Task 2 Supplemental Characterization Report

Volume II—Appendices 1–5

Prepared for

Connecticut Yankee Atomic Power Company
Haddam Neck Plant

Prepared by

CH2MHILL

November 2004

Appendix 1
2003 Packer Testing Data Quality Assessment

Data Quality Assessment of Bedrock Borehole Packer Test Results. Testing performed during summer and fall 2003.

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DATE: 10 February 2004

CH2M HILL has performed a data quality assessment (DQA) of the results of bedrock borehole packer testing performed at Connecticut Yankee Atomic Power Company Haddam Neck Plant (HNP). The DQA was performed as outlined below. The data set generated from the packer testing campaign was evaluated against criteria for measurement precision, accuracy, representativeness, completeness, and comparability to determine data validity and usability. This memorandum summarizes the results of the DQA and associated data qualifiers and identifies recommended corrective actions.

Summary of Data Collection Activities

A series of deep bedrock boreholes was drilled at HNP for the purpose of characterizing the hydraulic properties of the bedrock underlying the plant and to determine the apparent vertical extent of plant-related groundwater contamination. Performance of the packer testing was specified in the Phase II Hydrogeologic Characterization Work Plan (Malcom Pirnie, 2002). Information on the work practices and protocols applied during the testing was derived from discussions with Messrs. Matt Darois and Marty Harrington. Mr. Darois, a Radiation Safety Control Services hydrogeologist assigned to HNP, collected the majority of the field data for the packer tests. Mr. Harrington, a driller for Aquifer Drilling and Testing (ADT), drilled the boreholes (except Boreholes 121A and 118A, drilled by Mr. Derek Walker of ADT) and operated the packer sampling equipment. Each provided valuable first-hand information regarding the packer tests.

Eight-inch diameter boreholes were advanced from the ground surface to contact with bedrock and extended approximately 5 feet into bedrock. Four inch casings for the 4-inch boreholes and 6-inch casings for the 6-inch boreholes were then grouted into the bedrock to form a "rock socket". The intent of the rock socket is to attempt to seal the borehole from the overlying unconsolidated aquifer system. The boreholes were then advanced by air hammer drilling, uncased to depth. Initially, the drilling and sampling program followed the Malcom-Pirnie work plan. The first borehole drilled and tested, Borehole 121, was a 4-inch diameter borehole drilled 20 feet into bedrock. The borehole was then packer sampled over a 23-foot interval (3-feet into the cased interval). The borehole was then drilled an incremental 20 feet, and packer sampled over that deeper 23-foot interval. This alternating drilling and packer sampling technique called for in the work plan, was continued to 200 feet bgs. The second borehole, Borehole 118, followed the same technique to approximately

200 feet bgs. At that time, the decision was made to drill to the completion depth of the borehole, and packer sample from the bottom of the borehole, upward. This decision was based on the time constraints of pulling and reinstalling the packer system at each interval, and the problems encountered with the packer sampler device being damaged by the borehole wall during removal and reinstallation. Borehole 118 was subsequently drilled to a total depth of 400 feet, and packer sampled at 23 foot intervals starting at 395 feet bgs, and continuing upwards. All subsequent borings intended for packer testing were drilled 6-inch diameter continuously to completion depths of approximately 600 feet, and packer tested from the bottom of the borehole upward. The change to 6-inch diameter boreholes was intended to improve the packer installation and removal process. The total depth of the deep bedrock boreholes at HNP are shown in Table 1.

Table 1. Summary of Borehole Dimensions

Borehole ID	Depth to Bedrock (Ft)	Total Depth (Ft)	Diameter (Inches)
118	400	400	4
118A	22	578	6
119	41	612	6
120	35	552	6
121	200	200	4
121A	90.5	582	6

The original packer testing and sampling device (Figure 1) used a submersible pump to evacuate water from the packed interval and for sampling Borehole 121. When the maximum lift capacity of the pump was exceeded in Borehole 118, the submersible pump was replaced with a bladder pump. The bladder pump was subsequently found to provide insufficient pumping rates. It was replaced by a combination of a submersible pump and an air lift system to evacuate water from the packed interval at depths greater than about 200 feet bgs. The submersible pump was used to remove water from the interval between the packers down to the bottom of the pump intake. Once the water level in the packed interval dropped to the pump intake, the submersible pump would stop pumping. The air lift system was then used to raise the remaining water in the riser pipe to the ground surface. This method allowed maximum removal of water from the packed interval, and minimum dilution of subsequent purge volumes by water in the riser pipe. When this pumping method was proven to work, it was used from that point forward.

Extracted water was discharged at the testing site into a steel 700-gallon capacity "B-25" box of dimensions 3.9 feet high by 4 feet wide by 6 feet long. The volume discharged was determined by measuring the water level in the box before and after a pumping event. The elapsed time required to recharge and pump that volume of water was also recorded to determine the apparent yield of the isolated interval in gallons per minute. The intent of the sampling effort was to extract a minimum of three volumes of water from each isolated interval prior to collecting water samples for radiochemical analysis. After determining

yield and purging the required volumes (if possible), samples of the water were collected and analyzed for tritium content and in some cases gamma spectroscopy radionuclide concentrations by HNP's on-site radiochemistry laboratory. In selected cases, sequential samples were collected from successive volumes of water extracted from each isolated interval and analyzed for tritium concentration.

A schematic drawing of the packer assembly is shown in Figure 1. One particularly important feature of the packer assembly is the unpumpable heel of water that remains within the packed interval above the lower packer, but below the pump intake. The unpumpable heel would retain water that would mix with subsequent volumes of water entering the isolated interval, resulting in a mixed concentration not representative of the water entering the interval from the formation. Dimensions of the packer assembly that are important to this DQA are shown in Table 2.

Table 2. Packer Assembly Dimensions

Packer Assembly Element	Volume of Component (gallons)
Gross Isolated Interval	33.8
Internal Components (i.e., pump, riser pipe, packer heads)	8.0
Net Isolated Interval (not including volume in riser pipe above interval)	25.8
Unpumpable Heel	3.4
Net Pumpable Volume of Isolated Interval	22.4
Unpumpable Heel as Fraction of Net Isolated Interval	0.1

Incomplete seals between the inflatable packers and the borehole wall were detected in a few zones in each borehole. Incomplete seals were typically indicated by rapid decreases in water level in the zone above the uppermost packer during pumping from the isolated interval. This change in water level was observed by using an electrical water level meter to measure the water level within the well casing during pumping. When an incomplete seal was detected, the packer was moved up or down the borehole and re-inflated and re-tested for seal.

At the completion of packer testing, flexible synthetic borehole liners (Flexible Liner Underground Technology-FLUTe™) were deployed into the 6-inch and 4-inch boreholes to attempt to seal off the borehole sidewalls. The FLUTes fully deployed in the 4-inch boreholes, though it took several months for full deployment in borehole 118 below 200 feet bgs. The 6-inch FLUTes could only be deployed to about 250 feet bgs, apparently because the borehole water below that depth would not displace back into the formation. This suggests that the bedrock formation below that level did not yield, or take, water. This

information is consistent with the results of downhole geophysical logging conducted during the packer sampling program.

Summary of Data Collected

Samples were analyzed for tritium content by HNP's on-site radiochemistry laboratory. Samples from boreholes 118, 119, 120, 121 and 121A were analyzed for tritium using the resin adsorption method, with periodic distillation analysis checks. Samples from borehole 118A were analyzed for tritium by distillation, with periodic resin analysis checks.

The laboratory data reports generated from analysis of water samples collected from boreholes 118A, 119, 120, 121 and 121A are included in Attachment 1 of this memorandum. The results of the sampling and analysis, along with collected observations of hydraulic properties are shown in Figures 2 through 7. Laboratory data reports for samples collected from borehole 118 were not available at the time of this DQA. It was noted that isolated test interval elevations described in Figure 2 differ from the elevation intervals recorded on the corresponding laboratory record sheets. This difference was explained by Mr. Darois as resulting from height adjustments required to normalize the interval depth to depth below ground surface. The depth intervals shown in the lab report sheets were based on depth below the drill rig deck, which was elevated approximately 3 feet above ground surface.

Generally, the results show higher concentrations of tritium in the sampled zones above approximately 200 feet bgs. Below that depth, where sampled zones during the previous packer sampling yielded significantly less groundwater, sample tritium concentrations generally fluctuate from below minimum reportable concentration to that of a significant fraction of the concentrations found in the upper sections of the borehole. Five borehole composite water samples were taken in at various depths in borehole 121 of the mixed borehole water from the first purge of trapped water from the packer. Tritium concentrations in these samples of mixed borehole water yielded concentrations of 8,250 pCi/L, 7,180 pCi/L, 7,330 pCi/L, 4,100 pCi/L, and 6,720 pCi/L. Tritium concentrations in samples of groundwater from the deeper low yielding zones approached that of the mixed borehole water samples. Mixed borehole water is therefore a possible source of the deep tritium detections if the packer seal was not complete, or if a significant quantity remained behind without much dilution from groundwater from the packed interval.

Results of Data Quality Assessment

The Phase II Hydrogeologic Characterization Work Plan (Malcom-Pirnie, 2002) data quality objectives specify goals of "determining the cause, location, nature and condition of release areas and their associated SOCs" and "determining the degree and extent of the resulting plumes". The data were assessed for precision, accuracy, representativeness, completeness, and comparability. The individual assessment parameters are discussed in the following subsections.

Precision

Precision in measurements is evaluated through analysis of multiple duplicate samples. The following types of duplicate samples are typically assessed:

- Field duplicate, or split, samples that are collected in the field and submitted to the laboratory as blind samples (i.e., not identifiable to the laboratory as duplicates); and

- Laboratory duplicate, or replicate, samples that are prepared by the laboratory and analyzed by the laboratory to assess internal method precision.

Seven laboratory duplicates were identified in the data set provided for this sampling campaign. The Relative Percent Difference (RPD) for the laboratory duplicates are summarized in Table 3.

Table 3 Comparison of Laboratory Duplicates.

Borehole	Interval (Ft bgs)	Purged volume (Gallons)	Result (Pci/L)	Duplicate Result (Pci/L)	RPD (%)
120	504-527	56	1680	1820	8.00
119	359-380	93	6770	6190	8.95
119	359-380	115	1130	1100	2.69
119	359-380	120.6	1890	1950	3.13
119	359-380	123.4	6070	6720	10.16
119	359-380	125	8060	7900	2.01
119	460-483	105	1180	1030	13.57

RPD was calculated as:

$$RPD = \frac{|S1-S2|}{(S1+S2)/2} \times 100$$

Where: RPD = Relative Percent Difference reported as a %
S1=First measurement
S2=Second measurement
|S1-S2|=Absolute value of the difference between the two measurements
(S1+S2)/2=Average of the two measurements

Laboratory internal method precision is within the 20 percent RPD limit chosen for this analysis. No blind field duplicate measurements are recorded in the data set, and as such field precision cannot be assessed.

Accuracy

Accuracy is typically assessed through analysis of known standards and through the analysis of blanks and/or matrix spike samples. No blank and/or matrix spike information was identified in the data set provided to assess accuracy.

Representativeness

Representativeness refers to the degree to which a data set is actually a sample of a population. In this case representativeness refers to the degree to which these collected groundwater samples are actually groundwater from the bedrock formation in the packed-off intervals. This representativeness could be compromised by any of the following conditions:

- water leaking past either packer,
- residual mixed borehole water remaining in the packed interval,
- formation producing insufficient water volume to adequately purge the packed interval before sampling,
- inability to fully evacuate the packed interval during pumping,
- mixed borehole water bypassing the packer through interconnected fractures,

- potential cross contamination in the laboratory environment.

Laboratory cross contamination potentially could bias sample results, but no method blanks were included in the data set to assess this issue. The design of the packer sampling instrument prevented the full evacuation of water from between the packers. Approximately three gallons remained behind to be diluted by the subsequent purge volumes. As indicated in Table 2, this volume of unpumpable heel represents approximately 10% of the net isolated interval volume. The concentration of tritium in this unpumpable heel prior to pumping would be that of the borehole water, which could be as high as the maximum detected concentrations in the borehole. The method for determining leakage past the upper packer was limited to changes in water level as measured with a water level meter and verification of packer inflation pressure. The shallowest intervals in the bedrock at the site tend to be relatively transmissive (on the order of 2-20 gpm), so it is unrealistic to expect to be able to detect with a water level meter a change in water level caused by leakage at a few hundredths of a gallon per minute past the upper packer. In addition, no measurement of the seal of the lower packer was taken, other than verification of inflation pressure. If either of the two packer seals did leak, tritium mixed in the borehole water could contaminate the sample.

As the yield of the packed interval decreases with depth to low tenths and hundredths of gallons per minute, and the pressure gradient across the packer increases with depth, it becomes more and more likely that a significant portion of the sampled water leaked past the packer. In selected intervals, sequential water samples were collected from each packed interval volume (or fraction thereof) removed. These samples were each analyzed for tritium. Plots of tritium concentration versus either gallons purged or consecutive sample number for various boreholes (Figures 8-17) show five instances of concentrations fluctuating significantly as the last sample is being collected (Figures 8, 11, 13, 14 and 17). In some instances, purge volume was not documented during collection, and for these sample concentration was plotted versus consecutive sample number. These plots suggest poor seals, breakthrough of borehole water, or incomplete purging of the residual borehole water from the isolated zone. Good stabilization appears to be documented in Figures 9, 10, 12 and 16. The graphs that appear to document good stabilization fall into two categories; either they represent samples taken from shallow depths in the borehole that are hydraulically productive where tritium is not unexpected (Figure 12), or they document stabilization at or below the laboratory method detection limit or minimum reportable concentration (MRC) (Figures 9, 10 and 16). The graphs that document stabilization at or below the MRC for samples collected at depth suggest that in zones where the packer did not appear to leak, tritium concentrations are below the MRC. Thus, the apparent tritium detections in deep bedrock sample intervals appear to be an artifact of packer leakage or carry-over from incomplete purging. Representativeness of the samples from low yielding zones is questionable.

There is no regulatory or industry standard for yield below which a packer sample should not be considered representative. Many factors come into play when considering whether such a sample could be considered representative. The less smooth the walls of the borehole, the more likely that formation water will leak past the packer. Diamond bit coring systems make a much smoother borehole than air hammer systems (these boreholes were drilled by air hammer bit). As depths increase, so does the pressure gradient across the

packer, increasing the likelihood of seal failure. For these reasons, the analytical data for intervals yielding less than about 0.1 gpm should be rejected for questionable representativeness, given the absence of data demonstrating that the upper and lower seals were "leak free".

Completeness

Completeness refers to the ability of the data set to encompass the entirety of the target system. In other words, are data sufficient to answer the questions that prompted the data collection in the first place? Analytical requirements were specified in the Phase II Hydrogeologic Characterization Work Plan (Malcom Pirnie, 2002). Tritium and gamma spectroscopy radionuclide concentrations were specified for analysis in each sample collected. In addition, selected samples were to be analyzed for alpha-emitting radionuclides, and special analysis for hard to detect (HTD) plant-related beta-emitting radionuclides. A limited number of samples were analyzed by gamma spectroscopy; about half of those were performed to a 1000 second count, and not to sufficient detail to confirm plant related gamma radionuclides were below regulatory limits. No HTD analyses were performed on any of the packer samples.

Each packer-sampled borehole contains a substantial number of intervals at depth that were sampled, but which did not provide sufficient water yields to allow collection of a representative groundwater sample. If these data are rejected, the specified completeness goal of determining the degree and lateral and vertical extent of tritium in the crystalline bedrock system is not met.

Comparability

Comparability refers to the degree to which a data set, or single datum can be compared to another measurement for the purposes of assessing change over time or space. All tritium measurements of groundwater for this activity were made using liquid scintillation counting (the recommended counting method). Water samples, however, were prepared for the liquid scintillation counting using two different preparation methods: distillation and resin adsorption separation. Samples that are analyzed for tritium require preparation to remove all other non-tritium radionuclides. The presence of other substantial concentrations of beta- or photon-emitting radionuclides in the water sample would result in a positive bias of the tritium count and result in an inaccurately-high activity concentration. Distillation is the standard reference method for preparation of water samples to separate dissolved nuclides from the tritium, which is present as tritiated water in the sample. Resin adsorption can be effective at removing dissolved radionuclides from the sample as long as a sufficient quantity of an appropriate combined (i.e., anion + cation) exchange resin is used and the contact time is sufficient. Radiological samples from boreholes 118, 119, 120, 121 and 121A were prepared for tritium analysis using the resin adsorption method, with periodic distillation preparation comparisons. Samples from borehole 118A were prepared for tritium analysis by distillation, with periodic resin preparation checks. Consistency in sample preparation is important to the assessment of data comparability, particularly when evaluating environmental samples with low levels of tritium present. The data set contains 21 samples analyzed by both distillation and resin preparation methods (Table 4). Relative percent difference was calculated for each sample for which both preparation methods were used and the results were compared to the 20% RPD criterion selected for assessment of precision. If the two sample preparation methods

are indeed comparable, then the results should compare well when evaluated as duplicate analyses of the same sample.

Table 4. Comparison of Resin Adsorption versus Distilled Tritium Results

Borehole & Interval (Ft bgs)	Tritium - Distilled (pCi/L)	Tritium - Resin (pCi/L)	RPD (%)
Borehole 118A			
46-69	14200	12300	14.34
88-111	10200	8600	17.02
88-111	10000	9490	5.23
151-174	2710	2070	26.78
151-174	2100	1710	20.47
151-174	1880	2810	39.66
157-180	5030	2730	59.28
424-447	4060	3350	19.16
Borehole 119			
84-107	32700	32400	0.92
Borehole 120			
105-161	1470	1920	26.55
189-212	904	908	0.44
210-233	939	944	0.53
275-298	1420	1340	5.80
296-319	1480	1530	3.32
317-340	1380	981	33.80
338-361	1710	1570	8.54
359-382	1840	1760	4.44
387-403	1640	1600	2.47
504-527	1820	1680	8.00
Borehole 121A			
294-317	6080	5140	16.76
336-359	8700	7780	11.17

Six of the 21 paired analyses exceeded the 20 percent RPD criteria. All of these exceedences, however, involved samples containing low levels of tritium (i.e., less than ten times the laboratory reporting limit of about 1,000 pCi/L). In the case of these low concentration samples, the absolute difference between the compared methods was relatively small and, therefore, the elevated RPD is not considered to be significant. The results of this analysis therefore indicates that the resin-adsorbed samples are generally comparable with the distilled samples.

The comparison of distilled samples to resin-adsorbed samples indicates a further trend. The results for tritium by liquid scintillation counting of distilled samples were generally, although not always, higher than the analytical results for analysis of the same sample by resin adsorption (Figure 18). The reason for this difference is not apparent from the data at hand.

DQA Summary

The data set generated from the 2003 HNP packer testing campaign was evaluated against criteria for measurement precision, accuracy, representativeness, completeness, and comparability to determine data validity and usability. The following data deficiencies were noted:

- No field duplicate samples were collected to measure precision.
- No information was identified in the data set to assess accuracy of laboratory measurements (e.g., blanks, spikes, and standards).
- Not all of the analyses identified in the project work plan were performed on samples collected from the boreholes.
- Samples collected and analyzed for tritium do not appear to be representative of groundwater from the fractured matrix of the crystalline bedrock, specifically in zones exhibiting a low or deminimus groundwater yield.

The most critical issue is that of apparent non-representativeness of the samples from low-yielding zones. The packer sampling equipment was not designed to collect samples from low-yielding zones and was not instrumented to detect low rates of leakage past the packers that are comparable to the recharge rate of the lower-yielding zones. The methods used in packer sampling were not able to overcome these limitations. The reported tritium concentration values for low-yielding zones (i.e. those exhibiting less than 0.1 gpm yield) were biased in many instances by residual borehole water in the unpumpable heel; these data should not be considered representative and should be rejected. Tritium data to be rejected due to a non-representative status include 1) samples collected from zones from which less than three complete packed interval volumes were removed prior to sample collection (i.e., sample not collected from the fourth interval volume); 2) tritium data representing an interval where the volume purged was apparently insufficient to eliminate the influence of the unpumpable heel. Data collected from higher-yielding zones should be qualified as "estimated" to reflect and insufficient level of field precision and accuracy checks.

Recommended Corrective Actions

New groundwater samples should be collected from the target depths of interest in one of the boreholes to re-assess the above sampling results. Borehole 121A has been identified as a candidate for initial retesting. The new samples should be collected with a packer system designed to minimize the unpumpable water between the packers. The packer system should be instrumented with transducers to allow detection of small water pressures changes above, below, and between the packers. Sufficient QC samples (blanks, duplicates, etc.) should be included as part of the analytical suite to enhance the overall assessment of data quality. Sampling methods designed to minimize uncertainty should be followed. Information from this modified packer testing campaign should be used to identify discrete fracture zones within the crystalline bedrock that may be candidates for future site groundwater monitoring.

Figure 1 Packer Assembly Used in 2003 Packer Testing Campaign.

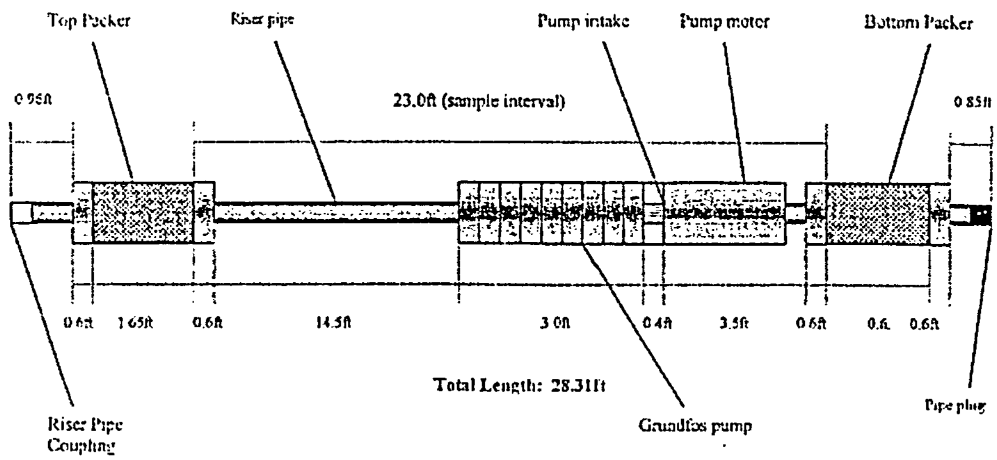

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Figure 2. Packer test sample results for bedrock Borehole 118A

September 2003

6" diameter steel casing

3' steel casing stick- up

Grade

Bedrock surface at 10 feet bgs

Open bedrock 6" borehole: 18 - 578'

Interval	Fill time (min)	Purge volumes	Gross volume	Result	Yield (gpm)
3 - 24'		0.00	0	No Sample	<0.01
22 - 45'	20	11.0	247	1,330 pCi/L	11.24
43 - 66'		13.0	293	14,200 pC/L [1]	>10
64 - 87		0.0		NO SEAL	
85 - 108	574	4.7	111	10,000 pCi/L	0.14
106 - 129'		0.0		NO SEAL	
127 - 150'		0.0		NO SEAL	
148 - 171'		5.0	123	1,880 pC/L	>5
154 - 177'		5.8	140	2,520 pCi/L [3]	>10
169 - 192'	0	0.0		NO SEAL	
190 - 213'	0	0.0		NO SEAL	
211 - 234'	0	0.0		NO SEAL	
232 - 255'	0	0.0		NO SEAL	
238 - 261'	9916	4.5	118	<1000 pCi/L [3,4]	0.01
253 - 276'	518	1.1	44	No Sample[2]	0.01
274 - 297'	1271	1.2	48	No Sample[2]	<0.01
295 - 218'	4220	1.0	44	No Sample[2]	<0.01
316 - 339'	984	0.5	35	No Sample[2]	<0.01
337 - 360'	322	0.4	35	No Sample[2]	<0.01
358 - 381'	241	0.2	32	No Sample[2]	<0.01
379 - 402'	969	1.0	51	No Sample[2]	<0.01
400 - 423'	424	0.3	37	No Sample[2]	<0.01
421 - 444'	1007	1.4	63	No Sample[2]	<0.01
442 - 465'	380	0.0	27	No Sample[2]	<0.01
463 - 486'	904	0.0	35	No Sample[2]	<0.01
484 - 507'	359	0.0	35	No Sample[2]	<0.01
505 - 528'	429	0.1	42	No Sample[2]	<0.01
526 - 549'	198	0.0	19	No Sample[2]	<0.01
547 - 570'	205	0.0	9	No Sample[2]	<0.01

Note: A seal could not be established at the following intervals within this zone:(160-183)(167-190), (169-192), (188-211), (193-216), (192-215), (190-212), (196-219), (211-234) ,(244-267)

Bottom of borehole ~578 feet bgs.

* All purge volumes and depths are approximate

1- Purged water in sample had a dark rusty brown color within the selected packer interval.

2- Purged water volume is less than one packer interval volume. Interval is classified as "extremely low yield"

[shaded box] 3-An interval at 21' normal intervals would not seal. Packer assembly was moved to the indicated depth

4-MRC -less than the Minimum Reportable Concentration.

[box] Packer would not seal at the indicated interval

Fill time is time after removal of first purge to final sampling.

Gross volume is measured volume of total water purged at time of final sampling.

Purge volume calculated as = (Gross volume - Volume in the riser pipe) / Volume of water between the packers.

Yield is calculated as = (Gross volume-(Volume in the riser pipe+Volume in the packed interval)) / Total refill time

Connecticut Yankee Atomic Power Co. Haddam Neck Plant

Figure 3. Packer test sample results for bedrock Borehole 118

As of April 2003

4-inch PVC grouted into bedrock

Grade

Soil

Bedrock at ~8 feet bgs

Purge Number — Concentrations in pCi/L

Bedrock	1	2	3	4
24' - 47'	7,110	8,150	7,670	6,180
45 - 68'	8,700	8,820	9,940	
66 - 89'	6,570	6,100	6,660	7,000
87' - 110'	6,590	5,690	7,330	
108' - 131'	6,350	5,970	5,630	5,800
129' - 152'	4,870	4,400	4,320	
150' - 173'	<1,070[1]	<1,080[1]	<1,090[1]	
171' - 194'	3,340	3,760	2,870	
192' - 215'	2,500	3,270	2,160	
213' - 236'	2,870	2,090	1,500	
234' - 257'	2,180	1,960	2,450	
255' - 278'	2,930	3,470	3,220	
276' - 299'	4,280			
297' - 320'	3,730			
318' - 341'	6,060			
339' - 364'	5,360	3,400	3,790	
371' - 395'	5,280	4,300	4,280	

All depths are approximate   Bottom of borehole at ~400 ft bgs.

Not to scale

Volume and yield information were not collected during packer sampling.

1- MRC-Minimum reportable concentration

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Figure 4. Packer test sample results for bedrock Borehole 119

July 2003

3' steel casing stick- up

Grade

6" steel casing

Open bedrock 6" borehole 46 - 612'

Bedrock surface at 39.5 feet bgs

46'

Interval	Fill time (min)	Purge volumes	Gross volume	Result	Yield (gpm)
42' - 65'			>3	14,300 pCi/L [4]	
63' - 86'			>3	35,300 pCi/L [4]	
84' - 107'			>3	32,700 pCi/L [4]	
105' - 128'			>3	13,300 pCi/L [4]	
126' - 149'			>3	8,120 pCi/L [4]	
143' - 166'			>3	4,140 pCi/L [4]	
170' - 193'	1021	2.6	69	<1,030 pCi/L [3]	0.03
191' - 214'	155	1.3	42	4,900 pCi/L	0.04
212' - 235'	182	1.9	58	6,660 pCi/L	0.11
233' - 256'	4062	3.0	85	<987 pCi/L [3]	0.01
254' - 277'	221	1.0	40	No Sample [1]	<0.01
275' - 298'	1085	4.5	120	1,610 pCi/L	0.07
296' - 319'	286	1.3	52	5,780 pCi/L	0.03
317' - 340'	1124	1.4	55	3,850 pCi/L	0.01
338' - 361'	4340	0.7	40	No Sample [1]	<0.01
359' - 380'	2974	4.3	123	7,940 pCi/L	0.02
378'-401'	0	?[2]	?[2]	1,940 pCi/L [2]	?[2]
397'-420'	5598	2.9	95	4,000 pCi/L	0.01
418' - 441'	2644	4.4	130	<1,200 pCi/L [3]	0.03
439' - 462'	287	4.0	122	<1,210 pCi/L [3]	0.23
460' - 483'	7216	3.0	103	<1,060 pCi/L [3]	0.01

* All purge volumes and depths are approximate

Bottom of borehole at ~612 ft bgs.

[1] No sample was collected due to low water recovery, interval is classified as "extremely low yield".

[2] Purge volume unknown due to instrument failure

[3] MRC- Minimum reportable concentration.

[4] Purge water and samples were taken using a Grundfos Rediflow pump; quantitative purge volumes were not recorded.

Fill time is time after removal of first purge to final sampling.

Gross volume is measured volume of total water purged at time of final sampling.

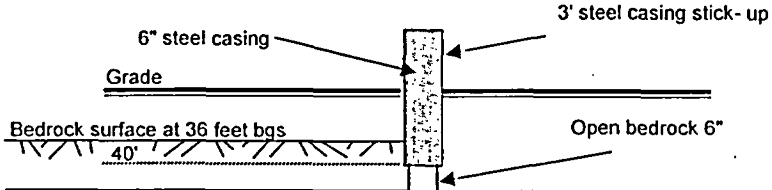
Purge volume calculated as = (Gross volume - Volume in the riser pipe) / Volume of water between the packers.

Yield is calculated as = (Gross volume-(Volume in the riser pipe+Volume in the packed interval)) / Total refill time

Connecticut Yankee Atomic Power Co. Haddam Neck Plant

Figure 5. Packer test sample results for bedrock Borehole 120

July 2003



Interval	Fill time (min)	Purge volumes	Gross volume	Result	Yield (gpm)
42 - 65'	285	1.4	34.0	5,080 pCi/L	0.03
63' - 86'	2374	4.9	114.0	5,160 pCi/L	0.04
84 - 107'	13	7.5	173	<MRC[1]	11.18
105 - 161'	10	13.8	316	1,470 pCi/L[2]	28.65
147 - 170'	1110	5.1	125	<MRC[1]	0.08
168 - 191'	5726	2.1	60	<1,030 pCi/L[1]	<0.01
189 - 212'	162	4.1	105	<904 pCi/L[1]	0.43
210 - 233'	76	4.5	116	<939 pCi/L[1]	1.03
231 - 254'	2694	4.5	117	<940 pCi/L[1]	0.03
252 - 275'	1223	1.3	47	1,300 pCi/L	<0.01
273' - 296'	210	1.1	45	1,420 pCi/L	0.01
294 - 317'	1210	1.0	45	1,480 pCi/L	<0.01
315 - 338'	5572	1.6	59	1,380 pCi/L	<0.01
336 - 359'	198	1.1	49	1,710 pCi/L	<0.01
357 - 380'	191	1.0	50	1,840 pCi/L	<0.01
378 - 403'	9669	0.0	28	1,640 pCi/L	<0.01
399 - 422'	187	1.0	53	1,930 pCi/L	<0.01
420 - 443'	5441	1.0	54	1,830 pCi/L	<0.01
441 - 464'	977	1.2	60	2,010 pCi/L	<0.01
462 - 485'	434	1.0	57	1,600 pCi/L	<0.01
483 - 506	272	1.0	60	*No Sample*[3]	<0.01
504 - 527'	299.00	0.3	46	1,940 pCi/L	<0.01

Bottom of borehole ~552 ft bgs.

[1] MRC-Minimum reportable concentration, recorded as MRC where actual MRC value not recorded on data sheet.
[2] Packer would not seal during sampling. The head above the top packer dropped appoximately 10 ft during the fill time
[3] Insufficient yield to sample.

Fill time is time after removal of first purge to final sampling
Gross volume is measured volume of total water purged at time of final sampling
Purge volume calculated as = (Gross volume - Volume in the riser pipe) / Volume of water between the packers.
Yield is calculated as = (Gross volume-(Volume in the riser pipe+Volume in the packed interval)) / Total refill time

Connecticut Yankee Atomic Power Co. Haddam Neck Plant

Figure 6. Packer test sample results for bedrock Borehole 121A

August 2003

6" steel casing

3' steel casing stick- up

Grade

Bedrock surface at 90.5 feet bgs

Open bedrock 6" borehole: 95 -582'

Interval	Fill time (min)	Purge volumes	gross volume	Result	Yield(gpm)
84 - 107'	1489	4.1	97	<1,100 pCi/L	0.05
105 - 128'	7074	4.2	102	<1,090 pCi/L	0.01
126 - 144'	183	1.3	37	No Sample[1]	0.03
147 - 170'	20	8.8	207	8,890 pCi/L	8.72
168 - 191'	1421	5.0	123	8,630 pCi/L	0.06
189 - 212'	1224	1.1	39	No Sample[1]	<0.01
210 - 233'	5508	1.1	40	No Sample[1]	<0.01
231 - 254'	382	1.1	42	No Sample[1]	<0.01
252 - 275'	1082	1.9	61	No Sample[1]	0.02
273 - 296'	1594	5.1	134	2,610 pCi/L	0.06
294 - 317'	7318	5.3	140	6,080 pCi/L	0.01
315 - 338'	2680	2.6	82	<1,110 pCi/L	0.01
336 - 359'	1477	4.6	128	8,700 pCi/L	0.05
357 - 380'	206	0.3	33	No Sample[1]	<0.01
378 - 401'	388	0.3	35	No Sample[1]	<0.01
399 - 422'	81	0.1	32	No Sample[1]	<0.01
420 - 443'	183	0.1	35	No Sample[1]	<0.01
441 - 464'	6840	2.9	98	7,400 pCi/L	<0.01
462 - 485'	231	0.1	37	No Sample[1]	<0.01
483 - 506'	928	0.0	37	No Sample[1]	<0.01
504 - 527'	260	0.0	35	No Sample[1]	<0.01
525 - 548'	179	0.0	32	No Sample[1]	<0.01
546 - 569'	267	0.0	33	No Sample[1]	<0.01

* All purge volumes and depths are approximate

Bottom of borehole ~ 582 ft bgs.

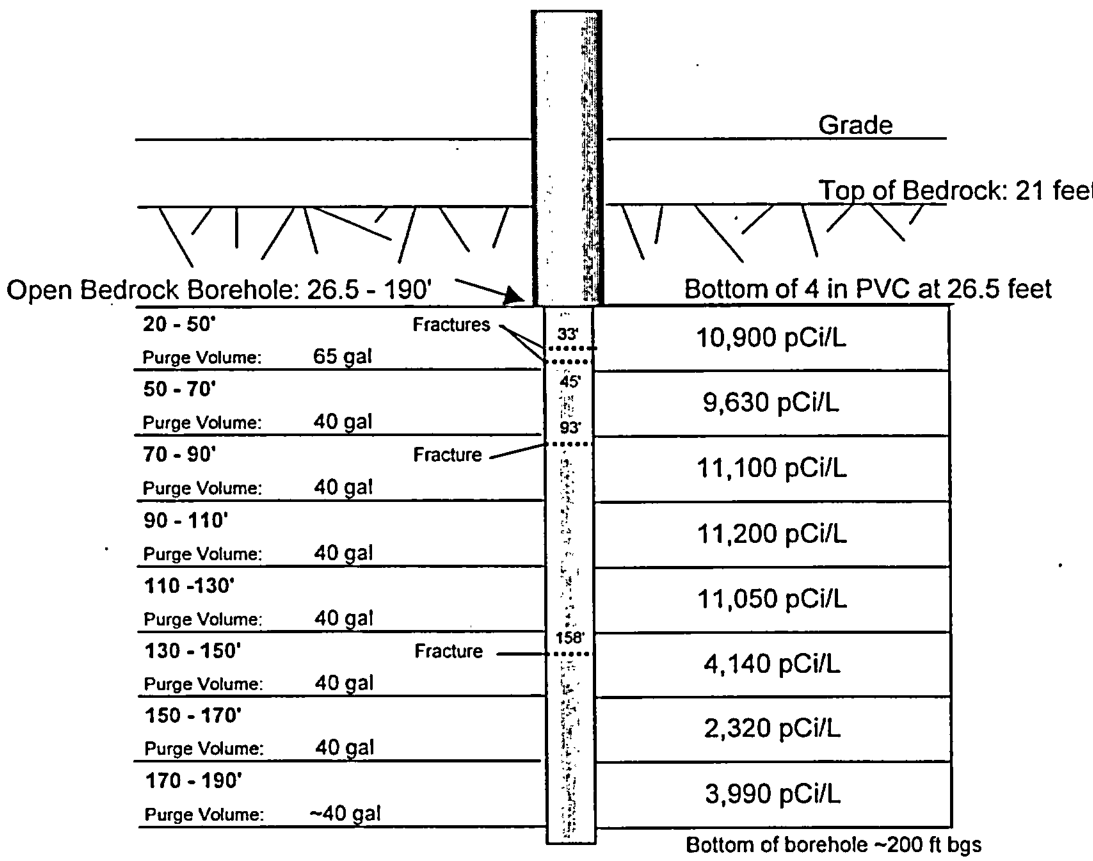
Volume of water between the packers.

Total refill time

Connecticut Yankee Atomic Power Co. Haddam Neck Plant

Figure 7. Packer tests sample results for bedrock Borehole 121

February 2003



* Not to Scale. Nominal depth intervals. All purge volumes are approximate.
* Fractures noted by field geologist during drilling.

Purge volume calculated as = (Gross volume - Volume in the riser pipe) / Volume of water between the packers.

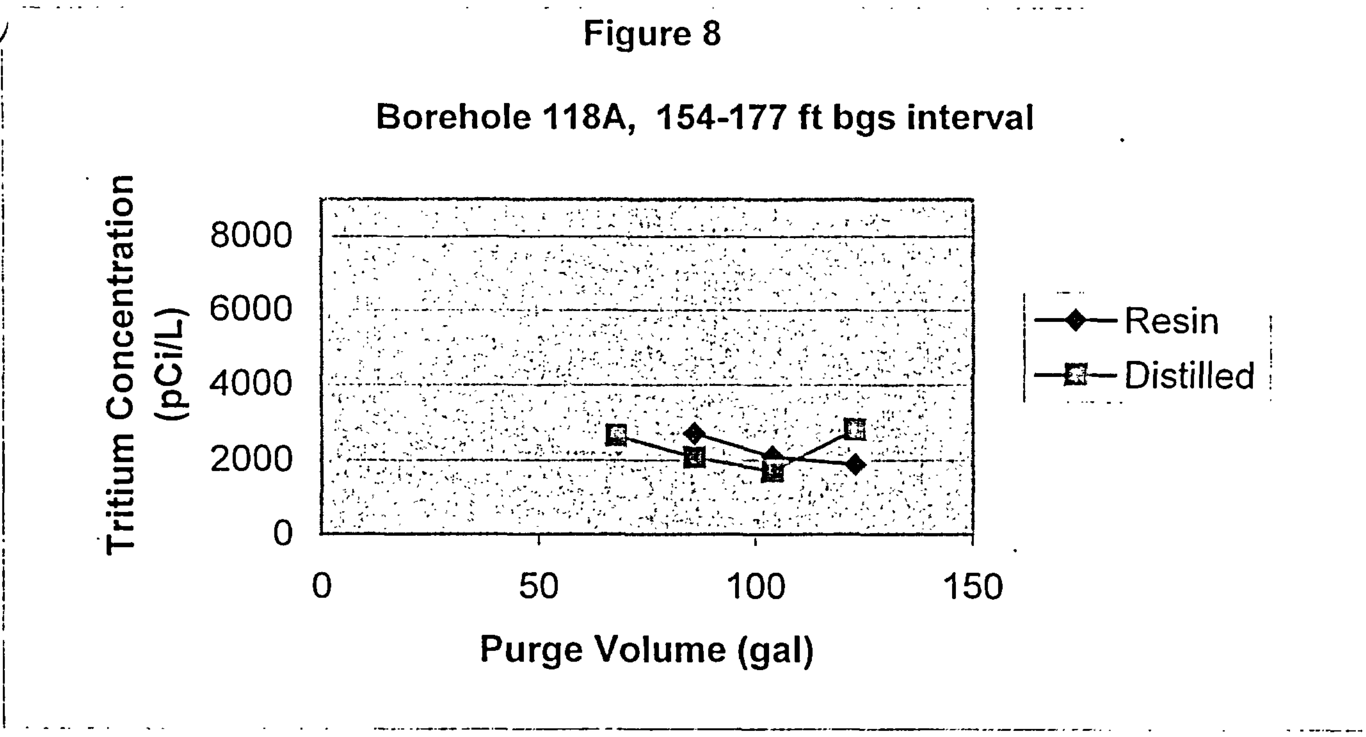


Figure 8
Borehole 118A, 154-177 ft bgs interval
Tritium Concentration (pCi/L)
8000
6000
4000
2000
0
0
50
100
150
Purge Volume (gal)
Resin
Distilled

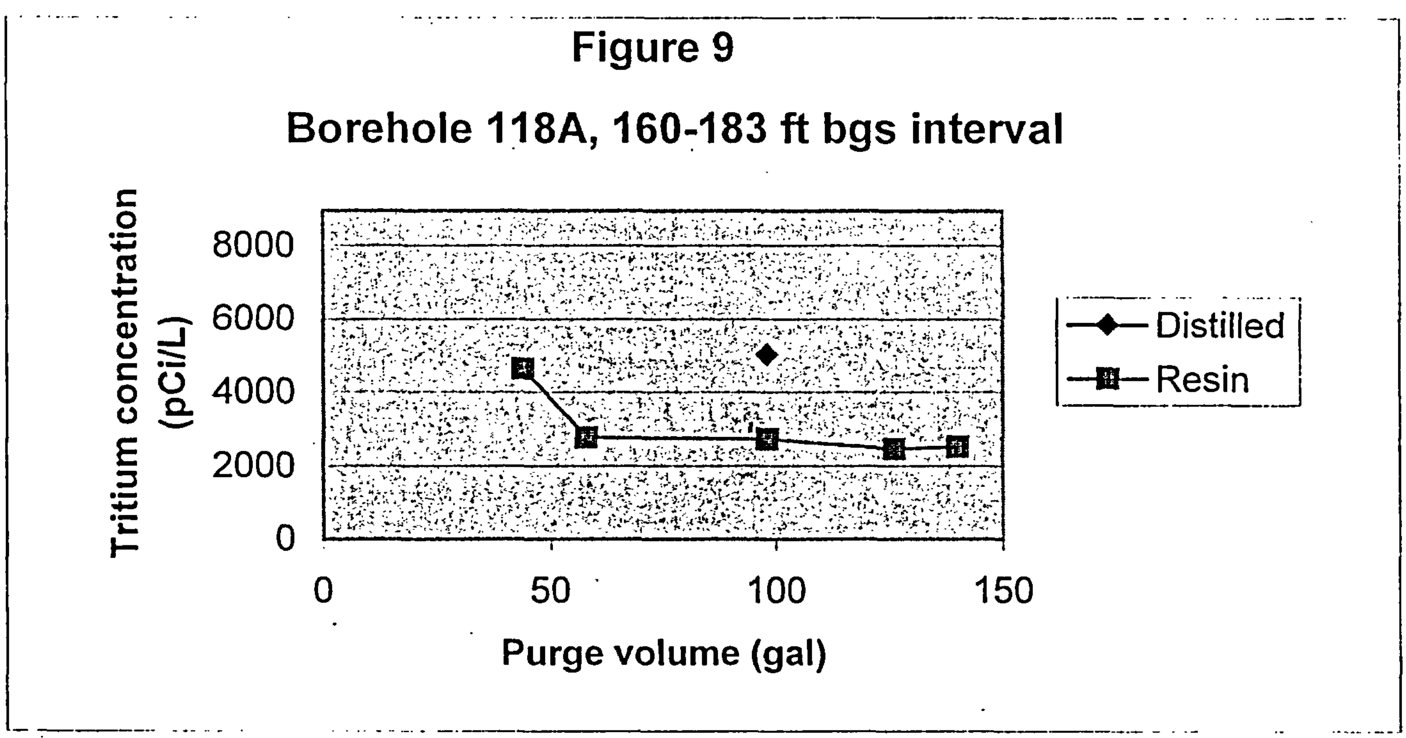


Figure 9
Borehole 118A, 160-183 ft bgs interval
Tritium concentration (pCi/L)
8000
6000
4000
2000
0
0
50
100
150
Purge volume (gal)
Distilled
Resin

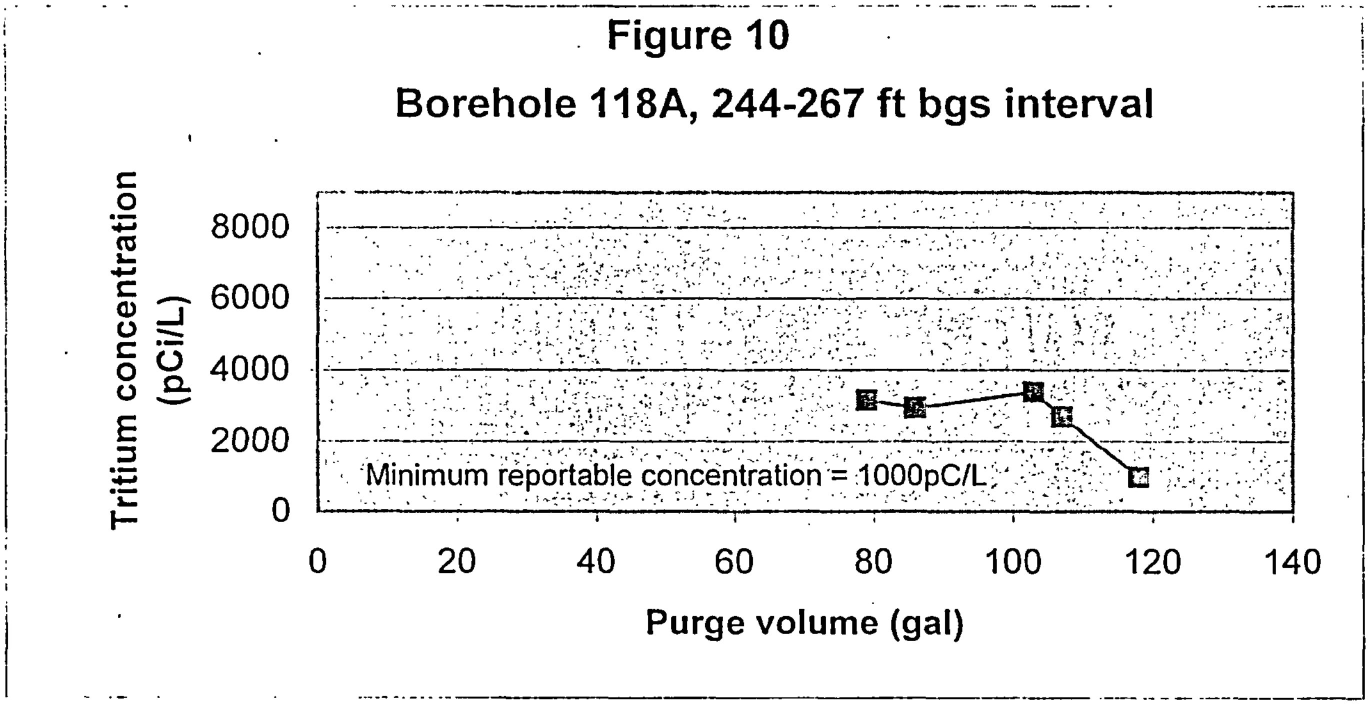


Figure 10
Borehole 118A, 244-267 ft bgs interval
Tritium concentration (pCi/L)
8000
6000
4000
2000
0
Minimum reportable concentration = 1000pC/L
0
20
40
60
80
100
120
140
Purge volume (gal)

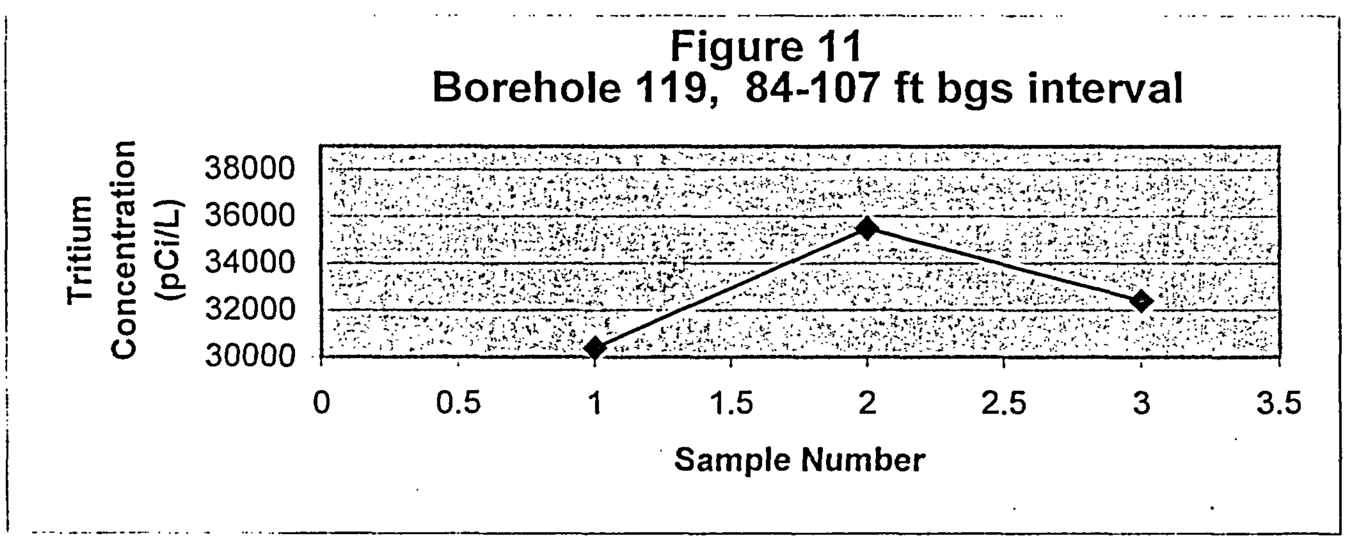


Figure 11
Borehole 119, 84-107 ft bgs interval
Tritium Concentration (pCi/L)
38000
36000
34000
32000
30000
0
0.5
1
1.5
2
2.5
3
3.5
Sample Number

Figure 12
Borehole 119, 126-149 ft bgs interval

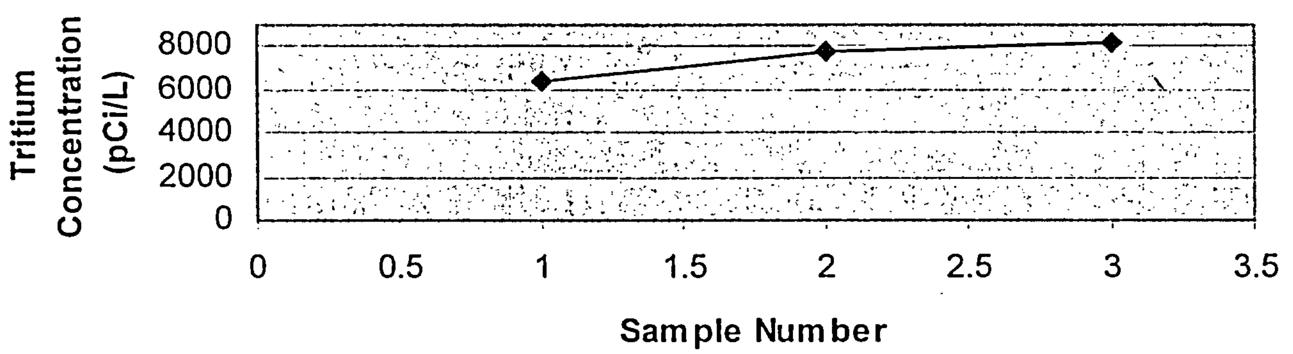


Figure 13
Borehole 119, 143-166 ft bgs interval

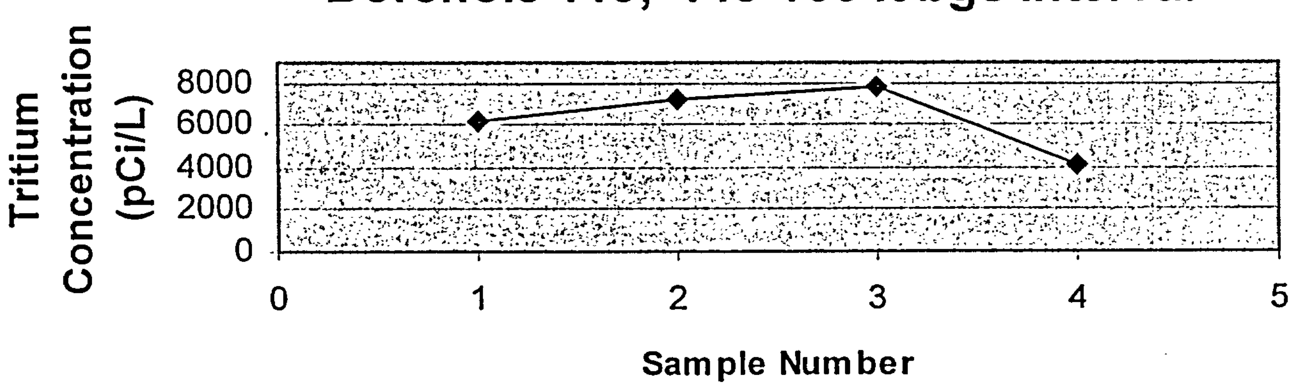


Figure 14

Borehole 119, 359-380 ft bgs interval

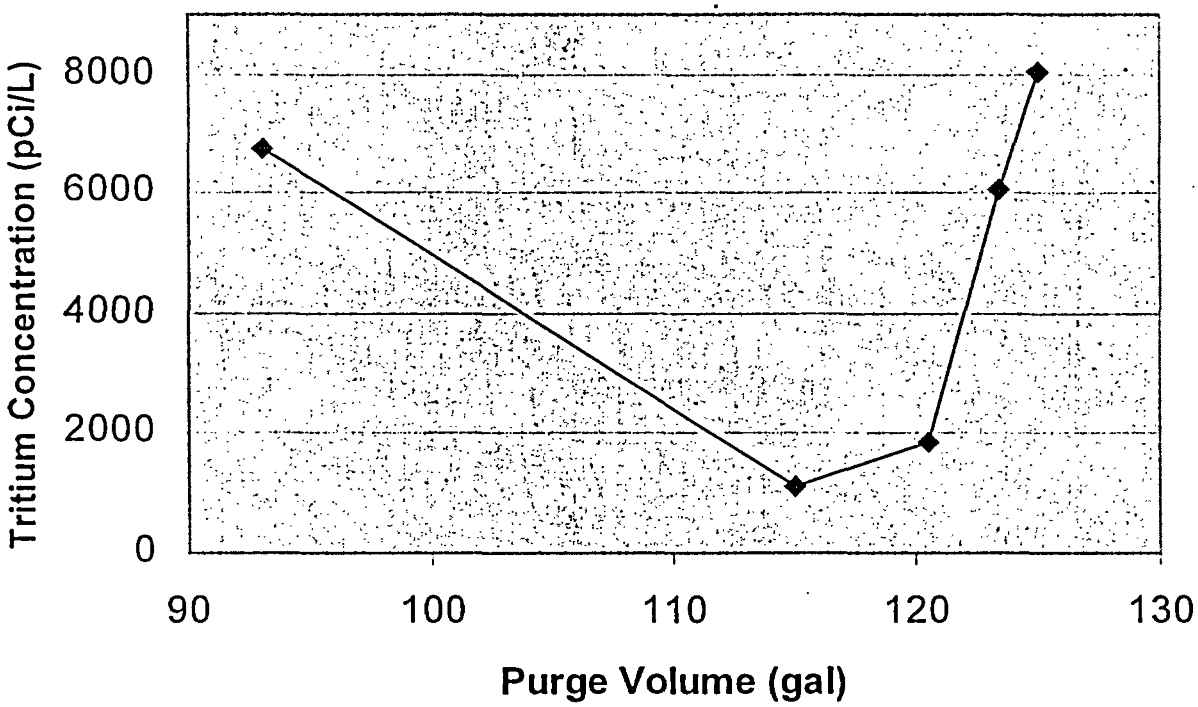


Figure 15

Borehole 119, 387-408 ft bgs interval

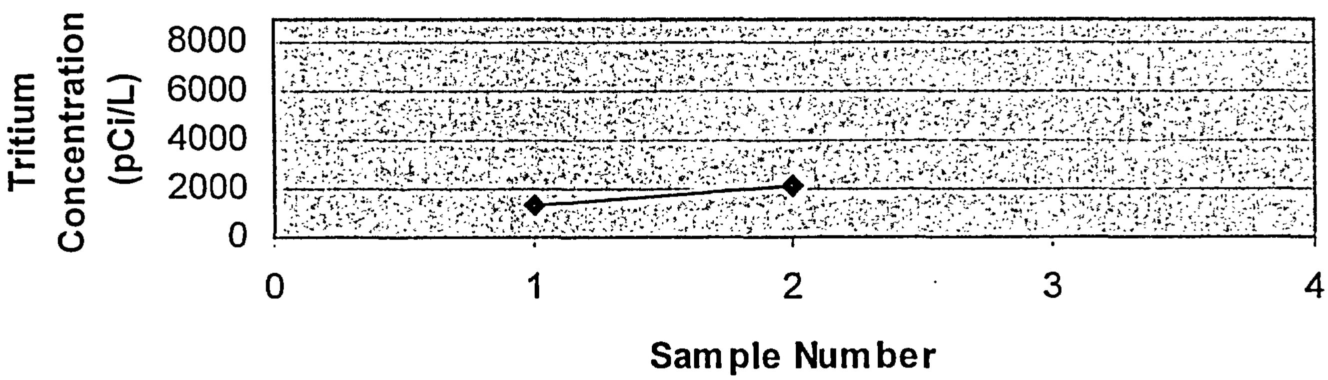


Figure 16
Borehole 119, 460-483 ft bgs interval

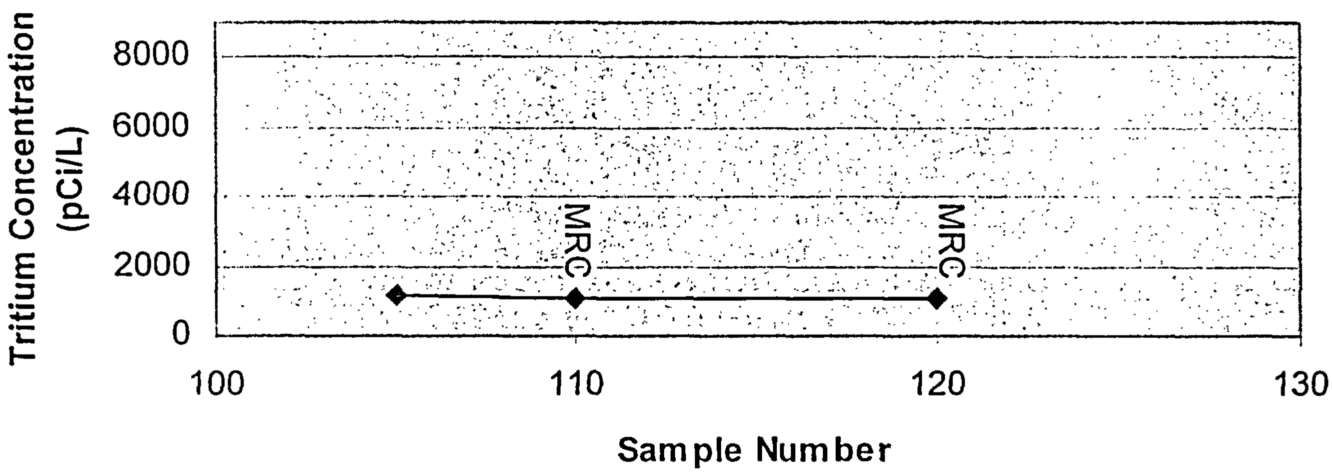


Figure 17

Borehole 121A, 294-317 ft bgs interval

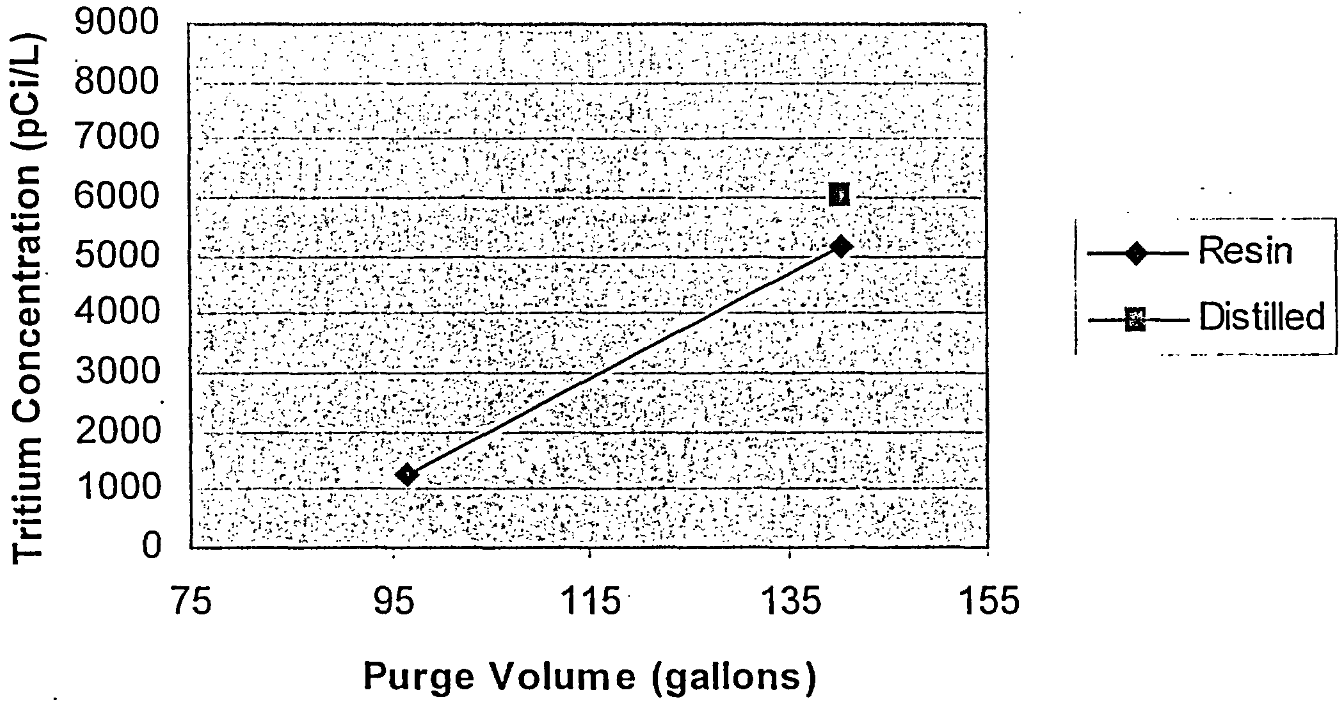
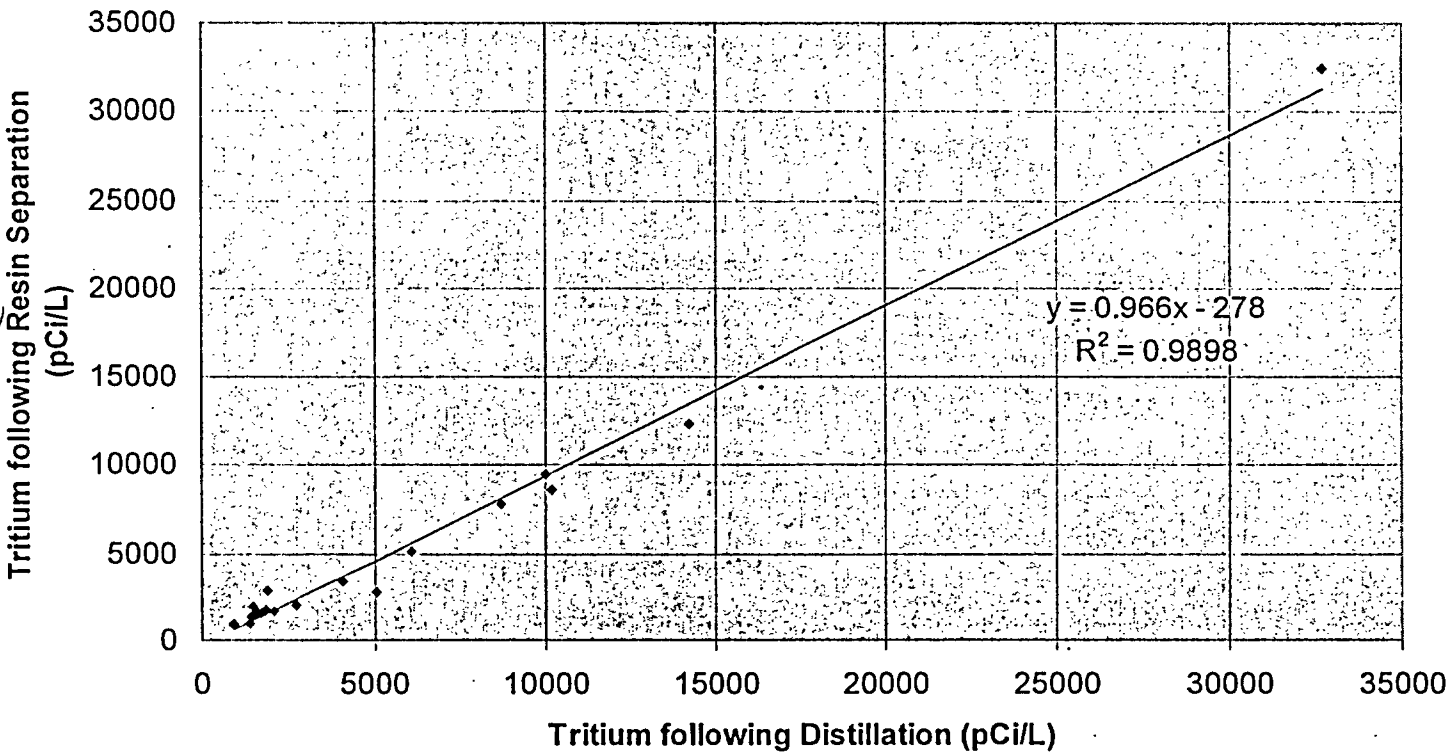
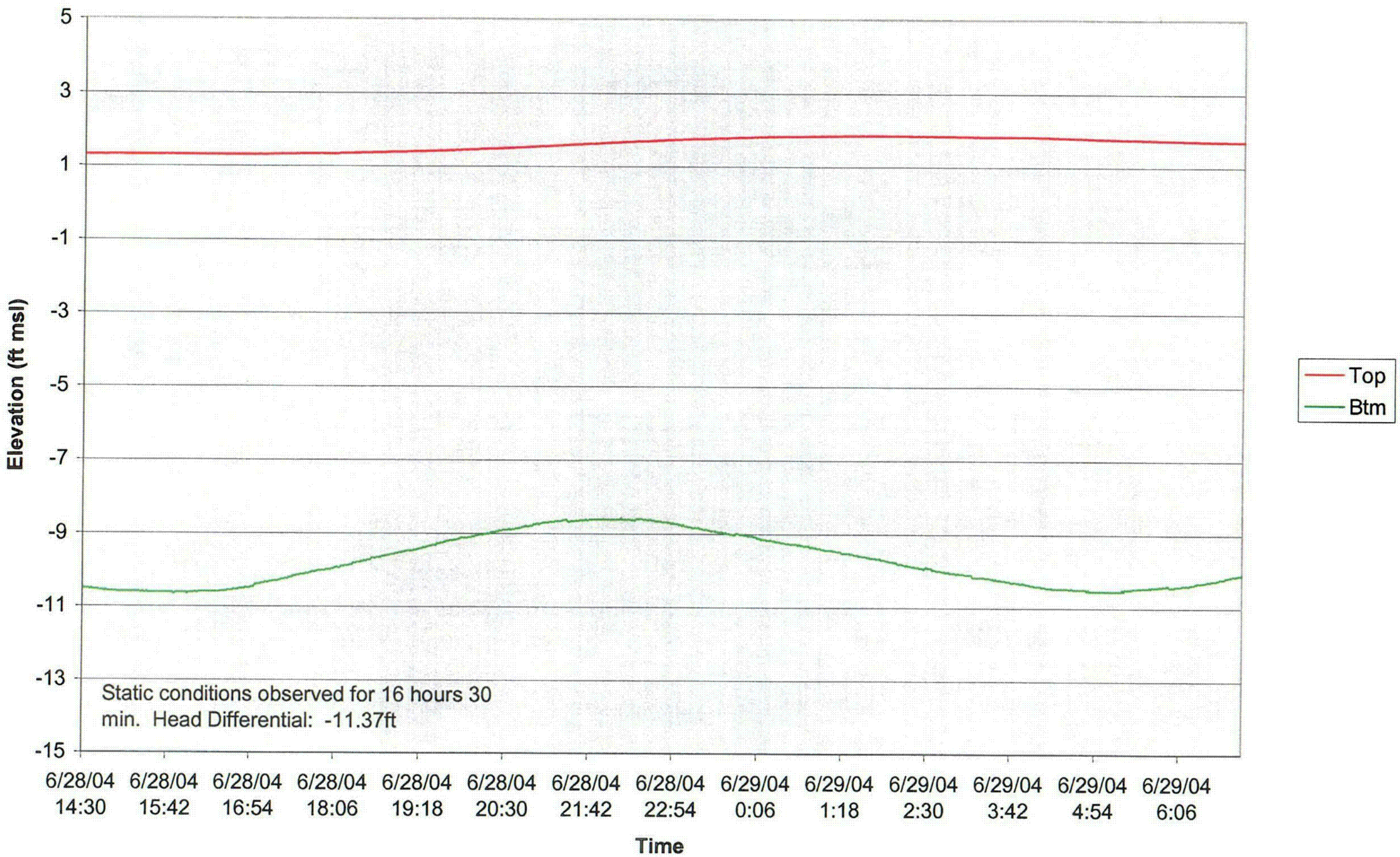


Figure 18
Comparison of Tritium Sample Preparation Methods
(CY packer testing samples, 2003)



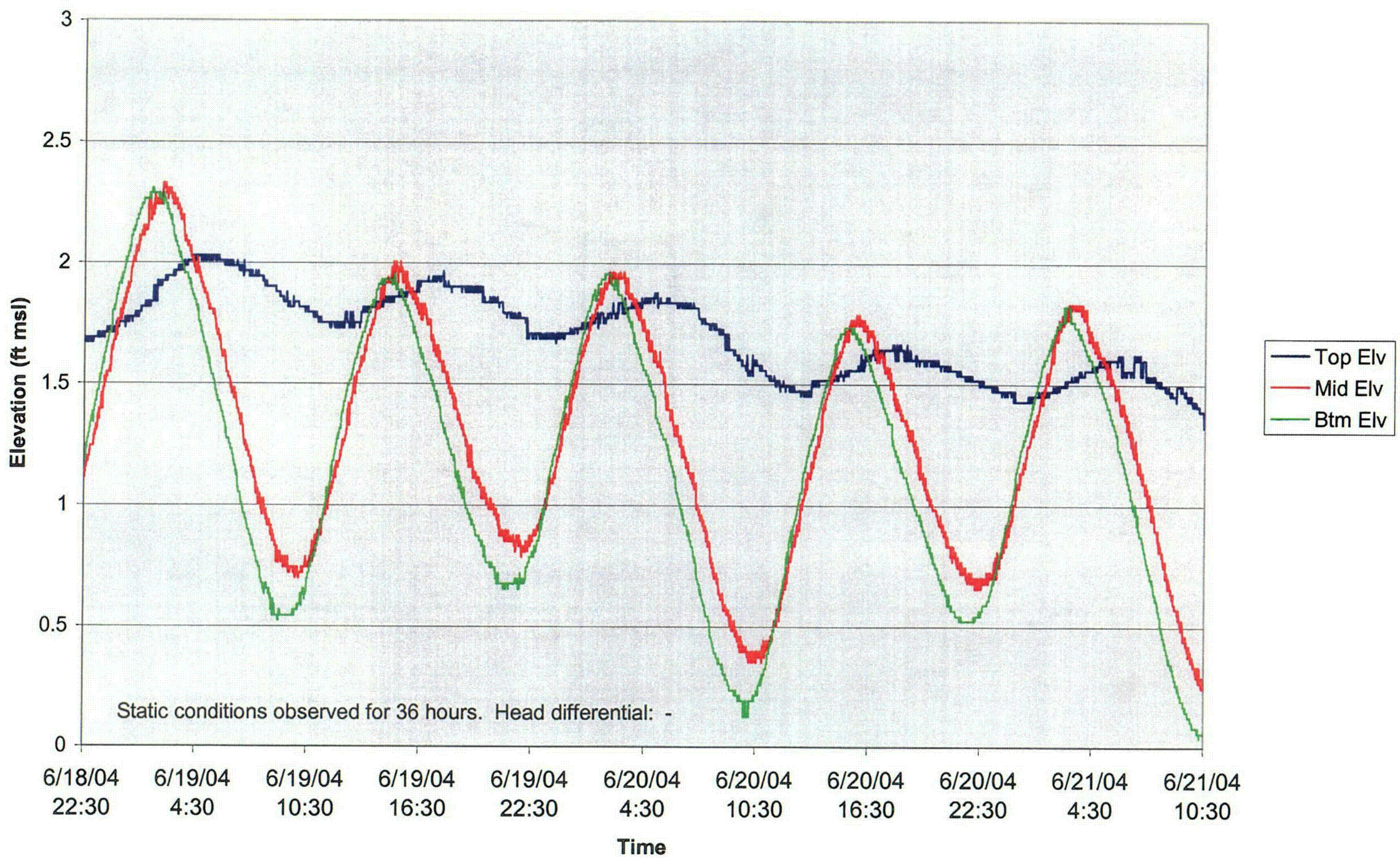
Appendix 2
2004 Packer Testing Graphs

Water Elevation During Packer Isolation in Borehole 121A at 103-108 Feet (BGS)



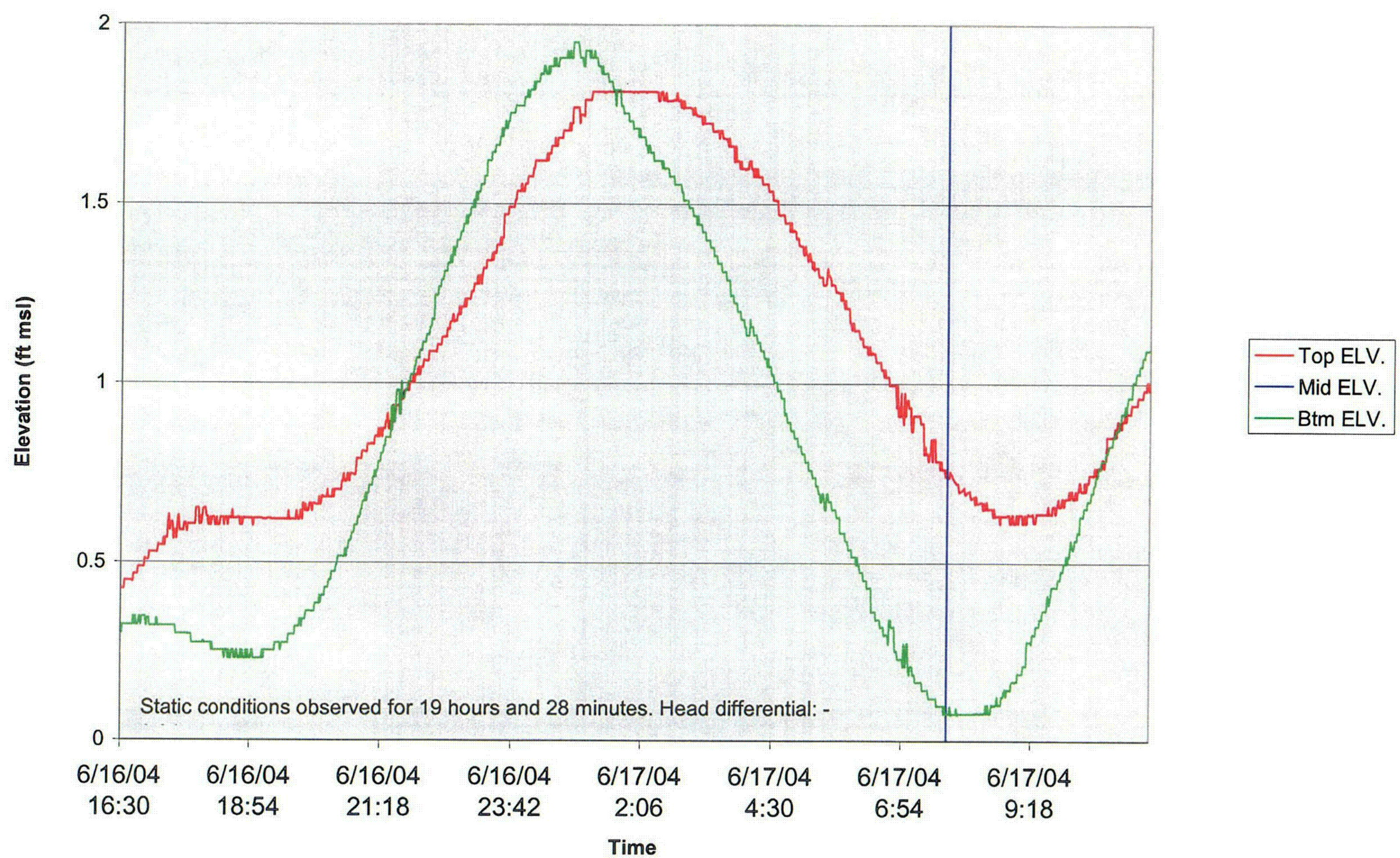
C01

Water Elevations During Packer Isolaton and Pumping in Borehole 121A at 114-119 Feet (BGS)

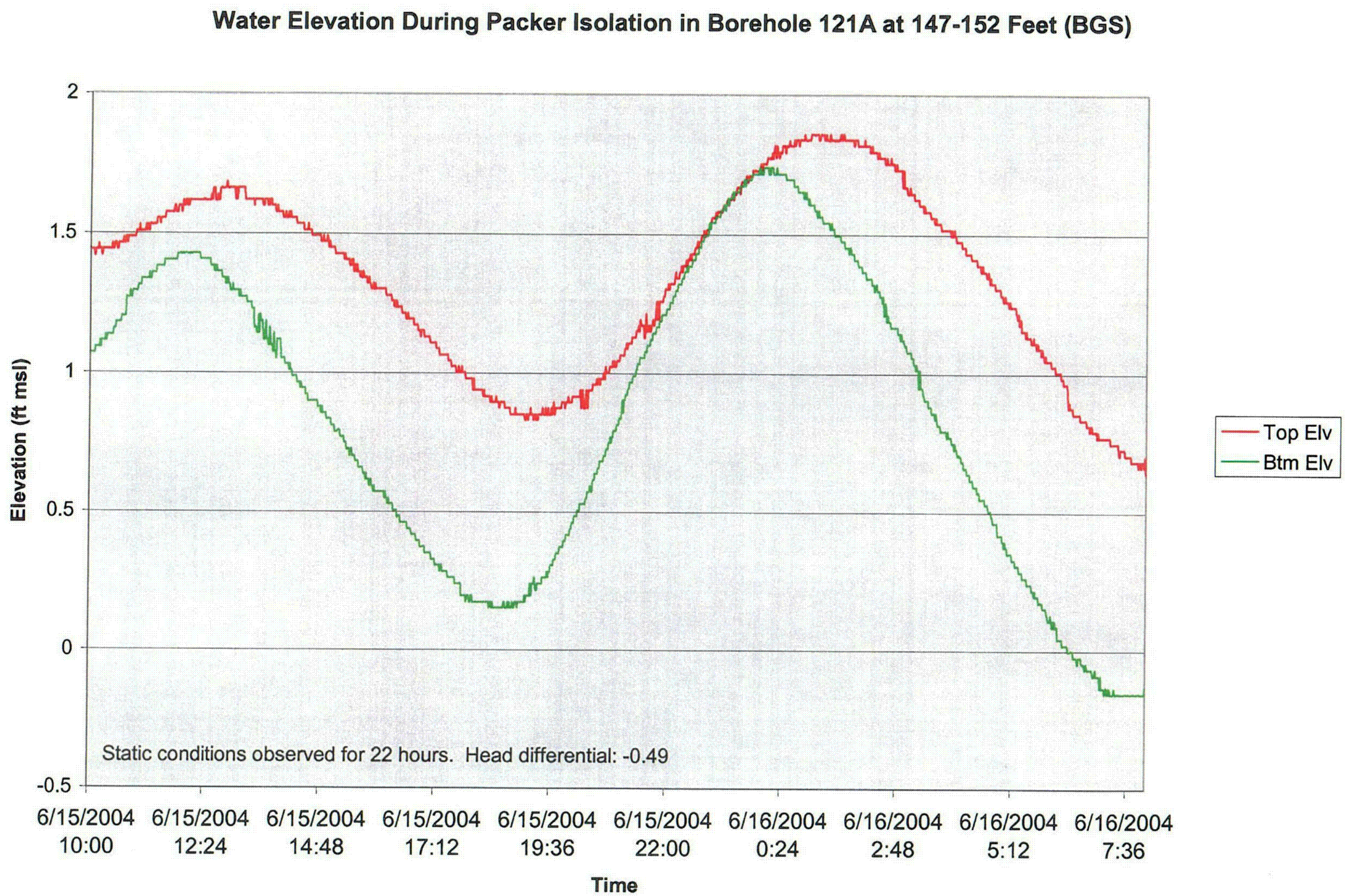


C02

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 145-150 Feet (BGS)

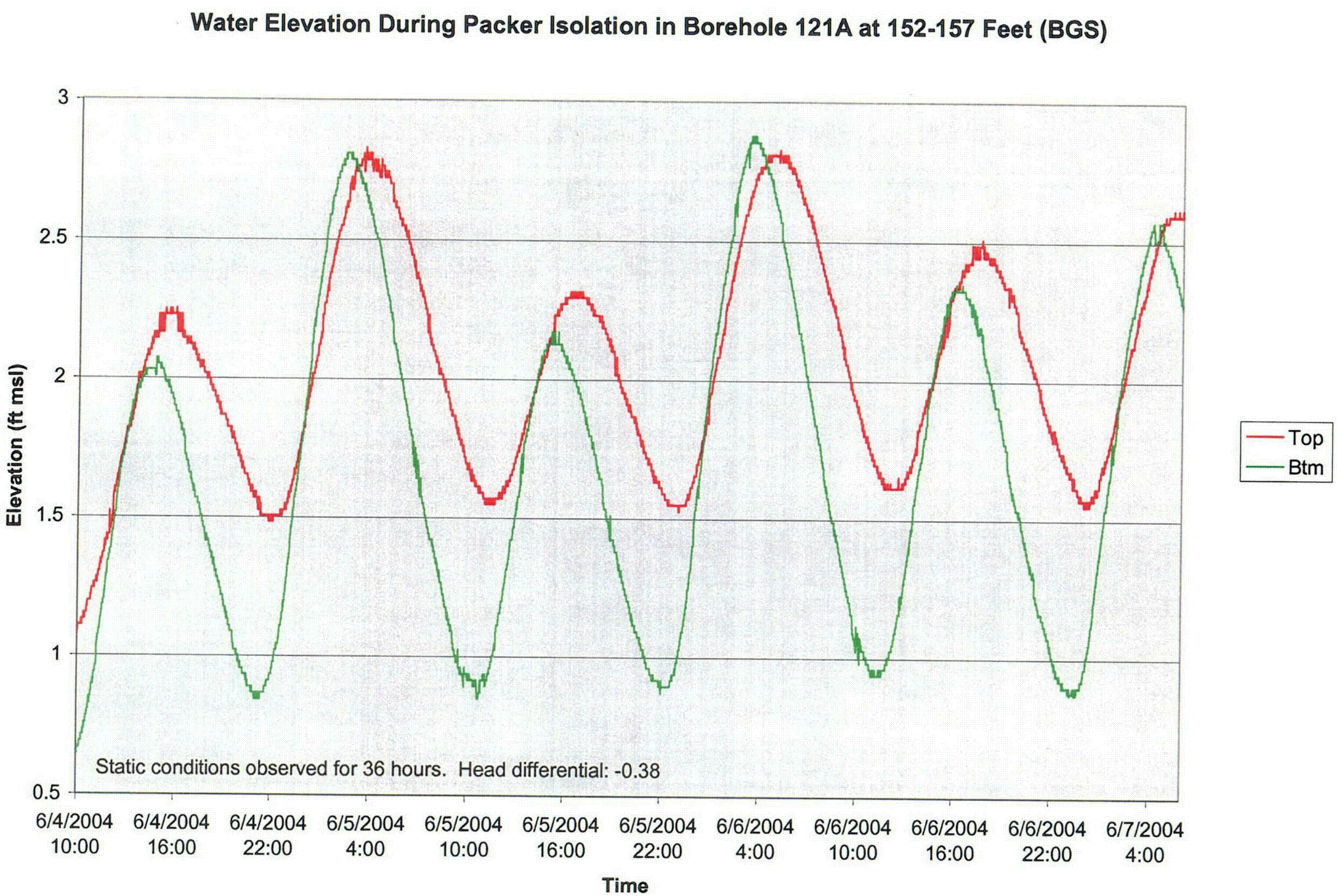


C03



Water Elevation During Packer Isolation in Borehole 121A at 147-152 Feet (BGS)
2
1.5
1
0.5
0
-0.5
Elevation (ft msl)
Top Elv
Btm Elv
Static conditions observed for 22 hours. Head differential: -0.49
6/15/2004 10:00
6/15/2004 12:24
6/15/2004 14:48
6/15/2004 17:12
6/15/2004 19:36
6/15/2004 22:00
6/16/2004 0:24
6/16/2004 2:48
6/16/2004 5:12
6/16/2004 7:36
Time

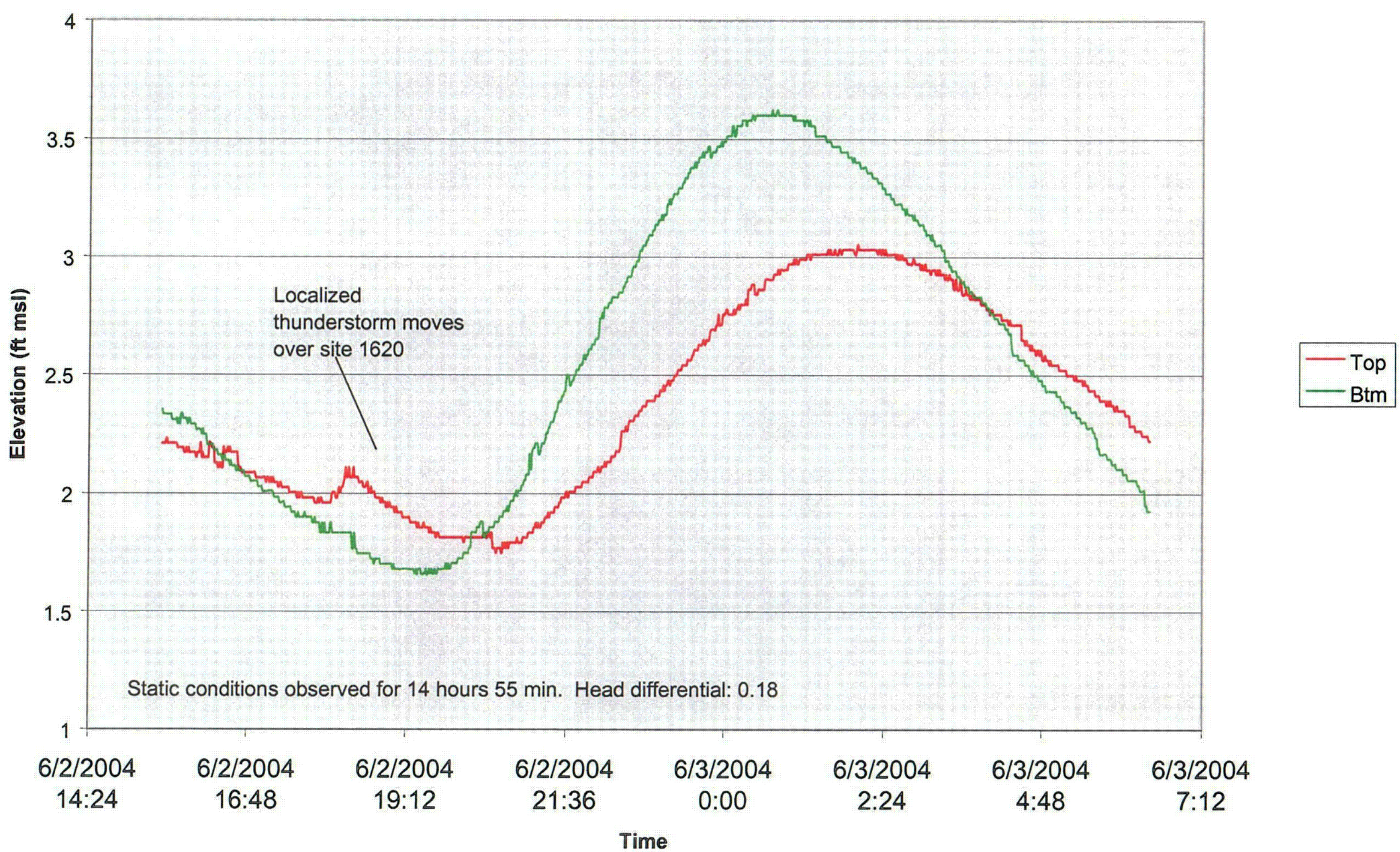
C04



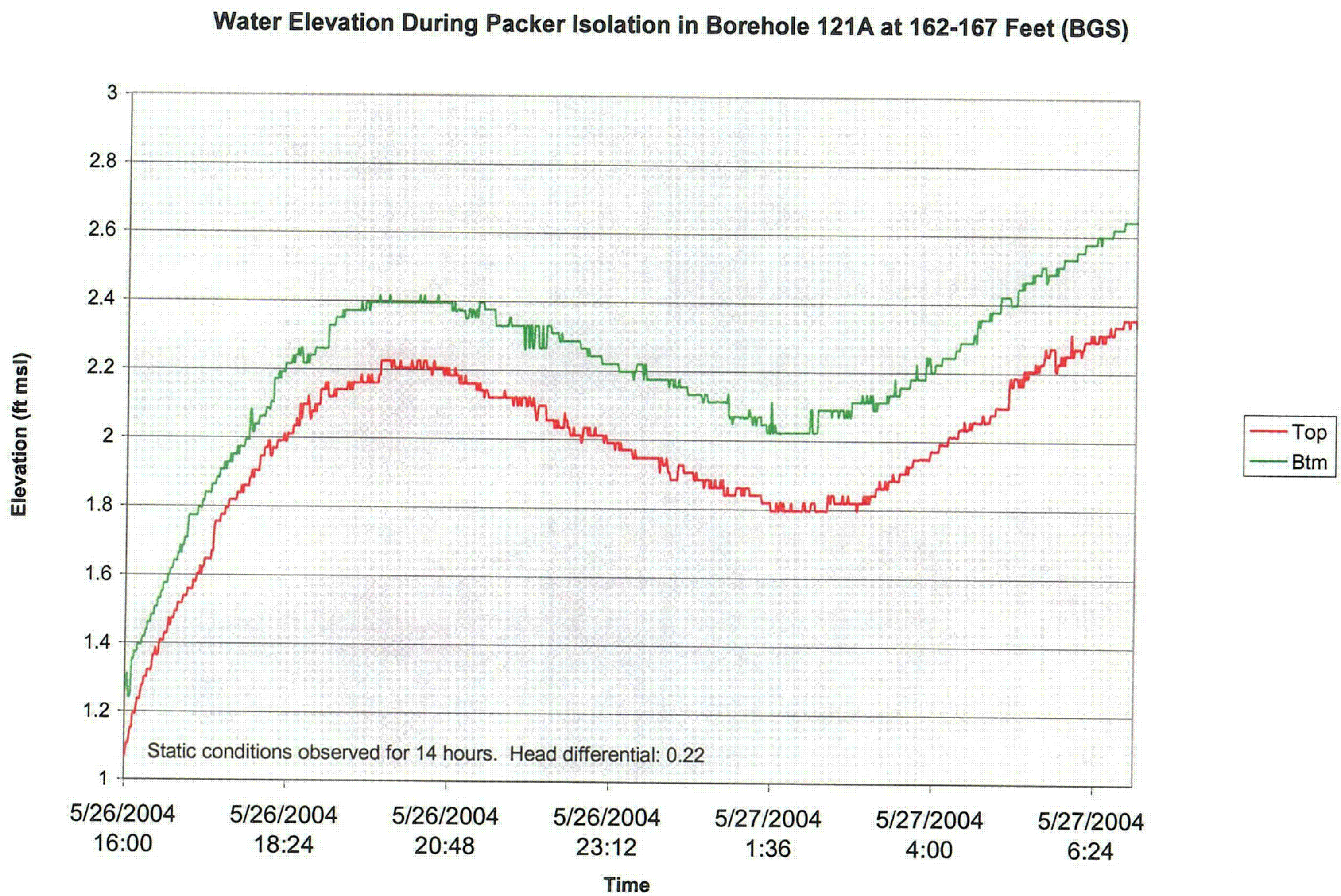
Water Elevation During Packer Isolation in Borehole 121A at 152-157 Feet (BGS)
3
2.5
2
1.5
1
0.5
Elevation (ft msl)
Top
Btm
Static conditions observed for 36 hours. Head differential: -0.38
6/4/2004 10:00
6/4/2004 16:00
6/4/2004 22:00
6/5/2004 4:00
6/5/2004 10:00
6/5/2004 16:00
6/5/2004 22:00
6/6/2004 4:00
6/6/2004 10:00
6/6/2004 16:00
6/6/2004 22:00
6/7/2004 4:00
Time

C05

Water Elevation During Packer Isolation in Borehole 121A atr 157-162 Feet (BGS)



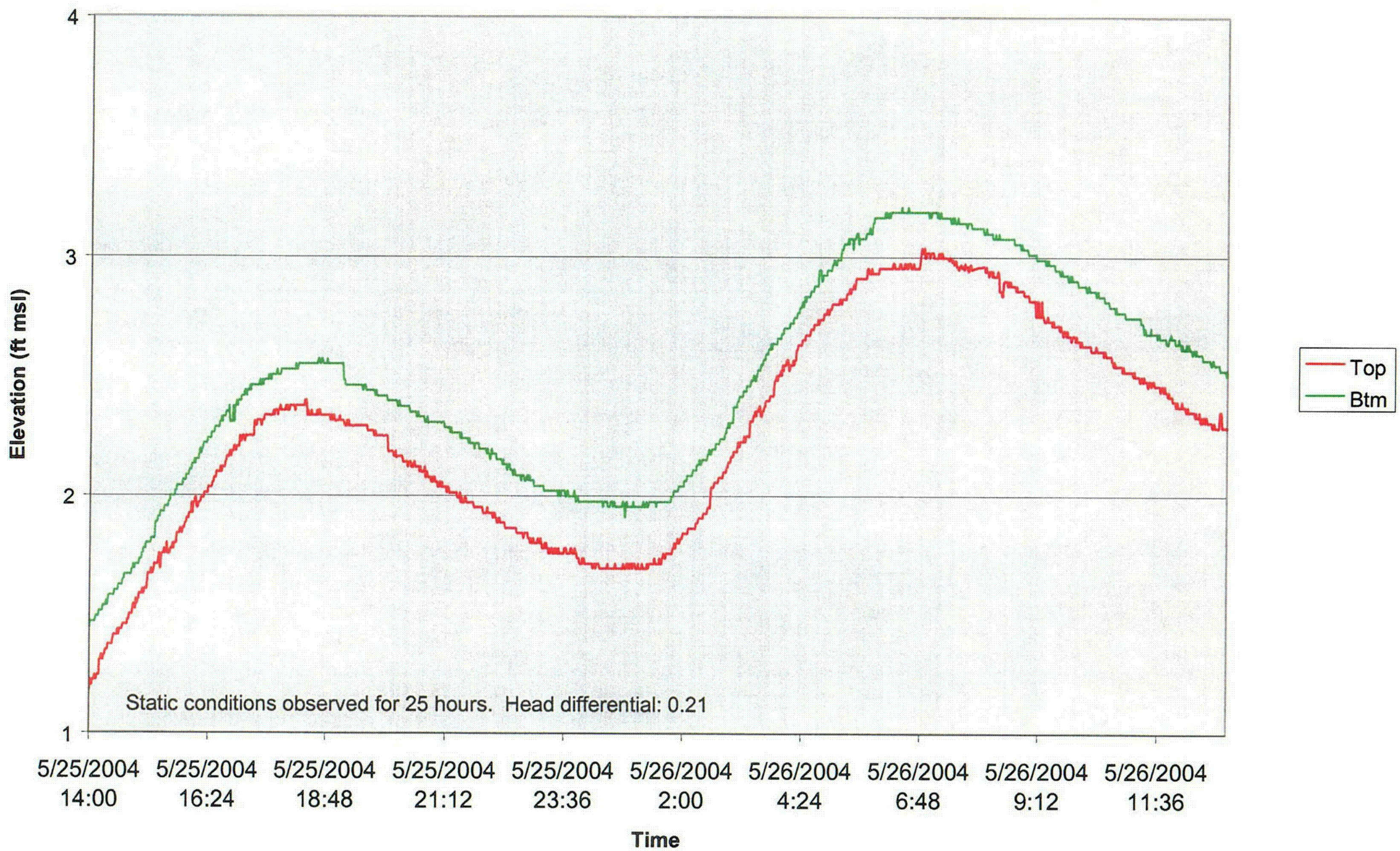
006



Water Elevation During Packer Isolation in Borehole 121A at 162-167 Feet (BGS)
Elevation (ft msl)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
Static conditions observed for 14 hours. Head differential: 0.22
5/26/2004 16:00
5/26/2004 18:24
5/26/2004 20:48
5/26/2004 23:12
5/27/2004 1:36
5/27/2004 4:00
5/27/2004 6:24
Time
Top
Btm

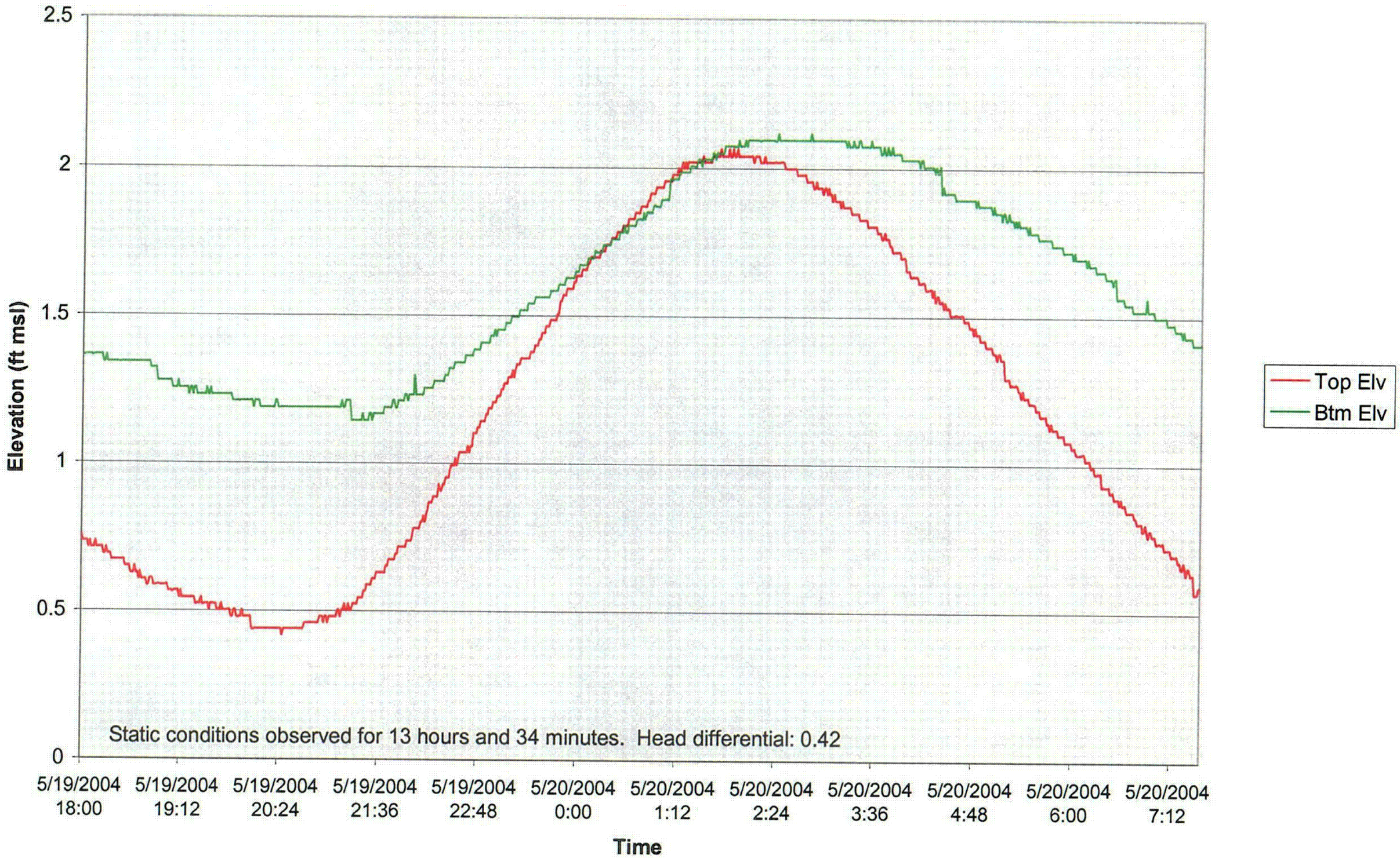
C07

Water Elevations During Packer Isolation in Borehole 121A at 168-173 Feet (BGS)



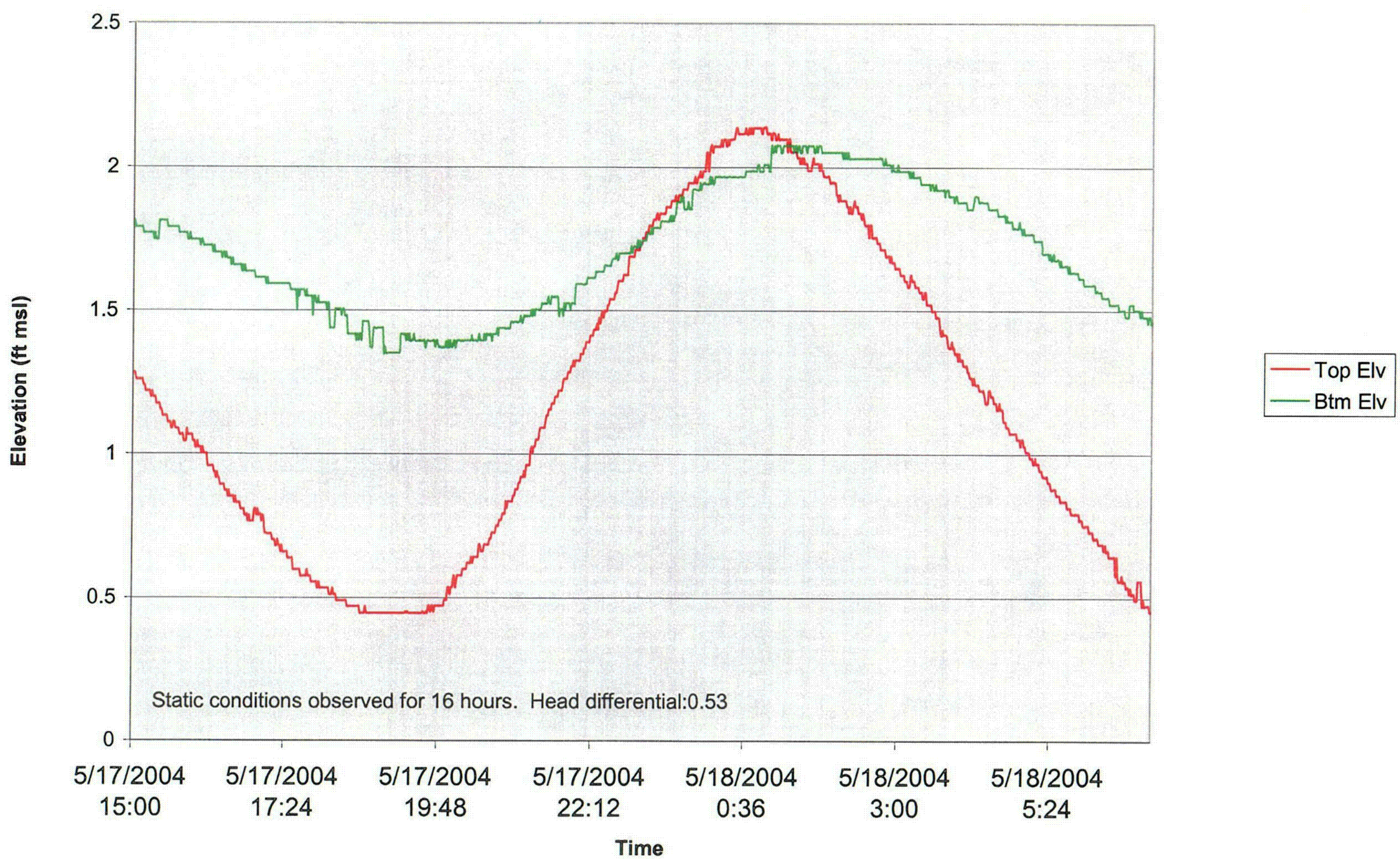
C08

Water Elevation During Packer Isolation in Borehole 121A atr 173-178 Feet (BGS)

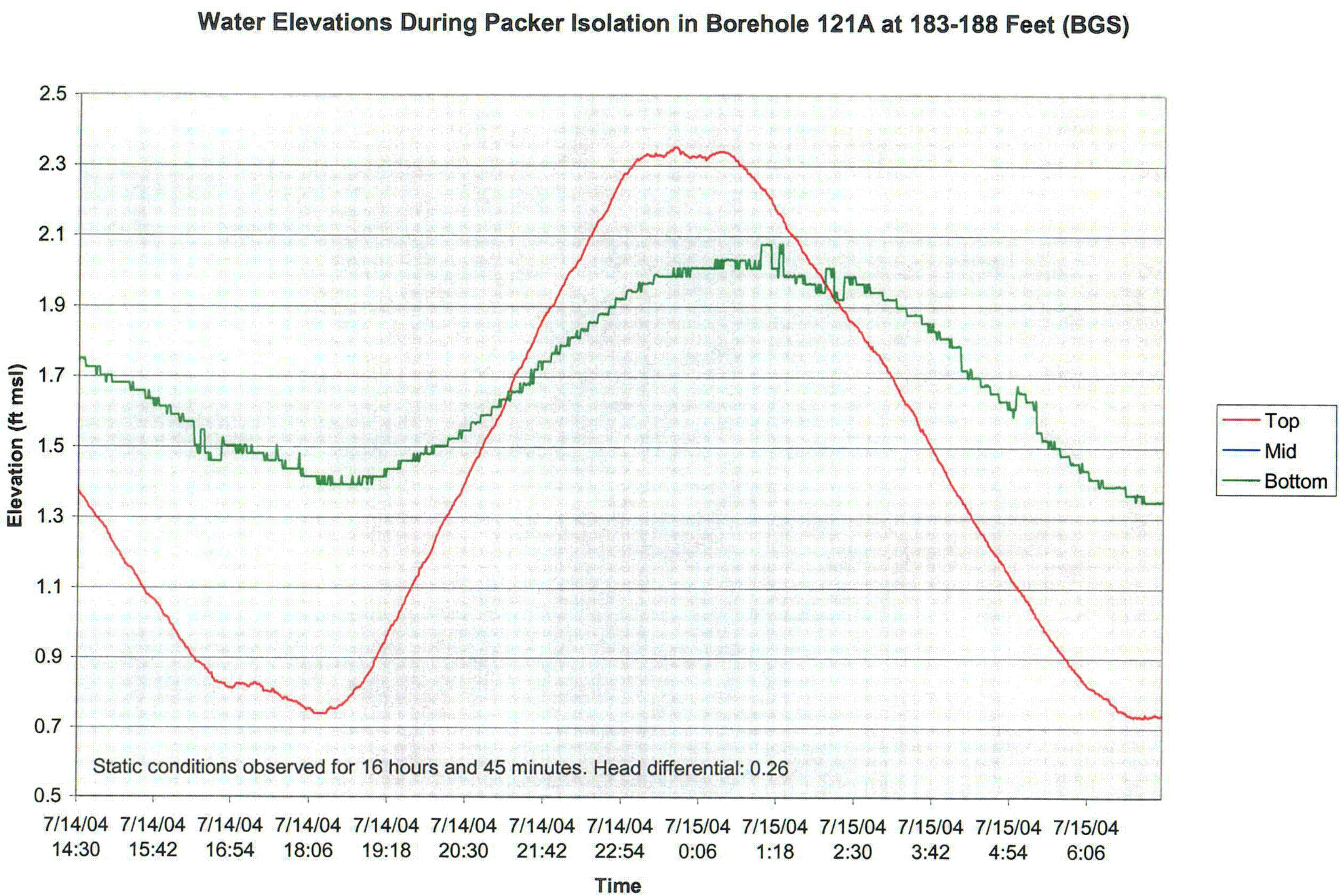


C09

Water Elevation During Packer Isolation in Borehole 121A at 178-183 Feet (BGS)



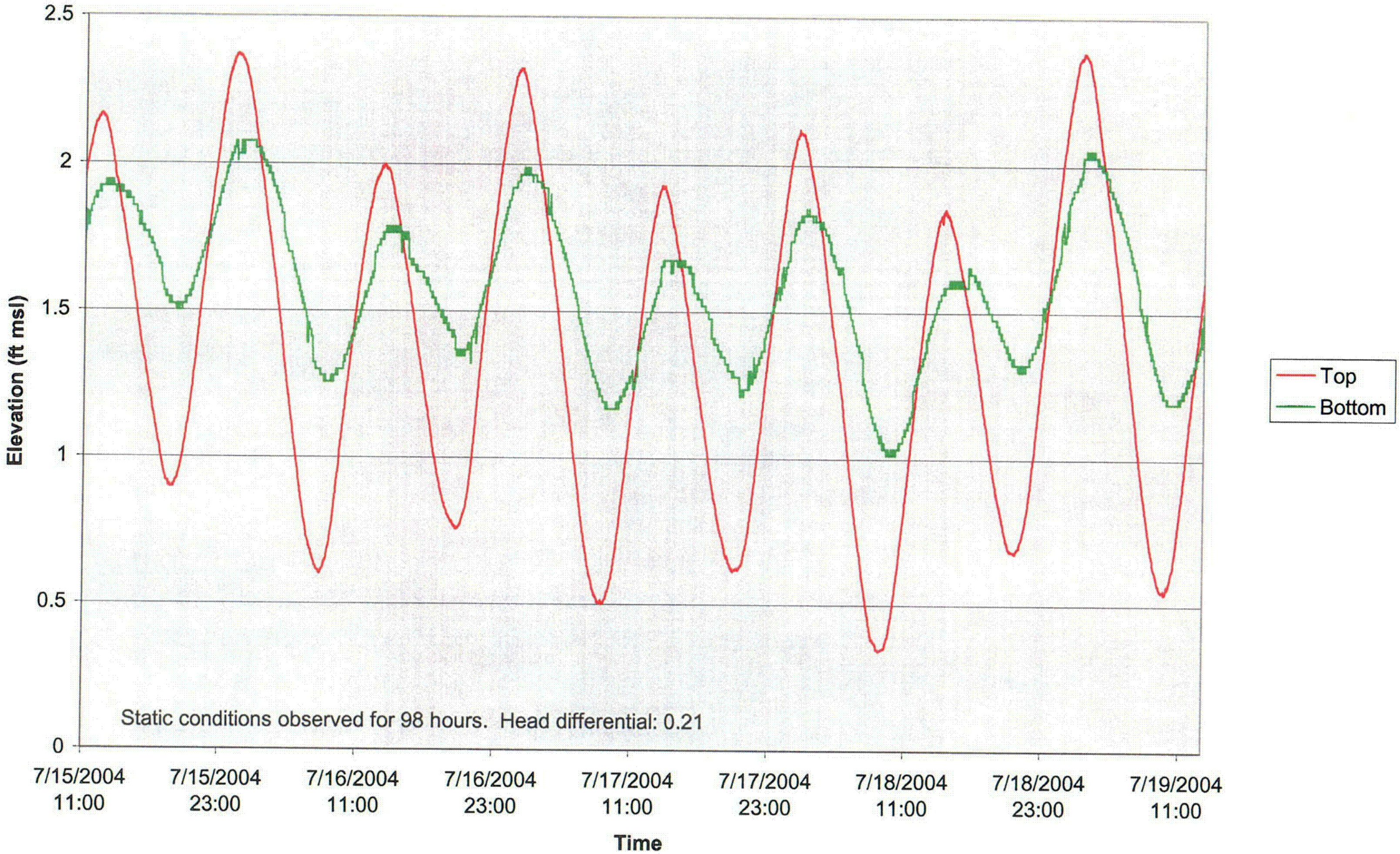
C10



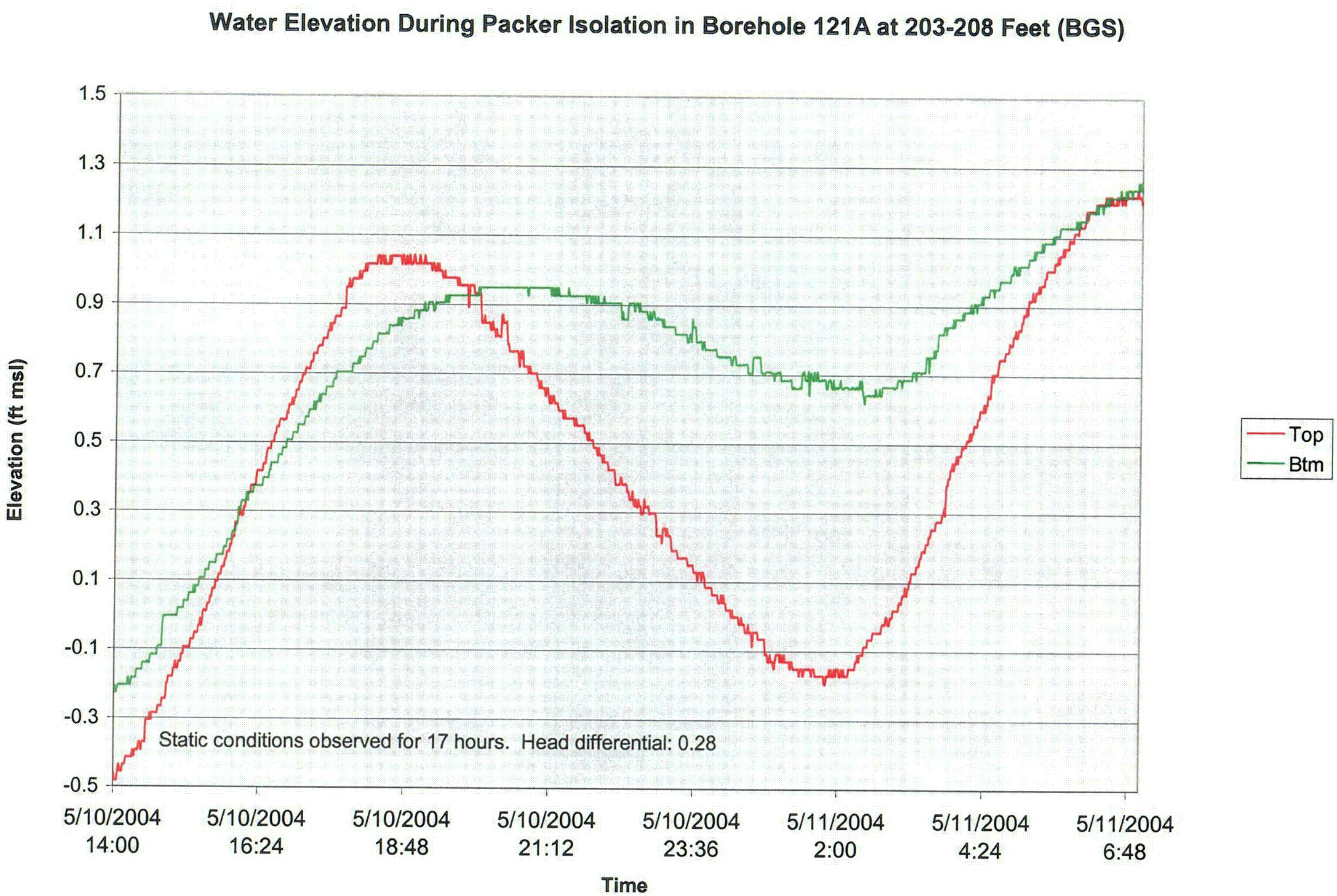
Water Elevations During Packer Isolation in Borehole 121A at 183-188 Feet (BGS)
Elevation (ft msl)
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
Static conditions observed for 16 hours and 45 minutes. Head differential: 0.26
7/14/04 14:30
7/14/04 15:42
7/14/04 16:54
7/14/04 18:06
7/14/04 19:18
7/14/04 20:30
7/14/04 21:42
7/14/04 22:54
7/15/04 0:06
7/15/04 1:18
7/15/04 2:30
7/15/04 3:42
7/15/04 4:54
7/15/04 6:06
Time
Top
Mid
Bottom

C11

Water Elevation During Packer Isolation in Borehole 121A at 188-193 Feet (BGS)

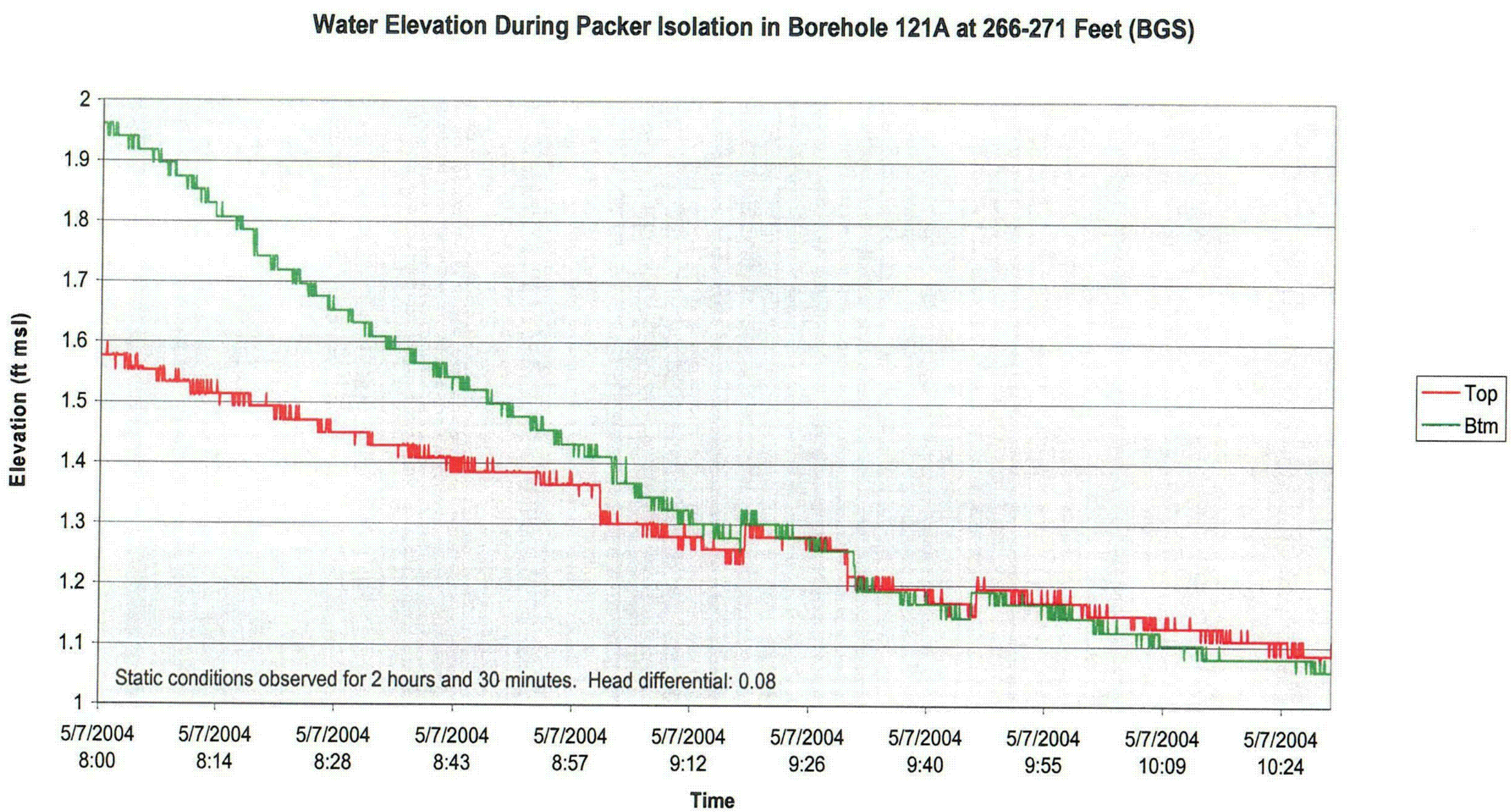


C12



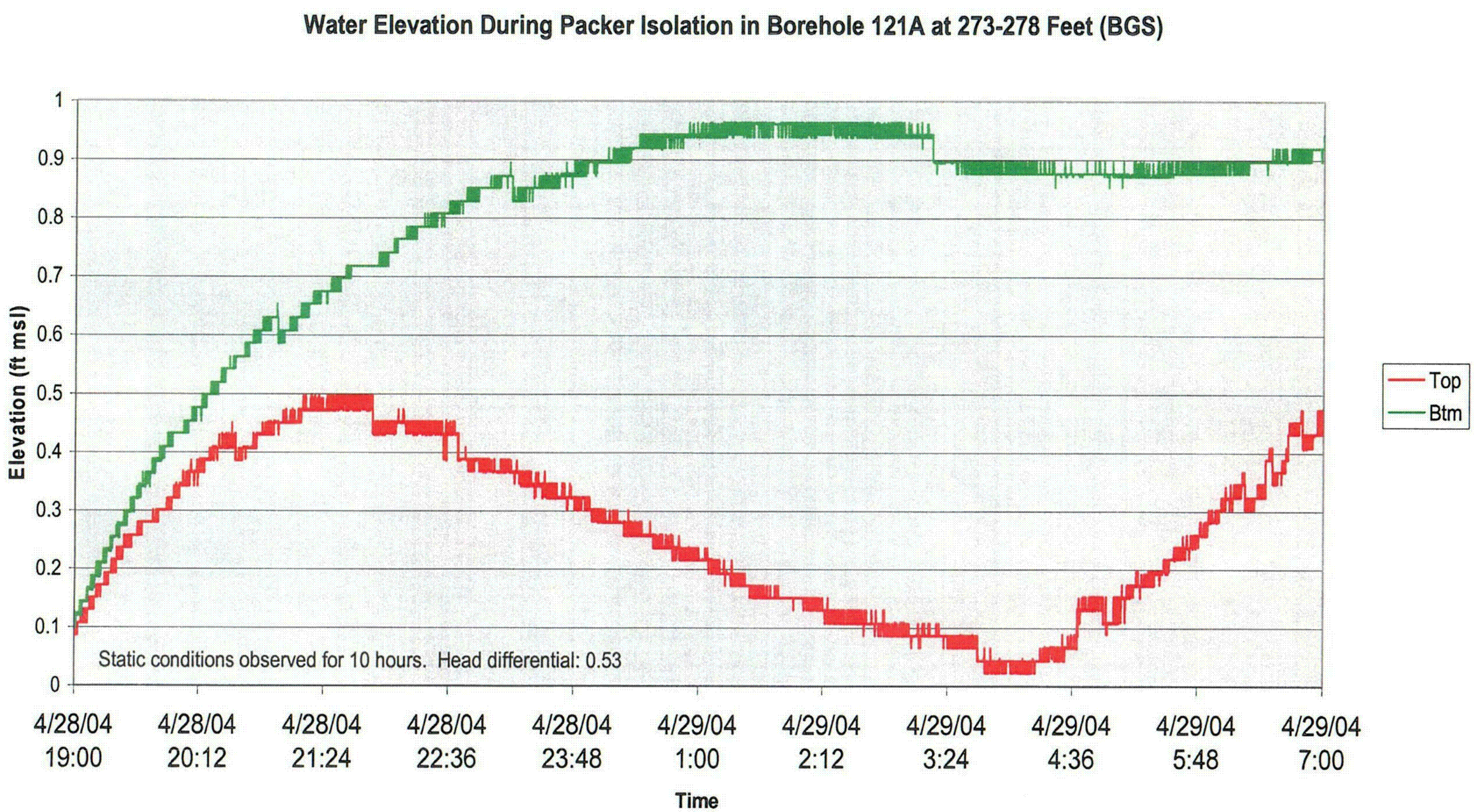
Water Elevation During Packer Isolation in Borehole 121A at 203-208 Feet (BGS)
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
Elevation (ft msl)
Static conditions observed for 17 hours. Head differential: 0.28
5/10/2004 14:00
5/10/2004 16:24
5/10/2004 18:48
5/10/2004 21:12
5/10/2004 23:36
5/11/2004 2:00
5/11/2004 4:24
5/11/2004 6:48
Time
Top
Btm

C13



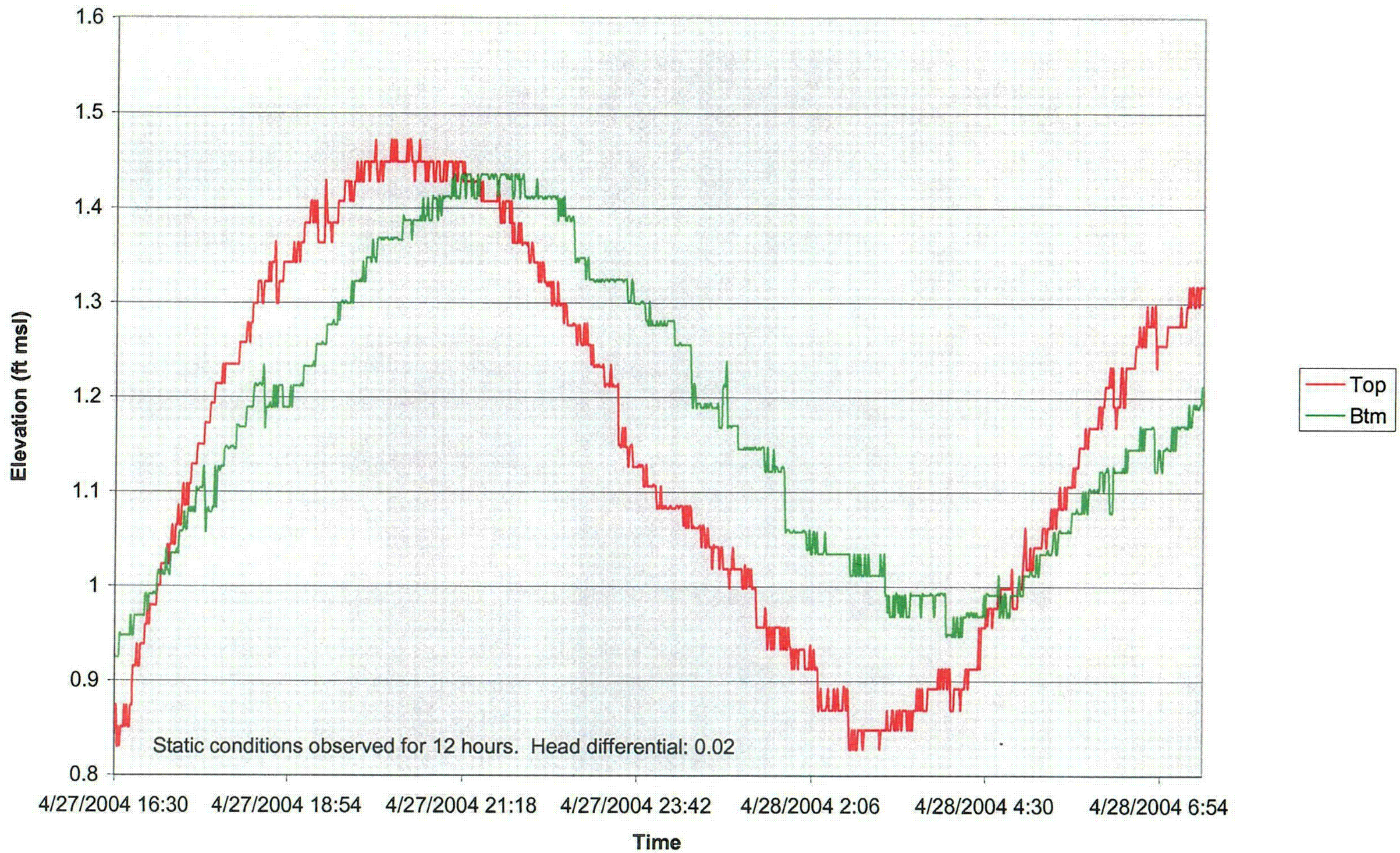
Water Elevation During Packer Isolation in Borehole 121A at 266-271 Feet (BGS)
Elevation (ft msl)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
Static conditions observed for 2 hours and 30 minutes. Head differential: 0.08
5/7/2004 8:00
5/7/2004 8:14
5/7/2004 8:28
5/7/2004 8:43
5/7/2004 8:57
5/7/2004 9:12
5/7/2004 9:26
5/7/2004 9:40
5/7/2004 9:55
5/7/2004 10:09
5/7/2004 10:24
Time
Top
Btm

C14


Water Elevation During Packer Isolation in Borehole 121A at 273-278 Feet (BGS)
Elevation (ft msl)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Static conditions observed for 10 hours. Head differential: 0.53
4/28/04 19:00
4/28/04 20:12
4/28/04 21:24
4/28/04 22:36
4/28/04 23:48
4/29/04 1:00
4/29/04 2:12
4/29/04 3:24
4/29/04 4:36
4/29/04 5:48
4/29/04 7:00
Time
Top
Btm

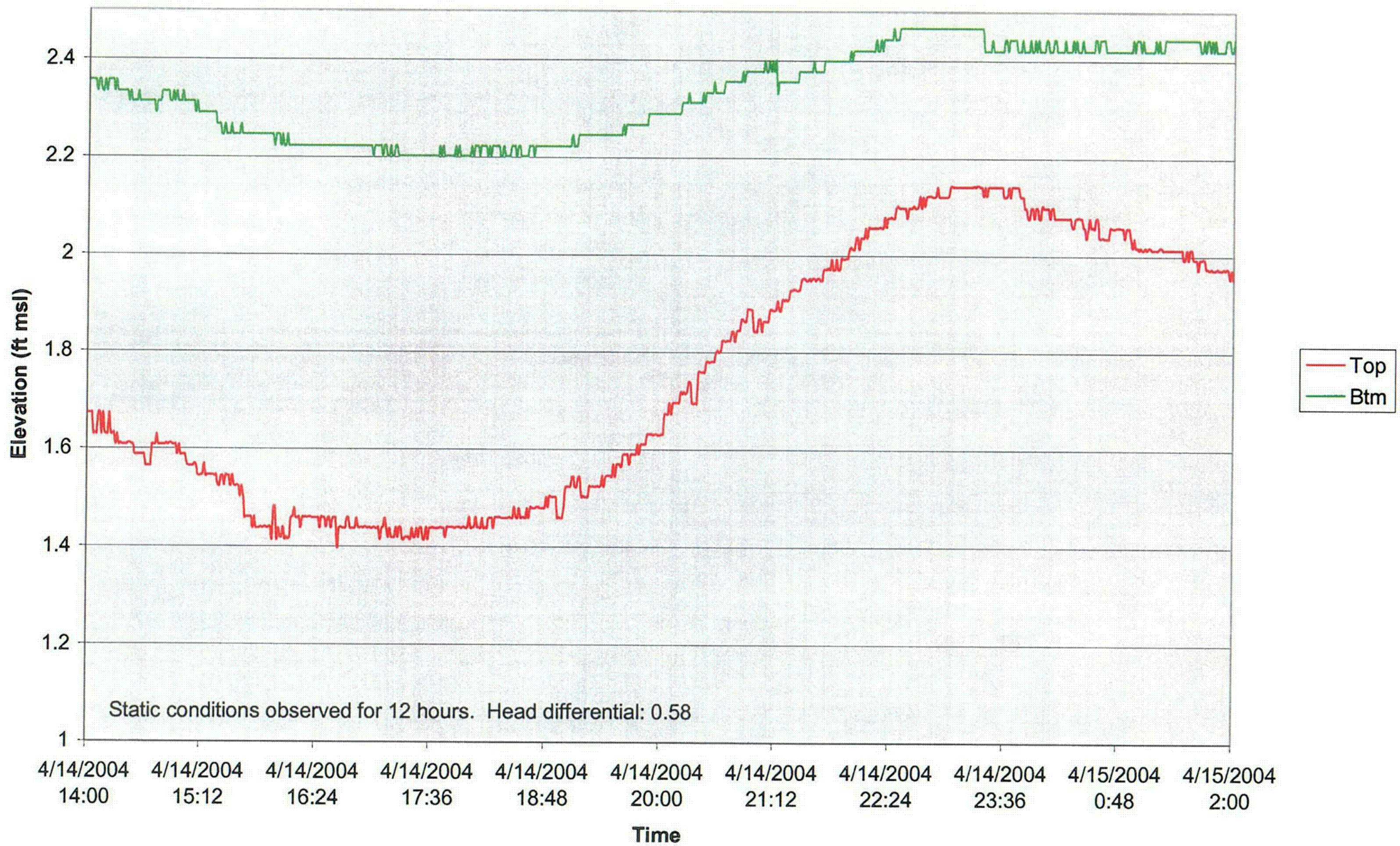
C15

Water Elevation During Packer Isolation in Borehole 121A at 297-302 Feet (BGS)

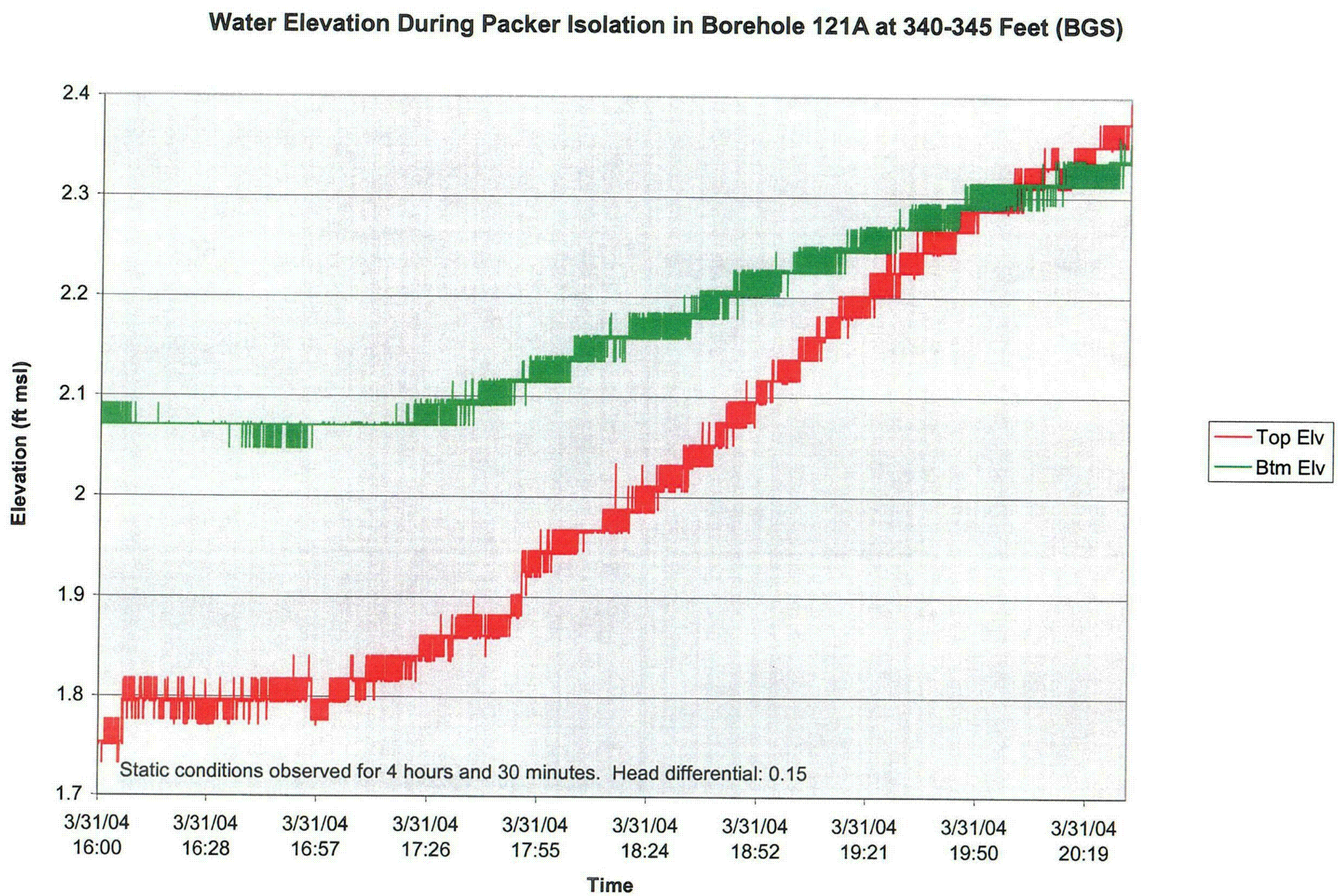


C16

Water Elevation During Packer Isolation in Borehole 121A at 317-322 Feet (BGS)

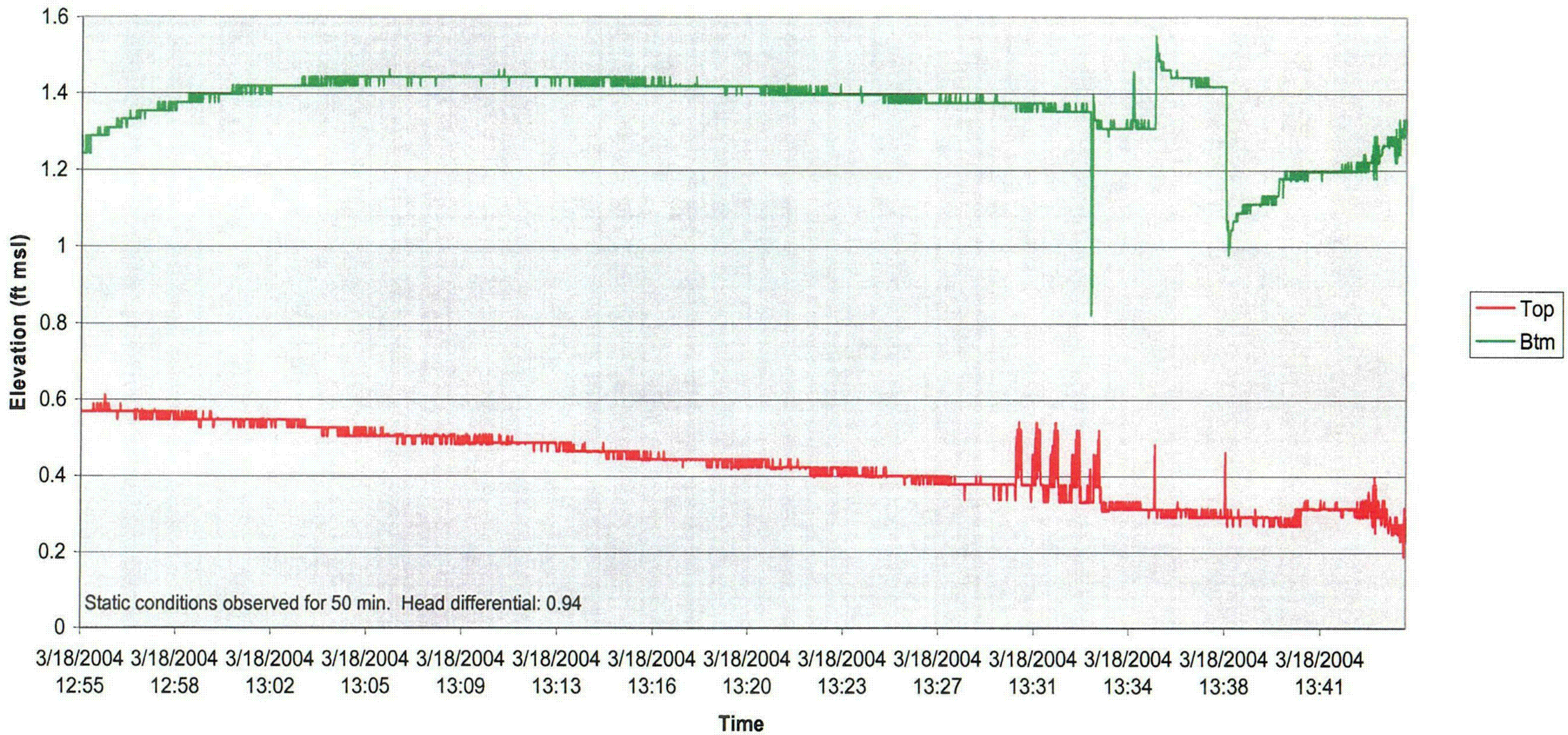


C17


Water Elevation During Packer Isolation in Borehole 121A at 340-345 Feet (BGS)
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
Elevation (ft msl)
Static conditions observed for 4 hours and 30 minutes. Head differential: 0.15
3/31/04 16:00
3/31/04 16:28
3/31/04 16:57
3/31/04 17:26
3/31/04 17:55
3/31/04 18:24
3/31/04 18:52
3/31/04 19:21
3/31/04 19:50
3/31/04 20:19
Time
Top Elv
Btm Elv

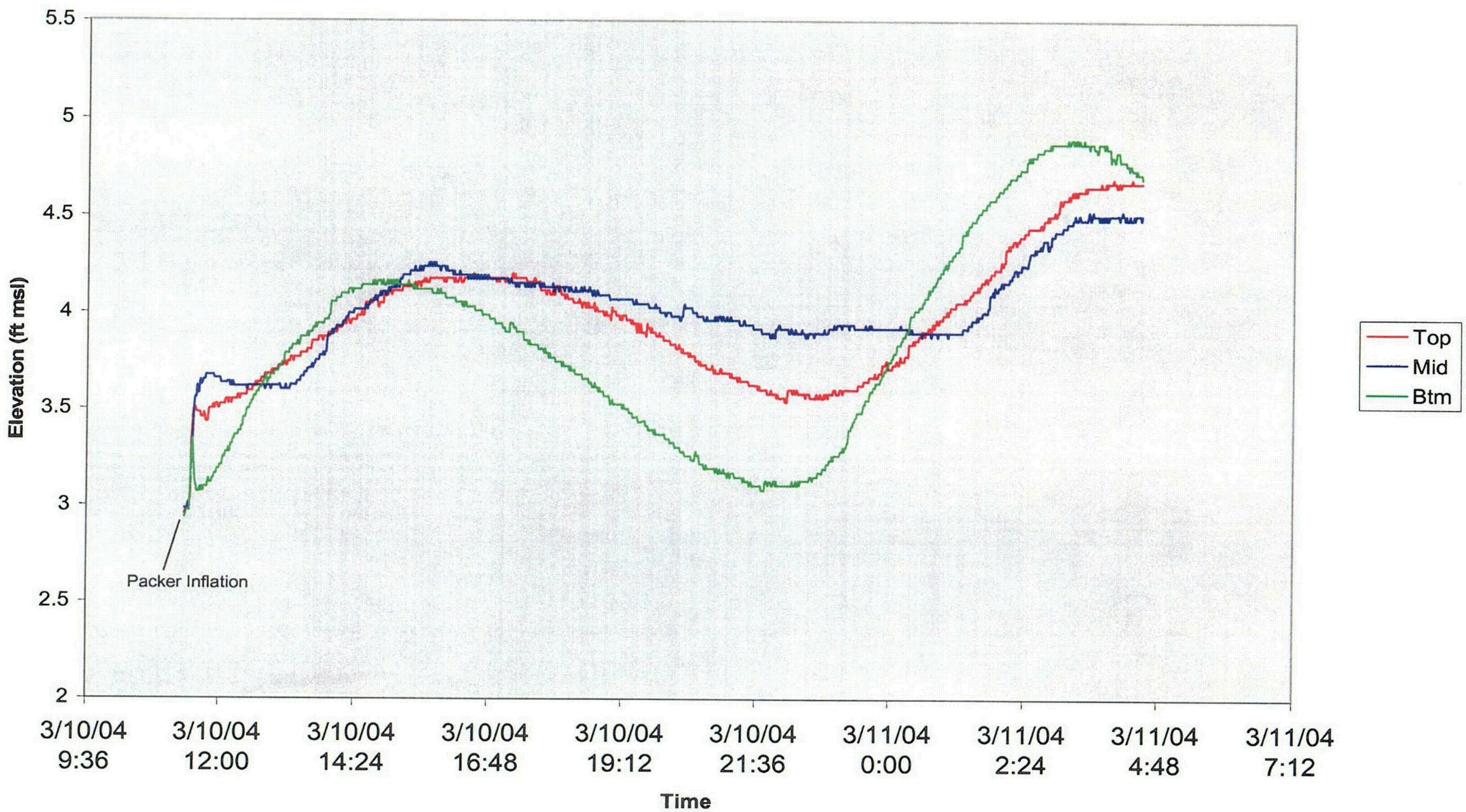
C18

Water Elevations During Packer Isolation in Borehole 121A at 466 - 471 Feet (BGS)



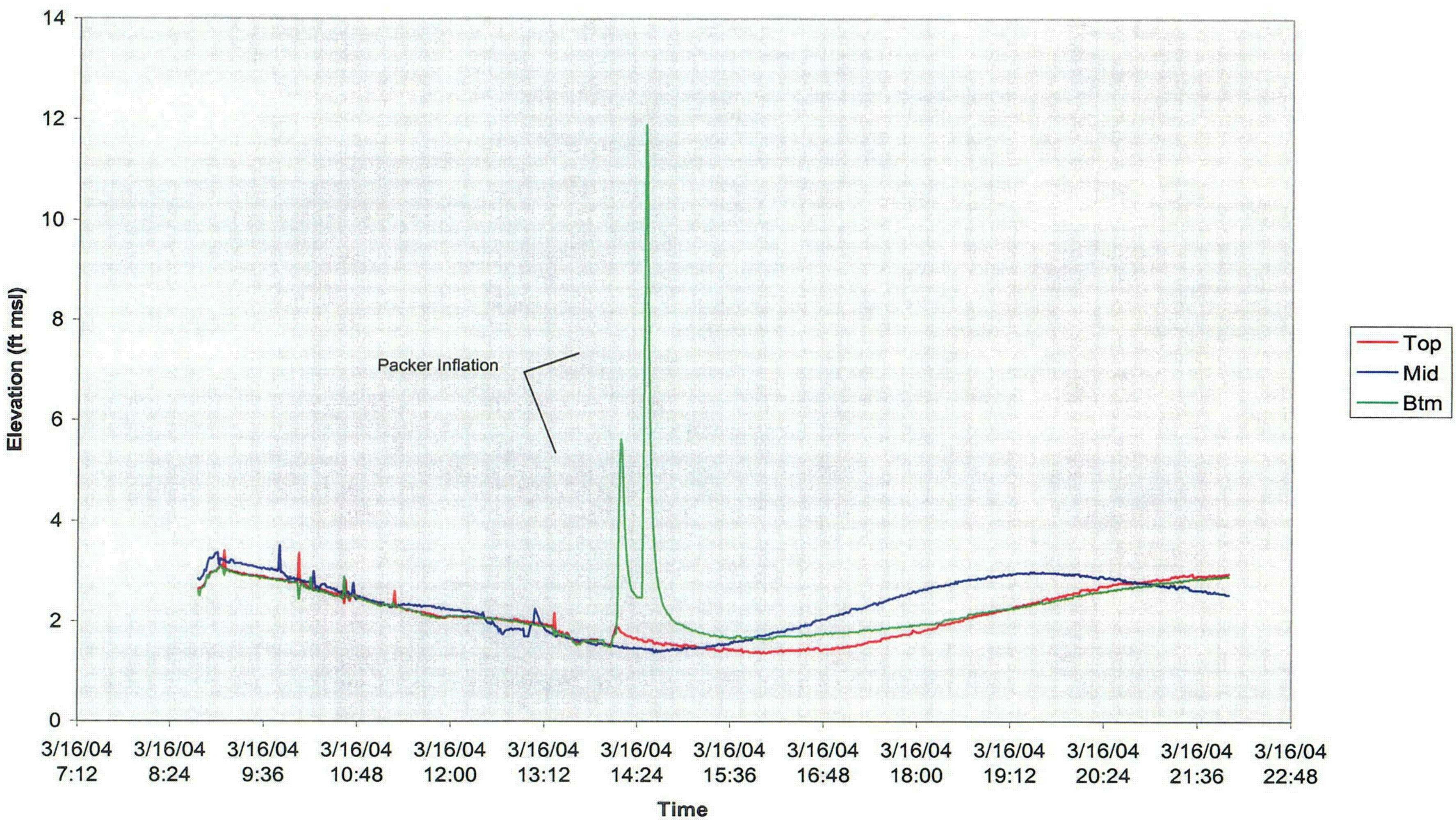
C19

Water Elevation During Packer Isolation in Borehole 121A at 150-155 Feet (BGS)

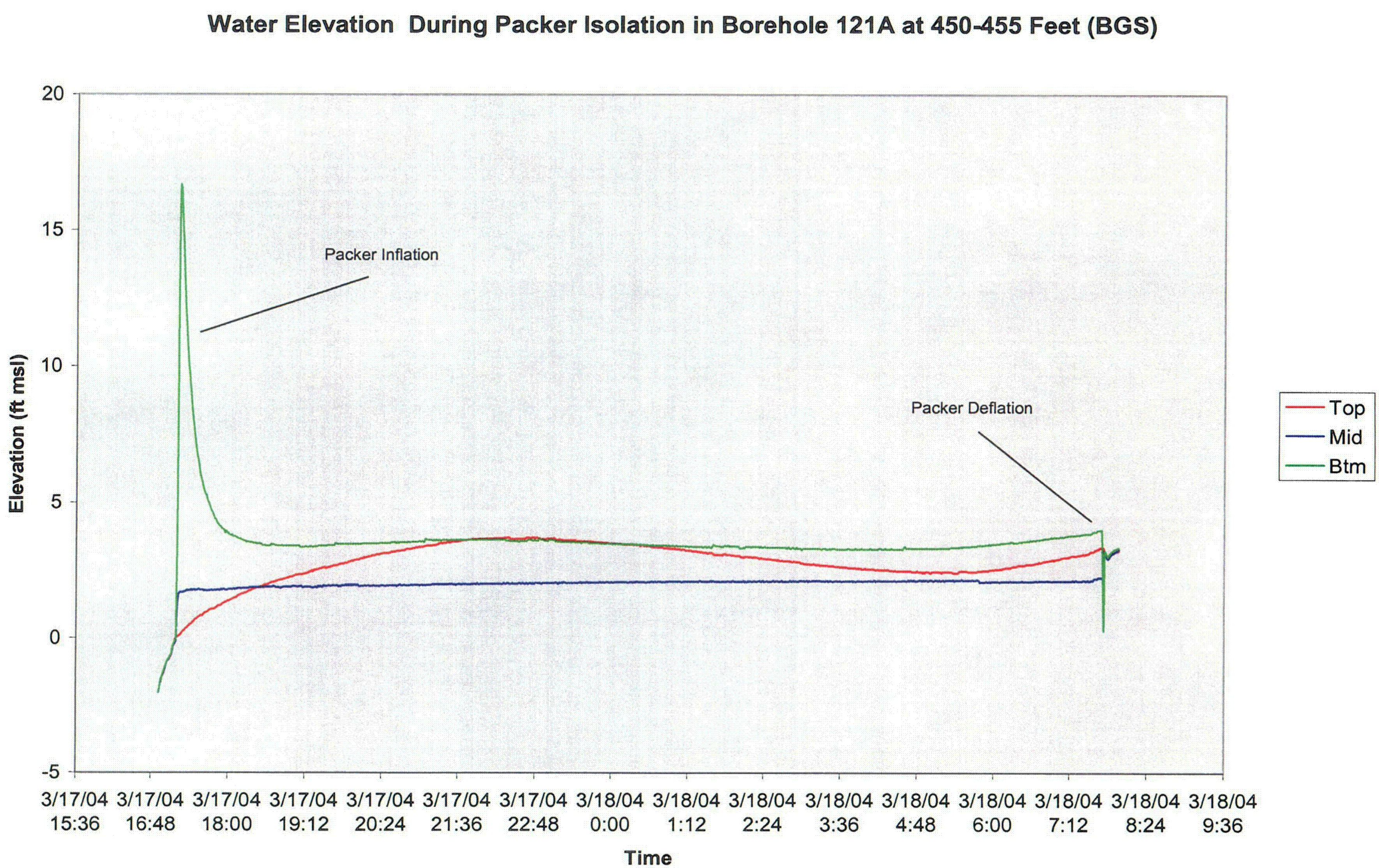


C20

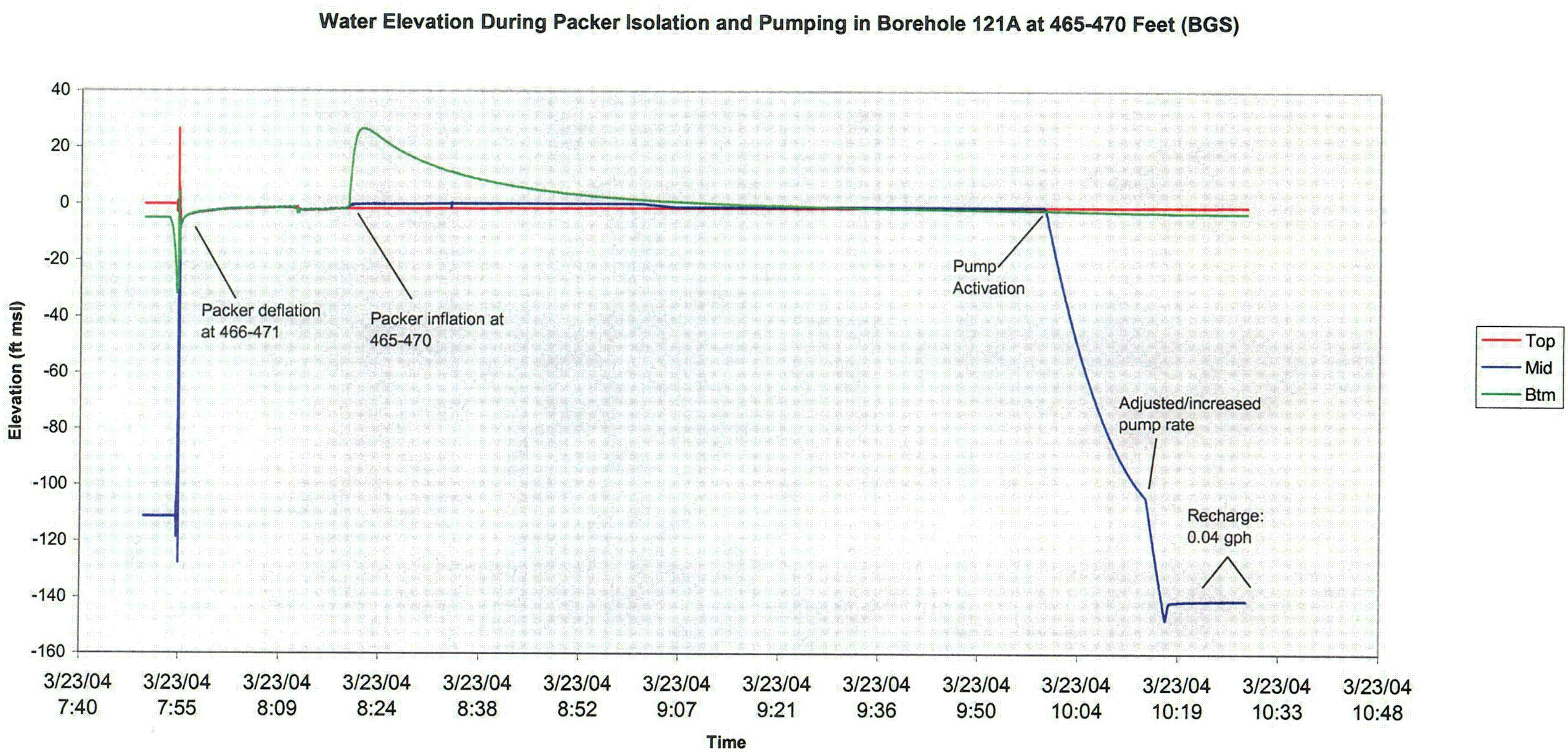
Water Elevation During Packer Isolation in Borehole 121A at 300-305 Feet (BGS)



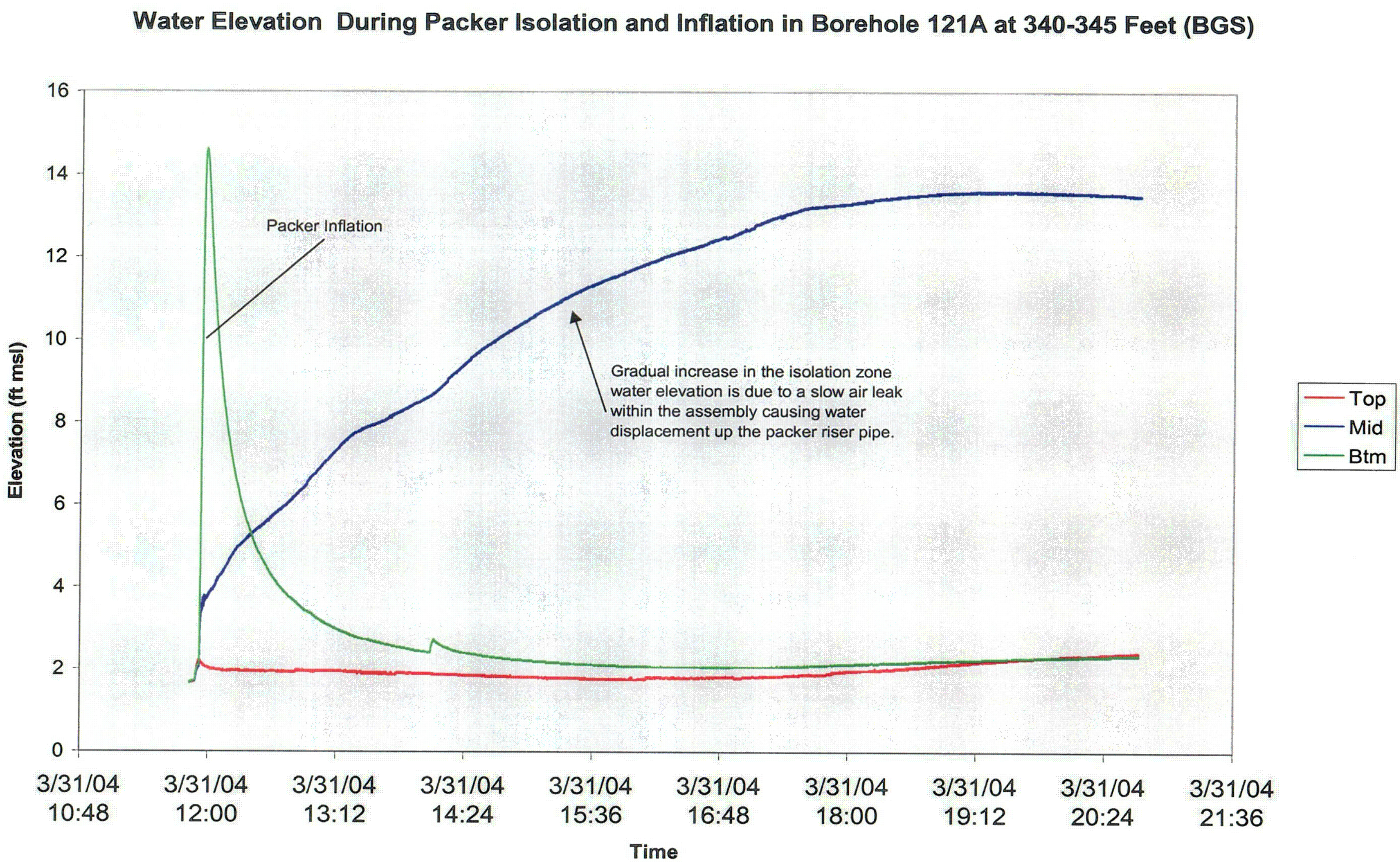
C21


Water Elevation During Packer Isolation in Borehole 121A at 450-455 Feet (BGS)
Elevation (ft msl)
20
15
10
5
0
-5
Packer Inflation
Packer Deflation
Top
Mid
Btm
3/17/04 15:36
3/17/04 16:48
3/17/04 18:00
3/17/04 19:12
3/17/04 20:24
3/17/04 21:36
3/17/04 22:48
3/18/04 0:00
3/18/04 1:12
3/18/04 2:24
3/18/04 3:36
3/18/04 4:48
3/18/04 6:00
3/18/04 7:12
3/18/04 8:24
3/18/04 9:36
Time

C22


Water Elevation During Packer Isolation and Pumping in Borehole 121A at 465-470 Feet (BGS)
Elevation (ft msl)
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
Packer deflation at 466-471
Packer inflation at 465-470
Pump Activation
Adjusted/increased pump rate
Recharge: 0.04 gph
3/23/04 7:40
3/23/04 7:55
3/23/04 8:09
3/23/04 8:24
3/23/04 8:38
3/23/04 8:52
3/23/04 9:07
3/23/04 9:21
3/23/04 9:36
3/23/04 9:50
3/23/04 10:04
3/23/04 10:19
3/23/04 10:33
3/23/04 10:48
Time
Top
Mid
Btm

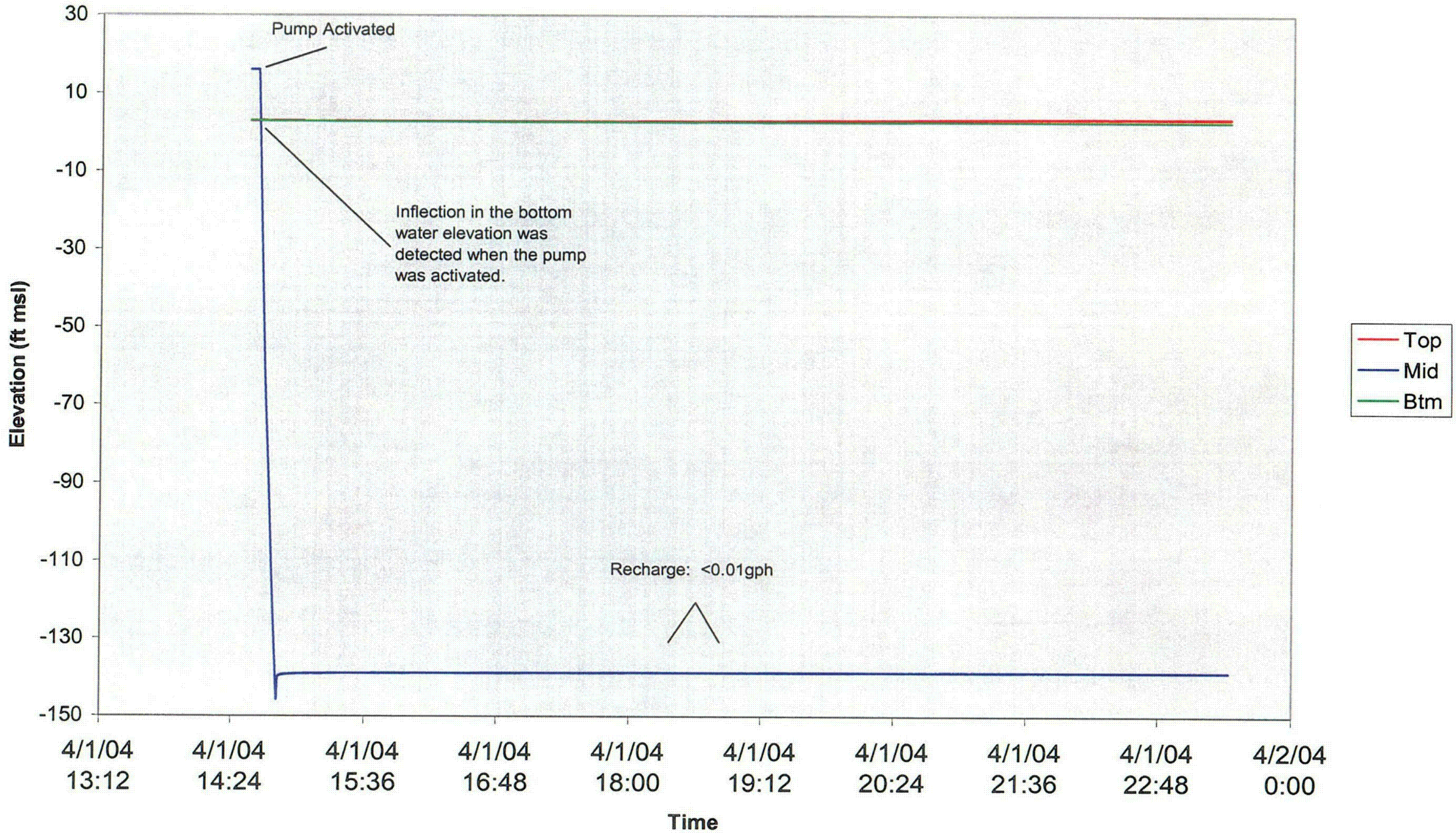
C23



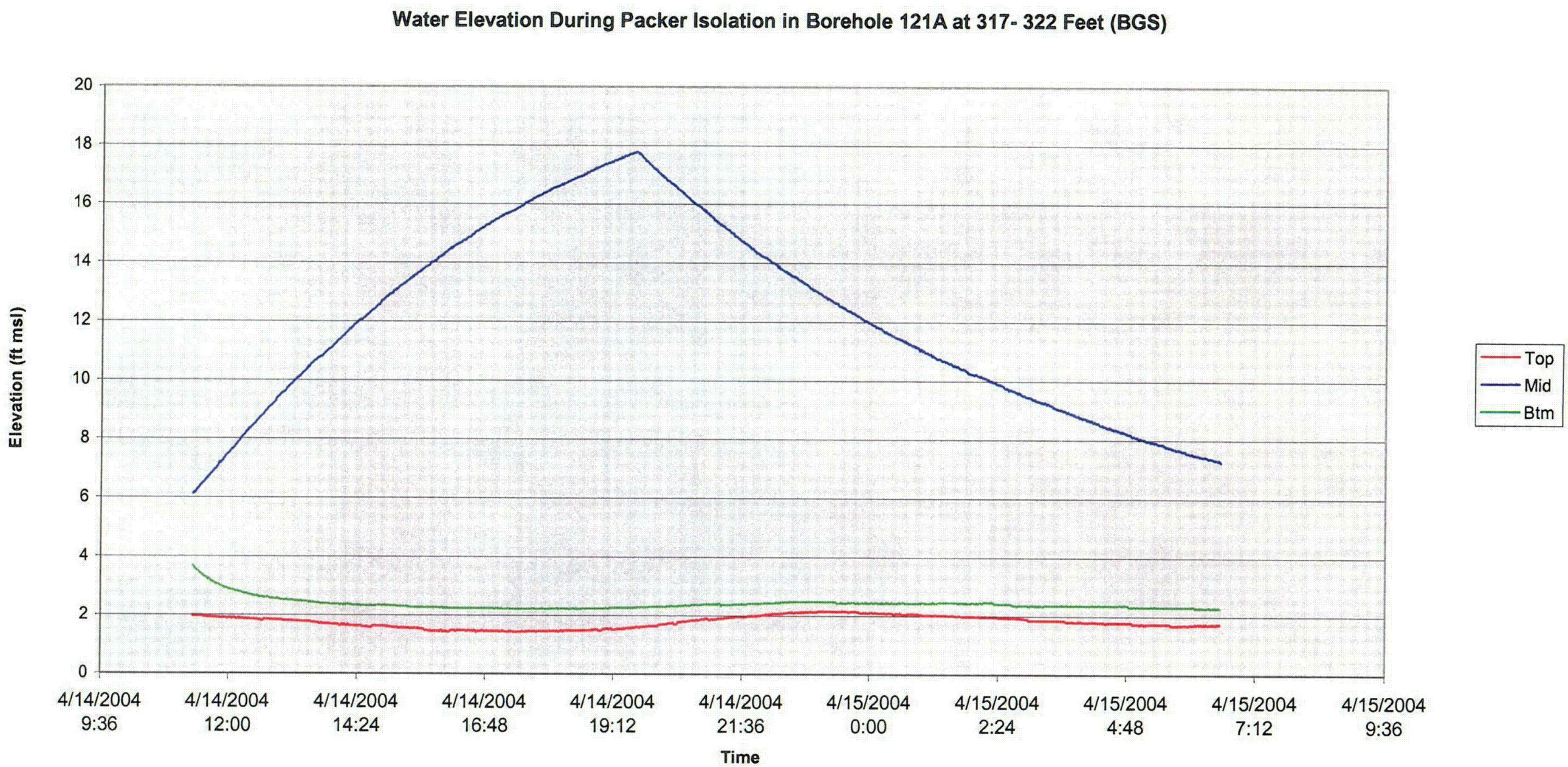
Water Elevation During Packer Isolation and Inflation in Borehole 121A at 340-345 Feet (BGS)
Elevation (ft msl)
16
14
12
10
8
6
4
2
0
Packer Inflation
Gradual increase in the isolation zone water elevation is due to a slow air leak within the assembly causing water displacement up the packer riser pipe.
3/31/04 10:48
3/31/04 12:00
3/31/04 13:12
3/31/04 14:24
3/31/04 15:36
3/31/04 16:48
3/31/04 18:00
3/31/04 19:12
3/31/04 20:24
3/31/04 21:36
Time
Top
Mid
Btm

C24

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 340-345 Feet (BGS)

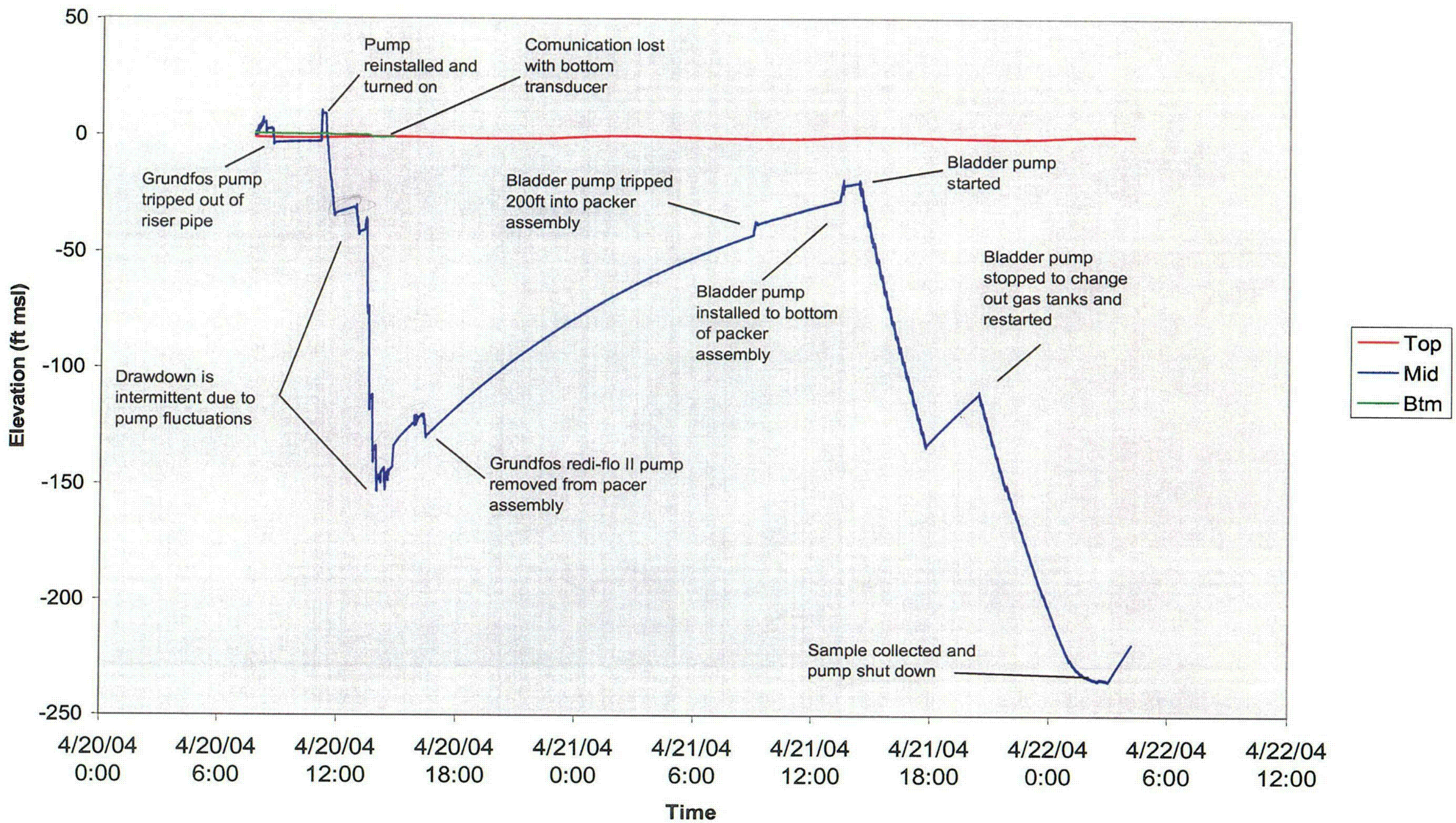


C25


Water Elevation During Packer Isolation in Borehole 121A at 317- 322 Feet (BGS)
Elevation (ft msl)
20
18
16
14
12
10
8
6
4
2
0
4/14/2004 9:36
4/14/2004 12:00
4/14/2004 14:24
4/14/2004 16:48
4/14/2004 19:12
4/14/2004 21:36
4/15/2004 0:00
4/15/2004 2:24
4/15/2004 4:48
4/15/2004 7:12
4/15/2004 9:36
Time
Top
Mid
Btm

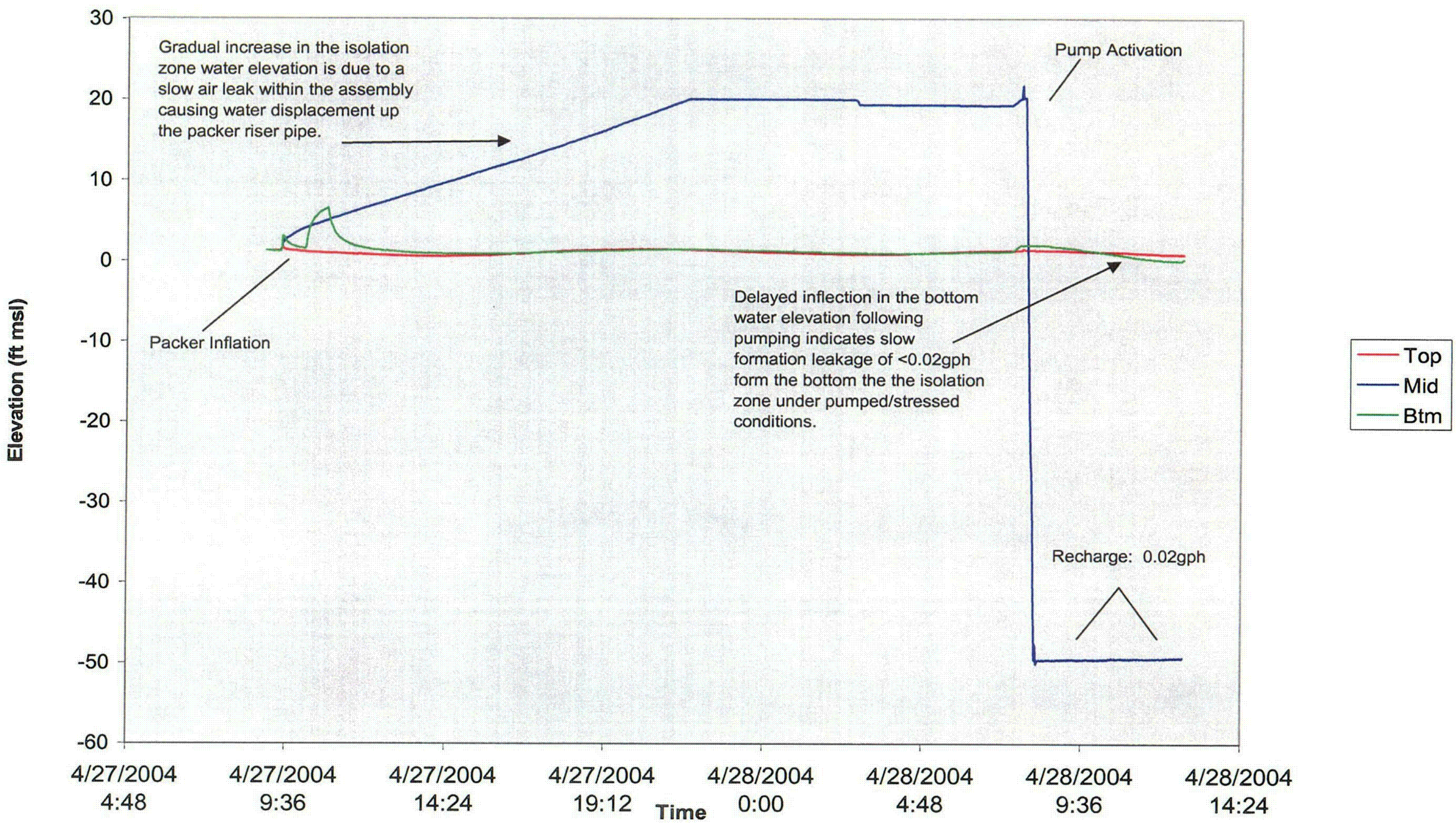
C26

Water Elevation During Packer Isolation and Pumping at 317-322 Feet (BGS)



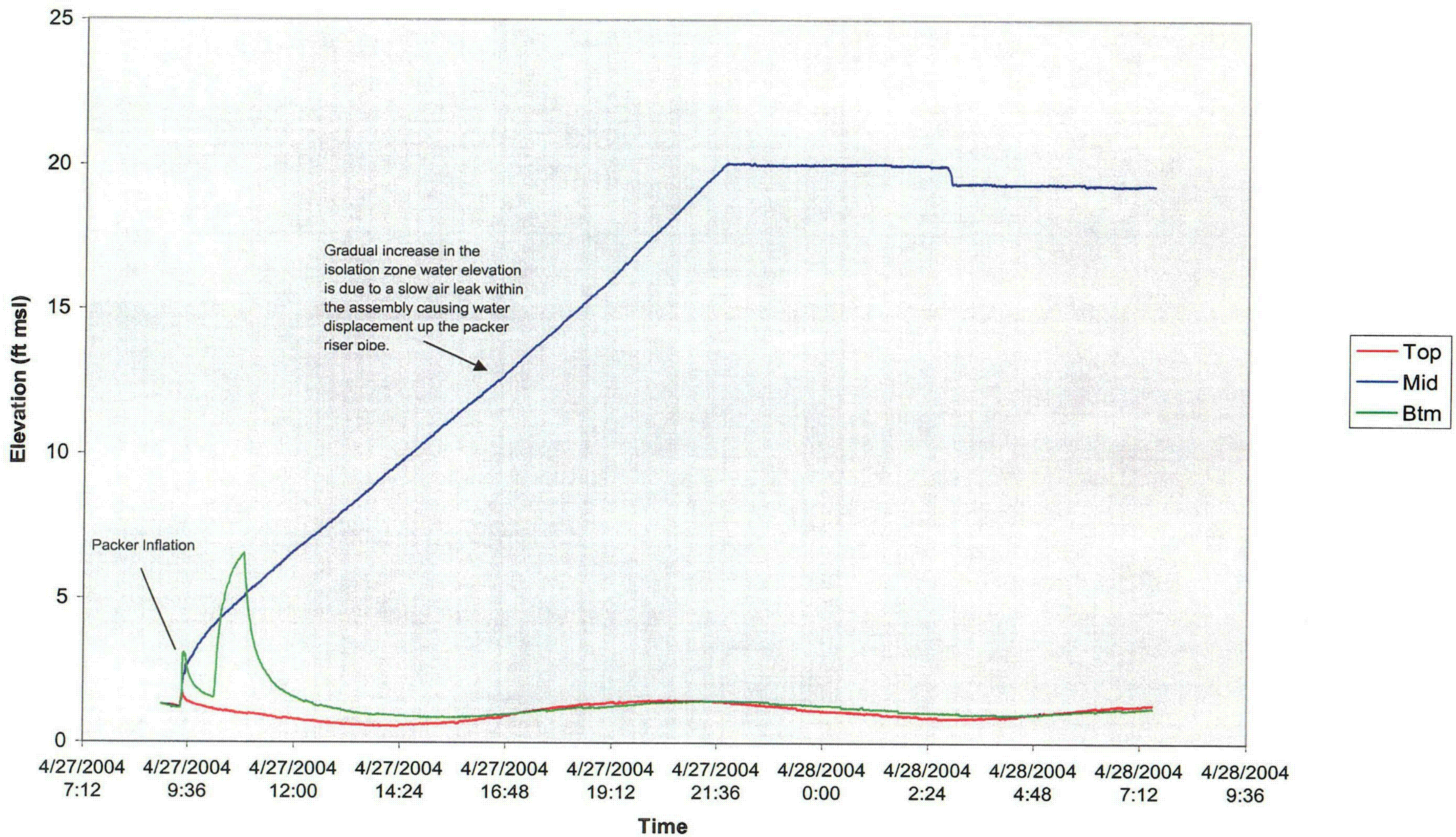
C27

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 297.5-302.5 Feet (BGS)



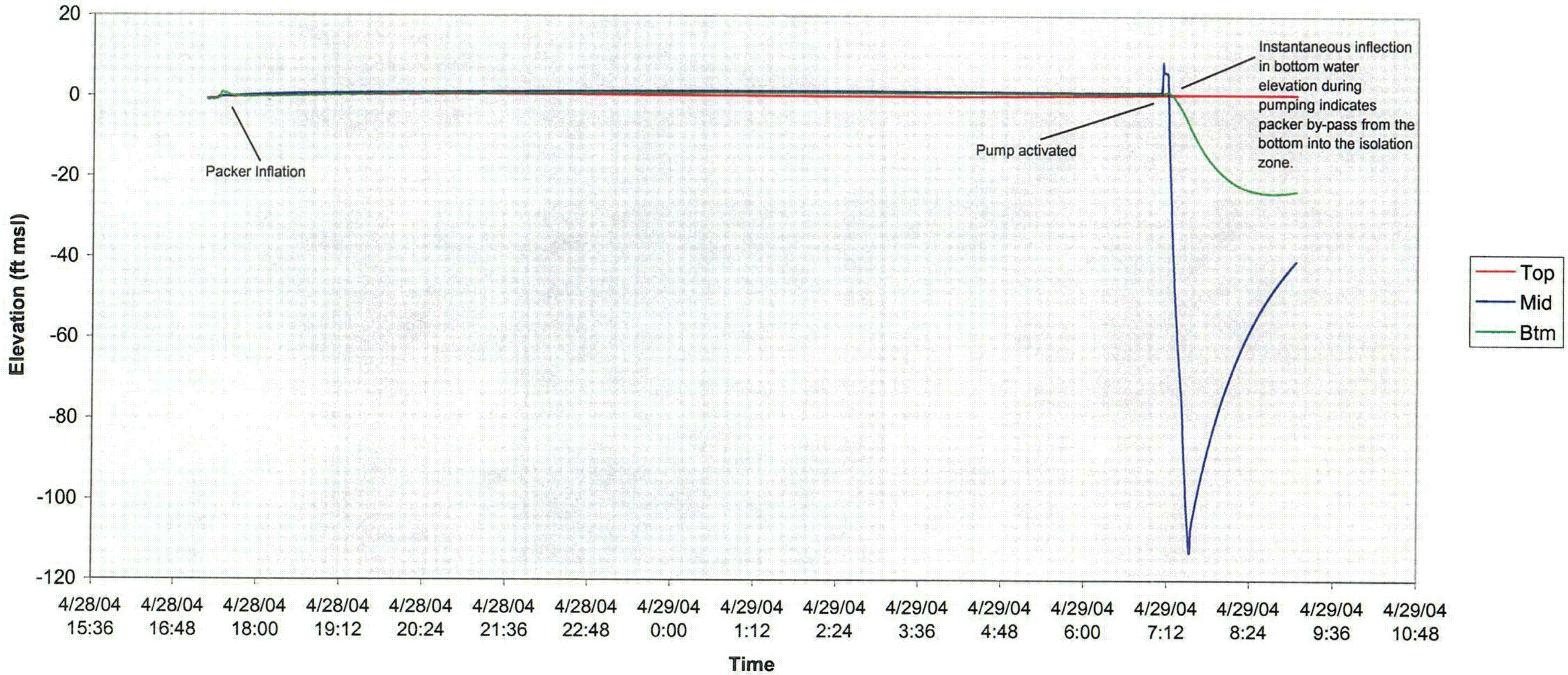
C28

Water Elevation During Packer Isolation in Borehole 121A at 297.5-302.5 Feet (BGS)

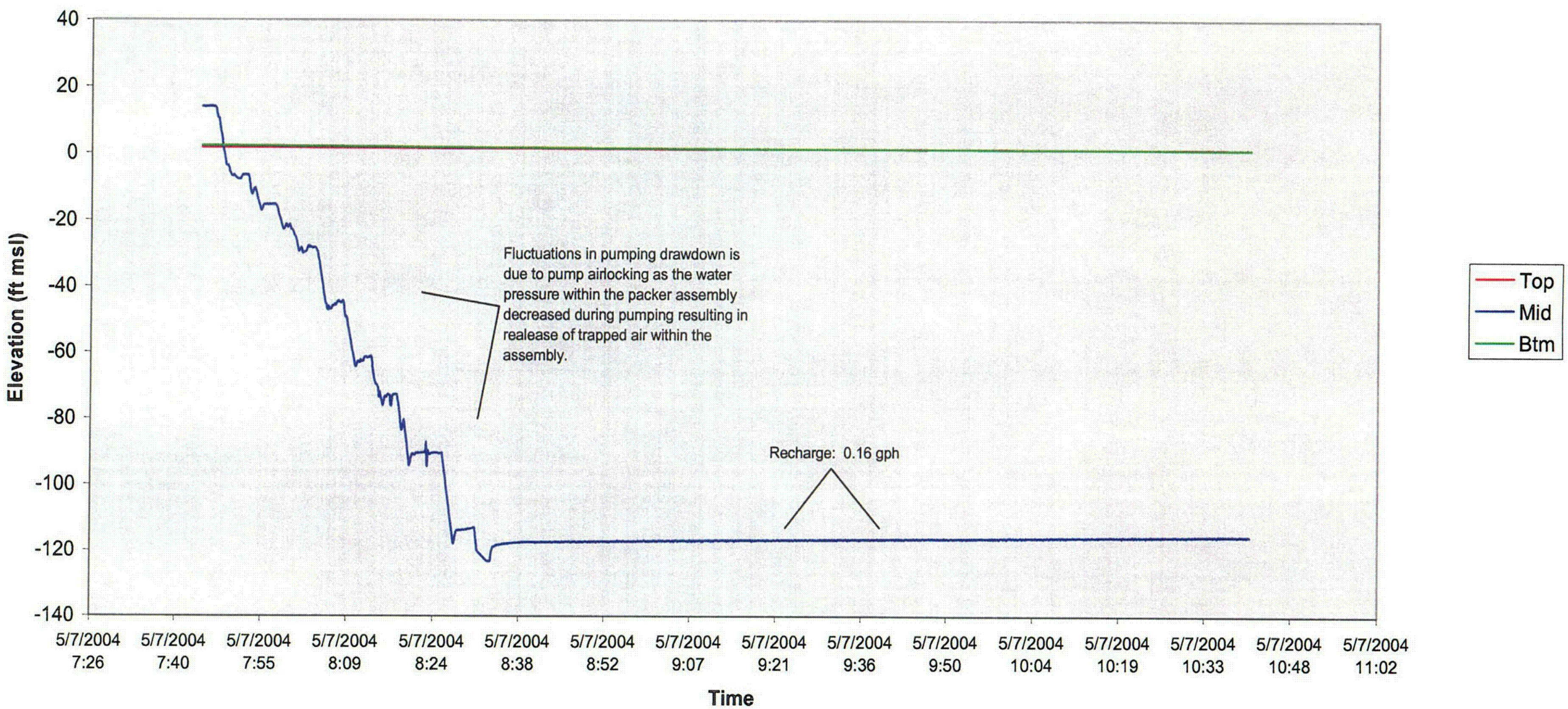


C29

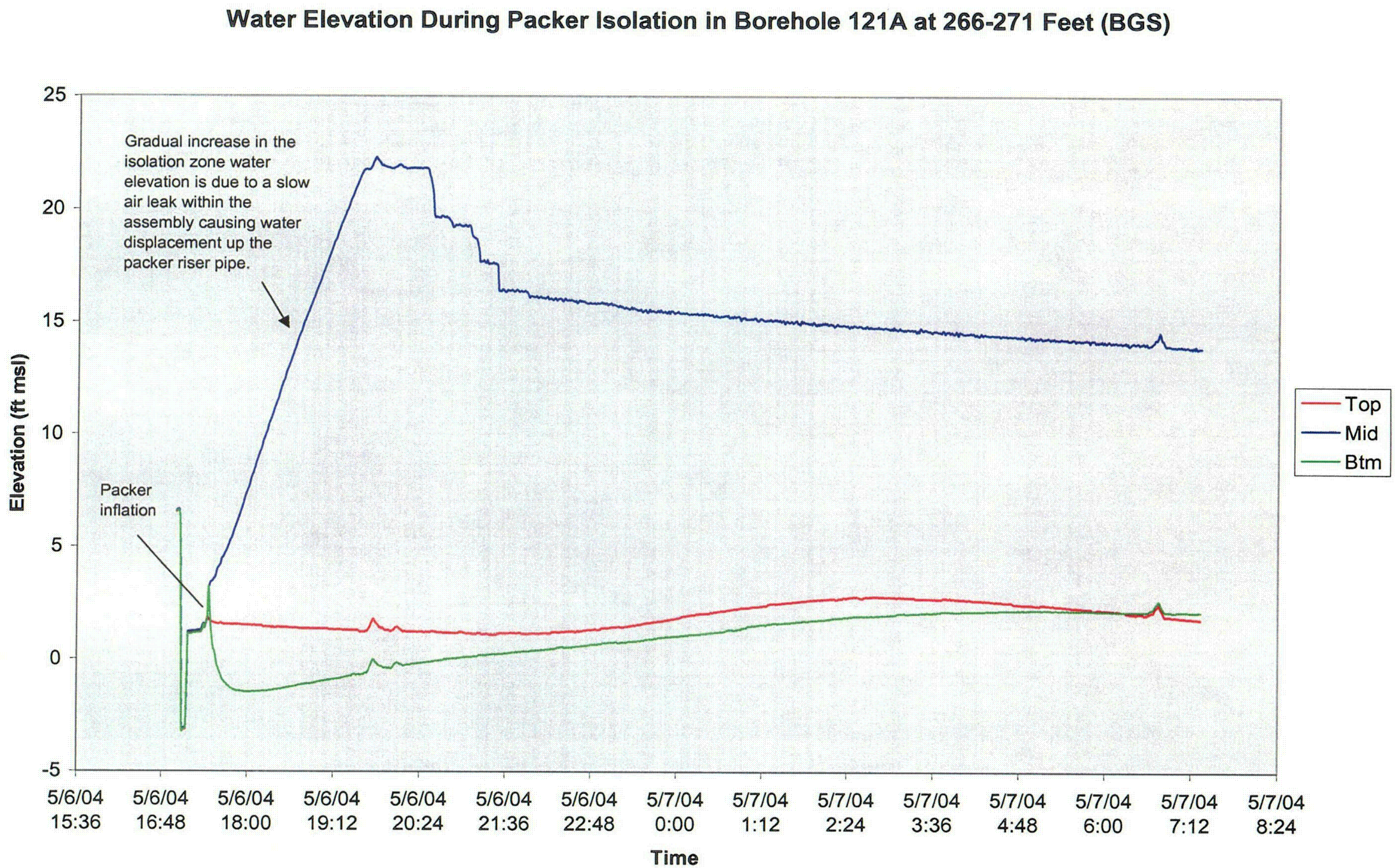
Water Elevation During Packer Isolation and Pumping in Borehole 121A at 273-278 Feet (BGS)



Water Elevation During Packer Isolation and Pumping in Borehole 121A at 266-271 Feet (BGS)

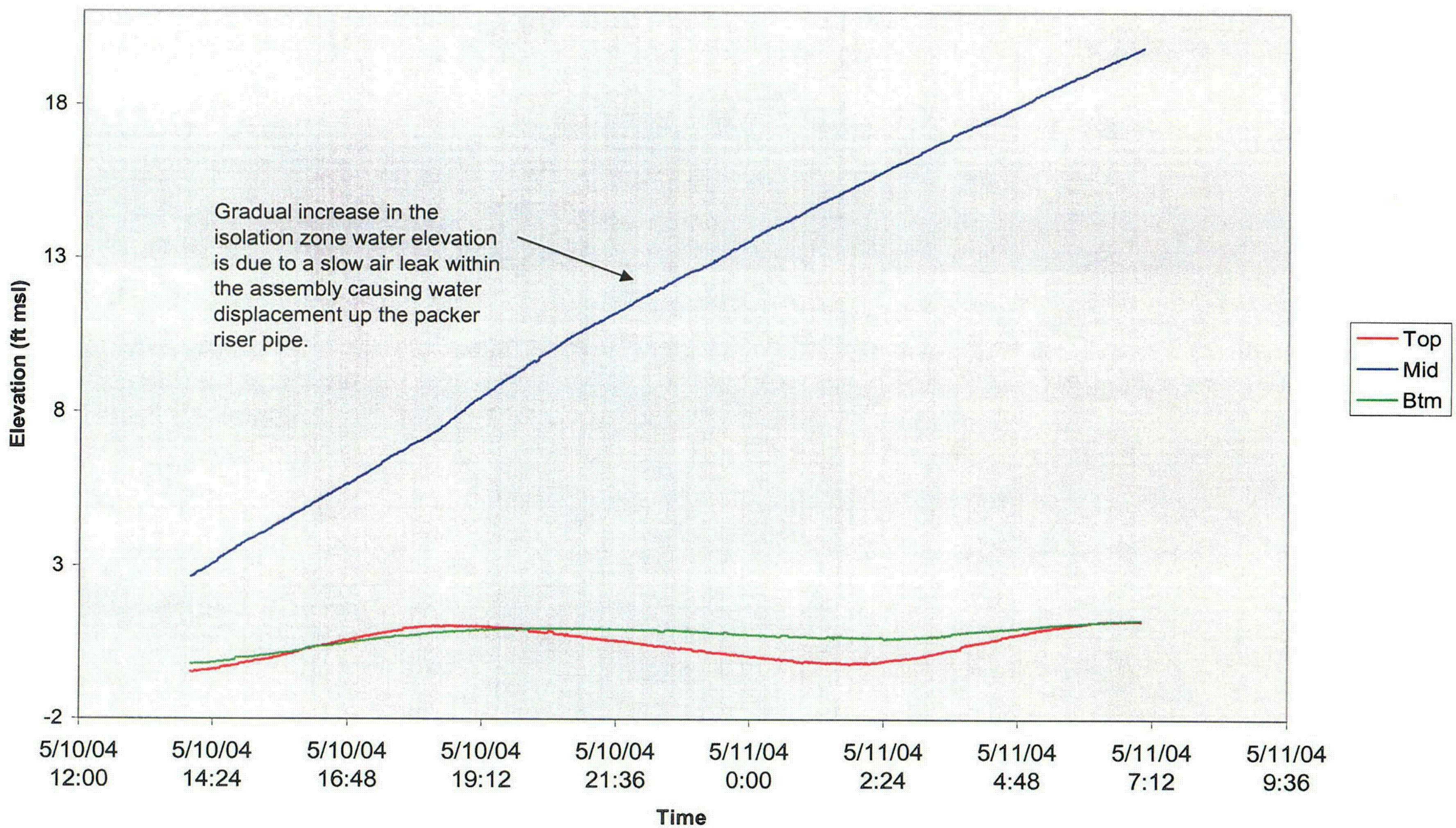


C31


Water Elevation During Packer Isolation in Borehole 121A at 266-271 Feet (BGS)
Gradual increase in the isolation zone water elevation is due to a slow air leak within the assembly causing water displacement up the packer riser pipe.
Packer inflation
Elevation (ft msl)
25
20
15
10
5
0
-5
5/6/04 15:36
5/6/04 16:48
5/6/04 18:00
5/6/04 19:12
5/6/04 20:24
5/6/04 21:36
5/6/04 22:48
5/7/04 0:00
5/7/04 1:12
5/7/04 2:24
5/7/04 3:36
5/7/04 4:48
5/7/04 6:00
5/7/04 7:12
5/7/04 8:24
Time
Top
Mid
Btm

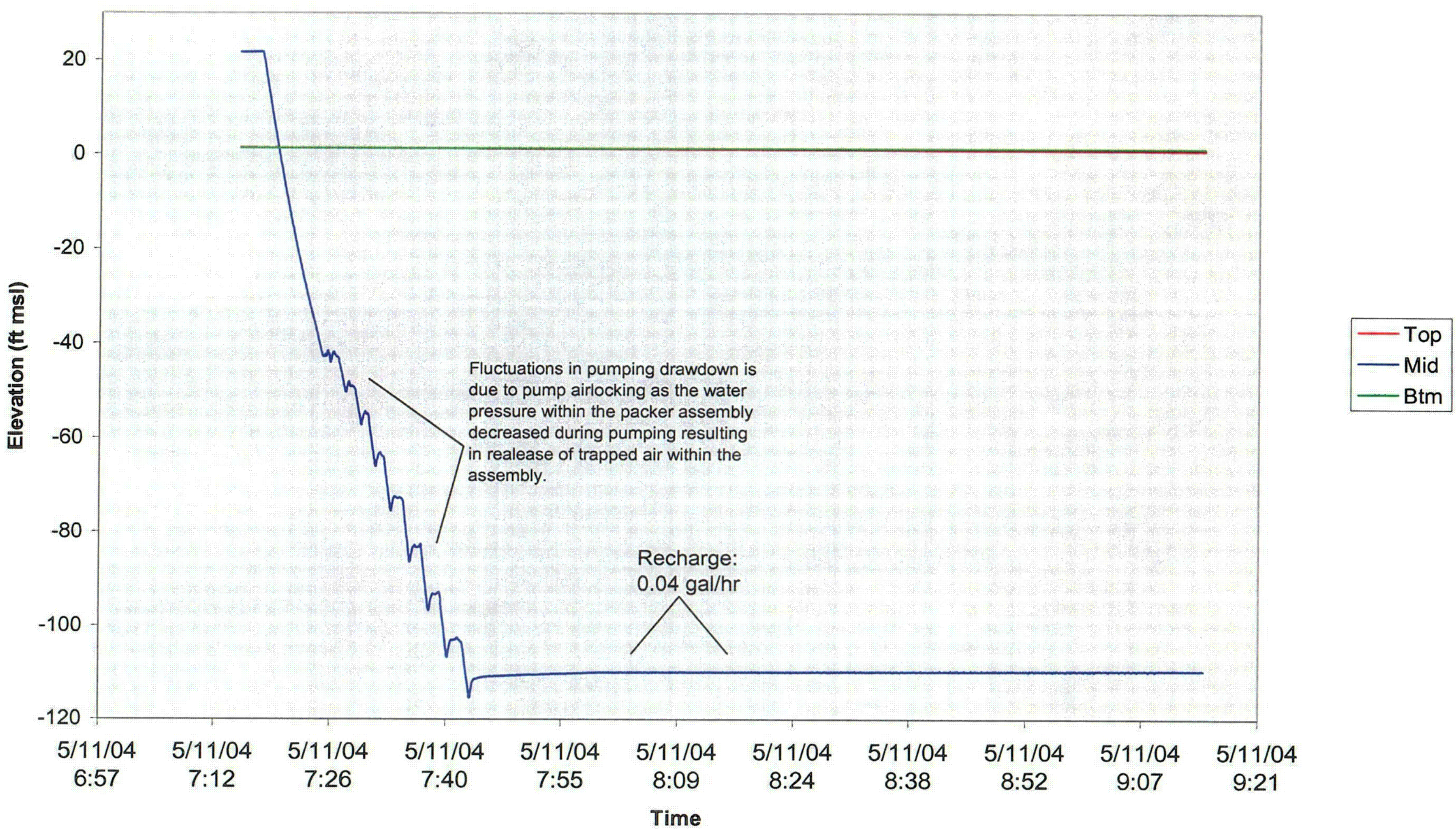
C32

Water Elevation During Packer Isolation in Borehole 121A at 203-208 Feet (BGS)



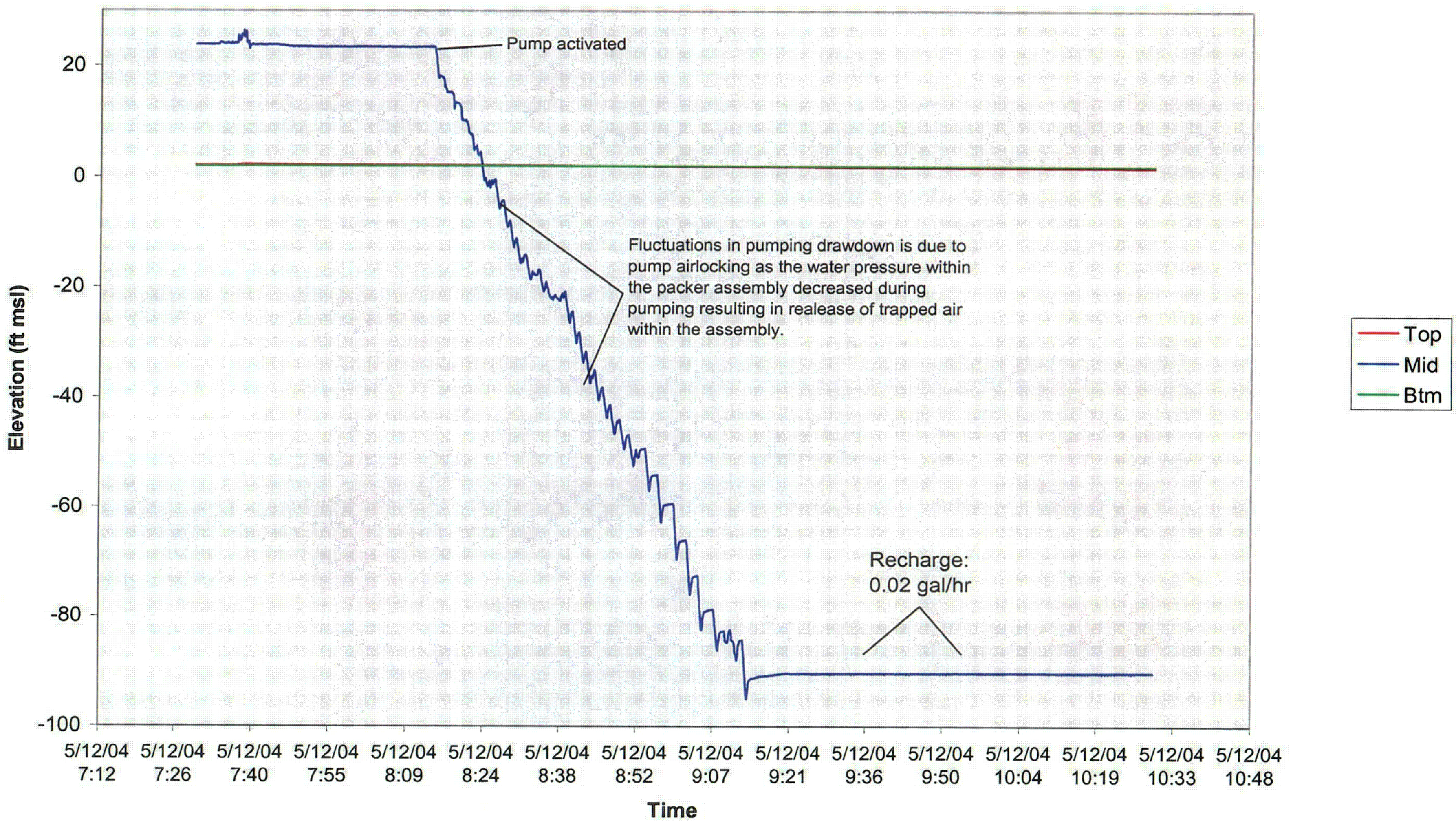
C33

Water ElevationDuring Packer Isolation and Pumping in Borehole 121A at 203-208 Feet (BGS)



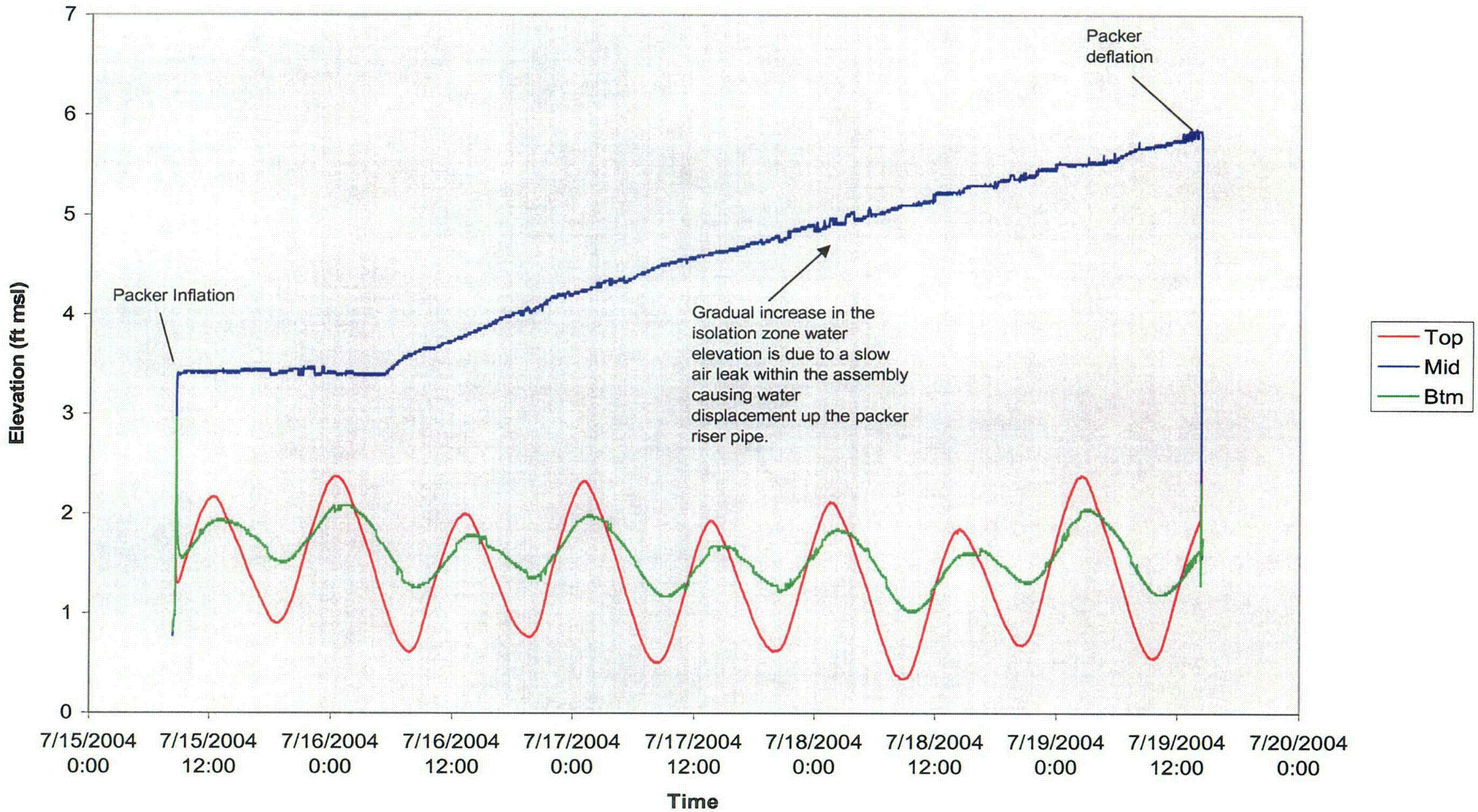
C34

Water Elevation During Packer Isolation and Pumping in Borehole at 188-193 Feet (BGS)

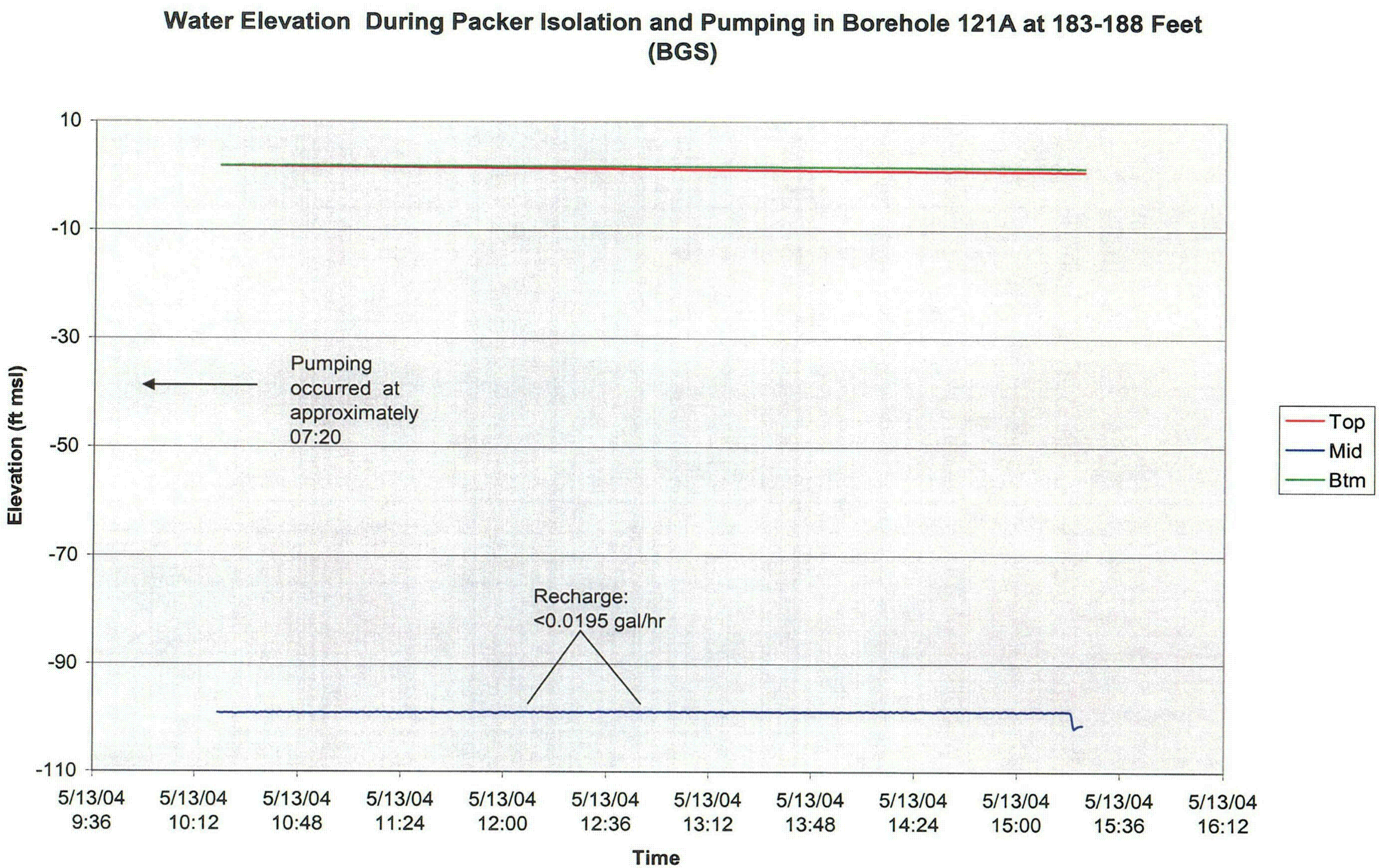


C35

Water Elevation During Packer Isolation in Borehole 121A at 188-193 Feet (BGS)



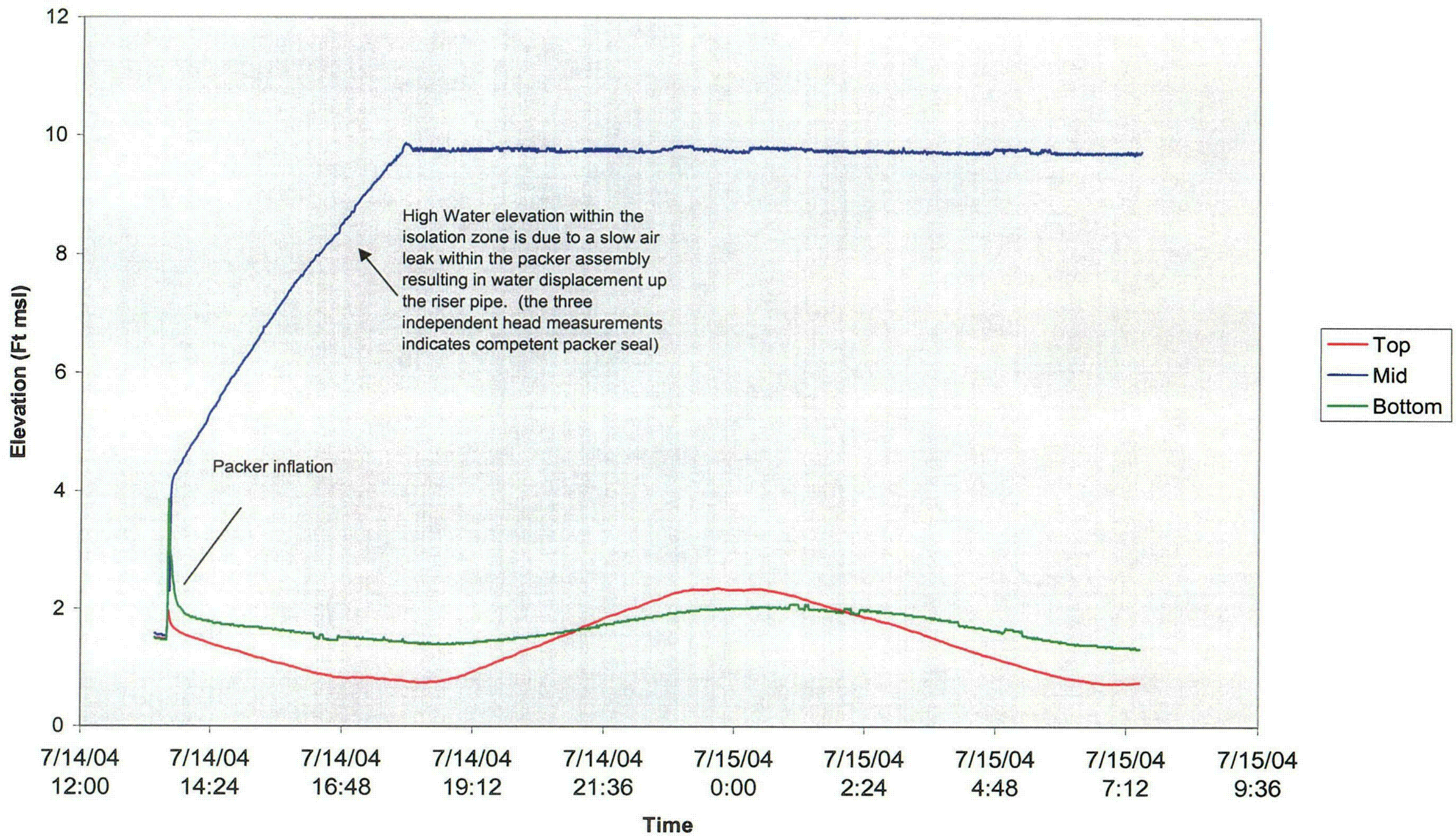
C36



Water Elevation During Packer Isolation and Pumping in Borehole 121A at 183-188 Feet (BGS)
10
-10
-30
-50
-70
-90
-110
Elevation (ft msl)
Pumping occurred at approximately 07:20
Recharge: <0.0195 gal/hr
Top
Mid
Btm
5/13/04 9:36
5/13/04 10:12
5/13/04 10:48
5/13/04 11:24
5/13/04 12:00
5/13/04 12:36
5/13/04 13:12
5/13/04 13:48
5/13/04 14:24
5/13/04 15:00
5/13/04 15:36
5/13/04 16:12
Time

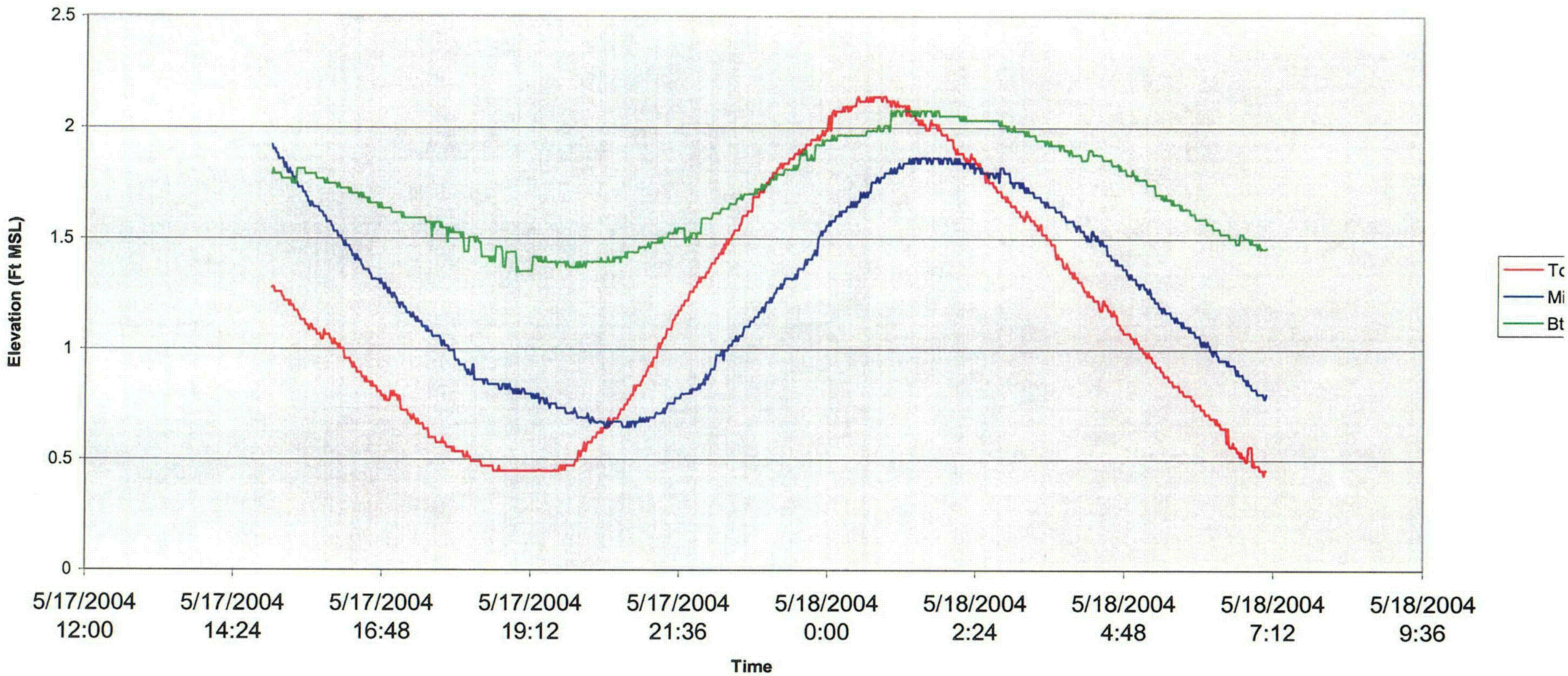
C37

Water Elevation During Packer Isolation in Borehole121A at 183-188 Feet (BGS)



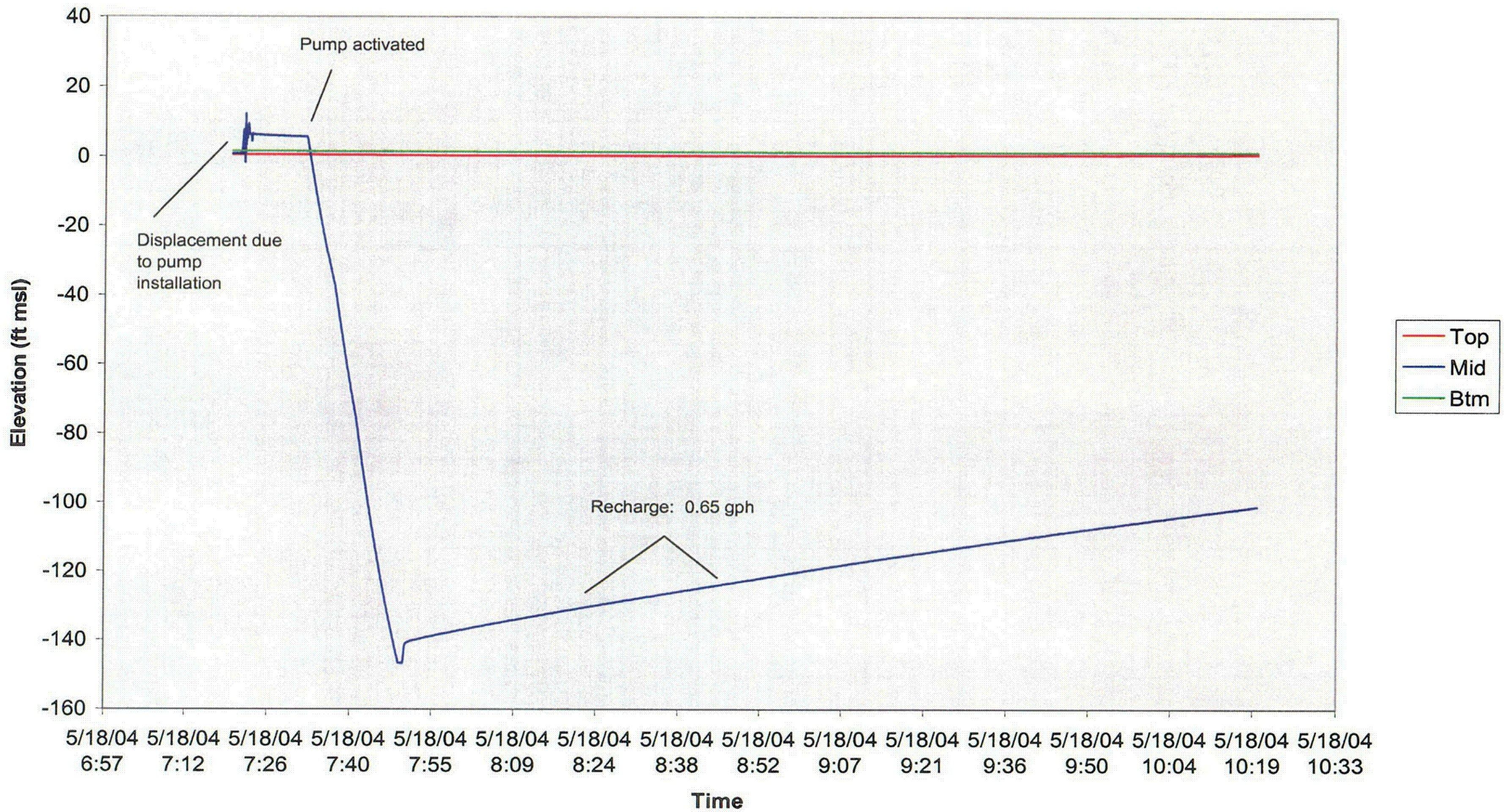
C38

Water Elevations During Packer Isolation in Borehole 121A at 178-183 Feet (BGS)



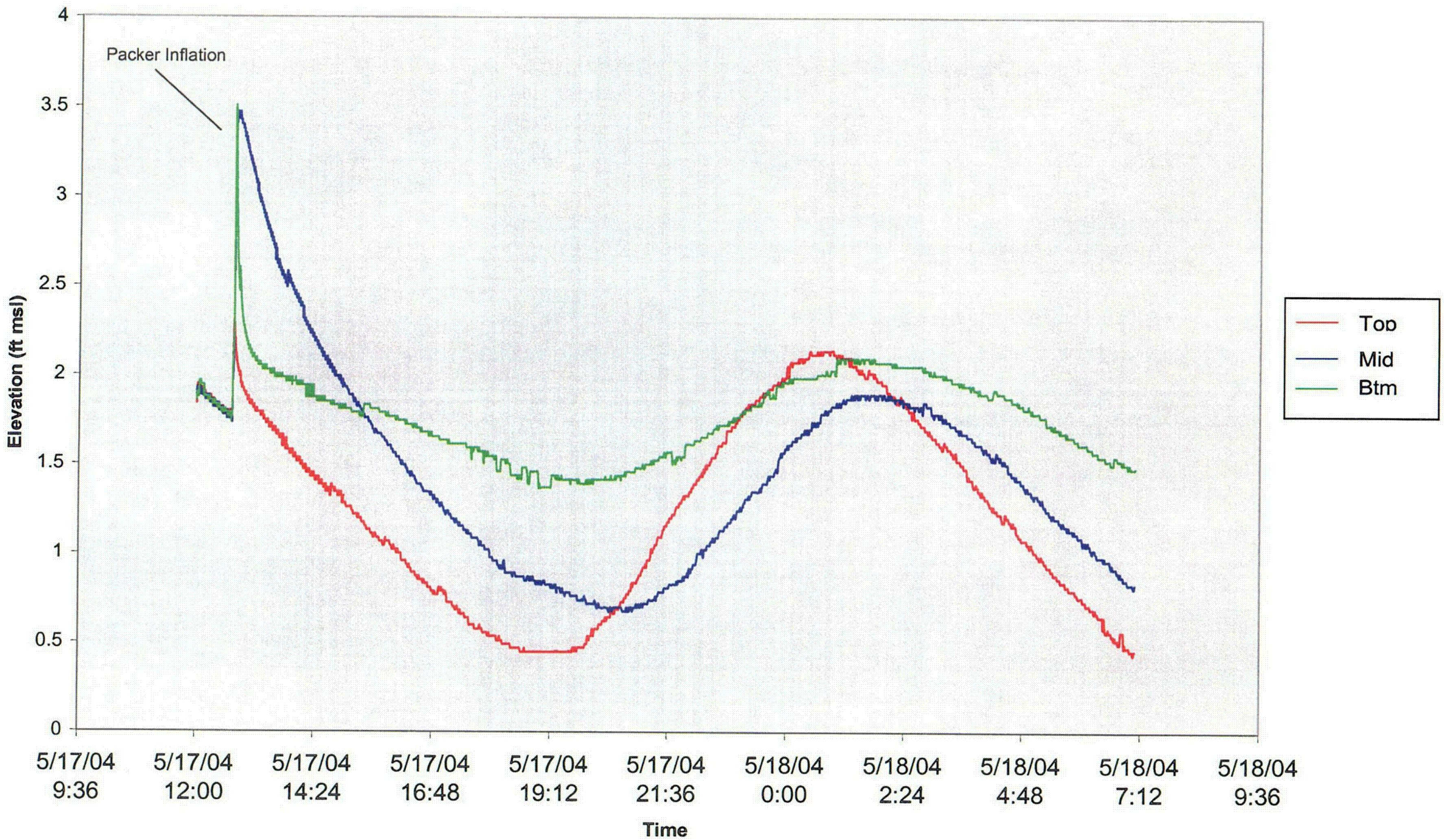
C39

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 178-183 Feet (BGS)

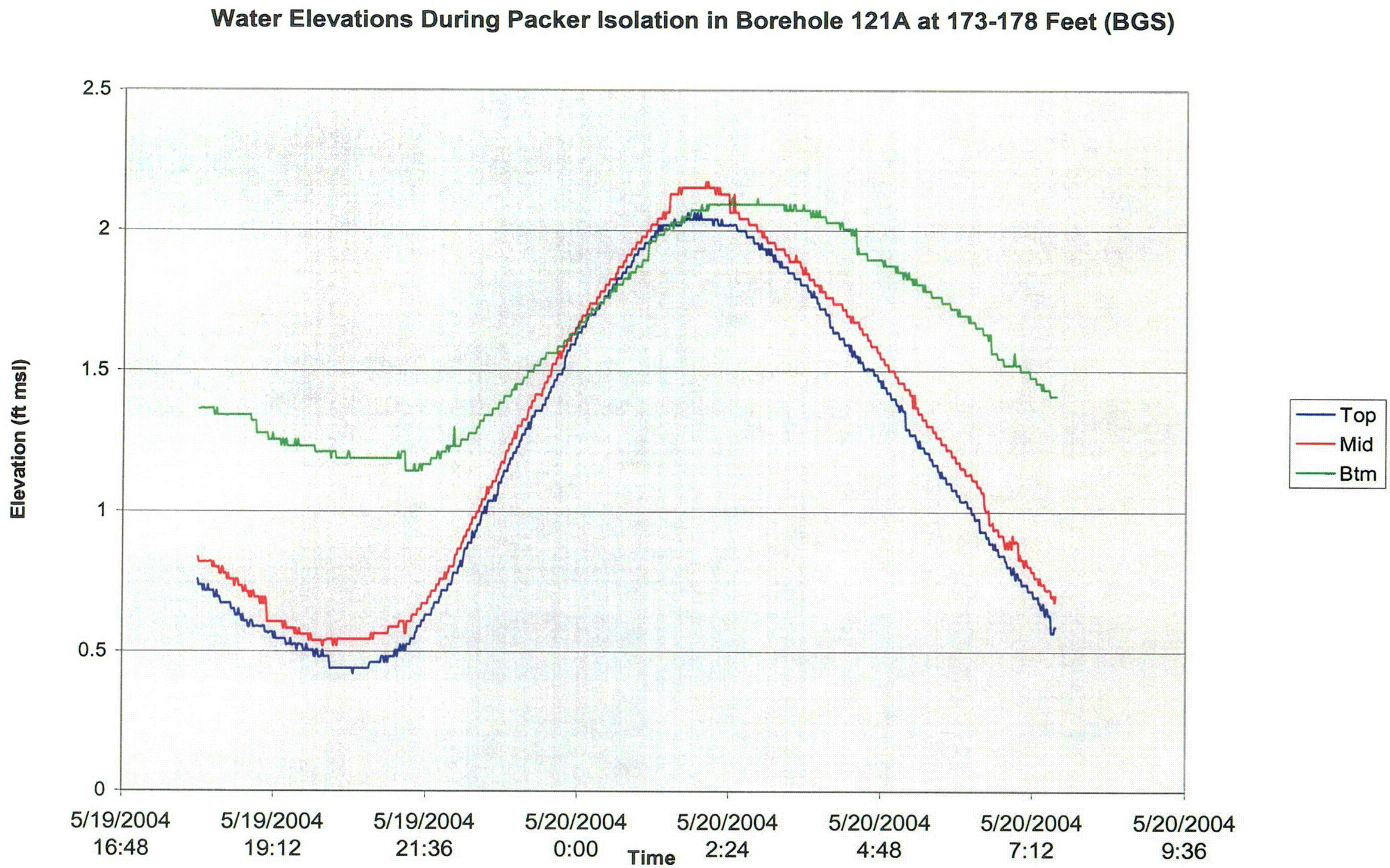


C40

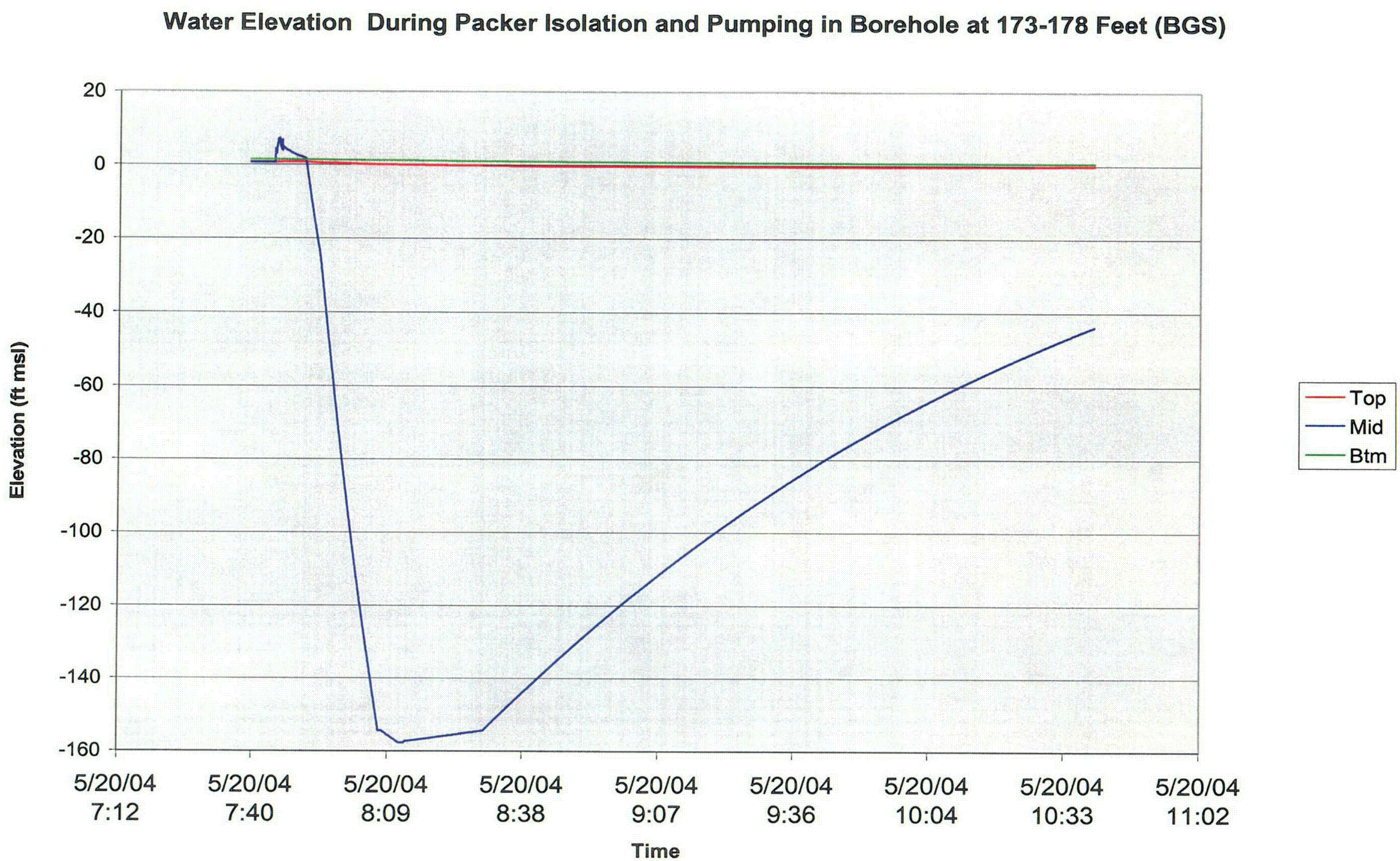
Water Elevation During Packer Isolation in Borehole 121A at 178-183 Feet (BGS)



C41

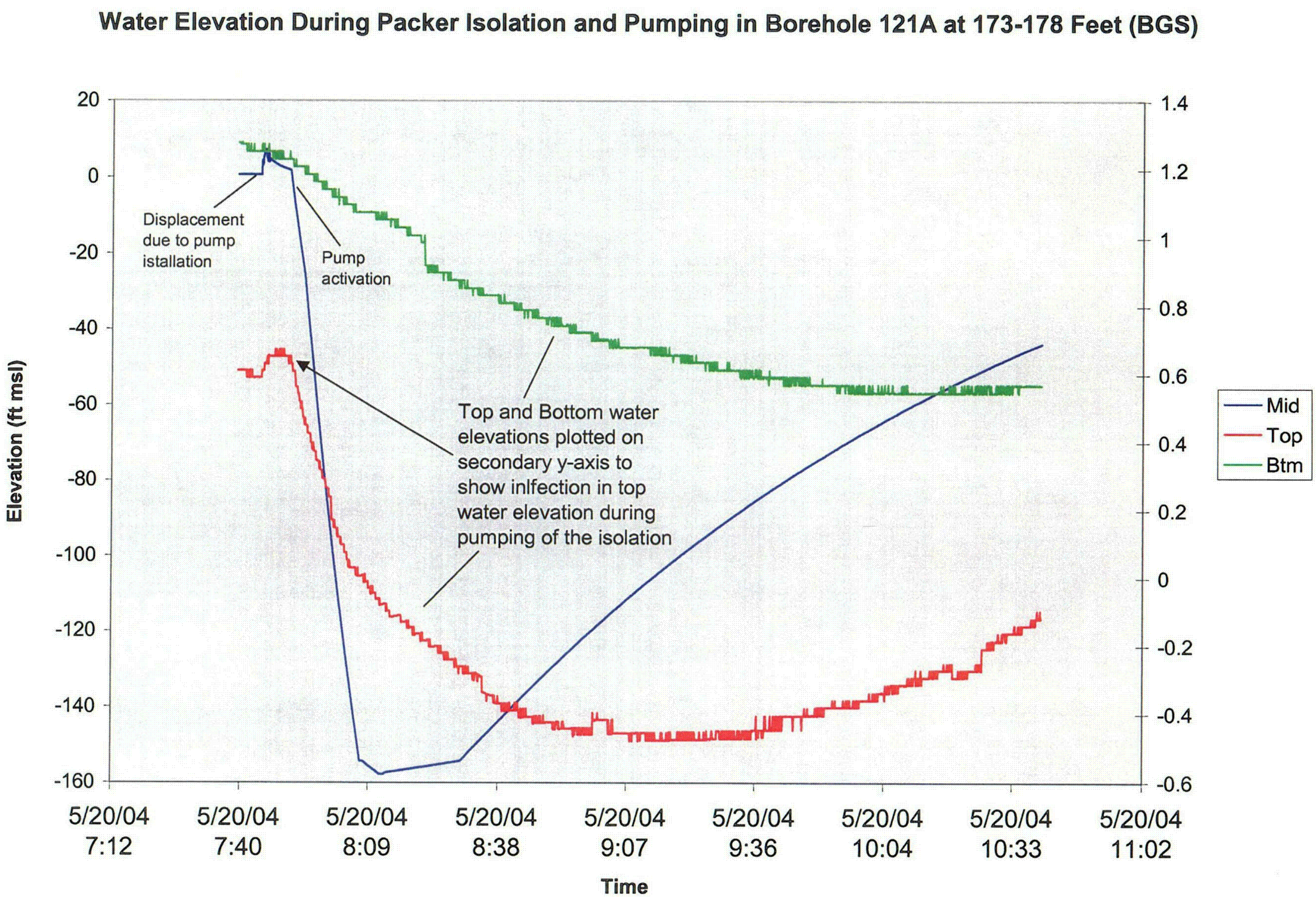

Water Elevations During Packer Isolation in Borehole 121A at 173-178 Feet (BGS)
Elevation (ft msl)
2.5
2
1.5
1
0.5
0
5/19/2004 16:48
5/19/2004 19:12
5/19/2004 21:36
5/20/2004 0:00
5/20/2004 2:24
5/20/2004 4:48
5/20/2004 7:12
5/20/2004 9:36
Time
Top
Mid
Btm

C42



Water Elevation During Packer Isolation and Pumping in Borehole at 173-178 Feet (BGS)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
Elevation (ft msl)
5/20/04 7:12
5/20/04 7:40
5/20/04 8:09
5/20/04 8:38
5/20/04 9:07
5/20/04 9:36
5/20/04 10:04
5/20/04 10:33
5/20/04 11:02
Time
Top
Mid
Btm

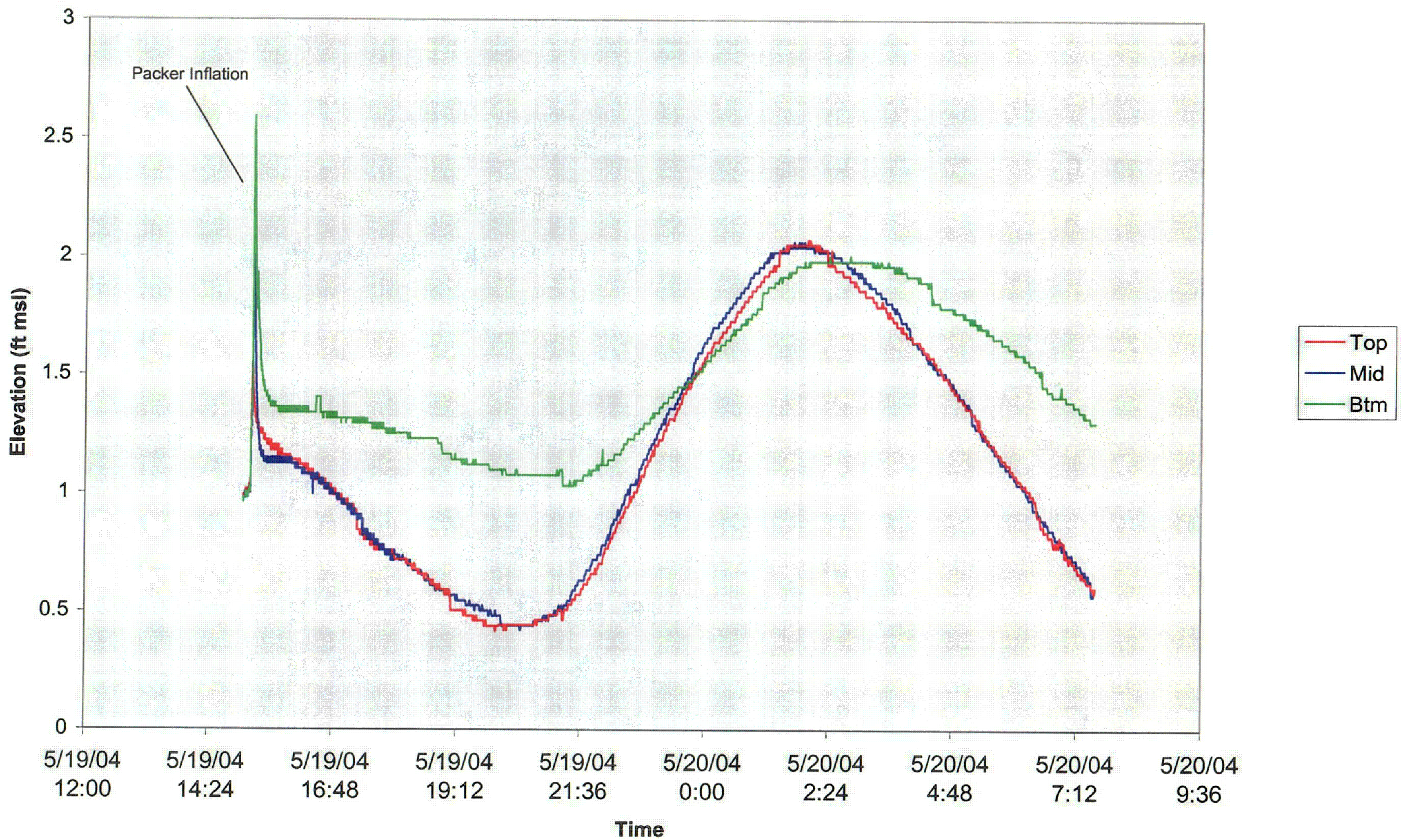
C43



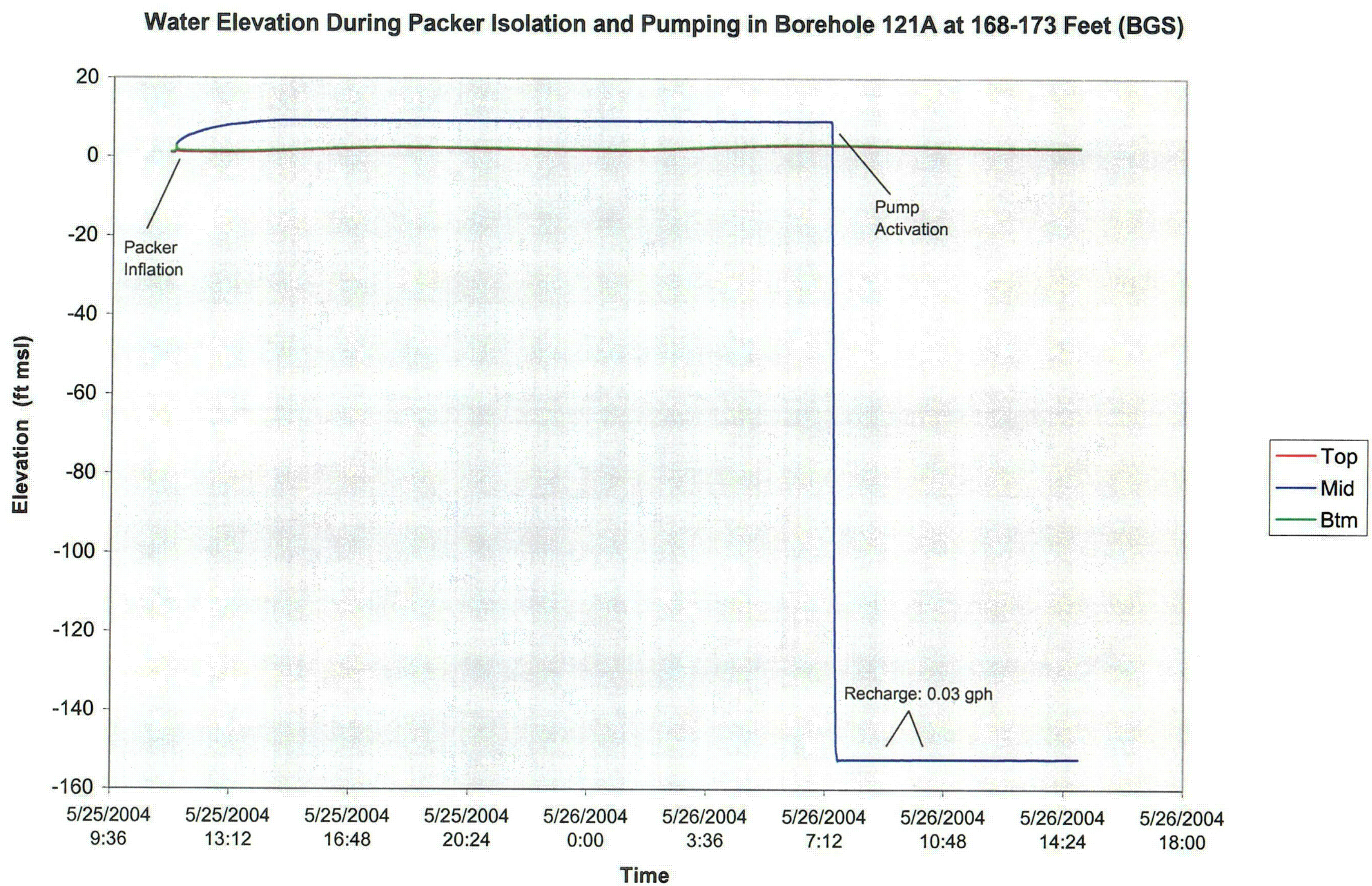
Water Elevation During Packer Isolation and Pumping in Borehole 121A at 173-178 Feet (BGS)
Elevation (ft msl)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
Displacement due to pump istallation
Pump activation
Top and Bottom water elevations plotted on secondary y-axis to show inlfection in top water elevation during pumping of the isolation
5/20/04 7:12
5/20/04 7:40
5/20/04 8:09
5/20/04 8:38
5/20/04 9:07
5/20/04 9:36
5/20/04 10:04
5/20/04 10:33
5/20/04 11:02
Time
Mid
Top
Btm

C44

Water Elevation During Packer Isolation in Borehole 121A at 173-178 Feet (BGS)

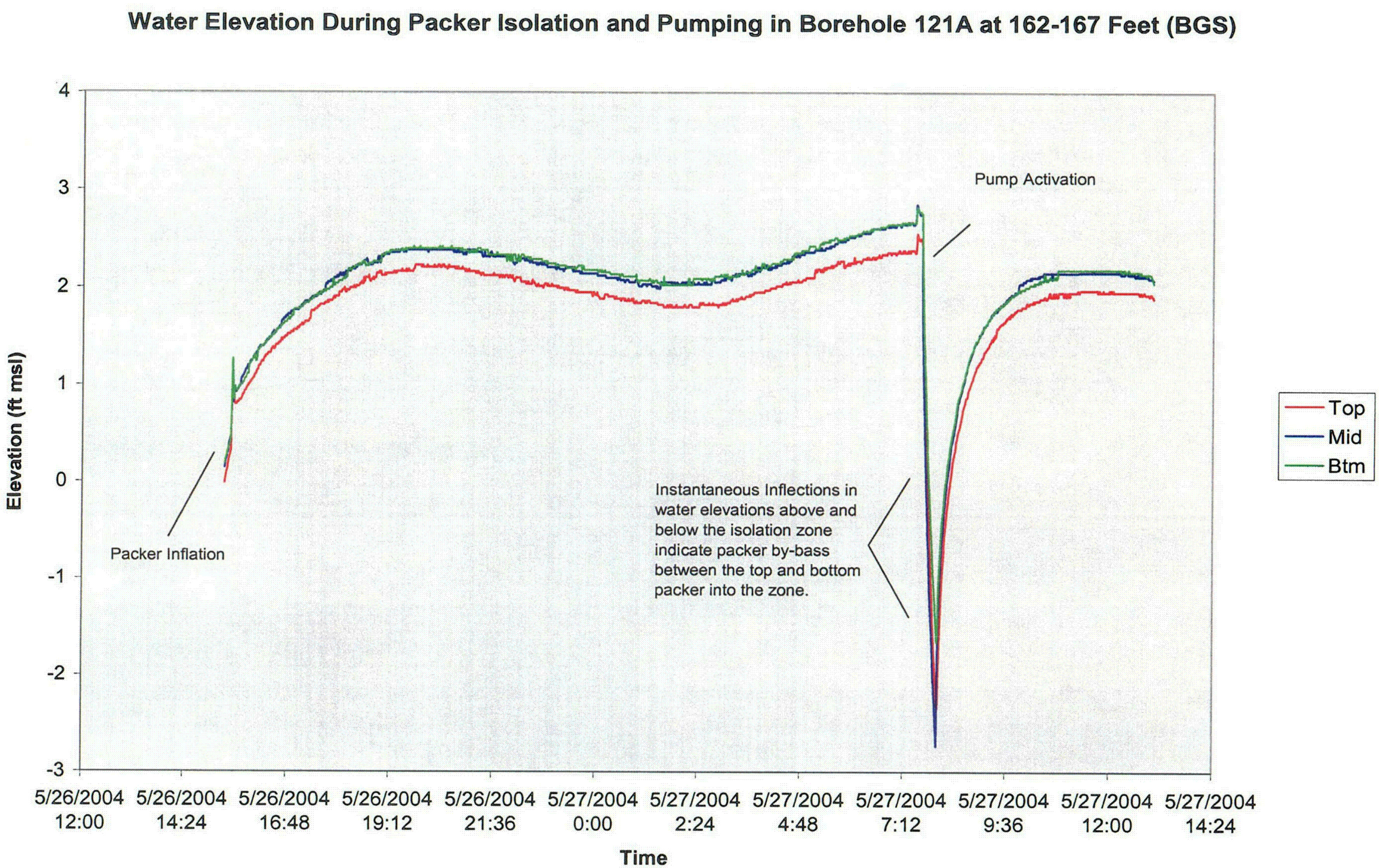


C45



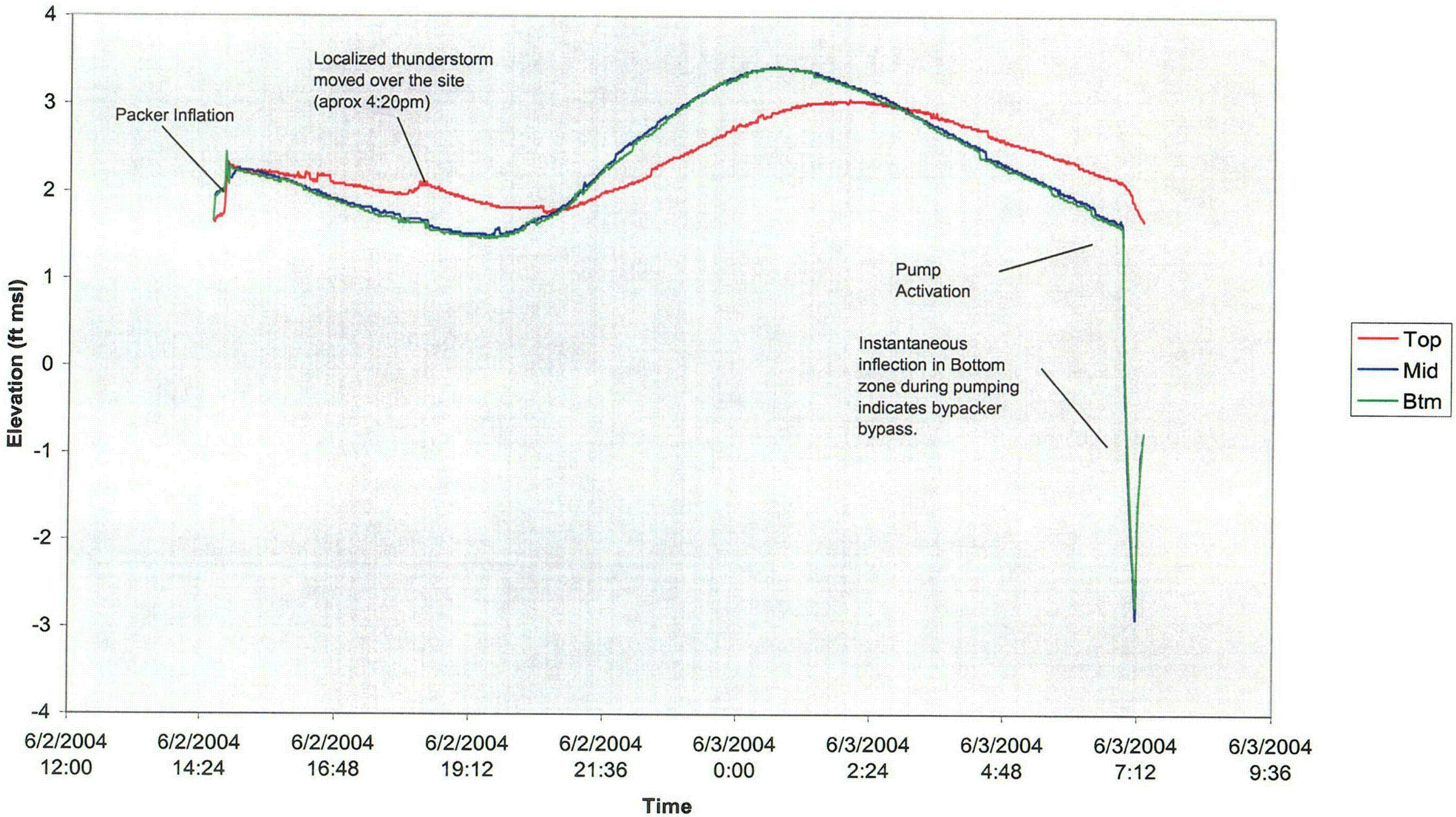
Water Elevation During Packer Isolation and Pumping in Borehole 121A at 168-173 Feet (BGS)
Elevation (ft msl)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
Packer Inflation
Pump Activation
Recharge: 0.03 gph
5/25/2004 9:36
5/25/2004 13:12
5/25/2004 16:48
5/25/2004 20:24
5/26/2004 0:00
5/26/2004 3:36
5/26/2004 7:12
5/26/2004 10:48
5/26/2004 14:24
5/26/2004 18:00
Time
Top
Mid
Btm

C46


Water Elevation During Packer Isolation and Pumping in Borehole 121A at 162-167 Feet (BGS)
Elevation (ft msl)
4
3
2
1
0
-1
-2
-3
Pump Activation
Packer Inflation
Instantaneous Inflections in water elevations above and below the isolation zone indicate packer by-bass between the top and bottom packer into the zone.
Top
Mid
Btm
5/26/2004 12:00
5/26/2004 14:24
5/26/2004 16:48
5/26/2004 19:12
5/26/2004 21:36
5/27/2004 0:00
5/27/2004 2:24
5/27/2004 4:48
5/27/2004 7:12
5/27/2004 9:36
5/27/2004 12:00
5/27/2004 14:24
Time

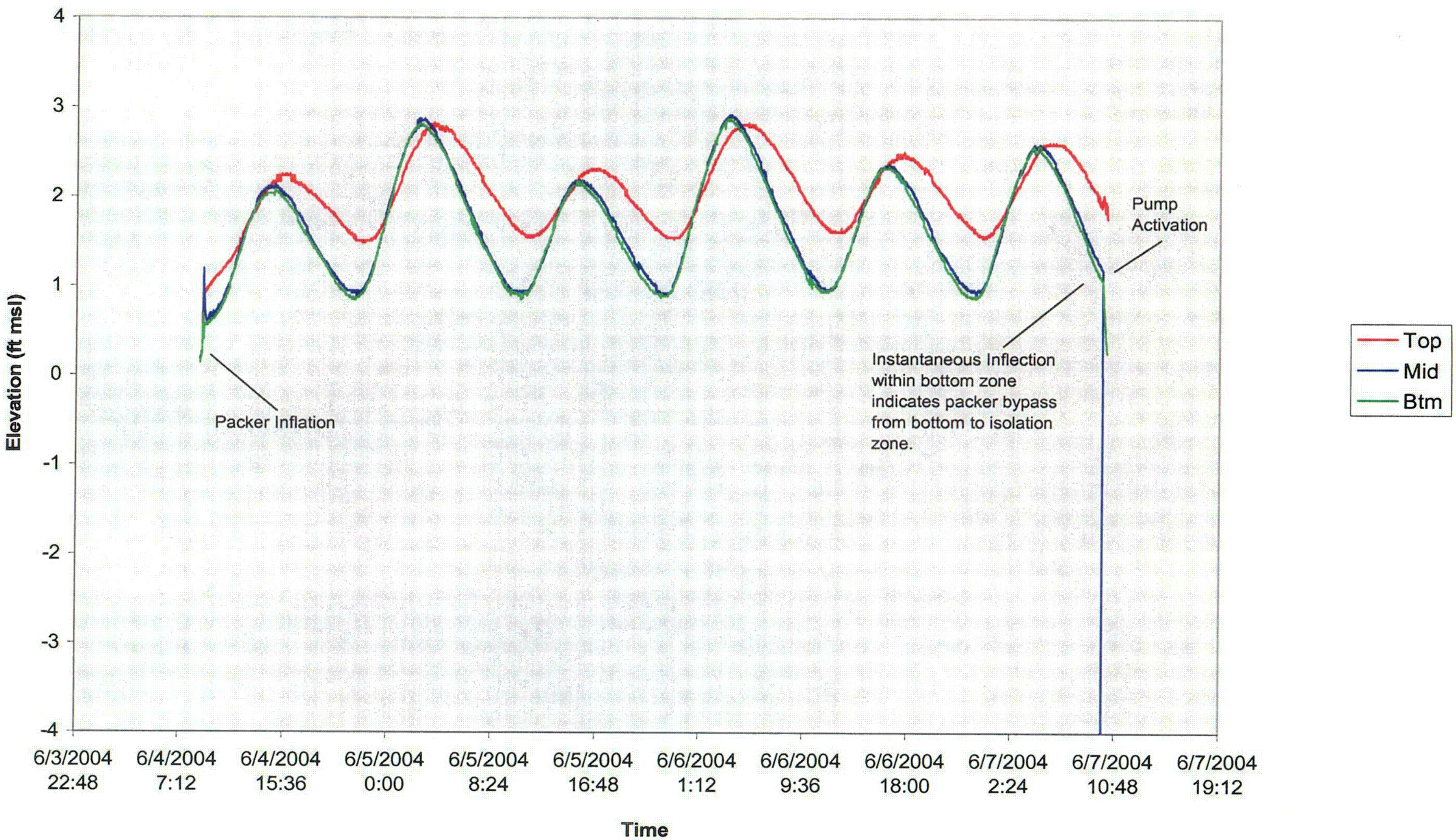
C47

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 157-162 Feet (BGS)



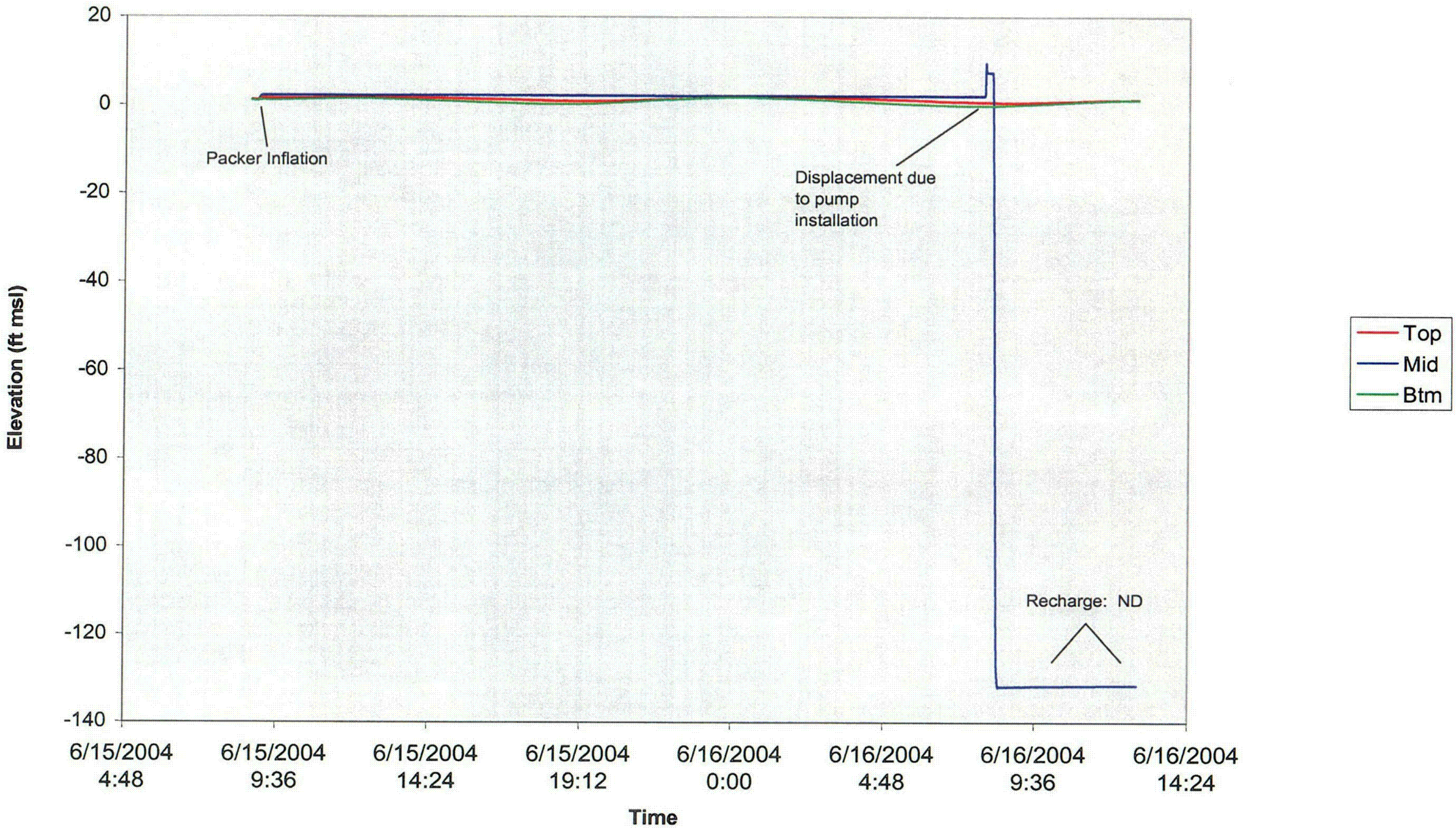
C48

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 152-157 Feet (BGS)



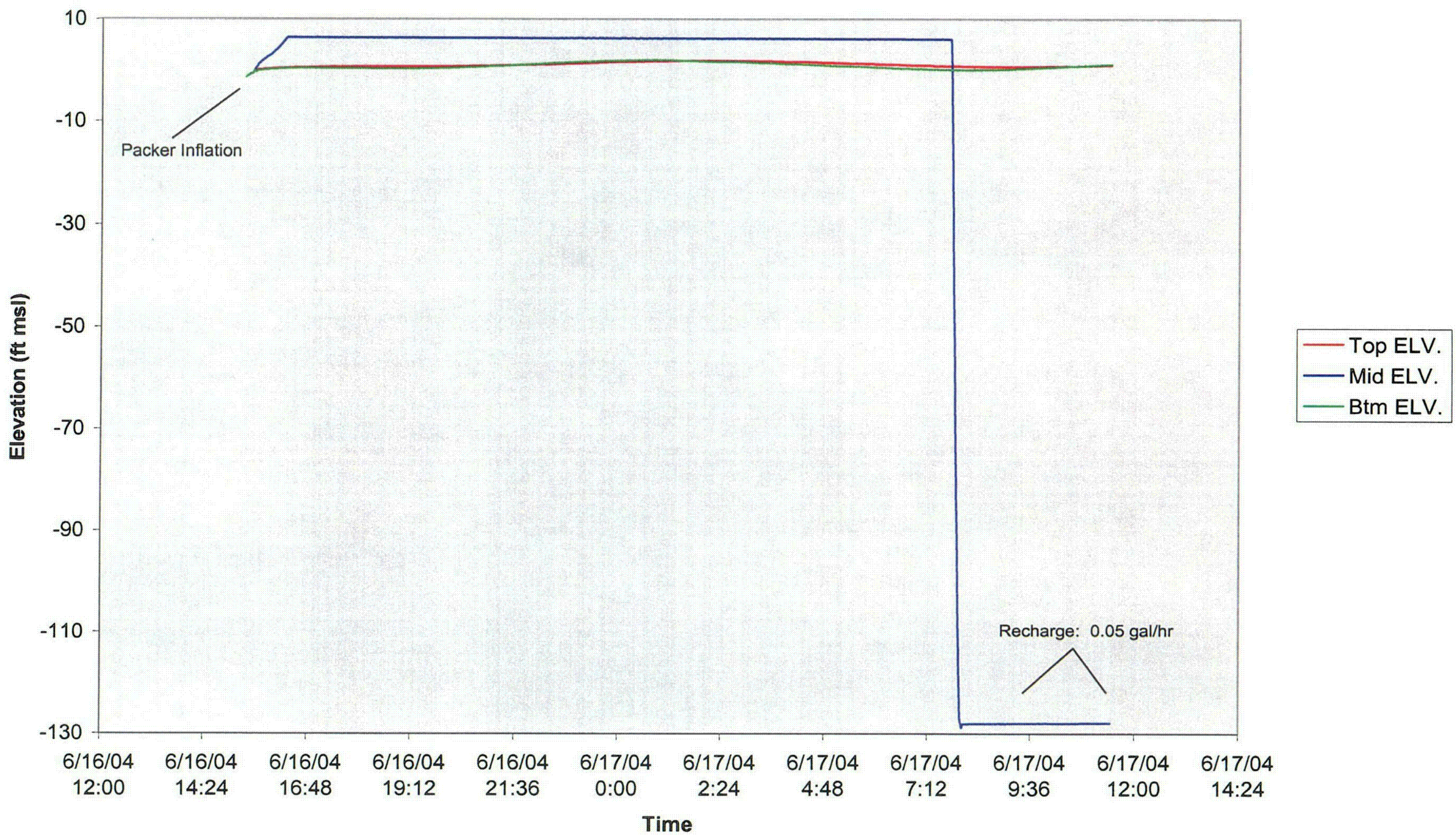
C49

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 147-152 Feet (BGS)

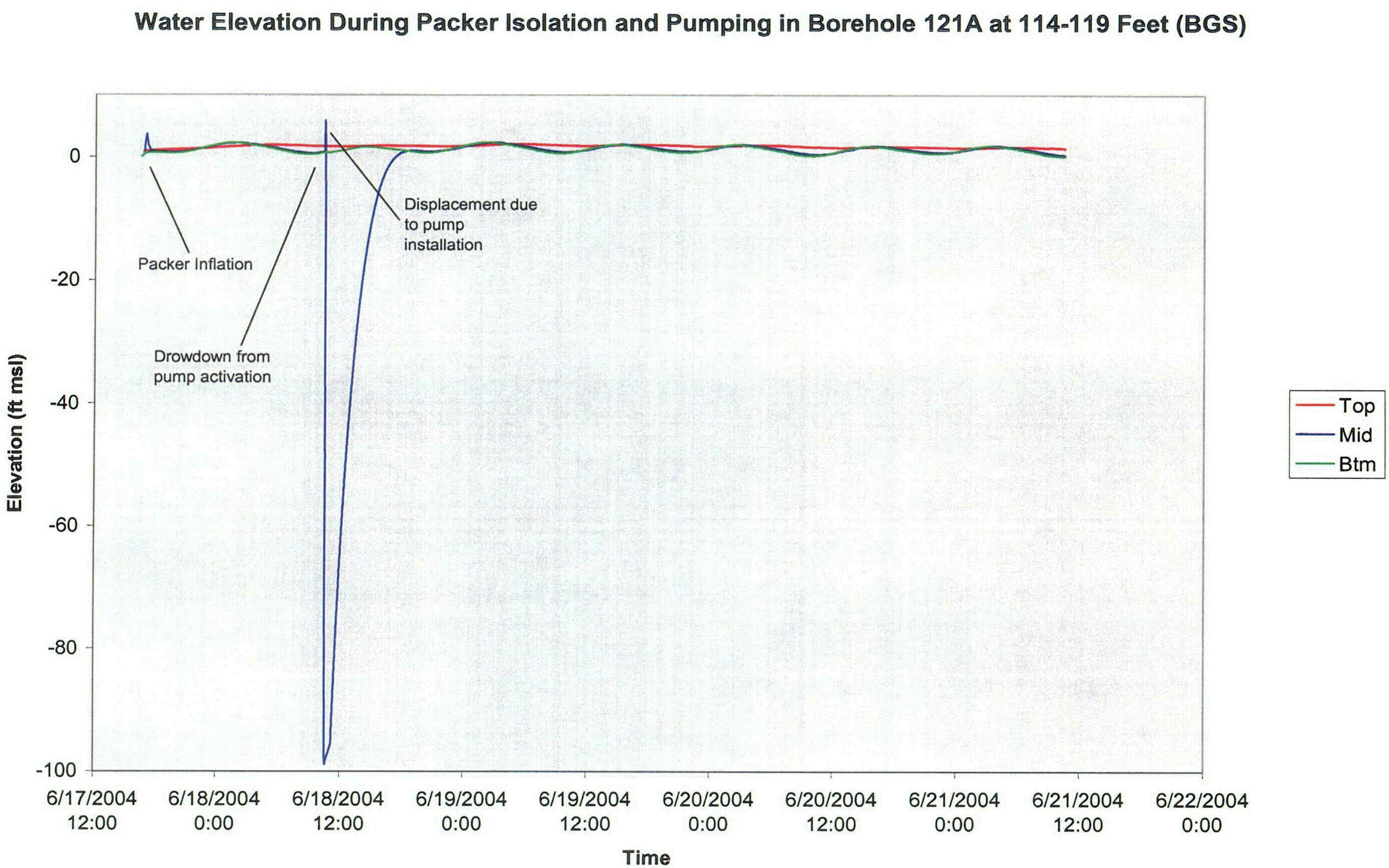


c50

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 145-150 Feet (BGS)



C51

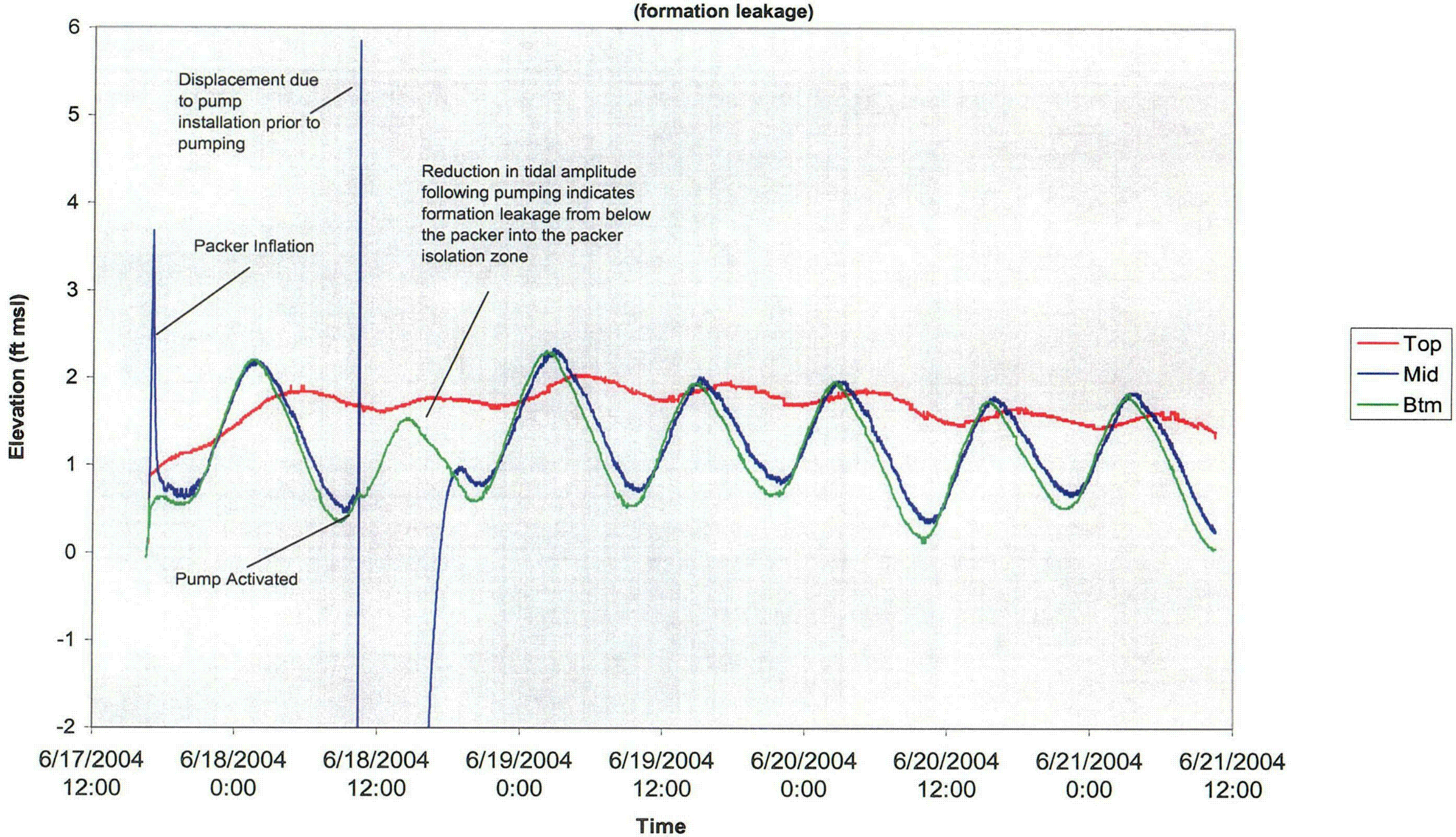


Water Elevation During Packer Isolation and Pumping in Borehole 121A at 114-119 Feet (BGS)
Elevation (ft msl)
0
-20
-40
-60
-80
-100
Packer Inflation
Drowdown from pump activation
Displacement due to pump installation
6/17/2004 12:00
6/18/2004 0:00
6/18/2004 12:00
6/19/2004 0:00
6/19/2004 12:00
6/20/2004 0:00
6/20/2004 12:00
6/21/2004 0:00
6/21/2004 12:00
6/22/2004 0:00
Time
Top
Mid
Btm

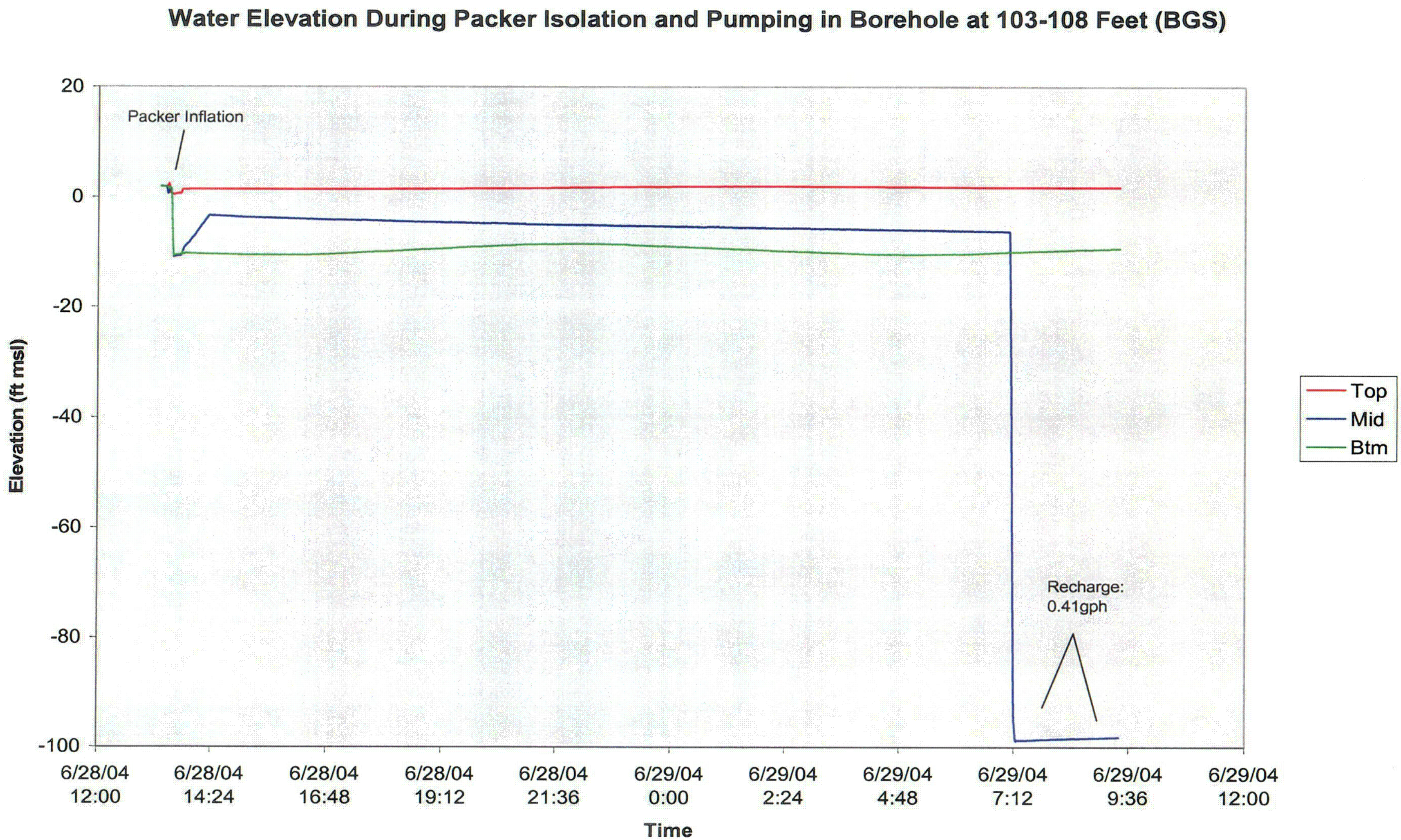
C52

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 114-119 Feet (MSL).

(formation leakage)



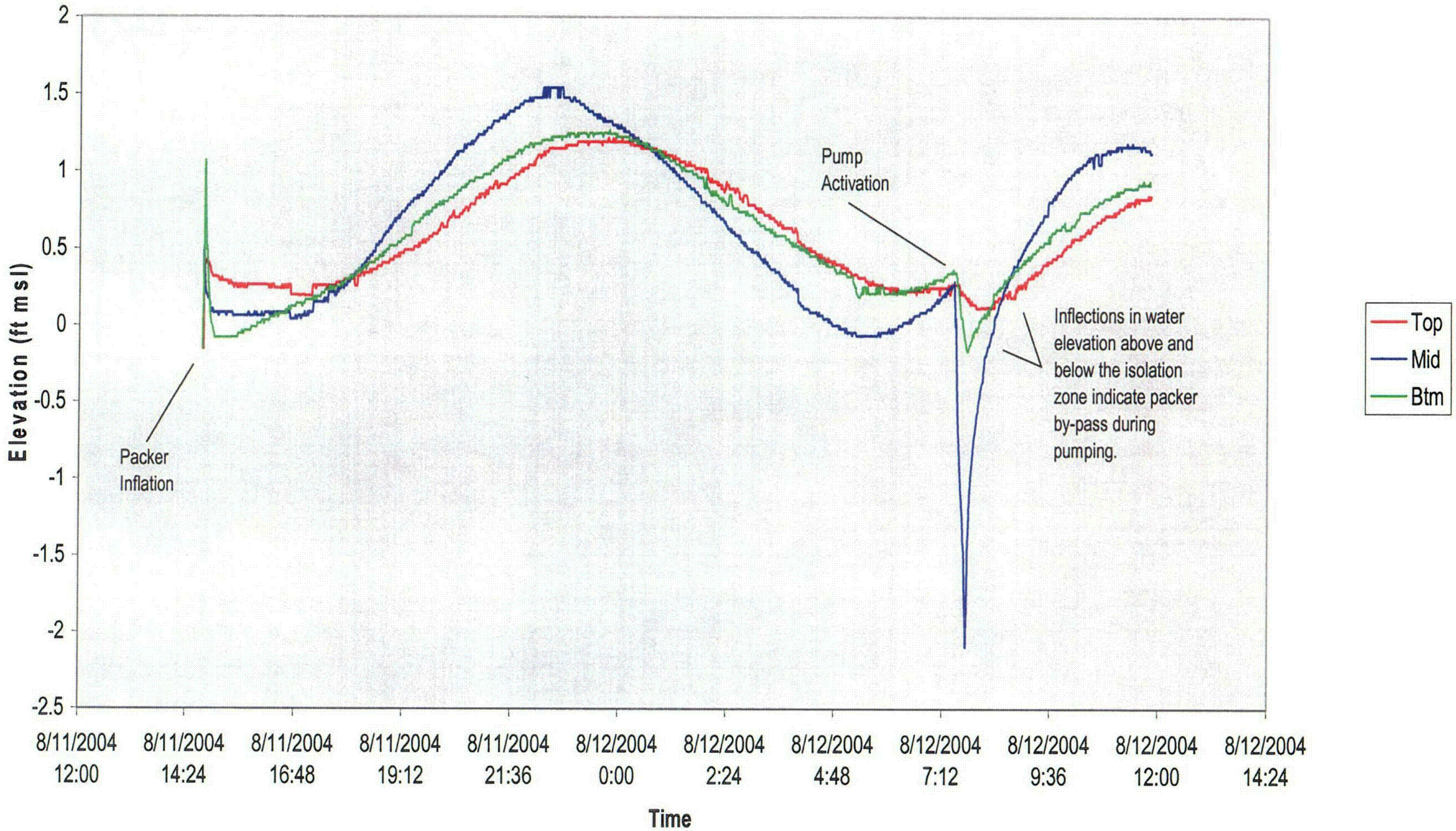
C53



Water Elevation During Packer Isolation and Pumping in Borehole at 103-108 Feet (BGS)
Packer Inflation
Recharge:
0.41gph
Elevation (ft msl)
20
0
-20
-40
-60
-80
-100
6/28/04 12:00
6/28/04 14:24
6/28/04 16:48
6/28/04 19:12
6/28/04 21:36
6/29/04 0:00
6/29/04 2:24
6/29/04 4:48
6/29/04 7:12
6/29/04 9:36
6/29/04 12:00
Time
Top
Mid
Btm

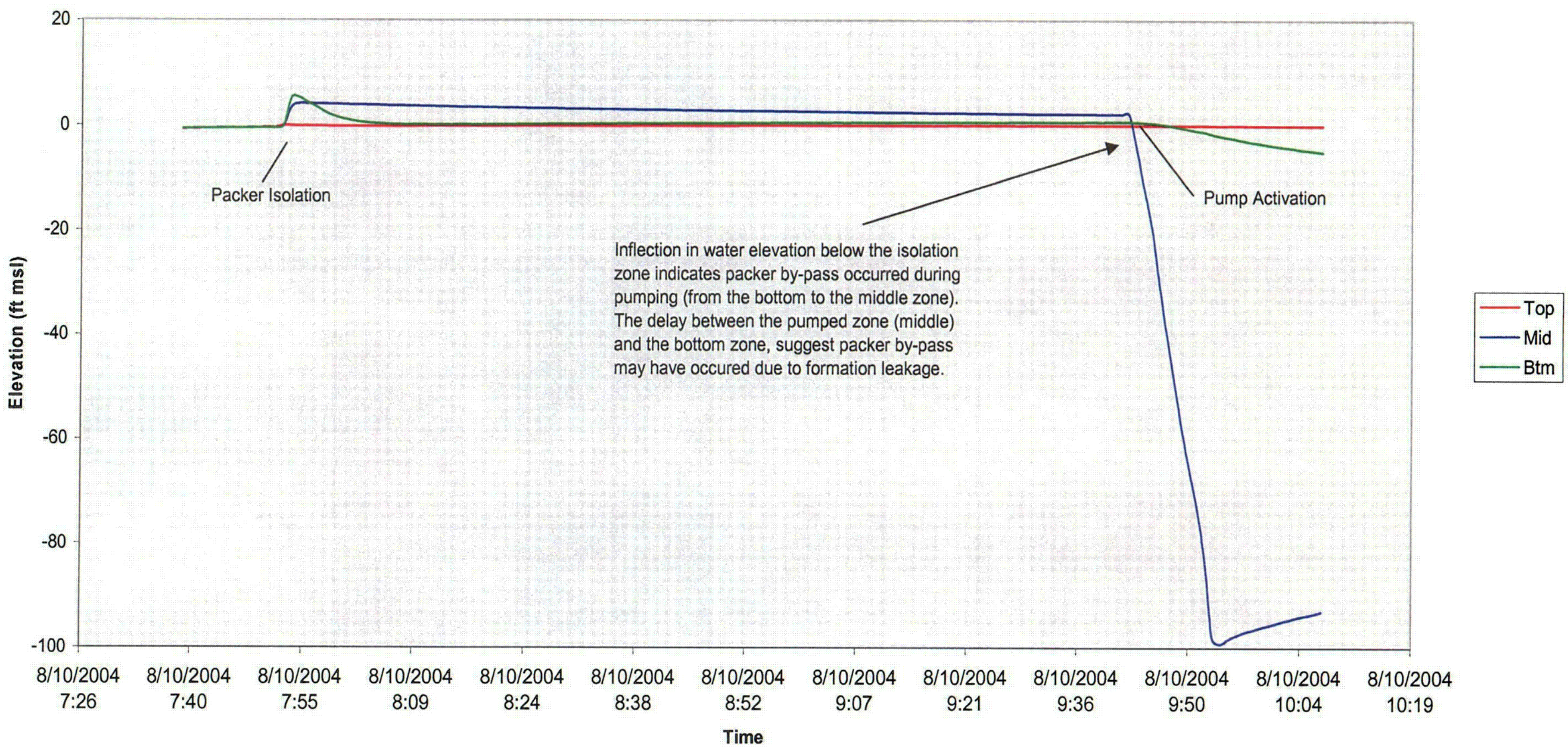
C54

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 155-178 Feet (BGS)

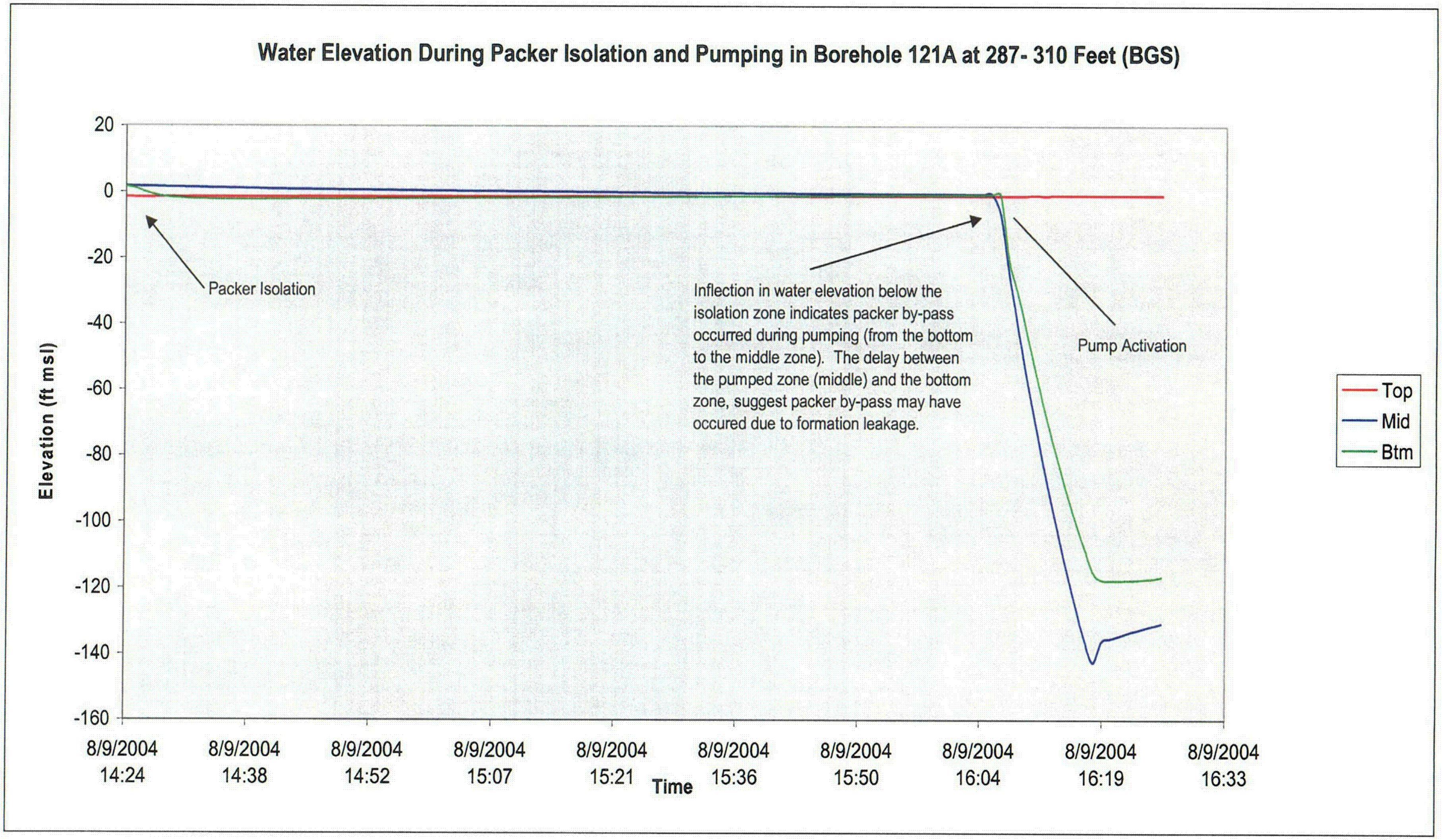


C55

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 291- 314 Feet (BGS)



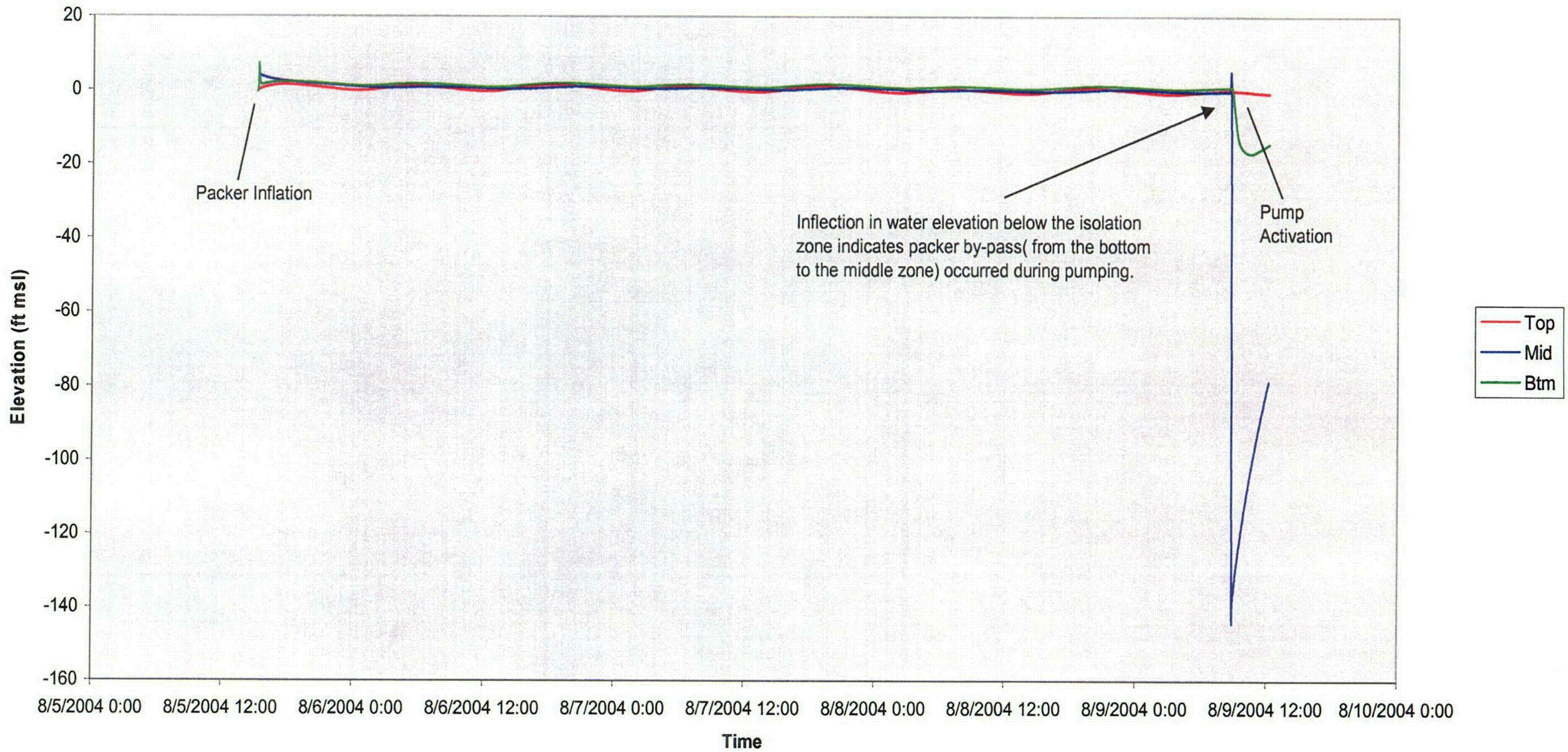
C56



Water Elevation During Packer Isolation and Pumping in Borehole 121A at 287- 310 Feet (BGS)
Elevation (ft msl)
20
0
-20
-40
-60
-80
-100
-120
-140
-160
Packer Isolation
Inflection in water elevation below the isolation zone indicates packer by-pass occurred during pumping (from the bottom to the middle zone). The delay between the pumped zone (middle) and the bottom zone, suggest packer by-pass may have occured due to formation leakage.
Pump Activation
8/9/2004 14:24
8/9/2004 14:38
8/9/2004 14:52
8/9/2004 15:07
8/9/2004 15:21
8/9/2004 15:36
8/9/2004 15:50
8/9/2004 16:04
8/9/2004 16:19
8/9/2004 16:33
Time
Top
Mid
Btm

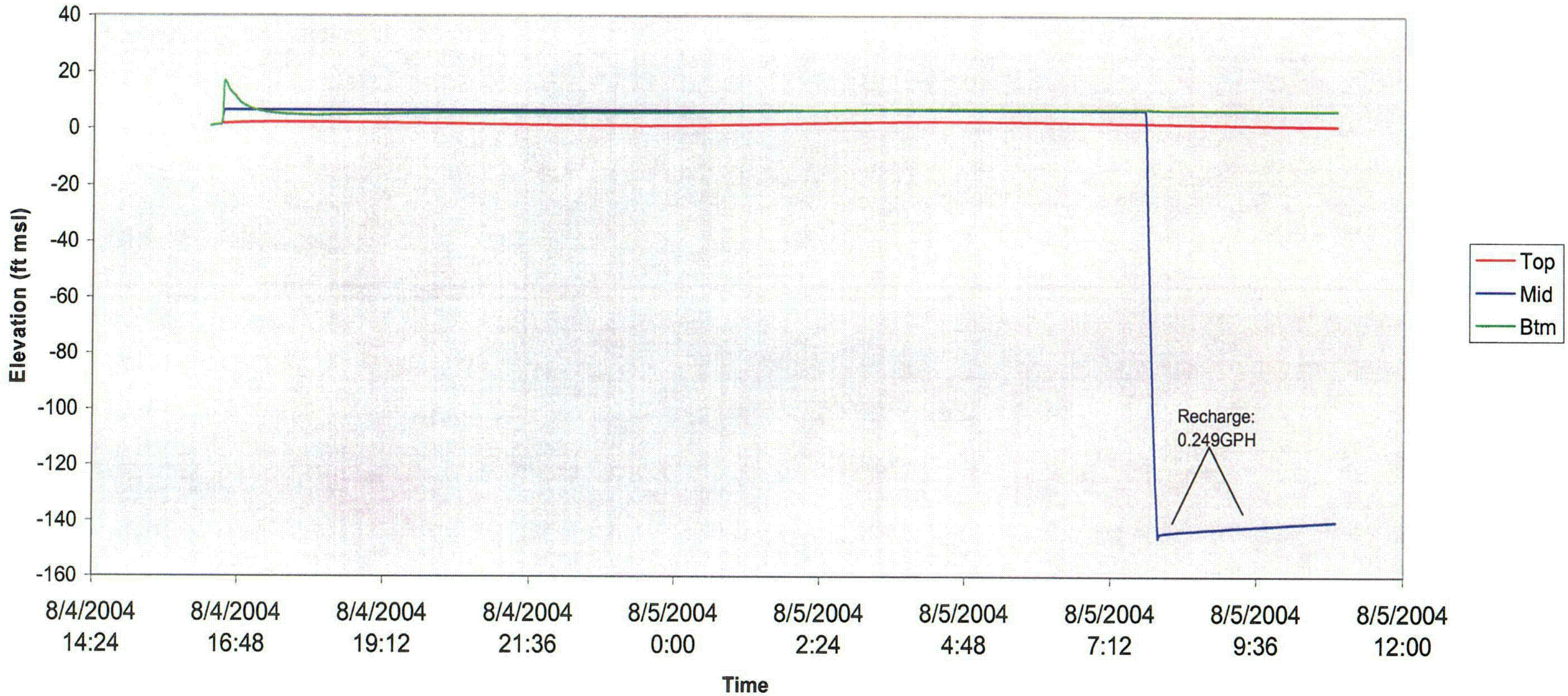
C57

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 292- 315 Feet (BGS)



C58

Water Elevation During Packer Isolation and Pumping in Borehole 121A at 324.2-347.2 Feet (BGS) (second attempt, packer pressure at 400PSI)



C59

Appendix 3
2004 Onsite and Offsite Analytical Data Quality Assessment

Data Quality Assessment of Bedrock Borehole 121A Packer Test On-site Laboratory Results Collected in the Spring and Summer of 2004

CH2M HILL has performed a data quality assessment (DQA) of the on-site laboratory results of bedrock borehole packer testing performed in Borehole 121A at the Connecticut Yankee Atomic Power Company Haddam Neck Plant (HNP). The DQA was performed as outlined below. The data set generated from the packer testing event was evaluated against criteria for measurement precision, accuracy, representativeness, completeness, and comparability to determine data validity and usability. The following summarizes the results of the DQA.

Summary of Data Collection Activities

Following a critical review of the 2003 packer testing campaign, the results of tritium analysis of groundwater were rejected as non-representative. An effort was initiated to develop an alternative testing protocol to verify or refute the apparent vertical distribution of tritium in deep bedrock. Because of the measurement uncertainty exhibited by the 2003 test results, it was decided to verify the new test protocol in one borehole.

The revised test protocol and re-configured packer assembly was applied to borehole 121A and the results indicate that the apparent lower boundary of detectable tritium contamination in the fractured bedrock aquifer unit is between 188 and 317 feet bgs. Other information collected (the flow zones at 165.9 to 166.8 feet bgs, 180 feet bgs, and 278.0-278.8 feet bgs identified in the hydrophysical logging) would suggest that the boundary is at approximately 180 feet bgs. This delineation is based both on the hydrophysical flow zones defined, and the hydrophysical analytical results. As the revised packer testing proceeded in borehole 121A, additional testing (i.e., hydrophysical logging) was implemented in all four six-inch boreholes. The combined results of packer testing and hydrophysical logging provided a valid basis for designing the bedrock monitoring system.

Borehole BH-121A was selected for the first application of the revised packer test protocol. This borehole was chosen because the analytical results collected there during the 2003 packer sampling program indicated a relatively uniform distribution of tritium below 144 feet bgs, and the borehole was believed to be sited within a tritium plume. The 2004 packer testing program was designed to collect pressure gradient measurements and discrete zone samples from selected depths in borehole 121A to clarify contaminant migration directions and distribution.

Summary of Data Collected

Five groundwater samples were collected under conditions believed to be representative of groundwater at discrete elevations. These samples were analyzed for tritium content by HNP's on-site radiochemistry laboratory by the distillation method. Additional samples were submitted for radiochemical analysis by an off-site contractor laboratory. Offsite analytical results are discussed in a separate DQA.

Results of Data Quality Assessment

The Phase II Hydrogeologic Characterization Work Plan (Malcom-Pirnie, 2002) data quality objectives specify goals of "determining the cause, location, nature and condition of release areas and their associated SOCs" and "determining the degree and extent of the resulting plumes". The testing activity, however, was intended to remain as a screening-level measurement to be used in design of the final bedrock aquifer monitoring system. The data were assessed for precision, accuracy, representativeness, completeness, and comparability. The individual assessment parameters are discussed in the following subsections.

Precision

Precision is the measurement of the repeatability of a measurement or measurement technique. Precision is evaluated through analysis of multiple duplicate samples. The following types of duplicate samples are typically assessed:

- Field duplicate, or split, samples that are collected in the field and submitted to the laboratory as blind samples (i.e., not identifiable to the laboratory as duplicates); and
- Laboratory duplicate, or replicate, samples that are prepared by the laboratory and analyzed by the laboratory to assess internal method precision.

Due to an average 1-volume sample collection time of 4.5 hours, duplicate and/or field samples were not collected for tritium analysis from borehole 121A. Split samples, however, were collected for tritium analysis from borehole 121A and were sent to the HNP's on-site radiochemistry laboratory, as well as an offsite laboratory. Both laboratories analyzed the samples by the distillation method. The results are discussed in the representativeness and comparability sections below (see Table 1). Following completion of the bedrock aquifer monitoring system, subsequent sampling events will include collection of field duplicate samples for analysis.

Accuracy

Accuracy is typically assessed through analysis of known standards and through the analysis of blanks and/or matrix spike samples. The on-site HNP laboratory performs calibration according to existing laboratory procedures. No blank, standard, or matrix spike information was provided by the on-site laboratory to assess accuracy.

Representativeness

Representativeness refers to the degree to which a data set is actually a sample of a population. In this case representativeness refers to the degree to which these collected

groundwater samples are actually groundwater from the bedrock formation in the isolated intervals. This representativeness could be compromised by any of the following conditions:

- water leaking past either packer,
- residual mixed borehole water remaining in the packed interval,
- formation producing insufficient water volume to adequately purge the packed interval before sampling,
- inability to fully evacuate the packed interval during pumping,
- mixed borehole water bypassing the packer through interconnected fractures,
- potential cross contamination in the laboratory environment.

To ensure that above conditions did not occur, precise protocol measures were conducted. The sampling protocols can be found in the Revised Packer Assembly and Sampling Protocols for Borehole 121A at the CY HNP (CH2M HILL, March 2004) technical memorandum (technical memorandum). The protocols employed during the packer testing were intended to enhance the quality and representativeness of the groundwater samples collected from borehole 121A.

A total of five bedrock fracture zones were found to meet the criteria for collection of representative samples – i.e., the packer assembly was demonstrated to exhibit a satisfactory seal against the borehole wall and the zone produced sufficient volume of water to allow collection of the sample volume in a reasonable length of time. One of the zones sampled exhibited an imperfect packer seal, but was sampled because it was located in the midst of a very productive zone of fractures and in the professional judgement of the project hydrogeologist a representative sample could be collected.

Data logging pressure transducers located above, below, and within the packer-isolated interval were used to document the status of the packer seal during testing.

The effects of residual borehole water within the isolated interval were suspected of contributing to the non-representative samples collected and analyzed during the 2003 packer testing campaign. An algorithm was created using Microsoft Excel™ spreadsheet software to evaluate the contribution of residual water in the isolated interval to the measured tritium concentration in samples collected from uncontaminated zones. This effect is most pronounced in zones that produce little water and may not completely purge in reasonable lengths of time. The algorithm calculates the expected residual tritium concentration in samples collected following various purge volumes based on the measured initial tritium concentration in the borehole water and assuming dilution of that borehole water with uncontaminated formation water.

The interval from 317 to 322 feet bgs was such an interval in Borehole BH-121A. The packer seal was found to be acceptable and sampling proceeded. Three groundwater samples were collected from this interval during the 22-hour period of pumping for sample collection, one at the beginning of purging the zone, one after purging 84 gallons (approximately 1.5 system volumes) and a final sample collected after purging 96 gallons (approximately 2 system volumes). All three samples were analyzed for tritium by the on-site laboratory with results of 1,560 pCi/L, <1,230 pCi/L, and <1,230 pCi/L for the first, second, and third sample, respectively.

Using the initial observed concentration of 1,560 pCi/L of tritium, the purge effectiveness algorithm estimated a final tritium concentration of 568 pCi/L after purging 96 gallons of water from the formation. The third sample was also submitted for analysis of tritium content by the off-site laboratory, which has a lower minimum detectable concentration capability than the on-site facility. The result of the off-site analysis of the third sample was 496 pCi/L. This result is consistent with the predicted concentration indicating that the zone from 317 to 321 ft bgs is not contaminated, but the volume of water removed prior to sampling was not sufficient to completely remove the effects of residual borehole water within the isolated interval. The results of the heel dilution algorithm calculation are shown in Attachment A of this DQA.

The samples collected from the zones meeting the sample collection criteria are found to be representative of formation water with the exception of the sample from 317 to 321 feet bgs, which exhibits residual effects of borehole water in the sample. These samples are found to be usable for assessment of apparent vertical distribution of tritium in Borehole BH-121A based on representativeness.

Completeness

Completeness refers to the ability of the data set to encompass the entirety of the target system. The data should be sufficient to answer the questions that prompted the data collection in the first place. Due to the difficulty of retaining a tight seal during sample collection, only a fraction of the zones examined during packer testing were actually sampled. Of the 29 samples collected in Borehole 121A, five were considered valid Completeness objectives may be defined during planning as the number of valid measurements as a percent of the planned, or intended, number of measurements. Completeness was calculated as:

$$C = \frac{Nv}{Np} \times 100$$

Where: C = Completeness of the data set, presented as a %

Nv = The number of valid, usable, measurements collected in the data set

Np = The number of valid, usable, measurements planned, or initially identified for collection

Approximately 20% of the originally anticipated zones to sample were actually sampled. Of the zones exhibiting physical properties conducive to sample collection, however, 100% were sampled and analyzed..

Comparability

Comparability refers to the degree to which a data set, or single datum can be compared to another measurement for the purposes of assessing change over time or space. Split samples were collected for Tritium analysis from borehole 121A and were sent to HNP's on-site

radiochemistry laboratory, as well as an offsite laboratory. Both laboratories analyzed the samples by the distillation method.

Five split samples were identified in the data set provided for this sampling event. The Relative Percent Difference (RPD) for the split samples are summarized in Table 1.

Table 1. Comparison of On-site Lab. Tritium Results to Offsite Lab. Tritium Results

Borehole	Interval (ft bgs to ft bgs)	On-site Result (Pci/L)	Offsite Result (Pci/L)	RPD (%)
121A	103 to 108	<1,280	1,290	--
121A	152 to 157	3,200	2,430	27%
121A	153 to 176	8,170	8,170	0%
121A	178 to 183	6,360	6,060	5%
121A	317 to 322	<1,230	496	--

Notes:

-- = RPD could not be calculated because the actual value of the on-site laboratory result is unknown. The result was reported as "less than" a certain number.

RPD was calculated as:

$$RPD = \frac{|S1-S2|}{(S1+S2)/2} \times 100$$

Where: RPD = Relative Percent Difference reported as a %
S1 = First measurement
S2 = Second measurement
|S1-S2| = Absolute value of the difference between the two measurements
(S1+S2)/2 = Average of the two measurements

One of the five paired analyses exceeded the 20 percent RPD criteria. The absolute value of the difference between the two results, however, is relatively small. Large RPD is frequently encountered in analysis of samples with low concentrations of target analytes, where small absolute differences may result in large RPD. The reported samples are found acceptable for use in this assessment. The minimum detectable concentration (MDC) varied between the on-site and off-site laboratories, with the off-site MDC being about 30-50% of the on-site MDC. The results of the paired samples that included values less than the MDC are consistent between the two laboratories.

The results of tritium analysis of groundwater collected from the fractured bedrock formation during the 2004 packer testing campaign in borehole BH-121A are not comparable to the results of tritium analyses resulting from the 2003 packer testing campaign. The instrumented packer assembly and measurement protocols employed during the 2004 effort produced a set of definable representative samples. The samples collected during the 2003 testing campaign could not be confirmed to be representative.

DQA Summary

The tritium analysis data collected during the 2004 packer testing campaign in borehole BH-121A are found to be usable for assessment of hydraulic characteristics of the bedrock formation and for assessment of the apparent distribution of tritium in the fractured bedrock aquifer system. The data are usable to support design of a bedrock aquifer monitoring system.

The data set generated from the 2004 borehole 121A packer testing event was evaluated against criteria for measurement precision, accuracy, representativeness, completeness, and comparability to determine data validity and usability. The following data deficiencies were noted:

- No field duplicate samples were collected to measure precision on a single laboratory basis.
- No blank and/or matrix spike information was provided by the on-site laboratory to assess accuracy (e.g., blanks, spikes, and standards).
- Due to the difficulty of obtaining effective packer seals during examination of selected borehole zones, representative samples could not be collected from all of the fractured rock zones originally identified for testing.

Based partially on the inability to obtain packer-seal in numerous intervals, the alternative assessment method (i.e., hydrophysical™ logging) was used to supplement data collection in a total of 4 bedrock boreholes, including BH-121A.

Created by Matt Darois 10/26/2004

This spreadsheet calculates the residual heel concentration in the zone from 317-322 feet bgs assuming the pumping rate is the recharge rate of the formation.

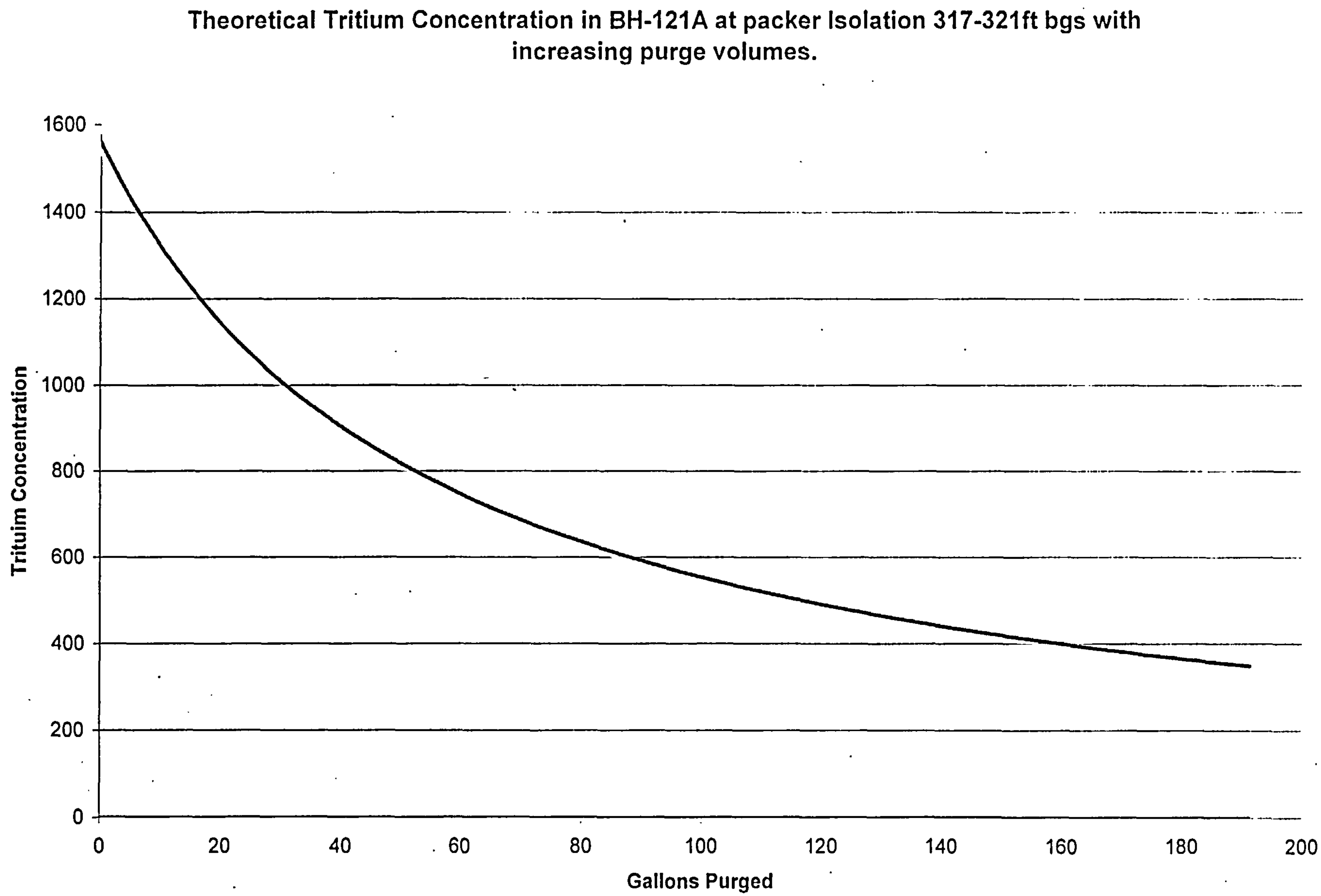
The dilution of the zone is calculated by the formula:

$$C_{tG} = \frac{C_{oG} V_0}{V_t + V_0}$$

The residual activity concentration is then converted to pCi/L and plotted against time

t =	Elapsed time
C_{0L} =	Original concentration in pCi/L
V_0 =	Original volume of isolated borehole water (packer riser pipe + isolation zone)
V_t =	Volume of purged water at time t
Q =	Purge rate of zone and discharge rate of formation (assumes they are equal).
C_{tL} =	Activity concentration at time t in pCi/L
C_{tG} =	Activity concentration at time t in pCi/gal
C_{oG} =	Original activity concentration in pCi/gal

Assumptions: Water is entering the isolation zone at a rate aproximate to the extraction rate.


Theoretical Tritium Concentration in BH-121A at packer Isolation 317-321ft bgs with increasing purge volumes.
Tritium Concentration
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
200
Gallons Purged

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
0	1,560	55	0	0.04	1560	412.15324	412.1532
10	1,560	55	0.4	0.04	1549	409	412.1532
20	1560	55	0.8	0.04	1538	406	412.1532
30	1560	55	1.2	0.04	1527	403	412.1532
40	1560	55	1.6	0.04	1516	401	412.1532
50	1560	55	2	0.04	1505	398	412.1532
60	1560	55	2.4	0.04	1495	395	412.1532
70	1560	55	2.8	0.04	1484	392	412.1532
80	1560	55	3.2	0.04	1474	389	412.1532
90	1560	55	3.6	0.04	1464	387	412.1532
100	1560	55	4	0.04	1454	384	412.1532
110	1560	55	4.4	0.04	1444	382	412.1532
120	1560	55	4.8	0.04	1435	379	412.1532
130	1560	55	5.2	0.04	1425	377	412.1532
140	1560	55	5.6	0.04	1416	374	412.1532
150	1560	55	6	0.04	1407	372	412.1532
160	1560	55	6.4	0.04	1397	369	412.1532
170	1560	55	6.8	0.04	1388	367	412.1532
180	1560	55	7.2	0.04	1379	364	412.1532
190	1560	55	7.6	0.04	1371	362	412.1532
200	1560	55	8	0.04	1362	360	412.1532
210	1560	55	8.4	0.04	1353	358	412.1532
220	1560	55	8.8	0.04	1345	355	412.1532
230	1560	55	9.2	0.04	1336	353	412.1532
240	1560	55	9.6	0.04	1328	351	412.1532
250	1560	55	10	0.04	1320	349	412.1532
260	1560	55	10.4	0.04	1312	347	412.1532
270	1560	55	10.8	0.04	1304	345	412.1532
280	1560	55	11.2	0.04	1296	342	412.1532
290	1560	55	11.6	0.04	1288	340	412.1532
300	1560	55	12	0.04	1281	338	412.1532
310	1560	55	12.4	0.04	1273	336	412.1532
320	1560	55	12.8	0.04	1265	334	412.1532
330	1560	55	13.2	0.04	1258	332	412.1532
340	1560	55	13.6	0.04	1251	330	412.1532
350	1560	55	14	0.04	1243	329	412.1532
360	1560	55	14.4	0.04	1236	327	412.1532
370	1560	55	14.8	0.04	1229	325	412.1532
380	1560	55	15.2	0.04	1222	323	412.1532
390	1560	55	15.6	0.04	1215	321	412.1532
400	1560	55	16	0.04	1208	319	412.1532
410	1560	55	16.4	0.04	1202	317	412.1532
420	1560	55	16.8	0.04	1195	316	412.1532
430	1560	55	17.2	0.04	1188	314	412.1532
440	1560	55	17.6	0.04	1182	312	412.1532
450	1560	55	18	0.04	1175	311	412.1532
460	1560	55	18.4	0.04	1169	309	412.1532
470	1560	55	18.8	0.04	1163	307	412.1532
480	1560	55	19.2	0.04	1156	306	412.1532
490	1560	55	19.6	0.04	1150	304	412.1532
500	1560	55	20	0.04	1144	302	412.1532
510	1560	55	20.4	0.04	1138	301	412.1532
520	1560	55	20.8	0.04	1132	299	412.1532
530	1560	55	21.2	0.04	1126	297	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
540	1560	55	21.6	0.04	1120	296	412.1532
550	1560	55	22	0.04	1114	294	412.1532
560	1560	55	22.4	0.04	1109	293	412.1532
570	1560	55	22.8	0.04	1103	291	412.1532
580	1560	55	23.2	0.04	1097	290	412.1532
590	1560	55	23.6	0.04	1092	288	412.1532
600	1560	55	24	0.04	1086	287	412.1532
610	1560	55	24.4	0.04	1081	285	412.1532
620	1560	55	24.8	0.04	1075	284	412.1532
630	1560	55	25.2	0.04	1070	283	412.1532
640	1560	55	25.6	0.04	1065	281	412.1532
650	1560	55	26	0.04	1059	280	412.1532
660	1560	55	26.4	0.04	1054	278	412.1532
670	1560	55	26.8	0.04	1049	277	412.1532
680	1560	55	27.2	0.04	1044	276	412.1532
690	1560	55	27.6	0.04	1039	274	412.1532
700	1560	55	28	0.04	1034	273	412.1532
710	1560	55	28.4	0.04	1029	272	412.1532
720	1560	55	28.8	0.04	1024	271	412.1532
730	1560	55	29.2	0.04	1019	269	412.1532
740	1560	55	29.6	0.04	1014	268	412.1532
750	1560	55	30	0.04	1009	267	412.1532
760	1560	55	30.4	0.04	1005	265	412.1532
770	1560	55	30.8	0.04	1000	264	412.1532
780	1560	55	31.2	0.04	995	263	412.1532
790	1560	55	31.6	0.04	991	262	412.1532
800	1560	55	32	0.04	986	261	412.1532
810	1560	55	32.4	0.04	982	259	412.1532
820	1560	55	32.8	0.04	977	258	412.1532
830	1560	55	33.2	0.04	973	257	412.1532
840	1560	55	33.6	0.04	968	256	412.1532
850	1560	55	34	0.04	964	255	412.1532
860	1560	55	34.4	0.04	960	254	412.1532
870	1560	55	34.8	0.04	955	252	412.1532
880	1560	55	35.2	0.04	951	251	412.1532
890	1560	55	35.6	0.04	947	250	412.1532
900	1560	55	36	0.04	943	249	412.1532
910	1560	55	36.4	0.04	939	248	412.1532
920	1560	55	36.8	0.04	935	247	412.1532
930	1560	55	37.2	0.04	931	246	412.1532
940	1560	55	37.6	0.04	927	245	412.1532
950	1560	55	38	0.04	923	244	412.1532
960	1560	55	38.4	0.04	919	243	412.1532
970	1560	55	38.8	0.04	915	242	412.1532
980	1560	55	39.2	0.04	911	241	412.1532
990	1560	55	39.6	0.04	907	240	412.1532
1000	1560	55	40	0.04	903	239	412.1532
1010	1560	55	40.4	0.04	899	238	412.1532
1020	1560	55	40.8	0.04	896	237	412.1532
1030	1560	55	41.2	0.04	892	236	412.1532
1040	1560	55	41.6	0.04	888	235	412.1532
1050	1560	55	42	0.04	885	234	412.1532
1060	1560	55	42.4	0.04	881	233	412.1532
1070	1560	55	42.8	0.04	877	232	412.1532
1080	1560	55	43.2	0.04	874	231	412.1532
1090	1560	55	43.6	0.04	870	230	412.1532
1100	1560	55	44	0.04	867	229	412.1532
1110	1560	55	44.4	0.04	863	228	412.1532
1120	1560	55	44.8	0.04	860	227	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
1130	1560	55	45.2	0.04	856	226	412.1532
1140	1560	55	45.6	0.04	853	225	412.1532
1150	1560	55	46	0.04	850	224	412.1532
1160	1560	55	46.4	0.04	846	224	412.1532
1170	1560	55	46.8	0.04	843	223	412.1532
1180	1560	55	47.2	0.04	840	222	412.1532
1190	1560	55	47.6	0.04	836	221	412.1532
1200	1560	55	48	0.04	833	220	412.1532
1210	1560	55	48.4	0.04	830	219	412.1532
1220	1560	55	48.8	0.04	827	218	412.1532
1230	1560	55	49.2	0.04	823	218	412.1532
1240	1560	55	49.6	0.04	820	217	412.1532
1250	1560	55	50	0.04	817	216	412.1532
1260	1560	55	50.4	0.04	814	215	412.1532
1270	1560	55	50.8	0.04	811	214	412.1532
1280	1560	55	51.2	0.04	808	213	412.1532
1290	1560	55	51.6	0.04	805	213	412.1532
1300	1560	55	52	0.04	802	212	412.1532
1310	1560	55	52.4	0.04	799	211	412.1532
1320	1560	55	52.8	0.04	796	210	412.1532
1330	1560	55	53.2	0.04	793	210	412.1532
1340	1560	55	53.6	0.04	790	209	412.1532
1350	1560	55	54	0.04	787	208	412.1532
1360	1560	55	54.4	0.04	784	207	412.1532
1370	1560	55	54.8	0.04	781	206	412.1532
1380	1560	55	55.2	0.04	779	206	412.1532
1390	1560	55	55.6	0.04	776	205	412.1532
1400	1560	55	56	0.04	773	204	412.1532
1410	1560	55	56.4	0.04	770	203	412.1532
1420	1560	55	56.8	0.04	767	203	412.1532
1430	1560	55	57.2	0.04	765	202	412.1532
1440	1560	55	57.6	0.04	762	201	412.1532
1450	1560	55	58	0.04	759	201	412.1532
1460	1560	55	58.4	0.04	757	200	412.1532
1470	1560	55	58.8	0.04	754	199	412.1532
1480	1560	55	59.2	0.04	751	198	412.1532
1490	1560	55	59.6	0.04	749	198	412.1532
1500	1560	55	60	0.04	746	197	412.1532
1510	1560	55	60.4	0.04	744	196	412.1532
1520	1560	55	60.8	0.04	741	196	412.1532
1530	1560	55	61.2	0.04	738	195	412.1532
1540	1560	55	61.6	0.04	736	194	412.1532
1550	1560	55	62	0.04	733	194	412.1532
1560	1560	55	62.4	0.04	731	193	412.1532
1570	1560	55	62.8	0.04	728	192	412.1532
1580	1560	55	63.2	0.04	726	192	412.1532
1590	1560	55	63.6	0.04	723	191	412.1532
1600	1560	55	64	0.04	721	190	412.1532
1610	1560	55	64.4	0.04	719	190	412.1532
1620	1560	55	64.8	0.04	716	189	412.1532
1630	1560	55	65.2	0.04	714	189	412.1532
1640	1560	55	65.6	0.04	711	188	412.1532
1650	1560	55	66	0.04	709	187	412.1532
1660	1560	55	66.4	0.04	707	187	412.1532
1670	1560	55	66.8	0.04	704	186	412.1532
1680	1560	55	67.2	0.04	702	186	412.1532
1690	1560	55	67.6	0.04	700	185	412.1532
1700	1560	55	68	0.04	698	184	412.1532
1710	1560	55	68.4	0.04	695	184	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
1720	1560	55	68.8	0.04	693	183	412.1532
1730	1560	55	69.2	0.04	691	183	412.1532
1740	1560	55	69.6	0.04	689	182	412.1532
1750	1560	55	70	0.04	686	181	412.1532
1760	1560	55	70.4	0.04	684	181	412.1532
1770	1560	55	70.8	0.04	682	180	412.1532
1780	1560	55	71.2	0.04	680	180	412.1532
1790	1560	55	71.6	0.04	678	179	412.1532
1800	1560	55	72	0.04	676	178	412.1532
1810	1560	55	72.4	0.04	673	178	412.1532
1820	1560	55	72.8	0.04	671	177	412.1532
1830	1560	55	73.2	0.04	669	177	412.1532
1840	1560	55	73.6	0.04	667	176	412.1532
1850	1560	55	74	0.04	665	176	412.1532
1860	1560	55	74.4	0.04	663	175	412.1532
1870	1560	55	74.8	0.04	661	175	412.1532
1880	1560	55	75.2	0.04	659	174	412.1532
1890	1560	55	75.6	0.04	657	174	412.1532
1900	1560	55	76	0.04	655	173	412.1532
1910	1560	55	76.4	0.04	653	173	412.1532
1920	1560	55	76.8	0.04	651	172	412.1532
1930	1560	55	77.2	0.04	649	171	412.1532
1940	1560	55	77.6	0.04	647	171	412.1532
1950	1560	55	78	0.04	645	170	412.1532
1960	1560	55	78.4	0.04	643	170	412.1532
1970	1560	55	78.8	0.04	641	169	412.1532
1980	1560	55	79.2	0.04	639	169	412.1532
1990	1560	55	79.6	0.04	637	168	412.1532
2000	1560	55	80	0.04	636	168	412.1532
2010	1560	55	80.4	0.04	634	167	412.1532
2020	1560	55	80.8	0.04	632	167	412.1532
2030	1560	55	81.2	0.04	630	166	412.1532
2040	1560	55	81.6	0.04	628	166	412.1532
2050	1560	55	82	0.04	626	165	412.1532
2060	1560	55	82.4	0.04	624	165	412.1532
2070	1560	55	82.8	0.04	623	165	412.1532
2080	1560	55	83.2	0.04	621	164	412.1532
2090	1560	55	83.6	0.04	619	164	412.1532
2100	1560	55	84	0.04	617	163	412.1532
2110	1560	55	84.4	0.04	615	163	412.1532
2120	1560	55	84.8	0.04	614	162	412.1532
2130	1560	55	85.2	0.04	612	162	412.1532
2140	1560	55	85.6	0.04	610	161	412.1532
2150	1560	55	86	0.04	609	161	412.1532
2160	1560	55	86.4	0.04	607	160	412.1532
2170	1560	55	86.8	0.04	605	160	412.1532
2180	1560	55	87.2	0.04	603	159	412.1532
2190	1560	55	87.6	0.04	602	159	412.1532
2200	1560	55	88	0.04	600	159	412.1532
2210	1560	55	88.4	0.04	598	158	412.1532
2220	1560	55	88.8	0.04	597	158	412.1532
2230	1560	55	89.2	0.04	595	157	412.1532
2240	1560	55	89.6	0.04	593	157	412.1532
2250	1560	55	90	0.04	592	156	412.1532
2260	1560	55	90.4	0.04	590	156	412.1532
2270	1560	55	90.8	0.04	588	155	412.1532
2280	1560	55	91.2	0.04	587	155	412.1532
2290	1560	55	91.6	0.04	585	155	412.1532
2300	1560	55	92	0.04	584	154	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
2310	1560	55	92.4	0.04	582	154	412.1532
2320	1560	55	92.8	0.04	581	153	412.1532
2330	1560	55	93.2	0.04	579	153	412.1532
2340	1560	55	93.6	0.04	577	153	412.1532
2350	1560	55	94	0.04	576	152	412.1532
2360	1560	55	94.4	0.04	574	152	412.1532
2370	1560	55	94.8	0.04	573	151	412.1532
2380	1560	55	95.2	0.04	571	151	412.1532
2390	1560	55	95.6	0.04	570	151	412.1532
2400	1560	55	96	0.04	568	150	412.1532
2410	1560	55	96.4	0.04	567	150	412.1532
2420	1560	55	96.8	0.04	565	149	412.1532
2430	1560	55	97.2	0.04	564	149	412.1532
2440	1560	55	97.6	0.04	562	149	412.1532
2450	1560	55	98	0.04	561	148	412.1532
2460	1560	55	98.4	0.04	559	148	412.1532
2470	1560	55	98.8	0.04	558	147	412.1532
2480	1560	55	99.2	0.04	556	147	412.1532
2490	1560	55	99.6	0.04	555	147	412.1532
2500	1560	55	100	0.04	554	146	412.1532
2510	1560	55	100.4	0.04	552	146	412.1532
2520	1560	55	100.8	0.04	551	145	412.1532
2530	1560	55	101.2	0.04	549	145	412.1532
2540	1560	55	101.6	0.04	548	145	412.1532
2550	1560	55	102	0.04	546	144	412.1532
2560	1560	55	102.4	0.04	545	144	412.1532
2570	1560	55	102.8	0.04	544	144	412.1532
2580	1560	55	103.2	0.04	542	143	412.1532
2590	1560	55	103.6	0.04	541	143	412.1532
2600	1560	55	104	0.04	540	143	412.1532
2610	1560	55	104.4	0.04	538	142	412.1532
2620	1560	55	104.8	0.04	537	142	412.1532
2630	1560	55	105.2	0.04	536	142	412.1532
2640	1560	55	105.6	0.04	534	141	412.1532
2650	1560	55	106	0.04	533	141	412.1532
2660	1560	55	106.4	0.04	532	140	412.1532
2670	1560	55	106.8	0.04	530	140	412.1532
2680	1560	55	107.2	0.04	529	140	412.1532
2690	1560	55	107.6	0.04	528	139	412.1532
2700	1560	55	108	0.04	526	139	412.1532
2710	1560	55	108.4	0.04	525	139	412.1532
2720	1560	55	108.8	0.04	524	138	412.1532
2730	1560	55	109.2	0.04	523	138	412.1532
2740	1560	55	109.6	0.04	521	138	412.1532
2750	1560	55	110	0.04	520	137	412.1532
2760	1560	55	110.4	0.04	519	137	412.1532
2770	1560	55	110.8	0.04	517	137	412.1532
2780	1560	55	111.2	0.04	516	136	412.1532
2790	1560	55	111.6	0.04	515	136	412.1532
2800	1560	55	112	0.04	514	136	412.1532
2810	1560	55	112.4	0.04	513	135	412.1532
2820	1560	55	112.8	0.04	511	135	412.1532
2830	1560	55	113.2	0.04	510	135	412.1532
2840	1560	55	113.6	0.04	509	134	412.1532
2850	1560	55	114	0.04	508	134	412.1532
2860	1560	55	114.4	0.04	506	134	412.1532
2870	1560	55	114.8	0.04	505	134	412.1532
2880	1560	55	115.2	0.04	504	133	412.1532
2890	1560	55	115.6	0.04	503	133	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
2900	1560	55	116	0.04	502	133	412.1532
2910	1560	55	116.4	0.04	501	132	412.1532
2920	1560	55	116.8	0.04	499	132	412.1532
2930	1560	55	117.2	0.04	498	132	412.1532
2940	1560	55	117.6	0.04	497	131	412.1532
2950	1560	55	118	0.04	496	131	412.1532
2960	1560	55	118.4	0.04	495	131	412.1532
2970	1560	55	118.8	0.04	494	130	412.1532
2980	1560	55	119.2	0.04	493	130	412.1532
2990	1560	55	119.6	0.04	491	130	412.1532
3000	1560	55	120	0.04	490	130	412.1532
3010	1560	55	120.4	0.04	489	129	412.1532
3020	1560	55	120.8	0.04	488	129	412.1532
3030	1560	55	121.2	0.04	487	129	412.1532
3040	1560	55	121.6	0.04	486	128	412.1532
3050	1560	55	122	0.04	485	128	412.1532
3060	1560	55	122.4	0.04	484	128	412.1532
3070	1560	55	122.8	0.04	483	127	412.1532
3080	1560	55	123.2	0.04	481	127	412.1532
3090	1560	55	123.6	0.04	480	127	412.1532
3100	1560	55	124	0.04	479	127	412.1532
3110	1560	55	124.4	0.04	478	126	412.1532
3120	1560	55	124.8	0.04	477	126	412.1532
3130	1560	55	125.2	0.04	476	126	412.1532
3140	1560	55	125.6	0.04	475	126	412.1532
3150	1560	55	126	0.04	474	125	412.1532
3160	1560	55	126.4	0.04	473	125	412.1532
3170	1560	55	126.8	0.04	472	125	412.1532
3180	1560	55	127.2	0.04	471	124	412.1532
3190	1560	55	127.6	0.04	470	124	412.1532
3200	1560	55	128	0.04	469	124	412.1532
3210	1560	55	128.4	0.04	468	124	412.1532
3220	1560	55	128.8	0.04	467	123	412.1532
3230	1560	55	129.2	0.04	466	123	412.1532
3240	1560	55	129.6	0.04	465	123	412.1532
3250	1560	55	130	0.04	464	123	412.1532
3260	1560	55	130.4	0.04	463	122	412.1532
3270	1560	55	130.8	0.04	462	122	412.1532
3280	1560	55	131.2	0.04	461	122	412.1532
3290	1560	55	131.6	0.04	460	121	412.1532
3300	1560	55	132	0.04	459	121	412.1532
3310	1560	55	132.4	0.04	458	121	412.1532
3320	1560	55	132.8	0.04	457	121	412.1532
3330	1560	55	133.2	0.04	456	120	412.1532
3340	1560	55	133.6	0.04	455	120	412.1532
3350	1560	55	134	0.04	454	120	412.1532
3360	1560	55	134.4	0.04	453	120	412.1532
3370	1560	55	134.8	0.04	452	119	412.1532
3380	1560	55	135.2	0.04	451	119	412.1532
3390	1560	55	135.6	0.04	450	119	412.1532
3400	1560	55	136	0.04	449	119	412.1532
3410	1560	55	136.4	0.04	448	118	412.1532
3420	1560	55	136.8	0.04	447	118	412.1532
3430	1560	55	137.2	0.04	446	118	412.1532
3440	1560	55	137.6	0.04	445	118	412.1532
3450	1560	55	138	0.04	445	117	412.1532
3460	1560	55	138.4	0.04	444	117	412.1532
3470	1560	55	138.8	0.04	443	117	412.1532
3480	1560	55	139.2	0.04	442	117	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{tL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
3490	1560	55	139.6	0.04	441	116	412.1532
3500	1560	55	140	0.04	440	116	412.1532
3510	1560	55	140.4	0.04	439	116	412.1532
3520	1560	55	140.8	0.04	438	116	412.1532
3530	1560	55	141.2	0.04	437	116	412.1532
3540	1560	55	141.6	0.04	436	115	412.1532
3550	1560	55	142	0.04	436	115	412.1532
3560	1560	55	142.4	0.04	435	115	412.1532
3570	1560	55	142.8	0.04	434	115	412.1532
3580	1560	55	143.2	0.04	433	114	412.1532
3590	1560	55	143.6	0.04	432	114	412.1532
3600	1560	55	144	0.04	431	114	412.1532
3610	1560	55	144.4	0.04	430	114	412.1532
3620	1560	55	144.8	0.04	429	113	412.1532
3630	1560	55	145.2	0.04	429	113	412.1532
3640	1560	55	145.6	0.04	428	113	412.1532
3650	1560	55	146	0.04	427	113	412.1532
3660	1560	55	146.4	0.04	426	113	412.1532
3670	1560	55	146.8	0.04	425	112	412.1532
3680	1560	55	147.2	0.04	424	112	412.1532
3690	1560	55	147.6	0.04	423	112	412.1532
3700	1560	55	148	0.04	423	112	412.1532
3710	1560	55	148.4	0.04	422	111	412.1532
3720	1560	55	148.8	0.04	421	111	412.1532
3730	1560	55	149.2	0.04	420	111	412.1532
3740	1560	55	149.6	0.04	419	111	412.1532
3750	1560	55	150	0.04	419	111	412.1532
3760	1560	55	150.4	0.04	418	110	412.1532
3770	1560	55	150.8	0.04	417	110	412.1532
3780	1560	55	151.2	0.04	416	110	412.1532
3790	1560	55	151.6	0.04	415	110	412.1532
3800	1560	55	152	0.04	414	110	412.1532
3810	1560	55	152.4	0.04	414	109	412.1532
3820	1560	55	152.8	0.04	413	109	412.1532
3830	1560	55	153.2	0.04	412	109	412.1532
3840	1560	55	153.6	0.04	411	109	412.1532
3850	1560	55	154	0.04	411	108	412.1532
3860	1560	55	154.4	0.04	410	108	412.1532
3870	1560	55	154.8	0.04	409	108	412.1532
3880	1560	55	155.2	0.04	408	108	412.1532
3890	1560	55	155.6	0.04	407	108	412.1532
3900	1560	55	156	0.04	407	107	412.1532
3910	1560	55	156.4	0.04	406	107	412.1532
3920	1560	55	156.8	0.04	405	107	412.1532
3930	1560	55	157.2	0.04	404	107	412.1532
3940	1560	55	157.6	0.04	404	107	412.1532
3950	1560	55	158	0.04	403	106	412.1532
3960	1560	55	158.4	0.04	402	106	412.1532
3970	1560	55	158.8	0.04	401	106	412.1532
3980	1560	55	159.2	0.04	401	106	412.1532
3990	1560	55	159.6	0.04	400	106	412.1532
4000	1560	55	160	0.04	399	105	412.1532
4010	1560	55	160.4	0.04	398	105	412.1532
4020	1560	55	160.8	0.04	398	105	412.1532
4030	1560	55	161.2	0.04	397	105	412.1532
4040	1560	55	161.6	0.04	396	105	412.1532
4050	1560	55	162	0.04	395	104	412.1532
4060	1560	55	162.4	0.04	395	104	412.1532
4070	1560	55	162.8	0.04	394	104	412.1532

t (min)	C_{oL} (pCi/L)	V_o (Gal)	V_t (Gal)	Q (Gal)	C_{iL} (pCi/L)	C_{tG} (pCi/gal)	C_{oG} gal
4080	1560	55	163.2	0.04	393	104	412.1532
4090	1560	55	163.6	0.04	392	104	412.1532
4100	1560	55	164	0.04	392	104	412.1532
4110	1560	55	164.4	0.04	391	103	412.1532
4120	1560	55	164.8	0.04	390	103	412.1532
4130	1560	55	165.2	0.04	390	103	412.1532
4140	1560	55	165.6	0.04	389	103	412.1532
4150	1560	55	166	0.04	388	103	412.1532
4160	1560	55	166.4	0.04	388	102	412.1532
4170	1560	55	166.8	0.04	387	102	412.1532
4180	1560	55	167.2	0.04	386	102	412.1532
4190	1560	55	167.6	0.04	385	102	412.1532
4200	1560	55	168	0.04	385	102	412.1532
4210	1560	55	168.4	0.04	384	101	412.1532
4220	1560	55	168.8	0.04	383	101	412.1532
4230	1560	55	169.2	0.04	383	101	412.1532
4240	1560	55	169.6	0.04	382	101	412.1532
4250	1560	55	170	0.04	381	101	412.1532
4260	1560	55	170.4	0.04	381	101	412.1532
4270	1560	55	170.8	0.04	380	100	412.1532
4280	1560	55	171.2	0.04	379	100	412.1532
4290	1560	55	171.6	0.04	379	100	412.1532
4300	1560	55	172	0.04	378	100	412.1532
4310	1560	55	172.4	0.04	377	100	412.1532
4320	1560	55	172.8	0.04	377	100	412.1532
4330	1560	55	173.2	0.04	376	99	412.1532
4340	1560	55	173.6	0.04	375	99	412.1532
4350	1560	55	174	0.04	375	99	412.1532
4360	1560	55	174.4	0.04	374	99	412.1532
4370	1560	55	174.8	0.04	373	99	412.1532
4380	1560	55	175.2	0.04	373	98	412.1532
4390	1560	55	175.6	0.04	372	98	412.1532
4400	1560	55	176	0.04	371	98	412.1532
4410	1560	55	176.4	0.04	371	98	412.1532
4420	1560	55	176.8	0.04	370	98	412.1532
4430	1560	55	177.2	0.04	370	98	412.1532
4440	1560	55	177.6	0.04	369	97	412.1532
4450	1560	55	178	0.04	368	97	412.1532
4460	1560	55	178.4	0.04	368	97	412.1532
4470	1560	55	178.8	0.04	367	97	412.1532
4480	1560	55	179.2	0.04	366	97	412.1532
4490	1560	55	179.6	0.04	366	97	412.1532
4500	1560	55	180	0.04	365	96	412.1532
4510	1560	55	180.4	0.04	364	96	412.1532
4520	1560	55	180.8	0.04	364	96	412.1532
4530	1560	55	181.2	0.04	363	96	412.1532
4540	1560	55	181.6	0.04	363	96	412.1532
4550	1560	55	182	0.04	362	96	412.1532
4560	1560	55	182.4	0.04	361	95	412.1532
4570	1560	55	182.8	0.04	361	95	412.1532
4580	1560	55	183.2	0.04	360	95	412.1532
4590	1560	55	183.6	0.04	360	95	412.1532
4600	1560	55	184	0.04	359	95	412.1532
4610	1560	55	184.4	0.04	358	95	412.1532
4620	1560	55	184.8	0.04	358	95	412.1532
4630	1560	55	185.2	0.04	357	94	412.1532
4640	1560	55	185.6	0.04	357	94	412.1532
4650	1560	55	186	0.04	356	94	412.1532
4660	1560	55	186.4	0.04	355	94	412.1532

1 Data Quality Assessment Offsite Analytical

Current quality assurance/quality control (QA/QC) efforts in support of the Groundwater Monitoring Program at the Haddam Neck Plant (HNP) are designed to assess and enhance the reliability and validity of field and laboratory measurements conducted to support these programs. General quality requirements are provided in References LTP 2002 and GMP-QAPP 2002.

1.1 Data Quality Metrics

On the analytical side, accuracy, precision, and detection sensitivity are the primary indicators used to assess laboratory data quality. These parameters are evaluated through laboratory QC checks (e.g., matrix spikes, laboratory blanks), replicate sampling and analysis, analysis of blind standards and blanks, and inter-laboratory comparisons.

Acceptance criteria have been established for each of these parameters. When a parameter is outside the criteria, corrective actions are taken to minimize future occurrence. Numerical criteria for evaluating precision, accuracy and completeness performance are generally available, while metrics for representativeness and comparability are more qualitative in nature.

The data quality metrics for radiochemical constituents are summarized as follows:

• Precision	Relative Percent Difference (RPD) < 25% or
	within 2-σ TPU of the Initial Value
• Accuracy	Laboratory Control Sample Recovery 100% +/- 30
	Laboratory Blank Analysis Results Non-Detect
	Laboratory Blank Analysis Results < MDC
• Representativeness	Qualitative assessment of sample location, sample timing, sample collection method, sample preservation, handling, shipment
• Completeness	Valid measurements for critical samples = 100%
• Comparability	Qualitative assessment of sample collection and measurement methods
	Assignment of sample locations to hydrostratigraphic units.
	Sample MDC < CRDL

1.1.1 Precision

Precision was evaluated through the use of duplicate and split or replicate samples. Field QC samples typically consist of duplicates, splits and blank samples. Field duplicate samples are used to assess sampling and measurement precision. Field split samples are used to assess measurement precision. Field splits and duplicates are typically examined to independently monitor laboratory performance and to identify potential problem areas where improvements are necessary.

Internal or lab QC samples are comprised of lab control spikes, matrix spikes, method blanks, duplicates and replicates. The precision or reproducibility of lab measurements is evaluated through the use of matrix duplicates. These duplicates are processed at a frequency of one matrix duplicate per batch. Internal acceptance criteria for duplicate samples are summarized as follows:

- Accuracy within 20%
- Accuracy within allowed uncertainty and based on contract required detection limit (CRDL)

Sample and duplicate analysis results greater than 5 times the CRDL, must fall within ± 20% of the observed value. Sample or duplicate analysis results less than the product of 5 times the CRDL, the difference should be less than or equal to the CRDL.

Approximately 12% of the total number of samples analyzed, for radiochemical and boron constituents were internal lab duplicates or replicates. Results of the data quality assessment for precision are discussed in the following subsections.

1.1.1.1 Field Duplicates

No field duplicate samples were collected during the 2004 packer testing campaign.

1.1.1.2 Lab Duplicates

A total of 47 lab replicate samples were processed during 2004 packer testing campaign. Only 4 of these replicate samples contained sufficient analyte concentrations to be used in the precision evaluation. The lab duplicate results are summarized in Table 2-2. Three (3) of four (4) lab duplicate results are within 10% of the initial sample results and indicate satisfactory precision. The gross alpha replicate results at the 152-157 foot depth were outside the acceptance criteria at +25.4% but were within statistical agreement limits (+1.8-σ), given the uncertainty of the measurements and based on a simple comparison of two mean values with known variances.

1.1.2 Accuracy

Laboratory performance for accuracy is measured by several indicators, including nationally based performance evaluation studies, double-blind standard analyses and internal laboratory QA/QC programs. Measurement accuracy was evaluated by three methods:

- Calculation of percent recovery of laboratory control samples (e.g., calibration standards, blank spikes, and matrix spikes);
- Comparison of reported minimum detectable concentration (MDC) to selected performance standards (e.g., drinking water standards);
- Comparison of method blank analyses to the MDC.

Results of the data quality assessment for accuracy are discussed in the following subsections.

1.1.2.1 External Laboratory Performance Evaluations

This section provides a detailed discussion of external performance indicators for the GEL laboratories. The GEL lab took part in US Department of Energy (DOE) Quality Assessment Program and the DOE's Mixed Analyte Performance Evaluation Program. The GEL lab also participated in the Environmental Resource Associates (ERA) RadCheM™ PT program. Results of those studies related to GW monitoring at HNP, are described in this section.

DOE Quality Assessment Program

DOE 's Quality Assessment Program (QAP) evaluates how laboratories perform when they analyze radionuclides in water, air filter, soil, and vegetation samples. This program is coordinated by the Environmental Measurements Laboratory (EML) in New York City, New York. EML provides blind standards that contain specific amounts of one or more radionuclides to participating laboratories. Gamma emitters typically include K-40, Mn-54, Co-60, Cs-137, Bi-212, Pb-212, Bi-214 and Pb-214. Alpha emitters typically include U-234, Th-234, U-238, Pu-238, Pu-239, Am-241 and Cm-244. The beta and hard-to-detect (HTD) radionuclides typically include H-3, Fe-55, Ni-63 and Sr-90.

After sample analysis, each participating laboratory forwards the results to EML for comparison with known values and with results from other laboratories. Using a cumulative normalized distribution, acceptable performance yields results between the 15th and 85th percentiles. Acceptable with warning results are between the 5th and 15th percentile and between the 85th and 95th percentile. Not acceptable results include the outer 10% (less than 5th percentile or more than 95th percentile) of historical data.

For the nine (9) QAP studies conducted from June 2000 through June 2004 (see References EML-608, 611, 613, 615, 617, 618, 621, QAP59 and QAP60), the percentages of acceptable or acceptable with warning results are summarized as a function of media and analysis type in Table 2-3. Overall, approximately 97.1% of the GEL data was in the acceptable or acceptable with warning performance category. For gamma isotopic analyses, 97.4% of the reported lab data was in the acceptable or acceptable with warning category. Approximately 98% of the alpha isotopic results and 94% of the HTD beta results were in the acceptable or acceptable with warning range. The DOE QAP60 program is the last performance evaluation that will be provided by the DOE.

DOE Mixed Analyte Performance Evaluation Program

DOE's Mixed Analyte Performance Evaluation Program (MAPEP) examines laboratory performance in the analysis of soil and water samples containing metals, volatile and semi-volatile organic compounds and radionuclides. The program is conducted at the Radiological and Environmental Sciences Laboratory (RESL) in Idaho Falls, Idaho, and is similar in operation to DOE 's QAP discussed above. DOE evaluates the accuracy of the MAPEP results for radiological and inorganic samples by determining if they fall within a 30% bias of the reference value. Analytical results with a reported bias less than or equal to 20% are flagged as acceptable. Analytical results with a reported bias greater than 20% but less than or equal to 30% are flagged as acceptable with warning.

RESL provides blind standards that contain specific amounts of one or more radionuclides to participating laboratories. Gamma emitters typically include K-40, Mn-54, Co-57, Co-60, Zn-65, Cs-134 and Cs-137. Alpha emitters typically include U-234, U-238, Pu-238, Pu-239 and Am-241. The beta and hard-to-detect (HTD) radionuclides typically include Fe-55, Ni-63 and Sr-90.

The MAPEP program also uses false positive testing on a routine basis to identify laboratory results that indicate the presence of a particular radionuclide in a sample, when in fact the actual activity of the radionuclide is far below the required detection limit. False positive test nuclides typically include Sr-90, Fe-55 or Pu-238. Acceptable performance is indicated when the reported range encompassing the results (i.e., net concentration ± 3-σ uncertainty) included zero. Unacceptable performance is indicated when this range does not include zero.

For the ten MAPEP studies conducted through May 2002 (see References MAPEP-S6, S7, S8, S9, S10 and MAPEP-W7, W8, W9, W10, W11), the percentages of acceptable or acceptable with warning results are summarized as a function of media in Table 2-4.

Overall, about 96% of the GEL data was in the acceptable or acceptable with warning performance category for all media. For gamma isotopic analyses, 100% of the reported lab data was in the acceptable or acceptable with warning category. Approximately 96% of the alpha isotopic results and 86% of the HTD beta results were in the acceptable or acceptable with warning range. GEL experienced some problems with the low level false positive testing where 70% of the reported results were in the acceptable or acceptable with warning range.

ERA RadCheM™ Proficiency Testing (PT) Program

Environmental Resource Associates (ERA) RadCheM™ PT program is based on the National Standards for Water Proficiency Testing Studies Criteria Document (Reference NSWPT 1998). ERA examines laboratory performance in the analysis of water samples containing gross alpha/beta, naturals including uranium, mixed beta and gamma emitters. The program is conducted by ERA in Arvada, Colorado. ERA evaluates the accuracy of submitted results for radiological samples by determining if they fall within EPA or NELAC control limits.

ERA provides blind standards that contain specific amounts of one or more radionuclides to participating laboratories. Gamma emitters typically include Co-60,

Zn-65, I-131, Ba-133, Cs-134, Cs-137 and Ra-226. Alpha and beta analyses typically include gross alpha, gross beta, H-3, Sr-89, Sr-90, Ra-228 and natural uranium.

The GEL lab participated in five (5) of the last (6) ERA studies (see References ERA-52, 53, 54, 55 and 57). The percentages of acceptable or acceptable with warning results for these five (5) studies are summarized as a function of analysis type in Table 2-5. Overall, 98.4% of the GEL reported lab data was in the acceptable or acceptable with warning performance category for all media.

1.1.2.2 Field Blank Results

A decontamination station is typically established near monitoring wells sampled with non-dedicated equipment to provide for the proper decontamination of dedicated sampling equipment. All non-disposable equipment used during the program was subject to decontamination. These components included the groundwater sampling pumps, electrical lead wires and support cable, as well as the flow-through cell in which field parameters were measured.

A total of three (3) equipment blanks were collected during the 2004 packer testing campaign. Equipment rinsate blank samples were collected from the bladder pump, Grundfos pump and the riser pipe during the course of packer testing. The equipment blanks were collected prior to packer test use. Plant de-ionized (DI) water was used for the equipment rinsate blank samples.

Equipment blank results for boron were greater than the method detection limit (MDL) of 0.54-µg/L. The reported equipment blank concentrations ranged from 2.34 to 12.9-µg/L indicating a positive trend at these analyte concentrations.

All three (3) equipment blank results for H-3 were detected at concentrations greater than 2-σ TPU and greater than the nominal minimum detectable concentration (MDC) of 140-pCi/L. The reported equipment blank ranged from 325 to 329-pCi/L indicating a positive trend at these analyte concentrations. The precision of these three (3) measurements and the sequence of equipment blank collection suggest that plant DI water may be the source of H-3 at these analyte levels.

All remaining equipment blanks were non-detect or negative at the 2-σ TPU level suggesting little or no influence at these levels.

1.1.2.3 Method Blank Results

A total of 50 lab blank samples were processed during 2004 packer testing campaign. Analytical blank results for boron were greater than the method detection limit (MDL) of 0.54-µg/L. The reported concentration was 15-µg/L for both analytical blank results indicating a positive bias at these analyte concentrations.

One (1) of two (2) lab analytical blanks was statistically positive at the 2-σ TPU level but less than the MDC for gross alpha, gross beta, Sr-90 and Cs-134. The gross alpha, gross beta and Sr-90 analyses are performed by gas proportional counting (GPC). Statistically

positive results for three (3) of the six (6) GPC analytical blanks suggests a positive bias with this analytical technique at these levels.

Cesium-134 is determined by gamma isotopic analysis. Only one (1) of twenty (20) gamma isotopic analytical blanks were positive and less than the MDC, suggesting little or no analytical bias in the gamma isotopic analyses at these levels.

1.1.2.4 Internal Lab Performance Evaluations

Individual internal QC results are contained within Appendices D-1 and indicate that the recovery rates for the laboratories are within acceptable ranges for the analyses performed. Approximately 50% of the samples analyzed by GEL during the packer testing event were QC samples. These lab QC samples are comprised of lab control spikes, matrix spikes, method blanks, duplicates and replicates. Attached in Table 2-6 is a summary of the number of QC samples processed by the GEL lab during the 2004 packer sample testing events.

Internal Performance Criteria

GEL performed a minimum of one laboratory control sample (LCS), one method or reagent blank (MB), and one duplicate sample analysis for each analysis performed in a batch of samples according to References GEL QAP 2003 and CY-ISC-SOW 2003. Batch sizes are composed of one to a maximum of 20 environmental samples. Matrix spike (MS) samples are also analyzed when the analytical method involves chemical or physical separation and does not use an internal standard or carrier, and sufficient sample volume exists.

Internal acceptance criteria for LCS and MS samples are summarized as follows:

- Accuracy within QC acceptance limits (see Table 2-7)
- Results within 2-σ TPU of the observed value
- Accuracy within allowed uncertainty and based on contract required detection limit (CRDL)

Matrix Spikes (MS) are first corrected for any ambient test nuclide activity. Samples with ambient activity greater than 4 times the expected value of the spike are not required to fulfill MS acceptance criteria. The activity levels of target analytes in LCS and MS samples are greater than 10 times but less than 100 times the *a priori* lower limit of detection (LLD). Acceptance criteria for LCS and MS samples are 75% to 125%. Additionally, all QC and sample results must have chemical recoveries or chemical yields within the range of 15% to 125%.

Internal Performance Results for Accuracy

The percentages of acceptable results are summarized as a function of analysis method in Table 2-8. Overall, about 98.4% of the GEL performance data for LCS and MS samples were acceptable according to performance criteria. GEL experienced some problems with the boron analyses where two (2) of three (3) or 67% of the reported results were within acceptable limits.

Internal Performance – Method Blank Results

Method or reagent blank results are evaluated or compared to the contract required detection limit (CRDL) and the lowest sample activity in a batch. Acceptable method blanks are those results that are less than the CRDL or less than 5% of the lowest sample activity in the batch. Method blank results that do not meet the acceptance criteria are critically examined according to the GEL SOPs and documented through GEL's nonconformance reporting (NCR) system. Method blank failures are also documented in the case narrative of the analytical report. Method blank activity levels are not subtracted from sample activity levels. All method blank results met internal GEL performance criteria.

1.1.2.5 Intra-Lab Performance Evaluations

The on-site HNP laboratory performed tritium and gamma isotopic analyses to support off-site sample shipments. Off-site analyses are similar to those provided on-site. Comparability of analytical results is discussed in the "*Data Quality Assessment of the Bedrock Borehole 121A Packer Test On-site Laboratory Results Collected in the Spring and Summer of 2004*", Appendix 3 with this DQA.

1.1.3 Completeness

Completeness was evaluated by comparison of the number of valid measurements produced to the number of measurements planned. The target for completeness of valid measurements for all radionuclides for this sampling event was 100%. This objective was selected to maximize sampling resources.

Valid results were generated for twenty-five (25) analytes in five (5) samples. Valid results were also generated for twenty-four (25) analytes in three (3) equipment blank samples. Valid results were generated for a total of 200 analyte tests, resulting in completeness of 100%.

1.1.4 Comparability

Comparability was evaluated qualitatively through assessment of sampling and measurement methods. The analytical methods used for this determination are comparable to methods used to measure dissolved species in natural waters. The analytical techniques used during the straddle packer testing are comparable to quarterly groundwater sample events.

Sample collection and control was performed using work processes and trained staff according to References RPM 5.3-0, GW-WPIR 2001 and RPM 5.3-1. The tasks included sample planning, sample collection, chain-of-custody preparation and sample shipping. The General Engineering Lab (GEL) in Charleston, SC was used as the primary lab for the radiological and boron analyses. Methods employed for radiological constituents were developed by the vendor laboratory and are recognized as acceptable within the radiochemical industry. The boron methods employed were standard EPA methods. The contract required detection limits (CRDL) are identified in the laboratory Statement of Work (CY-ISC-SOW 2003) are summarized in Table 2-1.

Samples were collected and maintained in a secure manner until they were shipped offsite for analysis. Samples were packaged for transport to the laboratory with protective packing material in insulated coolers with custody seals.

1.1.4.1 Radiochemical Data Reporting Convention

All reported analytical results include the net concentration, the 2-σ total propagated uncertainty concentration (TPU), and the minimum detectable concentration (MDC). Net concentration results greater than the 2-σ TPU generally imply that statistically significant activity is present with a 95% certainty. Net concentration results less than the 2-σ TPU indicate zero or statistically insignificant activity. Net concentration results reported as negative values imply that the radioactivity in the sample is less than the average or long-term background.

The reported TPU is a combination of the counting uncertainty and any other factors that contribute to the overall uncertainty including uncertainties in the sample mass, chemical yield and determination of calibration factors. Total propagated uncertainty values reported at 2-σ allow direct comparison with the net concentration for statistical significance.

Detection limits are essential for evaluating data quality and demonstrating that the desired sample analytical sensitivity was achieved. The lower limit of detection (LLD) is the lower limit at which a measurement can be differentiated from background with some degree of confidence. The LLD for a radionuclide is typically computed from the counting error associated with the instrument background, or blank counting conditions, at the time of analysis and is usually expressed in terms of counts, or count rate. In contrast, the MDC includes conversion factors to relate background count rate to radionuclide activity or concentration. The contractual (or *a priori*) MDCs for these results identified in the laboratory Statement of Work (CY-ISC-SOW 2003) are summarized in Table 2-1. These contract required detection limits (CRDL) are based on the resident farmer scenario with a 1 millirem per year Total Effective Dose Equivalent (TEDE) annual dose. All reported MDC concentrations are *a posteriori* and include sample specific corrections for radioactive decay, chemical yield and sample mass.

1.1.4.2 Analyte Sensitivity

All analytical results in the form of the sample specific MDL or MDC were evaluated against the contract required detection limit (CRDL) to ensure that sensitivity requirements were met. The sensitivity requirement is relaxed when statistically significant activity is identified in order to conserve lab cost and instrument resources. The target for sensitivity compliance for all radionuclides for this sampling event was 100%. This objective was selected to maximize sampling resources.

In all cases, the CRDL for Am-241 of 0.5 pCi/liter was not achieved when analyzed by gamma spectrometry, but it was easily achieved by alpha spectrometry. Only the alpha spectrometry results for Am-241 will be evaluated against the sensitivity criterion.

A total of 190 of the 192 results or 99% of the analyte tests met the sensitivity criterion. Two (2) Pu-241 results did not meet the CRDL of 15-pCi/L. These were noted in the

case narrative. The samples were prepared there (3) times due to matrix problems encountered during analytical preparation. The final sample preparations did not meet the sensitivity requirement due to limited remaining sample volume

1.1.5 Analytical Bias Assessment

Sstatistical methods were employed to evaluate analytical bias with regard to the underlying baseline or background distribution. A false-positive error is an instance when a nuclide or analyte is declared to be present but is, in fact, absent. A false-negative error is an instance when an analyte is declared to be absent but is, in fact, present. Historically, commercial analytical laboratories used by CYAPCo have exhibited some difficulty with the reporting of false-positive results, based on MAPEP performance evaluation (PE) data and trend analysis of analytical sample results. These difficulties were generally limited to radioisotopes analyzed via liquid scintillation counting (LSC) and to a lesser extent, gas proportional counting (GPC).

Positive and negative trends and biases have been observed in the past with nuclides analyzed via LSC at levels near the reported MDC. Low-level analytical positive trends have also been observed for Sr-90, gross alpha and gross beta analyses, which are analyzed via gas proportional counting (GPC). Significant trends with gamma or alpha isotopic analysis results are less common.

No example of positive bias was observed during the 2004 packer sample event. A negative bias was observed for Fe-55 and Tc-99, which are analyzed by LSC. The magnitude of the negative concentration bias is 2 to 3 times the standard deviation of the limiting mean concentration.

Statistical and visual methods were employed to evaluate trends in the analytical results as a function of nuclide. Rank order plots for the 2004 packer sample event were prepared as a function of nuclide (see Appendix E). Due to the limited data set (there were 5 packer test samples), replicates, equipment blanks and lab analytical blanks were included in the rank trending. The analytical data were treated as follows:

- Net concentration results were arranged in ascending order
- Standard distributional statistics were calculated (i.e., mean, median, minimum, maximum and standard deviation for the net concentration, 2-σ TPU and MDC)
- Net concentration results with associated TPU error bars were graphed as a function of rank order
- Expected zero mean concentration and 2-σ zero mean concentration control limits graphed as a function of rank order
- Average MDC graphed as a function of rank order

Graphing the expected zero mean and associated 2-σ zero mean concentration control limits provides a visual indication of biases in the analytical technique at concentration levels near or below the MDC. The expected ± 2-σ zero mean control limits were based on actual sample data when activity was near or less than the MDC. In most cases, the average 2-σ TPU provides restrictive control limits that are more sensitive than the

standard deviation of the mean concentration, which is subject to the influence from positive outliers. For analyses that were generally statistically significant with respect to background (i.e., gross alpha, gross beta), analytical blank data were used to estimate the 2-σ zero mean control limits.

Statistical methods were used in order to accurately identify and quantify biases in the underlying distribution of the analytical lab data. Some basis statistical parameters for the 2004 packer sample event are summarized in Table 2-9. These methods included parametric distribution testing, use of outlier detection methodology, and identification of statistical significant bias. Due to a limited number of packer test samples, the data sets were comprised of packer test samples, equipment blanks, lab replicates and lab blanks.

A typical groundwater analysis data subset (i.e., by nuclide) was assumed to be comprised of two distributions, an underlying background or zero analyte component randomly distributed around zero, and an unknown spatially or temporal varying distribution characterized by statistically significant or higher analyte concentrations. In most circumstances, the limiting mean value of the underlying blank is expected to be a constant with random fluctuations normally distributed around zero, after correcting for instrument background or blank conditions. In the case of a systematic bias in the blank, the limiting mean value of the blank distribution will be normal and randomly distributed around a non-zero (i.e., positive or negative) value. When the data are sorted in ascending order with regard to analyte concentration, the underlying background will be distributed on the low analyte concentration end while the spatially or temporally varying analyte results (i.e., statistically significant results), will be distributed on the high concentration end of the data sub-set.

Given the rank order of the data set, a modified Z-score method was used starting on the low analyte concentration end, to identify statistical outliers on the high analyte concentration end of the data set. The Z-score test is a standard statistical method to identify outlier data. Positive outliers as identified were assumed to be nonzero or part of the spatially or temporally distributed data. All others results were considered to be part of the zero analyte or baseline distribution. The limiting mean and standard deviation of these baseline mean results were used as an indicator for technique bias at concentrations near the MDC.

The underlying background or baseline data were evaluated for normality based on Filliben's r-statistic, also known as the normal probability plot correlation coefficient. Filliben's r-statistics near unity are characteristic of normally distributed data. Results of the normality testing for the 2004 packer sample events are summarized in Table 2-. Standard hypothesis testing was also used to determine if the limiting mean bias was statistically different from zero. The limiting mean baseline results were evaluated for statistical significance using the Student's t-test. In order to concentrate our efforts on analyses with the most significant bias, we used a 3-σ criterion to identify with a high degree of confidence (i.e., at the 99.97 % confidence level) analyses with significant bias with respect to the underlying background or baseline. Our selection of a 3-σ criterion in this case is based on conventional control chart theory where the analytical technique

is said to be in control (i.e., no apparent bias) when the observed limiting mean value is within ± 3-σ of the expected zero analyte concentration. Results of t-testing for the 2004 sample packer event are also included in Table 2-10. Some typical examples of the application of these statistical based methods as a function of general analysis type or nuclide-of-interest are as follows.

1.1.5.1 Gamma Emitters

Manganese-54 is a gamma emitter, determined by photon counting or gamma isotopic analysis. Manganese-54 is produced by neutron reactions with structural stainless steel and has an expected low radionuclide inventory due to a short radioactive half-life of 312.7 days. It has decayed through greater than 7 half-lives since plant shutdown and less than 0.5% of its shutdown activity or inventory remains. Mn-54 is not expected to be present in detectable quantities in groundwater samples from the HNP and is a good candidate analysis to demonstrate a zero analyte or underlying background distribution.

Figure 2-1 is a rank order plot of Mn-54 concentrations in groundwater for the 2004 packer test sampling event. The Mn-54 results are graphed with their corresponding 2-σ TPU error bars. An average and 1-σ standard deviation concentration of -0.13 ± 0.81 pCi/L was observed in this data set while the average MDC was 2.6 pCi/L. The control limits are ± 1.62 pCi/L based on the 2-σ standard deviation of the limiting mean. Approximately half the data points are distributed above or below the zero concentration level. Note that all the 2-σ TPU error bars cross the zero concentration level.

The limiting mean value of -0.13 pCi/L is statistically equal to a zero concentration level based on the t-statistic and 11 (n-1) degrees of freedom. The data are also normally distributed around the limiting mean value as illustrated by the frequency distribution in Figure 2-2. As expected, no significant Mn-54 activity is indicated in this trend plot and the data are equally distributed around zero. These results are typical of gamma isotopic analysis where no analyte is present and the background or energy baseline is easily and accurately determined.

Cesium-137 is a gamma emitter, determined by photon counting or gamma isotopic analysis. Cesium-137 is a fission product with a 30.17-year radioactive half-life. Due to a high radionuclide inventory and radioactive half-life, or decay considerations, Cs-137 has been detected in groundwater samples from the HNP.

Figure 2-3 is a rank order plot of Cs-137 concentrations from the 2004 packer test sampling event. An average and 1-σ standard deviation concentration of 0.41 ± 0.79 pCi/L was observed for the limiting zero mean while the average MDC was 2.9 pCi/L. The control limits are ± 1.76 pCi/L based on 2-σ standard deviations of the limiting mean. The baseline data are normally distributed around the limiting mean value of 0.41 pCi/L in Figure 2-4 and the limiting mean value is not statistically different from zero, based on the t-test. These results are again typical of gamma isotopic analysis with zero analyte data.

Cobalt-60 is a gamma emitter with a high radionuclide inventory at HNP due to its presence in structural material. Cobalt-60 has a radioactive half-life of 5.271-years and about 42% of its shutdown inventory or activity remains. Cobalt is a common impurity in stainless steel and is the dominant external dose producing isotope in reactor interior components on a 10-year time scale.

Figure 2-5 is a rank order plot of Co-60 concentrations in groundwater for the 2004 packer test sampling event. An average and 1-σ standard deviation concentration of 0.61 ± 1.05 pCi/L was observed for the limiting zero mean while the average MDC was 2.9 pCi/L. The control limits are ± 2.10 pCi/L based on 2-σ standard deviations. The baseline data are normally distributed around the limiting mean value of 0.61 pCi/L (Figure 2-6). The limiting mean is statistical equal to zero based on the t-test and all the 2-σ TPU error bars cross the zero concentration level.

1.1.5.2 Beta and X-Ray Emitters via LSC

Figure 2-7 is a rank order plot of C-14 concentrations in groundwater for the 2004 packer test sampling event. C-14 is a beta emitter, determined by chemical separation and LSC. Due to an expected low radionuclide inventory, C-14 is not expected to be present in detectable quantities in groundwater samples from the HNP. An average and 1-σ standard deviation concentration of 2.7 ± 21.9 pCi/L was observed in this data set while the average MDC was 75 pCi/L. The control limits are ± 43.8 pCi/L based on the average 2-σ standard deviation. Note that all of the data points are distributed above the zero concentration level. Approximately half the data points are distributed above or below the zero concentration level. Note that all the 2-σ TPU error bars cross the zero concentration level except in the extreme positive range of the data set.

The limiting mean value of 2.7 pCi/L is statistically equal to a zero concentration level based on the t-statistic and 10 (n-1) degrees of freedom. The data are also normally distributed around the limiting mean value as illustrated by the frequency distribution in Figure 2-8. No bias is indicated in this trend plot and the data are equally distributed around the limiting mean. These results are typical of LSC analysis where there is no significant bias and the underlying baseline is normally distributed.

Figure 2-9 is a rank order plot of Ni-63 in water for the 2004 packer test sampling event. Nickel-63, decays by low energy beta emission and is determined by LSC analysis. Nickel-63 has a radioactive half-life of 100-years. An average and 1-σ standard deviation concentration of 1.74 ± 3.40 pCi/L was observed in this sample event data set with an average MDC of 11.3 pCi/L. The Ni-63 data are normally distributed around the limiting mean value of 1.74 pCi/L as indicated in Figure 2-10. The limiting mean value is statistically equal to zero, based on the t-test and all the 2-σ TPU error bars cross the zero concentration level except in the extreme positive range of the data set.

Figure 2-11 is a rank order plot of Pu-241 in water for the 2004 packer test sampling event. Plutonium-241, decays by low energy beta emission and is determined by LSC analysis. An average and 1-σ standard deviation concentration of 2.7 ± 4.3 pCi/L was observed in this sample event data set with an average MDC of 16 pCi/L. The Pu-241 data are normally distributed around the limiting mean value of 2.7 pCi/L as indicated

in Figure 2-12. The limiting mean value is statistically equal to zero, based on the t-test and all the 2-σ TPU error bars cross the zero concentration level except in the extreme positive range of the data set.

Figure 2-13 is a rank order plot of Fe-55 in water for the 2004 packer test sampling event. Iron-55, which decays by electron capture and subsequent X-ray emission, is determined by LSC analysis. Iron-55 has a radioactive half-life of 2.7-years and only 19% of its shutdown inventory or activity remains. An average and 1-σ standard deviation concentration of -17.2 ± 6.9 pCi/L was observed in this sample event data set with an average MDC of 13.5 pCi/L. The Fe-55 data are normally distributed around the limiting mean value of -17.2 pCi/L as indicated in Figure 2-14. The limiting mean value is statistically less than zero, based on the t-test. These results are typical of LSC analysis where a significant negative systematic bias in the underlying baseline distribution exists.

We have observed a negative bias with Fe-55 analytical results in past groundwater sampling event results. We are currently working with the analytical lab to evaluate and fix this analytical bias, which has been attributed to a Fe-59 spillover correction. Iron-59 is a beta and gamma emitter added to lab samples to monitor chemical yield in groundwater samples.

Figure 2-15 is a rank order plot of Tc-99 in water for the 2004 packer test sampling event. Technetium-99, decays by beta emission and is determined by LSC analysis. Technetium-99 has a long radioactive half-life of 2.13(E+05) years. An average and 1-σ standard deviation concentration of -2.80 ± 1.71 pCi/L was observed in this sample event data set with an average MDC of 7.6 pCi/L. The Tc-99 data are normally distributed around the limiting mean value of -2.80 pCi/L as indicated in Figure 2-16. The limiting mean value is statistically less than zero, based on the t-test. Note that all concentration results were negative in this data set and all the 2-σ TPU error bars cross the zero concentration level except in the extreme negative range of the data set. This suggests that the analytical laboratory has some difficulty in determining the appropriate analytical blank contribution for Tc-99.

The Fe-55 and Tc-99 results were the only LSC radionuclide results that exhibited statistically significant analytical bias in the underlying distribution. CYAPCo will continue to statistically evaluate and monitor these data. In the meantime, we will report the data *as is* in order to evaluate any dose risk associated with groundwater monitoring in a conservative manner.

1.1.5.3 Beta and Alpha Emitters via GPC

Figure 2-17 is a rank order plot of Sr-90 in water for the 2004 packer test sampling event. An average and 1-σ standard deviation concentration of 0.29 ± 0.29 pCi/L was observed in the limiting mean concentration with an average MDC of 0.91 pCi/L. The control limits are ± 0.59 pCi/L based on the average 2-σ standard deviation of the limiting mean. The Sr-90 data are normally distributed around the limiting mean value of 0.29 pCi/L as indicated in Figure 2-18. The limiting mean value is statistically equal to zero, based on the t-test but 10 of the 12 reported Sr-90 results for this data set were

greater than the zero concentration. One of the internal lab blank concentrations detected Sr-90 at a concentration of 0.67± 0.62 pCi/L. These results are typical of GPC analysis where a positive systematic bias in the underlying baseline distribution may exist based on positive trends and lab analytical blank performance.

Similar results were obtained for gross alpha and gross beta analyses performed via GPC. In the case of gross alpha and gross beta, the positive trends observed in these analyses, is attributed to natural levels of gross alpha and beta radioactivity.

1.1.5.4 HTD Alpha Emitters

Figure 2-19 is a rank order plot of Cm-242 concentrations in groundwater for the 2004 packer test sampling event. Curium-242 is an alpha emitter with an expected low radionuclide inventory at HNP due to radioactive decay. Curium-242 has a radioactive half-life of 163.2 days and has decayed through greater than 14 half-lives since shutdown. Since less than 0.01% of the shutdown activity or inventory remains, Cm-242 is not expected to be present in detectable quantities in groundwater samples from the HNP.

An average and 1-σ standard deviation concentration of 0.002 ± 0.021 pCi/L was observed in this data set while the average MDC was 0.22 pCi/L. The control limits are ± 0.042 pCi/L based on 2-σ standard deviations in the analytical blank. Note that the individual 2-sigma error bars generally span the region of the control limits except in the negative regions of the graph. Here the 2-σ TPU is underestimated due to the presence of zeros in the analytical counting results. This is characteristic of low-level alpha counting where zero results are sometimes observed (i.e., zero counts observed in the detector region-of-interest) during the finite counting interval.

The baseline data are normally distributed around the limiting mean value of 0.002 pCi/L in Figure 2-20 and the limiting mean value is not statistically different from zero, based on the t-test. As expected, no significant Cm-242 activity is indicated in this trend plot. These results are typical of low-level alpha isotopic analysis where no analyte is present.

Figure 2-21 is a rank order plot of Am-241 concentrations in groundwater for the 2004 packer test sampling event. Americium-241 is an alpha emitter that has been detected in HNP process streams attributed to failed fuel. An average and 1-σ standard deviation concentration of 0.022 ± 0.039 pCi/L was observed in this data set while the average MDC was 0.27 pCi/L. The control limits are ± 0.077 pCi/L based on the average 2-σ TPU in the analytical blanks. Note that the individual 2-sigma error bars generally span the region of the control limits except in the negative regions of the graph.

The data are normally distributed around the limiting mean value of 0.022 pCi/L in Figure 2-22. The limiting mean value of 0.023 pCi/L is not statistically greater than zero analyte level based on the t-statistic and 11 (n-1) degrees of freedom. No significant positive trends were observed with the Am-241 isotopic data or other alpha emitters analyzed as part of the 2004 packer test sample event.

1.1.5.5 Radiochemical Bias Summary

Attached in Table 2-11 is a summary of the percentage of positive results detected at concentrations that were greater than 2-σ TPU and near the MDC level for the 2004 packer test sample event. This table provides an indication of the percentage of false positive results as a function of analysis method. Known statistically positive results for gross alpha, gross beta, H-3 and boron were not used in these summaries.

Only 1.7% or 2 of the 120 gamma isotopic analysis results were greater than the 2-σ TPU level, which is just slightly less than the expected rate of 2.5% if there were no significant gamma emitters present. One would expect a "false positive" rate of 2.5% based on the area under the standard normal distribution around a limiting mean concentration of zero, at the 95% confidence level. These results suggest that there is little bias in the gamma isotopic analytical results at levels near the MDC, and there is little gamma isotopic activity in these samples.

Alpha isotopic results for the 2004 packer test sample event indicate, an overall positive activity rates of 0% based on 60 analysis results. This also indicates no significant alpha activity present in these samples with minimal bias in the analytical technique at levels near the MDC.

The percentage of HTD beta results determined via LSC and with concentration levels greater than 2-σ TPU ranged from 0% to 16.7%. These results were normally distributed around a limiting mean concentration in all cases. Two (2) of the six (6) LSC analyses were characterized by a negative limiting mean distribution. The other remaining analyte results were characterized by a limiting mean distribution equal to zero concentration.

Gas proportional counting results for the 2004 packer test sample event indicate, an overall positive activity rates of 25% based on twelve (12) Sr-90 analysis results. These results were normally distributed around a limiting mean concentration equal to zero, but ten (10) of the twelve (12) Sr-90 results were greater than zero concentration indicating some minimal positive bias.

Factors that may affect the uncertainty of radiological analyses, and the ability to discern plant-related activity from the natural background activity include; interference from naturally occurring radionuclides due to incomplete radiochemical separation, specificity of radiochemical counting technique, and difficulty in identifying the ambient background or blank contribution. In low-level radiochemical counting, these limitations are imposed by the accurate determination of the systematic and random uncertainty associated with the analytical blank. Gamma isotopic and alpha isotopic analyses are the most specific counting methods with the least amount of systematic bias in the underlying background or blank. GPC and LSC are less specific counting methods and may be subject to systematic and random variability in the underlying blank distribution. CYAPCo will continue to statistically evaluate and trend lab data in order to understand limitations and irregularities in analytical results.

The observations and conclusions with regard to low-level analytical bias are summarized as follows:

- Statistically significant systematic biases were observed for two (2) HTD analyses based on statistical and graphical evaluations of the reported lab analytical data. Negative biases were observed for Fe-55 and Tc-99 analyzed by LSC.
- Positive systematic biases were observed in several of the HTD analyses by LSC and GPC. The affected analyses included gross alpha, gross beta, He-3, C-14 and Sr-90.
- An overall false positive rate on the order of 1.9% was observed for the LSC analyses results. This is nominally similar to the expected false positive rate of 2.5%, which is a noted overall improvement in the LSC analyses.
- No lab analytical bias was observed for the alpha or gamma emitters.

1.1.6 Laboratory Audits/Assessments/Oversight Activities

Laboratory activities are periodically assessed through surveillance and/or auditing activities to ensure that quality problems are prevented and/or detected. Periodic assessments support the continuous process improvement. No onsite audits or assessments were conducted at the GEL facility during this time period.

1.1.7 Issue Resolution/Case Narrative

Case narrative documents record detailed documentation of the analyses requested and provide additional documentation regarding problems encountered with sample receipt, sample analysis and data reporting. The forms are generated by the laboratory as required in the SOW and forwarded to the GW monitoring project with all hard copy data packages. The documentation is intended to identify occurrences, deficiencies and/or issues that may potentially have an adverse effect on data integrity.

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- Sample 178-183-5 was recounted for Sr-90 to verify result. The second count was reported.
- The Fe-55 results for 3 samples were extremely negative. The reported negative concentrations were greater than three (3) times the error due to the Fe-59 cross-talk correction.
- High hygroscopic salt content in evaporated samples can cause the sample mass to fluctuate due to moisture absorption during gross alpha and beta sample preparation. The salts were converted to an oxide by heating under a flame.

Volatile radioisotopes of carbon, hydrogen, technetium, polonium and some cesium may be lost during this process.

- The Pu-241 sample batch was re-prepped due to carrier/tracer yields and recovery. An NCR was issued for Pu-241 samples 178-183-4 and S-9. These samples were prepared 3-times due to matrix problems encountered during analytical preparation. These samples did not meet the CRDL due to limited remaining sample volume.
- The serial dilution for boron did not meet the acceptance criteria of less than 10% for the ICP-MS batches. Serial dilution is used to assess matrix suppression or enhancement.
- Gross alpha samples S152-157 and the matrix spike for this sample were recounted due to high relative percent difference/relative error ratio.
- Sample S103-108 for Tc-99 was recounted due to an extremely negative result. The reported negative concentration was greater than three (3) times the error.

CYAPCo is specifically working with the lab to resolve the Fe-59 cross-talk correction issues identified above and through trend analysis of the Fe-55 data. We will continue to monitor these case narratives and their impact on lab data quality.

1.2 Summary

Analysis of radiochemical constituents was performed on unfiltered water samples collected from MW121A during straddle packer testing during June and September 2004. Overall, assessments of QA/QC information indicate that groundwater monitoring data are acceptable for groundwater characterization and monitoring efforts. Groundwater sampling was performed in accordance with sample plans and work processes. Laboratory external performance data was good to excellent for all constituents. Performance test results for false positive testing require some process improvement. Laboratory internal performance data was good to excellent for all constituents but boron, which requires improvement. Measurement of boron and radiochemical constituents in samples collected from HNP met the identified data quality metrics for the straddle packer sample event.

Based upon the work performed during the implementation and development of this 2004 Packer Test Report, the following conclusions and recommendations have been developed for the radiochemical analyses presented in this report:

- Statistically significant systematic biases were observed for two (2) HTD-analyses based on statistical and graphical evaluations of the reported lab analytical data. Negative biases were observed for Fe-55 and Tc-99 analyzed by LSC.
- Positive trends were identified in several of the HTD analyses by LSC. An overall positive rate on the order of 6.8% was observed for the LSC analyses results, which is higher than an expected false positive rate of 2.5%.
- Positive trends were identified in the analyses performed by GPC. The affected analyses included gross alpha, gross beta, and Sr-90. Three (3) of six (6) or 50% of the lab analytical blank results had detectable concentrations that were greater than 2-σ TPU. An overall positive rate on the order of 25% was observed for Sr-90 results, which is higher than an expected false positive rate of 2.5%.

- No trend or lab analytical bias was observed for the alpha or gamma emitters.
- Equipment blank results for boron and H-3 indicated positive trends. All boron results were greater than the MDL. All H-3 results were detects with concentrations greater than 2-σ TPU and the MDC. The precision of the measurements suggest an impact from plant DI water used for the equipment blanks.
- Laboratory completed QA/QC sample results were within acceptable protocol ranges for all analyses.
- External and internal laboratory performance evaluation data was excellent overall with greater than 95% of the data within acceptance criteria. External false positive test performance of 60% requires improvement. Internal boron performance of 67% requires improvement.

Table 1-1: Required MDC Values

Nuclide	MDC (pCi/L)	Analysis Type	Nuclide	MDC (pCi/L)	Analysis Type
Gross α	3	Gas Prop.	Ag-108m	50	γ Spec.
Gross β	4	Gas Prop.	Cs-134	15	γ Spec.
H-3	400	LSC	Cs-137	15	γ Spec.
C-14	200	LSC	Eu-152	50	γ Spec.
Mn-54	50	γ Spec.	Eu-154	50	γ Spec.
Fe-55	25	LSC	Eu-155	50	Γ Spec.
Co-60	25	γ Spec.	Pu-238	0.5	A Spec.
Ni-63	15	LSC	Pu-239	0.5	A Spec.
Sr-90	2	GPC	Pu-241	15	LSC
Nb-94	50	γ Spec.	Am-241	0.5	A Spec.
Tc-99	15	LSC	Cm-243	0.5	A Spec.

Table 1-2: Lab Duplicate Results for 2004 Packer Test Sample Event

Sample ID	Analyte	Sample Concentration ± 2-σ TPU	Duplicate Concentration ± 2-σ TPU	Units	Ratio	Residual	Agreement
MW121A (153-176)	Boron	189	199	μg/L	1.05	+5.3%	-
MW121A (152-157)	Gross α	26.4 ± 4.8	33.1 ± 5.5	pCi/L	1.25	+25.4%	+1.8σ
MW121A (152-157)	Gross β	21.4 ± 3.7	23.2 ± 3.7	pCi/L	1.08	+8.4%	+0.7σ
Bladder Blank	H-3	325 ± 140	323 ± 138	pCi/L	0.99	-0.6%	-0.0σ

Table 1-3: DOE QAP Lab Performance Data Summary

Sample Media	Gamma Isotopic	Alpha Isotopic	HTD	Total
Air Filter	96.6%	97.2%	100.%	96.9%
Soil	97.2%	97.7%	100.%	97.7%
Vegetation	100.%	100.%	85.7%	98.0%
Water	96.9%	97.2%	91.7%	96.2%
All Totals	97.4%	97.8%	94.3%	97.1%

Table 1-4: MAPEP Lab Performance Data Summary

Sample Media	Gamma Isotopic	Alpha Isotopic	HTD	False Positive	Total
Water	100.%	96.0%	94.1%	60.0%	97.2%
Soil	100.%	96.0%	75.0%	80.0%	94.4%
All Totals	100.%	96.0%	86.2%	70.0%	95.8%

Table 1-5: ERA Lab Performance Data Summary for Water (ERA 52 – 55, 57)

Gamma Isotopic	Alpha Isotopic	HTD	Total
96.2%	100.%	100.%	98.4%

Table 1-6: QC Summary for 2004 Packer Test Sample Event

Sample Type	Nuclide Tests	Percent of Total Samples
Samples	200	50.3%
QC Blanks	50	12.6%
QC Lab Controls	54	13.6%
QC Matrix Spikes	47	11.8%
QC Duplicates	47	11.8%
Sample/QC Totals	398	100.%

Table 1-7: Lab QC Acceptance Limits

QC Category	GEL Acceptance Limits (%)
Duplicates	± 20%
Blank Spikes, Matrix Spikes	± 25%
Method Blanks	< CRDL

Table 1-8: Internal Performance Data Summary (LCS, MS)

Method	Blank Spikes	Matrix Spikes	Total
Boron	2/2	0/1	66.6%
γ-isotopic	6/6	6/6	100.%
α-isotopic	4/4	4/4	100.%
LSC	12/12	10/10	100%
GPC	10/10	6/6	100%
All Totals	34/34	26/27	95.2%

Table 1-9: Summary Statistics for 2004 Packer Test Sample Event

Analyte	Method	# of Samples	Min. Conc. (pCi/L)	Max. Conc. (pCi/L)	Mean Conc. (pCi/L)	Sdev. Conc. (pCi/L)	Median Conc. (pCi/L)	EPA MCL (pCi/L)	Conc.> 2-σ TPU	Conc.> MCL
Boron	ICP-MS	11	2.34	338	113.7	119.2	45.2		10	
Gross α	GPC	12	-0.14	129	18.0	36.7	1.37	15	7	3
Gross β	GPC	12	-1.7	35.0	8.85	11.8	2.6	50(S)	7	-
H-3	LSC	11	-137.0	8170	1782	2771	338.0	20000	9	0
C-14	LSC	11	-38.5	45.4	2.69	21.9	1.3	2000	1	0
Mn-54	γ	12	-1.71	1.04	-0.13	0.81	-0.04	300	0	0
Fe-55	LSC	12	-29.6	-7.76	-17.2	6.86	-17.3	2000	0	0
Co-60	γ	12	-1.40	2.69	0.61	1.05	0.36	100	0	0
Ni-63	LSC	12	-2.43	10.2	1.74	3.40	1.09	50	1	0
Sr-90	GPC	12	-0.16	0.78	0.29	0.29	0.25	8	3	0
Nb-94	γ	12	-0.96	1.13	0.05	0.68	0.01	-	0	0
Tc-99	LSC	12	-6.04	-1.03	-2.80	1.71	-2.28	900	0	0
Ag-108m	γ	12	-1.28	0.98	-0.18	0.75	-0.09	-	0	0
Cs-134	γ	12	-1.38	1.92	-0.01	0.96	-0.07	20000	1	0
Cs-137	γ	12	-0.38	2.01	0.41	0.79	0.10	200	1	0
Eu-152	γ	12	-2.54	3.88	1.56	2.07	2.40	60	0	0
Eu-154	γ	12	-3.17	2.24	-0.16	1.62	-0.22	200	0	0
Eu-155	γ	12	-7.00	1.76	-1.25	2.49	-1.09	600	0	0
Pu-238	α	12	-0.084	0.072	-0.003	0.045	0.005	15	0	0
Pu-239,240	α	12	-0.060	0.076	-0.001	0.042	0.010	15	0	0
Pu-241	LSC	12	-6.01	8.92	2.66	4.33	2.18	-	2	0
Am-241	γ	12	-8.94	3.70	-1.71	4.32	-0.63	15	0	-
Am-241	α	12	-0.018	0.089	0.022	0.039	0.006	15	0	0
Cm-242	α	12	-0.025	0.039	0.002	0.021	0.000	15	0	-
Cm-243,44	α	12	-0.054	0.046	0.001	0.028	0.000	15	0	0
Totals		297							42	3

Table 1-10: Limiting Mean Distribution Summary for 2004 Packer Test Sample Event

Nuclide	Analysis Method	Limiting Mean (pCi/L)	Limiting Sdev. (pCi/L)	# of Results (n)	Calculated t-value	Critical t-value[1]	Limiting Mean Bias	Filliben's r-statistic	Critical r-statistic[2]	Distribution
Gross α	GPC	0.18	0.36	6	1.235	6.431	-	0.915	0.890	Normal
Gross β	GPC	0.71	1.56	7	1.207	5.625	-	0.927	0.899	Normal
H-3	LSC	-72.9	90.7	2	-1.136	- n.a. -	-	- n.a. -	- n.a. -	-
C-14	LSC	2.69	21.9	11	0.407	4.393	-	0.976	0.922	Normal
Mn-54	γ	-0.13	0.81	12	-0.572	4.257	-	0.988	0.926	Normal
Fe-55	LSC	-17.2	6.86	12	-8.695	4.257	Negative	0.985	0.926	Normal
Co-60	γ	0.61	1.05	12	2.003	4.257	-	0.970	0.926	Normal
Ni-63	LSC	1.74	3.40	12	1.770	4.257	-	0.938	0.926	Normal
Sr-90	GPC	0.29	0.29	12	3.415	4.257	-	0.988	0.926	Normal
Nb-94	γ	0.05	0.68	12	0.232	4.257	-	0.981	0.926	Normal
Tc-99	LSC	-2.80	1.71	12	-5.675	4.257	Negative	0.943	0.926	Normal
Ag-108m	γ	-0.18	0.75	12	-0.816	4.257	-	0.980	0.926	Normal
Cs-134	γ	-0.01	0.96	12	-0.018	4.257	-	0.983	0.926	Normal
Cs-137	γ	0.41	0.88	12	1.630	4.257	-	0.938	0.926	Normal
Eu-152	γ	1.56	2.07	12	2.620	4.257	-	0.936	0.926	Normal
Eu-154	γ	-0.16	1.62	12	-0.352	4.257	-	0.992	0.926	Normal
Eu-155	γ	-1.25	2.49	12	-1.745	4.257	-	0.947	0.926	Normal
Pu-238	α	-1.71	4.32	12	-1.373	4.257	-	0.956	0.926	Normal
Pu-239,40	α	-0.001	0.042	12	-0.049	4.257	-	0.979	0.926	Normal
Pu-241	LSC	2.66	4.33	12	2.129	4.257	-	0.979	0.926	Normal
Am-241	α	0.022	0.039	12	1.925	4.257	-	0.938	0.926	Normal
Am-241	γ	-0.17	4.32	12	-0.137	4.257	-	0.956	0.926	Normal
Cm-242	α	0.002	0.021	12	0.296	4.257	-	0.945	0.926	Normal
Cm-243,44	α	0.001	0.028	12	0.110	4.257	-	0.984	0.926	Normal

Notes:

[1]Student t-statistic at the 99% Confidence Interval for n-1 degrees of freedom
[2]Filliben's r-statistic at the 95% Confidence Interval for n degrees of freedom

Table 1-11: Observed Positive Rates

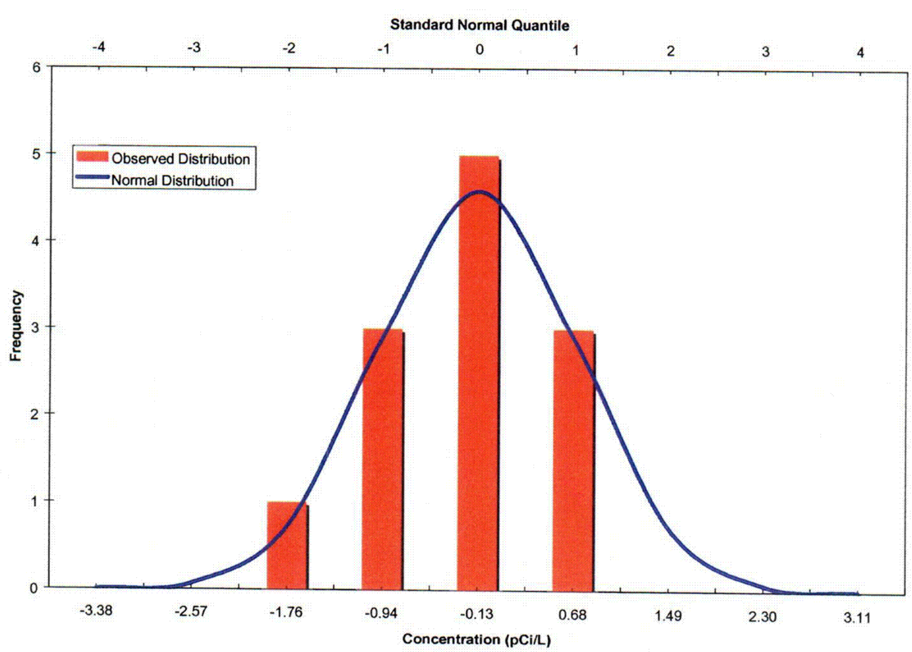
Analysis Type	Positive Results	Total Results	Positive Rate
Gamma Isotopic	2	120	1.7%
Alpha Isotopic	0	60	0.0%
HTD Beta via LSC	4	59	6.8%
HTD Sr-90 via GPC	3	12	25%

Table 1-12: Data Quality Metrics

Parameter	Data Quality Metric
Precision	▪ Relative Percent Difference (RPD) < 20%
Accuracy	▪ Laboratory Control Sample Recovery 100% +/- 25 ▪ MDC < 0.1 * Drinking Water Standard ▪ Laboratory Blank Analysis Results < MDC
Representativeness	▪ Qualitative assessment of sample location, sample timing, sample collection method, sample preservation, handling, shipment
Completeness	▪ Valid measurements for critical samples = 100%
Comparability	▪ Qualitative assessment of sample collection and measurement methods and assignment of sample locations to hydrostratigraphic units. ▪ Sample MDC < CRDL

Figure 1-1: Mn-54 Rank Order for 2004 Packer Test

Figure 1-2: Mn-54 Normality Plot for 2004 Packer Test



C60

Figure 1-3: Cs-137 Rank Order for 2004 Packer Test

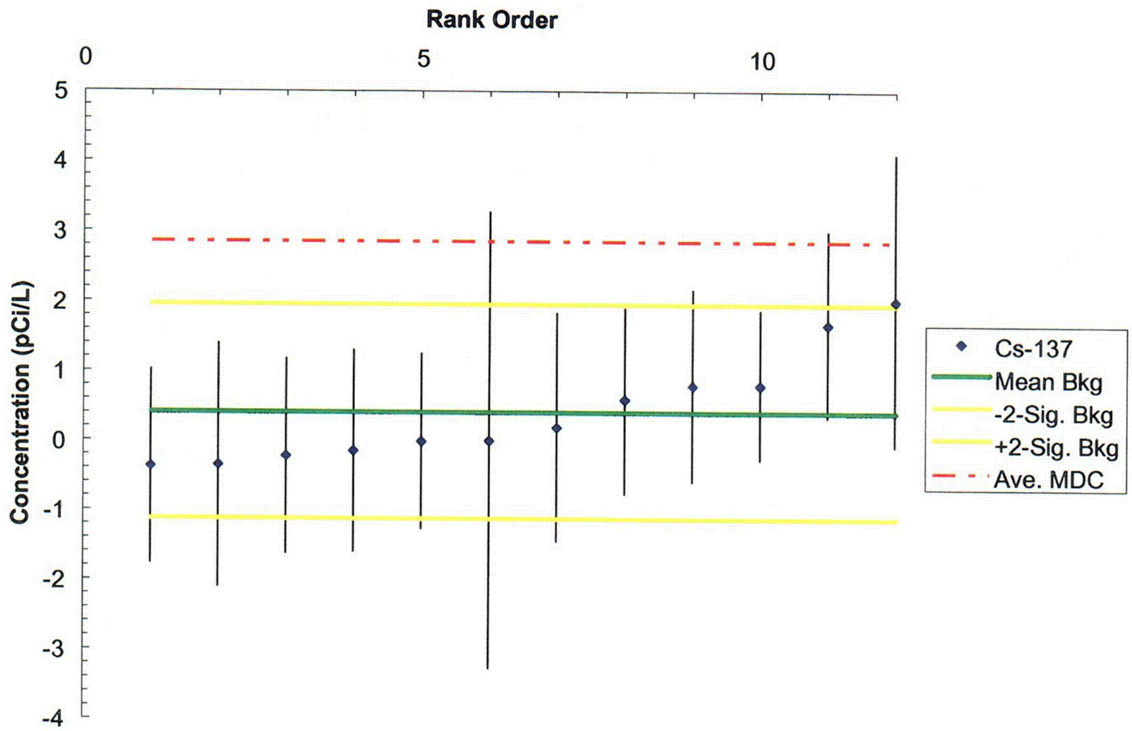
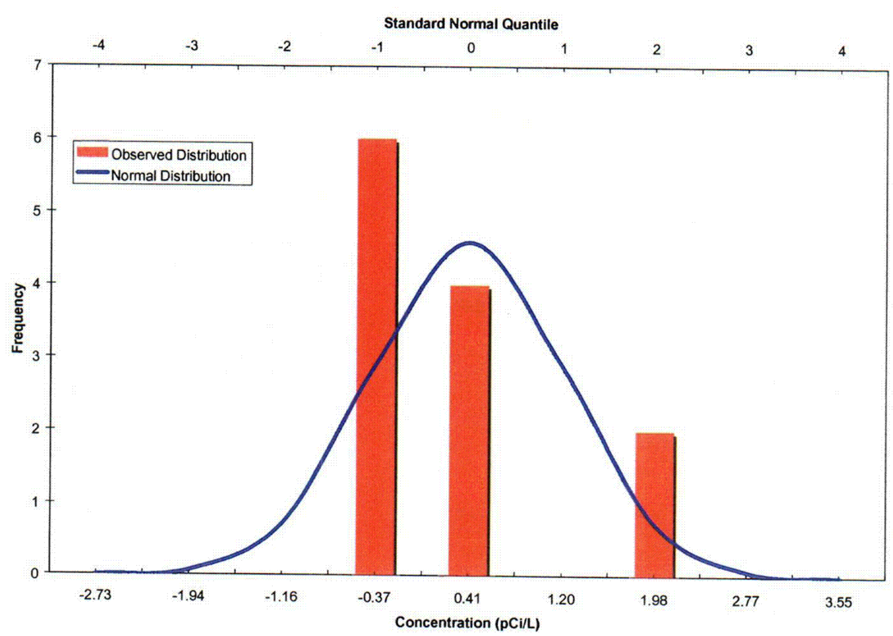


Figure 1-4: Cs-137 Normality Plot for 2004 Packer Test



C61

Figure 1-5: Co-60 Rank Order for 2004 Packer Test

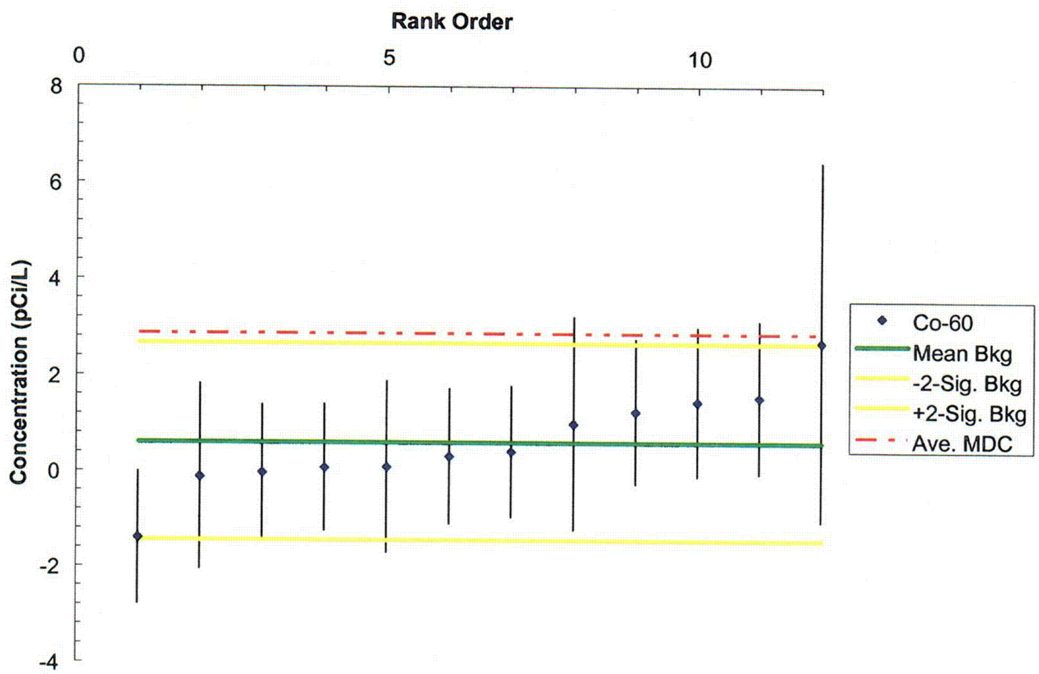
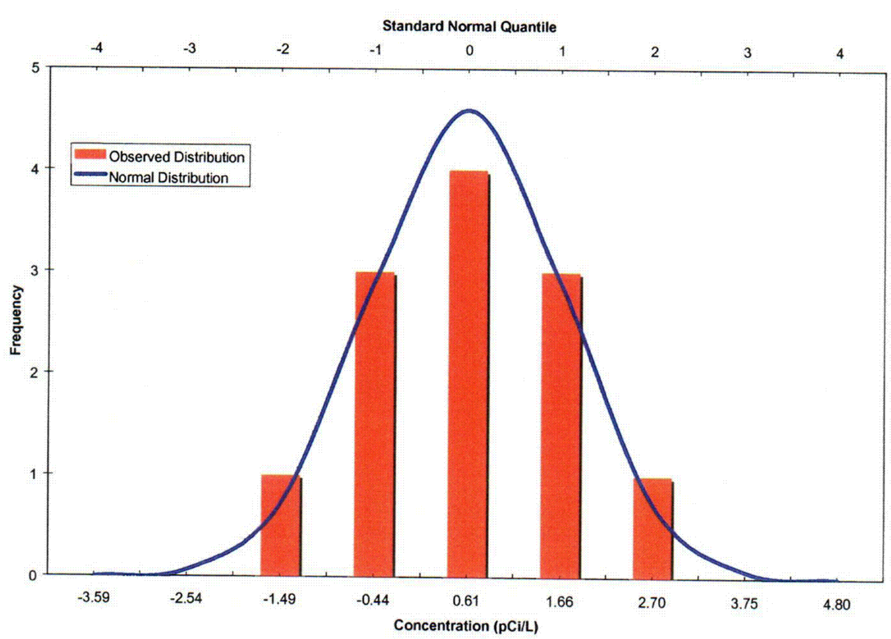


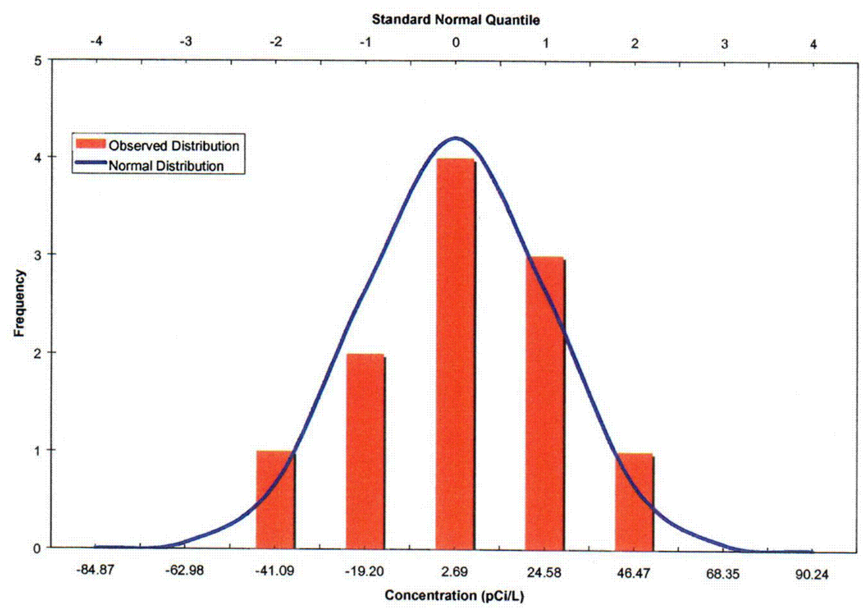
Figure 1-6: Co-60 Normality Plot for 2004 Packer Test



C62

Figure 1-7: C-14 Rank Order for 2004 Packer Test

Figure 1-8: C-14 Normality Plot for 2004 Packer Test



C63

Figure 1-9: Ni-63 Rank Order for 2004 Packer Test

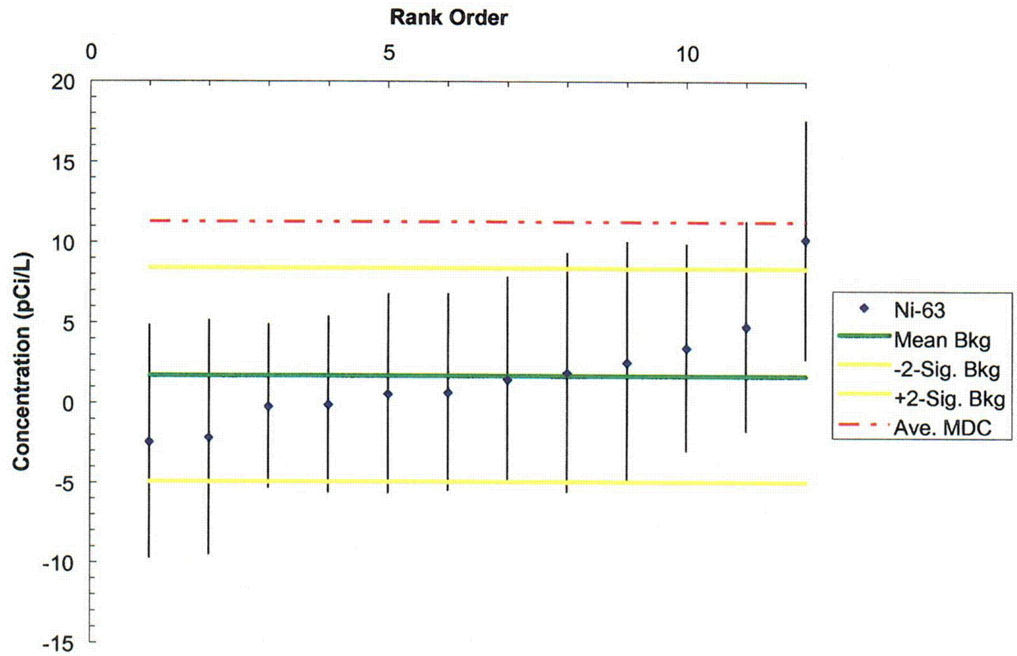
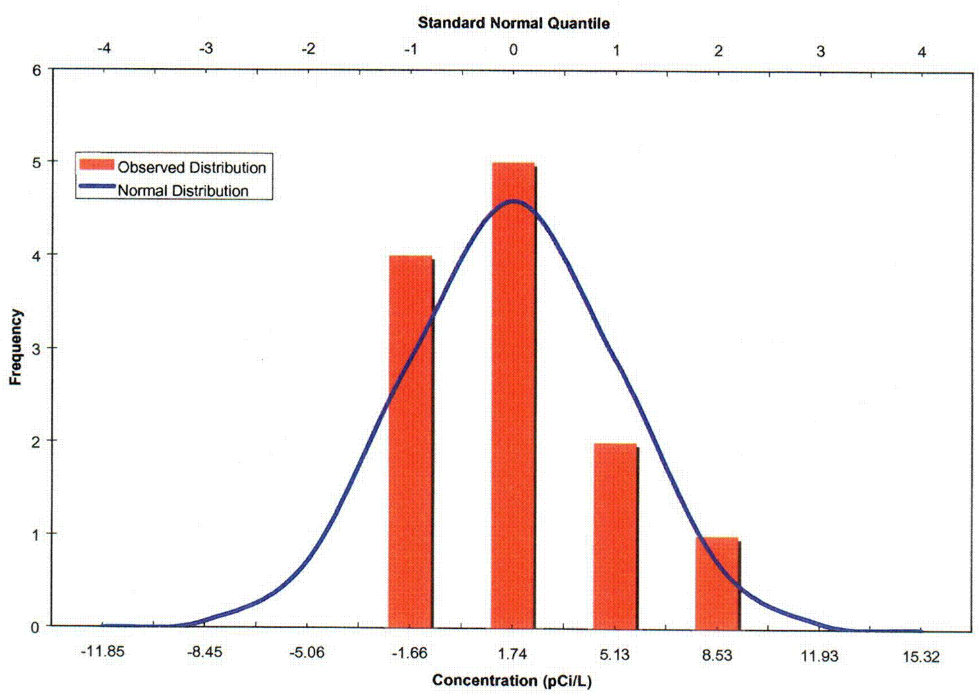


Figure 1-10: Ni-63 Normality Plot for 2004 Packer Test



C64

Figure 1-11: Pu-241 Rank Order for 2004 Packer Test

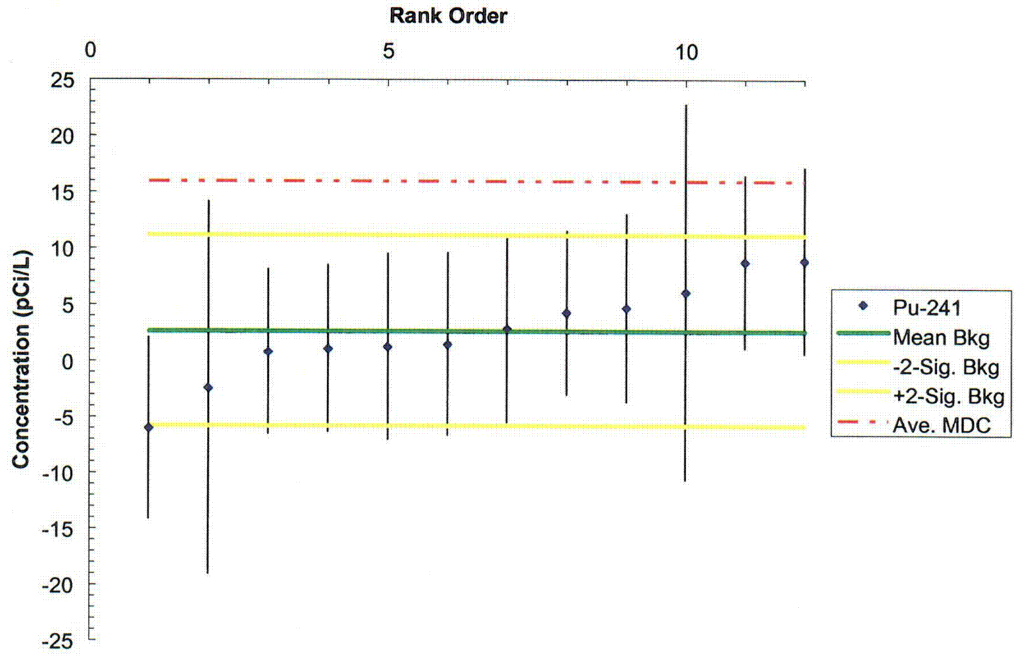


Figure 1-12: Pu-241 Normality Plot for 2004 Packer Test

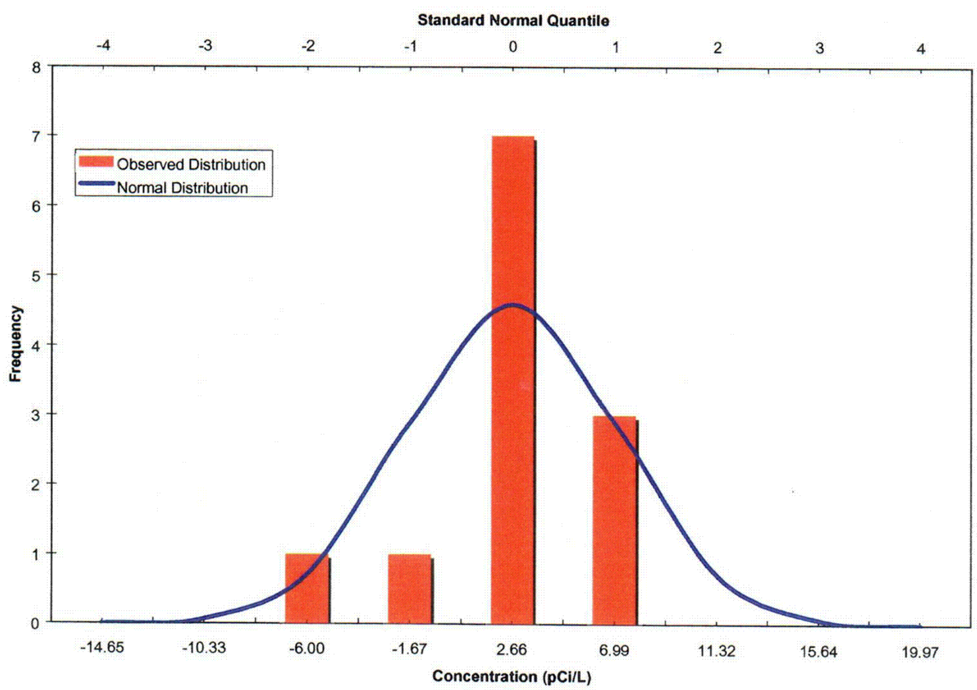


Figure 1-13: Fe-55 Rank Order for 2004 Packer Test

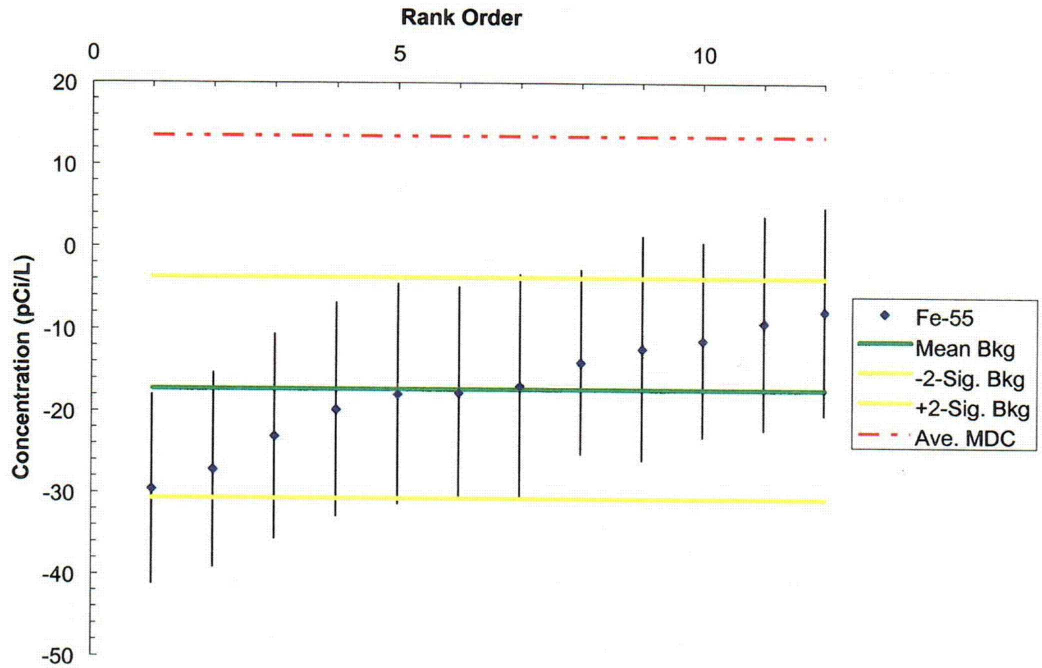
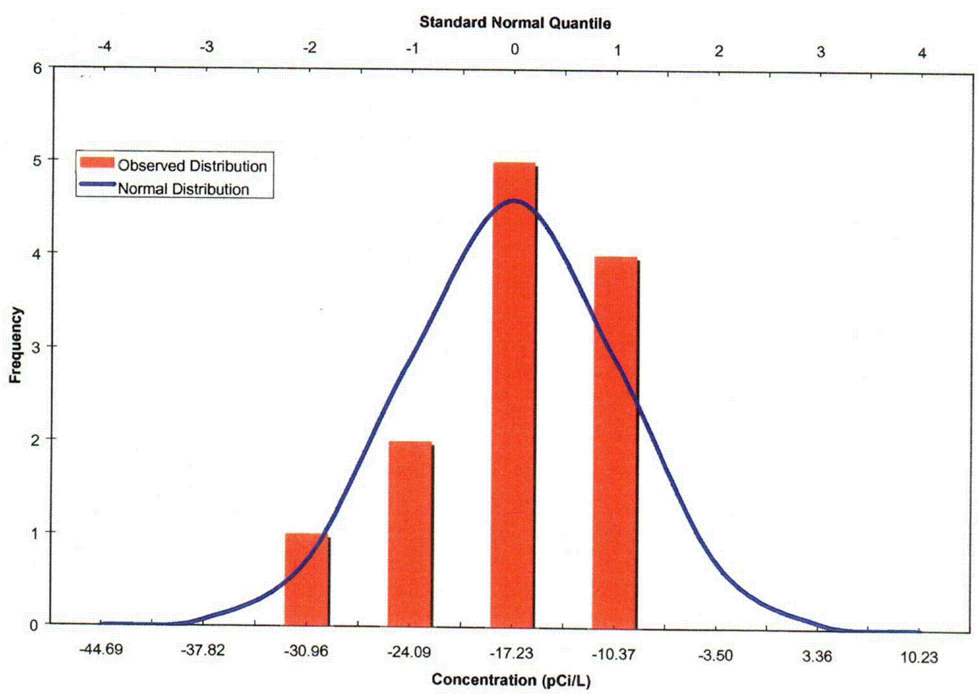


Figure 1-14: Fe-55 Normality Plot for 2004 Packer Test



C66

Figure 1-15: Tc-99 Rank Order for 2004 Packer Test

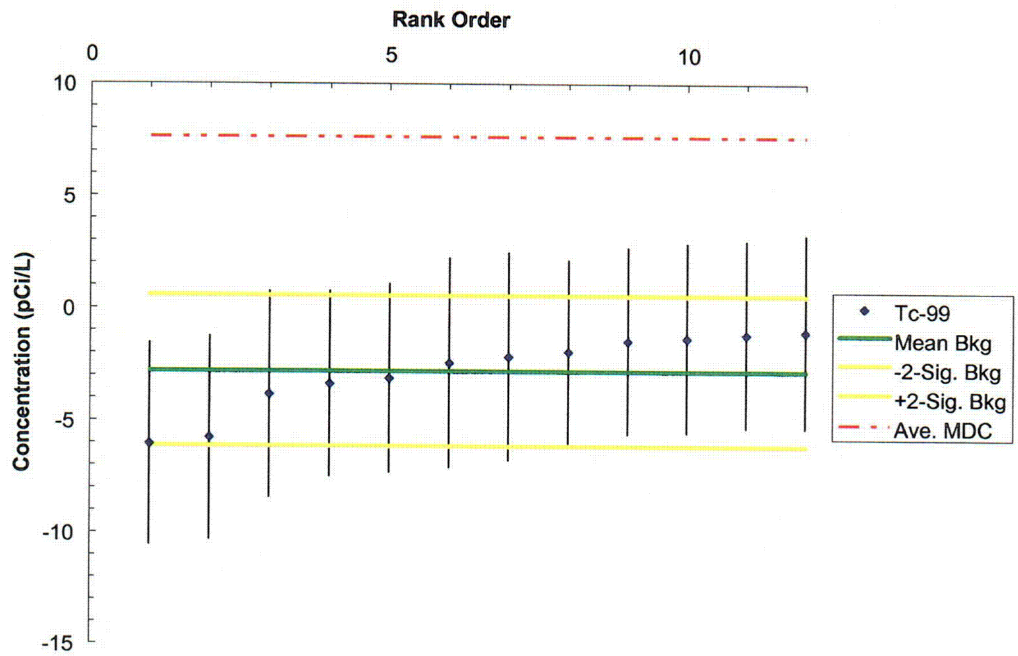


Figure 1-16: Tc-99 Normality Plot for 2004 Packer Test

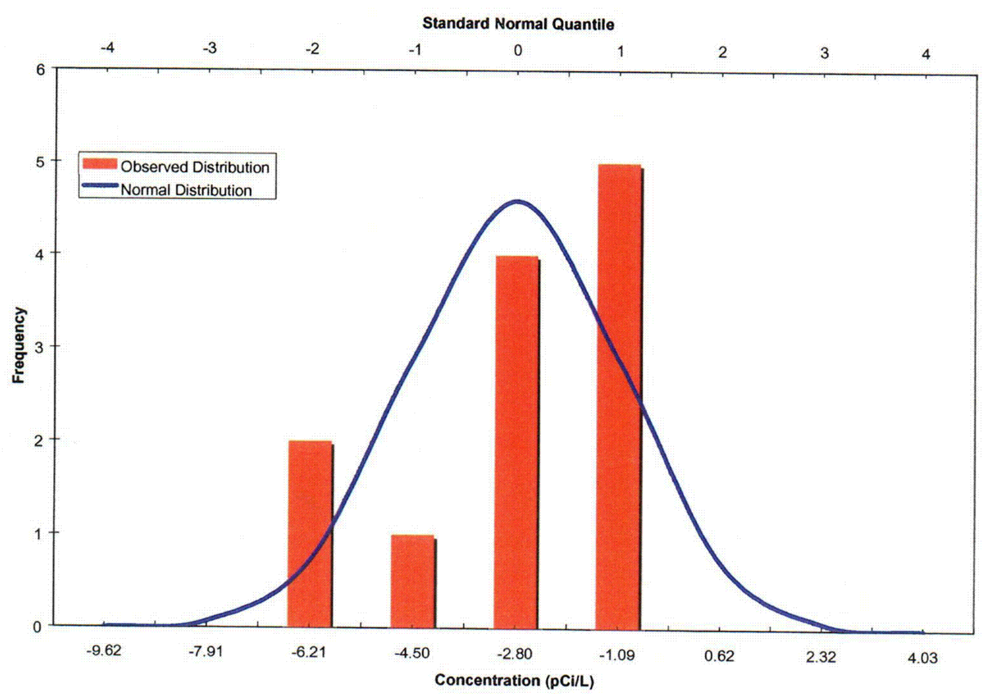


Figure 1-17: Sr-90 Rank Order for 2004 Packer Test

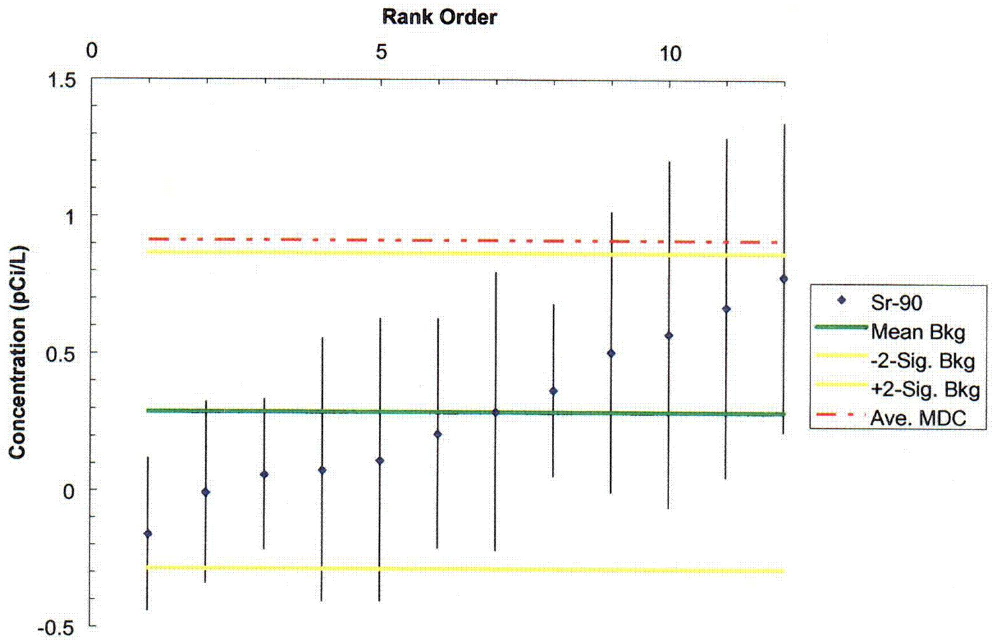


Figure 1-18: Sr-90 Normality Plot for 2004 Packer Test

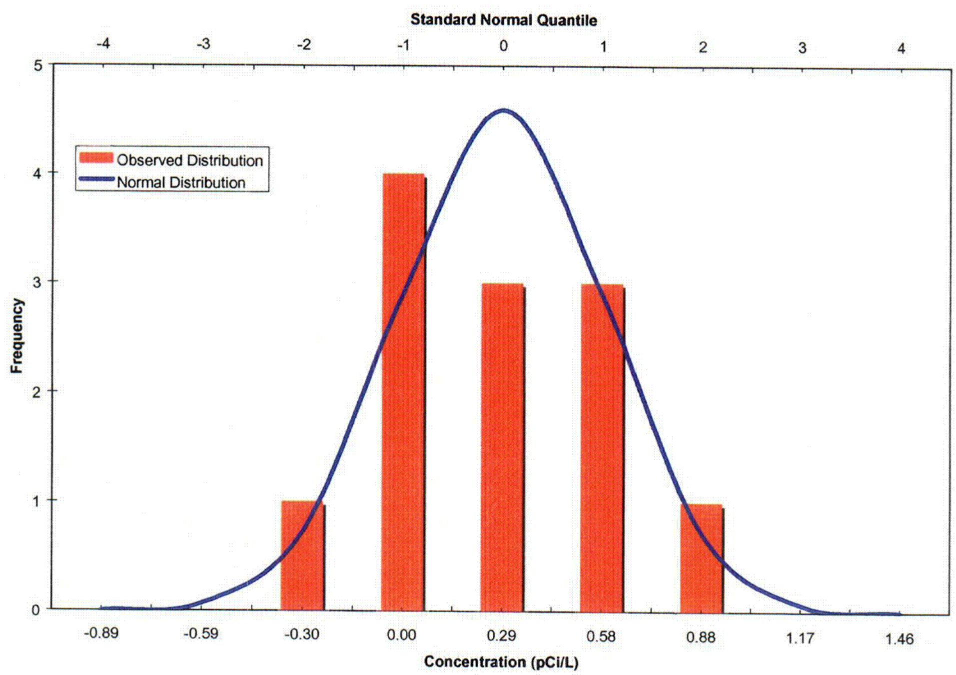


Figure 1-19: Cm-242 Rank Order for 2004 Packer Test

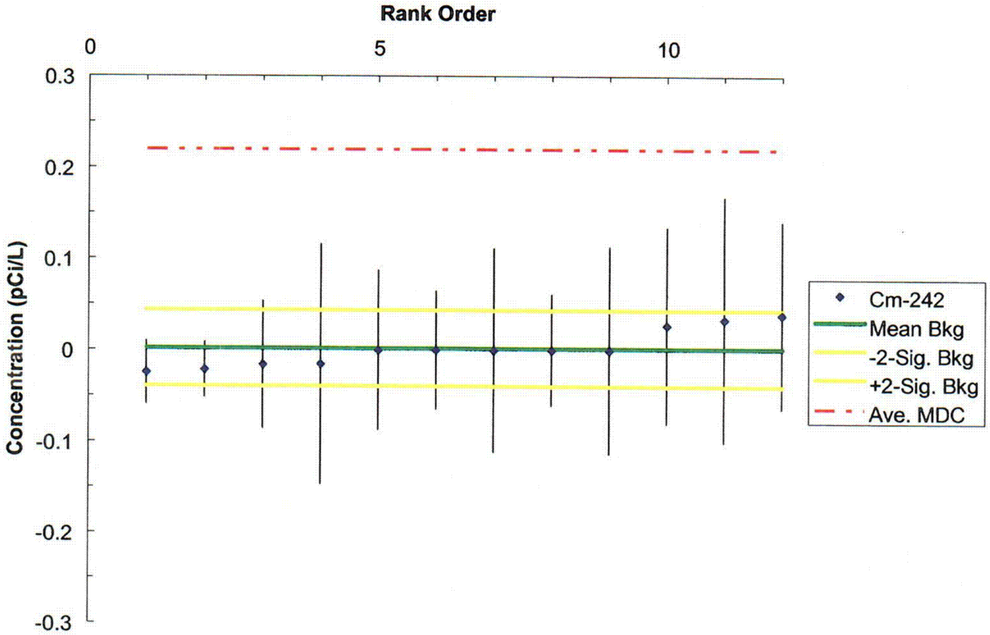


Figure 1-20: Cm-242 Normality Plot for 2004 Packer Test

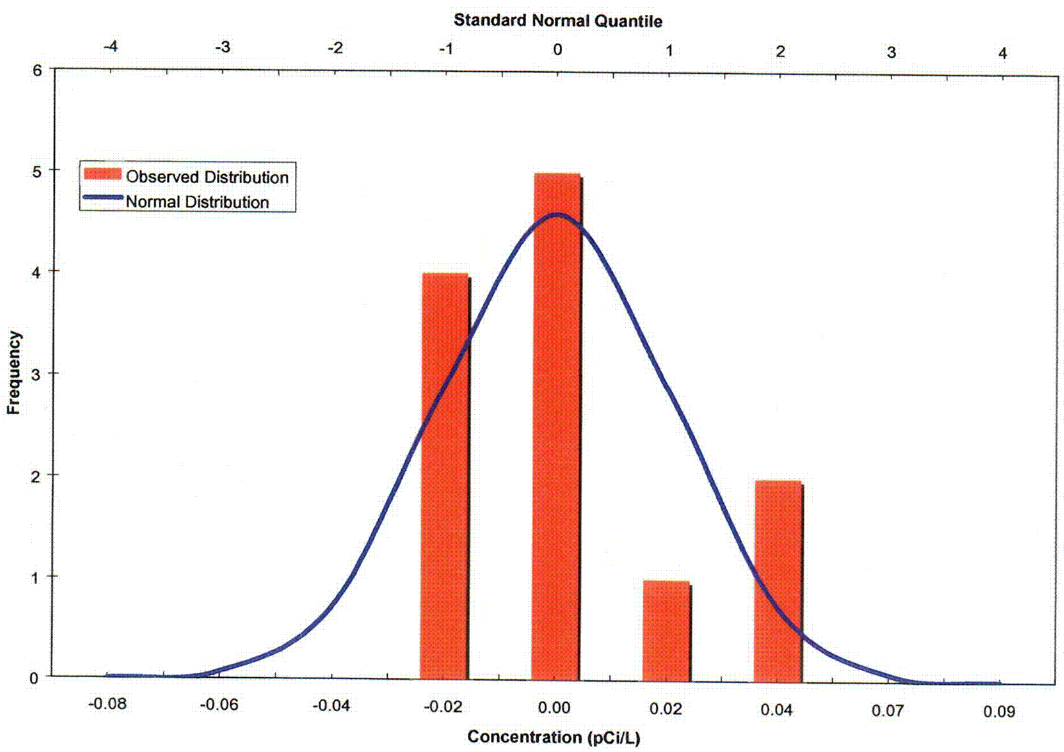


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Figure 1-21: Am-241 Rank Order for 2004 Packer Test

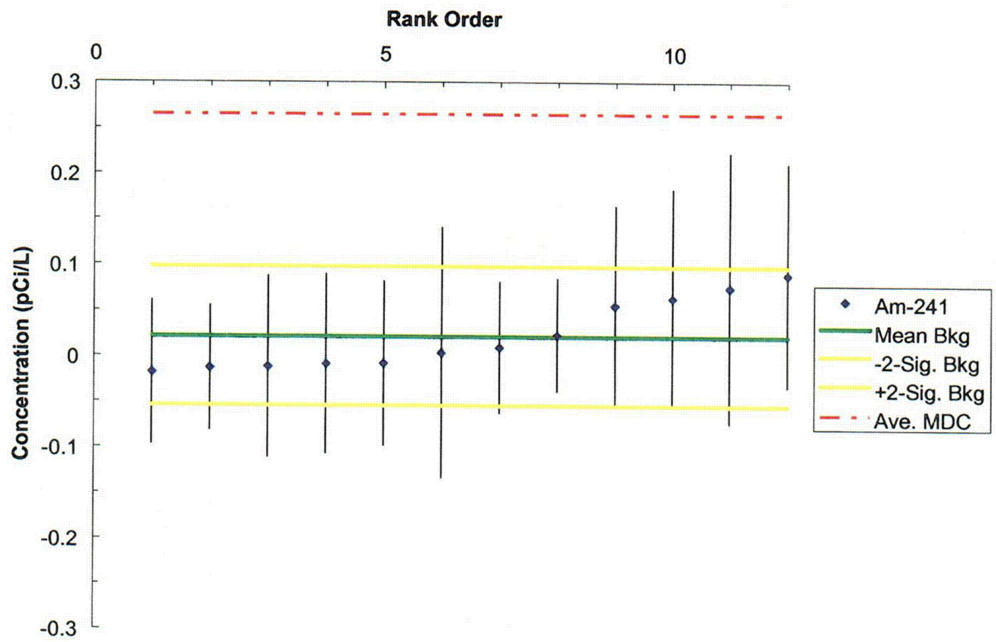

Figure 1-22: Am-241 Normality Plot for 2004 Packer Test