Norman, Yolande

From: James Ewart [jewart@chesterengineers.com]
Sent: Monday, August 30, 2010 4:36 PM
To: purcell.mark@epa.gov; Norman, Yolande
Cc: Coltrain.Katrina@epamail.epa.gov; Guo, Lifeng; e.esplain@yahoo.com; earle.dixon@state.nm.us; roy.blickwedel@corporate.ge.com; Bush, Larry (GE Aviation, US); Mark Jancin
Subject: Church Rock zone 3 injection test analysis report
Attachments: Well IW-A injection test rpt.pdf

On behalf of UNC, attached please find a hydrogeologic analysis of the July 2010 injection testing of well IW-A in the northern part of the Zone 3 hydrostratigraphic unit at the Church Rock tailings site.

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August 30, 2010

Ref. No. 10-6209-SC-101.Z3 **This Report Delivered by Email Only**

Mr. Mark Purcell
Superfund Division (6SF-RL)
U.S. Environmental Protection Agency
1445 Ross Avenue, Suite 1220
Dallas, TX 75202

Ms. Yolande Norman
Division of Waste Management and Environmental Protection
Office of Federal and State Materials and Environmental Management Programs
U.S. Nuclear Regulatory Commission
Mail Stop T-8F5
11545 Rockville Pike
Rockville, Maryland 20852

Re: Hydrogeologic Analysis of Injection Testing of Zone 3 Well IW-A, July 2010
United Nuclear Corporation's Church Rock Tailings Site, Gallup, New Mexico
Administrative Order (Docket No. CERCLA 6-11-89)
Materials License No. SUA-1475

Dear Mr. Purcell and Ms. Norman:

Introduction

On behalf of United Nuclear Corporation (UNC), Chester Engineers has prepared this analysis of recent injection testing in injection well IW-A, which is located in the northern part of the Zone 3 hydrostratigraphic unit (Figure 1). IW-A is one of three wells constructed in May and June 2010 to pilot test the injection of alkalinity amended water into Zone 3. IW-A is a pilot injection well. The other two new wells, MW-6 and MW-7 were constructed to monitor the reaction of Zone 3 to water injection. Construction information for the new wells is listed in Table 1. The locations of the pilot test wells and nearby extraction wells (NW-prefix) are shown in Figure 1. The plan for pilot testing is described in the remedial design report (RDR) submitted in May 2010 (Chester Engineers, May 2010). Chester Engineers (May 2010) also proposed a conceptual design for enhanced remediation of Zone 3 by operating an array of new injection wells in combination with existing extraction wells.

The purpose of the pilot test is to evaluate the potential for creating a hydraulic (or possibly an alkalinity) barrier, using multiple injection wells, to limit further northward advance of the seepage-impacted groundwater in the northern part of Section 36. This potential remedial option

was retained in the Revised Submittal, Site-Wide Supplemental Feasibility Study Part II (SWSFS Part II; Chester Engineers, July 2009) with a caveat that the formation may not accept sufficient quantities of fluid to be practicable, as occurred in the Zone 3 in-situ alkalinity stabilization test (Arcadis, June 2007). Secondary permeability restrictions have developed in portions of Zone 3 where the arkosic sandstones have been altered to clays by reaction with the acidic tailings seepage. The pilot test is being conducted in an area where the influence of tailings seepage has been comparatively recent and transitional (i.e. with respect to unimpacted groundwater).

Earlier (October-November 2009) tests of Well NBL-2 demonstrated the feasibility of injection at design rates via a vertical well into an unimpacted area in the northern portion of Zone 3 (Chester Engineers, December 2009). The primary objective of injection testing Well IW-A is to empirically assess the amount of water Zone 3 can accommodate by injection in the area designated for enhanced remediation in the RDR. A secondary objective is to determine an additional estimate of the hydraulic conductivity in this area. The average hydraulic conductivity of the northern portion of Zone 3 has previously been estimated to be 2.95×10^{-4} cm/s or 0.84 ft/day (N.A. Water Systems, April 2008). Chester Engineers (December, 2009) derived a similar estimate of hydraulic conductivity (0.87 ft/day) by analysis of the NBL-2 injection test data. The small difference of the two estimates was recognized to be fortuitous and less than the expected variability of this hydraulic parameter in Zone 3. However, the similarity of the estimates also indicated that the demonstrated injection capacity of Well NBL-2 (greater than 8 gallons per minute [gpm]), was not exceptional.

UNC conducted two tests in Well IW-A. During the first test, on July 1, 800 gallons of water were injected at a constant rate of approximately 3 gpm into Well IW-A, while water level responses were recorded in that well and monitoring wells MW-6 and MW-7. During the second test, on July 14, 1235 gallons of water were injected into Well IW-A at rates incremented in steps of approximately 1 gpm, 3 gpm, and 5 gpm. The injection water was piped from a 1600 gallon storage tank to below the water table in the well to minimize the potential for air bubbles to clog the pore spaces around the well. The water was obtained from the site's mill well, which taps the Westwater Canyon Formation. This is the same water source that was used for the previous in-situ alkalinity stabilization pilot test and the injection tests of Well NBL-2.

Frequent water-level measurements were made, starting before any water was injected. UNC used a pressure transducer and data logger (the In-Situ Level Troll) to collect these measurements. Manual measurements were made when the transducer was installed prior to the test and at convenient times during the test to verify the initial depth and later accuracy of the transducer measurements. Another reason for the pre-test manual measurement was to determine the position of the water table relative to the top of the Zone 3 hydrostratigraphic unit. This distance and the saturated thickness are factors used in estimating hydraulic conductivity from the test data.

Results of the Constant Rate Injection Test

The constant rate injection test of Well IW-A started at 12:05 on July 1, 2010, with the static water level at a depth of 192.88 ft. The water valve was closed at 16:37 with 800 gallons having been injected over a period of 4 hours, 32 minutes. The average injection rate over the test was 2.9 gpm. By the end of the injection phase of the test, the water level in Well IW-A had risen by approximately 80 ft. Figure 2 shows measured changes of flow rate and manually measured water levels in Well IW-A. These data are listed in Table 1. Data recorded from the pressure transducer during injection and recovery are shown in Figure 3.

Periodic measurements of water levels were made in wells MW-6 and MW-7 during the injection test. Well MW-6 is 70 ft and Well MW-7 is 162 ft from Well IW-A. The map locations of these wells and nearby extraction wells are shown in Figure 1. Water levels were observed to rise in MW-6 and MW-7 through the injection phase and the subsequent 45-hour recovery period. However, the water level changes are concluded to have been caused largely by factors other than the injection test. The analysis on which this conclusion is based is in the Appendix to this report.

The constant rate test on July 1 was a preliminary test of equipment and the capacity of Well IW-A to accommodate injection at a desired rate (1 gpm or more). The second test on July 14 was designed to determine the injection capacity and performance characteristics of the well. The results of that test and its analysis follow.

Results and Analysis of the Stepped Rate Injection Test

Summary of Test Data

Well IW-A was tested a second time by injection on July 14, 2010. The test was planned to employ three steps of 2.5 hour duration at injection rates of 1 gpm, 3 gpm, and 5 gpm. The objective was to test the performance of the well and provide data for the estimation of sustainable injection capacity.

Test data were recorded manually and with a pressure transducer and automated data logger. Manually recorded data are shown in Table 2; these include manual measurements of depth to water in the well and readings of injected water volume from a totalizing flow meter (Badger). Water level depths determined from the data logger record for the injection test and subsequent recovery period are shown in Figure 4. Measurements of water level recovery (equilibration) in IW-A continued until the afternoon of the following day (15:10 July 15).

Figure 5 is a time-series graph of the induced height of water above pre-test static (pressure

head) and periodic flow rates. These data were calculated from the flow and depth to water measurements described above. During the test, 1235 gallons of water were injected over a period of 7 hours, 42 minutes. The rate of injection was adjusted as planned for the first two 2.5-hour injection steps at 1 gpm and 3 gpm. The third step at 5 gpm was maintained for approximately 66 minutes. By this time (6 hours, 6 minutes) the water level had risen to within 4 ft of the top of the well. Injection rates were incrementally reduced throughout the remainder of the test to regulate the water level rise in the well. The injection rate had been reduced to 2.9 gpm when it was decided to end the test. By this time the water level was in the well riser and 4.3 ft below the level of the storage tank outlet. Table 3 is a summary of the results for each step of the test and the recovery period.

Analysis of Well Performance and Sustainable Injection Capacity

As indicated above, the objective of the stepped-rate test was to provide data for the estimation of sustainable injection capacity and well performance characteristics. The test fulfilled this objective despite inducing (in step three) an injection rate (5 gpm) that clearly exceeded the sustainable capacity of the well. As designed, the test provided information about the dependence of the induced pressure head (water level rise) on the rate of injection. The purpose of the well performance analysis is to estimate the effects of injection at rates different than those tested and, specifically, to estimate a sustainable injection capacity. The applicable method of analysis is the same as that used for a test that induces drawdown by pumping.

The analysis method is an extension of Hantush-Bierschenk's method (Krusemann and deRidder, 1990, pp. 201-203). The method employs the principle of superposition to fit Jacob's equation (see inset in Figure 6) to the variable rate (of injection) test data. The coefficients, a, b, and c, of the equation are estimated by regression on the adjusted time-head data. Figure 6 shows the fit of the equation to the data and the estimated values of the three coefficients. Coefficient b is the factor in the second term of the equation, which is also dependent on time. This term is typically described as the contribution of the aquifer to head changes, while the first and third terms (multiplied by coefficients a and c) are described as well loss terms.

The final part of the analysis of head dependence on flow rate is shown in Figure 7. This graph shows projected pressure head versus time for a range of injection rates from 1 gpm to 3 gpm. The projections are based on the fitted equation described above and shown in Figure 7. The projections indicate that at a rate of 3 gpm the capacity of Well IW-A would be exceeded within two days. At an injection rate of 2 gpm the capacity is projected to be exceeded in approximately 50 days. It is likely that interference effects from nearby extraction wells would influence the rate of water level rise prior to 50 days. The effect of this interference may induce equilibrium (i.e. no further water level rise) before the capacity of IW-A would be exceeded. While this is not certain, 2 gpm may be taken as a reasonable upper estimate of the injection capacity of Well IW-A. This rate is one quarter of that tested in well NBL-2 (Chester Engineers, December 2009) and an even smaller fraction of the estimated capacity of that well (greater than

8 gpm). The difference is due in part to a lesser hydraulic conductivity of Zone 3 in the vicinity of IW-A. The following section provides an analysis of hydraulic conductivity from the data collected from both injection tests.

Analysis of Hydraulic Conductivity

The Theis recovery method was used to analyze the recovery data from both tests. This method is applicable to the unconfined (water table) conditions observed in the Zone 3 water bearing strata screened in well IW-A. Citing Neumann (1975), Krusemann and deRidder (1990, p. 196) indicate that the Theis recovery method can be used if the analysis is restricted to late time recovery data. Accordingly, the cited condition was applied in the analysis of recovery data from the tests of well IW-A.

Figures 8 and 9 show the regressed fits of the Theis recovery function to the test recovery data from the two tests of well IW-A (for a description of the function, see Krusemann and deRidder, 1990, pp. 194-195). The function was fitted to the data by the method of least squares. The slope of the fitted line is used to estimate transmissivity, the hydraulic parameter quantifying the capacity of the formation to transmit water. Hydraulic conductivity is calculated by dividing transmissivity by the saturated thickness. The saturated thickness was calculated from the static water level measurement prior to the tests and determined to be 14.4 ft. The saturated thickness in the vicinity of Well IW-A was increased to a maximum of 30 ft (the length of screen) during injection. This range of saturated thickness resulted in estimated ranges of hydraulic conductivity of 0.07-0.15 ft/d from the results of the first test and 0.05-0.1 ft/d from the results of the second test.

Discussion

The ranges of hydraulic conductivity estimated from the two tests of Well IW-A differ by about 50 percent, which is not unusual for estimates of this type. However, these estimates of hydraulic conductivity are lower by factors of about 0.06 to 0.2 from the other estimates for the northern portion of Zone 3 made from the injection test of well NBL-2 (0.87 ft/day; Chester Engineers, December 2009) and broadly based flow data (0.84 ft/day; N.A. Water Systems, April 25, 2008). The estimate of 0.84 ft/day made for this area of Zone 3 was based on an analysis of very broadly based groundwater flow rates and hydraulic gradients. Therefore, it is considered to be an accurate estimate of the average hydraulic conductivity in the northern portion of Zone 3, which encompasses Wells IW-A and NBL-2. The much lower estimate derived in this report is applicable only to the formation immediately surrounding Well IW-A, and may be influenced by skin effects (e.g. formation damage from drilling). This stems from the limited extent of influence of the test and that the analysis was based on recovery data measured in Well IW-A.

A more representative measure of hydraulic conductivity in the area will be possible from

measurements in monitoring wells as the formation responds to the effects of long term injection during the pilot phase. With this will come an improved capacity to accurately predict the effects of proposed injection schemes that may employ wells in addition to IW-A (Chester Engineers, May 2010).

References

ARCADIS BBL, June 2007, In-Situ Alkalinity Stabilization Pilot Study, UNC Church Rock Site, Gallup, New Mexico.

Chester Engineers, May 2010, Remedial Design Report, Conceptual Approach to Enhanced Remediation in Zone 3, New Injection Wells Combined with Existing Extraction Wells, UNC Church Rock Tailings Site, Gallup, New Mexico.

Chester Engineers, December 2009, Hydrogeologic Analysis of Recent Zone 3 Injection Testing and Proposal for Enhanced Remediation, UNC Church Rock Tailings Site, Gallup, New Mexico.

Chester Engineers, July 2009, Revised Submittal: Site-Wide Supplemental Feasibility Study Part II, UNC Church Rock Tailings Site, Church Rock, New Mexico.

Krusemann, G.P. and N.A. deRidder, 1990, *Analysis and Evaluation of Pumping Test Data*, 2nd ed., International Inst. for Land Reclamation and Improvement, Wageningen, The Netherlands, 377 p.

N.A. Water Systems, April 2008, Recommendations and Summary of Hydrogeologic Analysis – Evaluation of Groundwater Flow in Zone 3 for the Design of a Pumping System to Intercept and Recover Impacted Groundwater, UNC Church Rock Tailings Site, Gallup, New Mexico.

Neuman, S.P., 1975, Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response, Water Resources Res., Vol. 11, pp.329-342.

Conclusion

In the SWSFS (Part II, Table 6), a potential remedy alternative, Alternative 8, is outlined and consists of a hydraulic barrier from injection wells for containment. Based on the results of the testing at NBL-2, UNC recommended pilot testing this potential remedy alternative by injecting alkalinity-amended water through Well IW-A located to the north of the NW-series of extraction wells and south of the Section 36 property boundary (Chester Engineers, December 2009, and May 2010).

The first phase of the pilot test program has begun with the installation and testing of Well IW-A. As expected, the testing revealed spatial variation in the hydraulic conductivity and injection-take rates. While the estimated injection capacity of Well IW-A is significantly less than that of Well NBL-2, it is sufficient to accommodate injection at rates greater than the 1 gpm assumed in the model simulations made for the remedial design (Chester Engineers, May 2010).

Estimates of hydraulic conductivity based on water level recovery data from Well IW-A were lower by factors of about 0.06 to 0.2 from other estimates for the northern portion of Zone 3 made from the injection test of well NBL-2 and from broadly based flow data. However, the current estimates are applicable only to the formation immediately surrounding well IW-A. It is expected that response data from longer-term pilot testing will provide a more representative basis for estimating the influence of injection on hydraulic heads in Zone 3 and nearby wells.

In conclusion, our analyses of the injection tests of Well IW-A indicate that there is sufficient injection capacity to meet the expected requirements for pilot testing. Therefore, it is recommended that the pilot testing proceed as planned (Chester Engineers, May 2010).

If you have any questions, please contact me at (412) 809-6719 or by email at jewart@chesterengineers.com.

Sincerely,

James A. Ewart, PhD, PG
Technical Consultant

Attachments

email cc: Earle Dixon, NMED
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Katrina Higgins-Coltrain, EPA
Roy Blickwedel, GE
Larry Bush, UNC

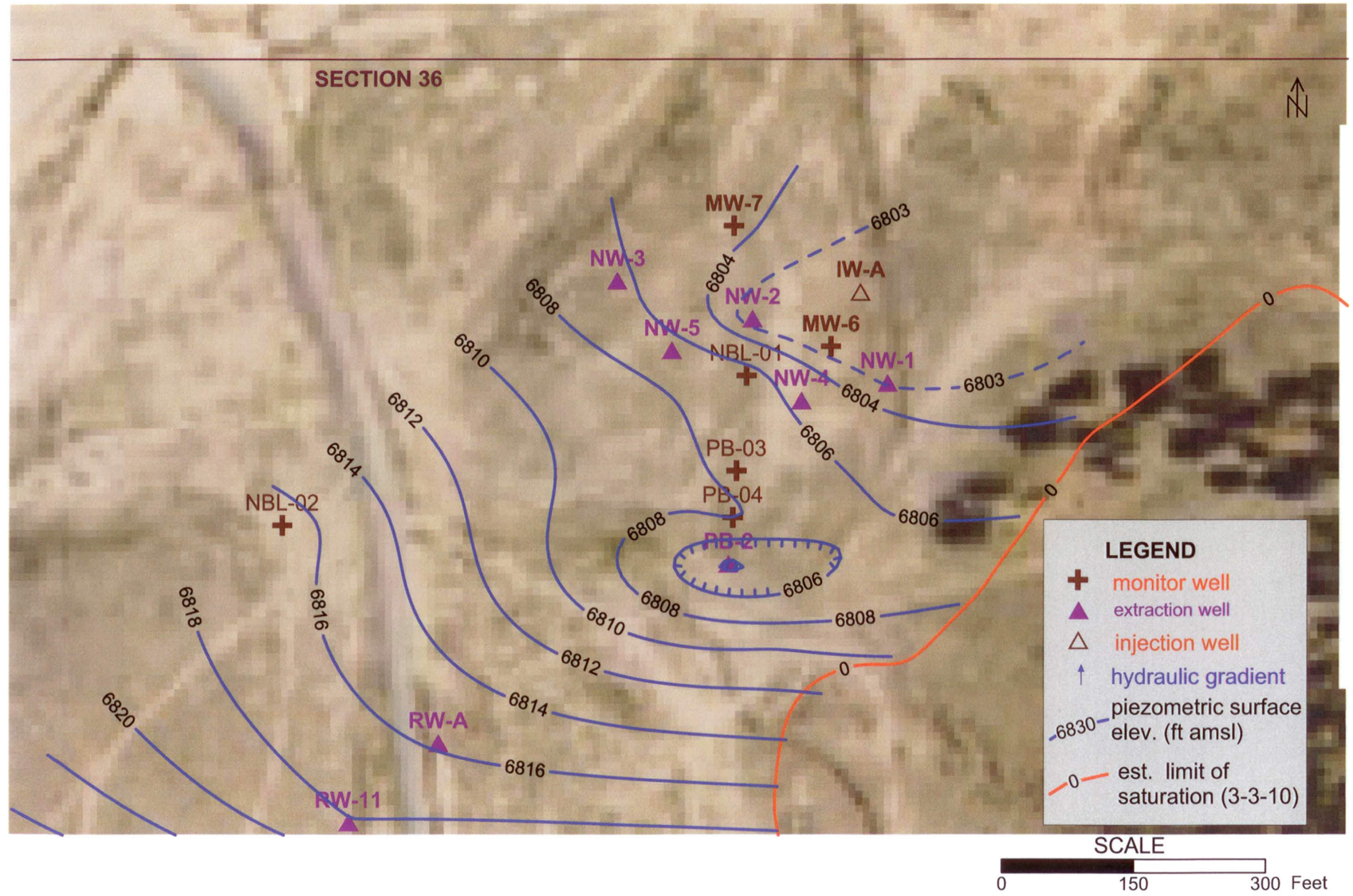

FIGURE 1
Estimated pre-inection piezometric surface elevations in Zone 3, based on July 1, 2010 measurements. Supplemented by April 2010 measurements at RW-A and NBL2; October 2009 measurement at RW-11, United Nuclear Corp, Church Rock, NM..

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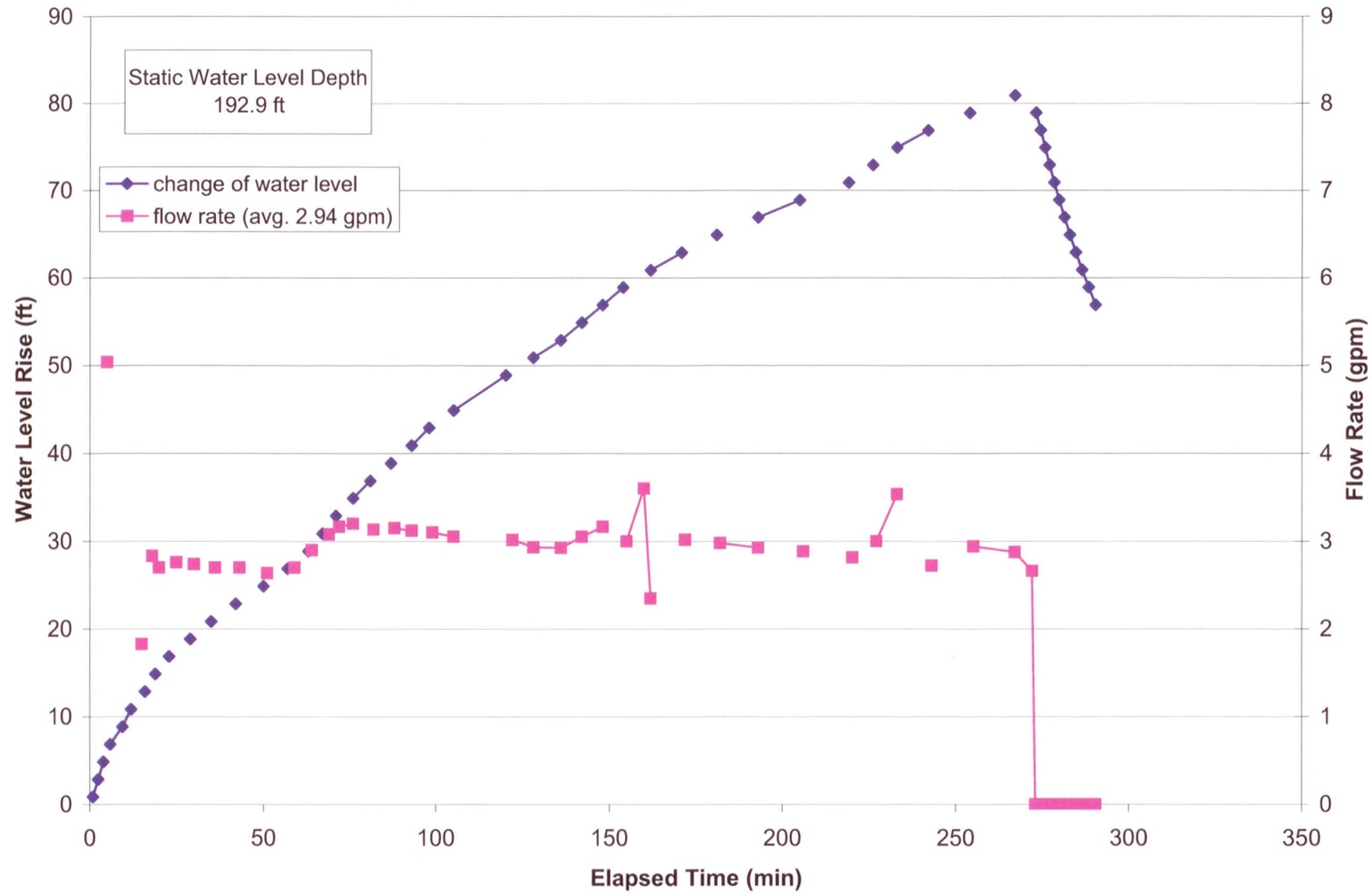

FIGURE 2
Water levels and flow rates measured in Well IW-A,
Injection test of well IW-A, July 1, 2010,
United Nuclear Corp, Church Rock, NM.

Chester Engineers

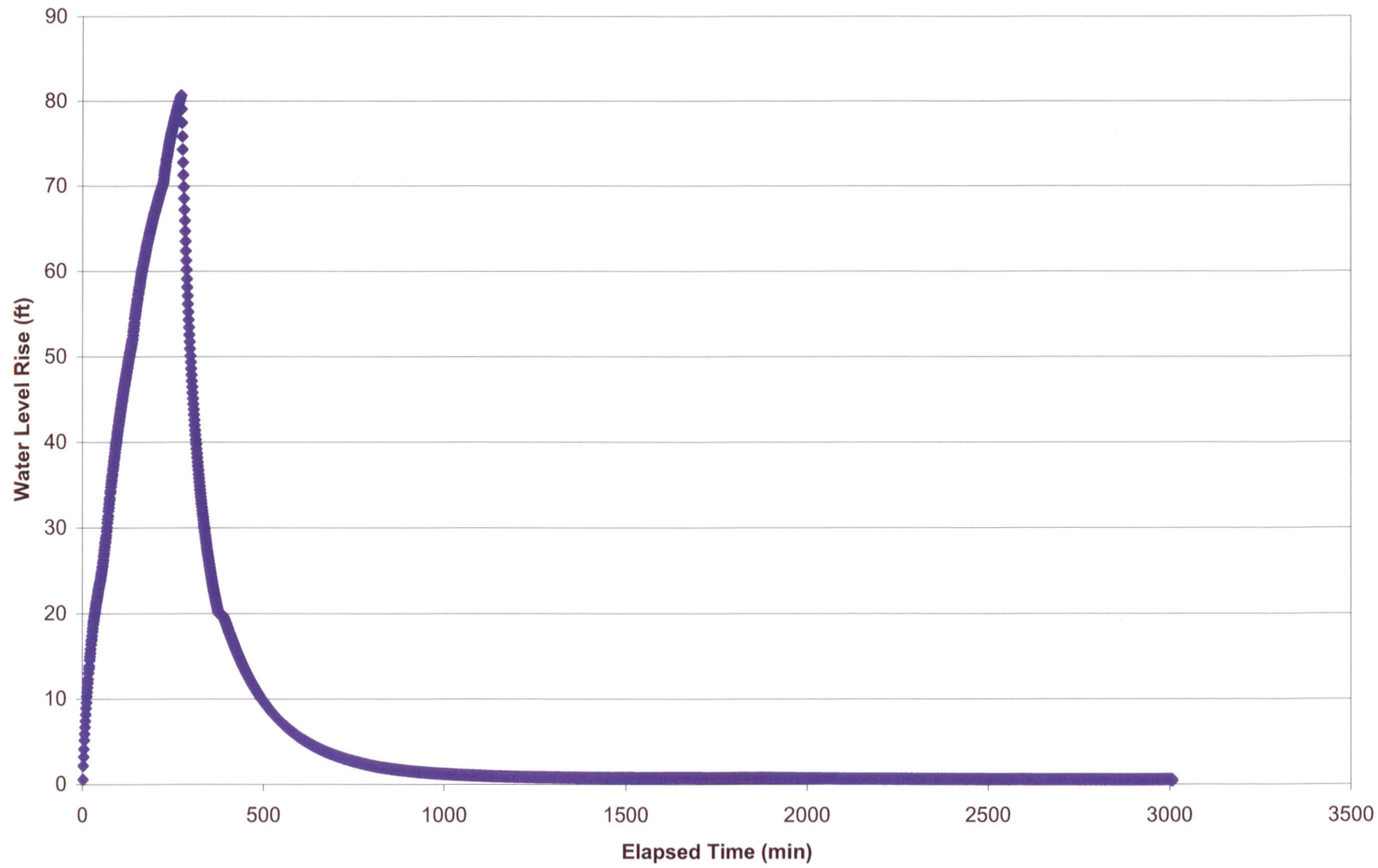

FIGURE 3
Water level changes measured by datalogger in Well IW-A,
Injection test of well IW-A, July 1, 2010,
United Nuclear Corp, Church Rock, NM.

Chester Engineers

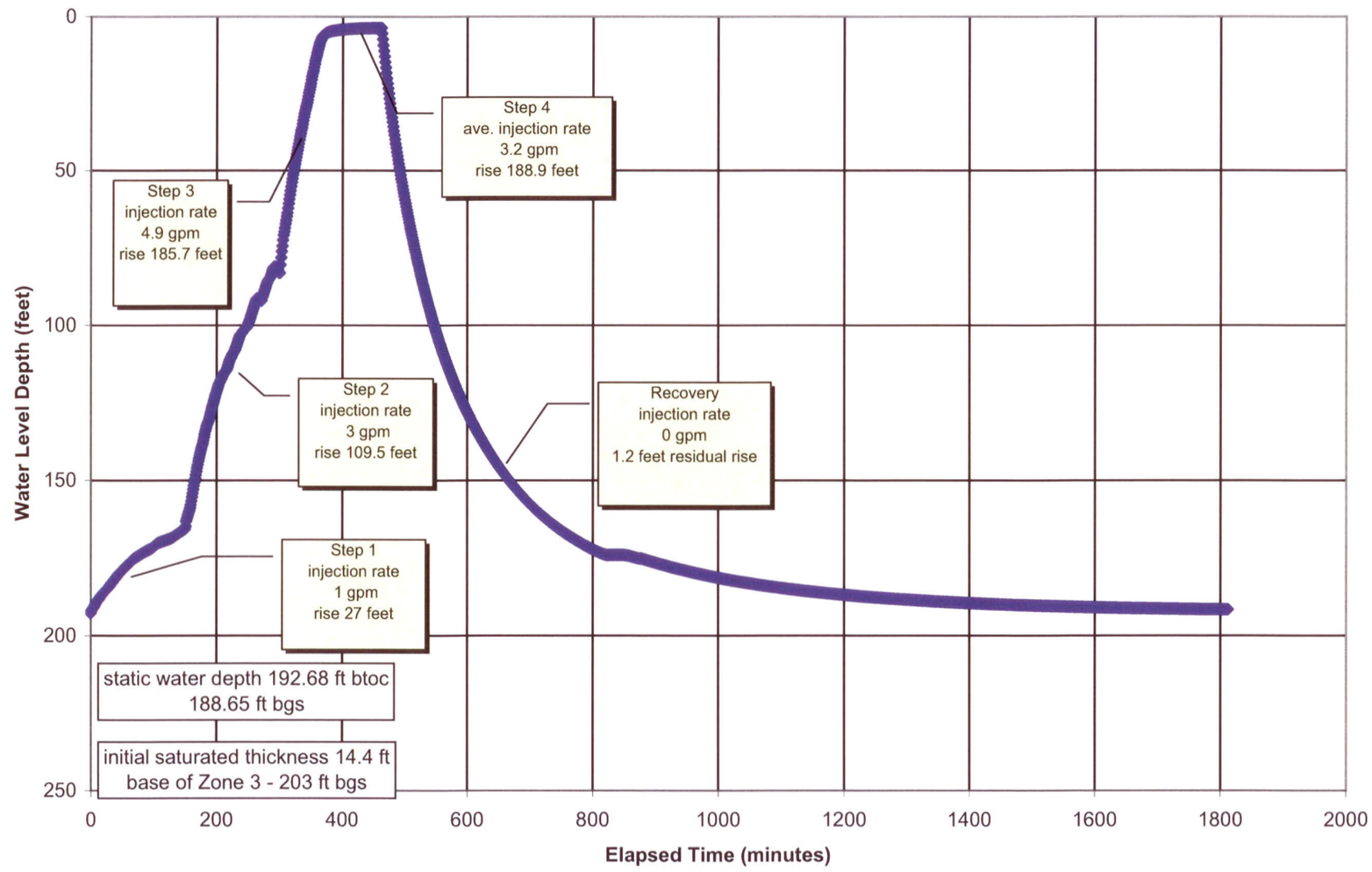

FIGURE 4
Water-level depths measured in Well IW-A,
July 14-15, 2010, injection test of Well IW-A,
United Nuclear Corp, Church Rock, NM.

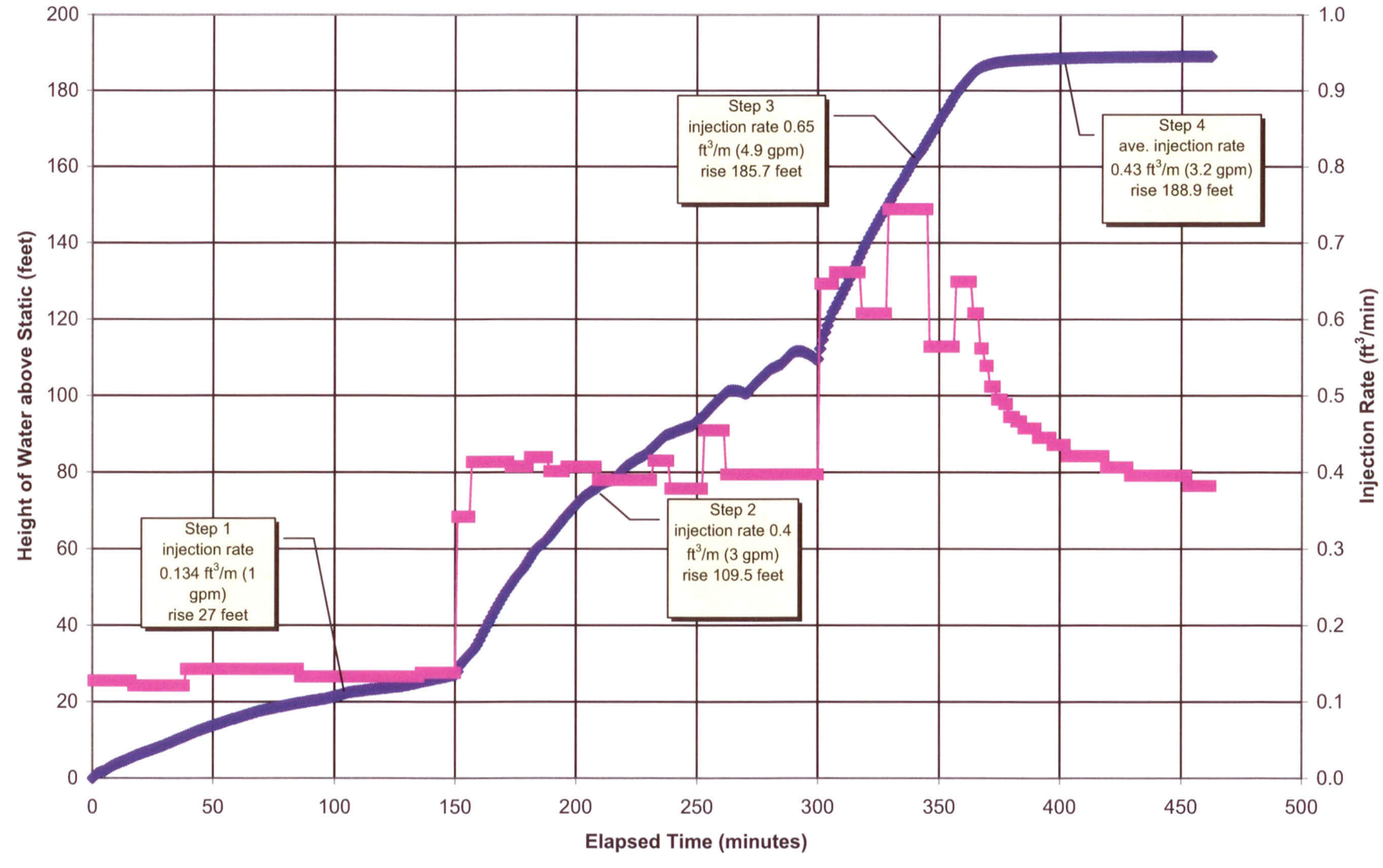

FIGURE 5
Water level rise and injection rate changes in Well IW-A,
July 14, 2010, injection test of Well IW-A,
United Nuclear Corp, Church Rock, NM.

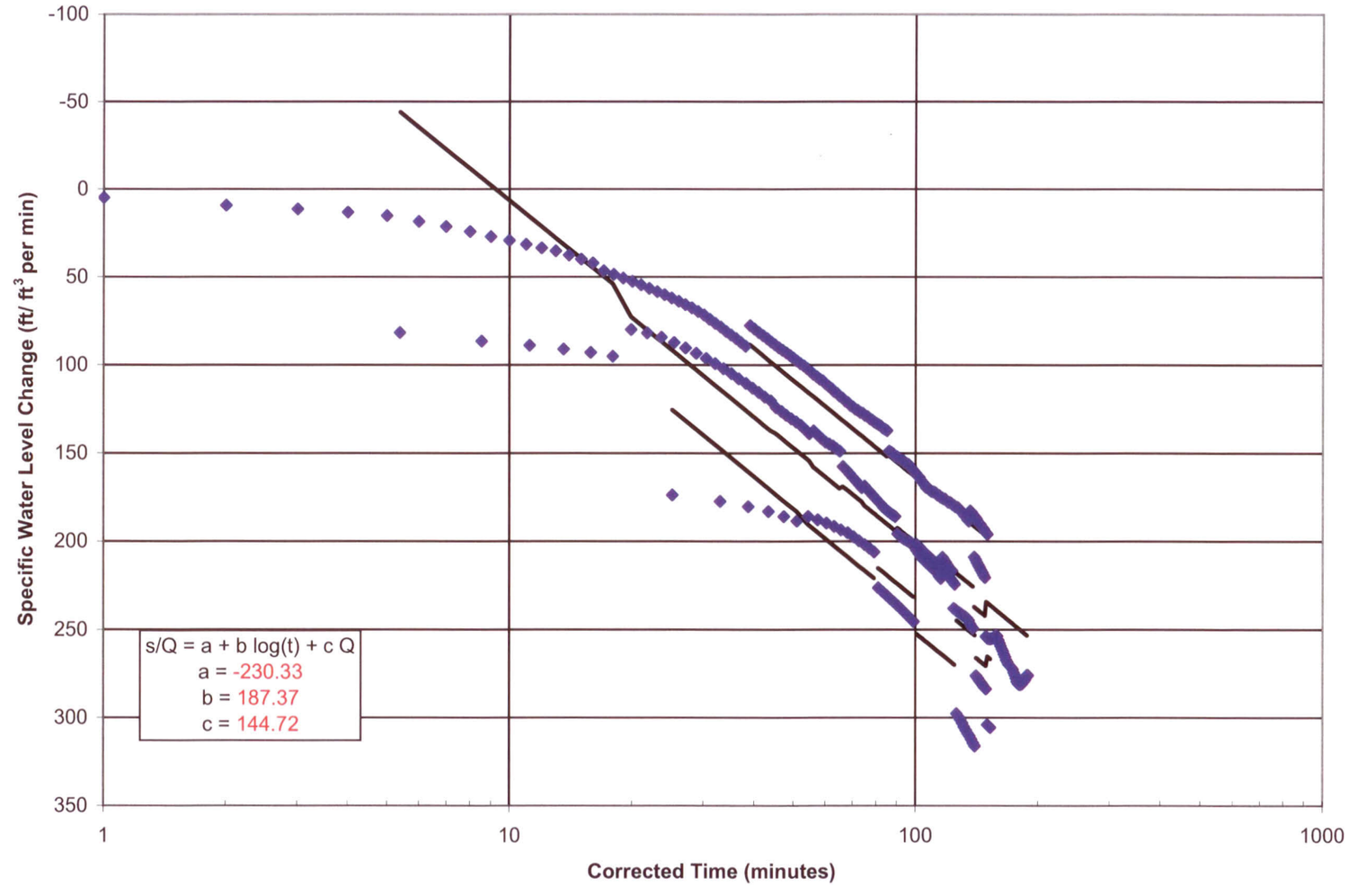

FIGURE 6
Well performance analysis of water level rise measured in Well IW-A,
July 14, 2010 injection test of Well IW-A,
United Nuclear Corp, Church Rock, NM.

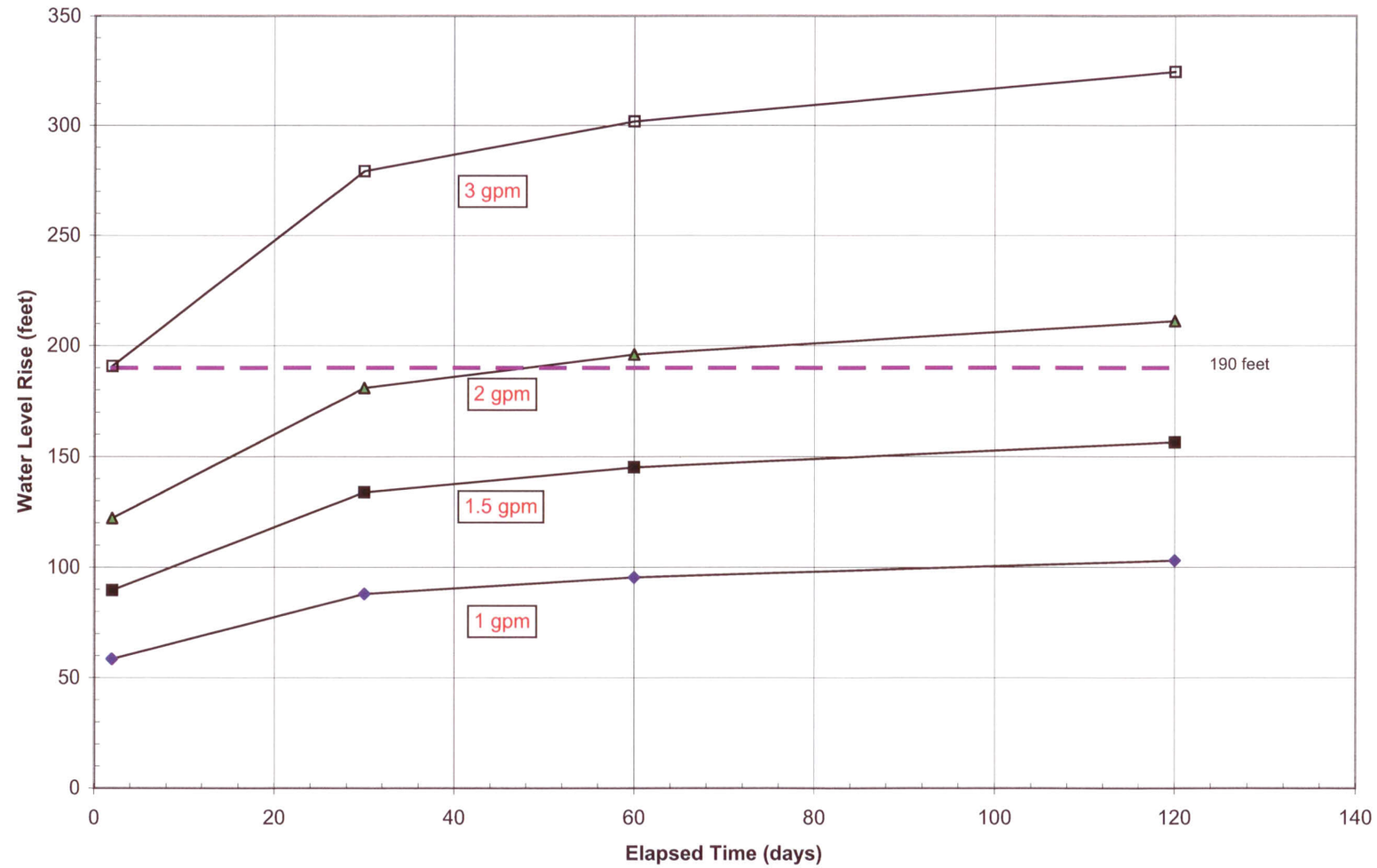

FIGURE 7

Projected water level rise in Well IW-A,
Based on analysis of stepped-rate pumping test of Well IW-A, July 14, 2010
United Nuclear Corp, Church Rock, NM.

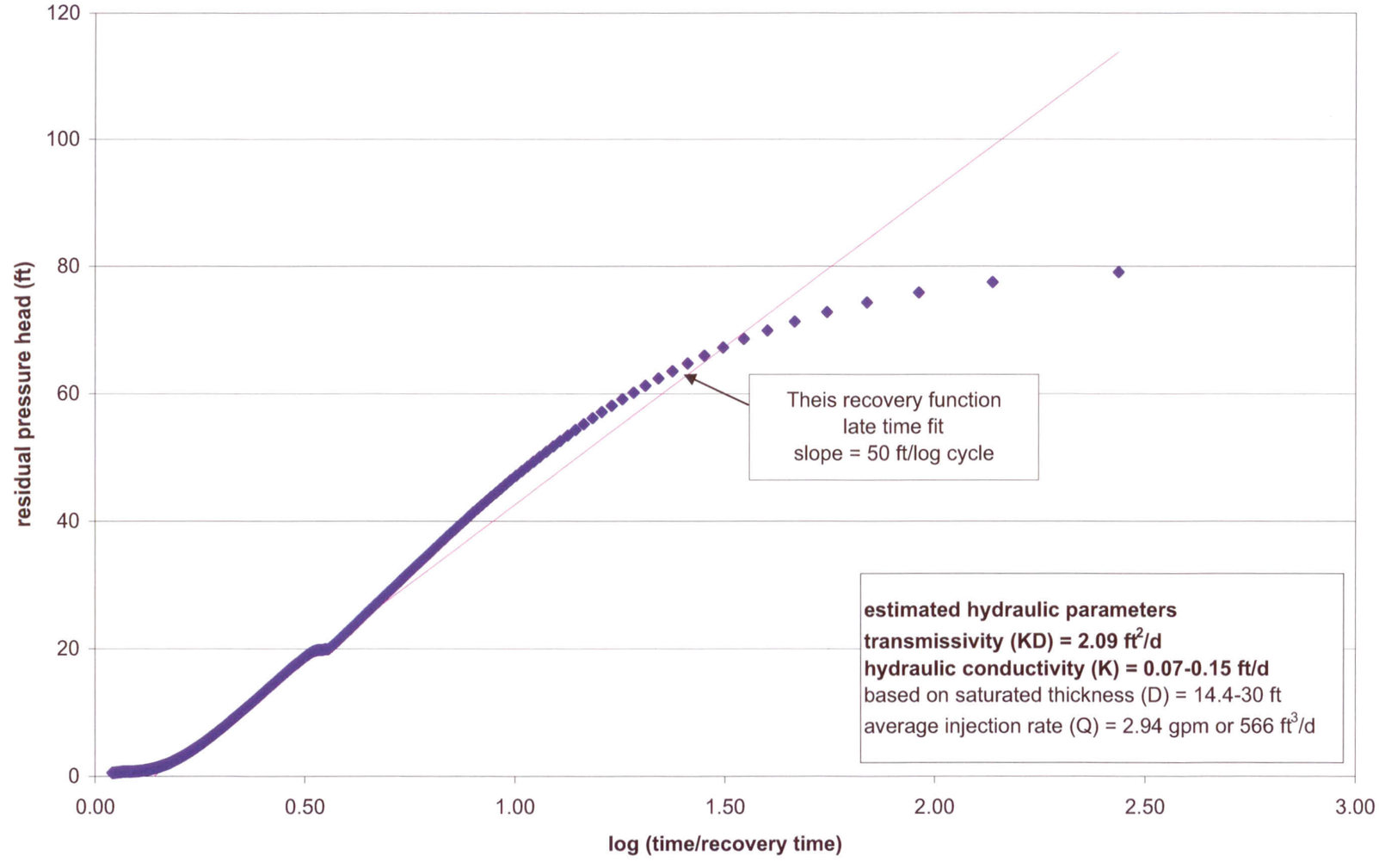

FIGURE 8
Theis Recovery Analysis
Injection test of well IW-A, July 1-3, 2010,
United Nuclear Corp, Church Rock, NM.

Chester Engineers

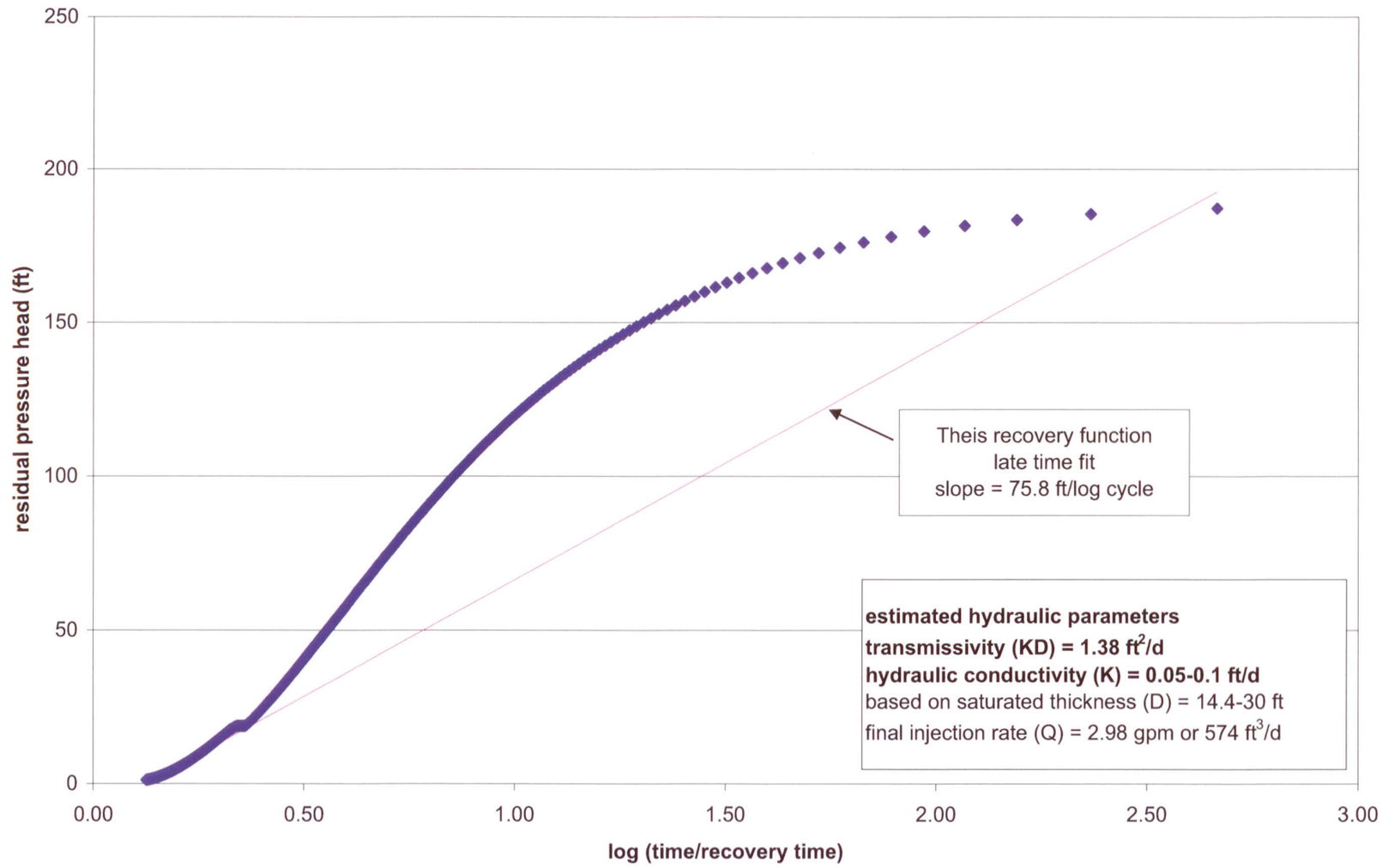

FIGURE 9
Theis Recovery Analysis
Injection test of well IW-A, July 14-15, 2010,
United Nuclear Corp, Church Rock, NM.

Chester Engineers

TABLE 1
Construction Information for New Wells
IW-A, MW-6, and MW-7

Location	Installation Date	Site East[1] (feet)	Site North[1] (feet)	Distance from IW-A (feet)	Drilled Diameter (ft)	30.5 ft Screen Bottom (ft bgs)	Top of Coal (ft bgs)	Measuring Point Elevation (ft amsl)	Casing Stickup (ft ags)
IW-A[2]	5/25/2010	62246	77927		10 1/4	201	203	6992.77	1.62
MW-6	5/27/2010	62212	77866	70	12 1/4	198	198	6990.94	2.26
MW-7	6/4/2010	62101	78001	162	12 1/4	205.5	205.5	6988.82	2.32

Notes:
1. Approximate location
2. IW-A casing stickup and measuring point elevation higher by 2.43 feet during injection tests

TABLE 2
Manual Measurements and Observations in Well IW-A
Injection Test of Well IW-A, July 1, 2010

Location	Date/Time	Elapsed Time (min)	Water Depth (ft btoc)	Water Level Rise (ft)	Badger Reading (gallons)	Flow (gpm)	Comments
IWA	7/1/10 10:55						Establish Test Measuring Point @ +2.12 ft above Original MP TD=204.99, SWL=192.81,
IWA	7/1/10 10:56				4264.3		Set Transducer @ 200 BTMP
IWA	7/1/10 11:44		192.88		4264.3		
IWA	7/1/10 12:05						Start Injection @ 3 gpm
IWA	7/1/10 12:06	1	192.00	0.88			
IWA	7/1/10 12:07	3	190.00	2.88			
IWA	7/1/10 12:09	4	188.00	4.88			
IWA	7/1/10 12:10	5			4289.5	5.04	
IWA	7/1/10 12:11	6	186.00	6.88			
IWA	7/1/10 12:14	9	184.00	8.88			
IWA	7/1/10 12:17	12	182.00	10.88			
IWA	7/1/10 12:20	15			4307.8	1.83	
IWA	7/1/10 12:21	16	180.00	12.88			
IWA	7/1/10 12:23	18			4316.3	2.83	
IWA	7/1/10 12:24	19	178.00	14.88			
IWA	7/1/10 12:25	20			4321.7	2.70	
IWA	7/1/10 12:28	23	176.00	16.88			
IWA	7/1/10 12:30	25			4335.5	2.76	
IWA	7/1/10 12:34	29	174.00	18.88			
IWA	7/1/10 12:35	30			4349.2	2.74	
IWA	7/1/10 12:40	35	172.00	20.88			
IWA	7/1/10 12:41	36			4365.4	2.70	
IWA	7/1/10 12:47	42	170.00	22.88			
IWA	7/1/10 12:48	43			4384.3	2.70	
IWA	7/1/10 12:55	50	168.00	24.88			
IWA	7/1/10 12:56	51			4405.4	2.64	
IWA	7/1/10 13:02	57	166.00	26.88			open throttle valve to 2.9gpm
IWA	7/1/10 13:04	59			4427.0	2.70	
IWA	7/1/10 13:08	63	164.00	28.88			
IWA	7/1/10 13:09	64			4441.5	2.90	
IWA	7/1/10 13:12	67	162.00	30.88			open throttle valve to 3.2gpm
IWA	7/1/10 13:14	69			4456.9	3.08	
IWA	7/1/10 13:16	71	160.00	32.88			
IWA	7/1/10 13:17	72			4466.4	3.17	
IWA	7/1/10 13:21	76	158.00	34.88	4479.2	3.20	
IWA	7/1/10 13:26	81	156.00	36.88			
IWA	7/1/10 13:27	82			4498.0	3.13	
IWA	7/1/10 13:32	87	154.00	38.88			
IWA	7/1/10 13:33	88			4516.9	3.15	
IWA	7/1/10 13:38	93	152.00	40.88	4532.5	3.12	Tank @ 1400 gals
IWA	7/1/10 13:43	98	150.00	42.88			
IWA	7/1/10 13:44	99			4551.1	3.10	
IWA	7/1/10 13:50	105	148.00	44.88	4569.4	3.05	

TABLE 2
Manual Measurements and Observations in Well IW-A
Injection Test of Well IW-A, July 1, 2010

Location	Date/Time	Elapsed Time (min)	Water Depth (ft btoc)	Water Level Rise (ft)	Badger Reading (gallons)	Flow (gpm)	Comments
IWA	7/1/10 14:05	120	144.00	48.88			
IWA	7/1/10 14:07	122			4620.7	3.02	
IWA	7/1/10 14:13	128	142.00	50.88	4638.3	2.93	
IWA	7/1/10 14:21	136	140.00	52.88	4661.7	2.93	open throttle valve to 3.2gpm
IWA	7/1/10 14:27	142	138.00	54.88	4680.0	3.05	
IWA	7/1/10 14:33	148	136.00	56.88	4699.0	3.17	
IWA	7/1/10 14:39	154	134.00	58.88			
IWA	7/1/10 14:40	155			4720.0	3.00	
IWA	7/1/10 14:45	160			4738.0	3.60	tank @ 1200 gals
IWA	7/1/10 14:47	162	132.00	60.88	4742.7	2.35	
IWA	7/1/10 14:56	171	130.00	62.88			
IWA	7/1/10 14:57	172			4772.9	3.02	
IWA	7/1/10 15:06	181	128.00	64.88			
IWA	7/1/10 15:07	182			4802.7	2.98	
IWA	7/1/10 15:18	193	126.00	66.88	4834.9	2.93	
IWA	7/1/10 15:30	205	124.00	68.88			
IWA	7/1/10 15:31	206			4872.4	2.88	
IWA	7/1/10 15:44	219	122.00	70.88			
IWA	7/1/10 15:45	220			4911.8	2.81	open throttle valve to 3.2gpm
IWA	7/1/10 15:51	226	120.00	72.88			
IWA	7/1/10 15:52	227			4932.8	3.00	tank @ 1000 gals
IWA	7/1/10 15:58	233	118.00	74.88	4954.0	3.53	
IWA	7/1/10 16:07	242	116.00	76.88			
IWA	7/1/10 16:08	243			4981.2	2.72	
IWA	7/1/10 16:19	254	114.00	78.88			
IWA	7/1/10 16:20	255			5016.5	2.94	
IWA	7/1/10 16:32	267	112.00	80.88	5051.0	2.88	
IWA	7/1/10 16:37	272			5064.3	2.66	Stop Injection
IWA	7/1/10 16:38	273	114.00	78.88		0	
IWA	7/1/10 16:39	274	116.00	76.88		0	
IWA	7/1/10 16:40	276	118.00	74.88		0	
IWA	7/1/10 16:41	277	120.00	72.88		0	
IWA	7/1/10 16:43	278	122.00	70.88		0	
IWA	7/1/10 16:44	280	124.00	68.88		0	
IWA	7/1/10 16:46	281	126.00	66.88		0	
IWA	7/1/10 16:47	283	128.00	64.88		0	
IWA	7/1/10 16:49	285	130.00	62.88		0	
IWA	7/1/10 16:51	286	132.00	60.88		0	
IWA	7/1/10 16:53	288	134.00	58.88		0	
IWA	7/1/10 16:55	290	136.00	56.88		0	
IWA	7/2/10 9:53	1308	192.06	0.82		0	
IWA	7/2/10 13:03	1498	192.11	0.77		0	
IWA	7/3/10 13:54	2989	192.28	0.60		0	

TABLE 3
Manual Measurements and Observations in Well IW-A
Injection Test of Well IW-A, July 14, 2010

Location	Date-Time	Elapsed Time (min)	Water Level Depth (ft BMP)	Flow Rate (gpm)	Badger Reading (gallons)	Comments
IWA	7/13/10 12:15		192.59			Deploy LevelTroll @ 200' BTMP
IWA	7/14/10 8:48		192.66		5064.7	XD DTW=192.68 @ 08:53
IWA	7/14/10 9:00				5064.7	Start 1 gpm injection
IWA	7/14/10 9:16	16		0.96	5080.0	
IWA	7/14/10 9:38	38	182.00	0.91	5100.0	
IWA	7/14/10 10:24	85		1.07	5150.0	
IWA	7/14/10 11:15	135		0.99	5200.0	time approximate
IWA	7/14/10 11:30	150		1.03	5215.50	Increase Injection Rate to 3 gpm
IWA	7/14/10 11:35	156		2.56	5230.0	
IWA	7/14/10 11:36	156	160.00			
IWA	7/14/10 11:51	172		3.09	5280.0	
IWA	7/14/10 11:55	175	140.00			
IWA	7/14/10 12:00	180		3.05	5304.9	
IWA	7/14/10 12:08	188		3.14	5330.0	
IWA	7/14/10 12:14	195		3.00	5350.0	
IWA	7/14/10 12:21	202	120.00			
IWA	7/14/10 12:27	208		3.05	5390.0	
IWA	7/14/10 12:50	230		2.91	5454.7	
IWA	7/14/10 12:58	238		3.10	5480.0	
IWA	7/14/10 13:08	248	100.00			
IWA	7/14/10 13:12	252		2.83	5520.0	
IWA	7/14/10 13:21	261		3.40	5550.0	
IWA	7/14/10 13:41	281		2.97	5610.0	
IWA	7/14/10 13:42	283	85.00			
IWA	7/14/10 14:00	300			5665.6	Increase Injection Rate to 5 gpm
IWA	7/14/10 14:05	305		4.83	5690.0	
IWA	7/14/10 14:10	311	65.00			
IWA	7/14/10 14:17	317		4.95	5750.0	
IWA	7/14/10 14:26	326	45.00			
IWA	7/14/10 14:28	328		4.55	5800.0	
IWA	7/14/10 14:37	337		5.57	5850.0	
IWA	7/14/10 14:45	345		6.15	5900.0	
IWA	7/14/10 14:45	346	25.00			
IWA	7/14/10 14:55	355	15.00			
IWA	7/14/10 14:57	357		4.22	5950.0	throttle valve wide open
IWA	7/14/10 15:03	363		4.85	5980.0	injection rate falling below 5 gpm because of lowering head pressure
IWA	7/14/10 15:05	366		4.55	5990.0	
IWA	7/14/10 15:07	368		4.20	6000.0	
IWA	7/14/10 15:10	370		4.03	6010.0	
IWA	7/14/10 15:13	373		3.82	6020.0	
IWA	7/14/10 15:15	376		3.70	6030.0	
IWA	7/14/10 15:16	377	5.00			
IWA	7/14/10 15:18	378		3.66	6040.0	
IWA	7/14/10 15:21	381		3.53	6050.0	

TABLE 3
Manual Measurements and Observations in Well IW-A
Injection Test of Well IW-A, July 14, 2010

Location	Date-Time	Elapsed Time (min)	Water Level Depth (ft BMP)	Flow Rate (gpm)	Badger Reading (gallons)	Comments
IWA	7/14/10 15:24	384		3.49	6060.0	
IWA	7/14/10 15:30	390		3.42	6080.0	
IWA	7/14/10 15:36	396		3.33	6100.0	
IWA	7/14/10 15:42	402		3.26	6120.0	
IWA	7/14/10 15:49	410	4.00			
IWA	7/14/10 15:58	418		3.15	6170.0	
IWA	7/14/10 16:04	425	3.80			
IWA	7/14/10 16:07	428		3.04	6200.0	
IWA	7/14/10 16:21	441		2.96	6240.0	
IWA	7/14/10 16:26	446				water level in supply tank is approximately 4.3' higher than water level in well.
IWA	7/14/10 16:31	452	3.70	2.92	6270.0	
IWA	7/14/10 16:42	462	3.70	2.86	6300.0	2.86 gpm - injection stopped - water level starting to fall
IWA	7/15/10 15:25	1825	191.58			

TABLE 4
Summary of stepped-rate injection test of Well IW-A, July 14, 2010
United Nuclear Corp, Church Rock, NM.

Date-Time	Step	Start Time (min)	Step Duration (min)	Average Discharge (ft^3/min)	Water level Rise (ft)	Specific Capacity (ft^2/min)
7/14/10 9:00 AM	1	0	150	0.134	27.07	4.96E-03
	2	150	150	0.401	109.54	3.66E-03
	3	300	66	0.652	185.69	3.51E-03
	4	366	96	0.429	188.93	2.27E-03
	5	462	1350	0	1.22	

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Appendix

Analysis of water level changes in monitoring wells and barometric pressure effects

Periodic measurements of water levels in wells MW-6 and MW-7 made during the July 1 injection test are graphed in Figure A-1. The water level rises measured in MW-6 and MW-7 were probably caused by factors other than the injected water. This conclusion is based on a simple comparison of volume of water injected (800 gallons or about 107 ft^3) with the volume of groundwater implied by the measured water level rise. If the mound of impression created by injection is idealized as a cylinder, the formula for the volume of groundwater within that mound is the product of the cylindrical volume and effective porosity (the pore space fraction of rock that can store water):

$$V_g = h\pi r^2 \rho$$

where

h is hieght of water level rise

r is the radial distance

ρ is effective porosity

Using the measured maximum water level rise at MW-7 (h = 0.33 ft), radial distance (r = 162 ft), and effective porosity, ρ, of 0.06 (N.A. Water Systems, April 2008) the formula above gives a groundwater volume of 1583 ft^3 or 11,840 gallons. This is a lower limit estimate, because the simplified cylindrical volume underestimates that of a mound of impression, which would have its apex at the point of injection. Therefore, it is clear that the 800 gallons injected during test can not have caused the measured water level rises in the monitoring wells. Using the same formula with V_g set equal to the injection volume of 800 gallons or 107 ft^3 gives a result for h at MW-7 of 0.02 ft. The actual water level rise attributable to the injection would be less than this (because of the simplified geometry assumed in the derivation of the volume formula).

Roughly half of the water level rises measured in Wells MW-6 and MW-7 may be attributable to barometric pressure change. Barometric pressures (recorded in Gallup NM) during the period of the test are plotted in Figure A-1. Corrections for barometric pressure change are listed in Tables A-1 and A-2 and plotted in Figure A-1. These corrections employ an average barometric efficiency (BE) of 0.62 estimated from data collected in the second test of Well IW-A.

An average barometric efficiency for Well IW-A was estimated by comparing water level changes measured on July 13 and 14 with barometric pressure changes recorded in Gallup over the same time period. These data are plotted in Figure A-2. The barometric efficiency is the ratio of well water level change to barometric pressure change, expressed as ft/water. The barometric efficiency estimate, while specific to well IW-A, provided a means of making approximate corrections to water level changes measured in Wells MW-6 and MW-7.

A probable second factor in the measured rise of water levels in MW-6 and MW-7 on July 1 was a reduction by approximately half of the pumping rate at nearby extraction well NW-2 (see Figure 1 for location). Pumping rates measured in all Zone 3 extraction wells during the time period of the two injection tests are plotted in Figure A-3. The noted reduction in pumping at EW-2 occurred approximately two days prior to the July 1 injection test.

Similar considerations hold for water level measurements made in MW-6 and MW-7 during the second injection test of July 14. While the amount of injected water was fractionally greater (1235 gallons versus 800 gallons), it was insufficient to have effected measurable reactions in the two monitoring wells. Therefore, the measurements are not included. The lack of a measurable response in the two monitoring wells did not affect the primary objective of the injection test, which was to assess the injection capacity of Well IW-A. The testing fulfilled its primary objective. Furthermore, no corrections were necessary for water level changes measured in Well IW-A, because those changes were very large relative to the possible influences of barometric pressure or extraction well pumping rate changes.

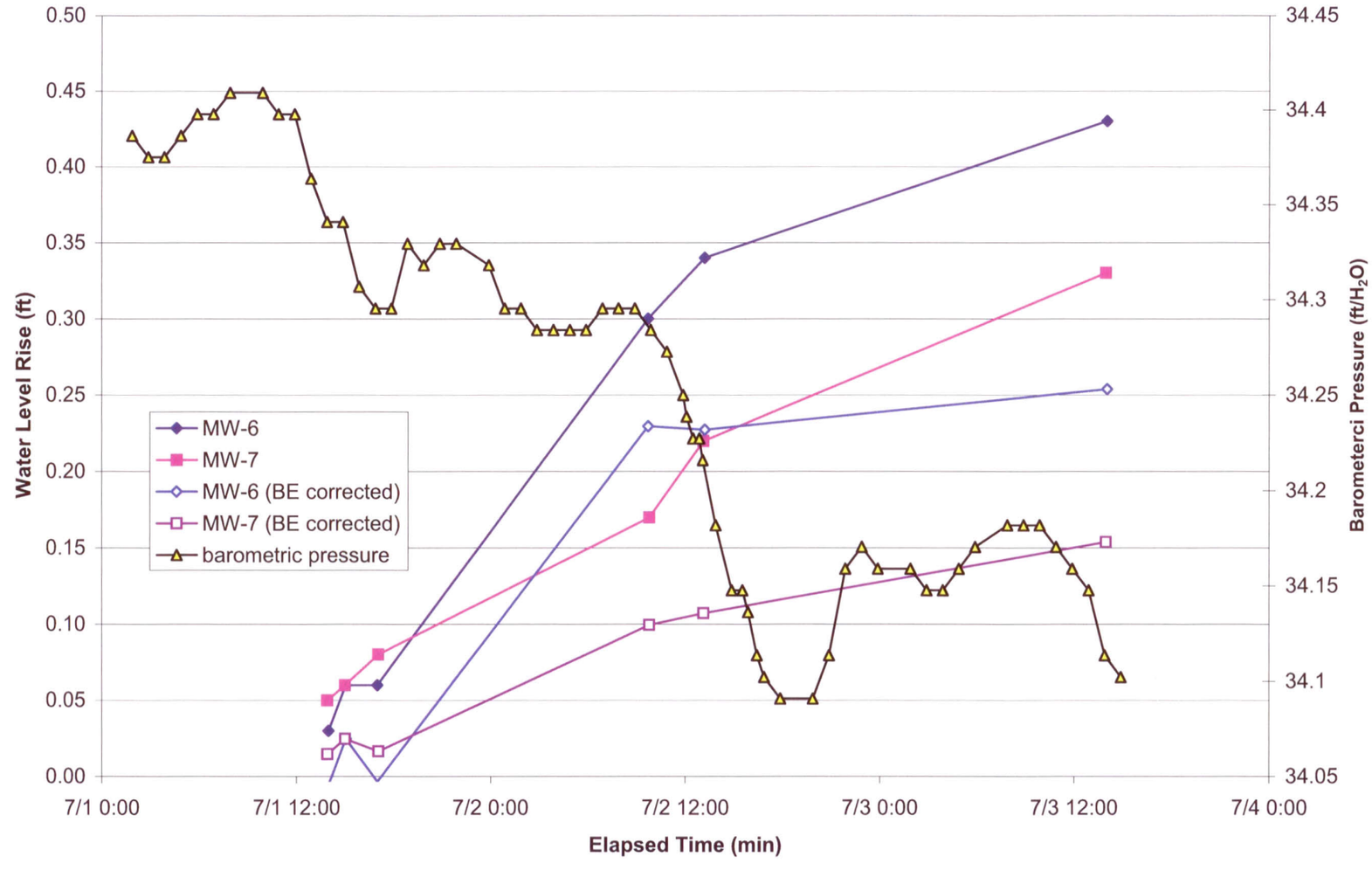

FIGURE A-1

Water level changes measured in Wells MW-6 and MW-7
compared with barometric pressure (Gallup, NM),
Injection test of well IW-A, July 1, 2010,
United Nuclear Corp, Church Rock, NM.

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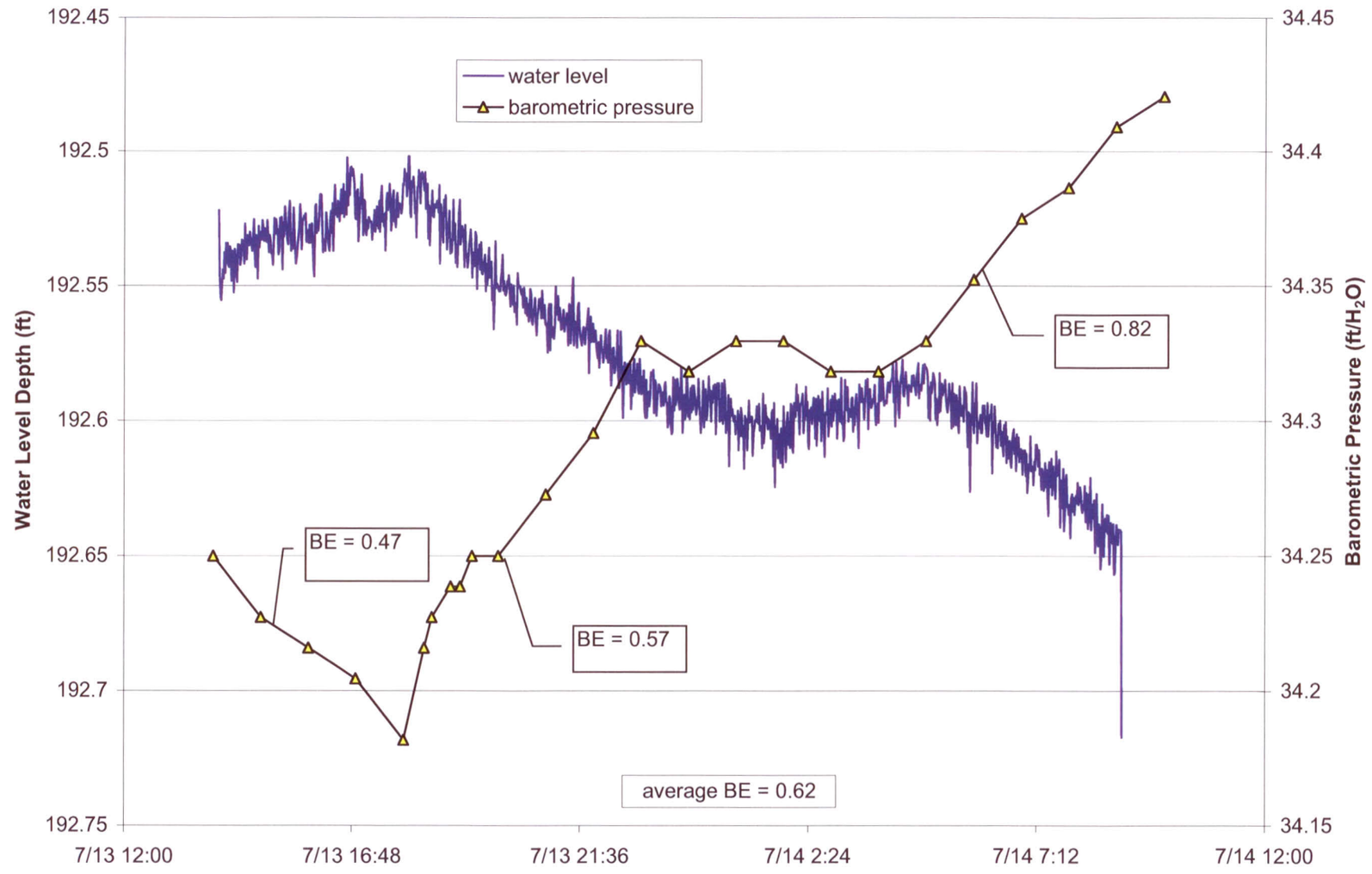

FIGURE A-2

Pre-test water level measurements in Well IW-A compared with barometric pressure (Gallup, NM) barometric efficiency (BE) calculated from ratios of water level rise/pressure change, United Nuclear Corp, Church Rock, NM.

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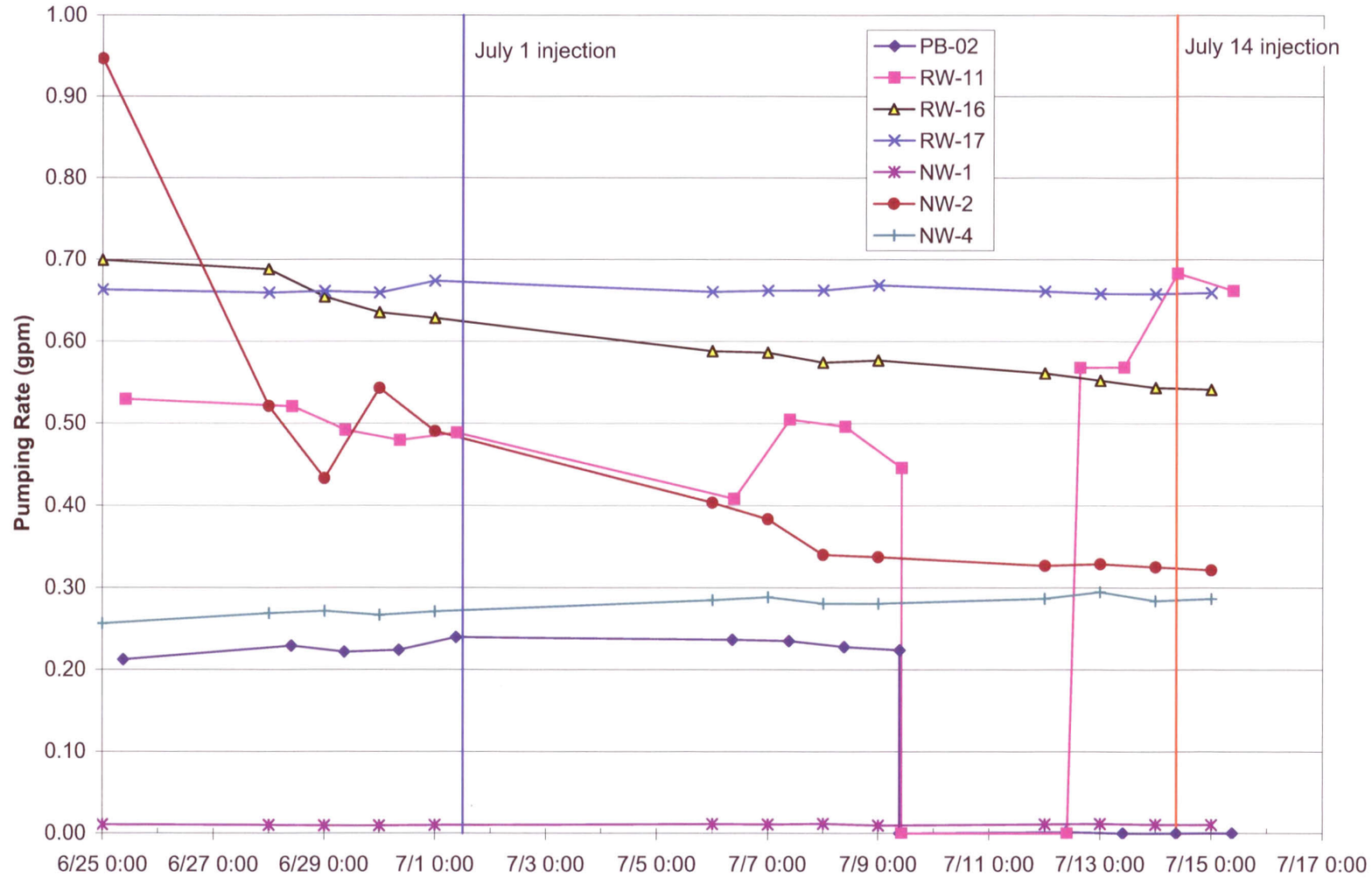

FIGURE A-3

Extraction well pumping rates during the period of injection testing of Well IW-A, July 2010
United Nuclear Corp, Church Rock, NM.

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TABLE A-1

Manual Measurements in Wells MW-6 and MW-7 and Corrections for Barometric Pressure

Injection Test of Well IW-A, July 1, 2010

Location	Date/Time	Elapsed Time (min)	Water Depth (ft btoc)	Water Level Rise (ft)	Barometric Pressure (ft/H2O)	Pressure Change	Corrected Water Level Change
MW6	7/1/10 11:02	-63	188.54		34.398		
MW6	7/1/10 13:57	112	188.51	0.03	34.341	-0.057	-0.01
MW6	7/1/10 15:03	178	188.48	0.06	34.341	-0.057	0.02
MW6	7/1/10 16:59	294	188.48	0.06	34.295	-0.102	0.00
MW6	7/2/10 9:43	1298	188.24	0.30	34.284	-0.114	0.23
MW6	7/2/10 13:13	1508	188.20	0.34	34.216	-0.182	0.23
MW6	7/3/10 14:01	2996	188.11	0.43	34.114	-0.284	0.25
MW7	7/1/10 10:57	-68	184.46		34.398		
MW7	7/1/10 13:54	109	184.41	0.05	34.341	-0.057	0.01
MW7	7/1/10 15:00	175	184.40	0.06	34.341	-0.057	0.02
MW7	7/1/10 17:04	299	184.38	0.08	34.295	-0.102	0.02
MW7	7/2/10 9:47	1302	184.29	0.17	34.284	-0.114	0.10
MW7	7/2/10 13:08	1503	184.24	0.22	34.216	-0.182	0.11
MW7	7/3/10 13:56	2991	184.13	0.33	34.114	-0.284	0.15