ECF-200ZP1-12-0074
Revision 0

Presentation & Initial Evaluation of Water-Level & Pumping Data for the Hanford 200-ZP-1 Groundwater Pump-and-Treat Remedy

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company
P.O. Box 1600
Richland, Washington 99352

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List of Term

AWLN	automated water-level network
COC	contaminant of concern
ECF	environmental calculation
EPA	U.S. Environmental Protection Agency
FY	fiscal year
gpm	gallons per minute
HISI	Hanford Information Systems Inventory
MNA	monitored natural attenuation
OU	operable unit
P&T	pump-and-treat
PNNL	Pacific Northwest National Laboratory
RD/RA	remedial design/remedial action
SALDS	State-Approved Land Disposal Site

1 Purpose

The objective of this environmental calculation (ECF) is to present an initial evaluation of the data collected (1) during shutdown of the interim 200-ZP-1 Operable Unit (OU) pump-and-treat (P&T) groundwater remedy, and (2) prior to and during the startup of the P&T component of the final 200-ZP-1 groundwater remedy (i.e., 200 West Area P&T facility). These analyses do not comprise a comprehensive assessment of the startup of the final 200-ZP-1 P&T remedy because the system has been operating for an insufficient amount of time to complete a more comprehensive analysis.

2 Background

The *Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit* (DOE/RL-2007-28) and the *Proposed Plan for Remediation of the 200-ZP-1 Groundwater Operable Unit* (DOE/RL-2007-33) describe the use of groundwater P&T technology for the 200-ZP-1 Groundwater OU as part of the final remedy for groundwater contaminated by several contaminants of concern (COCs). The *Record of Decision, Hanford 200 Area 200-ZP-1 Superfund Site, Benton County, Washington* (EPA et al., 2008) details the final remedy as combining P&T, monitored natural attenuation (MNA), flow-path control, and institutional controls. In particular, the P&T system is designed to capture and treat contaminated groundwater; natural attenuation processes will be used to reduce concentrations to below the cleanup levels; and flow-path control, which will be achieved by injecting the treated groundwater into the aquifer, will slow the natural eastward flow of most of the groundwater. As a result, the COCs will be contained within the capture zone and the amount of time available for natural attenuation processes will increase in order to reduce the contaminant concentrations not captured by the extraction wells.

Groundwater modeling was used to locate the P&T system injection and extraction wells, to estimate required injection and extraction rates, and to determine the location of injection wells for flow-path control. This modeling, which was conducted in accordance with and in support of the *200 West Area 200-ZP-1 Pump-and-Treat Remedial Design/Remedial Action Work Plan* (RD/RA work plan) (DOE/RL-2008-78), which is detailed in *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan* (DOE/RL-2009-38).

Although groundwater modeling will be used throughout the lifecycle of the remedy, evaluation of remedy performance also requires direct interpretation of monitoring data obtained in accordance with the approved operations and maintenance plan and approved performance monitoring plan. Details of these approved plans are found in the *200 West Area Pump-and-Treat Facility Operations and Maintenance Plan* (DOE/RL-2009-124), particularly in Appendix A of that plan. The operations and maintenance plan states, for example, that performance of the 200 West Area groundwater P&T system will be communicated to the U.S. Environmental Protection Agency (EPA) during quarterly briefings and will be summarized in the performance monitoring report (the latter of which is to be provided annually), and also that flow-path control performance will be summarized in the performance monitoring report. This ECF discusses the initial evaluations completed for monitoring data collected as part of planned 200-ZP-1 remedy performance monitoring.

3 Data Sets

This ECF describes evaluations of water-level and pumping data used to assess the shutdown of the interim 200-ZP-1 groundwater P&T remedy and the initial startup of the final 200-ZP-1 groundwater P&T remedy, including both water levels within the new groundwater extraction wells and changes in groundwater elevations throughout the 200-ZP-1 OU. These data and analyses provide initial indications

of the performance of the operating components of the final 200-ZP-1 remedy in terms of the hydraulic performance of the system wells and the hydraulic response of the aquifer.

The evaluations detailed in this ECF include the following:

- Well-specific and system-wide flow rates
- Extraction well-specific capacities
- Groundwater elevation maps
- Evaluation of aquifer properties

Implementation of the P&T component of the final 200-ZP-1 groundwater remedy will occur in several phases, as detailed in the RD/RA work plan (DOE/RL-2008-78), commencing with startup of a subset of extraction and injection wells operating at a combined rate of about 1,000 gallons per minute (gpm) (Table 3-1), with later phases in implementation of the remedy including a larger number of extraction and injection wells and greater total system capacity (DOE/RL-2008-78).

This ECF depicts data obtained during three periods during fiscal year (FY) 2012 (Table 3-2):

- **Spring 2012:** The interim 200-ZP-1 P&T remedy was operational, and the nearby State-Approved Land Disposal Site (SALDS) facility and T Tank Farm systems were also operational.
- **Early summer 2012:** The interim 200-ZP-1 P&T remedy was shut down and the final 200-ZP-1 remedy had not commenced startup. At this time, only the SALDS facility and T Tank Farm systems were operational.
- **Late summer 2012:** The final 200-ZP-1 remedy had commenced operating but was not yet fully operational. At this time, the SALDS facility was operational and the T Tank Farm system was offline.

3.1 Extraction and Injection Rates

Groundwater extraction and injection locations and rates for the interim 200-ZP-1 P&T remedy and the initial phase of the final 200-ZP-1 P&T remedy are summarized in this section.

3.1.1 Interim 200-ZP-1 Groundwater P&T Remedy

During FY 2012, the interim remedy system operated from January 1 to May 5. In general, 10 extraction and 4 injection wells operated during this period. The combined, total operating rate for the interim P&T system during this period is plotted in Figure 3-1, from which it is evident that the interim system began the year recovering nearly 400 gpm, but this declined over time as rates declined in selected wells and as wells were taken offline.

Throughout the period, extraction was dominated by the operation of well 299-W15-225 at a typical rate of about 250 gpm. Well 299-W15-225 was the first extraction well of the final P&T remedy and recovers groundwater at substantially greater rates than the interim extraction wells due to the long and deep screened interval, well design, and well development procedures.

Reinjection of treated groundwater occurred at the five injection wells of the interim P&T remedy, although the majority of reinjection occurred at wells 299-W15-29, 299-W18-36, 299-W18-38, and 299-W18-39.

Well-specific extraction and injection rates on the days for which groundwater elevation maps were prepared (as presented in this ECF) are discussed in Chapter 5.

Table 3-1. List of 200-ZP-1 Final Remedy Extraction and Injection Wells and Planned Start-up Date

Well Name	Well Code	Type	Easting	Northing	Nominal Flow Rate (gpm)	Maximum Flow Rate Observed (gpm)	Actual (or Planned) Startup Date
299-W15-225	YE-1	Extraction	566657.25	136108.88	80		9/4/2012
299-W14-20	YE-2	Extraction	566909.21	136284.62	80 to 130	151	8/13/2012
299-W14-73	YE-3	Extraction	567359.14	136204.21	80 to 130	153	7/13/2012
299-W14-74	YE-4	Extraction	567781.48	136381.29	80 to 130		7/13/2012
299-W12-2	YE-5	Extraction	568312.67	136610.25	80 to 130	170	7/13/2012
299-W11-50	YE-6	Extraction	566966.26	136756.64	80 to 130		8/13/2012
299-W11-90	YE-7	Extraction	567306.69	136519.63	80 to 130	168	8/13/2012
299-W11-96	YE-8	Extraction	567774.83	136772.24	80 to 130		7/13/2012
299-W17-3	YE-9	Extraction	566925.96	135324.90	80 to 130	169	7/13/2012
299-W17-2	YE-10	Extraction	566951.59	135806.14	80 to 130	167	7/13/2012
299-W19-111	YE-11	Extraction	567314.89	135462.69	80 to 130		Planned in FY 2013
299-W11-49	YE-12	Extraction	567361.68	135924.61	80 to 130	169	7/13/2012
299-W11-97	YE-13	Extraction	567201.24	137085.10	80 to 130		Planned in FY 2013
299-W6-15	YE-14	Extraction	567781.56	137076.33	80 to 130		Planned in FY 2013
299-W14-21	YE-15	Extraction	567721.52	135890.01	80 to 130	166	7/13/2012
299-W11-92	YE-16	Extraction	566692.79	136351.76	80 to 130	162	8/29/2012
299-W5-1	YE-17	Extraction	568329.58	137321.53	80 to 130		Planned in FY 2013
299-W12-3	YE-18	Extraction	568321.53	136998.09	80 to 130	169	7/13/2012
299-W12-4	YE-19	Extraction	568327.41	136363.65	80 to 130	167	7/13/2012
299-W14-22	YE-20	Extraction	568324.89	136116.49	80 to 130		Planned in FY 2013

Table 3-1. List of 200-ZP-1 Final Remedy Extraction and Injection Wells and Planned Start-up Date

Well Name	Well Code	Type	Easting	Northing	Nominal Flow Rate (gpm)	Maximum Flow Rate Observed (gpm)	Actual (or Planned) Startup Date
299-W22-90	YE-21	Extraction	566961.39	134483.24	20	47	8/13/2012
299-W22-91	YE-22	Extraction	566923.00	134131.00	30	38	8/13/2012
299-W22-92	YE-23	Extraction	567173.00	134037.00	30	39	8/13/2012
299-W6-13	YJ-1	Injection	567313.27	137630.48	100 to 200		Potable water use to test lines
299-W6-14	YJ-2	Injection	566939.86	137388.85	100 to 200		
299-W10-36	YJ-3	Injection	566018.98	137451.93	100 to 200		
299-W10-35	YJ-4	Injection	566067.33	136987.06	100 to 200		
299-W15-226	YJ-5	Injection	566033.26	136450.13	100 to 200		
299-W15-227	YJ-6	Injection	566034.41	135966.32	100 to 200		
299-W15-228	YJ-7	Injection	565754.61	135711.51			
	YJ-8	Injection					Substituted five 200-ZP-1 injection wells connection in FY 2012 (YJ-18, YJ-19, YJ-20, YJ-21, and YJ-22)
	YJ-9	Injection			100 to 150		Moved to north of YJ-10 - to be drilled in the future
699-46-68	YJ-10	Injection	569110.03	137599.95	100 to 150		
699-45-67	YJ-11	Injection	569257.00	137263.00			Offline
699-44-67	YJ-12	Injection	569338.00	136894.00	100 to 150		8/23/2012
699-43-67	YJ-13	Injection	569370.00	136560.00			Offline
699-42-67	YJ-14	Injection	569390.00	136200.00	100 to 150		8/23/2012
699-40-67	YJ-15	Injection	569420.00	135816.00	100 to 150		

Table 3-1. List of 200-ZP-1 Final Remedy Extraction and Injection Wells and Planned Start-up Date

Well Name	Well Code	Type	Easting	Northing	Nominal Flow Rate (gpm)	Maximum Flow Rate Observed (gpm)	Actual (or Planned) Startup Date
	YJ-16	Injection			100 to 150		
699-43-67B	YJ-17	Injection	569370.00	136560.00	100 to 150		8/23/2012
299-W15-29	YJ-18	Injection	565921.17	135506.00	100 to 150		Construction complete 7/26/12; programming complete 8/31/12
299-W18-36	YJ-19	Injection	565908.61	135419.40	100 to 150		Construction complete 7/26/12; programming complete 8/31/12
299-W18-37	YJ-20	Injection	565904.37	135323.43	100 to 150		Construction complete 7/26/12; programming complete 8/31/12
299-W18-38	YJ-21	Injection	565892.13	135232.92	100 to 150		Construction complete 7/26/12; programming complete 8/31/12
299-W18-39	YJ-22	Injection	565885.56	135141.11	100 to 150		Construction complete 7/26/12; programming complete 8/31/12
699-45-67B	YJ-23	Injection	569264.31	137265.00			

Table 3-2. Description of Remedy Operations Evaluated During FY 2012

Time Period	Operational Status of System			
	Interim Remedy	**Final Remedy**	**T Tank Farm**	**SALDS**
Spring 2012 (January 1 to May 8, 2012)	Operational	Not operational	Operational	Operational
Early summer 2012 (May 9 to July 12, 2012)	Not operational	Not operational	Operational	Operational
Late summer 2012 (July 13, 2012, to present)	Not operational	Operational	Not operational	Operational

SALDS = State-Approved Land Disposal Site

3.1.2 Final 200-ZP-1 Groundwater P&T Remedy

The P&T component of the final 200-ZP-1 remedy will consist of 23 injection and 23 extraction wells, operating at a combined rate of about 2,000 gpm. As detailed in the RD/RAWP, the final P&T system will be phased in, with the number of operating extraction and injection wells and the total operating capacity of the system increasing with each phase. The current operational status of each new extraction and injection well of the final P&T system is reported in Table 3-1.

Startup of the final P&T remedy commenced July 13, 2012. For the first few weeks of operation (during which time many aspects of the contaminant treatment train were implemented, tested, and evaluated), the system generally operated for between 8 and 12 hours each day during the daytime. For purposes of this ECF, operating rates for the groundwater extraction wells were available for about one month commencing July 28. The combined operating rate for the wells during this period is plotted in Figure 3-2. During this period, the maximum total extraction rate attained was about 1,200 gpm. Well-specific extraction rates on the days for which groundwater elevation maps were prepared are tabulated in Chapter 5. Reinjection of the treated groundwater took place at six injection wells of the final P&T remedy, although specific injection rates were not available at the time this ECF was prepared.

3.1.3 Other Remedies

Two additional systems operate in the vicinity of the interim and final 200-ZP-1 groundwater remedies, extracting and/or injecting at sufficient rates that their operations were considered in preparation of the groundwater elevation maps and in the evaluation of aquifer properties described in Chapter 5. These systems are as follows:

- The SALDS is permitted for the injection of tritium into the upper unconfined aquifer. During FY 2012, the SALDS typically operated at an injection rate of about 45 gpm.
- Extraction wells 299-W11-45 and 299-W11-46 are operated to recover groundwater contaminated with technetium-99 in the area of the T Tank Farm. These extraction wells typically operated at a combined rate of about 21.5 gpm from January 1 to June 4, when they ceased operation.

Actual extraction and/or injection rates for these systems on the specific days for which groundwater elevation maps were prepared are tabulated in Chapter 5.

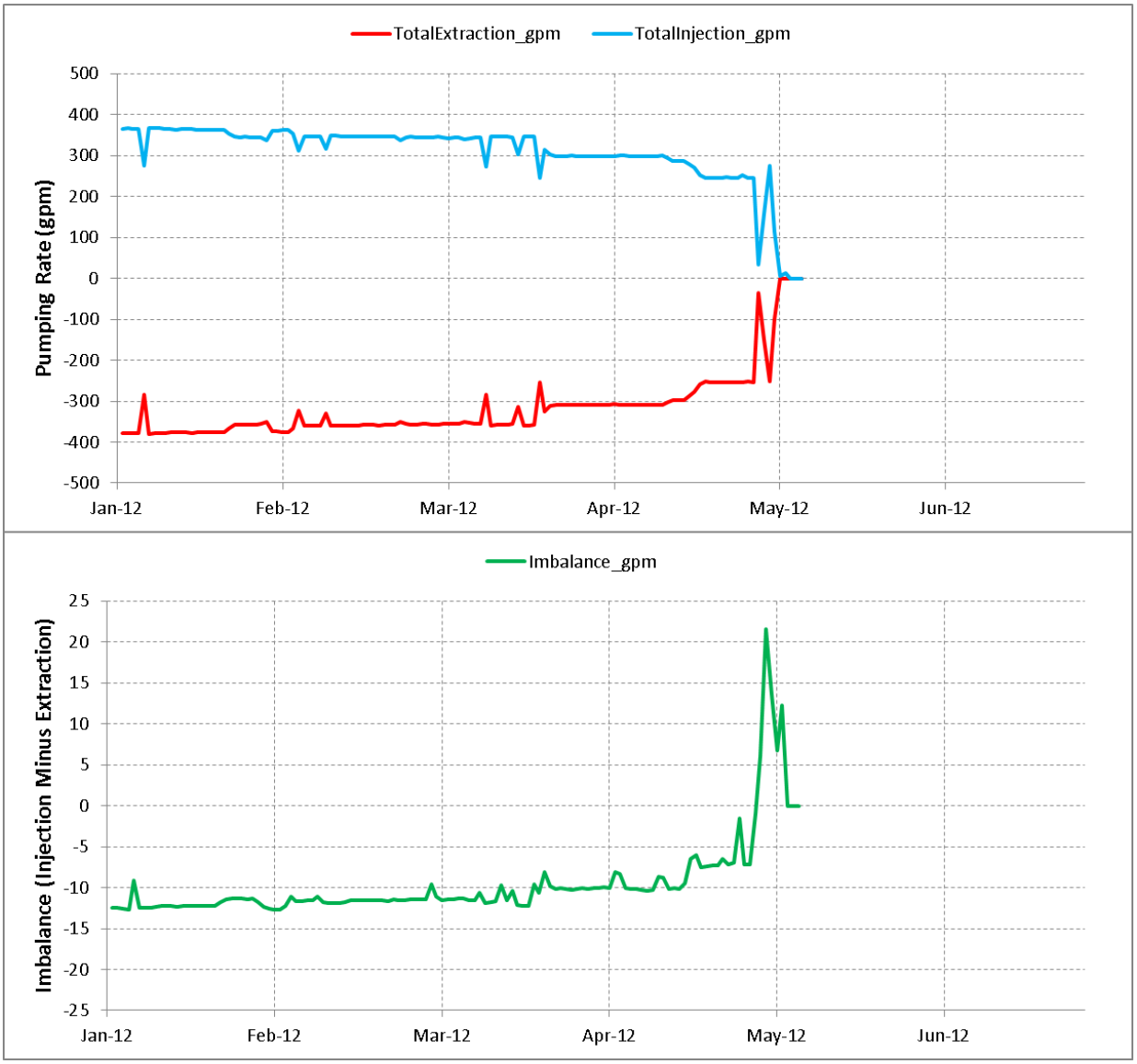

Figure 3-1. Combined Operating Rate for the 200-ZP-1 Interim Remedy Prior to FY 2012 Shutdown

3.2 Water-Level Data Within Extraction and Injection Wells

The newly installed extraction and injection wells of the final 200-ZP-1 remedy are fitted with transducers that record changes in water level within the wells for a variety of system operation and maintenance purposes. For the purpose of this ECF, the change in water level rather than the absolute water level in each operating extraction well of the final remedy was used (1) to confirm that the reported flow rates are consistent with the operation of the well, as indicated by the flow rates obtained; and (2) to calculate the specific capacity of each well when operating across a range of operating rates. A similar assessment of well capacity can be made for injection wells; however, rates were not available for the new injection wells at the time this ECF was prepared.

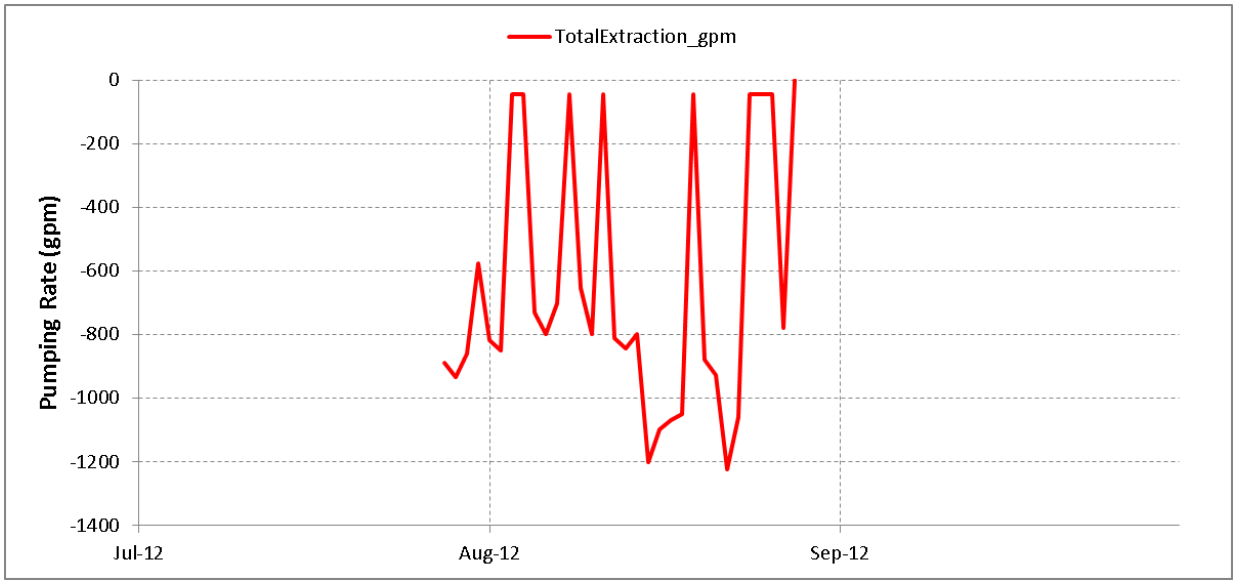

Figure 3-2. Combined Extraction Rate for the Final 200-ZP-1 P&T Remedy During FY 2012 Startup

3.3 Water-Level Data Within Monitoring Wells

Groundwater levels are recorded throughout the Central Plateau semi-continuously at a subset of monitoring wells that are fitted with pressure transducers and data loggers, and on a less frequent but fairly regular basis at a larger number of monitoring wells using manual depth-to-water measurements. Each type of water-level measurement is valuable for evaluating groundwater conditions. Each type of water-level measurement is described below.

About 30 monitoring wells are currently instrumented with data loggers in the vicinity of the 200-ZP-1 P&T remedy as part of the 200 West Area automated water-level network (AWLN). These wells are listed in Table 3-3. Additional monitoring wells that were previously identified to be fitted with pressure transducers and data loggers for incorporation in to the 200 West Area AWLN were not available at the time this ECF was prepared.

Water levels are obtained using manual depth-to-water measurements when monitoring wells are sampled. A “synoptic” set of water levels is obtained with the objective of providing a snapshot depiction of groundwater levels over a wide area. During the periods considered in this ECF, a comprehensive synoptic water-level data set was available for the month of April, and a smaller number of manual water-level measurements were available on each of the other dates for which a water-level map was prepared. Monitoring wells for which manual water-level measurements were available and were incorporated in the water-level mapping are listed in Table 3-4.

Table 3-3. 200 West Area AWLN Monitoring Wells Currently Instrumented with Data Loggers

Well	Easting (m)	Northing (m)	Screen Top Elevation (m)	Screen Bottom Elevation (m)
299-W10-4	566734.64	136578.08	144.56	130.85
299-W10-5	566578.60	136474.83	152.62	138.91
299-W10-26	566843.40	136400.59	139.30	128.60
299-W14-14	566898.39	136181.05	139.30	128.62
299-W15-37	566716.47	135248.32	203.03	203.03
299-W15-41	566757.59	136031.68	137.67	133.09
299-W15-49	566307.20	135972.91	137.27	126.60
299-W11-88	567874.67	137113.09	86.23	74.04
299-W12-01	568331.25	137206.12	138.93	128.26
299-W15-32	566773.43	135635.00	144.34	132.16
299-W13-01	568148.74	136048.60	104.38	93.72
299-W14-72	567328.44	135941.28	90.20	85.62
299-W11-40	566926.84	136709.67	137.86	127.18
299-W11-48	566881.97	136846.18	125.14	97.69
299-W15-30	566304.62	135748.94	143.66	131.49
299-W22-44	566955.99	134484.42	145.24	134.00
299-W22-50	566904.26	134139.76	138.59	134.02
299-W22-69	567179.60	134347.83	135.40	124.73
299-W22-80	566842.85	134125.65	138.36	127.68
299-W22-83	567009.08	134092.58	138.04	127.37
299-W22-84	566978.76	134547.62	137.80	127.13
299-W22-85	566902.90	134260.58	138.23	127.59
299-W22-86	567186.74	134041.31	135.87	125.18
699-35-78A	566063.59	134271.27	147.52	117.80
699-39-79	565890.90	135411.87	147.01	116.53
299-W19-107	567997.87	135205.66	122.77	118.19
299-W15-44	566685.02	136066.47	138.98	128.31
299-W11-39	566908.38	136779.92	137.82	127.14

Table 3-4. Locations of Wells with Manual Measurements

Well	Easting(m)	Northing(m)
299-W10-1	566663.10	136734.57
299-W10-14	566017.19	136608.90
299-W10-23	566823.73	136815.34
299-W10-27	566843.97	136441.78
299-W10-29	566082.98	136828.74
299-W10-30	566082.78	136739.33
299-W10-31	566266.44	136968.34
299-W11-10	568147.51	136610.04
299-W11-12	566927.14	136604.01
299-W11-18	567181.92	137161.48
299-W11-3	567641.72	136663.90
299-W11-41	566935.51	136677.78
299-W11-42	566920.44	136745.67
299-W11-43	567269.74	136971.04
299-W11-47	566933.82	136680.70
299-W11-87	568141.08	136608.70
299-W12-1	568331.25	137206.12
299-W13-1	568148.74	136048.60
299-W14-11	566901.69	136287.62
299-W14-13	566901.72	136282.38
299-W14-15	566899.69	136230.65
299-W14-16	567001.33	136318.48
299-W14-18	566897.47	136344.15
299-W14-6	566899.19	136100.84
299-W14-71	567733.43	135567.81
299-W15-152	566309.40	135550.00
299-W15-17	566306.89	135718.96
299-W15-2	566093.76	136336.24
299-W15-224	566307.89	135926.08
299-W15-31A	566377.11	135856.10
299-W15-33	566433.30	135966.70
299-W15-42	566581.83	135627.02
299-W15-50	566793.47	135790.72

Table 3-4. Locations of Wells with Manual Measurements

Well	Easting(m)	Northing(m)
299-W15-763	566809.21	136028.76
299-W15-94	566307.58	135640.34
299-W17-1	565310.68	135038.74
299-W18-1	566421.52	135465.21
299-W18-16	566605.05	135425.69
299-W18-21	566097.70	134978.69
299-W18-22	566088.63	134990.16
299-W18-30	566870.76	135193.62
299-W18-31	566721.54	135075.18
299-W18-40	566723.29	134996.41
299-W19-101	567939.14	135014.07
299-W19-105	567565.15	134745.44
299-W19-12	566897.13	135059.45
299-W19-34A	567673.64	135012.25
299-W19-34B	567662.88	135010.65
299-W19-35	567992.10	135015.16
299-W19-41	566896.53	135004.51
299-W19-42	566896.81	135122.90
299-W19-44	566896.95	135041.97
299-W19-45	566897.65	135087.65
299-W19-46	567782.67	134842.46
299-W19-47	566895.31	135161.86
299-W19-48	567822.93	134925.99
299-W19-49	567568.04	134894.38
299-W21-2	568124.39	134573.79
299-W22-45	566945.16	134292.51
299-W22-48	566996.64	134425.10
299-W22-81	567000.26	134354.19
299-W22-87	567541.75	134539.88
299-W22-96	567351.93	134145.58
299-W23-15	566794.00	134127.23
299-W23-20	566717.67	134446.19
299-W23-21	566707.74	134293.99

Table 3-4. Locations of Wells with Manual Measurements

Well	Easting(m)	Northing(m)
299-W6-11	567162.52	137634.83
299-W6-12	566915.53	137635.16
299-W6-3	567118.18	137299.13
299-W6-6	567318.74	137638.72
299-W7-3	566292.03	137638.64
299-W7-4	566408.77	137308.24
299-W9-2	565742.21	136872.84
699-35-66A	569857.86	134099.24
699-36-66B	569731.34	134469.01
699-36-70A	568466.68	134308.84
699-36-70B	568427.79	134625.98
699-37-66	569730.32	134797.15
699-38-70B	568469.10	135331.04
699-38-70C	569084.11	135325.58
699-40-65	570057.48	135881.16
699-43-69	568967.03	136488.48
699-44-64	570390.65	136897.43
699-45-69A	568729.30	137182.68
699-47-80AP	565562.03	137693.49
699-47-80AQ	565562.03	137693.49
699-47-80CP	565530.32	137718.18
699-47-80CQ	565530.32	137718.18
699-47-80CR	565530.32	137718.18
699-47-80CS	565530.32	137718.18
699-47-80CT	565530.32	137718.18
699-47-80CU	565530.32	137718.18
699-47-80DP	565494.17	137778.94
699-48-71	568387.91	138056.94
699-48-77A	566413.23	137968.86
699-48-77C	566468.95	138086.80
699-48-77D	566433.30	138119.27
699-49-79	565771.12	138271.11

4 Methods of Calculation

4.1 Removal of Barometric Effects

As described in *Aquifer Testing Recommendations for Well 299-W15-225: Supporting Phase I of the 200-ZP-1 Groundwater Operable Unit Remedial Design* (PNNL-18279) and *Field Test Report: Preliminary Aquifer Test Characterization Results for Well 299-W15-225: Supporting Phase I of the 200-ZP-1 Groundwater Operable Unit Remedial Design* (PNNL-19732), groundwater levels recorded at monitoring wells are affected by changes in barometric pressure. These effects do not propagate instantaneously through the vadose zone and saturated aquifer but rather are lagged (PNNL-18279; PNNL-19732). As a result, it is necessary to remove these barometric effects from the water-level data prior to evaluating the changes in water levels that are strictly due to changes in groundwater pumping.

To accomplish this, the Microsoft[1] Excel-based software Multiple Regression Correction in Excel (MRCX) (PNNL-19775) developed by Pacific Northwest National Laboratory (PNNL) was used. A multiple linear regression model is developed to represent the time-dependent relation between the AWLN water levels and the atmospheric pressure recorded at the nearby Hanford Site climate station. The MRCX software allows the user to develop the regression model in an interactive manner. The user terminates the regression process when a satisfactory match between the observed and regression-predicted water levels is generated. The software then uses the user-generated regression model to predict the barometric-corrected water levels based on the regression equation.

The MRCX software also produces a visual depiction of the lag relationship between the barometric forcing and the change in the water levels that indicates the barometric efficiency at the corresponding well screen.

4.2 Extraction Well-Specific Capacity

As defined in *Analysis and Evaluation of Pumping Test Data* (Kruseman and de Ridder, 1990), the specific capacity is the ratio of the pumping rate and the (stabilized) drawdown. Specific capacity describes the productivity of both the aquifer and the pumped well, and it is generally not a constant value for any well/aquifer combination, but instead decreases with increasing pumping rate. A step-drawdown test is typically performed to estimate the specific capacity, separating the linear and nonlinear well losses.

Step-drawdown tests were not conducted specifically for the current evaluation; instead, data from remedy operations were used for the analysis. Additionally, the specific capacity is assumed to be constant within the range of pumping discharges in the operational data (i.e., nonlinear losses were neglected). These simplifying assumptions provide a first-order estimate of the current well-specific capacity at rates consistent with the expected operations.

4.3 Groundwater Elevation Maps

4.3.1 Background to Application

Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance (SGW-42305) provides details on the development of water-level maps using universal kriging. The water-level maps presented in this ECF were prepared using a variant of the universal kriging technique described in SGW-42305 that was developed specifically for mapping

[1] Microsoft® Excel is a registered trademark of Microsoft Corporation, Redmond, California.

multiple data events, referred to as multi-event universal kriging. Overviews of universal kriging and multi-event universal kriging are provided in the following discussion.

Universal kriging is a variant of ordinary kriging that enables a deterministic trend to be incorporated in the interpolation. This trend describes a spatially varying mean assuming an underlying deterministic (usually physically based) structure or process ("Generalized Covariance Functions in Estimation" [Kitanidis, 1993]). In the hydrogeologic sciences, universal kriging has been used to map groundwater elevations when there is reason to suspect a physically based trend. For example, mean uni-directional groundwater flow is approximated with a linear trend in the data. The coefficients of this deterministic trend are obtained by solving the universal kriging system of equations. Implementation of universal kriging is often an iterative and investigative process that includes development and fitting of an analytical function representing the underlying deterministic trend and fitting of a semi-variogram model that describes the zero-mean variations about from the trend (*Semi-Variogram Estimation and Universal Kriging Program* [Skrivan and Karlinger, 1977]; "On the Use of a Main Trend for the Kriging Technique in Hydrology," [Volpi and Gambolati, 1978]; Kitanidis, 1993). However, as the proportion of the data variance that is explained by the trend increases, the magnitude of the residuals from the trend diminishes, which reduces the sensitivity of the resulting map to the selected residual variogram.

Universal kriging is generally used to map each data set independently. As such, the preparation of six water-level maps representing six different time periods would require six independent universal kriging exercises. However, information that is not independent between the six events is lost when the maps are prepared independently. For example, if it is known when preparing a water-level map that the background hydraulic gradient should be consistent between the six events, there is no procedure for enforcing this knowledge using traditional universal kriging methods. The multi-event universal kriging overcomes this limitation by forming and then solving a single block-diagonal kriging matrix that incorporates all of the deterministic trend definitions, unbiased constraints, and sample data co-variances for all data events. Therefore, trend terms that apply throughout all (or some subset of) the measurement events can be conditioned by all (or some subset of) the monitoring data, while those terms that apply only to individual events can be conditioned only by the monitoring data obtained during the corresponding event. The composite block-diagonal kriging matrix is solved in a single step, and the interpolated water-level maps for all monitored events are produced as output.

4.3.2 Application

The multi-event universal kriging technique was used to prepare six groundwater-level maps corresponding to the following periods of operation of the interim and final 200-ZP-1 groundwater P&T remedies:

- February 1 and April 11, 2012, when the interim 200-ZP-1 P&T remedy was operational
- May 10 and July 12, 2012, when the interim 200-ZP-1 P&T remedy was shut down and the final 200-ZP-1 remedy had not yet commenced startup
- August 14 and August 17, 2012, when the final 200-ZP-1 remedy had commenced startup but was no fully operational

In constructing the multi-event universal kriging matrix, the deterministic trend terms were incorporated as follows:

- The uniform background hydraulic gradient was assumed to apply throughout all periods and, therefore, is incorporated in and conditioned by the data measured in all six events.

- The effects of injection at the SALDS and extraction at the T Tank Farm are assumed to apply throughout all periods and, therefore, are incorporated in and conditioned by the data measured in all six events. (Note that extraction at the T Tank Farm was only available for the first four events.)
- Groundwater extraction and reinjection associated with the interim P&T remedy are assumed to apply only in the first and second periods when the interim system was operating.
- Groundwater extraction and reinjection associated with the final P&T remedy are assumed to apply only in the fifth and sixth periods when the final system startup was occurring.
- Injection at the SALDS was represented by a single drift term.
- Since the extraction and injection at the final P&T remedy are largely distributed throughout a greater thickness of the unconfined aquifer than other stresses, these terms are grouped separately in the multi-event universal kriging regression equation from stresses that occur largely at the water table.
- Since injection rates were not available for the final remedy injection wells, a uniform rate scalar of 1.0 was used for each of the injection wells known to be operating, enabling the multi-event universal kriging regression to scale the effects of the final remedy reinjection in order to minimize the variance of the multi-event universal kriging estimator.

Figure 4-1 depicts the block-diagonal kriging matrix resulting from using multi-event universal kriging to construct the six groundwater elevation maps that are presented Chapter 5.

4.4 Evaluation of Aquifer Properties

4.4.1 Background to Application

The transient analytic element solver, TTIM (*TTIM: A Multi-Aquifer Transient Analytic Element Model [Version 0.2]* [Bakker, 2012]), simulates transient multi-aquifer flow based on the Laplace-Transform analytic element method. The TTIM model computes heads with respect to a steady-state situation within a laterally homogeneous aquifer system that comprises an arbitrary number of layers. Point sinks (e.g., pumping wells) and line sinks (e.g., rivers) can also be incorporated into the TTIM model. While TTIM can be used to construct predictive models of groundwater flow, the explicit context for its use in the calculations presented here is the inference of aquifer properties (primarily transmissivity, and to a lesser extent storage) on the basis of changing water levels in response to changing groundwater extraction and reinjection. No predictive modeling was performed.

4.4.2 Application

A TTIM model was developed to evaluate whether the changes in groundwater levels in response to the shutdown of the interim 200-ZP-1 P&T remedy and startup of the final remedy were broadly consistent with estimates of the aquifer properties that were previously obtained. The TTIM model was constructed to evaluate water-level changes in response to pumping changes within the unconfined aquifer from January 1 through September 1, 2012. The unconfined aquifer was modeled as a seven-layer system. Injection and extraction wells representing the interim 200-ZP-1 P&T remedy were incorporated as point sinks in the model. Additionally, a background decline of 0.21 m/yr was incorporated in the TTIM model outputs rather than filtering this trend from the monitoring data.

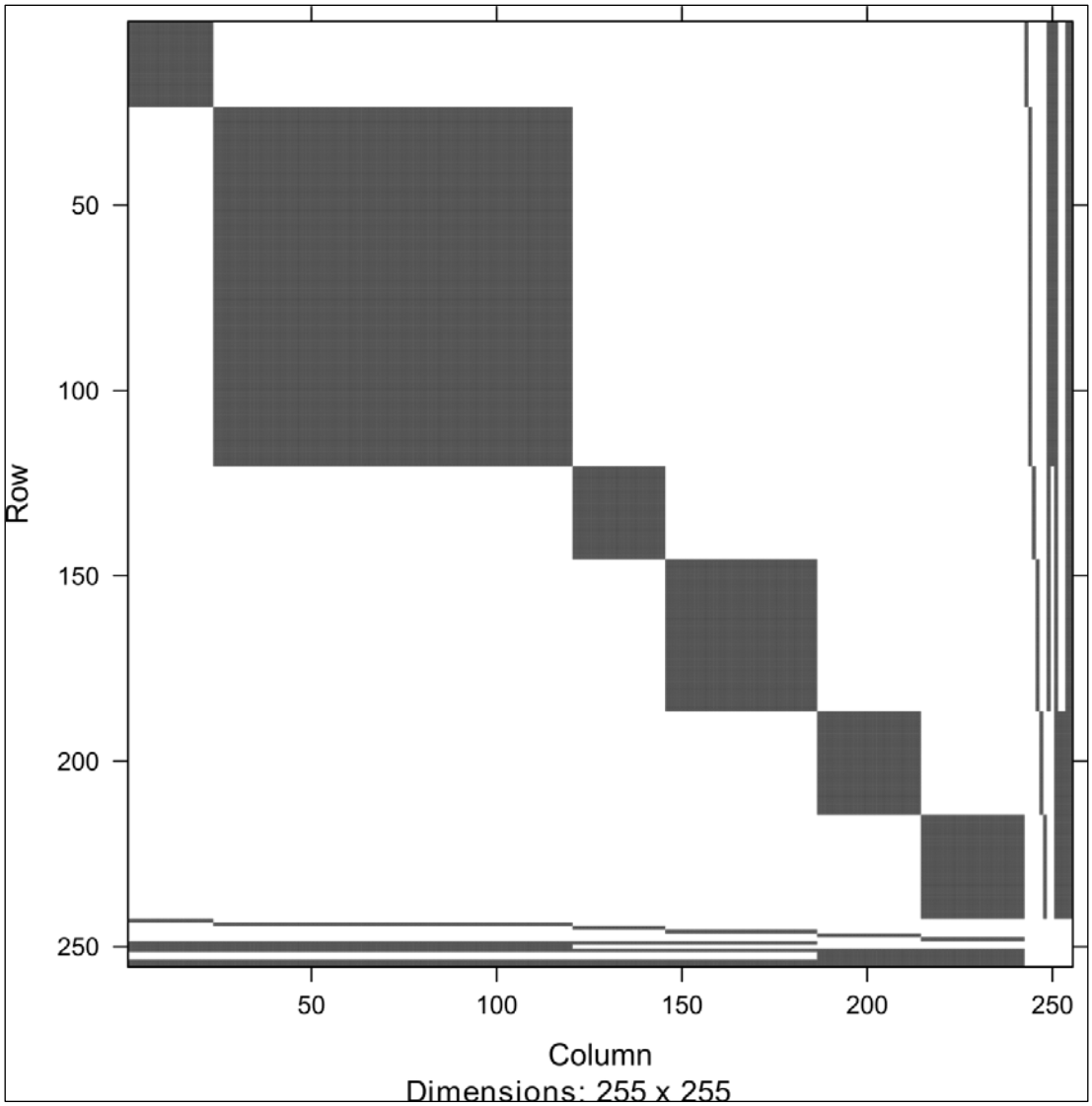

Figure 4-1. Block-Diagonal Multi-Event Universal Kriging Matrix for Six Water-Level Mapping Events

Aquifer properties (i.e., horizontal and vertical hydraulic conductivity, specific storage, and specific yield) were adjusted within reasonable ranges based upon previous studies (PNNL-18279; PNNL-18732) to evaluate whether the TTIM model could reasonably reproduce measured changes in water levels. Emphasis was placed on changes in groundwater levels in response to the shutdown of the interim P&T remedy (since startup of the final P&T remedy was ongoing during the evaluation and most of the final remedy extraction and injection wells were operating intermittently). Therefore, the results presented in this ECF provide an initial assessment of the aquifer response, which will be revisited once the final P&T remedy has been operating on a sustained basis.

5 Calculations and Results

Well-specific and system-wide flow rates for the extraction wells and injection wells of the interim 200-ZP-1 P&T remedy and for the extraction wells of the final 200-ZP-1 P&T remedy, as well as the operating rates for the SALDS injection system, are listed in Table 5-1. Groundwater extraction rates at the extraction wells of the final 200-ZP-1 P&T remedy are plotted in Figure 5-1.

Table 5-1. Well-Specific and System Wide Flow Rates

System	Well Name	Pumping Rates (gpm)						
		Well Code	2/1/2012	4/1/2012	5/10/2012	7/12/2012	8/14/2012	8/17/2012
Interim 200-ZP-1 remedy	299-W15-1		-10.5	-9.1	0.0	0.0	0.0	0.0
	299-W15-11		-10.5	-10.6	0.0	0.0	0.0	0.0
	299-W15-225		-251.9	-252.3	0.0	0.0	0.0	0.0
	299-W15-34		-10.8	-10.6	0.0	0.0	0.0	0.0
	299-W15-35		-17.7	0.0	0.0	0.0	0.0	0.0
	299-W15-36		0.0	0.0	0.0	0.0	0.0	0.0
	299-W15-40		0.0	0.0	0.0	0.0	0.0	0.0
	299-W15-43		-12.4	-12.3	0.0	0.0	0.0	0.0
	299-W15-45		-14.5	-13.8	0.0	0.0	0.0	0.0
	299-W15-46		-43.4	0.0	0.0	0.0	0.0	0.0
	299-W15-47		0.0	0.0	0.0	0.0	0.0	0.0
	299-W15-6		0.0	0.0	0.0	0.0	0.0	0.0
	299-W15-7		-4.9	0.0	0.0	0.0	0.0	0.0
	299-W15-29		138.2	107.2	0.0	0.0	0.0	0.0
	299-W18-36		85.7	71.7	0.0	0.0	0.0	0.0
	299-W18-37		1.0	1.1	0.0	0.0	0.0	0.0
	299-W18-38		69.2	58.7	0.0	0.0	0.0	0.0
	299-W18-39		69.8	60.1	0.0	0.0	0.0	0.0
T Tank Farm	299-11-45		-8.5	0.0	0.0	0.0	0.0	0.0
	299-11-46		-13.4	-21.4	-21.8	0.0	0.0	0.0
SALDS	SALDS		45.1	45.1	45.1	45.1	45.1	45.1
Final 200-ZP-1 remedy	299-W17-2	YE-10	0.0	0.0	0.0	0.0	-137.0	-90.0
	299-W11-49	YE-12	0.0	0.0	0.0	0.0	-90.0	-90.0
	299-W14-21	YE-15	0.0	0.0	0.0	0.0	-90.0	-90.0
	299-W11-92	YE-16	0.0	0.0	0.0	0.0	0.0	0.0
	299-W12-3	YE-18	0.0	0.0	0.0	0.0	0.0	-127.0
	299-W12-4	YE-19	0.0	0.0	0.0	0.0	-135.0	-135.0
	299-W14-20	YE-2	0.0	0.0	0.0	0.0	0.0	0.0
	299-W22-90	YE-21	0.0	0.0	0.0	0.0	0.0	0.0

Table 5-1. Well-Specific and System Wide Flow Rates

System	Well Name	Pumping Rates (gpm)						
		Well Code	2/1/2012	4/1/2012	5/10/2012	7/12/2012	8/14/2012	8/17/2012
	299-W22-91	YE-22	0.0	0.0	0.0	0.0	0.0	0.0
	299-W22-92	YE-23	0.0	0.0	0.0	0.0	0.0	0.0
	299-W14-73	YE-3	0.0	0.0	0.0	0.0	-90.0	-90.0
	299-W12-2	YE-5	0.0	0.0	0.0	0.0	-150.0	-145.0
	299-W11-50	YE-6	0.0	0.0	0.0	0.0	0.0	0.0
	299-W11-90	YE-7	0.0	0.0	0.0	0.0	0.0	0.0
	299-W17-3	YE-9	0.0	0.0	0.0	0.0	-100.0	-90.0

SALDS = State-Approved Land Disposal Site

5.1 Removal of Barometric Effects

Barometric effects were removed at 28 AWLN locations based on the methodology outlined in Section 4.1. The original and corrected water levels are plotted in Figure 5-2(a through g).The removal of barometric effects from the water levels generally results in smoothly varying water levels that reflect changes due to pumping. The following, however, should be noted:

- Data for wells 299-W14-72 and 299-W15-49 continue to show a relatively high-frequency variation.
- The corrected and uncorrected data for well 299-W15-32 appear to exhibit a longitudinal drift that may reflect transducer error.
- The data corrections for wells 299-W11-40 and 299-W15-32 appear to be slightly biased high, although for well 299-W15-32 this may at least, in part, be impacted by apparent transducer error.

5.2 Extraction Well-Specific Capacities

Thirteen of the final 200-ZP-1 groundwater extraction wells operated during the period evaluated in this ECF (July through August 2012), although on many occasions, only eight wells were consistently operating. At most wells, the extraction rates varied as the wells were tested and their rates adjusted. However, most extraction wells typically operated at rates ranging from about 90 to 150 gpm, although the flow data suggest that some wells appear capable of sustaining rates in excess of this range.

Specific capacities estimated for the 13 extraction wells using the methods described in Chapter 4 are listed in Table 5-2. Plots of extraction rate versus change in water level for each of the 13 pumped wells are shown in Figure 5-3, as well as the linear trend lines that were fitted for each well. As was noted in Chapter 4, in general it is possible to approximate the data with linear trend lines that pass through the origin. This implies that nonlinear well losses are relatively small. The likely validity of this inference and the general quality of the data used to make the specific capacity calculations are assessed together in Table 5-2 (under the heading “Reliability”). The specific capacity estimates that are categorized as “good” generally range between 2.0 and 6.0 gpm/ft. General comments are also provided in Table 5-2.

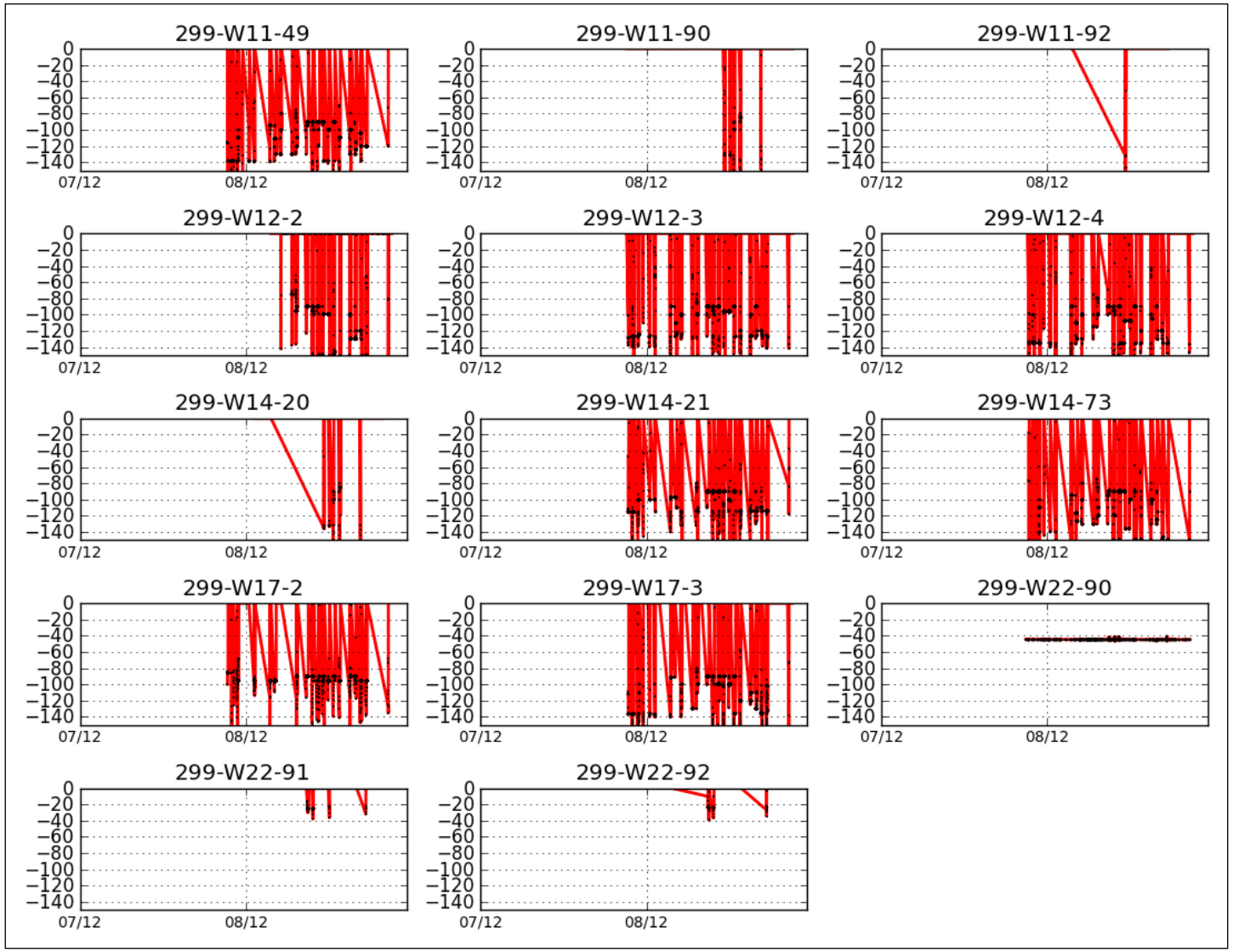

Figure 5-1. Final 200-ZP-1 P&T Remedy Extraction Well Flow Rates (in gpm)

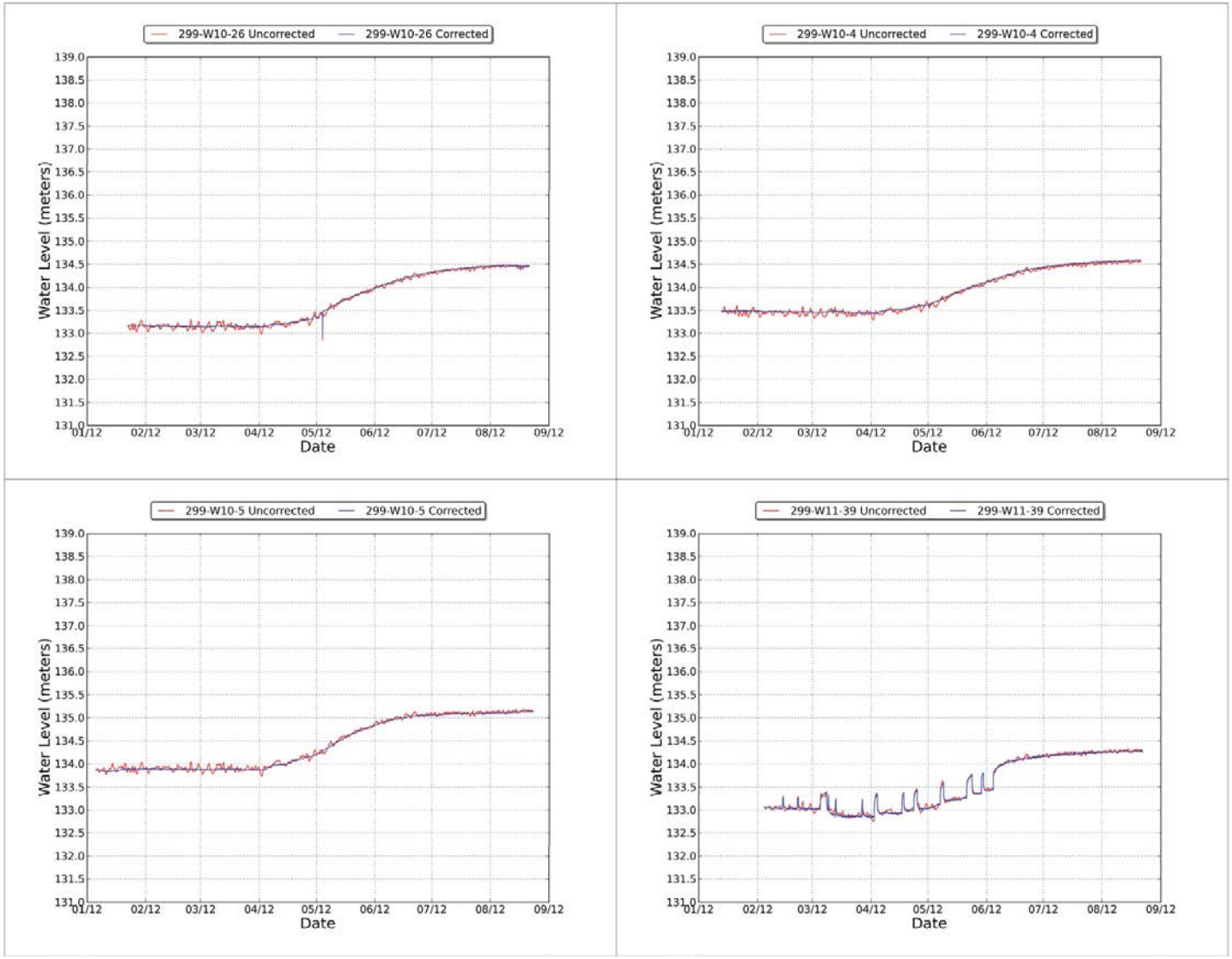

Figure 5-2a. Measured and Corrected Water Levels at AWLN Locations

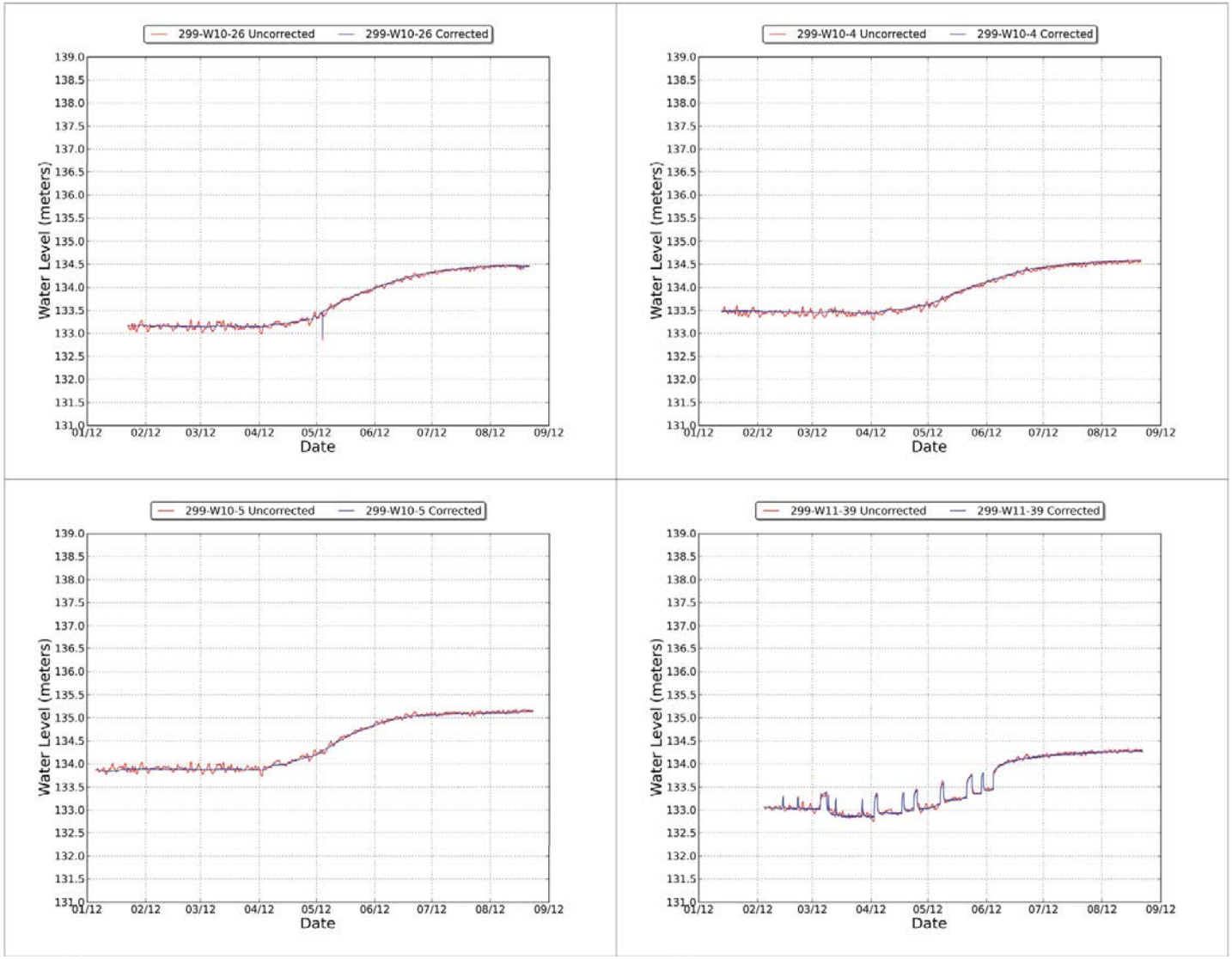

Figure 5-2b. Measured and Corrected Water Levels at AWLN Locations

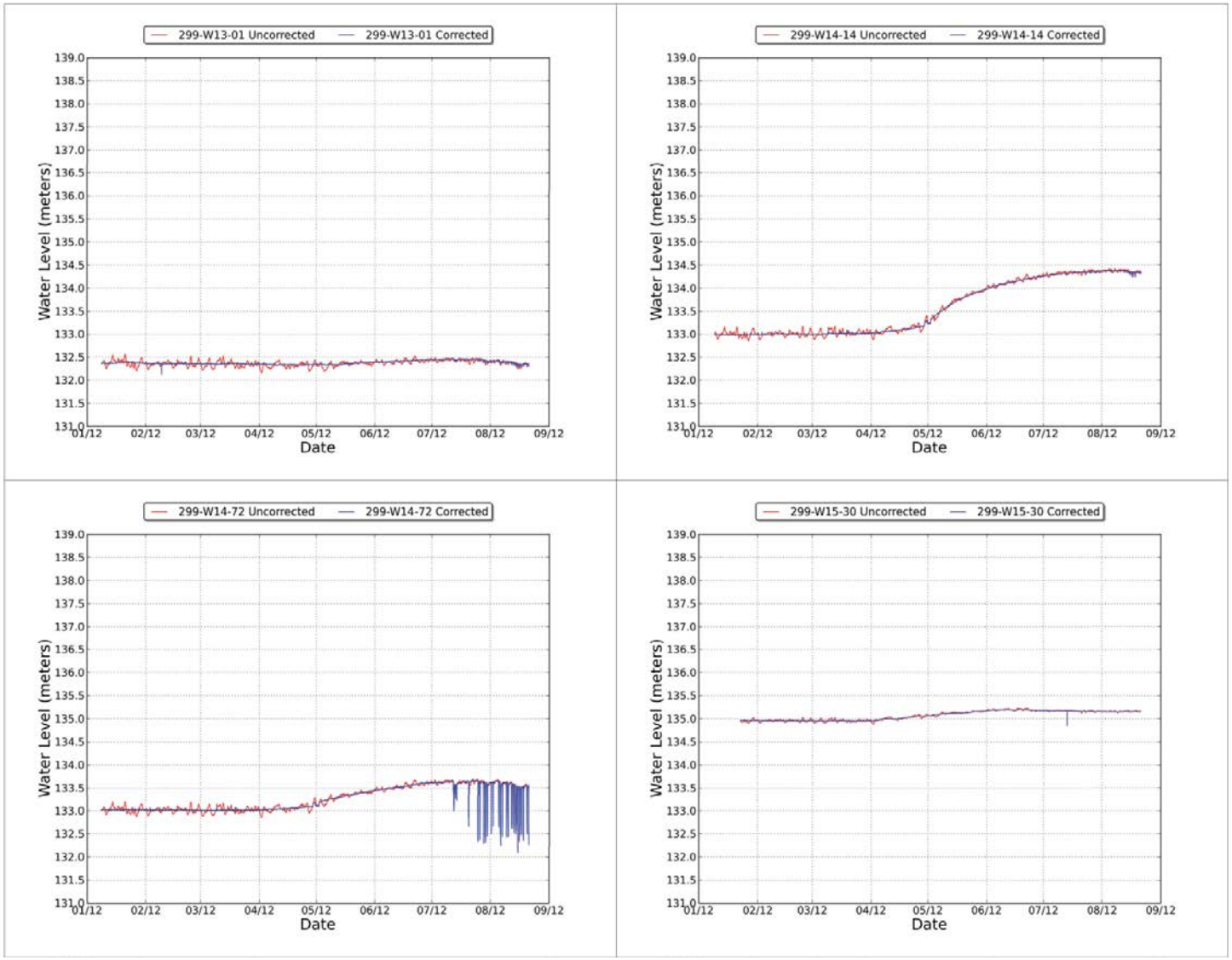

Figure 5-2c. Measured and Corrected Water Levels at AWLN Locations

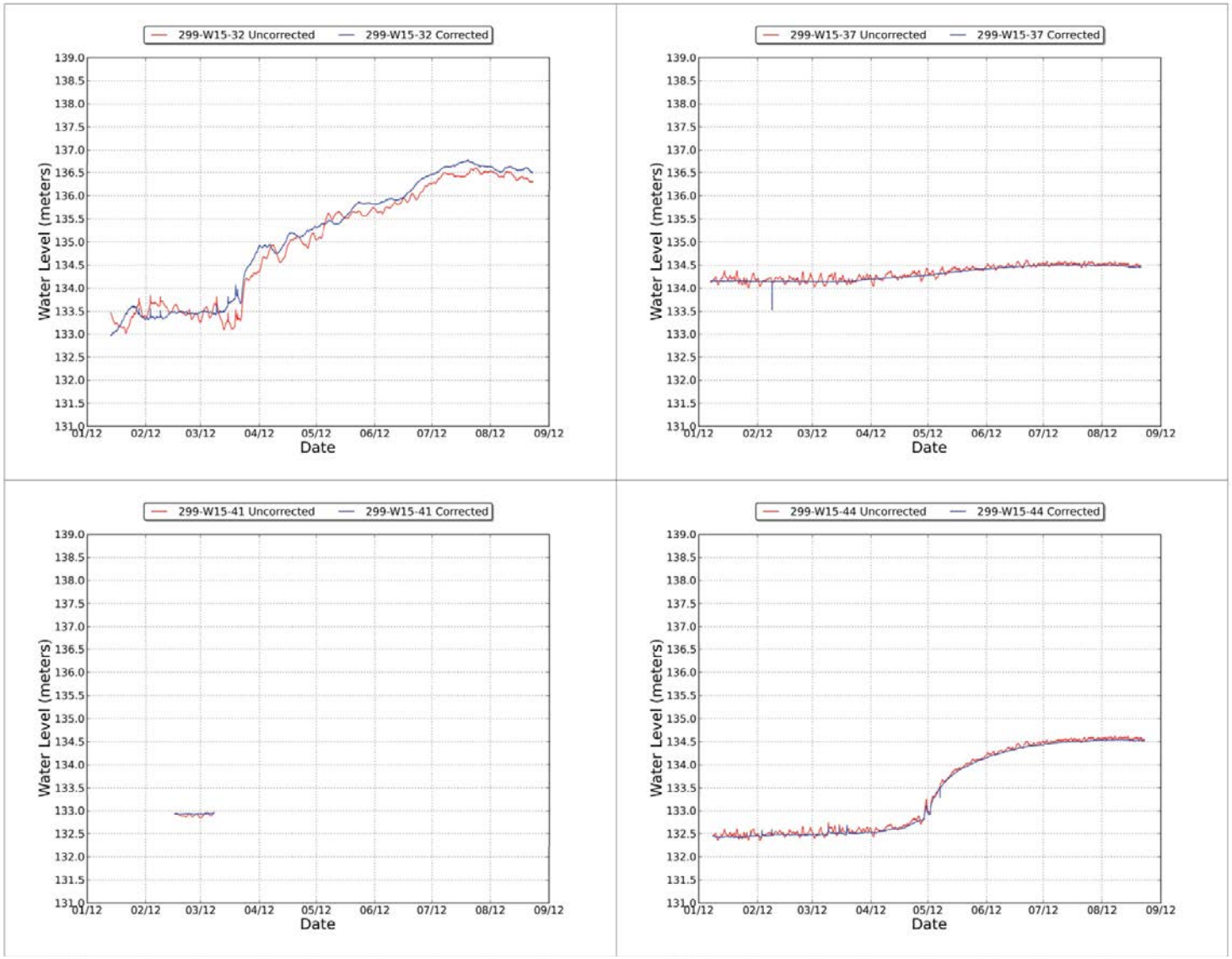

Figure 5-2d. Measured and Corrected Water Levels at AWLN Locations

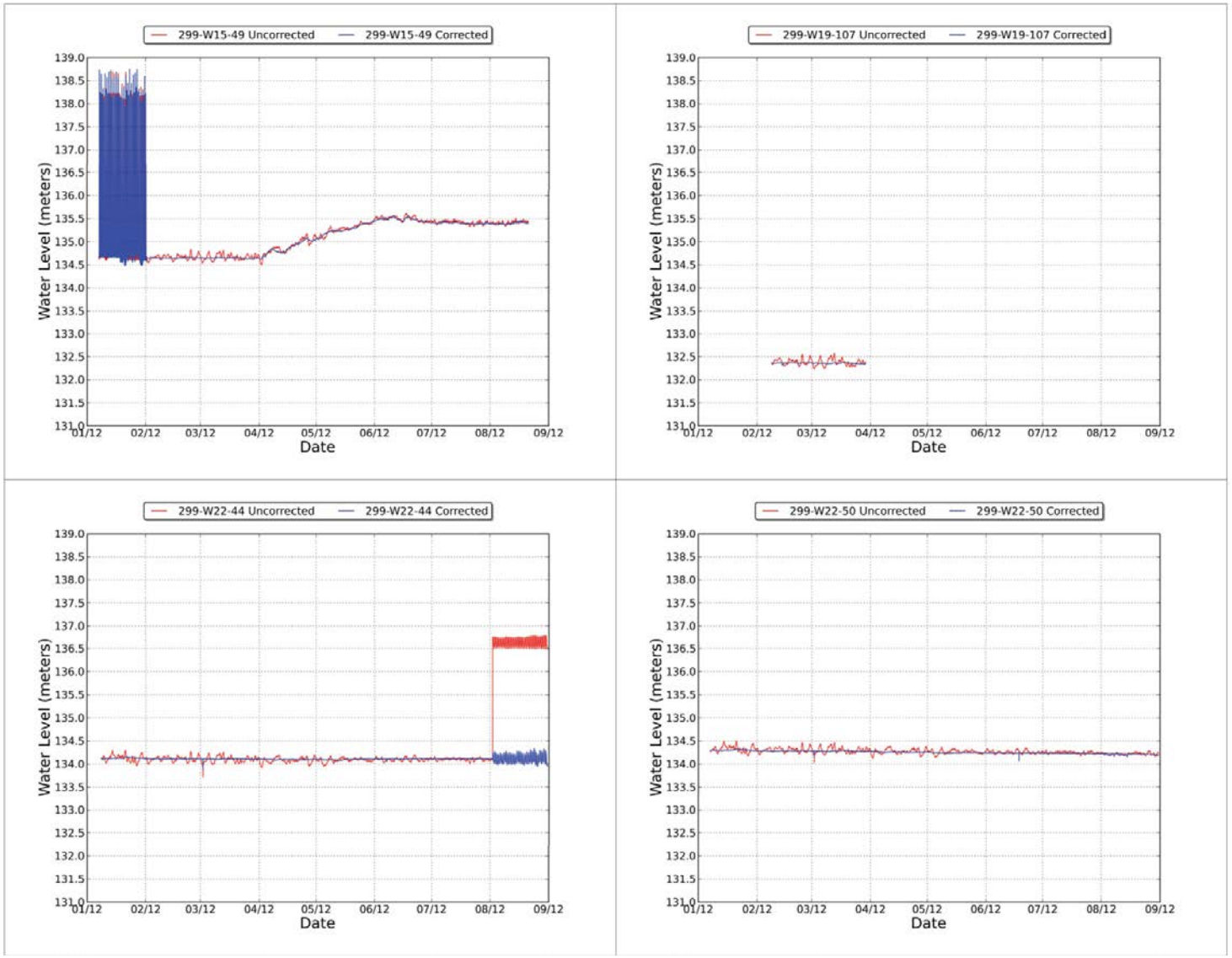

Figure 5-2e. Measured and Corrected Water Levels at AWLN Locations

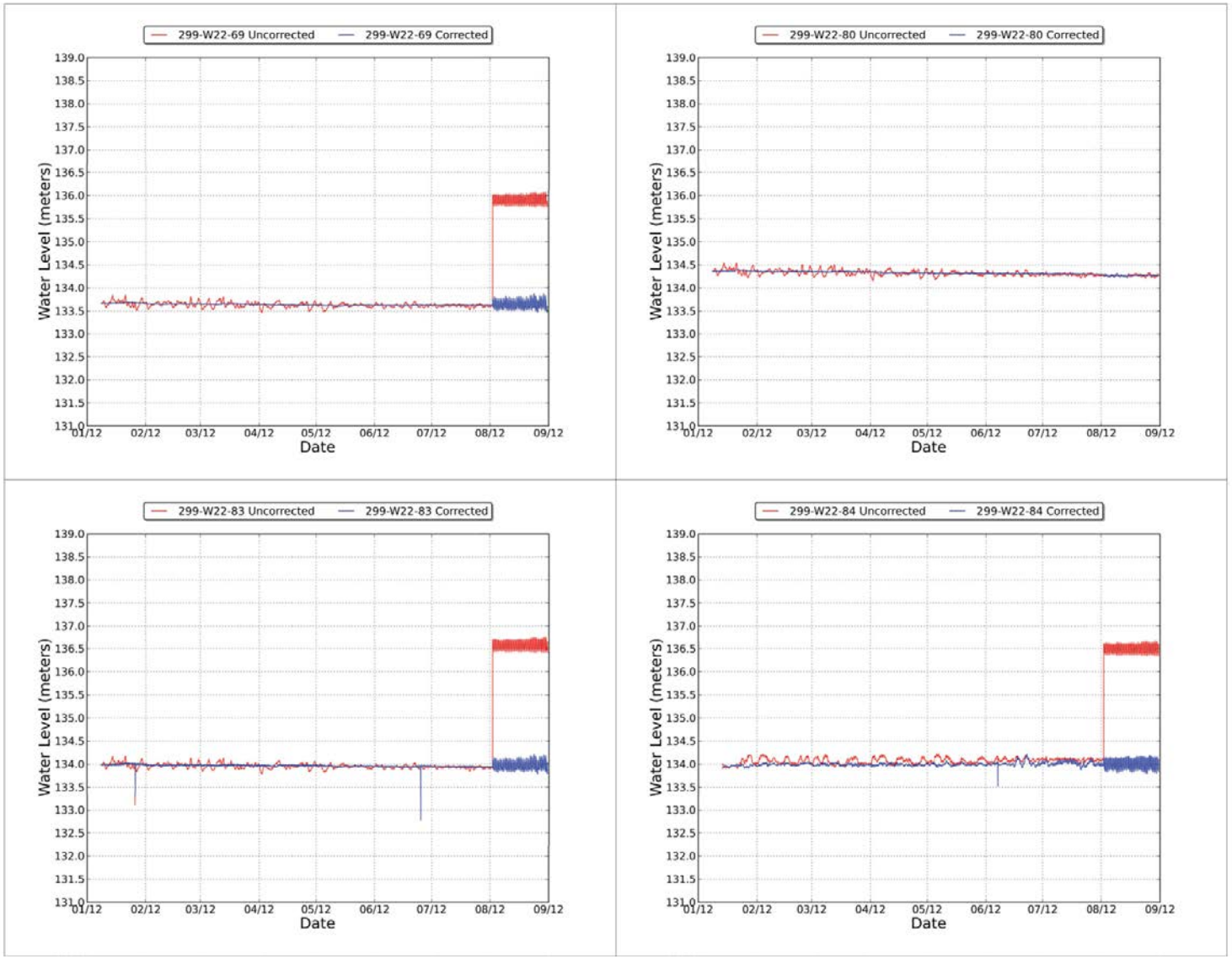

Figure 5-2f. Measured and Corrected Water Levels at AWLN Location

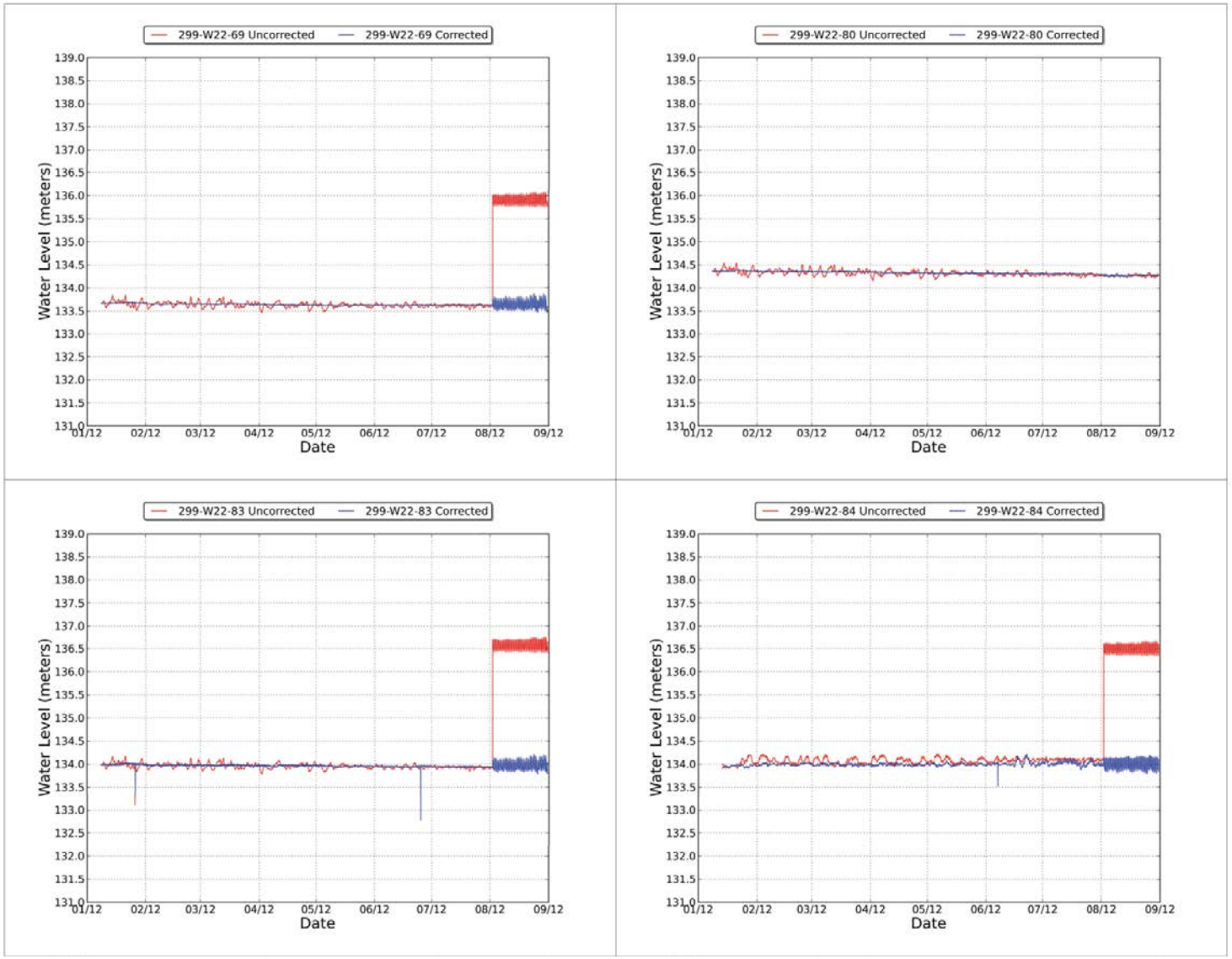

Figure 5-2g. Measured and Corrected Water Levels at AWLN Locations

Table 5-2. Calculated Specific Capacity at Extraction Wells

Well Name	Well Code	Easting (m)	Northing (m)	Specific Capacity (gpm/ft)	Reliability	Comments
299-W14-20	YE-2	566909.21	136284.62	3.9	High	
299-W14-73	YE-3	567359.14	136204.21	2.1	High	
299-W12-2	YE-5	568312.67	136610.25	3.7	High	
299-W11-90	YE-7	567306.69	136519.63	3.9	Moderate	Overestimated specific capacity because water levels did not reach steady state
299-W17-3	YE-9	566925.96	135324.90	2.6	High	
299-W17-2	YE-10	566951.59	135806.14	3.0	High	
299-W11-49	YE-12	567361.68	135924.61	3.1	High	
299-W14-21	YE-15	567721.52	135890.01	17.0	Low (*Tentative*)	Overestimated specific capacity because water levels did not reach steady state
299-W12-3	YE-18	568321.53	136998.09	2.4	High	
299-W12-4	YE-19	568327.41	136363.65	5.7	High	
299-W22-90	YE-21	566961.39	134483.24	2.0	Low (*Tentative*)	Too few data points
299-W22-91	YE-22	566923.00	134131.00	3.6	Low (*Tentative*)	Too few data points
299-W22-92	YE-23	567173.00	134037.00	2.8	Low (*Tentative*)	Too few data points

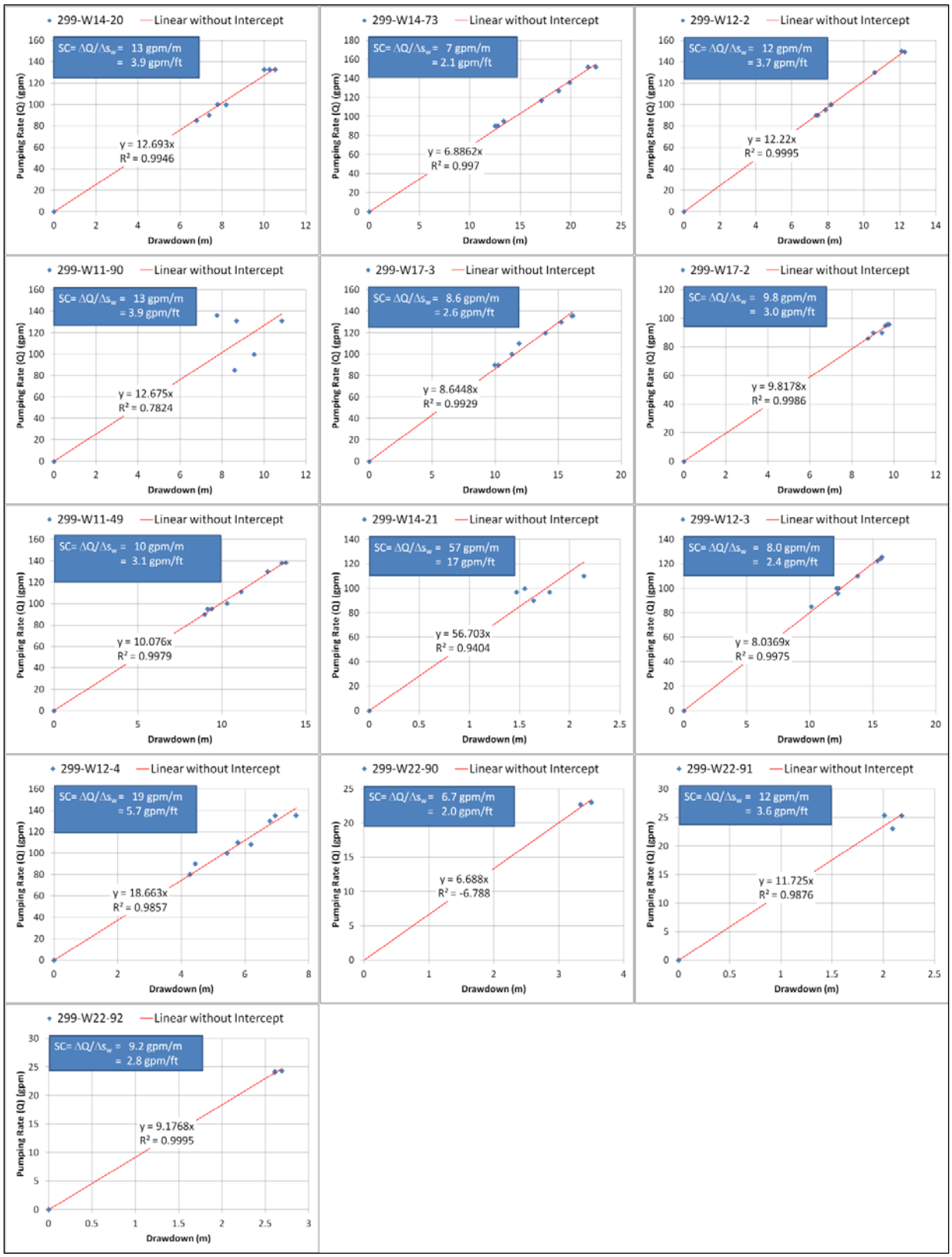

Figure 5-3. Calculated Well-Specific Capacities (Extraction Wells Only)

5.3 Groundwater Elevation Maps

The multi-event universal kriging calculation procedure described in Chapter 4 resulted in the construction of six groundwater elevation maps. The following figures depict the resulting groundwater elevation maps:

- Figures 5-4 and 5-5 present groundwater elevation maps prepared using data obtained February 1 and April 11, 2012, when the interim 200-ZP-1 P&T remedy was operational. The SALDS and T Tank Farm systems were also operational at this time. Figures 5-4 and 5-5 were constructed using the multi-event universal kriging technique, together with pumping rates at operating extraction and injection wells and the water levels obtained from the AWLN. April 11 also corresponds with the time frame of a comprehensive water-level synoptic event; as a result, Figure 5-5 also incorporates a large number of water levels obtained using manual depth-to-water measurements.

- Figures 5-6 and 5-7 present groundwater elevation maps prepared using data obtained May 10 and July 12, 2012, when the interim 200-ZP-1 P&T remedy was shut down and the final 200-ZP-1 P&T remedy had not commenced startup. At this time, only the SALDS and T Tank Farm systems were operational. Figures 5-4 and 5-5 were constructed using the multi-event universal kriging technique, together with pumping rates at operating extraction and injection wells and the water levels obtained from the AWLN.

- Figures 5-8 and 5-9 present groundwater elevation maps prepared using data obtained August 14 and August 17, 2012, when the final 200-ZP-1 P&T remedy had commenced startup but was not fully operational. At this time, the SALDS and T Tank Farm systems were also operational. Figures 5-8 and 5-9 were constructed using the multi-event universal kriging technique, together with pumping rates at operating extraction and injection wells and the water levels obtained from the AWLN.

- The residuals calculated from the multi-event universal kriging trend surface for each mapped event are presented as a traditional scatter plot in Figure 5-10, a plot of residual value versus easting coordinate of each corresponding well in Figure 5-11, and a plot of residual value versus northing coordinate of each corresponding well in Figure 5-12.

A common theme in all of the groundwater elevation maps is the background hydraulic gradient, which trends broadly from west to east, with a slight component to the north of east. In the February and April maps (Figures 5-4 and 5-5, respectively), an area of depressed water levels is evident close to the center of the map where extraction is concentrated, and an area of elevated water levels is evident in the west where the five interim remedy injection wells are located. The net effect of this injection/extraction operation produces a counter-clockwise rotation of hydraulic gradients in the area between the interim remedy extraction and injection wells, which during operations focused contaminant mass recovery in this area.

Following shutdown of the interim 200-ZP-1 P&T remedy in May, groundwater levels begin to recover, as shown in Figure 5-6.In Figure 5-6, the recovery appears partially complete, as evidenced by the relative absence of the areas of drawdown and mounding that are shown in Figure 5-4 and 5-5. However, mounding still appears evident in the area of the interim remedy injection wells, and some evidence exists of depressed water levels in the area of the interim remedy extraction wells. In July, the water levels are dominated by the west-to-east background hydraulic gradient.

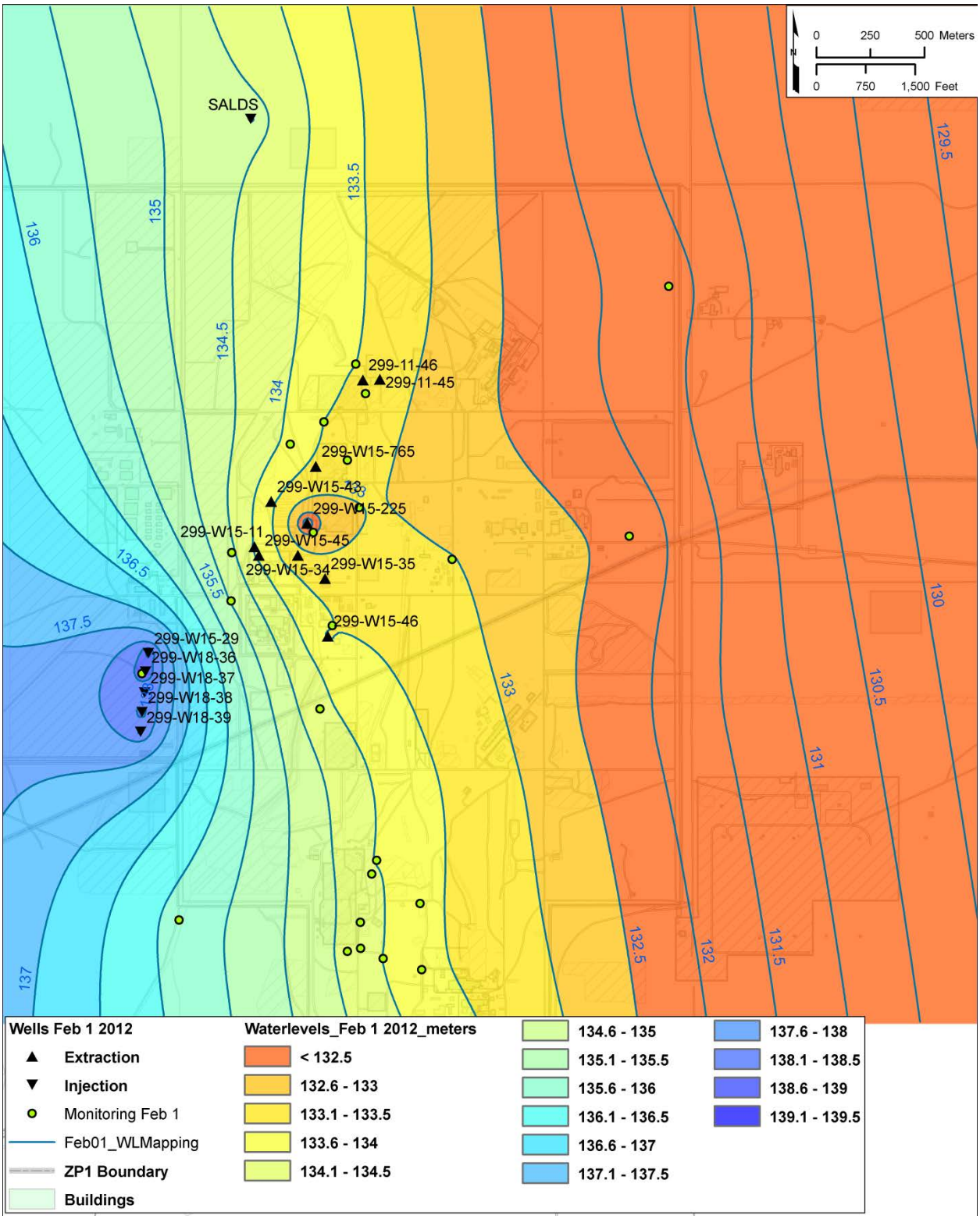

Figure 5-4. Groundwater Elevation Map for February 1, 2012

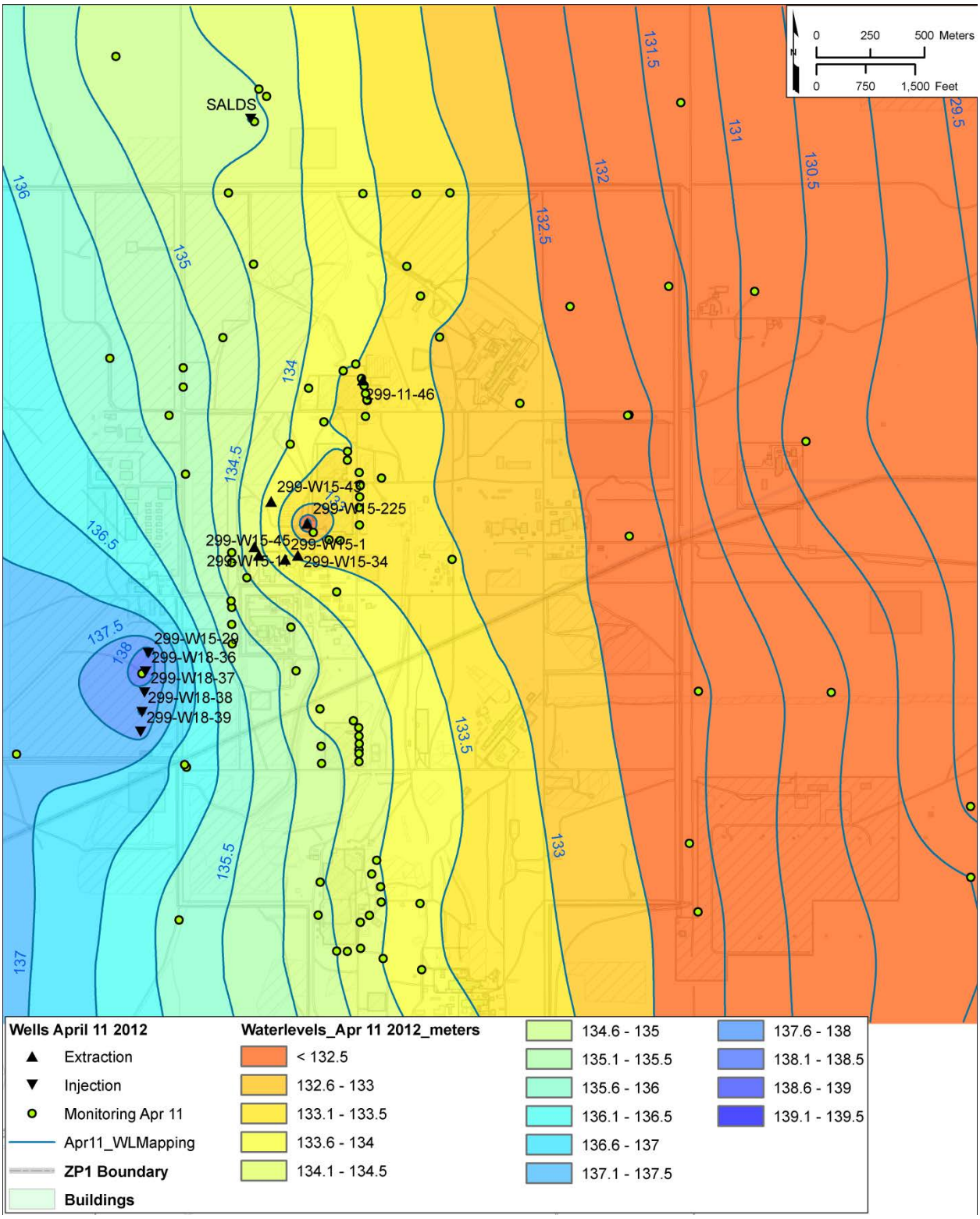

Figure 5-5. Groundwater Elevation Map for April 11, 2012

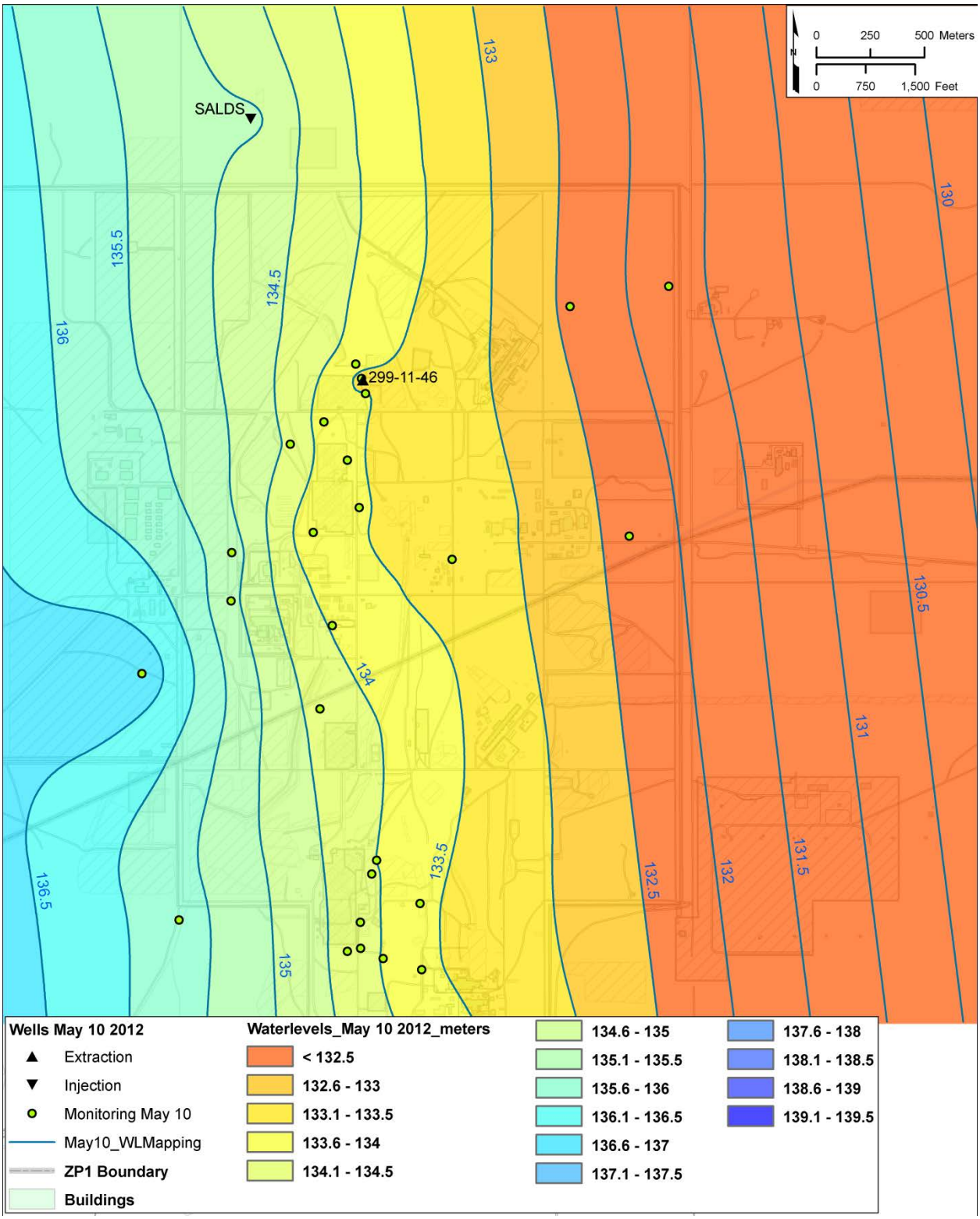

Figure 5-6. Groundwater Elevation Map for May 10, 2012

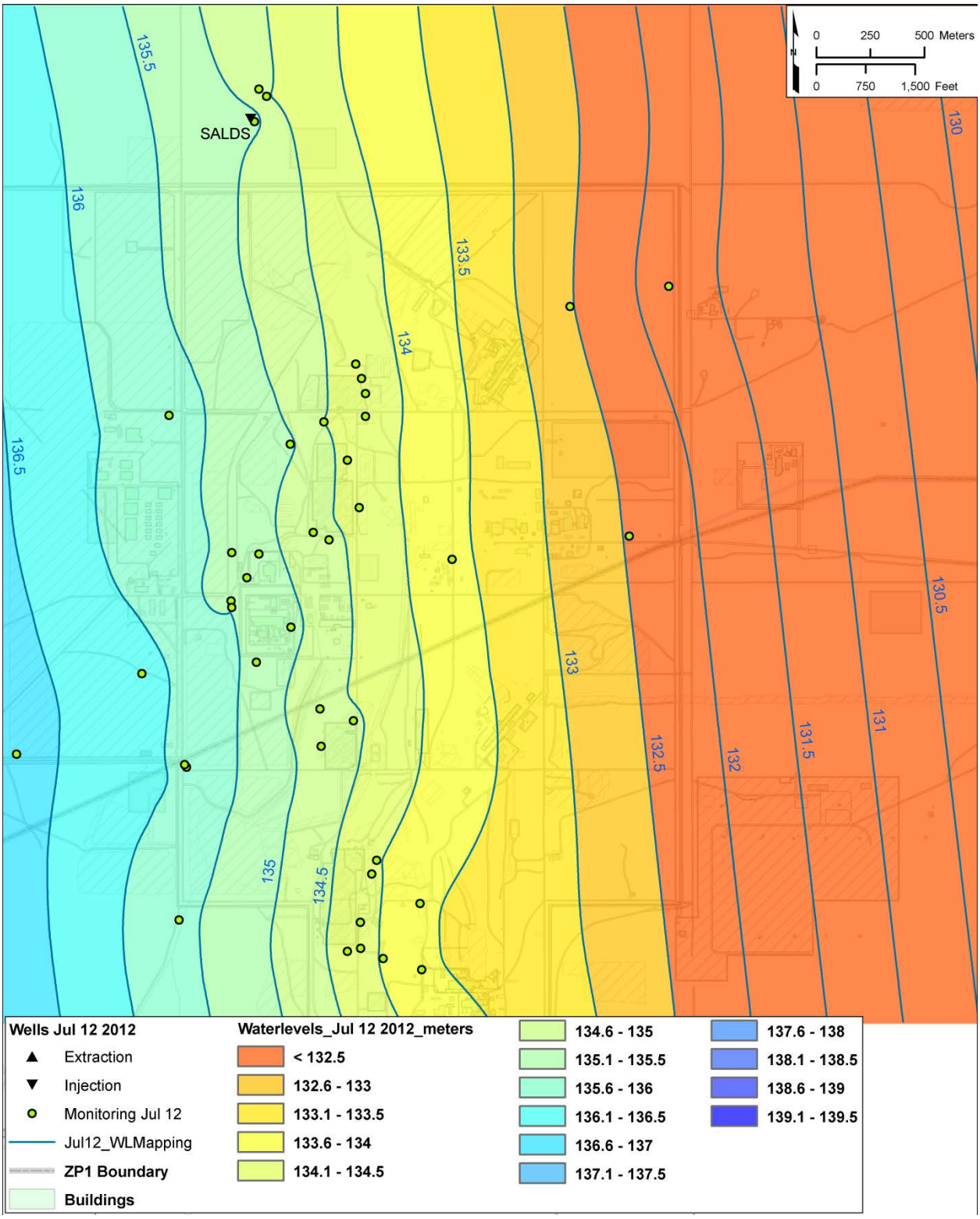

Figure 5-7. Groundwater Elevation Map for July 12, 2012

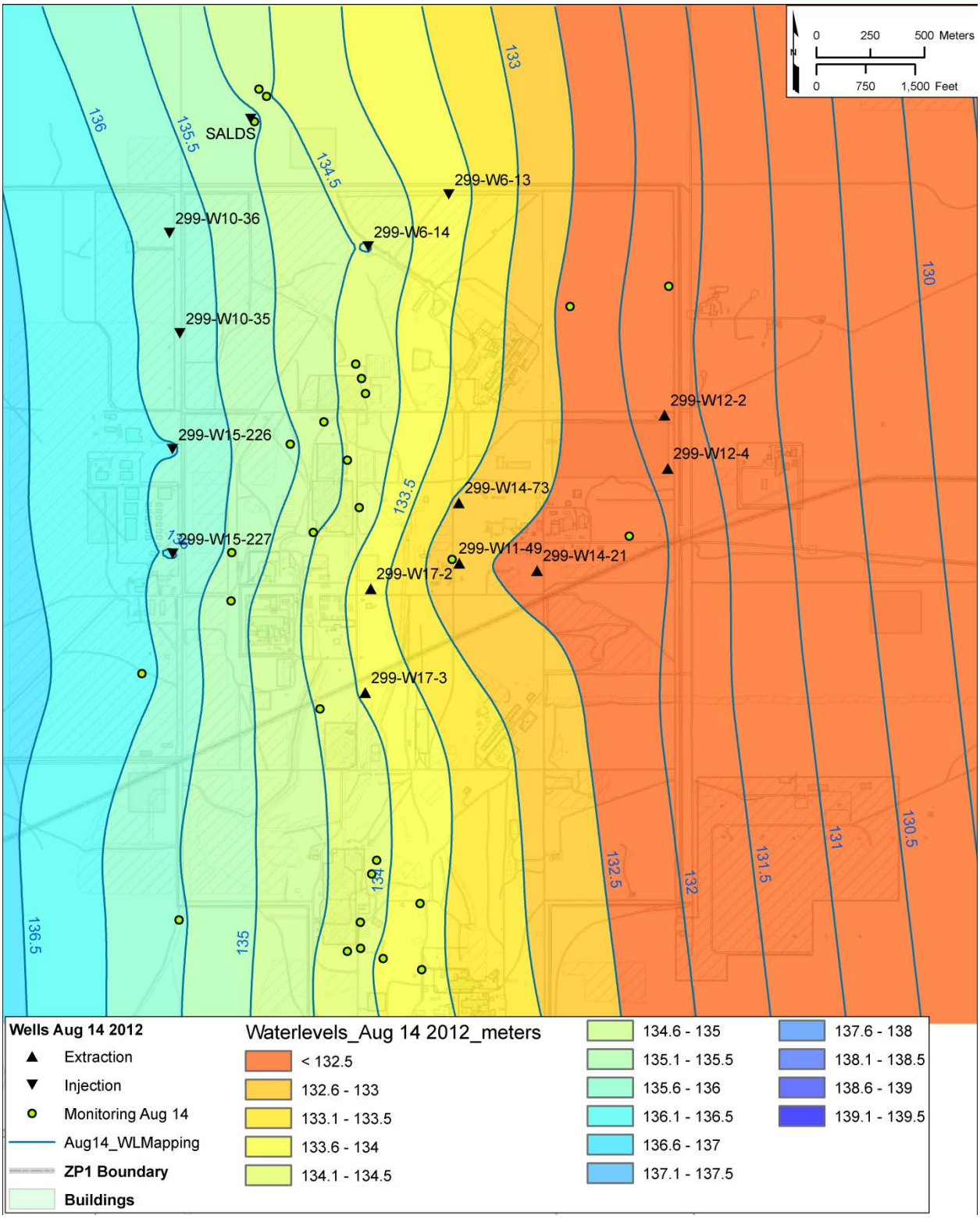

Figure 5-8. Groundwater Elevation Map for August 14, 2012

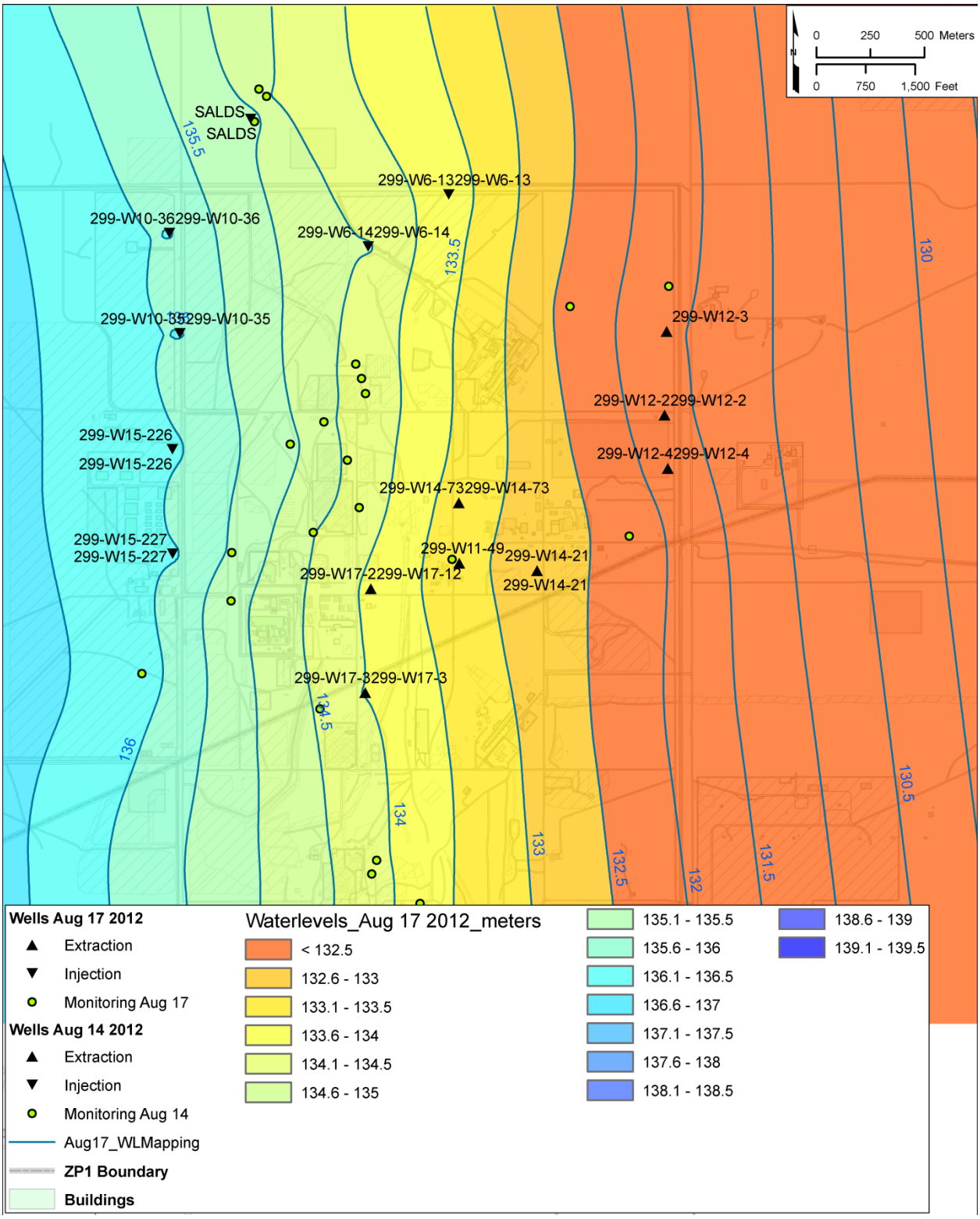

Figure 5-9. Groundwater Elevation Map for August 17, 2012

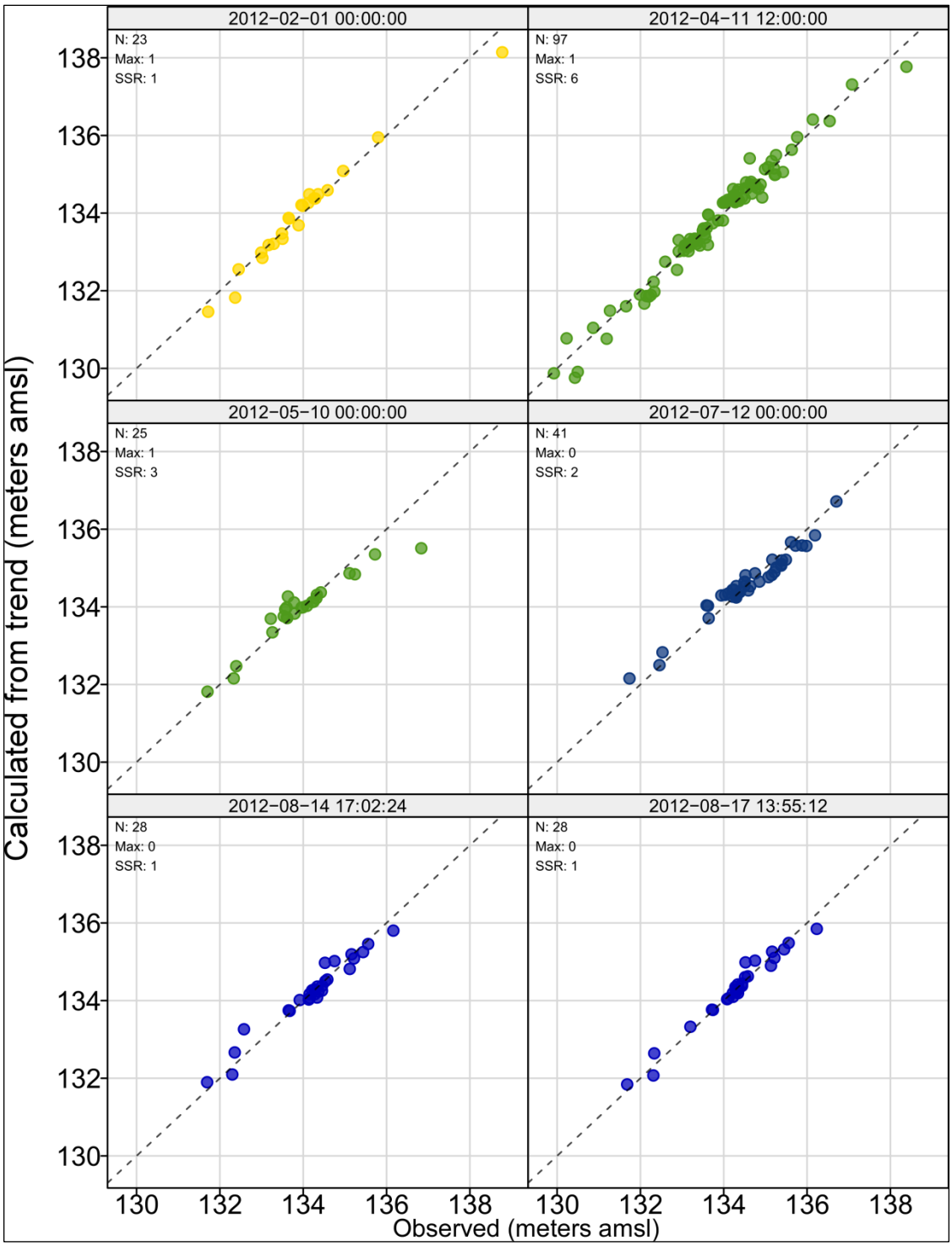

Figure 5-10. Scatter Plot of Multi-Event Universal Kriging Trend Values Versus Measured Values

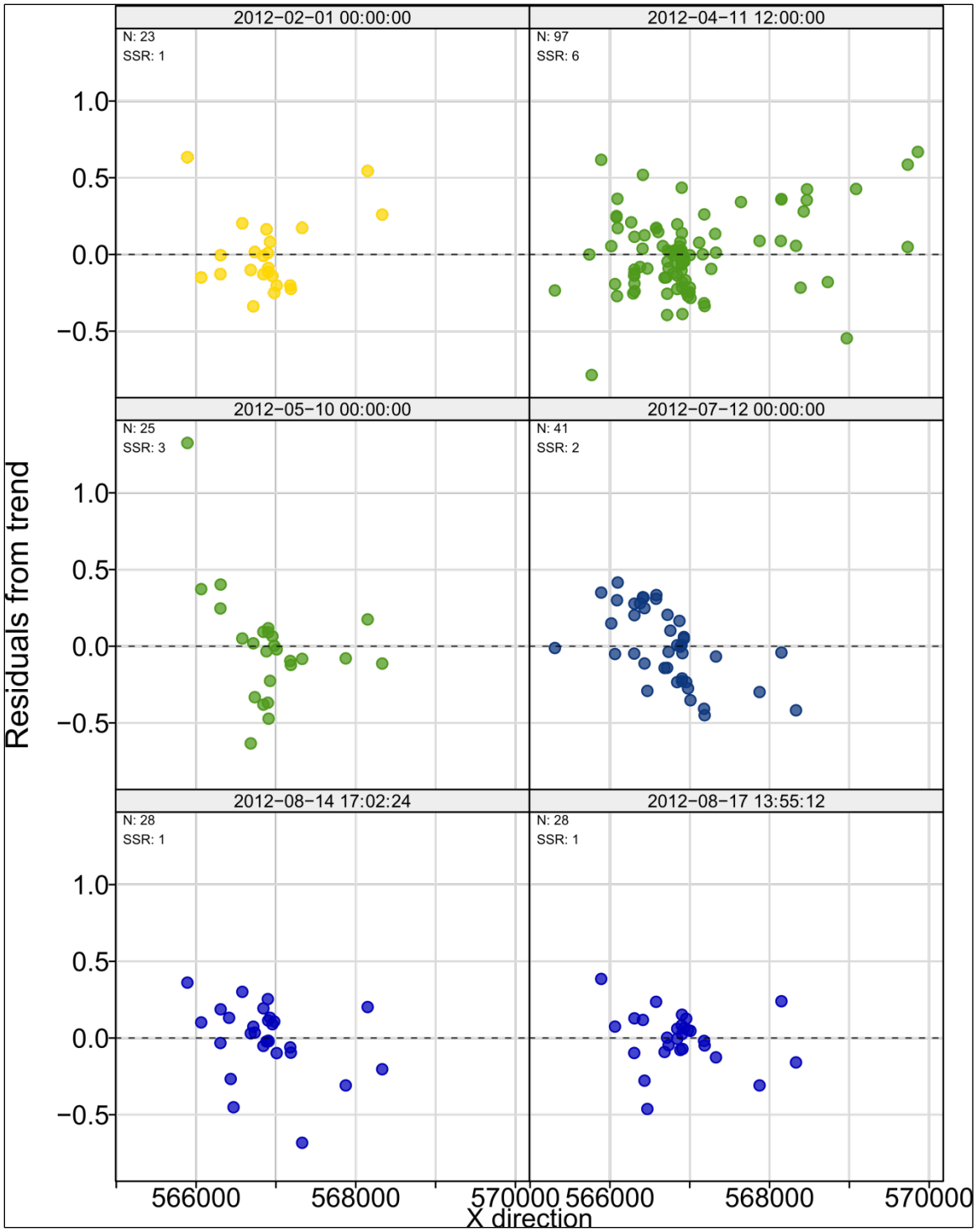

Figure 5-11. Multi-Event Universal Kriging Residuals Versus Easting Ordinate

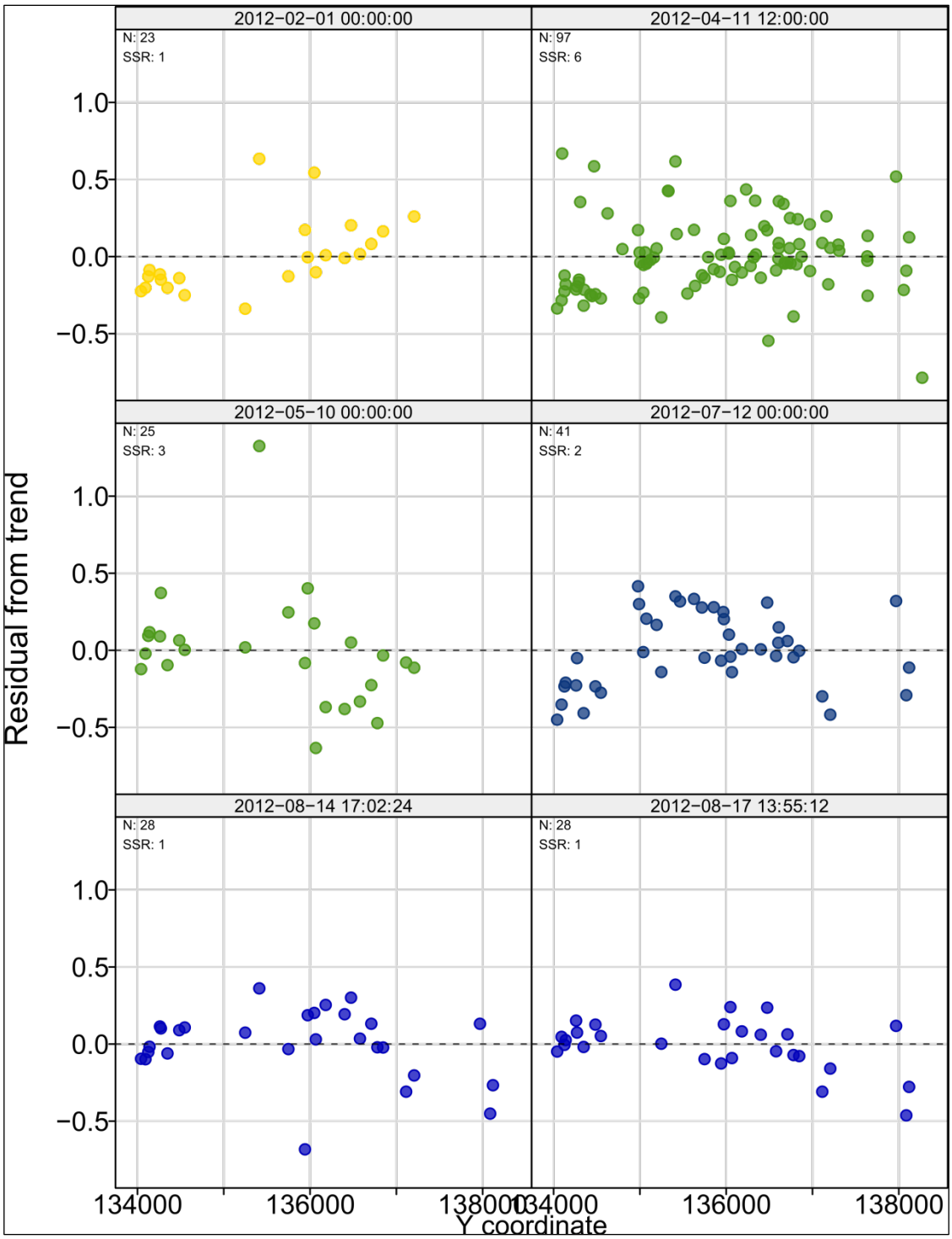

Figure 5-12. Multi-Event Universal Kriging Residuals Versus Northing Ordinate

The water-level maps constructed following the initial startup of the final 200-ZP-1 P&T remedy (Figures 5-8 and 5-9) depict only muted expressions of the drawdown and mounding that would be expected given the combined operating rate of the system of nearly 1,000 gpm on the two dates for which the maps were prepared (August 14 and August 17, respectively). Two principal factors result in this muted depiction:

- First and foremost, the relatively short duration of system operation on each day for which a map was prepared. The system only operated for a period of a few hours on most days, which is insufficient to enable substantial changes in groundwater elevations to manifest at distances of more than a few tens of meters from the pumped wells.
- Secondly, the hydraulic properties of the unconfined aquifer within which the 200-ZP-1 P&T system operates. The water table aquifer does not transmit the effect of either extraction or injection over great distances during brief periods of time due primarily to the water table storage capacity (i.e., specific yield), but also due to the relatively high aquifer transmissivity.

Based on these factors, the water levels not being affected to a large degree during the short-duration pumping events of the final 200-ZP-1 extraction and injection wells is consistent with expectations.

The scatter plot is shown in Figure 5-10 that compares the measured groundwater elevations for each mapped event with the multi-event universal kriging trend value at the corresponding location. There is generally good correspondence between the fitted trend and the measured values, suggesting no broad scale biases or dominant residuals from the multi-event universal kriging approach. The values of the residuals from the multi-event universal kriging trend versus the easting coordinate and the northing coordinate are shown in Figures 5-11 and 5-12, respectively. Spatial exploration of the residuals may yield improvements in the a priori specification of the multi-event universal kriging trend terms. However, although no formal tests of the residuals (e.g., tests for normality or bias) have been conducted, the plots suggest that the residuals are generally of fairly small valued (less than 0.5 m over a water-level range of about 8 m) and, as such, the resulting water-level maps are suitable to provide an overall depiction of groundwater flow patterns.

5.4 Evaluation of Aquifer Properties

Consistent with the findings presented in PNNL-18279 and PNNL-18732 (i.e., aquifer parameters cannot always be reliably estimated using standard single-well tests or hydrologic tests of short duration), the objective of this analysis is not to independently identify values for aquifer parameters. Instead, the objective of this analysis is to determine whether changes in groundwater elevation measured at the monitoring wells (instrumented with pressure transducers and data loggers) appear broadly consistent with results obtained previously by others and with the parameter values that were used in the design of the final 200-ZP-1 P&T remedy, as described in the feasibility study (DOE/RL-2007-28) and the RD/RA (DOE/RL-2008-78).

The vertical layering and aquifer parameters that were used in the TTIM model are listed in Table 5-3. Correspondence between the calculated and measured water levels at AWLN monitoring locations is shown in Figure 5-13(a through g). The results presented in Figure 5-13 suggest that groundwater-level responses are reasonably well reproduced using parameters that are broadly consistent with those previously obtained by others. This in turn suggests that data obtained during shutdown of the interim P&T remedy and startup of the final P&T remedy during calendar year 2012 are consistent with expectations developed from previous work and with assumptions that supported the design of the final 200-ZP-1 P&T remedy. It is noted, however, that the value used for the specific yield (0.03, or 3%) in the TTIM calculations is low and is not considered to be representative of the long-term drainable storage of

the water table aquifer. Further analysis, including calibration of the TTIM model, would be required to more accurately identify the values for the aquifer parameters.

Table 5-3. Estimated Aquifer Properties

Layer	Top Elevation (m)	Bottom Elevation (m)	Hydraulic Conductivity, K_H (m/d)	Vertical Anisotropy Ratio, K_Z/K_H	Specific Storage, S_S (m^{-1})	Specific Yield
1	135	121	5	0.1		0.03
2	121	107	5	0.1	1.00E-05	
3	107	93	5	0.1	1.00E-05	
4	93	80	5	0.1	1.00E-05	
5	80	68	0.008	0.01	1.00E-05	
6	68	55	5	0.1	1.00E-05	

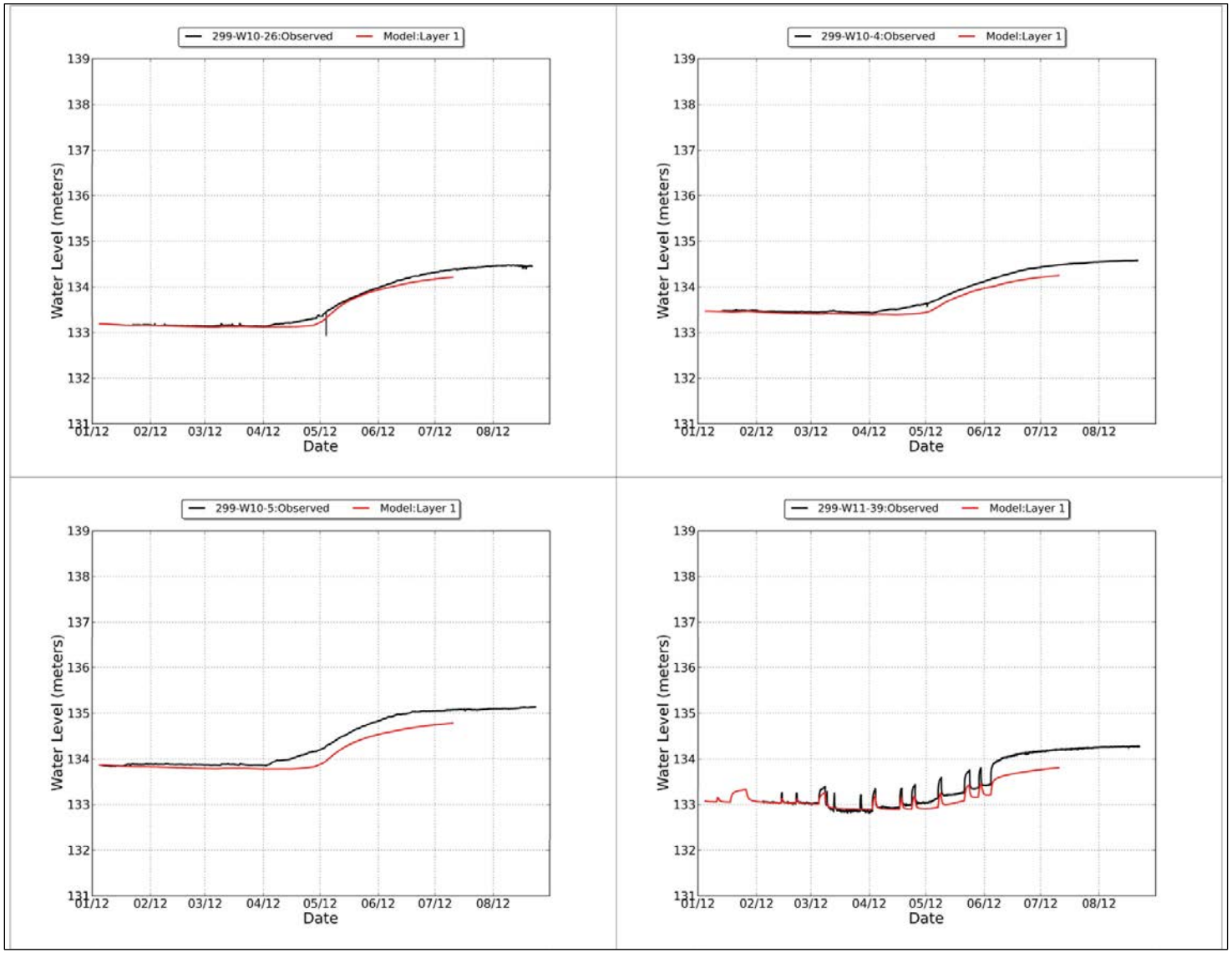

Figure 5-13a. Correspondence of Measured and Calculated Water Levels at AWLN Locations

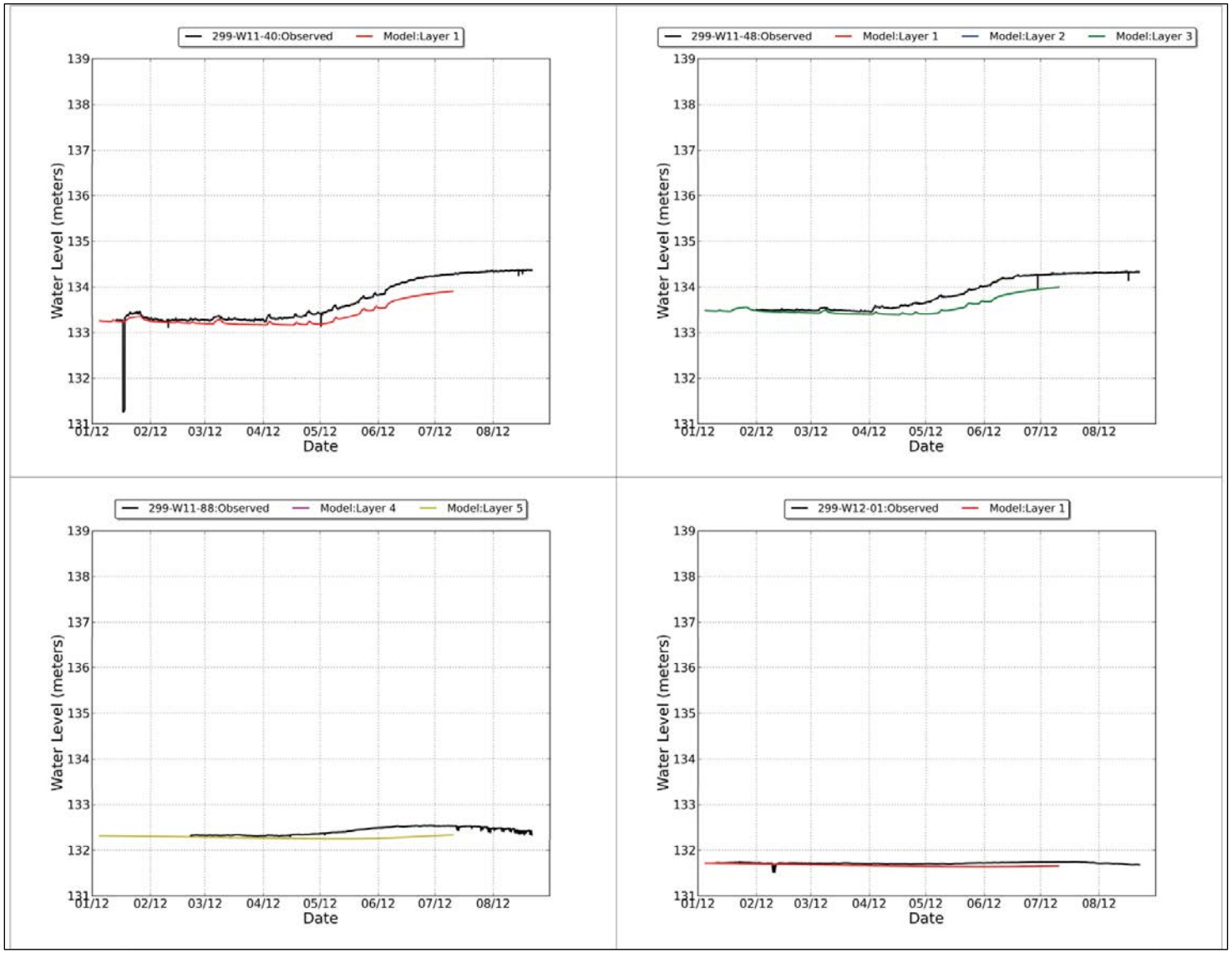

Figure 5-13b. Correspondence of Measured and Calculated Water Levels at AWLN Locations

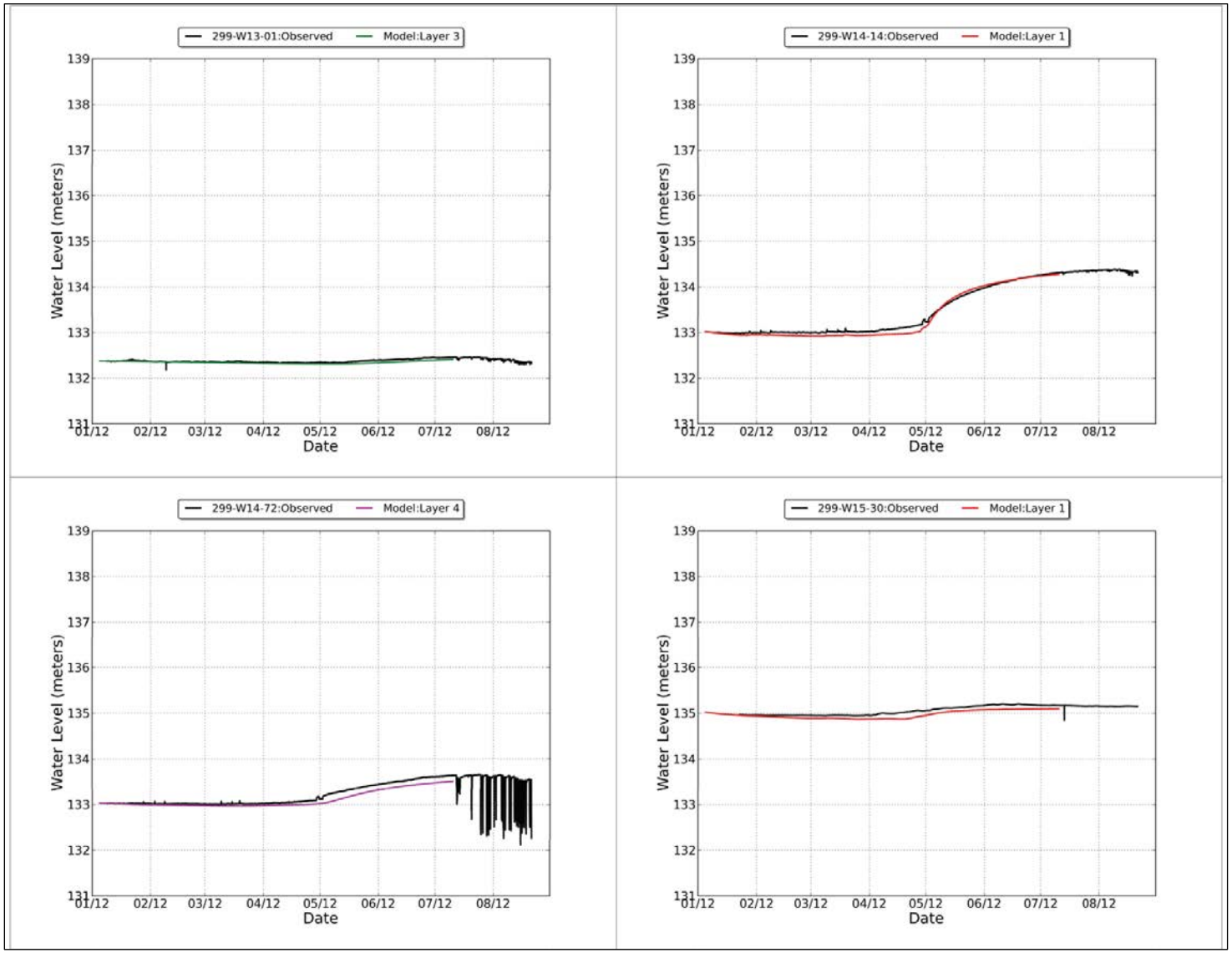

Figure 5-13c. Correspondence of Measured and Calculated Water Levels at AWLN Locations

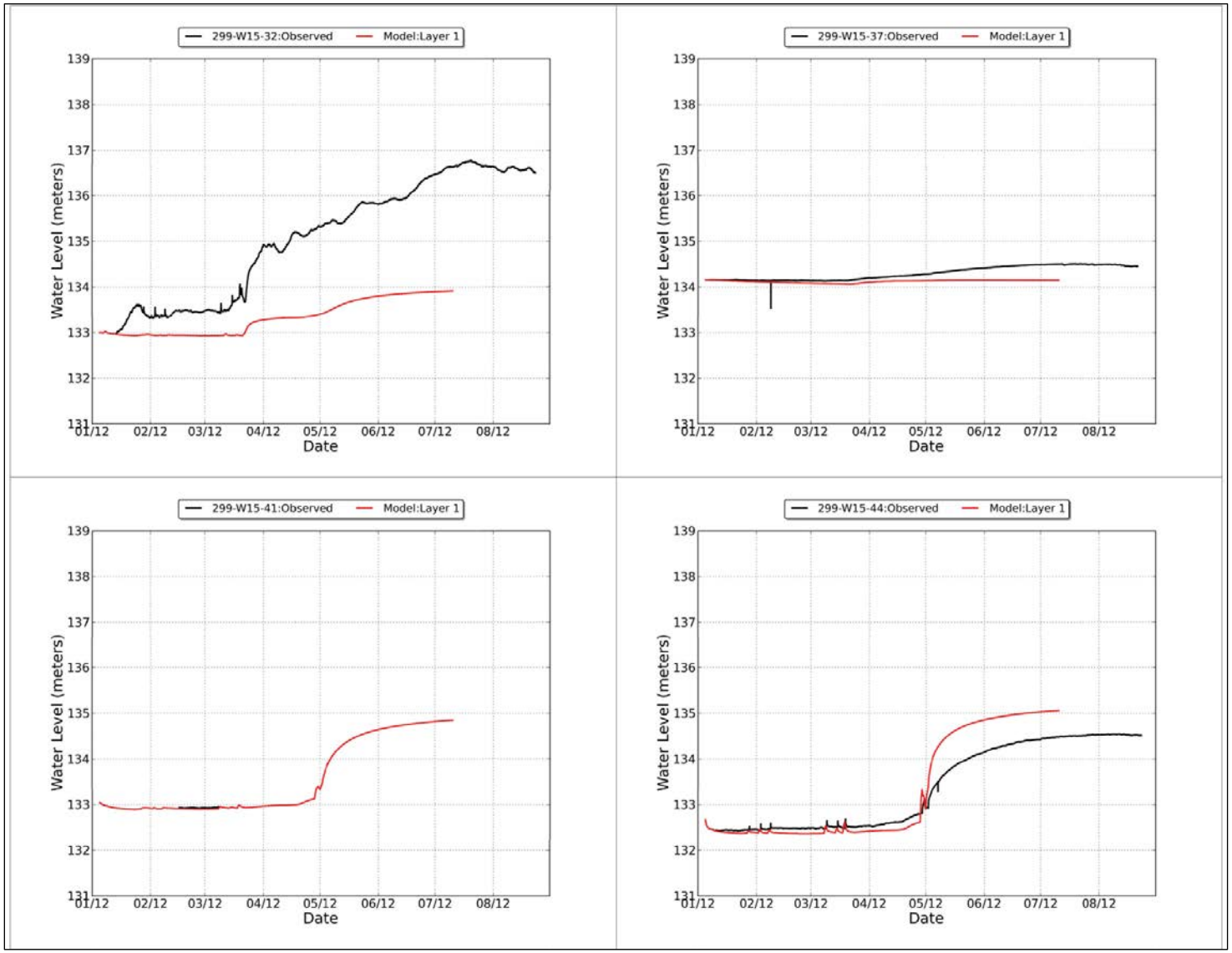

Figure 5-13d. Correspondence of Measured and Calculated Water Levels at AWLN Locations

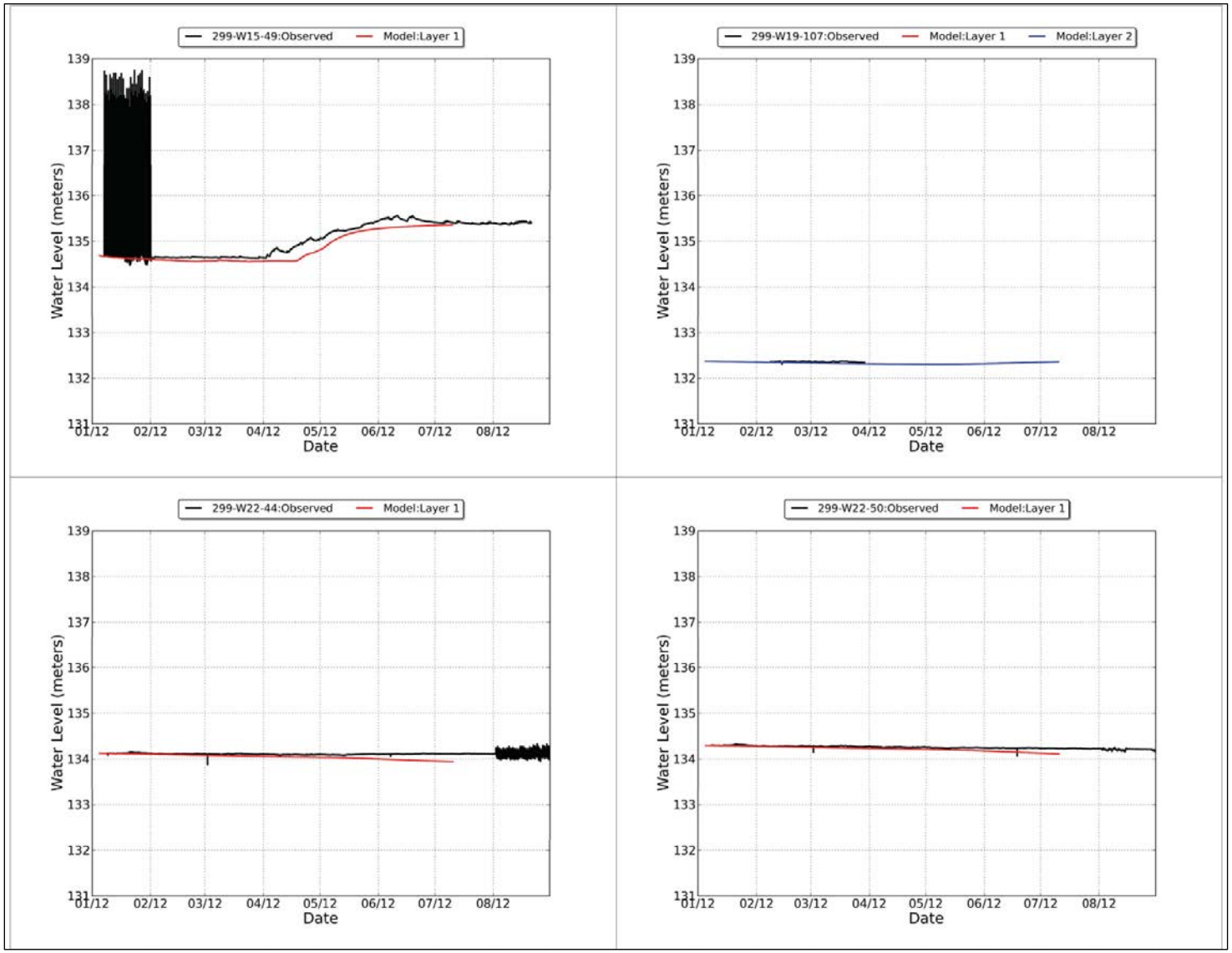

Figure 5-13e. Correspondence of Measured and Calculated Water Levels at AWLN Locations

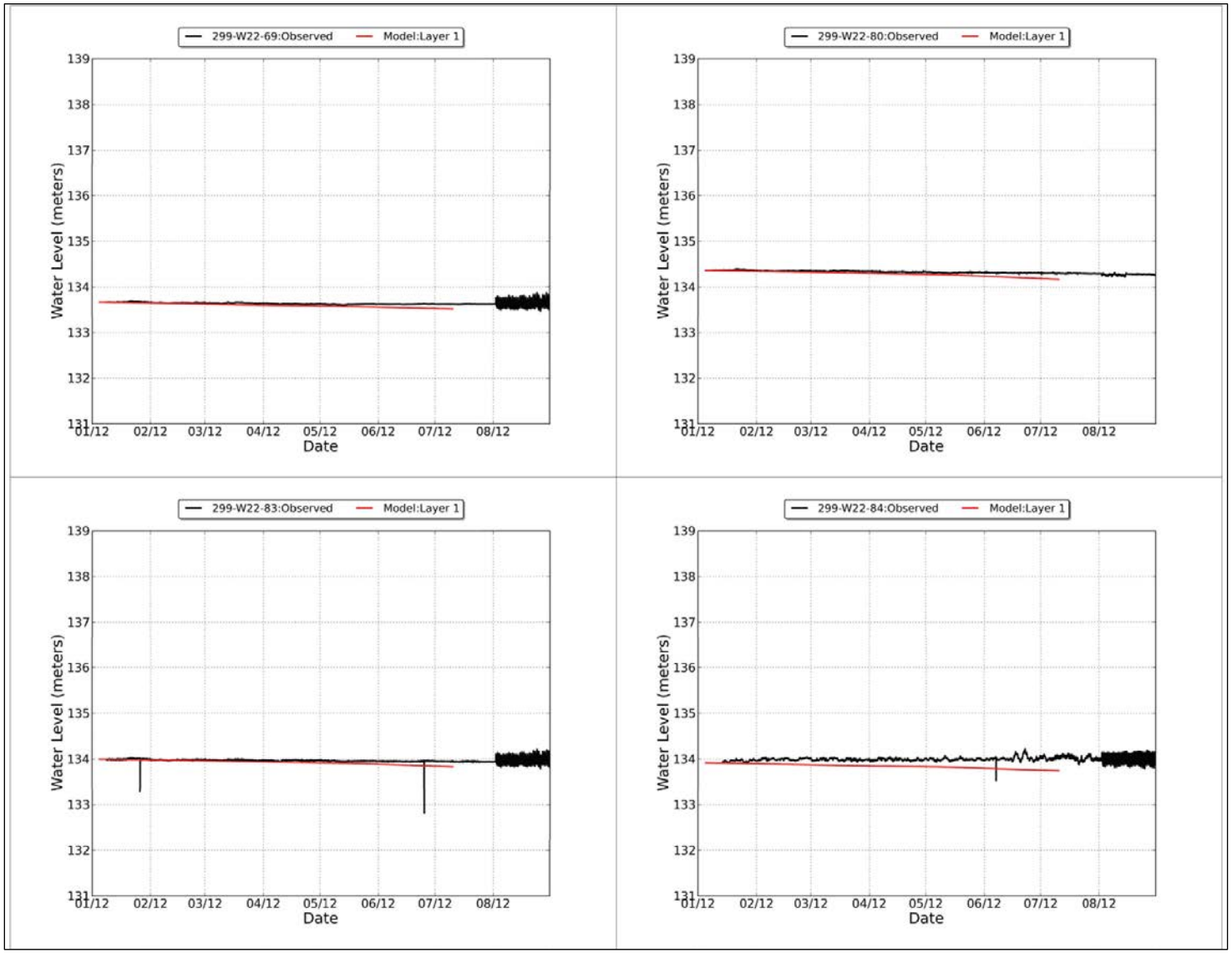

Figure 5-13f. Correspondence of Measured and Calculated Water Levels at AWLN Locations

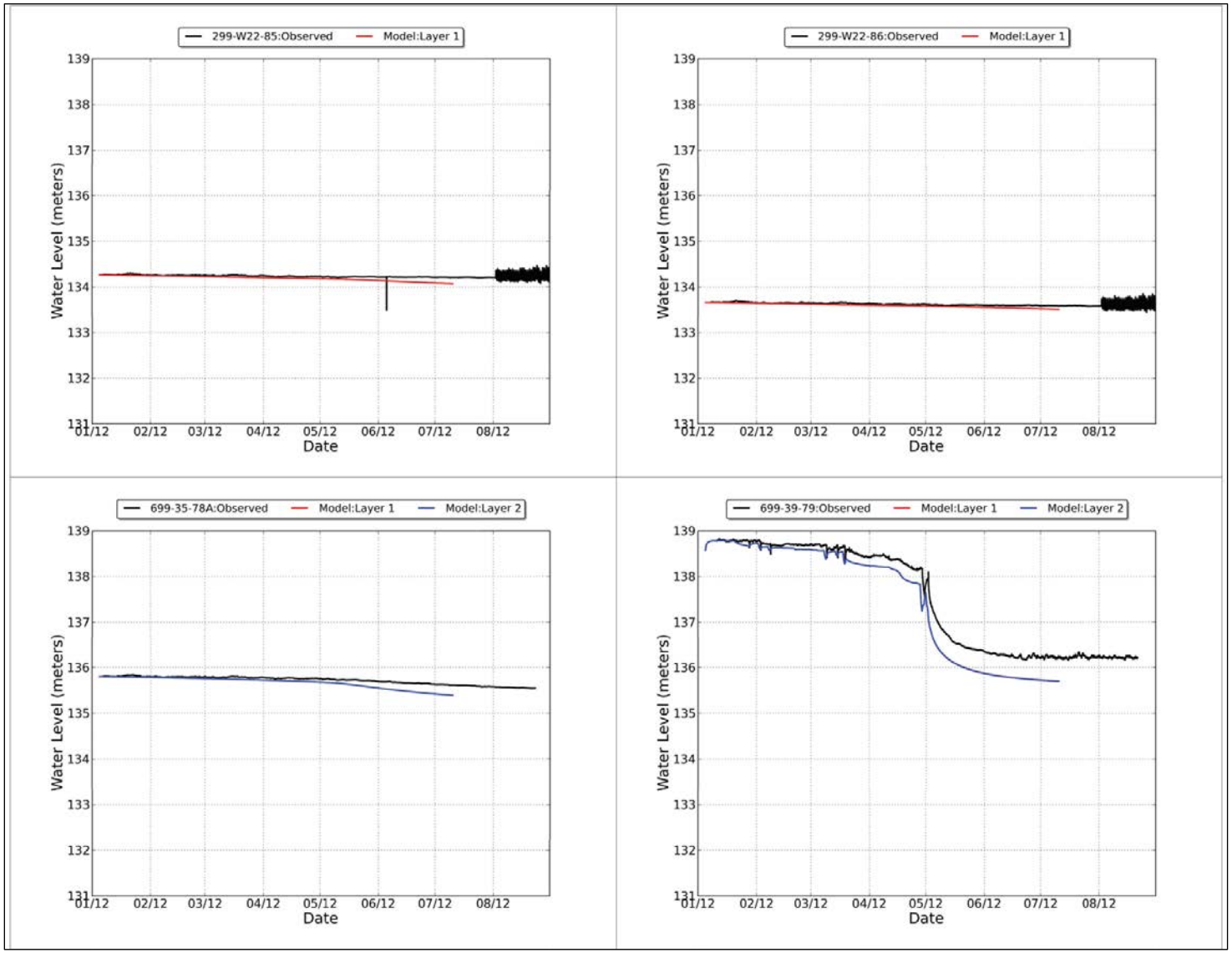

Figure 5-13g. Correspondence of Measured and Calculated Water Levels at AWLN Locations

6 Assumptions and Limitations

The following principal assumptions and limitations underlie the results presented in this ECF:

- Estimation of extraction well-specific capacity:
  - Nonlinear losses are assumed negligible.
  - Competition between pumped wells is assumed negligible (i.e., drawdown in the tested well due to pumping at surrounding wells is ignored).
- Removal of barometric effects:
  - Barometric pressure changes are the sole or principal contributor to fluctuations in groundwater levels, in addition to changes in pumping rates.
- Construction of groundwater elevation maps:
  - Assumptions underlying the Cooper-Jacob method ("A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History" [Cooper and Jacob, 1946]) for calculating drawdown due to pumping are assumed reasonably well adhered to. To the extent that these assumptions are violated, mapped groundwater-level patterns may deviate from actual groundwater-level patterns.
- Assessment of aquifer properties:
  - Although the principal water-bearing units documented in the *Groundwater Data Package for Hanford Assessments* (PNNL-14753) are incorporated in the TTIM model, the representation of the hydrostratigraphy is greatly simplified. For example, (1) each aquifer unit is assumed to be homogeneous, isotropic, and laterally infinite in extent; and (2) the transmissivity within each aquifer unit is assumed to be constant over time.

7 Software Applications

Software used for this calculation was in accordance with PRC-PRO-IRM-309, *Controlled Software Management*.

7.1 Approved Software

Not applicable to the calculations described in this ECF.

7.2 Support Software Descriptions

The following programs were used to perform the calculations described in this ECF:

- **TTIM:** TTIM is a solver for transient multi-aquifer flow based on the Laplace-transform analytic element method and is developed at the Delft University of Technology in Delft, The Netherlands (Bakker, 2012). TTIM is publically available, open-source freeware, available from www.ttim.googlecode.com.

  TTIM is proposed for inclusion as support software for MODFLOW and related codes (CHPRC-00258, Rev. 2, *MODFLOW and Related Codes Software Management Plan*) and is under consideration for inclusion by the software owner in the next revision of CHPRC-00258.

- **R:** The R programming environment is a language and environment for statistical computing and graphics (*R: A Language and Environment for Statistical Computing* [R Foundation, 2012]; "R: A Language for Data Analysis and Graphics" [Ihaka and Gentleman, 1996]. R programming was used to perform a variety of data processing tasks, including the tabulation and formatting of data in preparation for analysis. R is publically available, open-source freeware.
- **KT3D-H2O:** The KT3D-H2O software is listed in the Hanford Information Systems Inventory (HISI) under entries #2832 and #2833 (identical entries). This software was not classified as safety software. It was graded "N/A" based on negative responses to all software grading checklist questions. Consequently, there are no controlled use requirements pertaining to this software. KT3D-H2O was developed internally and is publically available freeware.
- **MRCX:** The MRCX (v.1.1) software (PNNL-19775, *Guide to Using Multiple Linear Regression in Excel (MRCX v.1.1) for Removal of River Stage Effects from Well Water Levels*) enables the removal of river-stage and barometric effects from well water levels with multiple regression techniques. The software was developed by PNNL as part of the Remediation Science and Technology project of CH2M HILL Plateau Remediation Company. MRCX was developed internally and is publically available freeware.

7.3 Statement of Valid Software Application

TTIM, R, KT3D-H2O, and MRCX were used in a manner consistent with their intended uses and are valid applications of these software packages for the problems addressed in this ECF.

8 References

Bakker, M., 2012, *TTIM: A Multi-Aquifer Transient Analytic Element Model (Version 0.2)*, Delft University of Technology, Delft, The Netherlands.

CHPRC-00258, 2010, *MODFLOW and Related Codes Software Management Plan*, Rev. 2, CH2M HILL Plateau Remediation Company, Richland, Washington.

Cooper, H.H., and C.E. Jacob, 1946, "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History," *American Geophysical Union Transactions*, 27(4):526-534.

DOE/RL-2007-28, 2008, *Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0808050315. http://www5.hanford.gov/arpir/?content=findpage&AKey=00098828.

DOE/RL-2007-33, 2008, *Proposed Plan for Remediation of the 200-ZP-1 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=00098832.

DOE/RL-2008-78, 2009, *200 West Area 200-ZP-1 Pump-and-Treat Remedial Design/Remedial Action Work Plan*, Rev. 0, Reissue, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0084101.

DOE/RL-2009-38, 2009, *Description of Modeling Analyses in Support of the 200-ZP-1 Remedial Design/Remedial Action Work Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0095363.

DOE/RL-2009-124, 2010, *200 West Area Pump-and-Treat Facility Operations and Maintenance Plan*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=1009071206.

EPA, Ecology, and DOE, 2008, *Record of Decision, Hanford 200 Area 200-ZP-1 Superfund Site, Benton County, Washington*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=0810240402.

Ihaka, R., and R. Gentleman, 1996, "R: A Language for Data Analysis and Graphics," *Journal of Computational and Graphical Statistics*, 5(3):299-314.

Kitanidis, P.K. "Generalized Covariance Functions in Estimation," *Mathematical Geology*, 25(5):525-540, 1993.

Kruseman, G.P., and N.A. de Ridder, 1990, *Analysis and Evaluation of Pumping Test Data*, 2nd Edition, Publication 47, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands.

PNNL-14753, 2006, *Groundwater Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14753Rev1.pdf.

PNNL-18279. 2009. *Aquifer Testing Recommendations for Well 299-W15-225: Supporting Phase I of the 200-ZP-1 Groundwater Operable Unit Remedial Design*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18279.pdf.

PNNL-18732, 2009, *Field Test Report: Preliminary Aquifer Test Characterization Results for Well 299-W15-225: Supporting Phase I of the 200-ZP-1 Groundwater Operable Unit Remedial Design*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18732.pdf.

PNNL-19775, 2010, *Guide to Using Multiple Linear Regression in Excel (MRCX v.1.1) for Removal of River Stage Effects from Well Water Levels*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19775rev1.pdf.

PRC-PRO-IRM-309, 2009 *Controlled Software Management*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

R Foundation, 2012, *R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.r-project.org/.

SGW-42305, 2009, *Collection and Mapping of Water Levels to Assist in the Evaluation of Groundwater Pump-and-Treat Remedy Performance*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www5.hanford.gov/arpir/?content=findpage&AKey=1001210169.

Skrivan, J.A., and M.R. Karlinger, 1977, *Semi-Variogram Estimation and Universal Kriging Program*, Program Number K603, U.S. Geological Survey Water Resources Division, Tacoma, Washington.

Volpi G., and G. Gambolati, 1978, "On the Use of a Main Trend for the Kriging Technique in Hydrology," *Advances in Water Resources*, 1(6):345-349.