

FINAL TECHNICAL REPORT

Upgrades to Earthquake Monitoring Systems in the Utah Region

September 2009–September 2011

U.S. Geological Survey Cooperative Agreement No. G09AC00467 (ARRA)

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November 28, 2011

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number G09AC00467. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Abstract

Upgrades to the University of Utah Seismograph Stations (UUSS) earthquake monitoring system consisted of updating outdated seismic recording equipment at 10 regional broadband stations, adding strong-motion sensors where needed; updating outdated seismic recording equipment at 14 legacy analog seismic stations; instrumenting four vacated EarthScope Transportable Array vaults; improving data-processing and communication systems; and training undergraduate students in seismic network operations. The project provided funding needed to fill a vacant position for a full-time seismic technician, including benefits; provided funding for ~25 days of work for various part-time employees who helped with field deployments and the data processing system; and provided funding to hire undergraduate students. The ARRA funding also allowed UUSS to preserve staffing levels threatened by cuts in state budgeting due to the nation-wide recession. The upgrades to the seismic instrumentation, data-processing, and communication systems have enhanced the UUSS ability to detect and characterize seismicity in Utah, and will allow UUSS to better meet Advanced National Seismic System (ANSS) performance standards.

Introduction

This final technical report summarizes activities related to upgrading and modernizing the University of Utah Seismograph Stations (UUSS) earthquake monitoring system—a.k.a. the Utah Regional Seismic Network (URSN)—under the American Recovery and Reinvestment Act (ARRA) from September 22, 2009 through September 15, 2011. Quarterly reports were informally submitted to the USGS Project Manager and are included here as an Appendix .

The completed work consisted of equipment upgrades to regional seismic systems, advances in the data processing system, and upgrades to communication systems in the URSN. As a result of this project we improved the existing seismic acquisition and processing infrastructure in Utah; hired a full-time seismic technician for two years, with benefits; hired undergraduate students (at a time when tuition was rising) thus providing advanced technical training to help meet ANSS objectives; and provided ~25 days of additional work to part-time employees who helped with field deployments and helped in advancing the data processing system.

Station Upgrades

The station upgrades consisted of three major field efforts: (1) upgrades to ten broadband stations, (2) upgrades to 14 analog short-period stations, including upgrades to the telemetry nodes, and (3) the adoption of four former EarthScope Transportable Array (TA) vaults. Figure 1 shows Utah's Wasatch Front area and the map distribution of URSN stations that were upgraded as part of this project. As shown, much of the effort was to upgrade stations near the Wasatch Fault. During the past 6,000 years, at least 20 surface-faulting earthquakes have occurred along the five central segments of this fault. A clear objective of ANSS is to record earthquake ground motions close to major active faults.

The upgrades to the targeted broadband stations included replacing out of date equipment such as REF TEK 72A-07 and 72A-08 dataloggers, Guralp CMG-40T broadband sensors, and serial radios; strong-motion sensors were added where needed. Table 1 summarizes the old and upgraded instrumentation for the broadband sites and tabulates the dates of completion. Figure 2 shows an example of a Power Density Function (PDF) plot for station CTU before and after the upgrade of the older Guralp CMG-40T broadband sensor to a more modern REF TEK 151 broadband sensor. The PDFs illustrate the corresponding level of

noise measured by the sensors before and after the upgrade. It is clear from this figure that the new triaxial sensor increases the useable frequency range of recording, especially at periods greater than 8 seconds. Similar improvements resulted at the other upgraded broadband stations. The greater sensitivity of the modern instrumentation will improve the ability to detect seismic events and to model corresponding waveforms from these stations. These improvements directly affect the ability of the network to meet ANSS performance standards.

The upgrades to the analog short-period sensors included the addition of digital recorders and three-component accelerometers. By upgrading from analog to digital, the dynamic range of the instrument is increased, allowing for a wider range of signals to be recorded. The accelerometers allow for on-scale recording of large nearby earthquakes. Capturing on-scale ground motion close to the fault is an objective of the ANSS. The upgrade from analog to digital recording also required upgrades to radios at telemetry nodes located on mountaintops throughout the state. The four adopted TA vaults were instrumented to match the short-period upgrades. The locations of the adopted vaults were chosen to improve overall network coverage. Dates of completion for these upgrades can be found in the Appendix.

Improved Communication Systems and Advances in Data Processing

The improvements in data processing and communications fall into two categories: (1) purchasing and installing equipment to harden network performance and (2) completing tasks related to migrating to the new ANSS Quake Monitoring System (AQMS). Equipment improvements included a new computer to handle exchange of data with other networks (both import and export), new back-up computers to service computer systems distributed throughout the state, and new radios to improve communication and data reliability. Many of the radios went to replace unreliable telemetry from 8 stations located in or near the Salt Lake Valley.

Migrating to AQMS requires a major change in data processing systems for UUSS, and as part of ARRA we worked on five aspects of the upgrade: (1) adding a second Oracle database, (2) loading of the station metadata, (3) configuring dataflow, (4) configuring and loading databases, and (5) configuring Utah-specific velocity models and magnitude equations. For several of these objectives, UUSS worked with AQMS developers to implement needed software changes.

Summary

As a result of the ARRA award UUSS was able to preserve staffing levels and hire a full-time seismic technician, with full benefits. UUSS was also able to provide part-time work for other professionals and undergraduate students. The upgrades to the outdated seismic instrumentation, communication systems, and data processing have provided significant infrastructure improvements. These improvements will enhance the UUSS ability to detect and characterize seismicity in Utah and allow UUSS to better meet the ANSS performance standards.

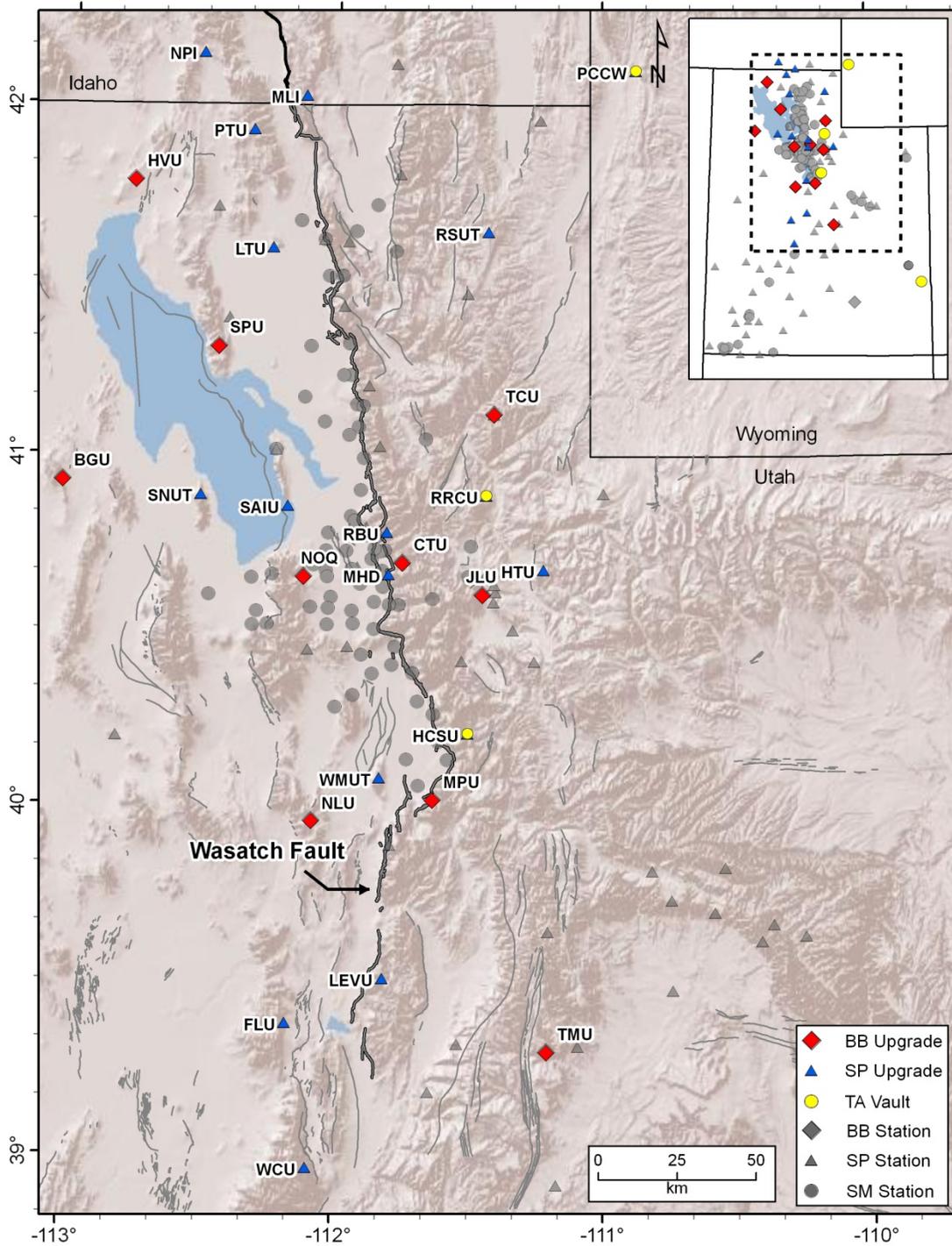


Figure 1. Locations of 28 stations upgraded during the ARRA award, including 10 broadband (BB) stations, 14 short-period (SP) stations and four vacant TA vaults. Gray symbols show the distribution of other URSN seismic stations.

Station CTU Before and After Upgrade

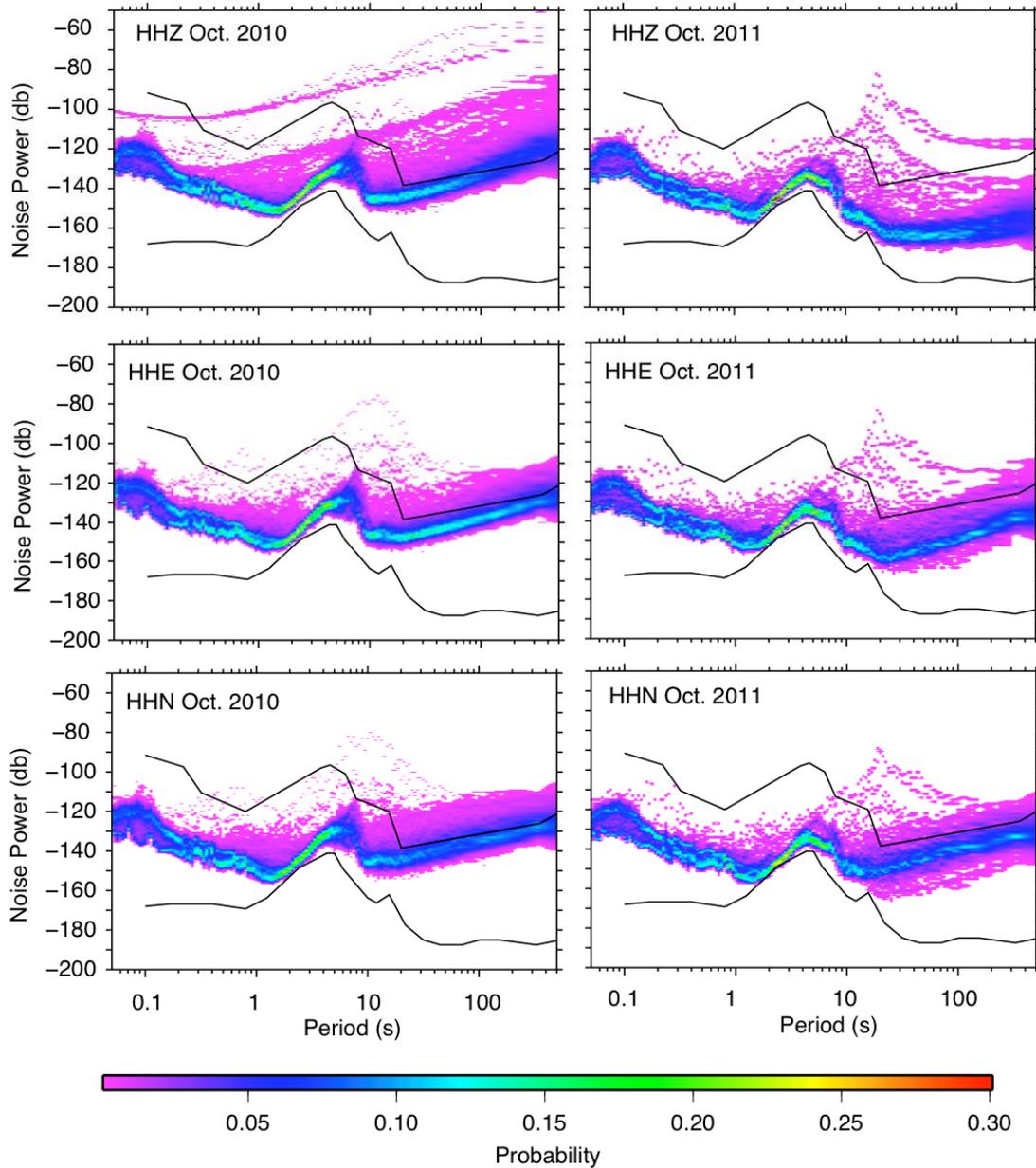


Figure 2. Continuous data PDFs for broadband station CTU computed (left) before and (right) after the ARRA supported upgrade. Calculations were made using a technique similar to that of *McNamara and Buland* [2004]. The same month in each year is shown to account for seasonal variations in ambient noise. The black curves in each panel show the Peterson Low and High Noise Models. In this case a Guralp 40T seismometer was replaced with a Reftek RT 151 seismometer.

Table 1. Broadband Station Upgrades								
Network Code	Station Code	Pre-Acquisition System	Pre-High-gain Sensor	Pre-Strong-motion Sensor	Post-Acquisition System	Post-High-Gain Sensor	Post-Strong-motion Sensor	Date of Completion
UU	BGU	72A-08	CMG-3ESP	FBA ES-T	<i>Q330</i>	<i>Trillium 120</i>	FBA ES-T	11/04/2009
UU	CTU	72A-07	CMG-40T	N/A	<i>RT130</i>	<i>REF TEK 151</i>	<i>REF TEK 147</i>	6/14/2011
UU	HVU	72A-07	CMG-40T	N/A	<i>Q330</i>	<i>Trillium 120</i>	<i>FBA ES-T</i>	11/12/2009
UU	JLU*	RT130	CMG-3ESP	MEMS	RT130	CMG-3ESP	MEMS	7/26/2010
UU	MPU	72A-07	CMG-40T	K2 w/int ES	<i>RT130</i>	<i>CMG-3ESP</i>	<i>FBA ES-T</i>	6/03/2010
UU	NLU	72A-08	CMG-3ESP	FBA ES-T	<i>RT130</i>	<i>CMG 3-T</i>	FBA ES-T	7/09/2010
UU	NOQ	72A-08	CMG-40T	FBA ES-T	<i>RT130</i>	<i>Trillium 120</i>	FBA ES-T	3/22/2010
UU	SPU	72A-08	CMG-3ESP	FBA ES-T	<i>RT130</i>	<i>CMG-3ESP</i>	FBA ES-T	6/30/2010
UU	TCU	72A-08	CMG-3ESP	FBA ES-T	<i>RT130</i>	CMG-3ESP	FBA ES-T	9/16/2010
UU	TMU	72A-08	CMG-40T	FBA ES-T	<i>RT130</i>	<i>REF TEK 151</i>	FBA ES-T	9/30/2010

* Radio upgrade only

Note: equipment that was replaced or added as part of upgrade is shown in italics

Appendix

Progress Report: USGS Award No. G09AC00467 (ARRA) Quarterly Period: October 1–December 31, 2009 Date of Report: December 22, 2009	
Progress Meeting Milestones	
<i>September 30, 2009</i>	
<ul style="list-style-type: none"> • Completion of Task 4-B (acquire two computers and one disk-storage array for spare equipment) 	Disk-storage array ordered December 2009. We are investigating cost-effective options for purchasing the spare computers
<ul style="list-style-type: none"> • Completion of Task 4-C (acquire three spare digital radios) 	Task complete, radios purchased October 2009
<i>December 31, 2009</i>	
<ul style="list-style-type: none"> • Completion of Task 3-B (acquire/install redundant data storage computer) 	Computer ordered December 2009
<ul style="list-style-type: none"> • Completion of Task 3-C (acquire/install replacement computer for Earthwork import/export) 	Computer ordered December 2009
<ul style="list-style-type: none"> • CISN: Dataflow configuration files in place 	Preliminary configuration files in place
<ul style="list-style-type: none"> • CISN: Database configuration files in place 	Preliminary configuration files in place
Other Achievements and Progress	
<p>With equipment provided early by the USGS, we completed the upgrade of 2 (of 10) broadband stations (HVU and BGU), six months ahead of schedule. This included required certification of each station and delivery of a corresponding dataless SEED volume to the National Earthquake Information Center.</p>	
<p>An order is being processed for 11 digital radios as part of Task 4-A (upgrading of telemetry of 8 existing strong-motion stations), targeted for completion by March 31, 2010.</p>	
<p>A new full-time seismic network engineer was hired on September 16, 2009, filling a position otherwise lost because of state budget cuts. The engineer will work part-time on this ARRA project. Also, a job advertisement was posted on December 11, 2009 for a full-time seismograph technician, who will also work part-time on this ARRA project.</p>	

Progress Report: USGS Award No. G09AC00467 (ARRA)

Quarterly Period: January 1–March 31, 2010

Date of Report: March 31, 2010

Progress Meeting Milestones

September 30, 2009

- | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|
| <ul style="list-style-type: none">• Completion of Task 4-B (acquire two computers and one disk-storage array for spare equipment) | Task complete, all computer equipment delivered by 3/8/2010 |
|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------|

December 31, 2009

- | | |
|---------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none">• Completion of Task 3-B (acquire/install redundant data storage computer) | Task completed, AQMS Oracle database replicated on 3/26/2010 |
| <ul style="list-style-type: none">• Completion of Task 3-C (acquire/install replacement computer for Earthwork import/export) | Installation 60% complete as of 3/31/2010 |
| <ul style="list-style-type: none">• CISN: Dataflow configuration files in place | Preliminary configuration files in place as of 9/25/2009
Updated CarlTrig and began testing 3/13/2010 |
| <ul style="list-style-type: none">• CISN: Database configuration files in place | Preliminary configuration files in place as of 9/25/2009 |

March 31, 2010

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| <ul style="list-style-type: none">• Completion of Task 4-A (acquire/install 11 new digital radios in the Wasatch Front urban corridor) | Task complete. |
| <ul style="list-style-type: none">• CISN: Integration of UUSS metadata | Using ISTI provided files since 9/25/2009 |
| <ul style="list-style-type: none">• CISN: Configure hypo2000 with Utah appropriate velocity models | Not started |

Other Achievements and Progress

A job advertisement was posted on December 11, 2009 for a full-time seismograph technician, who will work part-time on this ARRA project. A suitable candidate has been hired. His start date is April 1, 2010.

Progress Report: USGS Award No. G09AC00467 (ARRA)

Quarterly Period: April 1–June 30, 2010

Date of Report: June 30, 2010

Progress Meeting Milestones

<i>December 31, 2009</i>	
<ul style="list-style-type: none">• Completion of Task 3-C (acquire/install replacement computer for Earthworm import/export)	Will install Earthworm v7.4, which was released 4/29/2010. Install to be completed by 7/31/2010.
<ul style="list-style-type: none">• AQMS: Dataflow configuration files in place	Preliminary configuration files in place as of 9/25/2009 Updated CarlTrig and began testing 3/13/2010 Cont. CarlTrig testing 6/30/2010
<ul style="list-style-type: none">• AQMS: Database configuration files in place	Preliminary configuration files in place as of 9/25/2009
<i>March 31, 2010</i>	
<ul style="list-style-type: none">• AQMS: Integration of UUSS metadata	Using ISTI provided files since 9/25/2009 Local training to insert metadata information from dataless SEED volumes into AQMS databases 6/30/2010
<ul style="list-style-type: none">• AQMS: Configure hypo2000 with Utah appropriate velocity models	Installed hypoinverse2000 outside of AQMS (and associated velocity models) for configuring and testing purposes 6/08/2010
<i>June 30, 2010</i>	
<ul style="list-style-type: none">• Complete upgrade of 5 stations (Total 5/28)	BGU activated 11/04/2009; HVU activated 11/12/2009; NOQ activated 3/22/2010; MPU activated 6/03/2010*; SPU installed 6/30/2010*
<ul style="list-style-type: none">• AQMS: Incorporate UUSS magnitude relations	Not started
<ul style="list-style-type: none">• AQMS: Finalize configuration files	Work in progress

Other Achievements and Progress

The Utah Advisory Committee for Urban Strong Motion Monitoring met May 13, 2010 to discuss priorities for installing 9 NetQuakes instruments. 3/9 NetQuakes were installed this quarter.

The undergraduate student on this project graduated May 2010. A new student has been trained and will be involved in this project starting July 1, 2010.

*At these sites state-owned accelerometers have been installed to stay on schedule for the planned upgrades. We are still waiting for required GFE.

Progress Report: USGS Award No. G09AC00467 (ARRA) Quarterly Period: July 1–September 30, 2010 Date of Report: October 1, 2010	
Progress Meeting Milestones	
<i>December 31, 2009</i>	
<ul style="list-style-type: none"> • Completion of Task 3-C (acquire/install replacement computer for Earthworm import/export) 	Task completed 9/22/2010
AQMS: <ul style="list-style-type: none"> • Database configuration files in place 	Preliminary configuration files in place as of 9/25/2009
<i>March 31, 2010</i>	
<ul style="list-style-type: none"> • AQMS: Integration of UUSS metadata 	Using ISTI provided files since 9/25/2009 Local training to insert metadata information from dataless SEED volumes into AQMS databases 6/30/2010 Awaiting software fix to program fixgains from ISTI 9/30/2010
<ul style="list-style-type: none"> • AQMS: Configure hypo2000 with Utah appropriate velocity models 	Installed hypoinverse2000 outside of AQMS (and associated velocity models) for configuring and testing purposes 6/08/2010
<i>June 30, 2010</i>	
<ul style="list-style-type: none"> • AQMS: Incorporate UUSS magnitude relations 	Work in progress
<ul style="list-style-type: none"> • AQMS: Finalize configuration files 	Work in progress
<i>September 30, 2010</i>	
<ul style="list-style-type: none"> • Complete upgrade of 6 stations (Total 11/28) 	JLU activated 7/26/2010; NLU activated 7/9/2010; TCU activated 9/16/2010; HTU activated 9/22/2010; MHD activated 7/26/2010; O16A activated 8/17/2010; N16A activated 8/10/2010; R19A activated 8/17/2010; TMU installed 9/30/2010. TOTAL 13/28.
Other Achievements and Progress	
Total of 6/10 NetQuakes are installed. One of these is located near Jackson Hole, Wyoming per request from Harley Benz.	
Progress Report: USGS Award No. G09AC00467 (ARRA) Quarterly Period: October 1–December 31, 2010	

Date of Report: January 4, 2011	
Progress Meeting Milestones	
<i>December 31, 2009</i>	
AQMS: <ul style="list-style-type: none"> Database configuration files in place 	Preliminary configuration files in place as of 9/25/2009
<i>March 31, 2010</i>	
<ul style="list-style-type: none"> AQMS: Integration of UUSS metadata 	Task completed 12/31/2010
<ul style="list-style-type: none"> AQMS: Configure hypo2000 with Utah appropriate velocity models 	<p>Modified hypoinverse2000 to calculate and report negative magnitudes, to include options for using the Richter distance table and calculating a mean magnitude, and enhanced the output to include additional magnitude calculations 12/26/2010</p> <p>Modified code sent to Fred Klein for inclusion into standard release 12/27/2010. Klein has also agreed to add elevation corrections and separate P- and S-velocity models to the standard release and will look into options for different duration magnitude equations based on location</p>
<i>June 30, 2010</i>	
<ul style="list-style-type: none"> AQMS: Incorporate UUSS magnitude relations 	Work in progress
<ul style="list-style-type: none"> AQMS: Finalize configuration files 	Earthworm related configuration files complete 12/31/2010
<i>December 31, 2010</i>	
<ul style="list-style-type: none"> Complete upgrade of 6 stations (Total 17/28) 	LTU activated 10/27/2010; SAIU activated 11/10/2010; TMU activated 10/14/2010; WCU activated 10/8/2010; WMUT activated 11/10/2010. TOTAL 18/28.
Other Achievements and Progress	
Total of 7/10 <i>NetQuakes</i> are installed. One of these is located near Jackson Hole, Wyoming per request from Harley Benz. One of 10 has been returned to Menlo Park for repair.	
<i>NSMP Upgrades.</i> 19 Basalts were received 11/23/2010. We are awaiting instructions from NSMP regarding upgrading 9 stations currently using dial-up telemetry. 2/7 (7224, 12/15/2010 and 7226, 12/16/2010) stations with telemetry to UUSS have been upgraded. For the remaining 3 stations we need to determine telemetry options	
Progress Report: USGS Award No. G09AC00467 (ARRA)	
Quarterly Period: January 1–March 31, 2011	

Date of Report: March 31, 2011	
Progress Meeting Milestones	
<i>March 31, 2010</i>	
<ul style="list-style-type: none"> • AQMS: Configure hypo2000 with Utah appropriate velocity models 	<p>Downloaded the revised Hypoinverse (V1.3b) that has code changes requested by UUSS and others. Created a test environment and compiled a set of test events. Tested the revised code paying careful attention to the requested changes, particularly magnitude calculations, separate P and S velocity models, and elevation corrections. Provided feedback to Fred Klein.</p> <p>Began compiling recently determined velocity models for the Utah and Yellowstone regions for possible use with the new version of Hypoinverse.</p>
<i>June 30, 2010</i>	
<ul style="list-style-type: none"> • AQMS: Incorporate UUSS magnitude relations 	Communicated extensively with AQMS software developers to find out how the magnitude software works (especially in Jiggle) and identify the changes needed to enable compatibility with UUSS magnitude determination methods. Began testing the software and reported two bugs which are now fixed.
<ul style="list-style-type: none"> • AQMS: Finalize configuration files 	Earthworm related configuration files complete 12/31/2010
<i>March 31, 2011</i>	
<ul style="list-style-type: none"> • Plan for season two field work 	Datalogger configuration complete; Some telemetry set-ups upgraded in preparation for new instrumentation. 3/31/2011
Other Achievements and Progress	
Three UUSS staff members attended the ANSS NetOpsV workshop on AQMS held in Pasadena, CA February 2 – 3, 2011. Jim Pechmann led the discussion on magnitude determinations in AQMS.	
Total of 7/10 <i>NetQuakes</i> are installed. One of these is located near Jackson Hole, Wyoming per request from Harley Benz. Two new potential locations have been identified that meet the siting criteria provided by the Utah Strong-Motion Advisory Committee.	
<i>NSMP Upgrades.</i> Remaining 5/7 stations with telemetry to UUSS have been upgraded : 2272, 1/20/2011; 7212, 1/26/2011; 2286, 1/28/2011; 7228, 2/3/2011; and 7227, 2/4/2011. 3/3 stations that were on-site recording only have been upgraded and real-time telemetry added to UUSS: 2285, 3/4/2011; 7202, 3/14/2011; and 7203, 3/11/2011. 9 raven modems with cables and antennas received 3/8/2011 for upgrading dial-up stations. 2/9 dial-up stations upgraded: 2282, 3/23/2011; and 7231, 3/25/2011	
Progress Report: USGS Award No. G09AC00467 (ARRA)	
Quarterly Period: April 1–June 30, 2011	

Date of Report: June 30, 2011	
Progress Meeting Milestones	
<i>March 31, 2010</i>	
<ul style="list-style-type: none"> • AQMS: Configure hypo2000 with Utah appropriate velocity models 	<p>Completed testing of Hypoinverse (V1.3c).</p> <p>Continued compiling recently determined velocity models for the Utah and Yellowstone regions for possible use with the new version of Hypoinverse. Developed criteria for testing the different velocity models.</p>
<i>June 30, 2010</i>	
<ul style="list-style-type: none"> • AQMS: Incorporate UUSS magnitude relations 	<p>Submitted a list of requested changes to Jiggle, including some items needed to maintain compatibility with UUSS ML determination methods dating back to at least the late 1970s. Testing of the revised code revealed some significant (30 – 40%) discrepancies between synthetic Wood-Anderson amplitude measurements from the AQMS system and from our current local magnitude software, which we are currently investigating.</p>
<i>June 30, 2011</i>	
<ul style="list-style-type: none"> • Complete upgrade of 6 stations (Total 23/28) 	<p>RBU activated 4/26/2011; SNUT activated 5/11/2011; FLU activated 6/14/2011 CTU activated 6/16/2011; PTU activated 6/28/2011. TOTAL 23/28 activated.</p>
Other Achievements and Progress	
<p>Total of 7/11 <i>NetQuakes</i> are installed. One of these is located near Jackson Hole, Wyoming per request from Harley Benz. We have been unable to locate sites for the remaining instruments that match the criteria provided by the Utah Strong Motion Advisory Committee. Alternate locations have been identified.</p>	
<p><i>NSMP Upgrades.</i> Remaining 7/9 instruments slated for the dial-up stations returned to NSMP 4/9/2011.</p>	

Progress Report: USGS Award No. G09AC00467 (ARRA)

Quarterly Period: July 1–September 15, 2011

Date of Report: September 21, 2011

Progress Meeting Milestones

March 31, 2010

- AQMS: Configure hypo2000 with Utah appropriate velocity models

Initial models configured

June 30, 2010

- AQMS: Incorporate UUSS magnitude relations

Discrepancies between synthetic Wood-Anderson peak amplitude measurements from the AQMS system and from our current local magnitude software have been resolved with changes to the AQMS source code. UUSS magnitude relations are now incorporated into AQMS.

September 15, 2011

- Complete upgrade of 5 stations (Total 28/28)

LEVU activated 8/10/2011; RSUT activated 8/31/2011; MLI activated 7/13/2011; NPI activated 7/13/2011; PCCW (L17A) activated 7/26/2011. TOTAL 28/28 activated.

Other Achievements and Progress

Total of 11/11 *NetQuakes* are installed. One of these is located near Jackson Hole, Wyoming per request from Harley Benz.