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Ground water level measurements in selected boreholes near the site of the proposed repository

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FINAL TECHNICAL REPORT

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1.0 TABLE OF CONTENTS

LIST of FIGURES

LIST OF TABLES

2.0 PURPOSE

2.1 The purpose of this report is to summarize the work and present conclusions of Project Activity Task FY-04-005 conducted under DE-FC28-04RW12232 between the U.S. Department of Energy and the Nevada System of Higher Education (NSHE). The work was conducted in the Harry Reid Center for Environmental Studies of the University of Nevada – Las Vegas from Oct 1, 2003 to Sept 30, 2007.

2.2 The scope of this report includes a summation of purpose, methods, results, conclusions, recommendations, and intended use of the data produced under agreement.

3.0 QUALITY ASSURANCE

3.1 This work was conducted in accordance with the NSHE Quality Assurance Program. No subtask status was changed to non-Q. All conclusions of this report were based on qualified data; no unqualified data were used to support any conclusions.

4.0 INTRODUCTION

4.1 The Harry Reid Center for Environmental Studies at the University of Nevada - Las Vegas (HRC) acquired quarterly and continuous data on water levels from approximately 26 boreholes that comprise a periodic monitoring network (Table 1) between October 2003 and September 2007. During this period we continued to observe and analyze short and long-term ground water level trends in periodically monitored boreholes. In this report we summarize and discuss four key findings derived from analysis of water level data acquired during this period:

1. Rapid ground water level rise after storm events in Forty Mile Canyon
2. Seismically-induced ground water level fluctuations
3. A sample of synoptic observations and barometric influences on short term fluctuations
4. Long term ground water level trends observed from mid-2001 through late-2005

Table 1. Wells Comprising the Yucca Mountain Ground Water Level Network

Number	Number Measure-ments	YMP Well Name	Physiographic Location	Depth to Water (feet)[1]	Borehole Deviation Factor (feet)[2]	Measuring Point Correction Upper/Lower (feet)[3]	Reference Elevation Point (feet)[4]
1	1	UE29 a1	Upper Forty Mile Wash	91	NA	2.46	3984.20
2	1	UE29 a2	Upper Forty Mile Wash	97	NA	2.52	3985.12
3	1	UE29 UZN 91	Upper Forty Mile Wash	58	NA	2.00	3949.34
4	1	USW WT-1	Upper Busted Butte Wash	1545	-1.07	1.03	3939.64
5	1	USW WT-2	Tributary to Drill Hole Wash	1873	-1.46	-1.00	4268.80
6	1	UE-25 WT-3	South End Fran Ridge	985	-0.89	1.47	3378.76
7	1	UE-25 WT-4	Lower Prow Ridge	1440	-1.49	1.02	3835.00
8	1	UE-25 WT-6	Upper Yucca Wash	919	-0.67	1.52	4312.47
9	1	USW WT-7	Solitario Canyon	1380	-0.11	0.99	3925.76
10	1	USW WT-10	Crater Flat	1140	-0.1	1.28	3684.75
11	1	UE-25 WT-12	West Side Busted Butte	1135	-0.6	0.56	3525.14
12	1	UE-25 WT-13	Lower 40-Mile Wash	995	-0.04	-1.00	3387.50
13	1	UE-25 WT-14	Mouth of Drill Hole Wash – North End of Fran Ridge	1135	-0.28	1.02	3529.44
14	1	UE-25 WT-15	Lower 40-Mile Wash	1160	-0.62	1.03	3552.04
15	1	UE-25 WT-16	Upper Yucca Wash	1550	-0.21	1.03	3970.86
16	1	UE-25 WT-17	Busted Butte Wash	1295	-1.58	1.34	3686.91
17	1	UE-25 c-2	C-Well Complex	1319	-0.19	1.31	3713.55
18	1	USW G-2 (tube 2)	Prow Ridge	1751	-0.08	0.88	5097.95
19	2	USW H-1 (2tubes)	Upper Drill Hole Wash	1864 – 1877	-0.47	1.02	4274.16
20	1	USW H-3 Upper Interval	YM Crest	2464	-0.26	0.57	4867.03
21	1	USW H-4 (Lower Interval)	Tributary to Drill Hole Wash	1700	-0.21	1.96/1.01	4095.86
22	2	USW H-5 (Upper & Lower Intervals)	YM Crest	2307	-0.26	1.08/0.77	4850.92
23	2	USW H-6 (Upper & Lower Intervals)	Solitario Canyon	1726	-0.17	0.68/0.77	4270.75
24	1	USW VH-1	Crater Flat	603	-0.16	2.07	3159.39
25	1	UE-25 J-11	Jackass Flats	1042	NA	1.82	3442.19
26	1	UE-25 J-12	Jackass Flats	745	NA	0.64	3130.89
27	1	UE-25 J-13	Jackass Flats	930	NA	0.54	3939.64
28	1	UE-25 p1	Near C-Well Complex	1185.23	-0.07	-0.60	3655.54
29	1	USW SD-1 ST1	YM Crest	2510	-0.82	2.52	4906.42

Unqualified. For information only. Do not use for quality-affecting work. [1] Depths are approximate: DIDs 005SP.001 - 005 . [2] Adjusts for deviation from vertical by adding/subtracting a correction factor: MOY-950516-25-01 [3]Adjusts for height of well stickup: DTN MO9906GPS98410.000; [4]Reference Elevation Point: DTN MO9906GPS98410.000

5.0 METHODS AND MATERIALS

5.1 Ground water level measurements were obtained using two primary methods, manual and electronic. Manual methods involve the use of three types of tapes: two Powered Electric Tape (PET), and a Reference Steel Tape, and a hand-held steel tape. Electronic methods involve the use of commercially available pressure transducers which convert variations in water pressure overlying the transducer to user-defined measurements such as depth-to-water or water level altitude and store measurements in an on-board data logger. Tape-measured water level data are manually recorded in the field using standardized depth-to-water measurement forms then entered into spreadsheets in the office using Microsoft Excel®. Data reduction involves simple calculations embedded in spreadsheets (cell calculations) that account for a number of variables affecting water level measurements including borehole deviation, measurement point, ground surface elevation, calibration data for the instrument in use for the measurement.

Electronically-measured water level data are stored in a user-programmable, on-board microprocessor located in the downhole pressure transducer. Data are transmitted to surface using a laptop computer or hand-held personal data device in a proprietary data format, which may then be exported to commercial software for further processing, display, analysis, and reporting.

6.0 ASSUMPTIONS

6.1 Certain assumptions were made in conducting routine ground water level measurements. Most of these are equipment and borehole-related. The following have the greatest bearing on measurement accuracy, precision, and overall representativeness of the data collected with manual techniques:

- The powered electric tape is in good condition with legible graduation markings
- There are no errors in the observation or recording of the data;
- The water level in the borehole does not vary during the period of measurement;
- The water level in the borehole is representative of the water level of the formation which the borehole is open to;
- The water level is not significantly changed by the submergence of the tape and weight, and,
- The well is vented to the atmosphere and equilibrates prior to measuring.

7.0 RESULTS, DISCUSSION, AND CONCLUSIONS

7.1 Rapid Ground Water Level Rise After Storm Events in Forty Mile Canyon

During a series of wet winter storms between December 2004 and March 2005, we recorded the largest ground water level rise ever recorded in any Yucca Mountain borehole, almost 24 feet, in UE29 a1 an observation well emplaced in alluvial material along the main channel of upper Fortymile Wash (Figure 1). We combined water level data (blue line) from this borehole with precipitation gauge measurements (colored symbols for various rain gauges in the area) to assess possible relationships between precipitation, runoff, and ground water level rise.

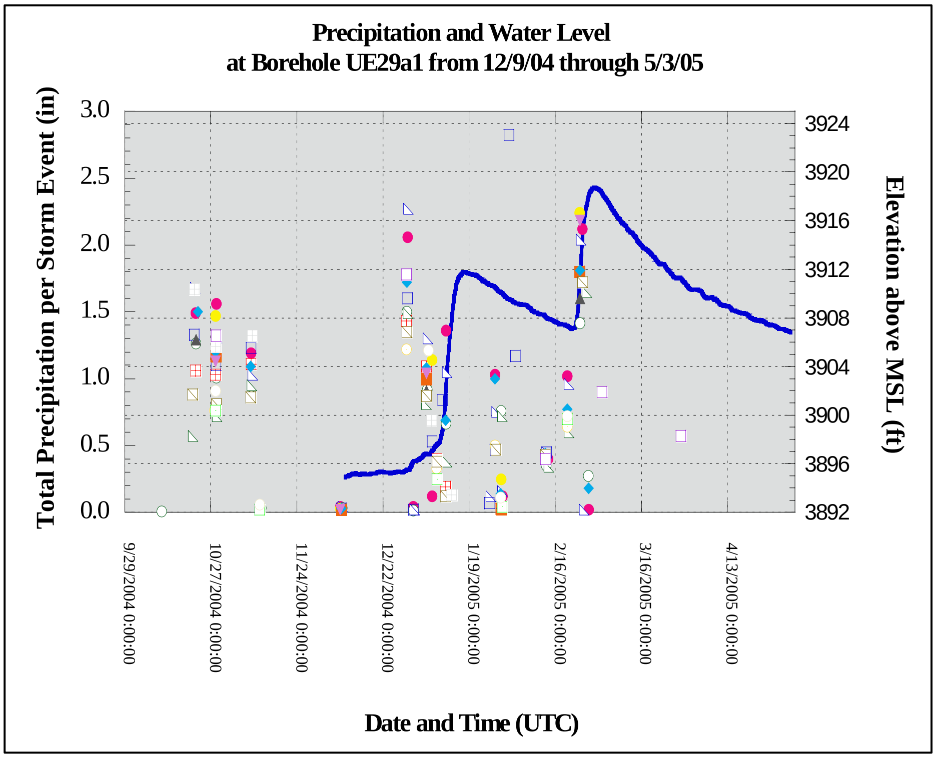

Figure 1. Ground Water Levels and Total Precipitation in UE29 a1 Borehole During Storm Events (A. Brandt Graph, 2005). MSL = mean sea level

7.2 Seismically-Induced Ground Water Level Fluctuations

We measured seismically-induced water level fluctuations in three regularly monitored boreholes resulting from the Indonesian earthquake of December 26, 2004: UE25 p1, USW H-4, and USW H-5. Early analysis showed the seismic wave reached these boreholes approximately 20 minutes after the initial shock in the Indian Ocean some 8,000 km from Yucca Mountain. Ground water levels in these wells were moving in response to barometrically-induced changes when the shock wave passed, inducing rapid level changes of less than 1-foot. An example of short-term response of water levels to seismic effects in borehole USW H-4 is shown in Figure 2, on 12/26/04 at approximately 0:00 hours Universal Coordinated Time (UTC).

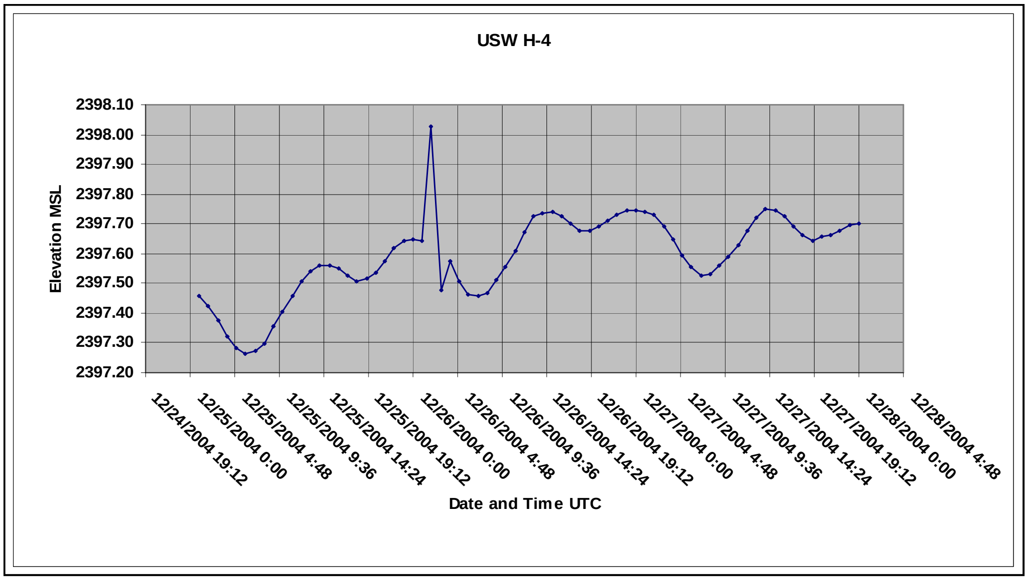

Figure 2. Seismically-Induced Ground Water Level Fluctuations in USW H-4 Borehole After Indonesian Tsunami-Producing Earthquake

7.3 Synoptic Measurements and Barometric Influences on Short Term Fluctuations

We produced large synoptic data sets consisting of tens of thousands of individual measurements using electronic measurement equipment. This enables wide area, simultaneous acquisition at multiple boreholes that may be useful for total flow system understanding. These data are synchronized to UTC for inter-comparison with seismic and other physical science information. These data were collected using hourly sampling rates except for UE25 WT13 which was sampled on a 24-hour rate. This program produced an archive of hundreds of thousands of QA measurements reported to the nearest 0.01-ft with 0.03-ft. accuracy. Much of the data were acquired in overlapping time periods, but not all. Nine boreholes comprised the synoptic measurement program: UE 25 WT13, UE25 p1, USW H4, USW H5, USW H6, USW WT2, USW WT 10, UE25 WT16, and UE29 a1. Figure 3 provides an example hydrograph showing simultaneous fluctuations in ground water levels in the USW H6 and USW WT10 boreholes which are located due west of Yucca Mountain crest near the Solitario Canyon fault.

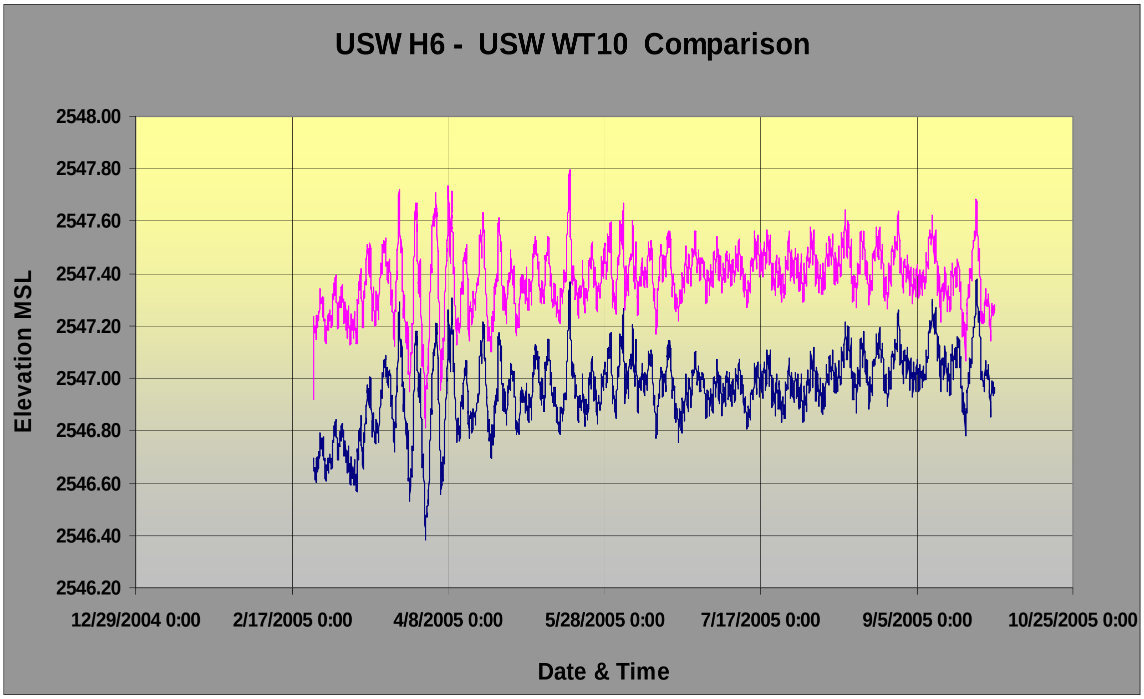

Figure 3. Simultaneous Ground Water Level Fluctuations in USW H-6 & USW WT-10

7.4 Long Term Trend Analysis

We analyzed ground water level data from boreholes in the periodic network acquired between July 2001 and December 2005 to determine overall trends which can suggest wide area changes in the potentiometric surface near Yucca Mountain. The trend summary indicated that in aggregate, ground water levels and the potentiometric surface near Yucca Mountain are remarkably stable.

- The mean fluctuation range of quarterly-measured ground water levels in 29 Yucca Mountain boreholes in the volcanic, carbonate, and alluvial flow systems comprising the periodic network for the mid 2001 –late 2005 period was 2.52 feet

- When the effects of the 2004 - 2005 precipitation-induced fluctuations in 3 boreholes located in alluvium (sediments deposited by flowing water) in upper reaches of Fortymile Wash are removed, mean fluctuation range was 1.33 feet

- Mean beginning-to-end-of-period change of quarterly-measured ground water levels from all flow system wells from the 2nd Quarter 2001 to the 4th Quarter 2005 was + 0.59 feet

- When the effects of the 2004 – 2005 precipitation-induced fluctuations in 3 alluvial system boreholes in Fortymile Wash were removed, mean beginning-to-end-of-period change was + 0.31 feet.

7.5 Conclusions Based on ‘Q’ Data.

7.5.1 Rapid Ground Water Level Rise After Storm Events in Forty Mile Canyon

The unprecedented rise was probably not caused by localized precipitation infiltration, but by large-scale runoff originating at higher elevations and moving through the Fortymile Wash system. These findings are consistent with current understanding that, of the four potential sources of inflow to the volcanic flow system underlying Yucca Mountain, the amount contributed by direct infiltration is probably the smallest. Examined in light of previous studies, these findings suggest precipitation at higher elevations, regional scale runoff, and large-scale, unsaturated zone lateral flow between alluvial horizons, rather than direct infiltration near the site, are the factors most likely contributing to present-day ground water recharge near Yucca Mountain (Page and Brandt, 2005). Continuous measurement techniques are unsurpassed for detecting and recording the intensity and duration of rapidly developing hydrologic events such as runoff-induced ground water level rises.

7.5.2 Seismically-Induced Ground Water Level Fluctuations

Normal fluctuations returned to borehole water levels in about 4 hours. Fluctuation levels were less than 1 foot (total) and no persistent level changes longer than 24 hours remained.. The December 2004 Indonesian earthquake is the most distant seismic event from Yucca Mountain known to have produced ground water fluctuations in boreholes on the network (approximately 8000 miles/14,500 kilometers distant) since inception of the UNLV level measurement program. Earlier large magnitude earthquakes that have produced such fluctuations have occurred in interior Alaska, Aleutian Islands and offshore Mexico. Continuous measurement techniques are unique in heir ability to detect rapid ground water level changes due to seismic events (Page, et al, 2003). Such techniques should be a part of any environmental monitoring program focused on short-and-long-term repository security and safety.

7.5.3 Synoptic Measurements and Barometric Influences on Short Term Fluctuations

Little quantitative analysis has been done on the large data sets acquired in boreholes in widely-place locations across the periodic network to explore possible relationships between atmospheric/barometric and other short-term influences on water levels. However, it is clear from examining representative hydrographs from boreholes in the lower volcanic flow system that magnitude and duration of water level fluctuations are highly correlated among boreholes. Short-term variations in the ground water flow system levels appear to be linked to barometric pressure variations. For example at UE29 a1, the relationship between barometric efficiencies and time-dependence of the Barometric Response Function clearly indicate unconfined characteristics. Long-term barometric efficiencies that exceed short-term responses indicates possible well bore storage effects in alluvial systems. Using barometric efficiency correction succeeds in dampening variation seen in total heads with respect to atmospheric pressure. These removal techniques may be useful for data analysis when assessing trends or responses to seismic events (Page and Brandt, 2006). A program of manually-acquired level data combined with continuous measurement techniques can provide near real time flow-system behavior if properly planned and executed.

7.5.4 Long-Term Trend Analysis

The mean fluctuation range of quarterly-measured ground water levels in 29 Yucca Mountain boreholes in the volcanic, carbonate, and alluvial flow systems comprising the periodic network for the mid 2001 – late 2005 period was 2.52 feet. When the effects of the 2004 - 2005 precipitation-induced fluctuations in 3 alluvial system boreholes in Fortymile Wash are removed, mean fluctuation range was 1.33 feet. Mean beginning-to-end-of-period change of quarterly-measured ground water levels from all flow system wells from the 2nd Quarter 2001 to the 4th Quarter 2005 was + 0.59 feet. When the effects of the 2004 – 2005 precipitation-induced fluctuations in 3 alluvial system boreholes in Fortymile Wash were removed, mean beginning-to-end-of-period change was + 0.31 feet. These results suggest that long-term ground water levels in the volcanic flow system near Yucca Mountain are essentially stable, although short-term fluctuations occur through atmospheric/barometric influences and seismically-induced changes (Page and Brandt, 2006). Regional-scale surface runoff from higher elevations also may affect ground water levels in boreholes that monitor alluvial systems.

8.0 INPUTS AND REFERENCES

8.1 Data Tracking Numbers and Files

Table 2 summarizes Data Tracking Numbers and specific data files used for preparation and analysis of data presented in Figures 1, 2, and 3.

Table 2. List of Data Tracking Numbers (DTN) For Data Used in Figures 1, 2, and 3

Figure	DTN	File Name	Title
1	MO0605UCC005SP.003	29a1_2005.xls	Ground Water Level Measurements from Boreholes Near the Site of the Proposed Repository: 1st, 2nd, 3rd, and 4th Quarters 2005
1	MO0604UCC007AB.003	401 – 407.xls 409 – 415.xls 417 – 419.xls 421.xls	Yucca Mountain Precipitation Data collected from 01/01/2005 through 12/31/2005.
2	MO0605UCC005SP.003	H04 Lower_2005.xls	Ground Water Level Measurements from Boreholes Near the Site of the Proposed Repository: 1st, 2nd, 3rd, and 4th Quarters 2005
3	MO0605UCC005SP.003	H06 Upper_2005.xls WT10_2005.xls	Ground Water Level Measurements from Boreholes Near the Site of the Proposed Repository:1st, 2nd, 3rd, 4th Quarters 2005.

8.2 Cited References

Page, S. and A. Brandt, 2005. "*Rapid Ground Water Level Rise Near Yucca Mountain Following Storm Events: Localized Infiltration or Regional Runoff?*", Las Vegas, Nevada: University of Nevada, Las Vegas, Harry Reid Center for Environmental Studies. Poster presented at Annual Devil's Hole Conference, Death Valley, CA, May 2005. MOL.20071128.0278-.0279

Page, S., K. Stetzenbach, and A. Brandt, 2003. "*Monitoring Small Ground Water Level Fluctuations In Yucca Mountain Wells Caused by Distant Earthquakes*", Las Vegas, Nevada: University of Nevada, Las Vegas, Harry Reid Center for Environmental Studies. Poster presented at Annual Devil's Hole Conference, Death Valley, CA, May 2003. MOL.20071128.0278-.0279

Page, S. and A. Brandt, 2006. "*Ground Water Level Trends in Yucca Mountain Boreholes: 2001- 2005 - With Barometric Effects Case Study*", Las Vegas, Nevada: University of Nevada, Las Vegas, Harry Reid Center for Environmental Studies. Poster presented at Annual Devil's Hole Conference, Death Valley, CA, May 2006. MOL.20071128.0278-.0279

9.0 SOFTWARE

9.1 Commercial Off-the-Shelf Software

The commercial off-the-shelf software (COTS) identified in Table 3 is integral to the operations and maintenance of the In-Situ, Inc. miniTROLL® Professional and LevelTROLL® model digital temperature-pressure sensors. This software has not been developed or modified and is controlled by calibrations.

Table 3. Measurement and Test Equipment Software Description

Software Name	Version	Description
Win-Situ ® 5	5.510.0 SP2	In-Situ, Inc. (vendor-supplied) instrument control and data management software used for standard PC interface with LevelTROLL® digital temperature-pressure sensors
Win-Situ® Mobile	5.2.0.2	In-Situ, Inc. (vendor-supplied) mobile instrument control and data management software used for hand held PDA interface with LevelTROLL® digital temperature-pressure sensors
Win-Situ® 4	4.2.1	In-Situ, Inc. (vendor-supplied) instrument control and data management software used for standard PC interface with miniTROLL® digital temperature-pressure sensors
Pocket-Situ 4	4.57.0.0	In-Situ, Inc. (vendor-supplied) mobile instrument control and data management software used for hand held PDA interface with miniTROLL® digital temperature-pressure sensors

Win-Situ® Sync	2.1.1.2	In-Situ, Inc. (vendor-supplied) software used to synchronize both Win-Situ® Mobile and Pocket-Situ 4 hand held PDA versions to PC-based Win-Situ® 5 and Win-Situ® 4 versions