshold magnitude, which likely varies over time. More realistically, the magnitude detection threshold will be represented by a probability distribution for detection, with a decreasing detection probability below the threshold value, and an increasing detection probability above.

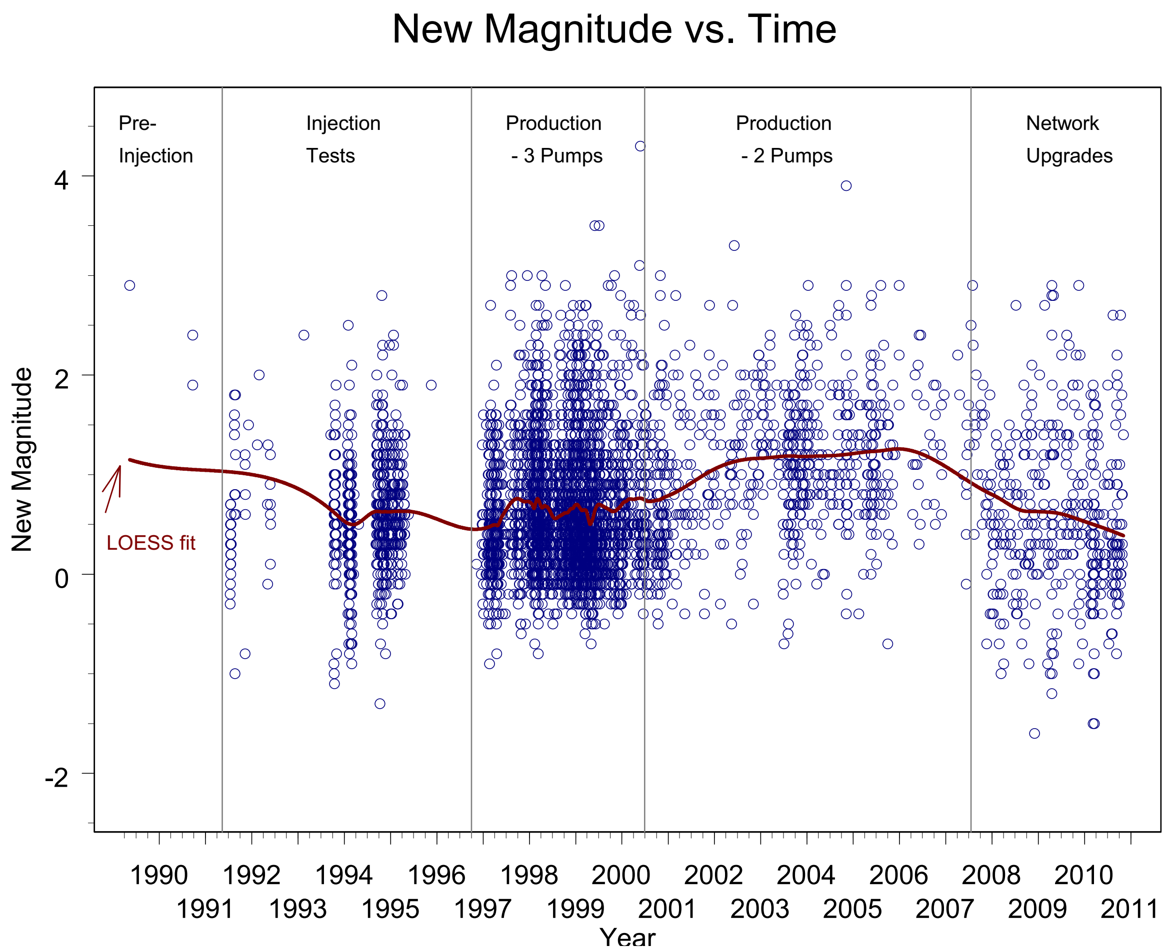

Figure B-2 Scatterplot of new magnitudes versus time. Each blue dot represents a single earthquake. Magnitudes are binned to 1/10 of a magnitude unit, and earthquake occurrence times are binned to 1 day. The occurrence of earthquakes is strongly correlated with injection operations. The number of small-magnitude earthquakes recorded is also correlated with the detection capability of the seismic network, which has been able to detect smaller earthquakes as the seismic network has been upgraded. A locally-weighted scatterplot smoother (LOESS) fit provides the overall trend of the recorded mean magnitude over the lifetime of the network.

Above the threshold magnitude of detection, the observed magnitude distribution should reflect the actual distribution of the underlying earthquake process. For active tectonic areas, an exponential distribution of magnitudes is commonly observed (with aftershocks and foreshocks removed), which is characterized by a decreasing number of earthquakes with increasing magnitude. The a priori distribution for induced PVSN earthquakes is unknown, however it is reasonable to assume that this distribution will also decrease with increasing magnitude.

Probability density distributions for the old and new magnitudes are shown in **Figure B-4**. As expected, the observed distributions are consistent with a decrease in recorded earthquakes at small magnitudes, which is attributed to a decreasing probability of detection, and a decrease at large magnitudes, which is attributed to a typical exponential distribution of the actual earthquakes. Comparison of the new and old magnitude distributions indicates that the

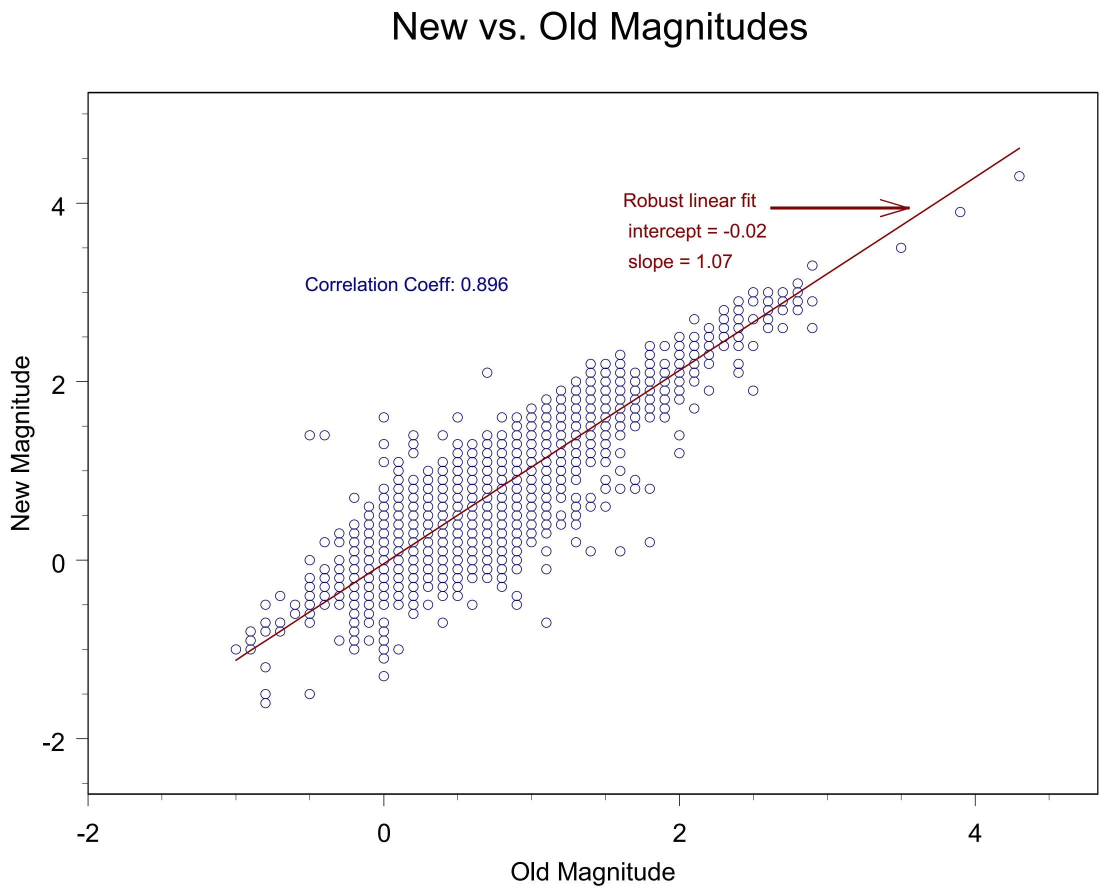

Figure B-3 Scatterplot of new versus old magnitudes showing strong, positive correlation. Each blue dot represents one or more earthquakes. For illustration, a robust linear fit to the scatterplot data was computed, and is shown by the red line. The slope is near unity, and the intercept is approximately 0.

distribution of the new magnitudes is less peaked than the old, and that the process of recalculating magnitudes has resulted in a shift away from the mean for a subset of earthquakes, but with little change in the overall mean value.

The distribution of the magnitude differences, defined as the new magnitude minus the old magnitude for each earthquake, provides another way of examining the effect of recalculating magnitudes. The scatterplot matrix suggests that there is little correlation between the old magnitude and the magnitude difference, and only a weak correlation between the new magnitude and the magnitude difference. Because the magnitude difference appears to be mostly independent of the new and old magnitudes, it is useful to examine its probability density distribution, which is provided in **Figure B-5**. The distribution of magnitude differences shows that the mean difference between new and old magnitudes is nearly zero, and has a standard deviation of about 0.3 magnitude units. This result indicates that the choice of tuning parameters made for the automatic magnitude calculations is consistent with the goal of avoiding a shift in mean magnitudes between the old and new.

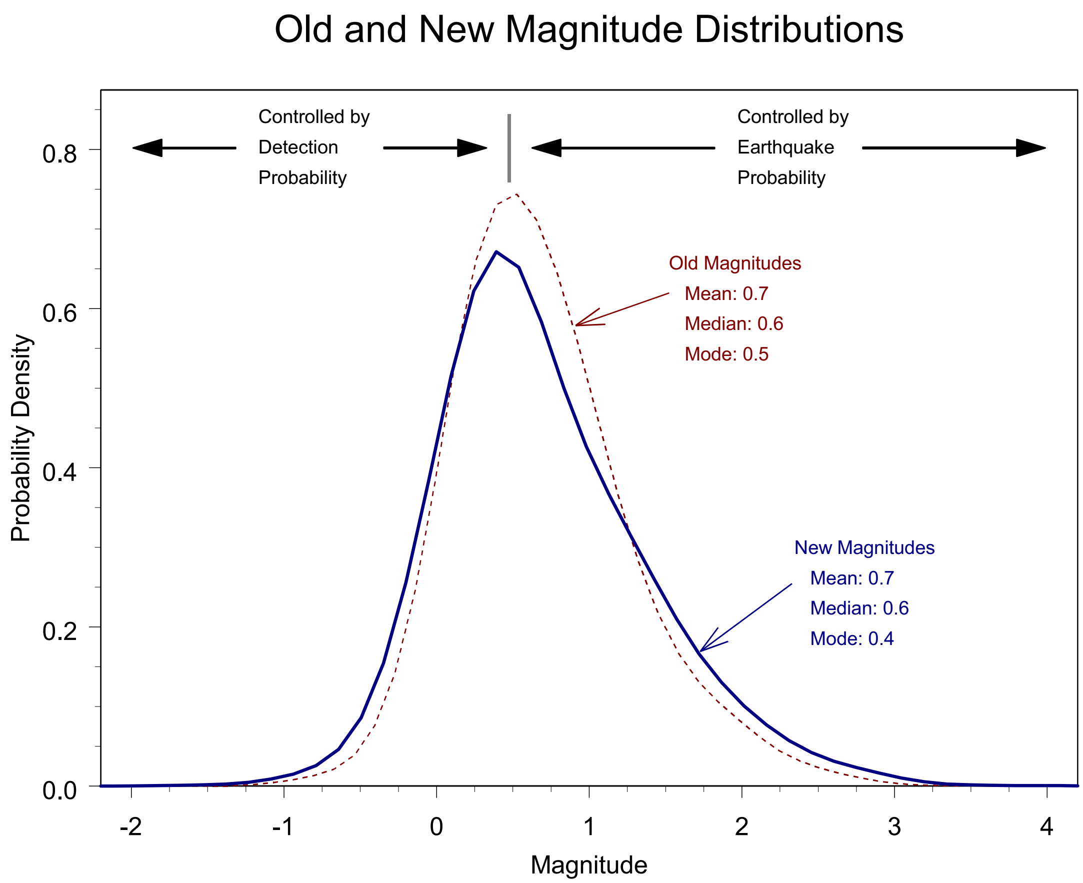

Figure B-4 Probability density functions for the old (solid blue line) and new (red dashed line) magnitudes of recorded local earthquakes. The shape of the observed distributions is controlled by the detection probability for small magnitudes, and by the underlying earthquake probability for large magnitudes. Tuning parameters were selected so that the means of the old and new magnitudes remained unchanged. The effect of the magnitude recalculation is to shift a subset of magnitudes away from the central peak, towards larger or smaller values. The result is a slightly less peaked shape to the distribution.

The observed magnitude difference distribution can be fit to standard probability distributions. To provide further insight, we have fit the observed magnitude difference distribution to two theoretical distributions, Logistic and Normal distributions. Both theoretical distributions appear to provide a good fit to the mean value and standard deviation of the observed magnitude difference distribution, with slightly better statistical measures found for the Logistic model. A quantile-quantile (QQ) plot of the observed distribution with the fitted Normal distribution (**Figure B-6**) indicates that the observed distribution has “thicker tails” than a Normal distribution. In contrast, a QQ plot of magnitude differences and logistic distribution (**Figure B-7**) indicates that the Logistic distribution provides a better fit to the tails of the observed

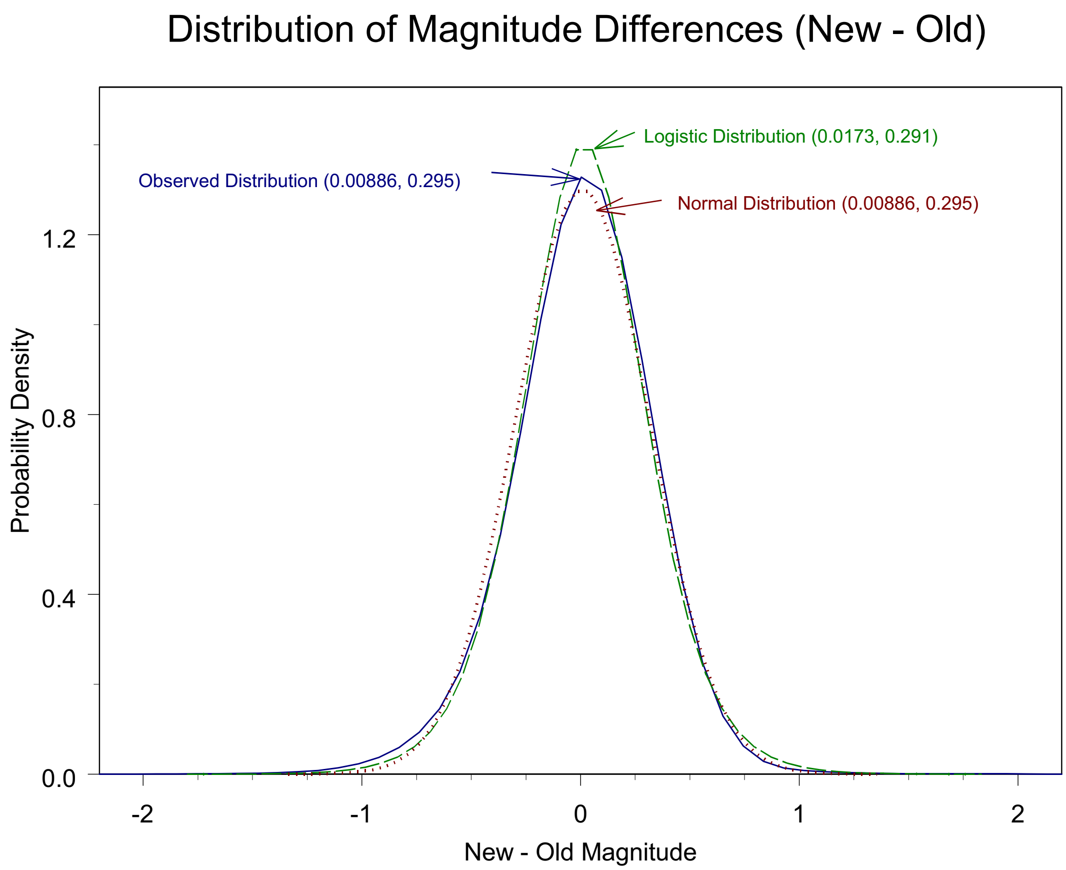

Figure B-5 Probability density distribution of magnitude differences between the new and old magnitudes calculated for all local PVSN earthquakes. The observed distribution was fit using two theoretical distributions, Logistic and Normal. Numbers in parentheses are the mean and standard deviation, respectively, for each distribution. Visually, both theoretical distributions provide a good fit to the observed differences.

magnitude difference distribution.

The magnitudes of the smallest and largest earthquakes are poorly constrained. For the smallest earthquakes, it may be possible to calculate durations for only a small number of stations, and the duration estimated for each station is likely to have considerable uncertainty due to the presence of noise. For the largest earthquakes, the duration of recording must be sufficiently long to provide a good duration estimate, with minimal extrapolation beyond the observed seismogram. Unfortunately, expected durations for large earthquakes tends to exceed several minutes. Until 2007, the PVSN recording system did not allow such long recordings (a holdover from the computer systems of the 1990s needed to avoid running out of storage space), and thus the duration of events were limited to about two minutes. Duration magnitudes for the largest events, which were recorded by this system, are therefore extrapolations beyond the actual record lengths, and thus are likely to have large uncertainty.

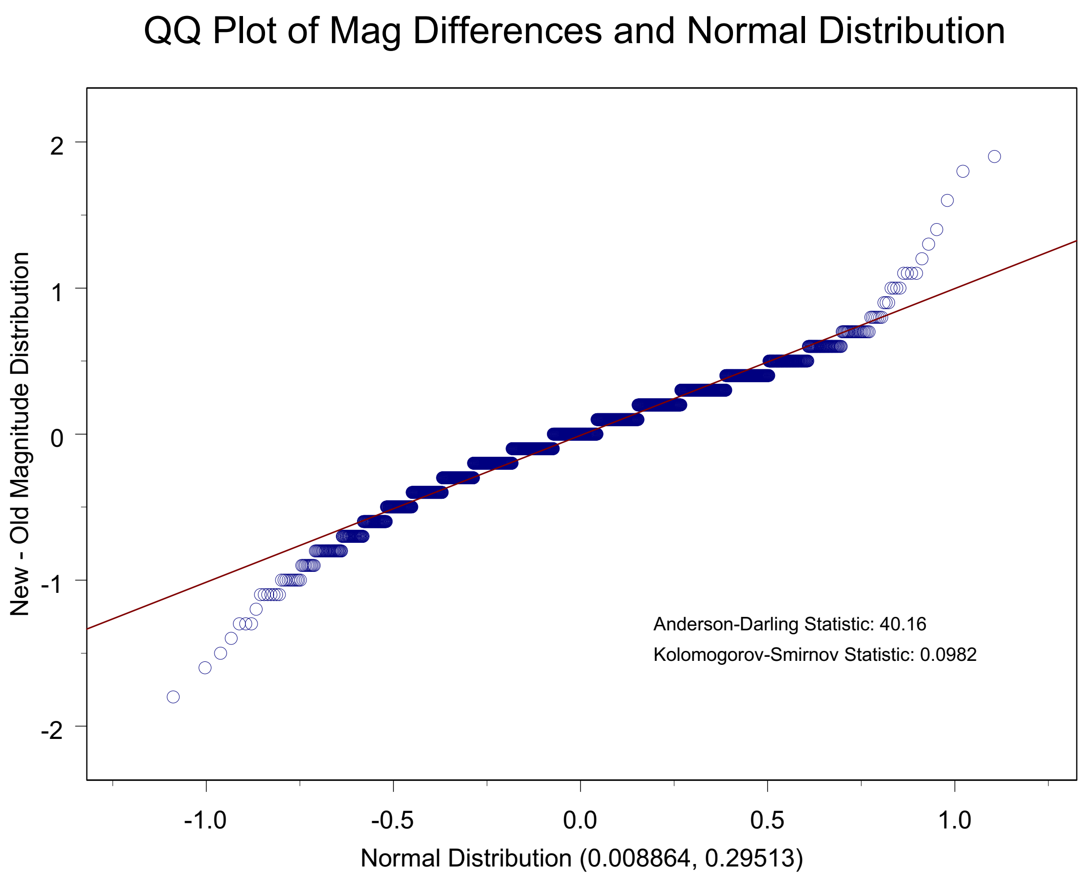

Figure B-6 Quantile-quantile plot of magnitude differences and fitted Normal distribution. Numbers in parentheses refer to the mean and standard deviation of the fitted Normal distribution. The red line represents a linear fit to the second and third quartiles.

It appears that the duration magnitude recalculation appears to have provided more reliable estimates of magnitude by considering all available data, and by introducing an automated procedure that minimizes subjective bias inherent in interactive analysis. Tuning parameters for the recalculation were selected to avoid large changes in the mean magnitudes, providing compatibility with previous magnitude estimates.

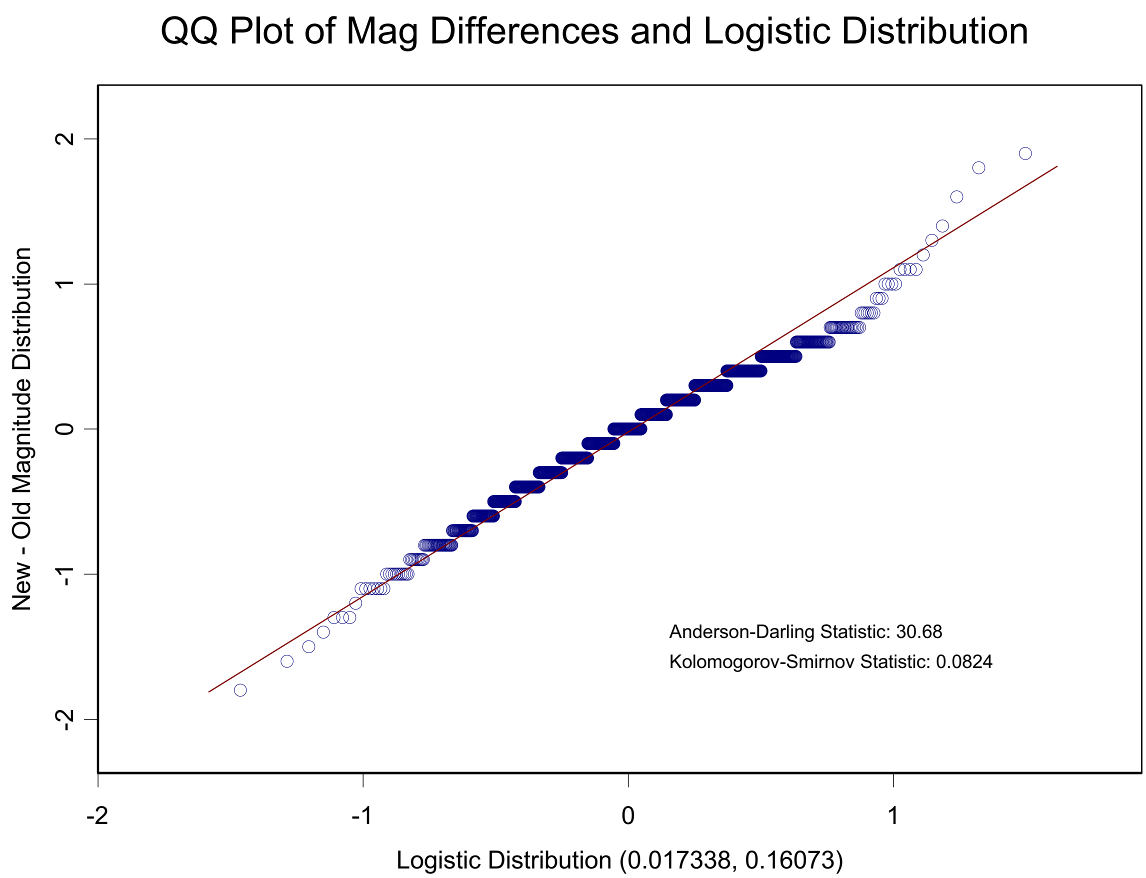

Figure B-7 Quantile-quantile plot of magnitude differences and fitted Logistic distribution. Numbers in parentheses refer to the mean (location) and scaling parameters of the fitted Logistic distribution. The red line represents a linear fit to the second and third quartiles.

APPENDIX C

2010 SITE VISIT REPORTS

Paradox Valley Seismic Network - Site Visit Summary

Site Visit Number: PVSN-2010-5 **Departure Date:** 4/19/2010 **Return Date:** 4/20/2010

Purpose: Repair router at Hopkins Field; Strong-motion instrument maintenance

Work Summary: Replaced defective fans in router at Hopkins Field; Performed preventive and remedial maintenance on the strong-motion instruments.

Action Items:

1	Prepare an evaluation of options for upgrading the remaining set of stations to be completed in calendar year 2010, including likely decommissioning and replacement of PV08 and PV09, and adding new stations.
2	Reach a decision on which sites to add, if any, and decide on the final set of stations to upgrade to digital.
3	Prepare documentation needed for permit applications.
4	Submit permit applications and obtain permits (by April 15th, if possible).
5	Plan for late April or May trip with USGS to perform site preparations for this final set of stations.

Personnel:

	Name	Organization
1	David Copeland	Reclamation, Seismotectonics & Geophysics, 86-68330

Work by Site:

	Site	Work Accomplished
1	Hopkins Field	Replace router fans
2	PVPP	Check phones; check system; replace batteries
3	PVEF	Check phones; check system; replace batteries
3	PVCC	Check phones; replace modem; check system; replace batteries

Paradox Valley Seismic Network - Site Visit Summary

Site Visit Number: PVSN-2010-6 **Departure Date:** 5/9/2010 **Return Date:** 5/21/2010

Purpose: Station repair and seismometer installation

Work Summary: Station repairs were completed at three sites; Station upgrades were completed at four sites; Digital seismometers were installed at five sites, bringing the total number of online, upgraded digital stations to 13. All seismometers at the visited sites were oriented to True North using a precision laser alignment tool.

Action Items:

1	Plan a trip for site visits for cultural and environmental resource specialists, as required for processing of permit requests for new stations.
2	Reach a decision on which sites to add, if any, and decide on the final set of stations to upgrade to digital.
3	Prepare documentation needed for permit applications.
4	Plan for a brief field trip to reorient seismometers at the two remaining digital sites (PV12 and PV14), and repair analog station PV15. Work should be done during the trip for item 1.
5	Plan for late August or September trip with USGS to perform site preparations for the final set of stations.

Personnel:

	Name	Organization
1	Chris Wood	Reclamation, Seismotectonics & Geophysics, 86-68330
2	Zeb Maharrey	US Geological Survey, Golden

Work by Site:

	Site	Work Accomplished
1	Hopkins Field	Replace PV04/PV12 antenna
2	PV01	Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Inscribe N/S line in seismometer vault with laser alignment tool. Install and test digital seismometer.
3	PV02	Upgrade GPS BOB, and Sensor Vault BOB. Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Measure existing orientation of seismometer and inscribe new N/S line in seismometer vault with laser alignment tool.
4	PV03	Upgrade GPS BOB, Sensor Vault BOB, and add low-voltage disconnect/automatic fuse blocks for station batteries. Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Measure existing orientation of seismometer and inscribe new N/S line in seismometer vault with laser alignment tool.
5	PV04	Disassemble station, install new tower base, and then reinstall station. Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Measure existing orientation of seismometer and inscribe new N/S line in seismometer vault with laser alignment tool.
6	PV05	Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Inscribe N/S line in seismometer vault with laser alignment tool. Install and test digital seismometer.
7	PV07	Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Inscribe N/S line in seismometer vault with laser alignment tool. Install and test digital seismometer.
8	PV10	Upgrade GPS BOB, Sensor Vault BOB, and add low-voltage disconnect/automatic fuse blocks for station batteries. Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Measure existing orientation of seismometer and inscribe new N/S line in seismometer vault with laser alignment tool.
9	PV11	Replace failed radio on digital station. Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Measure existing orientation of seismometer and inscribe new N/S line in seismometer vault with laser alignment tool.
10	PV13	Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Inscribe N/S line in seismometer vault with laser alignment tool. Install and test digital seismometer.

11	PV16	Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Inscribe N/S line in seismometer vault with laser alignment tool. Install and test digital seismometer.
12	PV17	Upgrade GPS BOB, Sensor Vault BOB, and add low-voltage disconnect/automatic fuse blocks for station batteries. Test GPS and seismometer cables with automated cable tester. Test antennas and transmission lines. Measure existing orientation of seismometer and inscribe new N/S line in seismometer vault with laser alignment tool.





Clockwise from upper left: (1) At PV04, a new enclosure and second solar panel were added to the original 23-foot tower in 2009. The tower was apparently toppled by wind loading in March, 2010 (top left). (2) The original PV04 tower base was found to consist of a 3-foot section secured with 120 lbs. of concrete, and excavated just 1-1/2 feet into sand. (3) A new 4-foot deep hole was excavated at the same location, but now extends 2 feet into rock. (4) A new 5-foot base section was emplaced with 1,000 lbs. of concrete (first 10-foot section is shown bolted to base) (5) PV04 has been entirely rebuilt on the new base.

A prototype laser alignment tool is being used to orient seismometers to true north. A north-south line is inscribed on the bottom of the seismometer vault (yellow). The seismometer is then rotated until its north-south indicators (bottom of the case) line up. The laser alignment tool uses a Brunton compass to determine true north. Precision is about 0.5 degrees, and is limited by the resolution of the compass dial. A calibration jig and 3-axis adjustment screws (left photo) align the compass with the laser. Original black line in the photo at left was inscribed using a straight-edge and plumb-bob method, which is less accurate. The faint red line in the photo at left is the laser. The original (black) line and the laser (red) line form an angle of just 1.5 degrees, which is readily observable. Of the 6 seismometers reoriented to date, the measured errors of the original north lines have ranged between 0 and 3.5 degrees.

Paradox Valley Seismic Network - Site Visit Summary

Site Visit Number: PVSN-2010-7 **Departure Date:** 6/21/2010 **Return Date:** 6/26/2010

Purpose: Visit proposed new sites with Reclamation cultural and environmental specialists to provide documentation for NEPA compliance. Finalize locations of seismometer vaults and tower bases. Perform radio checks to verify communications to new sites. Station repairs.

Work Summary: Cultural and environmental resource inventories were completed on all BLM sites. Radio checks were performed at all sites. Final seismometer vault and tower locations were determined for all sites. Electronics updates performed at PV12. A temporary protein source was reluctantly provided for an indigenous population of *leptoconops Americanus*.

Action Items:

1	Decide on final selection of new sites. All sites were found to have radio communications with established hub sites, however BR-2 is marginal. Tests with a 20' pole indicate that BR-2 may be visible from the adjacent road.Station BR-9 appears to have much better radio coverage, although is not as far wets on Carpenter Ridge as BR-2.
2	Track applications and determine realistic dates they may be available.
3	Schedule initial installation trip (September??)

Personnel:

	Name	Organization
1	Chris Wood	Reclamation, Seismotectonics & Geophysics, 86-68330
1	Mark Meremonte	USGS, Golden, Colorado

Work by Site:

	Site	Work Accomplished
1	BR-1	Cultural and environmental resource inventory; Stake final seismometer vault and tower locations; Perform Radio check.
2	BR-8	Cultural and environmental resource inventory; Stake final seismometer vault and tower locations; Perform Radio check.
3	BR-7	Cultural and environmental resource inventory; Stake final seismometer vault and tower locations; Perform Radio check.
4	BR-5	Cultural and environmental resource inventory; Stake final seismometer vault and tower locations; Perform Radio check.
5	BR-6	Cultural and environmental resource inventory; Stake final seismometer vault and tower locations; Perform Radio check.
6	BR-3	Cultural and environmental resource inventory; Stake final seismometer vault and tower locations; Perform Radio check.
7	BR-2	Stake final seismometer vault and tower locations; Perform Radio check.
8	BR-9	Stake final seismometer vault and tower locations; Perform Radio check.
9	PV-12	Install new LVD battery blocks; orient seismometer with laser tool.

Paradox Valley Seismic Network - Site Visit Summary

Site Visit Number: PVSN-2010-8 **Departure Date:** 10/13/2010 **Return Date:** 10/16/2010

Purpose: Repair and upgrade seismograph stations.

Work Summary: Several offline stations were repaired and minor upgrades were performed.

Action Items:

1	Troubleshoot and repair PV15 (analog) data transmission.
2	Replace GPS antenna at Hopkins Field (intermittant loss of fix).

Personnel:

	Name	Organization
1	Chris Wood	Reclamation, Seismotectonics & Geophysics, 86-68330

Work by Site:

	Site	Work Accomplished
1	PV01	Offline digital radio was rebooted and tested; no problems were found. Low-voltage disconnect (LVD) and automatic fusing circuits were installed to prevent discharge of all batteries in the event that any one battery fails, and to reduce lightning-induced transients. Station was brought back online.
2	PV03	Replaced defective broad-band digital seismometer (had a bad horizontal component), and installed a compatible GPS antenna.
3	PV12	Checked seismometer orientation and added foam insulation to vault.
4	PV14	Oriented seismometer with precision laser tool; added foam insulation; Installed LVD fusing circuits.
5	PV15	Replaced bad analog transmitter; installed lightning protection for transmitter; measured analog signal levels and verified operation of the station (note: station signals still are not being received at Hopkins Field, indicating additional problems at the PV02 repeater, or with the electronics at Hopkins Field - due to time limitations, these problems could not be fixed during this trip)
6	PV16	Replaced GPS antenna that had hung (although old antenna seemed to work once the power had been cycled). Timing restored for digital station.

Precision laser orientation tool in use at PV12.

Paradox Valley Seismic Network - Site Visit Summary

Site Visit Number: PVSN-2010-8 **Departure Date:** 12/7/2010 **Return Date:** 12/7/2010

Purpose: Replace GPS antenna at Hopkins Field

Work Summary: Replaced defective GPS antenna at Hopkins Field

Action Items:

1	None

Personnel:

	Name	Organization
1	David Copeland	Reclamation, Seismotectonics & Geophysics, 86-68330

Work by Site:

	Site	Work Accomplished
1	Hopkins Field	Replace GPS antenna