APPENDIX A

FY10 and FY14 Concentration Plots
Upgradient Performance Wells

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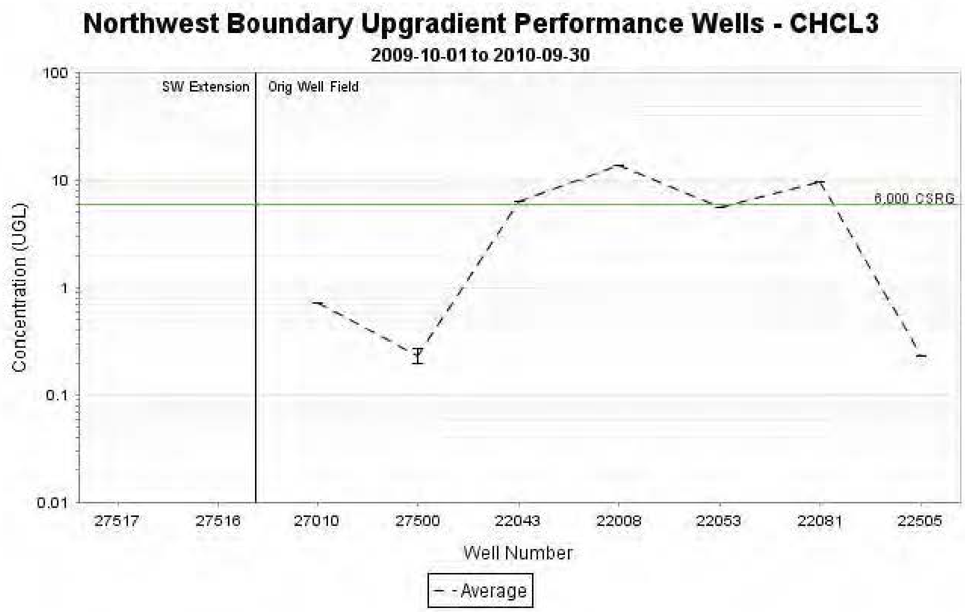
Figure A-1. NWBCS Upgradient Performance Wells – Chloroform, FY10 and FY14



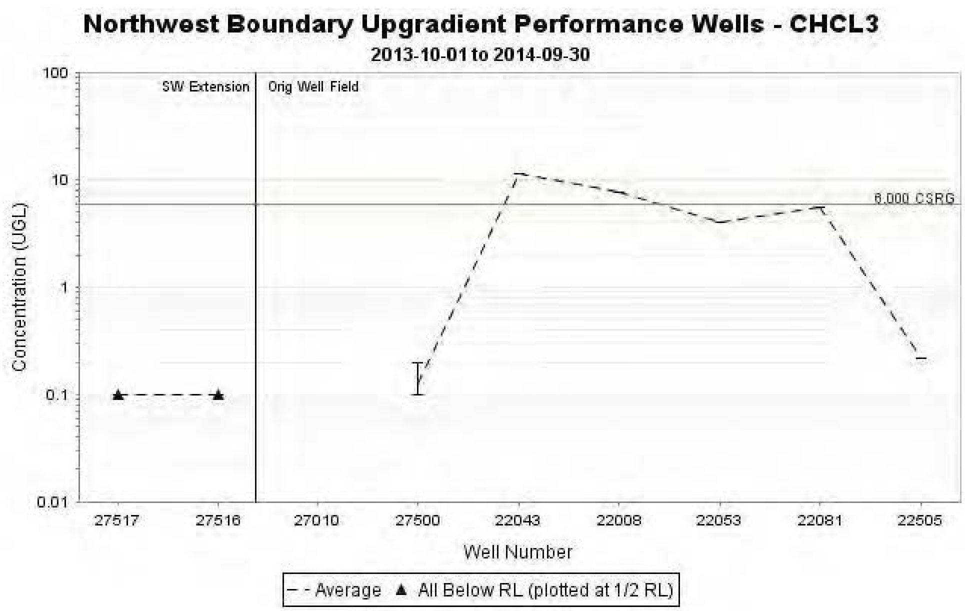
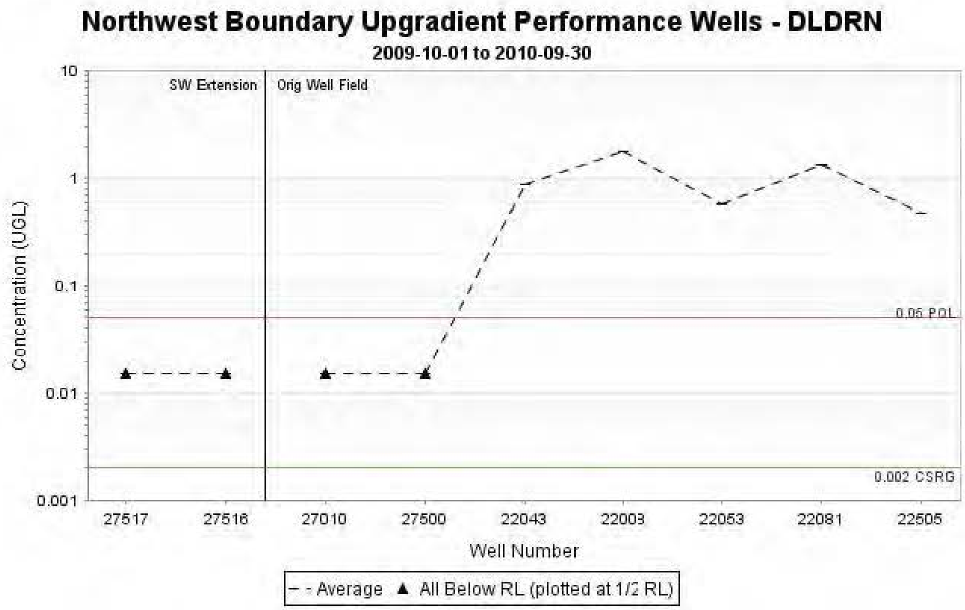


Figure A-2. NWBCS Upgradient Performance Wells – Dieldrin, FY10 and FY14



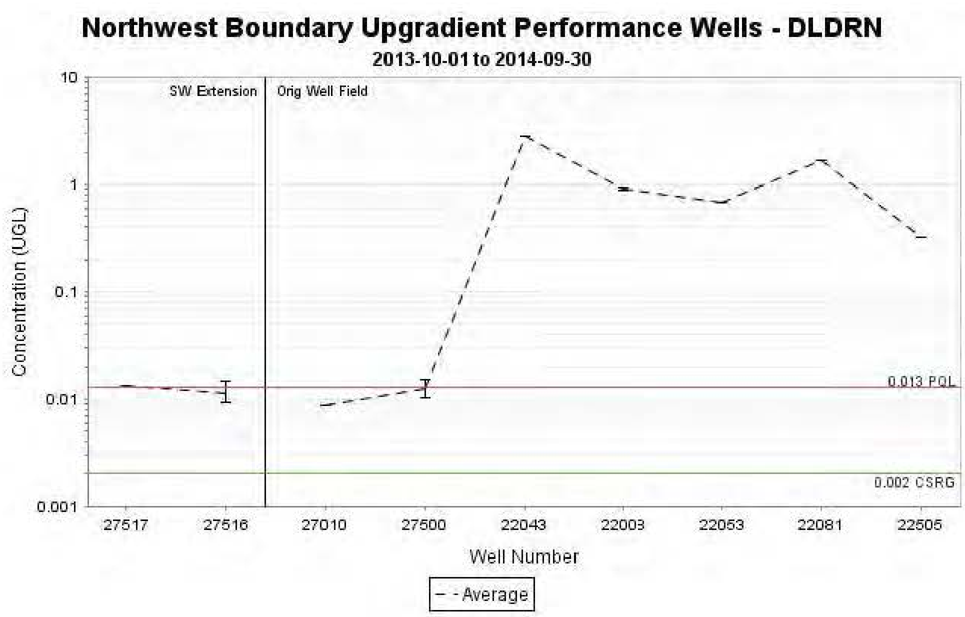
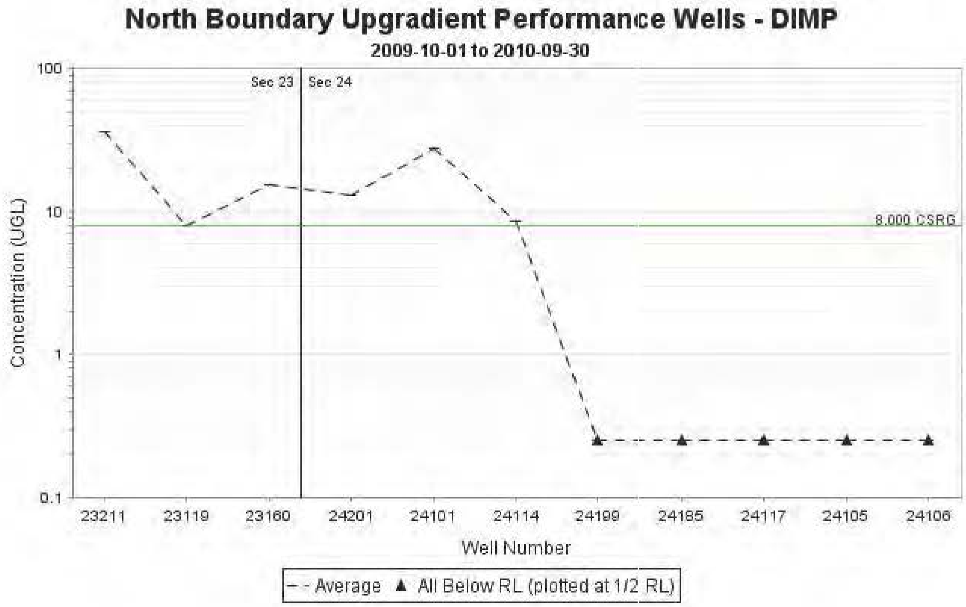


Figure A-3. NBCS Upgradient Performance Wells – DIMP, FY10 and FY14



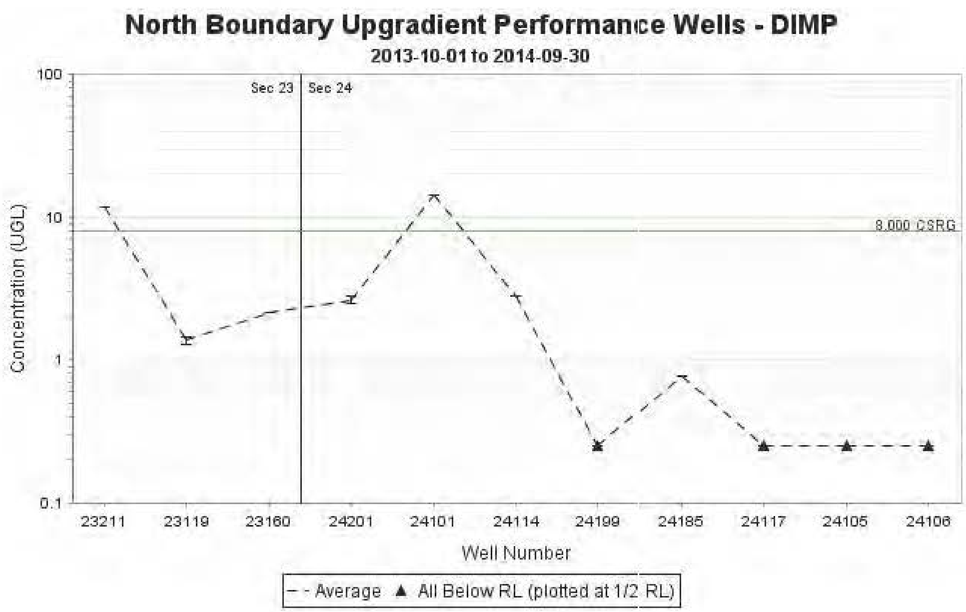
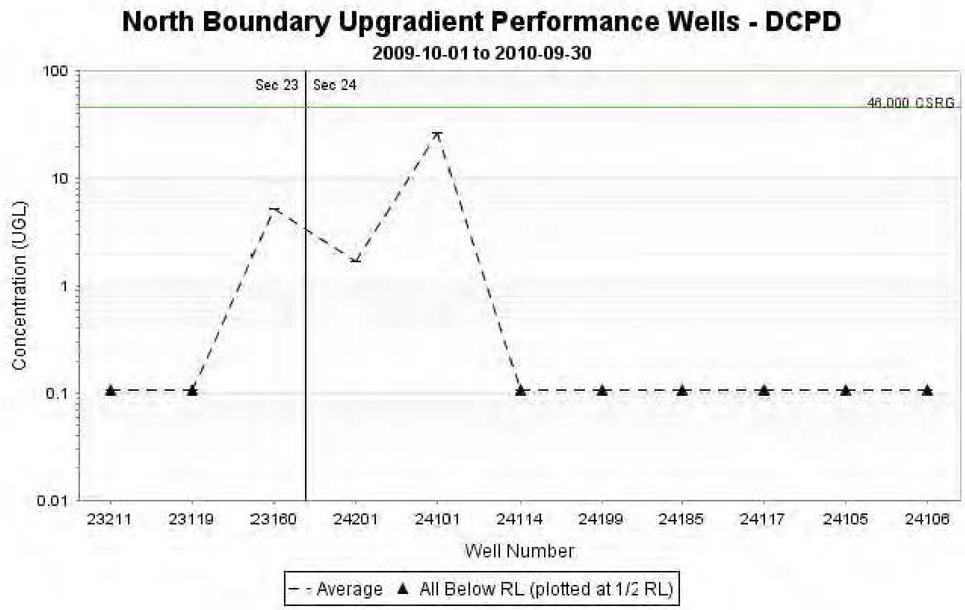


Figure A-4. NBCS Upgradient Performance Wells – DCPD, FY10 and FY14



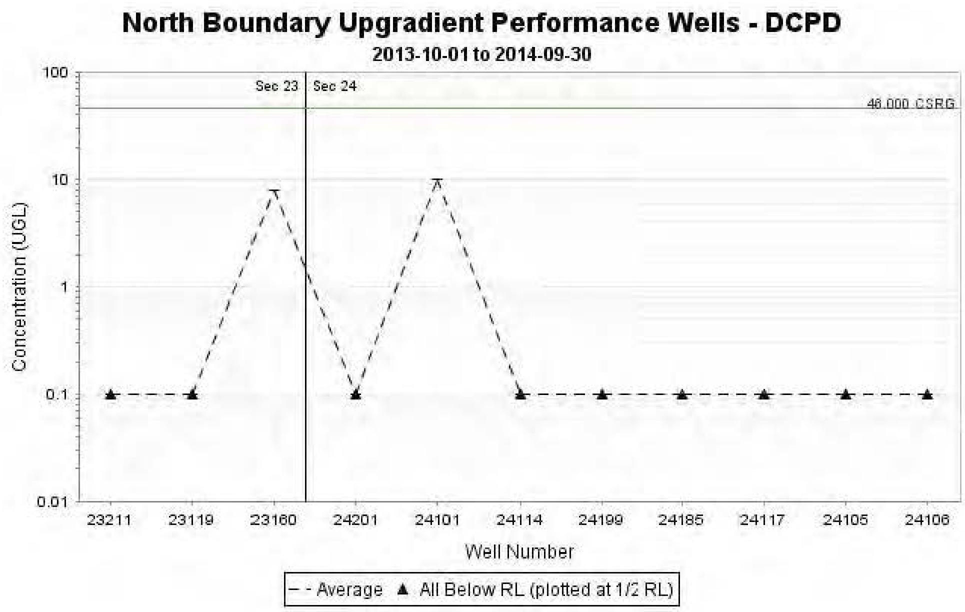
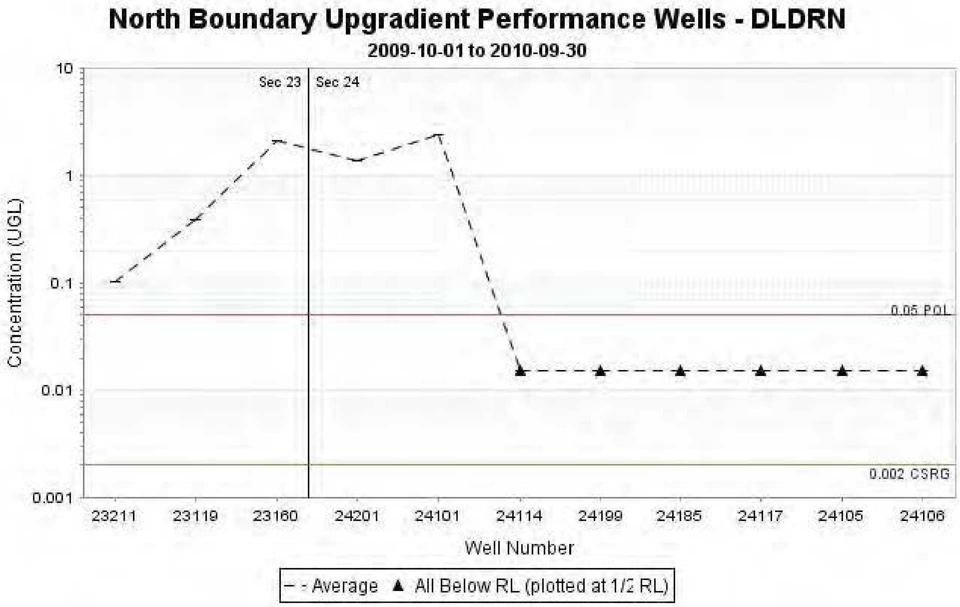


Figure A-5. NBCS Upgradient Performance Wells – Dieldrin, FY10 and FY14



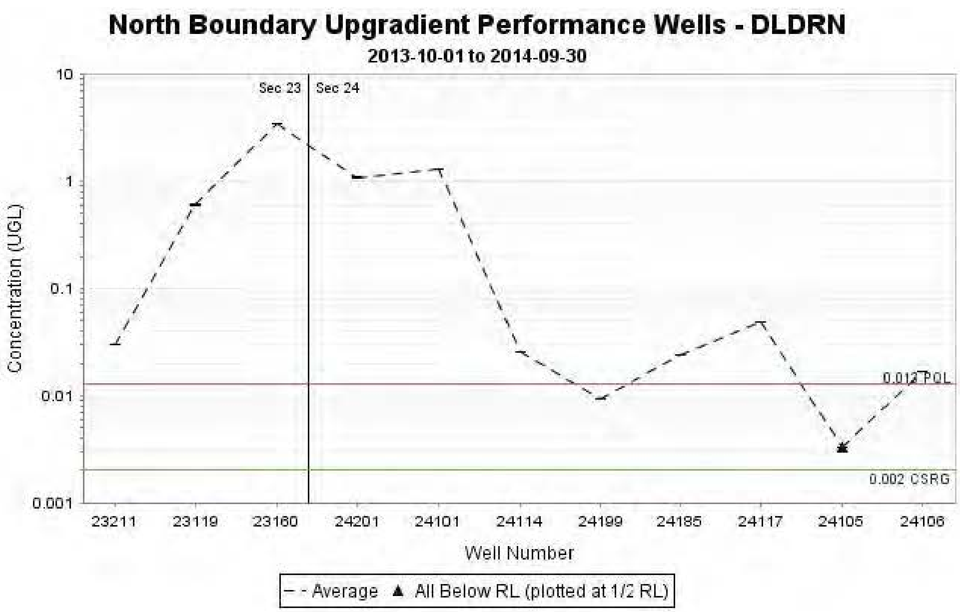
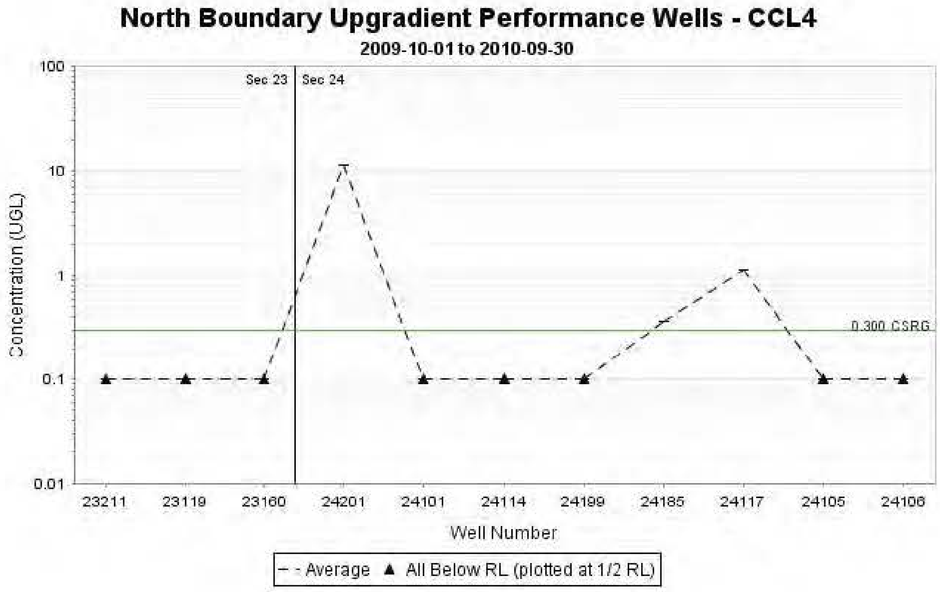


Figure A-6. NBCS Upgradient Performance Wells – Carbon Tetrachloride, FY10 and FY14



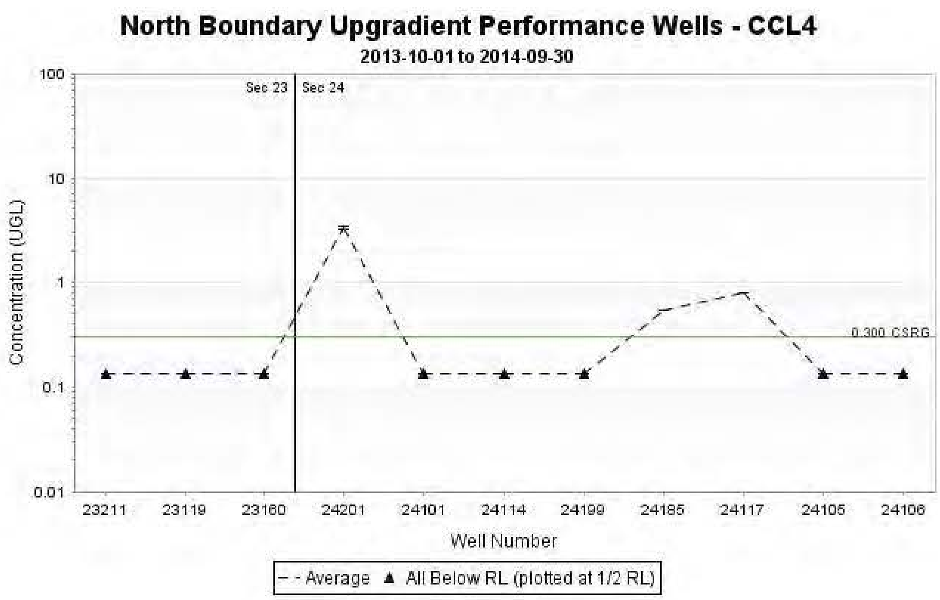
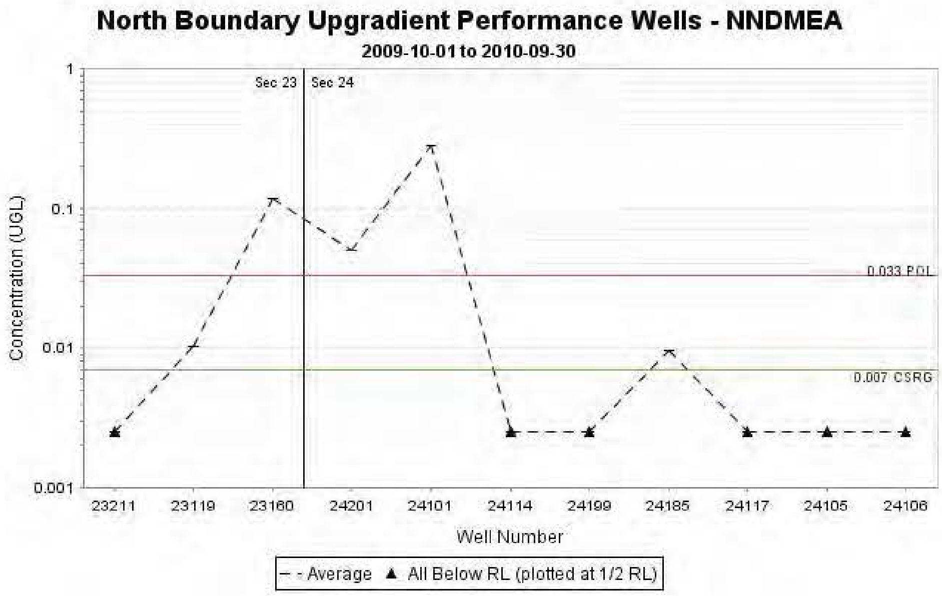


Figure A-7. NBCS Upgradient Performance Wells – N-Nitrosodimethylamine, FY10 and FY14



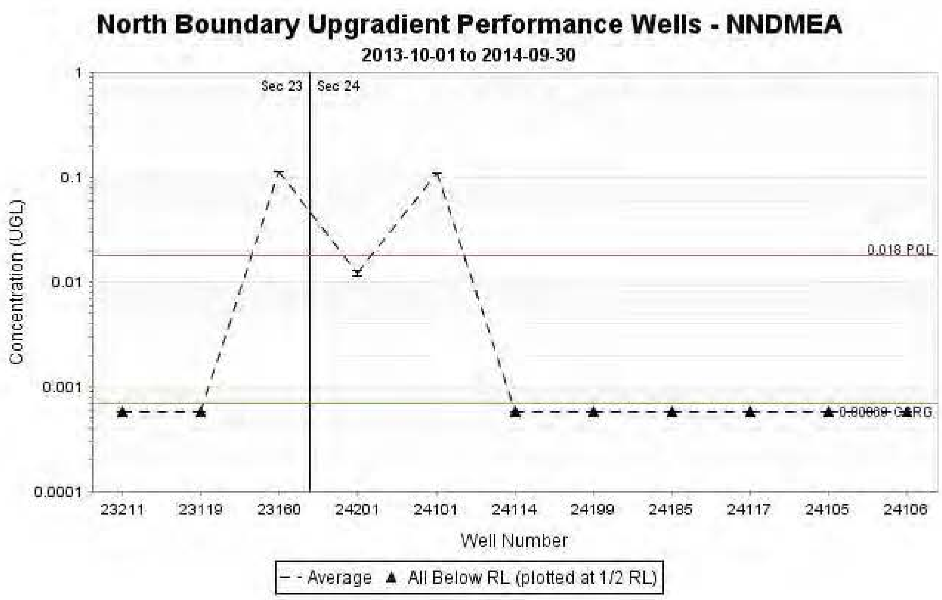
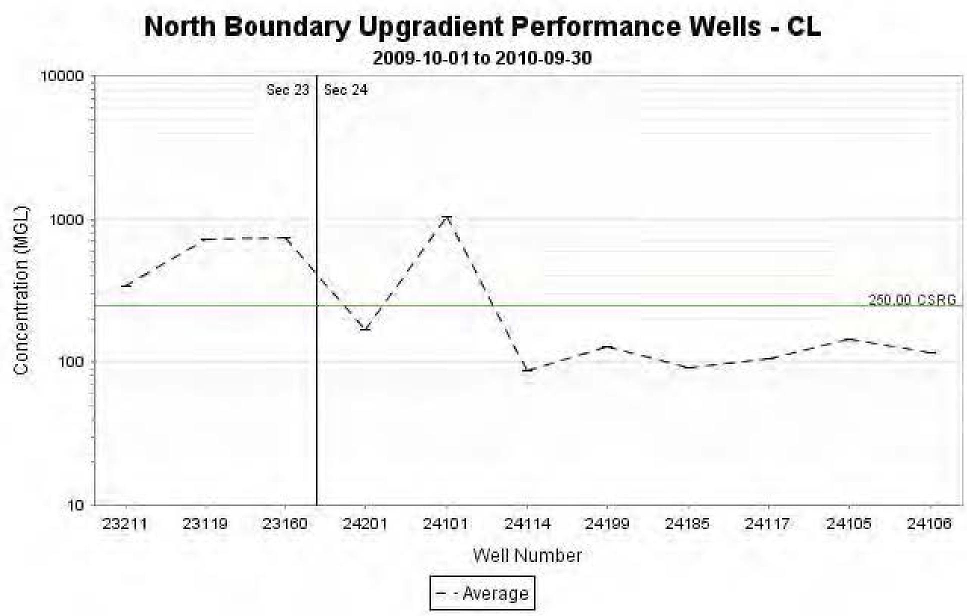


Figure A-8. NBCS Upgradient Performance Wells – Chloride, FY10 and FY14



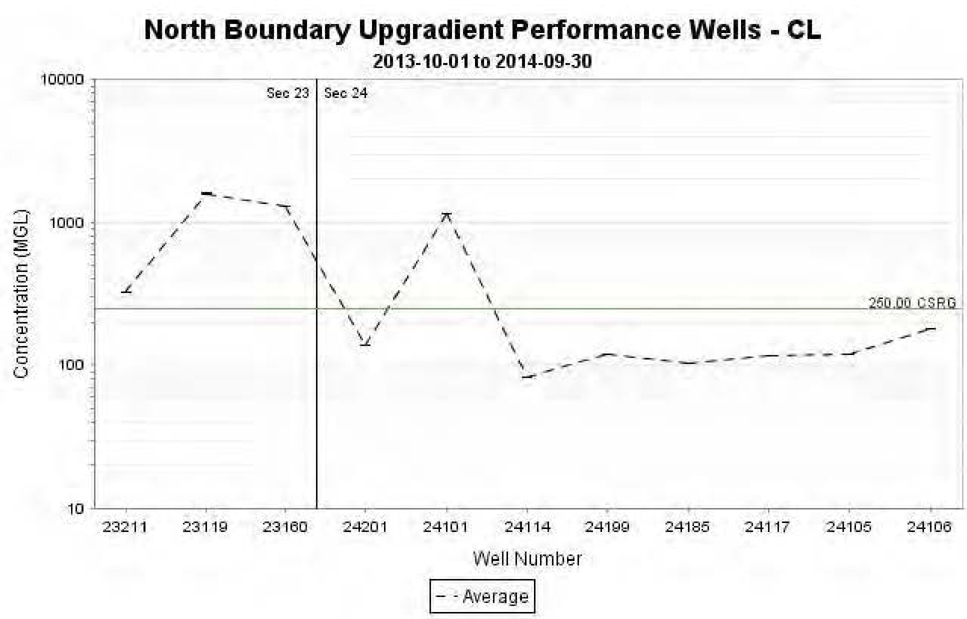
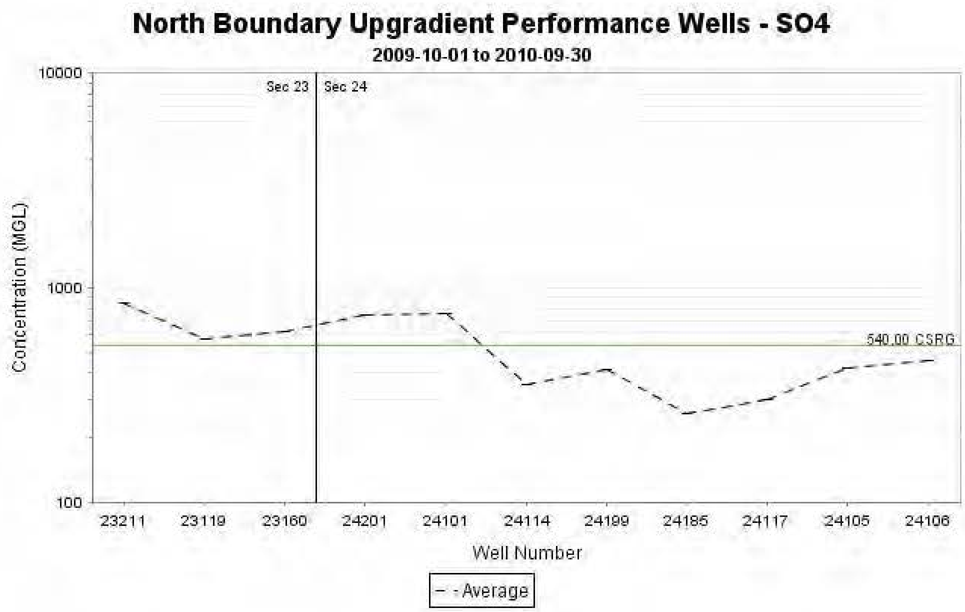


Figure A-9. NBCS Upgradient Performance Wells – Sulfate, FY10 and FY14



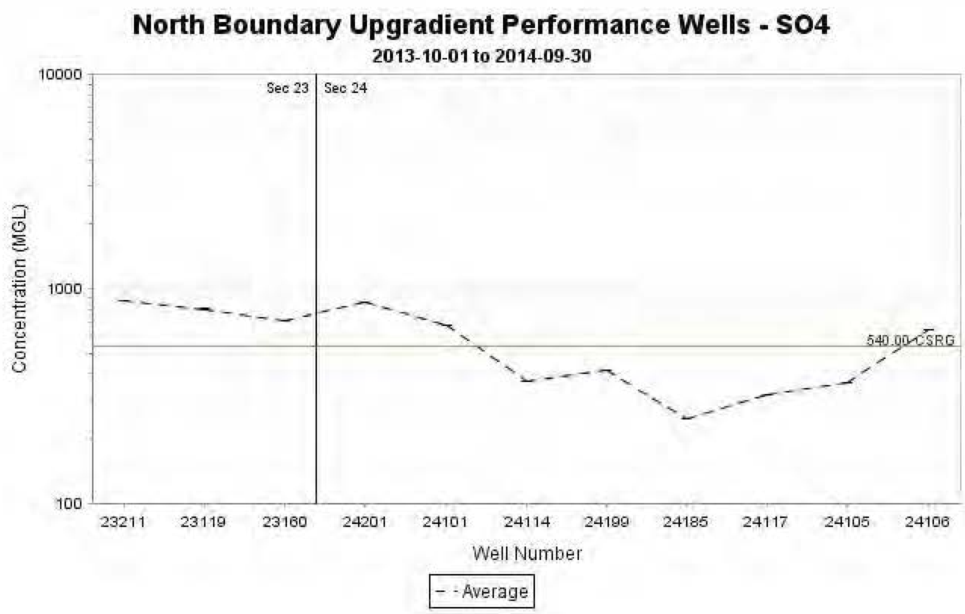
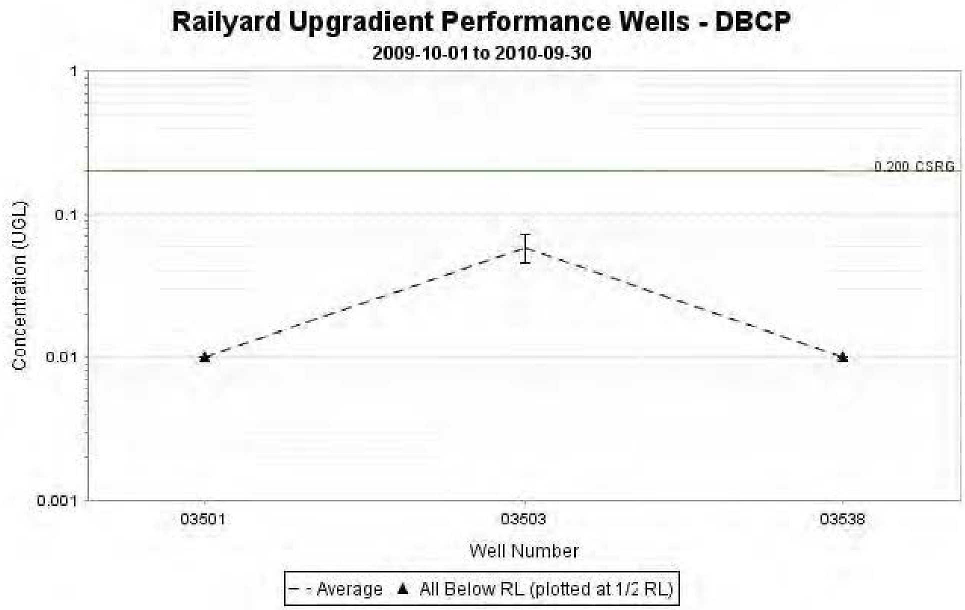


Figure A-10. RYCS Upgradient Performance Wells – DBCP, FY10 and FY14



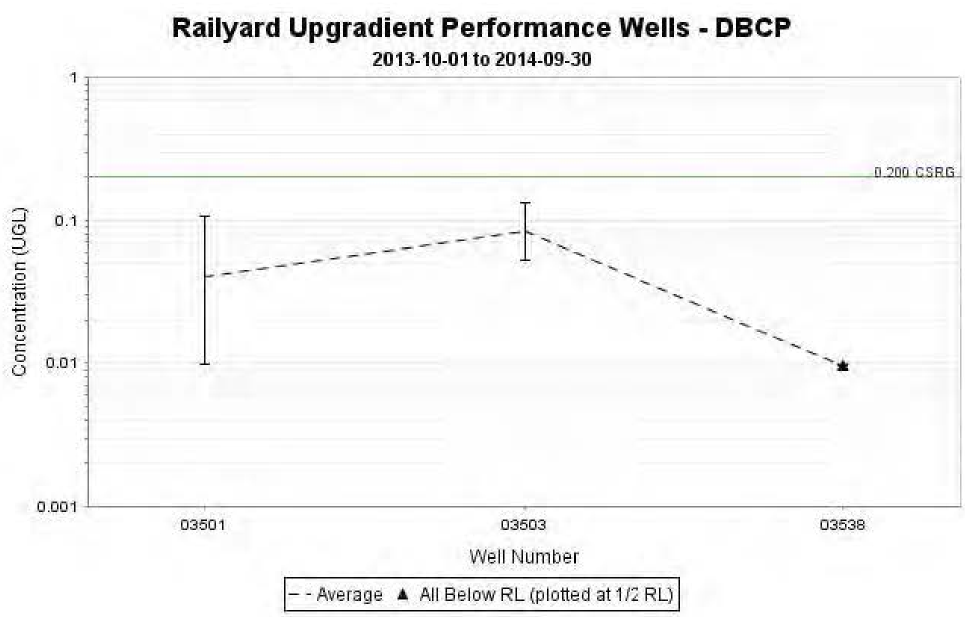
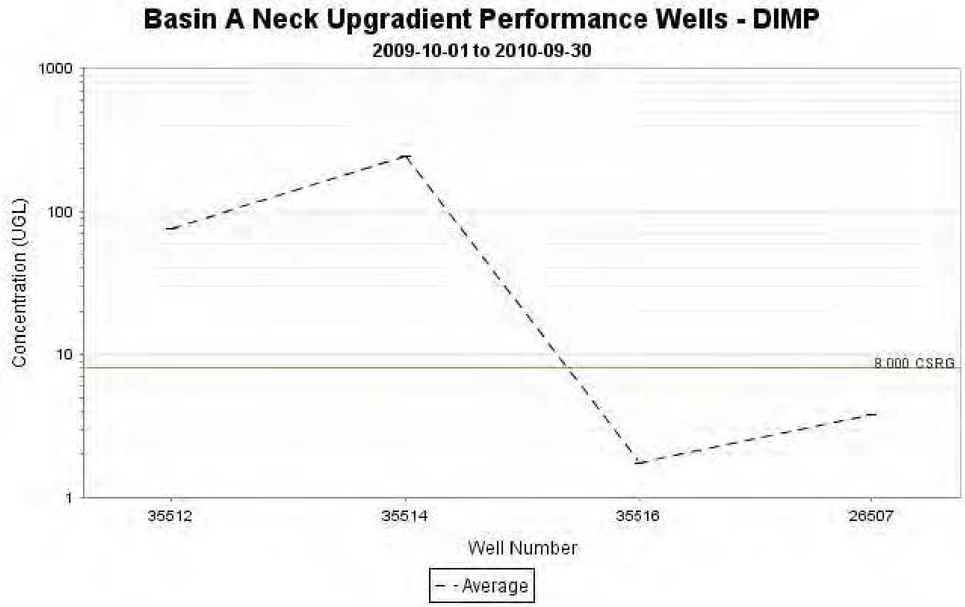


Figure A-11. BANS Upgradient Performance Wells – DIMP, FY10 and FY14



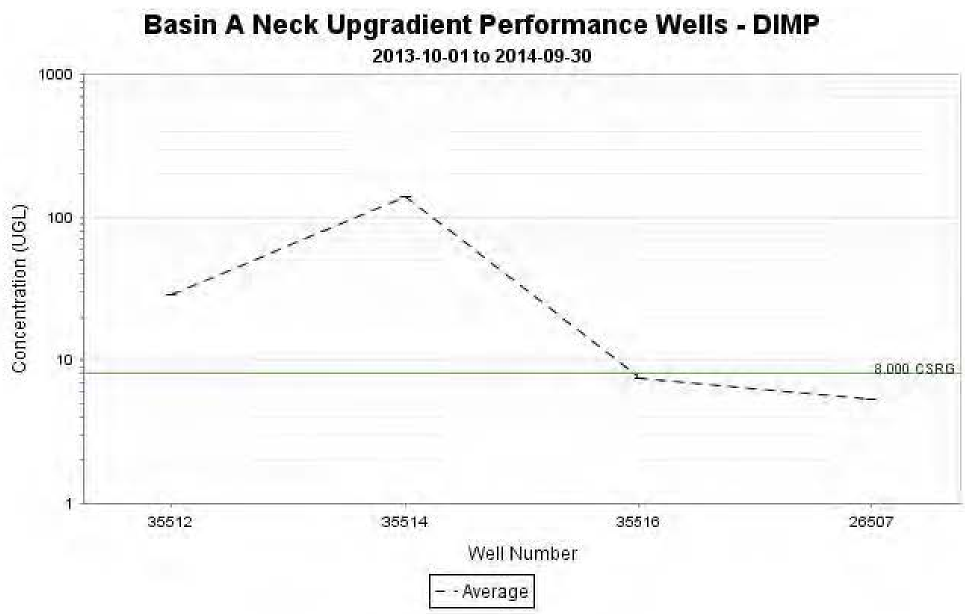
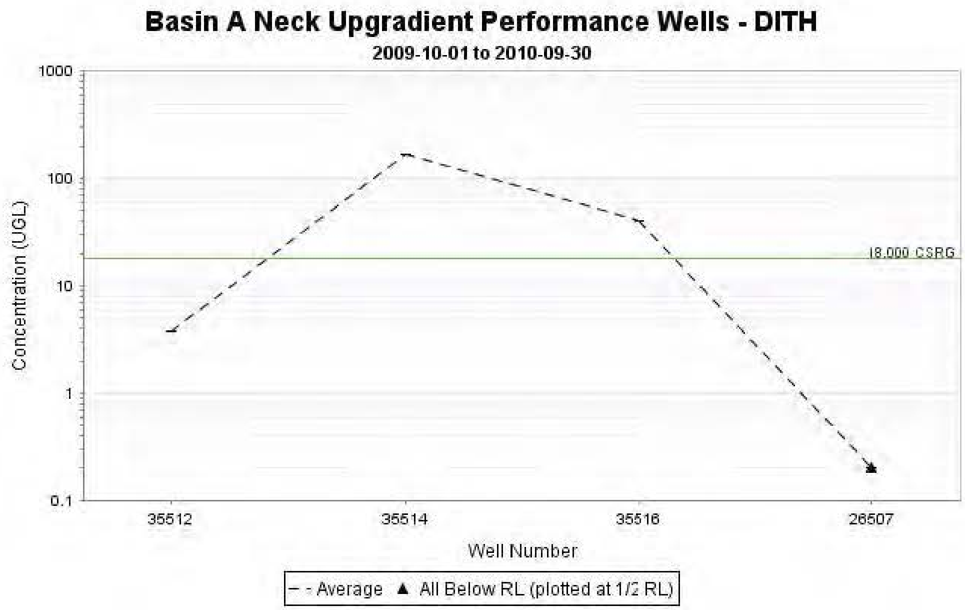


Figure A-12. BANS Upgradient Performance Wells – Dithiane, FY10 and FY14



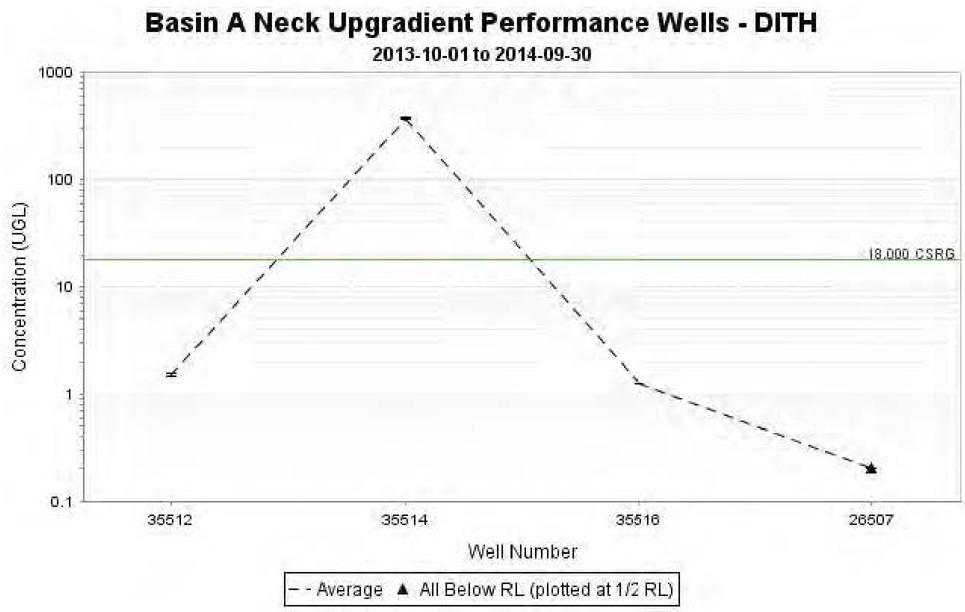
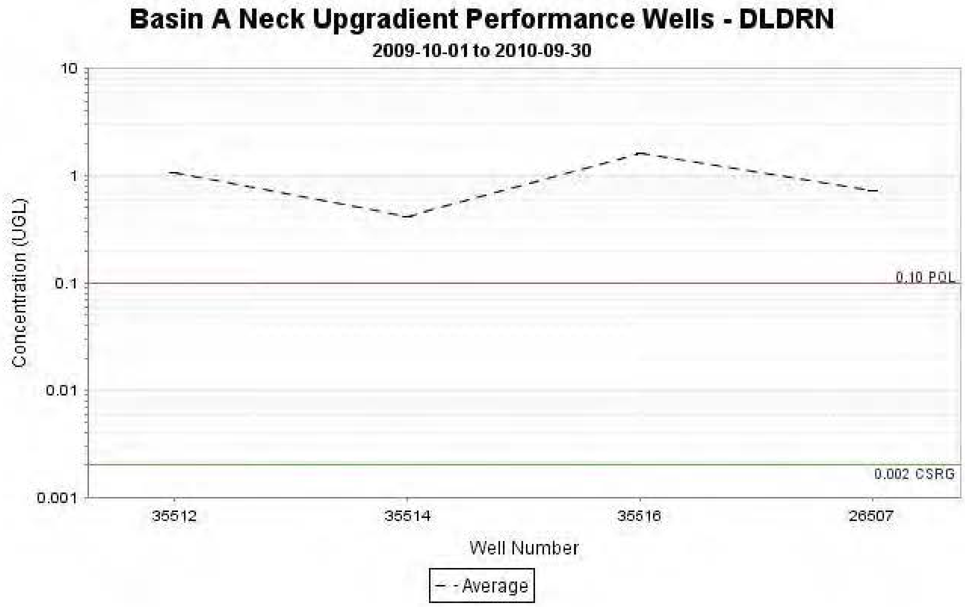


Figure A-13. BANS Upgradient Performance Wells – Dieldrin, FY10 and FY14



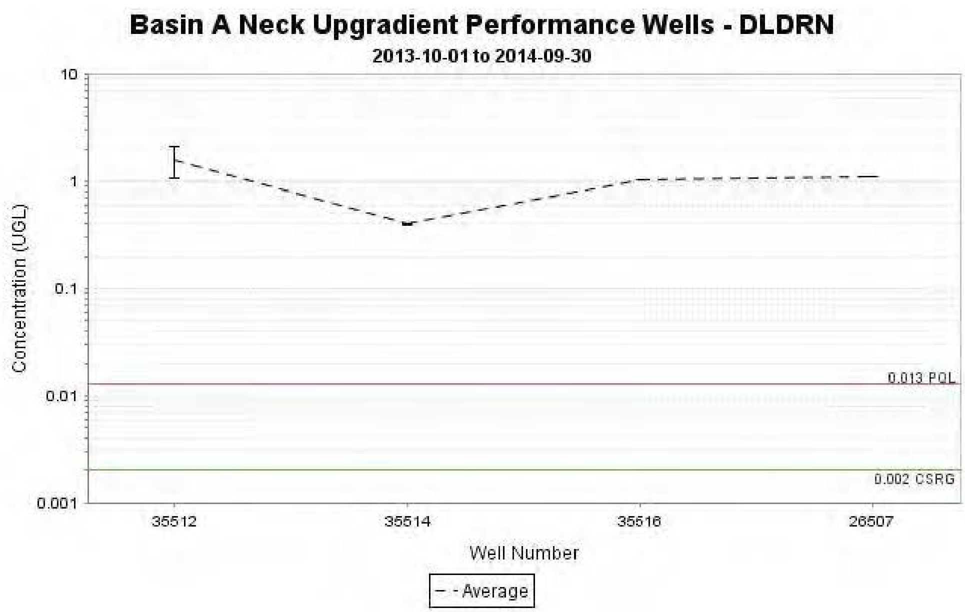
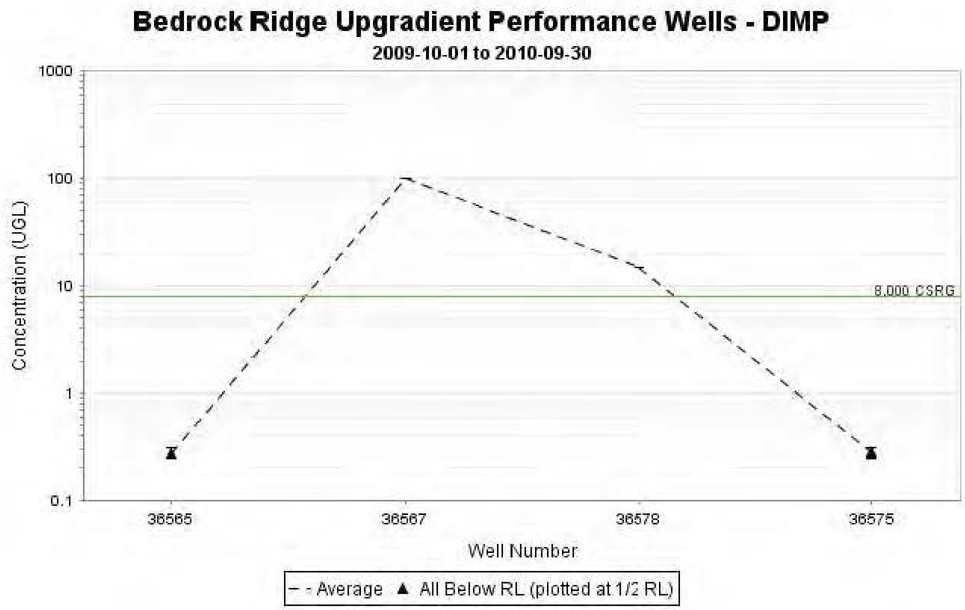


Figure A-14. BRES Upgradient Performance Wells – DIMP, FY10 and FY14



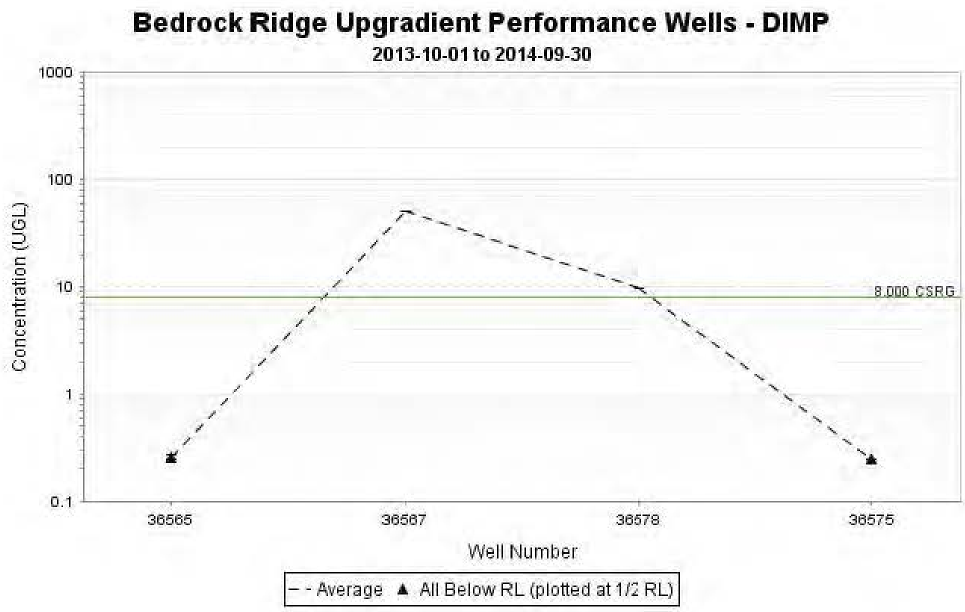
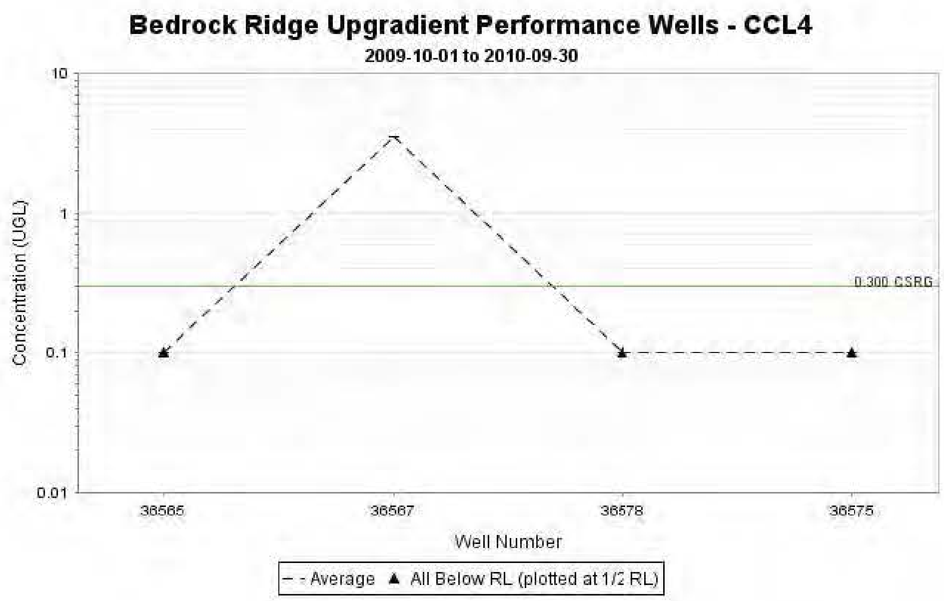


Figure A-15. BRES Upgradient Performance Wells – Carbon Tetrachloride, FY10 and FY14



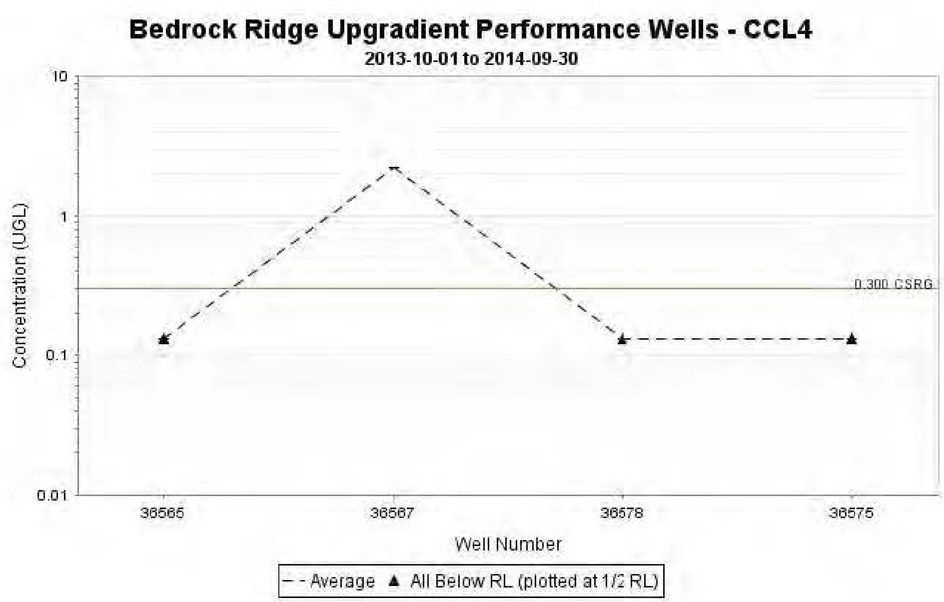
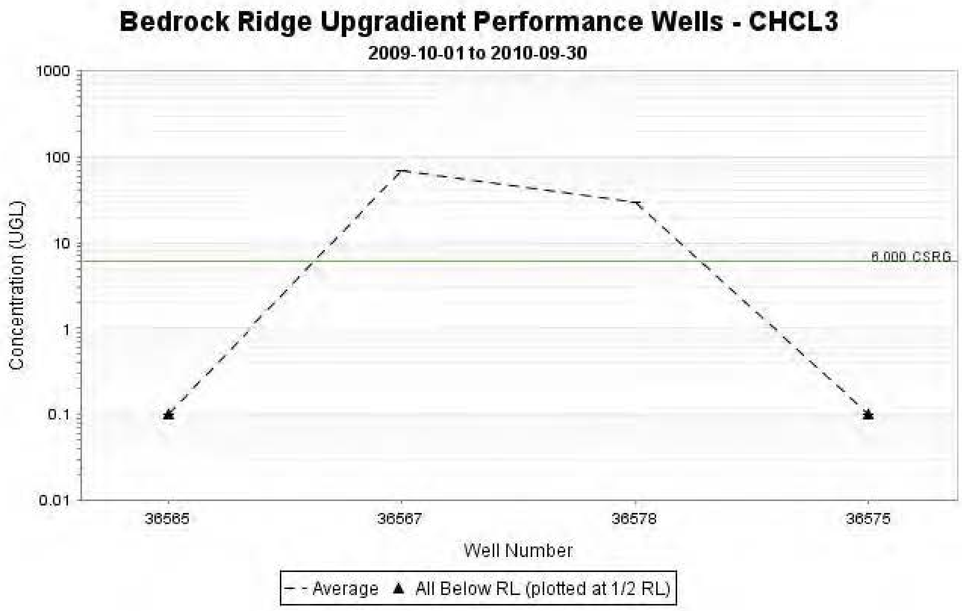


Figure A-16. BRES Upgradient Performance Wells – Chloroform, FY10 and FY14



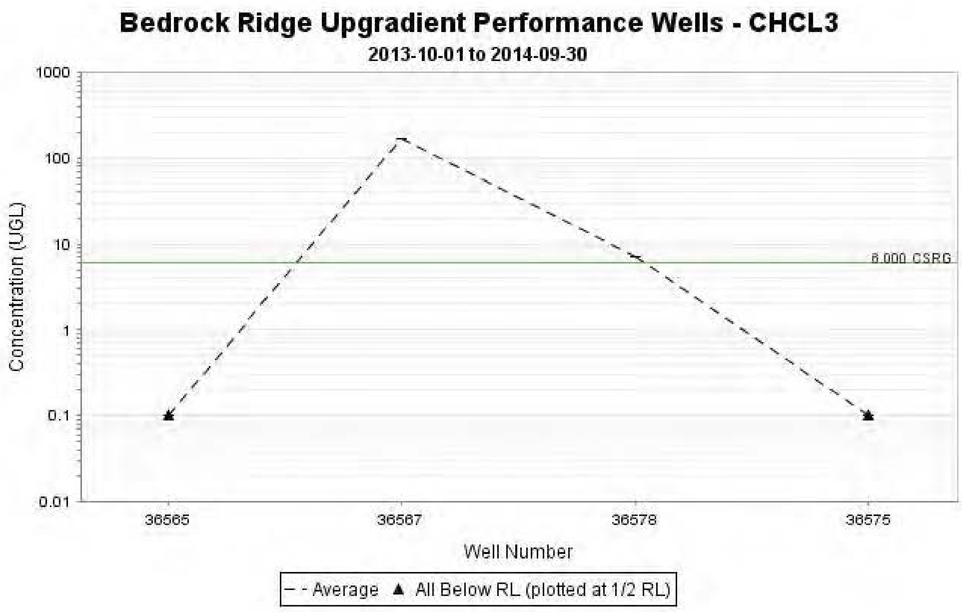
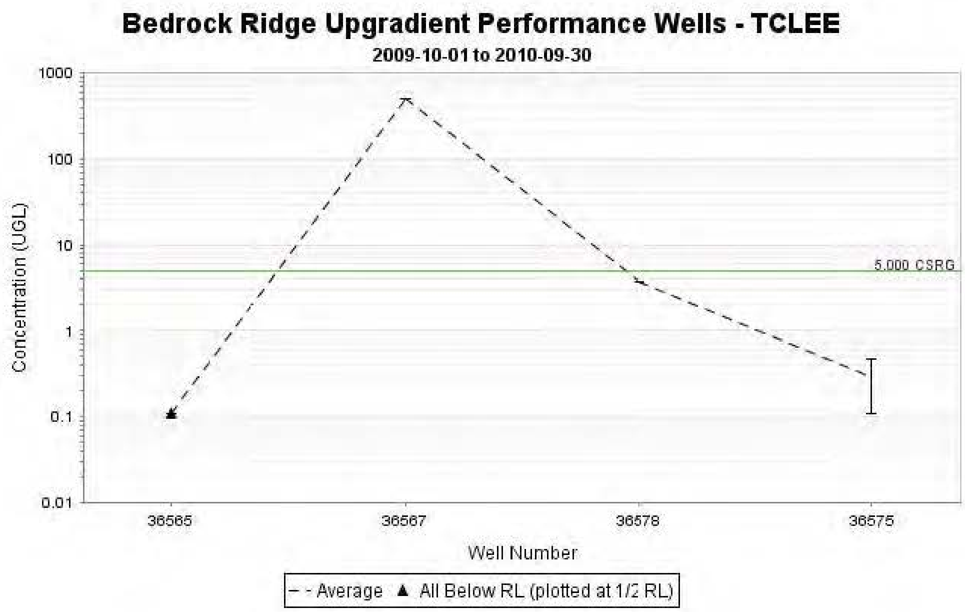


Figure A-17. BRES Upgradient Performance Wells – Tetrachloroethylene, FY10 and FY14



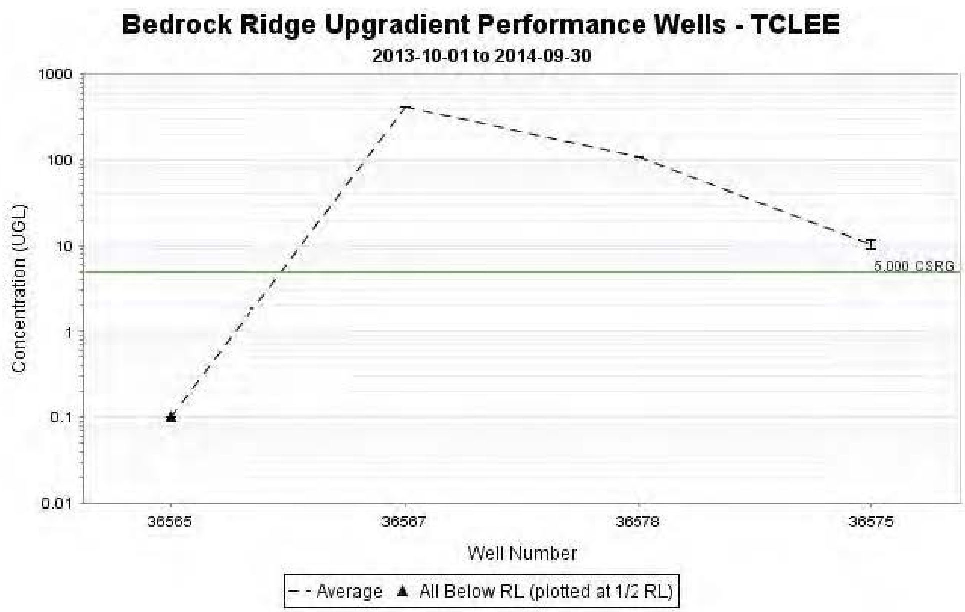


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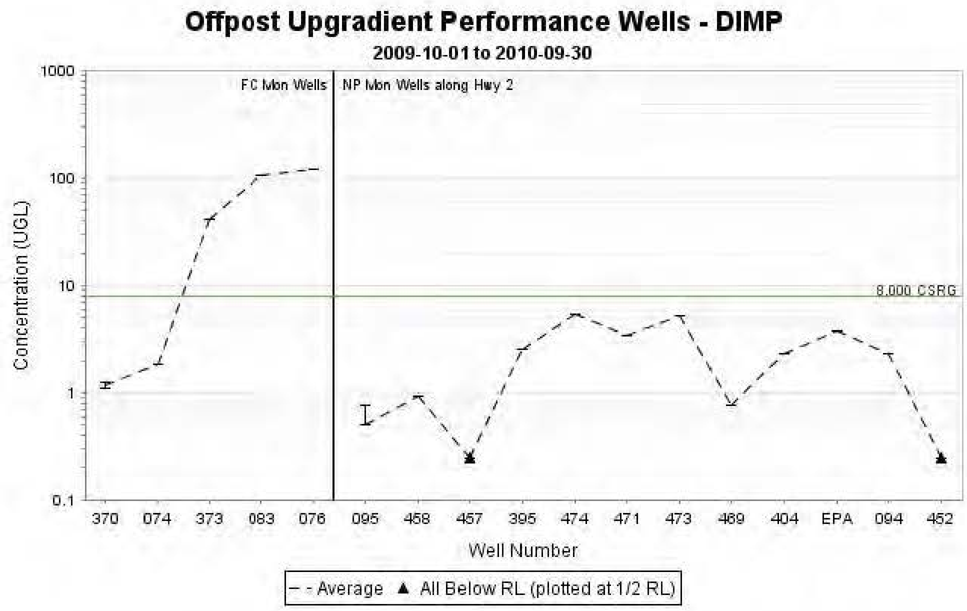
Figure A-18. OGITS Upgradient Performance Wells – DIMP, FY10 and FY14



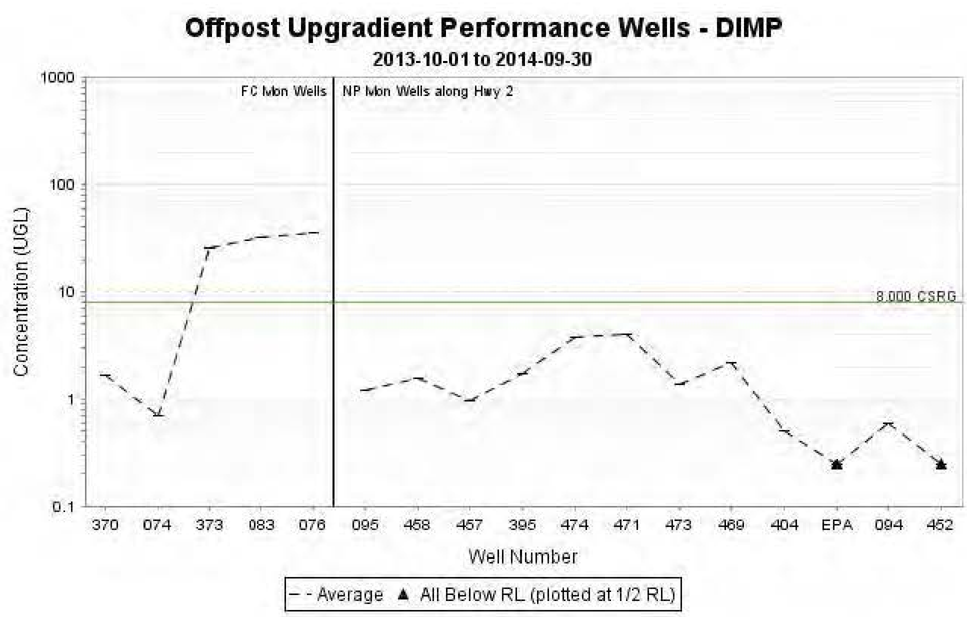
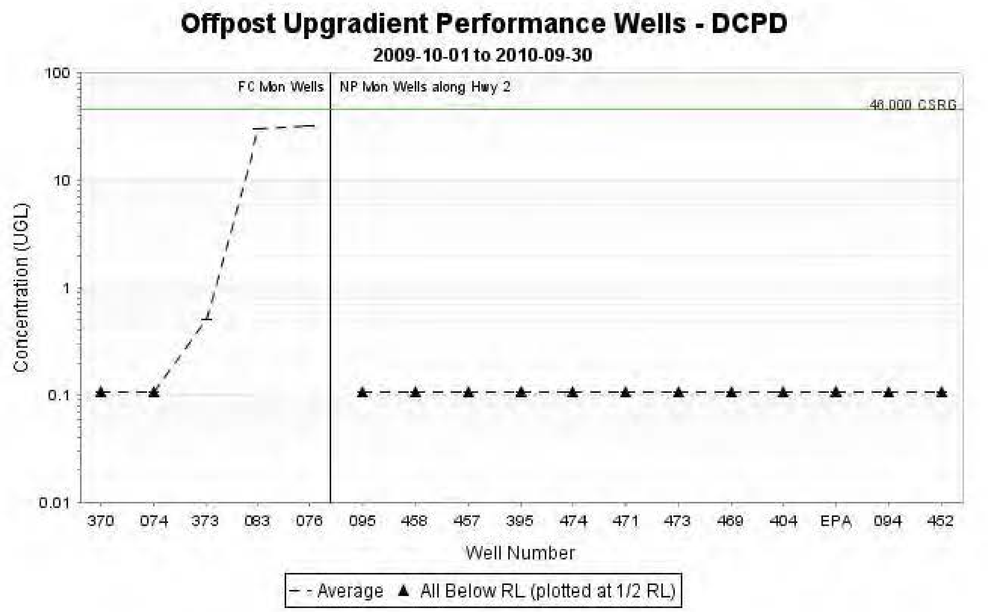


Figure A-19. OGITS Upgradient Performance Wells – DCPD, FY10 and FY14



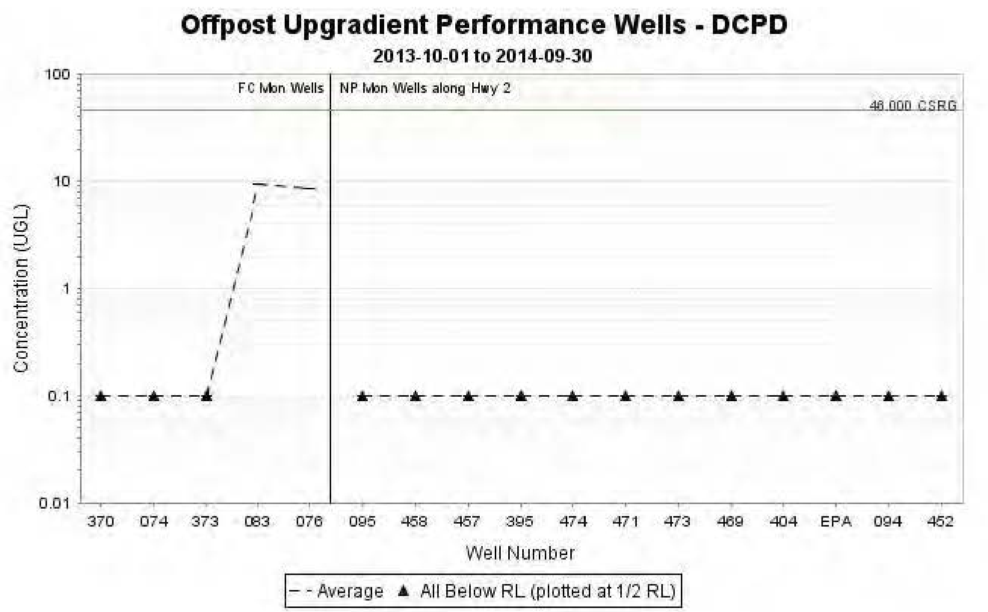
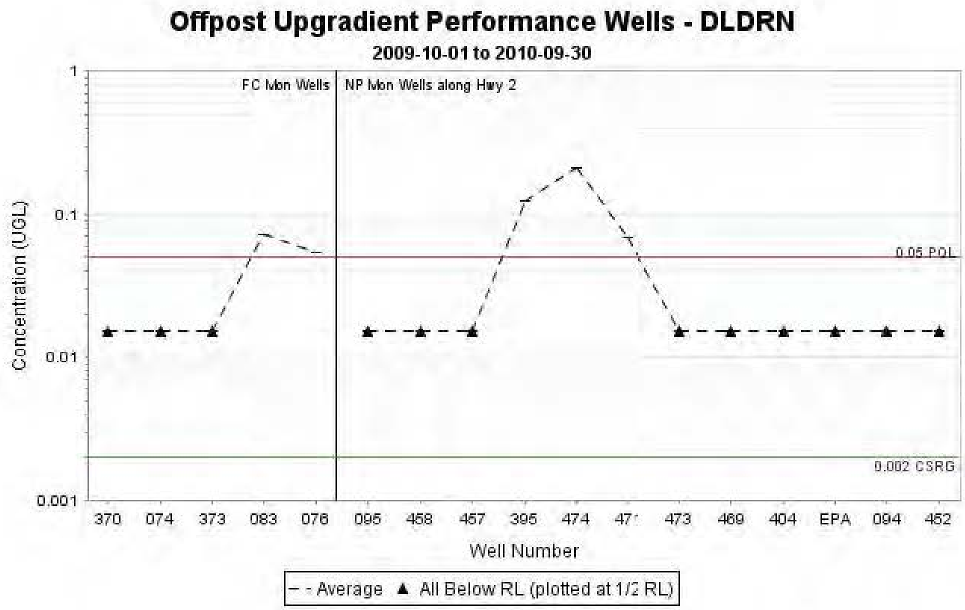


Figure A-20. OGITS Upgradient Performance Wells – Dieldrin, FY10 and FY14



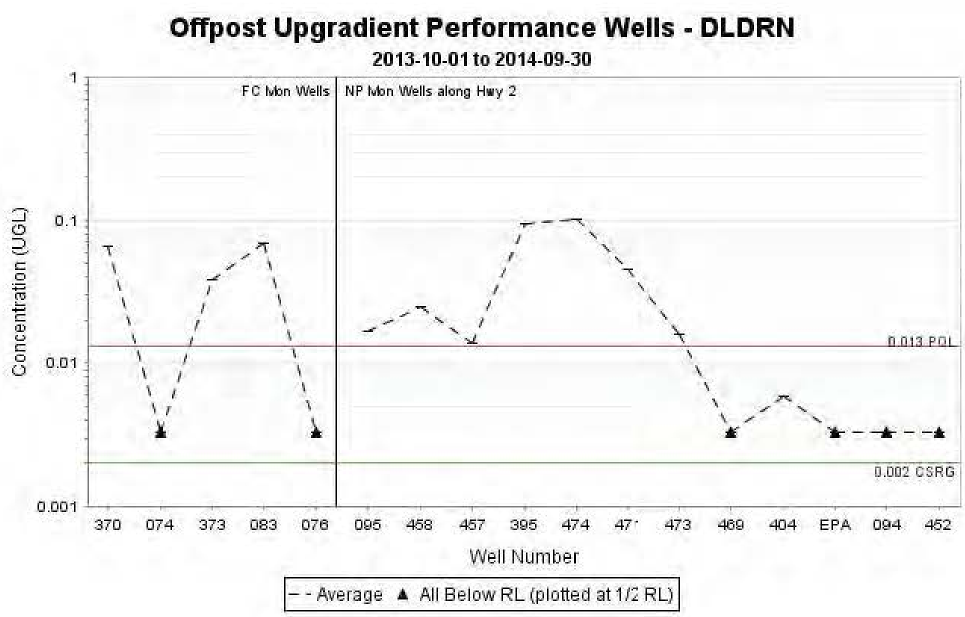
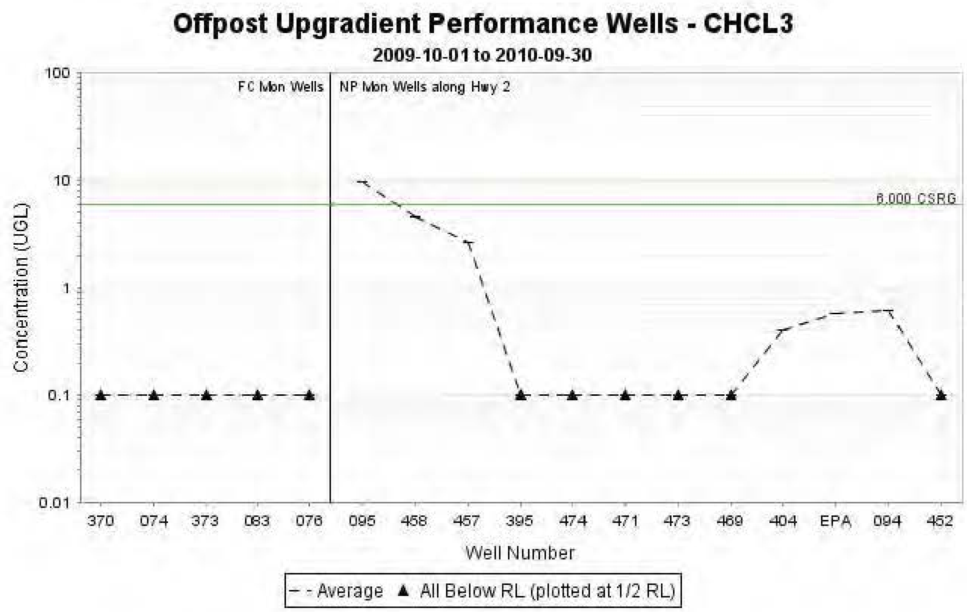
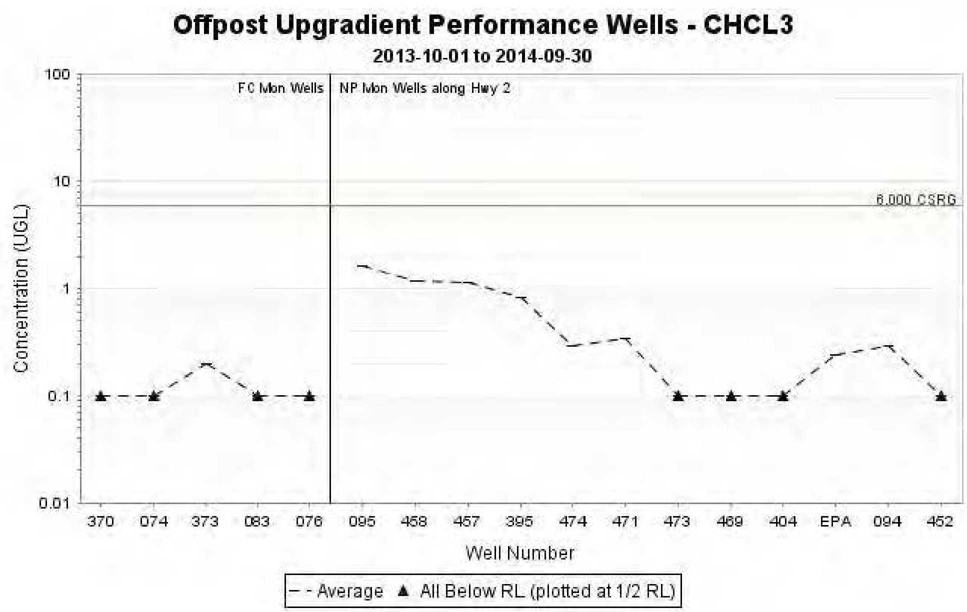


Figure A-21. OGITS Upgradient Performance Wells – Chloroform, FY10 and FY14





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APPENDIX B

North Boundary System Evaluation

FYSR Appendix B

North Boundary Containment System
Comparison of Former Conformance Well and Performance Well Hydrogeology and Water Quality Data

Introduction

The 2010 Long Term Monitoring Plan (LTMP) established criteria for assessing the North Boundary Containment System (NBCS) performance, which include primary criteria of maintaining a reverse hydraulic gradient along the slurry wall, and plume edge capture at the ends of the slurry wall. If the primary criteria cannot be met, secondary criteria are used to assess the system performance. The secondary criteria are to demonstrate that the concentrations of Containment System Remediation Goal (CSRG) analytes in the downgradient performance wells either are below CSRGs/Practical Quantitation Limits (PQLs) or are decreasing over a period of at least five years. The downgradient performance well network in the 2010 LTMP included a different group of wells than the conformance wells in the 1999 LTMP.

Residual contamination in the aquifer sediments north of the slurry wall and slow migration of contaminants in fine-grained sediments in the downgradient conformance wells caused a few contaminants to exceed the remediation goals even though a reverse gradient has been maintained and the concentrations have been below the CSRGs in the treatment plant effluent. Only a few of the 29 NBCS CSRG analytes have been detected historically above the remediation goals in the downgradient wells. For example, in FY14, 10 of the 29 NBCS CSRG analytes were detected above the CSRGs/PQLs in one or more upgradient performance wells. The 10 analytes included diisopropylmethyl phosphonate (DIMP), dieldrin, endrin, isodrin, 1,2-dichloroethane, carbon tetrachloride, n-nitrosodimethylamine, chloride, fluoride, and sulfate. In FY14, only five of the 10 analytes (DIMP, dieldrin, chloride, fluoride, and sulfate) were detected above the CSRGs/PQLs in the downgradient performance wells. Since a reverse hydraulic gradient has consistently been maintained, this downgradient contamination most likely has not been caused by underflow or bypass of the system, and thus, has not been considered to be representative of NBCS performance. If bypass or underflow of the NBCS were occurring, more of the 10 CSRG analytes detected above the CSRGs upgradient would be detected downgradient, but they are not. Historically (prior to FY14), more CSRG analytes were detected above the CSRGs/PQLs in upgradient wells, but the same five analytes have been detected downgradient.

Monitoring wells located closer to the NBCS slurry wall and former recharge wells in similar flow paths as the conformance wells were selected as downgradient performance wells in the 2010 LTMP in order to attempt to collect water quality data that are more indicative of system performance. Both sets of wells were sampled contemporaneously several times, including during the current FYR period, and have had similar results. Since the performance wells had similar water quality results as the former conformance wells, with Regulatory Agency approval, annual monitoring of the former conformance wells was discontinued in 2013. Some of the former conformance wells were included in the CSRG exceedance network and will continue to be sampled twice in five years to track contamination downgradient of the NBCS.

Since the former downgradient conformance wells and current downgradient performance wells are: 1) in similar flow paths, 2) they were sampled contemporaneously several times, and 3) had similar water quality results, the same mechanisms for causing the concentrations to exceed the CSRGs/PQLs in the conformance wells appear to be affecting the downgradient performance wells. Some of the downgradient performance wells are former recharge wells, which might cause differences in their water quality results. For example, if the former recharge wells were installed in higher permeability zones than the corresponding conformance wells, their contaminant histories might be affected. Additionally, the recharge wells were used from 1981 until 1988/1990, when they were replaced by recharge trenches, which could have flushed the aquifer of residual and pre-existing contamination and the current concentrations above CSRGs/PQLs might indicate bypass/underflow.

At the Regulatory Agencies' request, this appendix presents an evaluation of the hydrogeology of the area of the former conformance wells and downgradient performance wells, including possible effects on water quality caused by the use of former recharge wells. In response to Regulatory Agency comments, the conformance/performance well historical water quality data were also reviewed to further assess the two groups of wells and help determine whether similar mechanisms are causing contaminant concentrations to be above the remediation goals.

Background Information

In the 2005 FYRR, an analysis using historical chloride concentration trends indicated that the chloride present in downgradient conformance well 37339 between 1985 and 2005 migrated past the future location of the NBCS slurry wall between 1968 and 1973, about 10 years before the NBCS was installed. Since chloride is a conservative contaminant, these timeframes represent approximate groundwater travel times of between 17 and 32 years from the NBCS (well 23001) to well 37339. Using an average travel time of 25 years, the contaminated groundwater that was downgradient of the NBCS when it was completed in 1981 would not reach well 37339 until 2006. Thus, based on these estimates, concentrations of chloride, DIMP, fluoride, and sulfate above the CSRGs in well 37339 during the 2010 FYR period appeared to represent contamination that predated installation of the NBCS. The DIMP concentrations in well 37339 decreased to below the CSRG on a relatively consistent basis beginning in 2004, which strongly agrees with these estimates. This is evidence that contaminant concentrations in conformance well 37339 were not representative of system performance.

In many cases, the contaminant concentrations were high in the groundwater that migrated offpost before the NBCS was installed. The maximum concentrations at or downgradient of the north boundary for selected analytes (chloride [3,400,000 [ug/L]; DIMP [11,900 ug/L]; dieldrin [6.76 [ug/L]; fluoride [10,000 [ug/L]; and sulfate [3,100,000 ug/L]) may have been higher before monitoring began. These high concentrations likely caused substantial residual contamination to be retained in the aquifer sediments that may act as continuing sources of groundwater contamination that impact the downgradient conformance and performance wells. Additionally, groundwater levels were higher prior to 1981 and have been lower since then, which would cause a secondary source of contamination to have remained above the water table. Higher recent water levels may be mobilizing this residual contamination.

The concentrations of a few analytes above CSRGs/PQLs in some of the downgradient wells likely are caused by a combination of desorption of dieldrin from the aquifer sediments downgradient of the NBCS slurry wall; very slow migration of DIMP, chloride, fluoride, and sulfate in finer grained sediments (silts, clays, and claystones) in the alluvium and Denver Formation bedrock particularly in the western part of the system; and natural occurrence of sulfate in the Denver Formation. Gypsum crystals (CaSO4) frequently are observed in Denver well borelogs. In the western portion of the system, the alluvium frequently has been unsaturated and the groundwater flows through the bedrock. This groundwater contamination was already present downgradient of the system when it was installed and it is taking longer to flush out than for other contaminants and longer than in other areas of the system where the aquifer is more permeable.

Regarding flushing of the aquifer near former recharge wells, towards the end of their use, most of the flow was diverted from the recharge wells into the North Bog (located in Section 24 north of the recharge wells between monitoring wells 24162 and 24164) due to carbon fouling of the wells. This may account for incomplete flushing in some areas. Due to a problem with electrical line noise, most of the recorded flow during this time period was shown to be inaccurate (i.e., a high flow would be recorded when the flow was actually shut off).

Methodology

A series of NBCS cross sections were constructed in a 1985 report (WES 1985) that were along the east-west alignments of the following: 1) extraction wells, 2) slurry wall, 3) recharge wells, and 4) monitoring wells along the Rocky Mountain Arsenal north boundary. Several cross sections transverse to the well alignments were also constructed. These cross sections are provided in this appendix and are used to depict the hydrogeology of the alluvial aquifer for the comparison of the conformance wells and downgradient performance wells.

The drawing numbers from the 1985 report are used for reference in this appendix. Plate G-02 is the cross-section location map for cross sections A-A' through K-K'. Cross section A-A' (Plate G-03) and B-B' (Plate G-04) are along the extraction well and slurry wall alignments, respectively. Cross section C-C' (Plate G-05) is along the recharge well alignment and cross section D-D' (Plate G-06) is the north boundary monitoring well alignment. Cross sections E-E' through K-K' (Plates G-07 and G-08) are transverse to the well and slurry wall alignments. In each cross section, the lithology in the alluvium and Denver Formation are shown, along with the Top of Denver Formation and screened interval of the wells.

Contaminant concentration graphs of analytes that are present above CSRGs/PQLs are provided to show the historical concentrations in the former conformance wells and downgradient performance wells, NBCS effluent (PNEFEF) concentrations, and the water elevations in the wells. These graphs are included to compare the corresponding well data and illustrate where there are similarities and differences. Inorganic CSRG analytes chloride, fluoride, and sulfate are less affected by sorption than the organic contaminants and are useful for assessing the downgradient contamination. Recent concentrations (2009 through 2014) of chloride, fluoride, and sulfate in the upgradient performance wells and extraction wells were reviewed for comparison with the downgradient well concentrations. Normally, the upgradient well concentrations would be higher than the downgradient concentrations. Higher downgradient well concentrations of chloride, fluoride, and sulfate would tend to support the hypothesis of pre-existing contamination downgradient of the slurry wall causing CSRG exceedances. Refer to FYSR Figure 5.1.1.2-1 for the NBCS well locations.

Results

In the alluvium, the lithologies range from clay to gravelly sand. The alluvium was deposited by streams in channels eroded into the Denver Formation bedrock surface. The NBCS spans a bedrock channel with the ends of the slurry wall keyed into bedrock highs where the alluvium is unsaturated. The bedrock channel at the NBCS is oriented generally north-south. The deposition of the various alluvial lithologic units ranged from channel fill (sand and gravelly sand) to overbank deposits (silt and clay), which also are oriented generally north-south. The flow paths associated with the conformance wells that were used to select the performance wells also are orientated generally north-south. Consequently, the corresponding conformance and performance wells are typically completed in similar lithologic units.

A detailed discussion of the corresponding conformance and performance wells is provided below. The CSRGs and PQLs also are shown on the graphs, with the two dieldrin PQLs indicated as PQL1 (0.05 ug/L) and PQL2 (0.013 ug/L). The wells are discussed in order from west to east.

- Conformance well 37339 and performance wells 23434 and 23436.

All three wells are screened in alluvial clayey silt to silty clay (ML-CL) and bedrock claystone. Well 37339 is located near and is constructed in similar lithologic units as well 23196 on cross sections D-D' and E-E'.

DIMP concentrations are variable in well 37339: greater than the CSRG in 2007 and 2011 and less than the CSRG in other years. The DIMP concentrations are less than the CSRG in wells 23434 and 23436 (Figure B-1). Dieldrin concentrations are similar in all three downgradient wells (above and below the new PQL), with a recent increasing trend that may correspond to rising water levels (Figure B-2). Chloride (Figure B-3), fluoride (Figure B-4), and sulfate (Figure B-5) concentrations are similar, above the CSRGs, and above the effluent concentrations, with a recent increasing trend for chloride and sulfate, while the NBCS effluent concentrations have remained below the CSRGs. Increasing chloride and sulfate concentrations in wells 23434 and 23436 correspond with higher water levels, which may be mobilizing additional chloride and sulfate from the aquifer sediments. The chloride and sulfate concentrations in the downgradient wells are significantly higher than in the upgradient wells. The upgradient and downgradient fluoride concentrations are similar.

Wells 23434 and 23436 are located approximately 750 and 1,000 feet closer to the NBCS slurry wall, respectively, than well 37339. Thus, the travel times between the slurry wall and the wells would be less. However, migration in the fine-grained sediments (silt, clay, and claystone) would be very slow, which likely explains why chloride, fluoride, and sulfate concentrations typically are higher than the effluent concentrations and above the CSRGs in the wells. Although slow migration in the fine-grained sediments appears to be affecting the contaminant concentrations in wells 23434 and 23436, they likely are better choices for performance wells than well 37339. The same mechanisms probably explain the chloride, fluoride, sulfate, and dieldrin concentrations above the CSRGs/PQL in all three wells.

- Conformance well 23198 and performance well 23438

Well 23198 is screened in alluvial sand (SP and gravelly sand (SP-GP). Well 23438 is screened in alluvial sand (SP), sandy clay (CL), clayey sand (SC) and bedrock claystone.

DIMP concentrations are variable in well 23198 and below the CSRG in 23438 (Figure B-6). Dieldrin concentrations are above the PQL in well 23198 and below the PQL in well 23438 (Figure B-7). Chloride concentrations (Figure B-8) have been below the CSRG in both wells, but increased above the CSRG in 2014/2015, possibly due to rising water levels. Fluoride concentrations (Figure B-9) have been relatively stable in both wells, with concentrations above the CSRG in well 23198 and near the CSRG in well 23438. Sulfate concentrations (Figure B-10) have been relatively stable below the CSRG in both wells.

The water quality data indicate that there may have been more effective flushing of the aquifer near well 23438 due to its use as a recharge well in the 1980s and its closer proximity to the recharge trenches that began operation in 1988. The higher chloride concentrations in both wells in 2014/2015 suggest that some residual chloride contamination may still be present in the aquifer in this area. The data indicate that well 23438 may be more representative of current system effectiveness than well 23198 with the recent increase in chloride concentrations is an exception.

- Conformance well 23253 and performance well 23405.

Well 23253 is screened in alluvial well-graded sand (SW), fine- to coarse-grained sand and fine gravel based on continuous core. A bore log for well 23405 is not available, so there may be differences in lithology between the two wells.

DIMP (Figure B-11) and dieldrin (Figure B-12) concentrations are higher in well 23405 than in well 23253. Both DIMP and dieldrin show decreasing trends in well 23405. A potable water supply pipeline leak in 2010 caused significantly higher water levels near wells 23253 and 23405 and may have caused the increase in dieldrin concentrations in well 23405 in 2010. Since then, the dieldrin concentrations decreased until 2015, when they increased. The dieldrin trend in well 23405 appears to track the water level trend. The chloride, fluoride, and sulfate concentrations are near or below the CSRGs in both wells. The chloride and sulfate concentrations in well 23253 decreased and the fluoride concentration increased in 2010 likely in response to the potable water line leak. The chloride (Figure B-13), fluoride (Figure B-14), and sulfate (Figure B-15) concentrations in well 23253 track the effluent concentrations, but the fluoride and sulfate concentrations in well 23405 are significantly lower than in well 23253, in the plant effluent, and in the upgradient wells. The chloride concentrations in well 23405 track the effluent concentrations. The vertical hydraulic gradients are downward between the alluvium and the Denver UFS and CFS. Thus, discharge from the Denver to the alluvium is not feasible for causing the lower fluoride and sulfate concentrations in well 23405. The abnormally low fluoride and sulfate concentrations may indicate the presence of a stagnant zone near well 23405, which might explain the higher DIMP and dieldrin concentrations in well 23405 than in well 23253. Consequently, flushing of the aquifer near former recharge well 23405 appears incomplete, and well 23253 may be more representative of system effectiveness than well 23405.

- Conformance and performance well 24006

Well 24006 is both a former conformance well and a current performance well. Well 24006 is screened in alluvial clayey sand to clayey gravelly sand.

DIMP concentrations are below the CSRG (Figure B-16) and the dieldrin concentrations are similar to the former PQL of 0.05 ug/L and higher than the new PQL (Figure B-17). A rise in water levels in 2010 and 2011 corresponded to an increase in dieldrin concentrations in 2011. Since then, the dieldrin concentrations have declined. The chloride (Figure B-18), fluoride (Figure B-19), and sulfate (Figure B-20) concentrations are near or below the CSRGs and track the effluent concentrations. The dieldrin concentrations above the PQL in well 24006 since 2011 likely are caused by residual contamination in the clayey sands near well 24006. A possible more suitable well upgradient of well 24006 is former recharge well 24412. Although no borehole log is available for well 24412, it is likely to be screened in a sand with lower fines content than well 24006 based on the logs for adjacent wells and borings. Other potential alternate wells that have borehole logs (e.g., former recharge well 24413 and monitoring well 23043) are closed. No other wells besides 24412, are suitable for replacing 24006.

- Conformance well 24162 and performance well 24415.

Both wells are screened in alluvial gravelly sand. Well 24415 is also screened in alluvial silty clay.

DIMP concentrations are below the CSRG in both wells (Figure B-21). Dieldrin concentrations are similar and are above or near the former PQL and above the new PQL (Figure B-22). The dieldrin concentrations in both wells generally follow the water level trends. The chloride (Figure B-23), fluoride (Figure B-24), and sulfate (Figure B-25) concentrations are near or below the CSRGs and track the effluent concentrations. The two wells have similar water quality, although the dieldrin concentrations in well 24415 appear slightly more affected by water level fluctuations and the potentially associated mobilization from the aquifer sediments. The two wells are comparable and the same mechanisms probably explain the dieldrin concentrations above the PQL in both wells (e.g., desorption of residual contamination in the aquifer sediments). More flushing of the aquifer near former recharge well 24415 than conformance well 24162 is not indicated.

- Performance well 24418

There is no corresponding conformance well. Well 24418 is screened in alluvial sandy clay and fine sand.

DIMP concentrations are below the CSRG (Figure B-26). Dieldrin concentrations are above the former PQL and above the new PQL (Figure B-27). Well 24418 was not sampled prior to 2010 when water levels were lower. The water levels have been highly variable within a range of about three feet. Consequently, the dieldrin concentrations above the PQLs may be related to the presence of residual dieldrin in the aquifer sediments. The chloride (Figure B-28), fluoride (Figure B-29), and sulfate (Figure B-30) concentrations are near or below the CSRGs and track the effluent concentrations, except in 2012 and 2015 for chloride and sulfate when higher water levels appear to have caused the concentrations to increase above the CSRGs. These data suggest that residual dieldrin, chloride, and sulfate are present in the aquifer sediments and are mobilized by intermittently higher water levels.

Monitoring well 24163 is located father north and was sampled from 1984 to 1999 with no detections of dieldrin, with MRLs as low as 0.04 ug/L (Figure B-31). The lack of contamination above CSRGs/PQLs in this well during and prior to 1999 is why conformance wells were not selected in this part of the system in the 1999 LTMP. Well 24163 is screened in gravelly sand, and the lower fines content may explain why dieldrin was not detected. Water levels were relatively high and similar to or higher than current water levels during this time period, yet the dieldrin concentrations remained below the previous PQL. Based on the historical water quality data and lower fines content, well 24163 may be more representative of system performance than well 24418.

- Performance well 24421

There is no corresponding conformance well. Well 24421 is screened in alluvial silt, sandy clay, silty sand, and bedrock sandstone (hard).

DIMP concentrations are below the CSRG (Figure B-32). Dieldrin concentrations are below the former PQL and at or above the new PQL (Figure B-33). The water levels have been highly variable within a range of about four feet. The dieldrin concentrations above the new PQL may be related to the presence of residual dieldrin in the aquifer sediments. The recent chloride (Figure B-34), fluoride (Figure B-35), and sulfate (Figure B-36) concentrations are near or below the CSRGs and track the effluent concentrations, except in 2015 for chloride and sulfate when higher water levels appear to have caused the concentrations to increase above the CSRGs. These data suggest that residual dieldrin, chloride, and sulfate are present in the aquifer sediments and are mobilized by intermittently higher water levels.

Monitoring well 24164 is located father north and downgradient of well 24421 and was sampled from 1986 to 1999 with no detections of dieldrin, with MRLs as low as 0.024 ug/L (Figure B-37). The lack of contamination above CSRGs/PQLs in this well during and prior to 1999 is why conformance wells were not selected in this part of the system in the 1999 LTMP. Well 24164 is screened in sandy clay and gravelly sand, with the screened interval predominantly in gravelly sand. The lower fines content may explain why dieldrin was not detected in well 24164. Water levels were relatively high and similar to or higher than current water levels during this time period, yet the dieldrin concentrations remained below the previous PQL. Based on the historical water quality data and lower fines content, well 24164 may be more representative of system performance than well 24421.

- Conformance well 37338 and performance well 24424

Both wells are screened in alluvial silty to clayey sand (SM-SC), silty sand to poorly graded sand (SM-SP), and bedrock clayey siltstone. The alluvial sand in well 24424 also contains gravel with cobbles and boulders.

The DIMP concentrations (Figure B-38) are similar in both wells (well below the CSRG and less than the MRL). The dieldrin concentrations (Figure B-39) have decreased to below the former PQL and are similar (below, near or above the new PQL). The dieldrin concentrations in both wells appear to be affected by the fluctuating water levels, which have varied as much as 14 feet historically. The chloride (Figure B-40), fluoride (Figure B-41), and sulfate (Figure B-42) concentrations are near or below the CSRGs and generally have tracked the effluent concentrations, with variations that seem related to the fluctuating groundwater levels and interaction with surface water in First Creek. Since 2010, the concentrations of fluoride and sulfate in well 37338 have been well below the plant effluent concentrations, likely due to surface water interaction from First Creek, which has lower fluoride and sulfate concentrations than the plant effluent. First Creek surface water sampling site SW24004 is located near the NBCS. Well 37338 is closer to First Creek than well 24424, which likely explains the lower fluoride and sulfate concentrations in well 37338. The chloride concentrations have been near or above the plant effluent in both wells, with increases in 2009 and 2014 that appear related to higher groundwater levels. The chloride concentrations in upgradient wells are below the CSRG and the chloride concentrations in First Creek are lower than the plant effluent concentrations, averaging 79 mg/L. Thus, there may be more residual chloride than fluoride and sulfate in the aquifer sediments downgradient of the slurry wall. Dieldrin is not detected in First Creek surface water. The lower dieldrin concentrations in both wells since 2010 may be related to increased recharge from First Creek and dilution of the groundwater.

Since well 24424 is farther from First Creek, it may be less subject to surface water interaction and may be the more representative well. Residual chloride and dieldrin in the aquifer sediments may still be mobilized from higher groundwater levels, and the mechanisms that affected conformance well 37338 would still apply to performance well 24424. The similar dieldrin concentrations in the two wells suggest that flushing of the aquifer by former recharge well 24424 was not more complete than at well 37338.

- Conformance well 24166 and performance well 24004

Well 24166 is screened in alluvial sand with gravel and bedrock claystone. Well 24004 is screened in silty fine sand with occasional pebbles and cobbles, and clayey gravelly sand (SC).

DIMP concentrations are similar in both wells, well below the CSRG, and less than the MRL (Figure B-43). Dieldrin concentrations are similar, near or above the former PQL, and above new PQL (Figure B-44). The chloride (Figure B-45), fluoride (Figure B-46), and sulfate (Figure B-47) concentrations are near or below the CSRGs and generally have tracked the effluent concentrations, with variations that seem related to the fluctuating groundwater levels and interaction with surface water in First Creek. Since 2010, the concentrations of chloride, fluoride, and sulfate in well 24004 have been well below the plant effluent concentrations, likely due to surface water interaction with First Creek, which has lower chloride, fluoride, and sulfate concentrations than the plant effluent. Well 24004 is closer to First Creek than well 24166, which likely explains the lower chloride, fluoride, and sulfate concentrations in well

24004. In 2014, the sulfate concentration in well 24166 was also well below the effluent concentration, suggesting more interaction with First Creek.

Since the wells have very similar dieldrin concentrations, they are comparable and residual dieldrin in the aquifer sediments near both wells likely is causing the concentrations to remain above the PQL. Neither well seems more representative than the other.

- Performance well 37362

There is no corresponding conformance well. Well 37362 is screened in alluvial silty clay, gravelly sand, silty sand, clayey sand, and bedrock siltstone.

DIMP concentrations are below the CSRG and typically below the MRL (Figure B-48). Dieldrin concentrations are usually below the former PQL and at or below the new PQL, except in 2013 (Figure B-49). The 2013 dieldrin concentration was higher than any previous sample, and therefore was suspect. The water levels have been highly variable within a range of about eight feet. The dieldrin concentrations above the new PQL may be related to the presence of residual dieldrin in the aquifer sediments. The recent chloride (Figure B-50) and sulfate (Figure B-51) concentrations are near or below the CSRGs. The fluoride concentrations (Figure B-52) have been at or above the CSRG. These data suggest that residual dieldrin and fluoride are present in the aquifer sediments and are mobilized by intermittently higher water levels.

Former recharge well 24429 is located upgradient of well 37362 and is screened in silty sand, sand, and gravel. It has never been sampled, but based on lower fines content, well 24430 may be more representative of system performance than well 37362. Wells 24430 and 24431 appear unsuitable for potential performance wells because well 23430 contains more clay than 24429, and well 24431 is dry.

Conclusions and Recommendations

1. Similar mechanisms causing concentrations of a few CSRG analytes to be above the CSRGs/PQLs appear to apply both to the former conformance wells and to the current downgradient performance wells. These mechanisms appear unrelated to system effectiveness.

2. The NBCS recharge wells were installed in uniform spacing and distance from the slurry wall to create a reverse hydraulic gradient along the length of the slurry wall. The variation in the lithology across the NBCS indicates that the design of the recharge well array was independent of the hydrogeology. The corresponding conformance and performance wells generally were completed in similar lithologic units. Sometimes the former conformance well is in a more permeable unit and sometimes the current performance well/former recharge well is in a more permeable unit. Therefore, the assumption that the recharge wells were installed in more permeable areas is incorrect.

3. The assumption that flushing of the contaminants occurred in the vicinity of each recharge well also appears incorrect. While the more mobile contaminants such as DIMP may have been flushed from the aquifer sediments, the flushing of the more sorptive compound dieldrin appears

incomplete. The data suggest that flushing of one of the former recharge wells (23438) may have been greater than the corresponding conformance well (23198), but the flushing of the other former recharge wells is not indicated.

4. As stipulated in the 2010 LTMP, when the primary performance criteria are met, the NBCS is functioning as intended. The mechanisms causing the downgradient concentrations of a few analytes to be above the CSRGs/PQLs appear to be unrelated to system performance. Therefore, when the primary criteria are met, the NBCS is functioning as intended, and the downgradient performance well water quality data should be reported, but not be considered in the NBCS performance evaluation. Army/Shell recommends that the LTMP be revised accordingly.

5. Changes to the downgradient performance well network also are recommended based on the evaluation above. Table 1 lists proposed revisions to the downgradient performance well network.

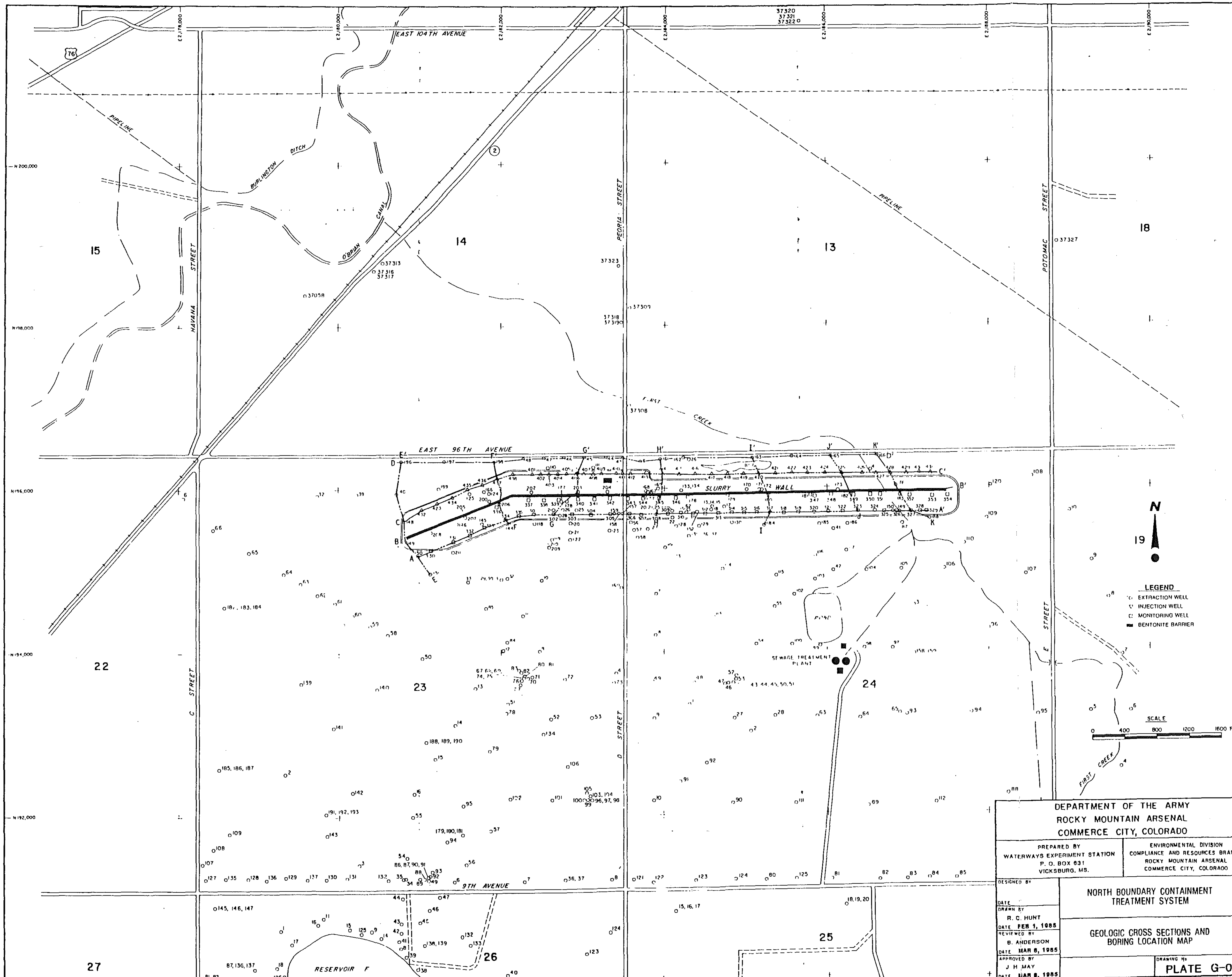
Table 1. Proposed Alternate Performance Wells

2010 LTMP Performance Well	Proposed Alternate Performance Well	Rationale
23405	23253	Stagnant zone near well 23405, no borelog for well 23405
24006	24412	Lower fines content and more permeable aquifer at 24412
24418	24163	Lower fines content and more permeable aquifer at 24163
24421	24164	Lower fines content and more permeable aquifer at 24164
37362	24429	Lower fines content and more permeable aquifer at 24429

Reference

WES 1985 Environmental Laboratory, USAE Waterways Experiment Station, 1985. *1984 North Boundary Containment/Treatment System Performance Report, Rocky Mountain Arsenal, Denver, Colorado.* December.

FIGURES


EAST 104TH AVENUE
76
PIPELINE
BURLINGTON DITCH
O'BRIAN CANAL
HAVANA STREET
PEORIA STREET
POTOMAC STREET
FIRST CREEK
EAST 96TH AVENUE
SLURRY WALL
SEWAGE TREATMENT PLANT
9TH AVENUE
RESERVOIR F
C STREET
D STREET
E STREET
15
14
13
18
19
22
23
24
25
26
27
N
LEGEND
EXTRACTION WELL
INJECTION WELL
MONITORING WELL
BENTONITE BARRIER
SCALE
0 400 800 1200 1600 FT
N 200,000
N 198,000
N 196,000
N 194,000
N 192,000
N 190,000
E 2,178,000
E 2,180,000
E 2,182,000
E 2,184,000
E 2,186,000
E 2,188,000
E 2,190,000
DEPARTMENT OF THE ARMY
ROCKY MOUNTAIN ARSENAL
COMMERCE CITY, COLORADO
PREPARED BY
WATERWAYS EXPERIMENT STATION
P. O. BOX 631
VICKSBURG, MS.
ENVIRONMENTAL DIVISION
COMPLIANCE AND RESOURCES BRANCH
ROCKY MOUNTAIN ARSENAL
COMMERCE CITY, COLORADO
DESIGNED BY
DATE
DRAWN BY
R. C. HUNT
DATE FEB 1, 1985
REVIEWED BY
B. ANDERSON
DATE MAR 6, 1985
APPROVED BY
J H MAY
DATE MAR 6, 1985
NORTH BOUNDARY CONTAINMENT TREATMENT SYSTEM
GEOLOGIC CROSS SECTIONS AND BORING LOCATION MAP
DRAWING No
PLATE G-02

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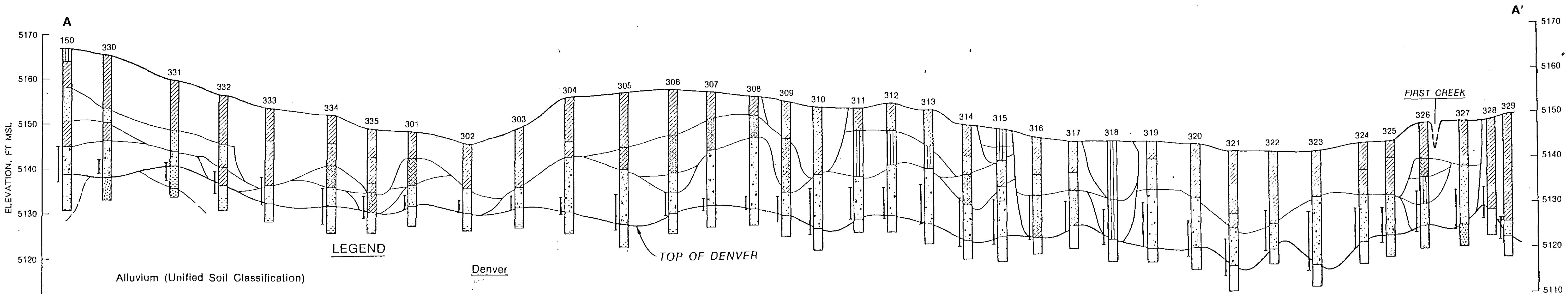

LEGEND

Alluvium (Unified Soil Classification)

- CH, Clay Flat
- CL, Clay, Silty Clay
- ML, Silt
- SC, Clayey Sand
- SM, Silty Sand
- SP, Sand
- SP-GP, Gravelly Sand

Denver

- Clayshale, Claystone
- Sandy Clayshale, Clayshale w/Sand-Silt Lenses
- Silt, Siltstone, Sandy Siltstone
- Sand, Sandstone, Silty Sandstone

SCREENED INTERVAL

SCALE

0 200 400 600 FT

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DESIGNED BY DATE	NORTH BOUNDARY CONTAINMENT TREATMENT SYSTEM
DRAWN BY R. C. HUNT DATE FEB 1, 1985	
REVIEWED BY B. ANDERSON DATE MAR 8, 1985	CROSS SECTION A-A'
APPROVED BY J. H. MAY DATE MAR 8, 1985	DRAWING No PLATE G-03

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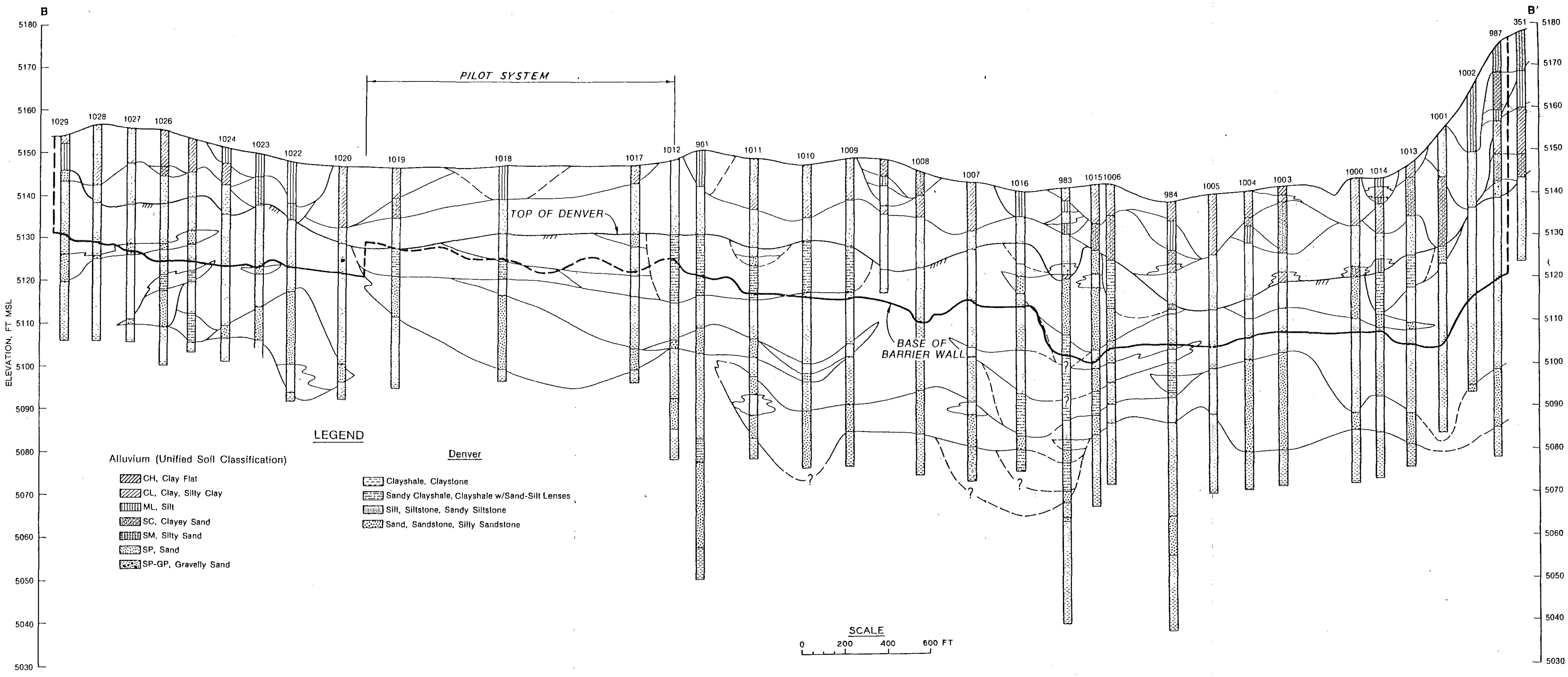

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REVIEWED BY B. ANDERSON DATE MAR 8, 1985	CROSS SECTION B-B'
APPROVED BY J. H. MAY DATE MAR 8, 1985	DRAWING No PLATE G-04

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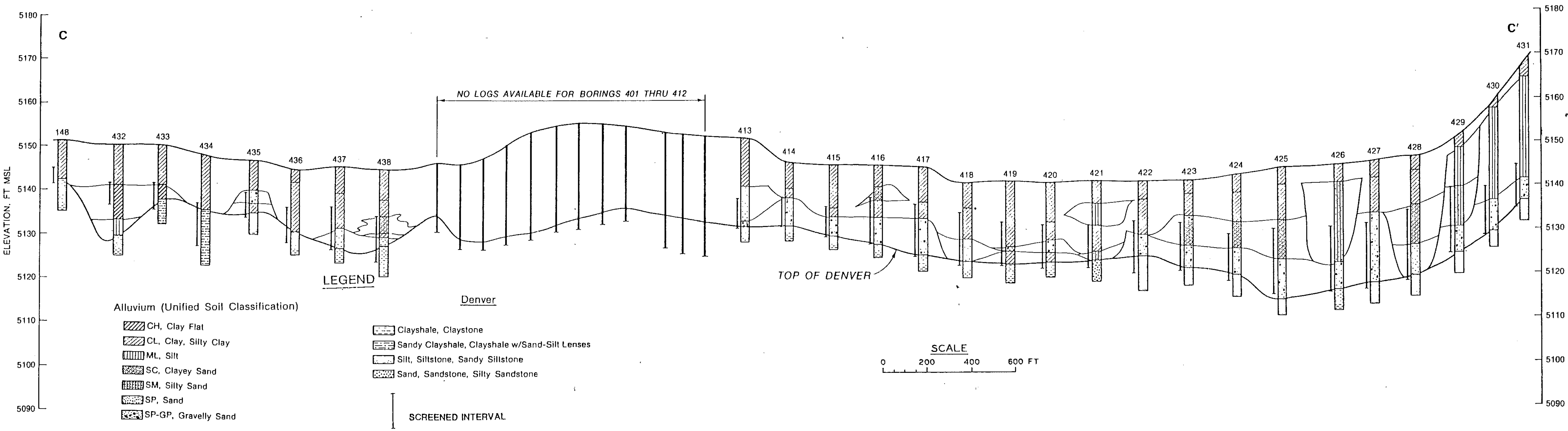

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REVIEWED BY B. ANDERSON DATE MAR 8, 1985	CROSS SECTION C-C'
APPROVED BY J. H. MAY DATE MAR 8, 1985	DRAWING No PLATE G-05

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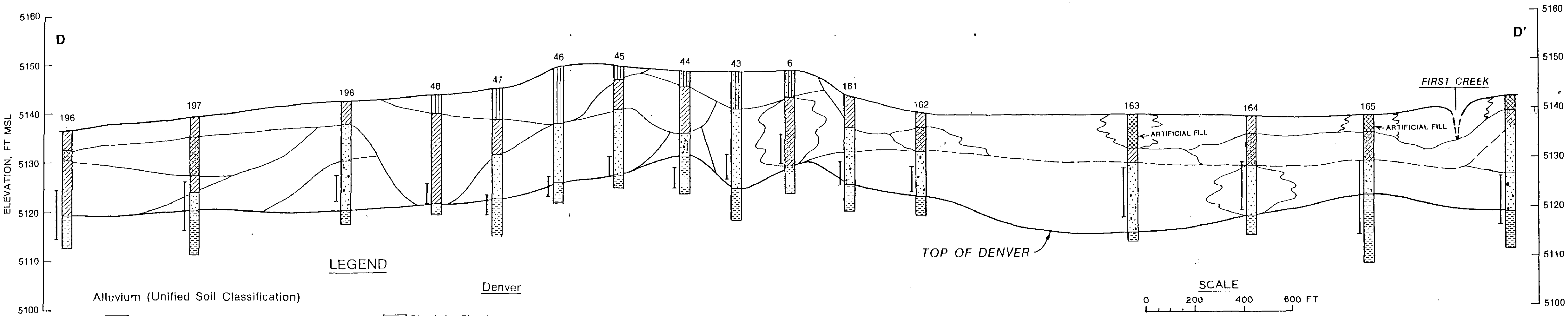

LEGEND

Alluvium (Unified Soil Classification)

- CH, Clay Flat
- CL, Clay, Silty Clay
- ML, Silt
- SC, Clayey Sand
- SM, Silty Sand
- SP, Sand
- SP-GP, Gravelly Sand

Denver

- Clayshale, Claystone
- Sandy Clayshale, Clayshale w/Sand-Silt Lenses
- Silt, Siltstone, Sandy Siltstone
- Sand, Sandstone, Silty Sandstone

| SCREENED INTERVAL

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APPROVED BY J. H. MAY DATE MAR 8, 1985	DRAWING No. PLATE G-06

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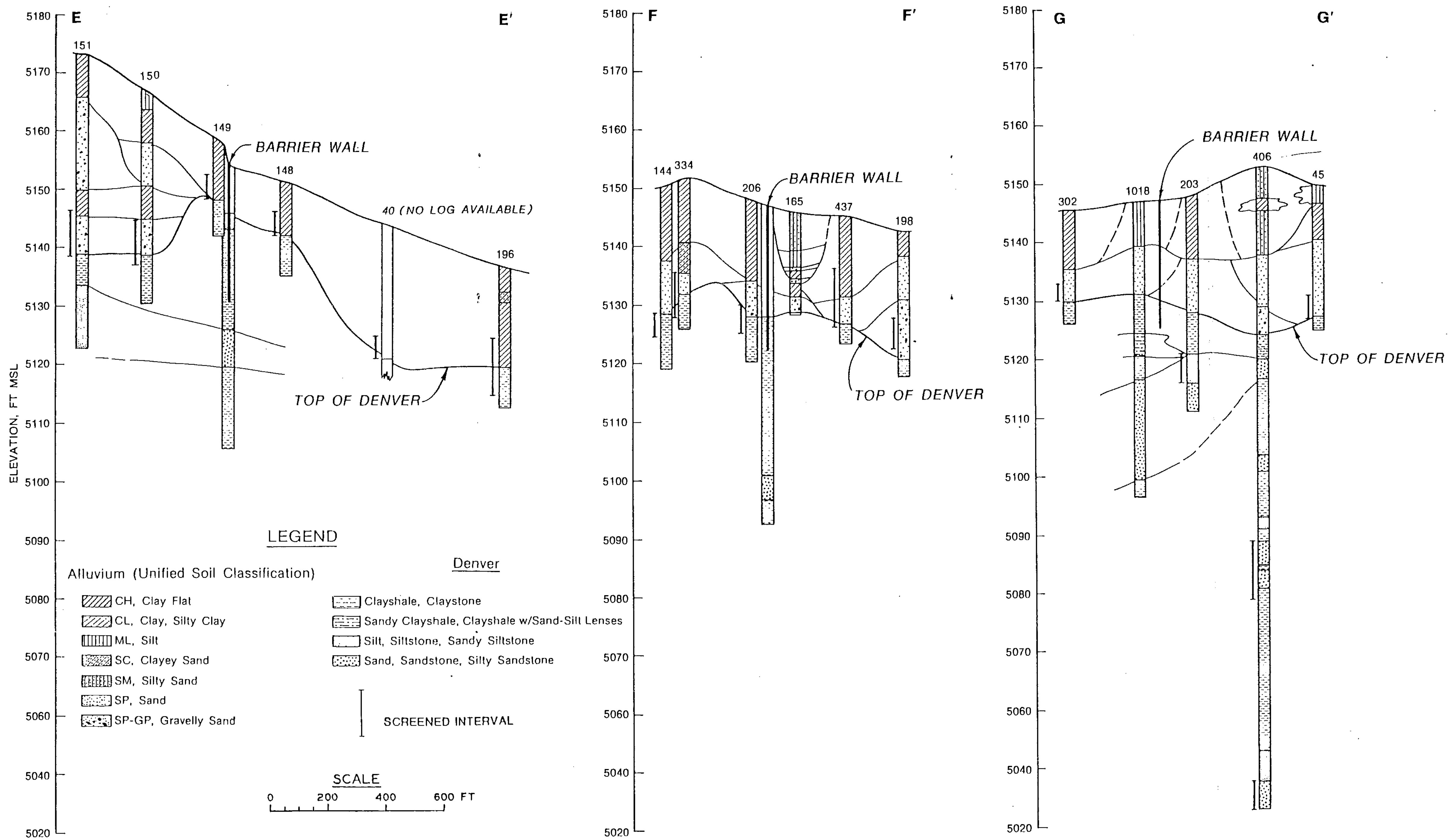

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REVIEWED BY B. ANDERSON DATE MAR 8, 1985	CROSS SECTIONS E-E', F-F' and G-G'
APPROVED BY J. H. MAY DATE MAR 8, 1985	DRAWING No. **PLATE G-07**

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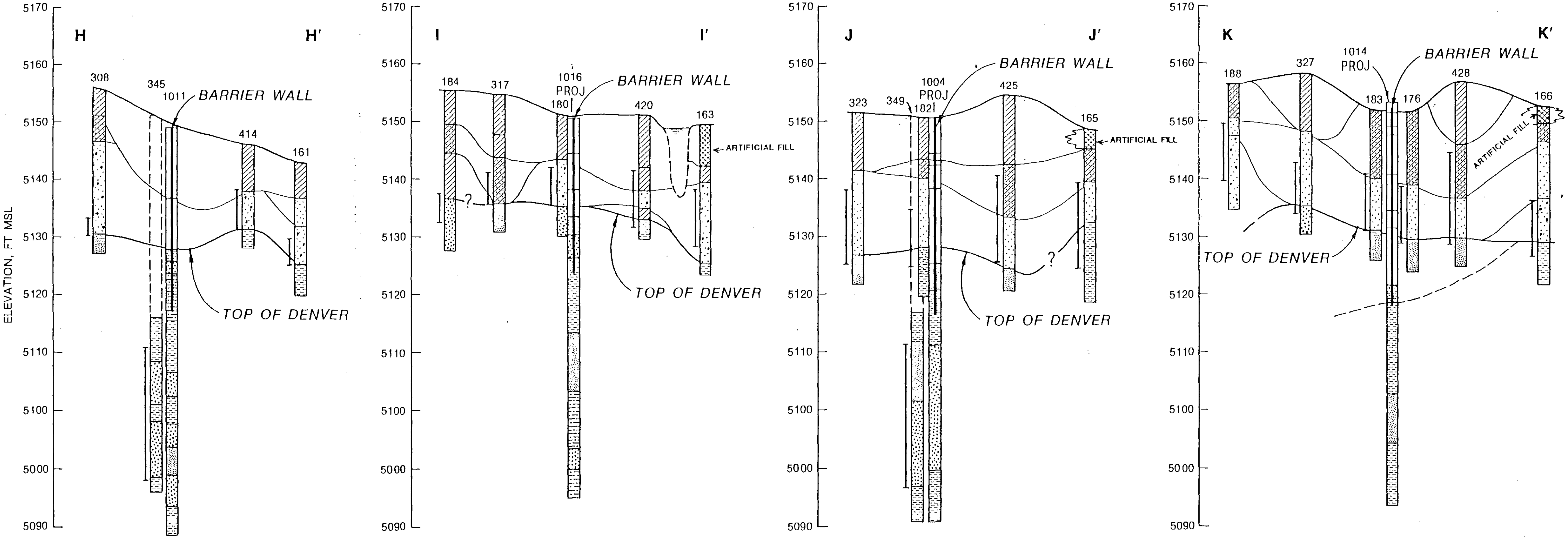

LEGEND

Alluvium (Unified Soil Classification)

- CH, Clay Flat
- CL, Clay, Silty Clay
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Denver

- Clayshale, Claystone
- Sandy Clayshale, Clayshale w/Sand-Silt Lenses
- Silt, Siltstone, Sandy Siltstone
- Sand, Sandstone, Silty Sandstone

SCREENED INTERVAL

SCALE

0 200 400 600 FT

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REVIEWED BY B. ANDERSON DATE MAR 8, 1985	CROSS SECTIONS H-H', I-I', J-J' and K-K'
APPROVED BY J. H. MAY DATE MAR 8, 1985	DRAWING No. **PLATE G-08**

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North Boundary Containment System

Conformance and Performance Well Graphs

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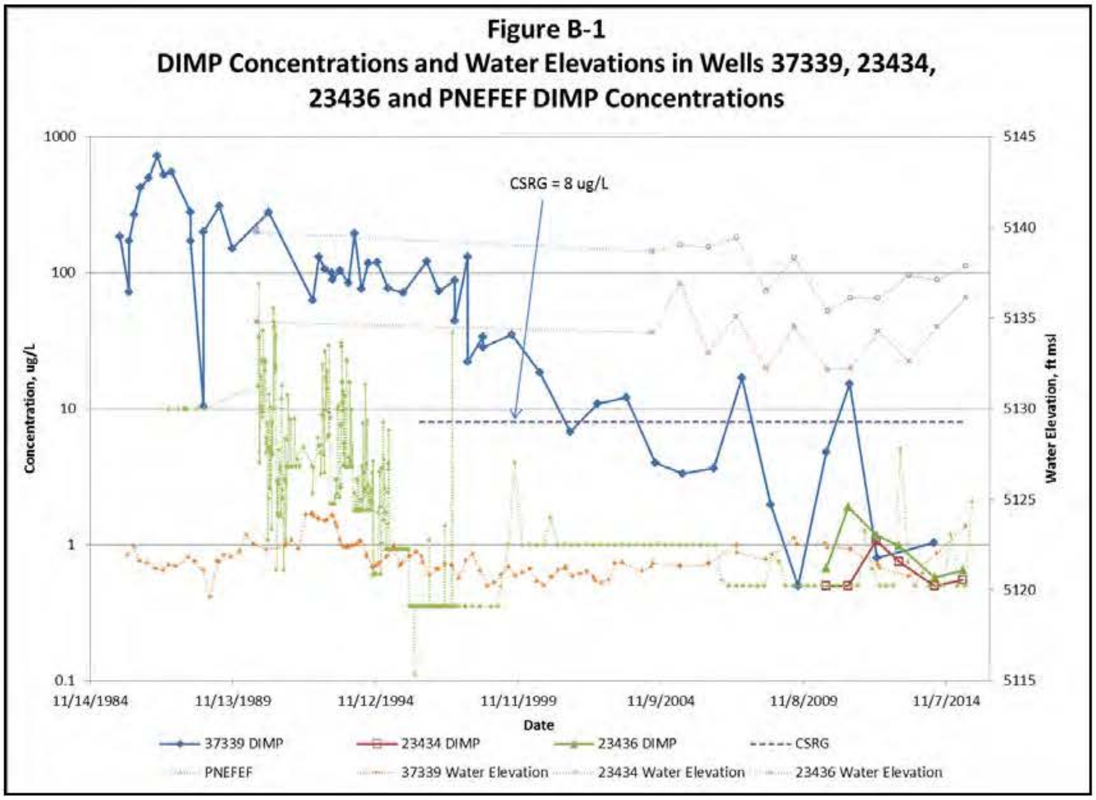


Figure B-1
DIMP Concentrations and Water Elevations in Wells 37339, 23434, 23436 and PNEFEF DIMP Concentrations
CSRG = 8 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
37339 DIMP
23434 DIMP
23436 DIMP
CSRG
PNEFEF
37339 Water Elevation
23434 Water Elevation
23436 Water Elevation

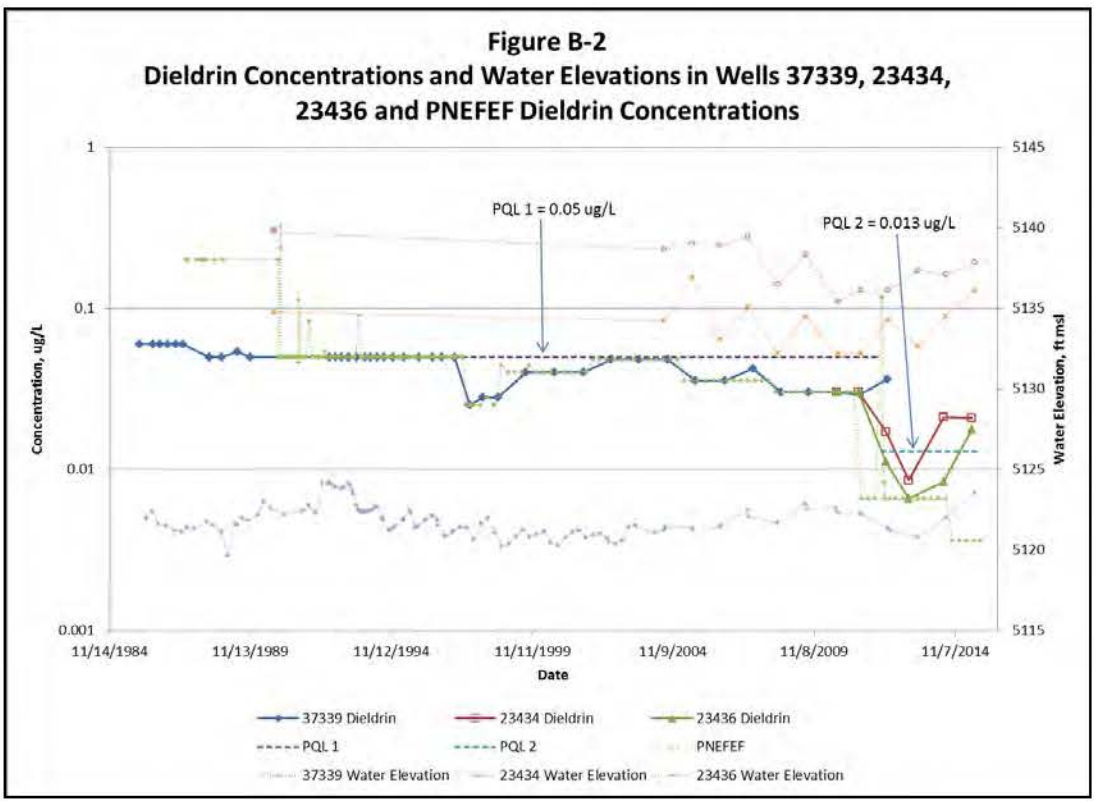


Figure B-2
Dieldrin Concentrations and Water Elevations in Wells 37339, 23434, 23436 and PNEFEF Dieldrin Concentrations
PQL 1 = 0.05 ug/L
PQL 2 = 0.013 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
37339 Dieldrin
23434 Dieldrin
23436 Dieldrin
PQL 1
PQL 2
PNEFEF
37339 Water Elevation
23434 Water Elevation
23436 Water Elevation

Figure B-3
Chloride Concentrations and Water Elevations in Wells 37339, 23434, 23436 and PNEFEF Chloride Concentrations

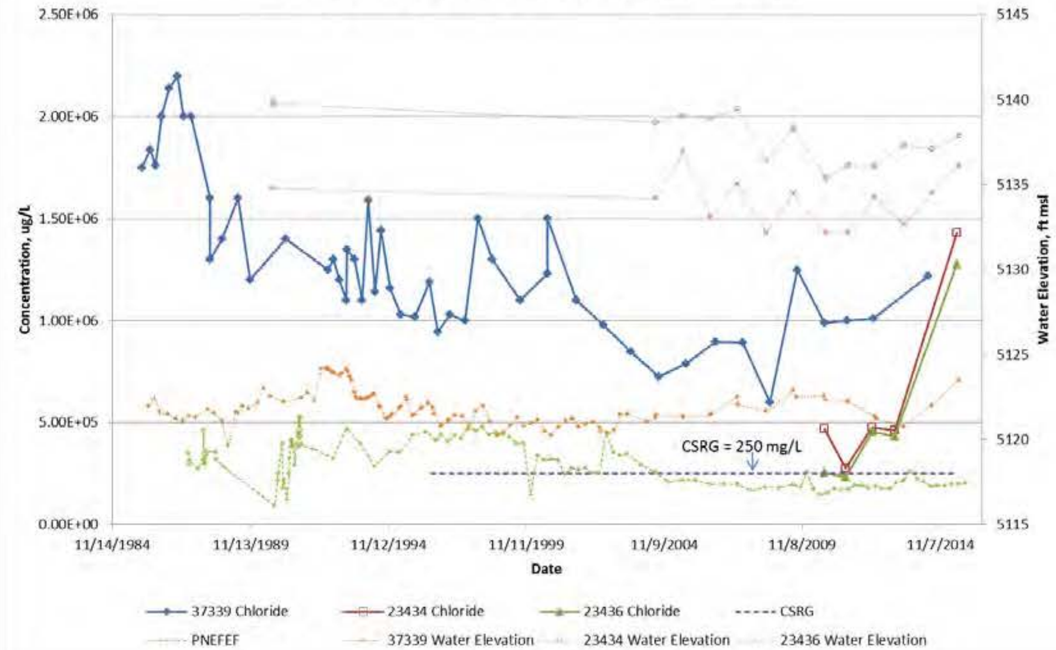
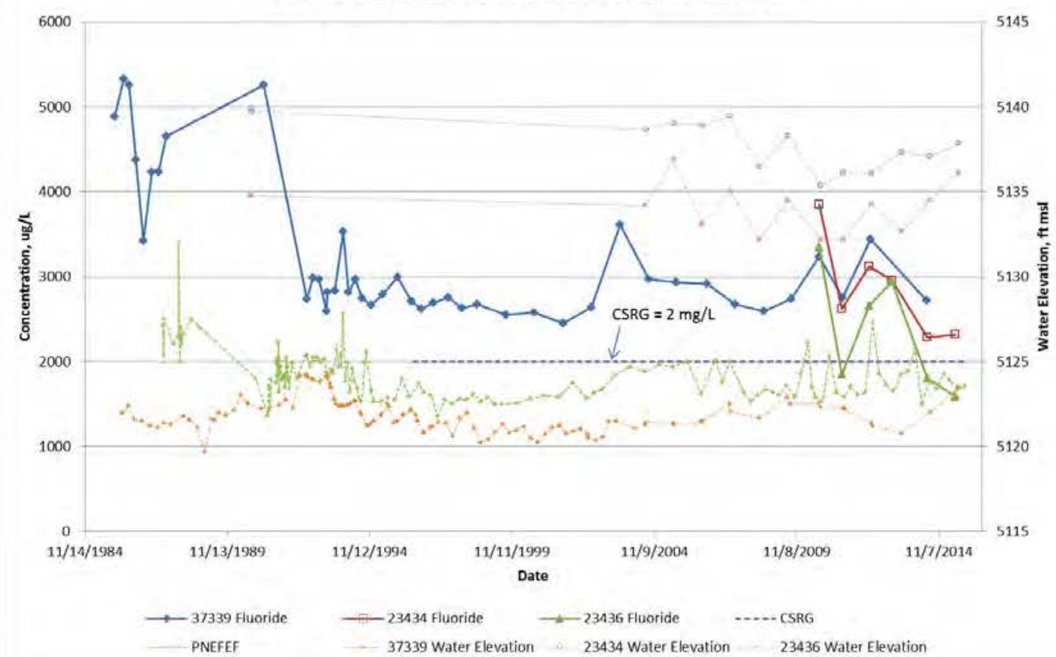


Figure B-4
Fluoride Concentrations and Water Elevations in Wells 37339, 23434, 23436 and PNEFEF Fluoride Concentrations



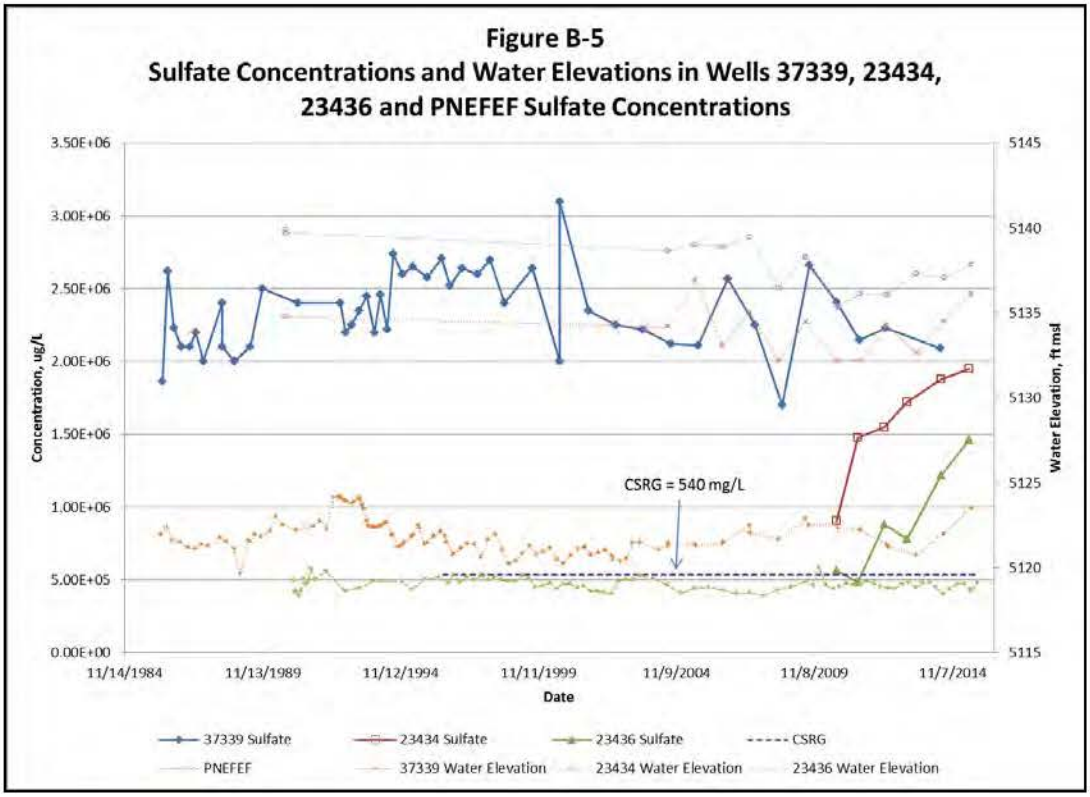


Figure B-5
Sulfate Concentrations and Water Elevations in Wells 37339, 23434, 23436 and PNEFEF Sulfate Concentrations
Concentration, ug/L
Water Elevation, ft msl
Date
CSRG = 540 mg/L
3.50E+06
3.00E+06
2.50E+06
2.00E+06
1.50E+06
1.00E+06
5.00E+05
0.00E+00
5145
5140
5135
5130
5125
5120
5115
11/14/1984
11/13/1989
11/12/1994
11/11/1999
11/9/2004
11/8/2009
11/7/2014
37339 Sulfate
23434 Sulfate
23436 Sulfate
CSRG
PNEFEF
37339 Water Elevation
23434 Water Elevation
23436 Water Elevation

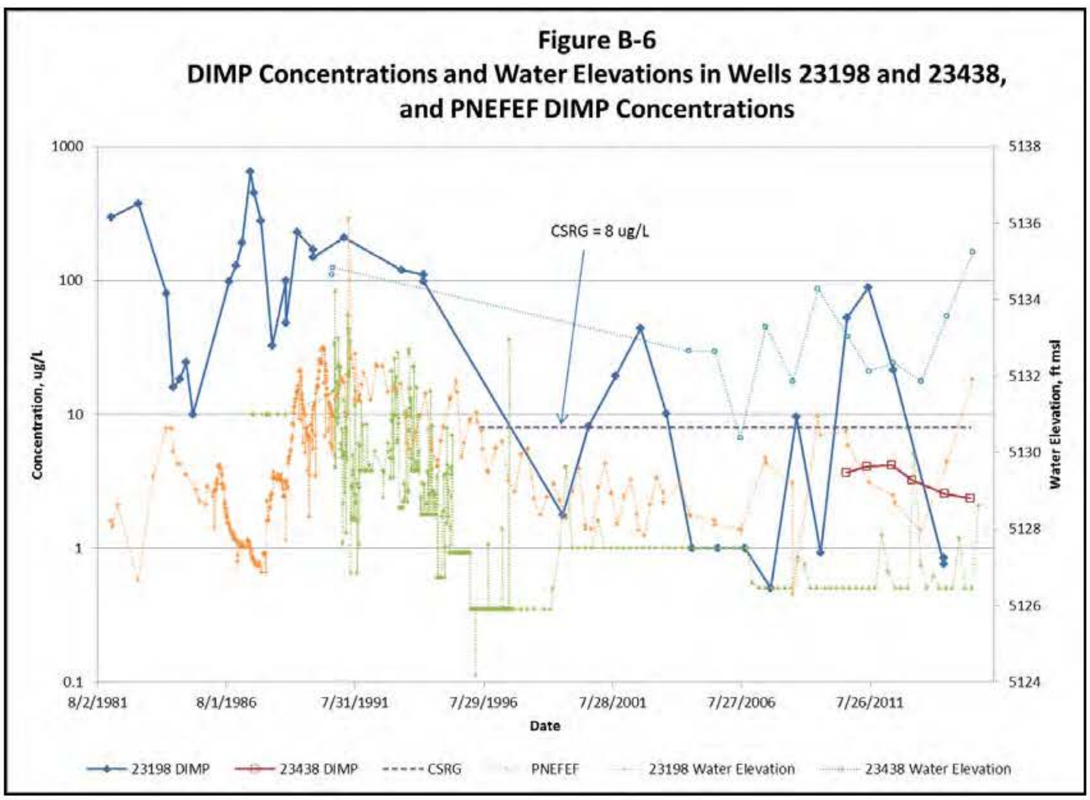


Figure B-6
DIMP Concentrations and Water Elevations in Wells 23198 and 23438, and PNEFEF DIMP Concentrations
Concentration, ug/L
Water Elevation, ft msl
Date
CSRG = 8 ug/L
1000
100
10
1
0.1
5138
5136
5134
5132
5130
5128
5126
5124
8/2/1981
8/1/1986
7/31/1991
7/29/1996
7/28/2001
7/27/2006
7/26/2011
23198 DIMP
23438 DIMP
CSRG
PNEFEF
23198 Water Elevation
23438 Water Elevation

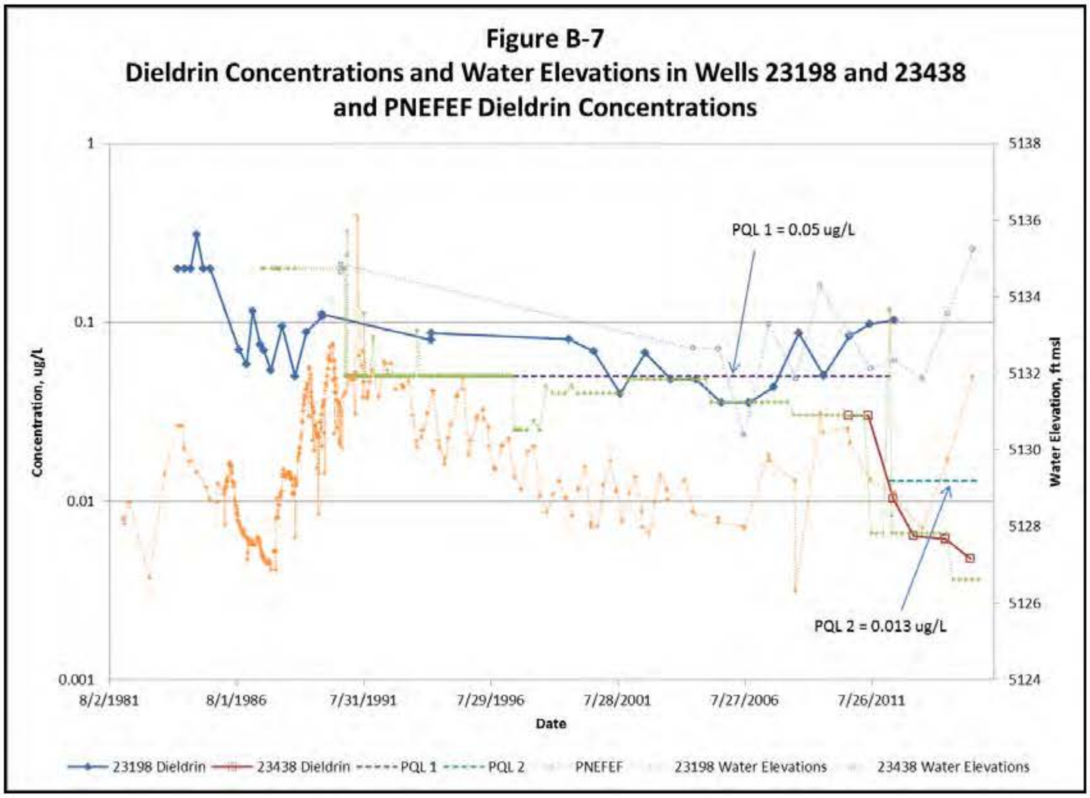


Figure B-7
Dieldrin Concentrations and Water Elevations in Wells 23198 and 23438
and PNEFEF Dieldrin Concentrations
PQL 1 = 0.05 ug/L
PQL 2 = 0.013 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
23198 Dieldrin
23438 Dieldrin
PQL 1
PQL 2
PNEFEF
23198 Water Elevations
23438 Water Elevations

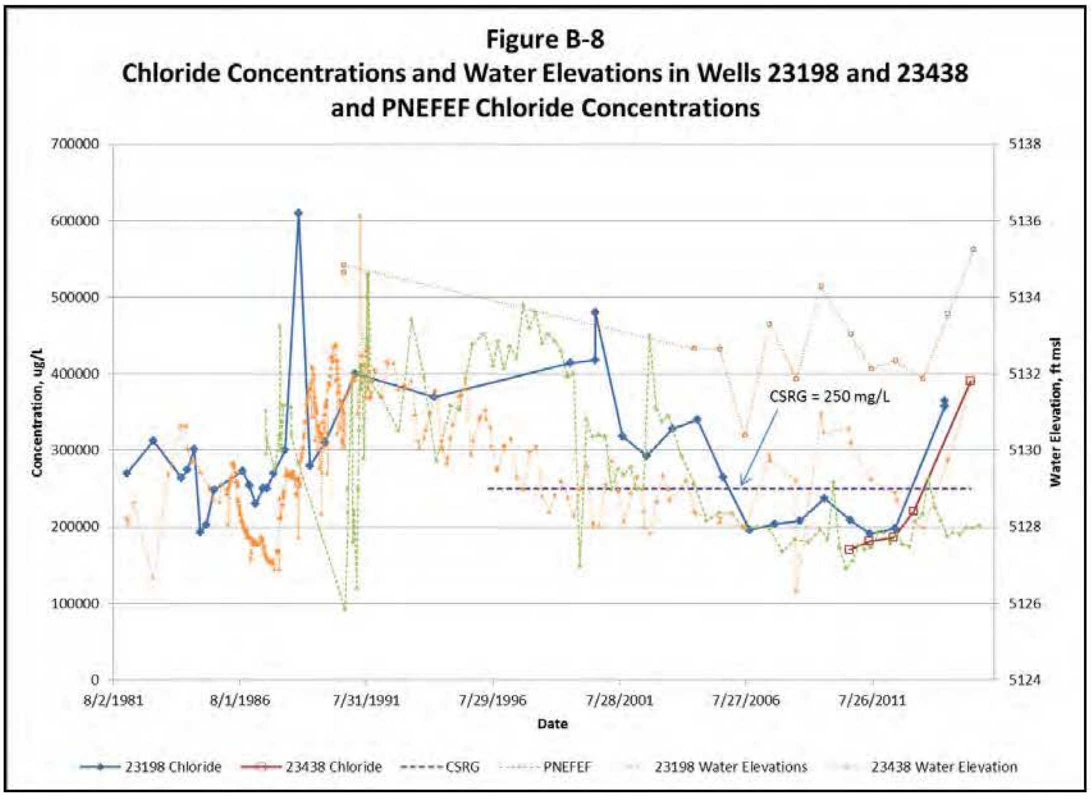


Figure B-8
Chloride Concentrations and Water Elevations in Wells 23198 and 23438
and PNEFEF Chloride Concentrations
CSRG = 250 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
23198 Chloride
23438 Chloride
CSRG
PNEFEF
23198 Water Elevations
23438 Water Elevation

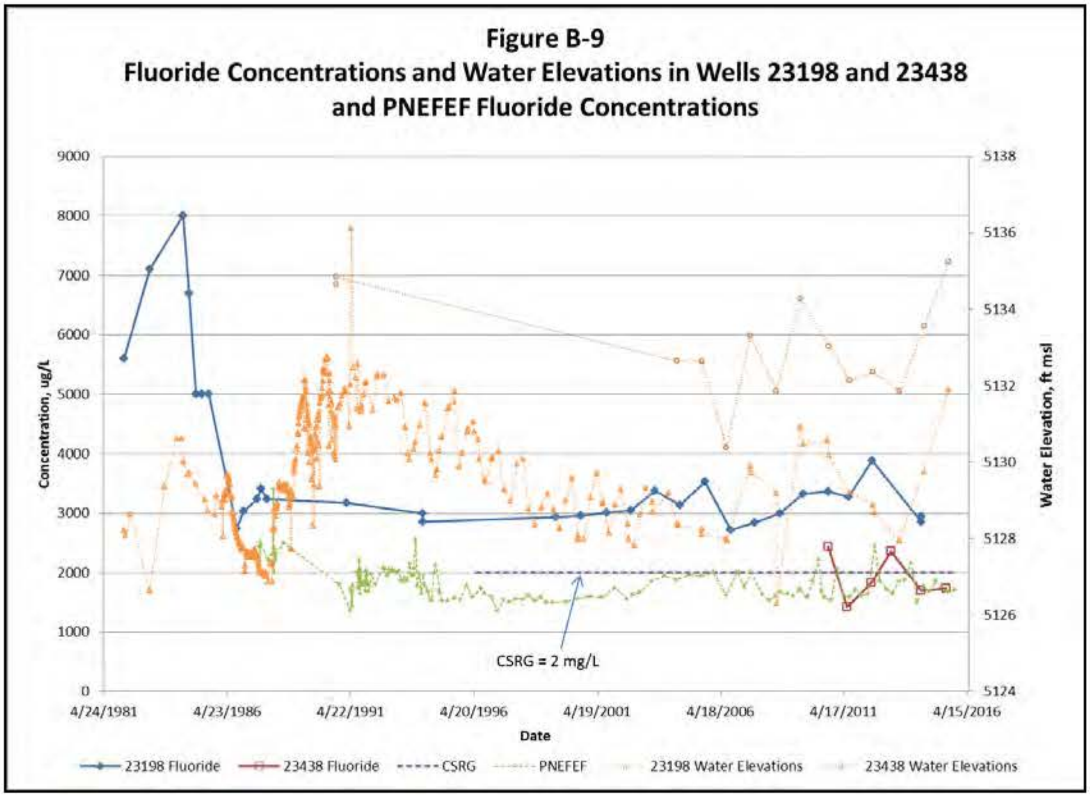


Figure B-9
Fluoride Concentrations and Water Elevations in Wells 23198 and 23438
and PNEFEF Fluoride Concentrations
Concentration, ug/L
Water Elevation, ft msl
Date
CSRG = 2 mg/L
23198 Fluoride
23438 Fluoride
CSRG
PNEFEF
23198 Water Elevations
23438 Water Elevations

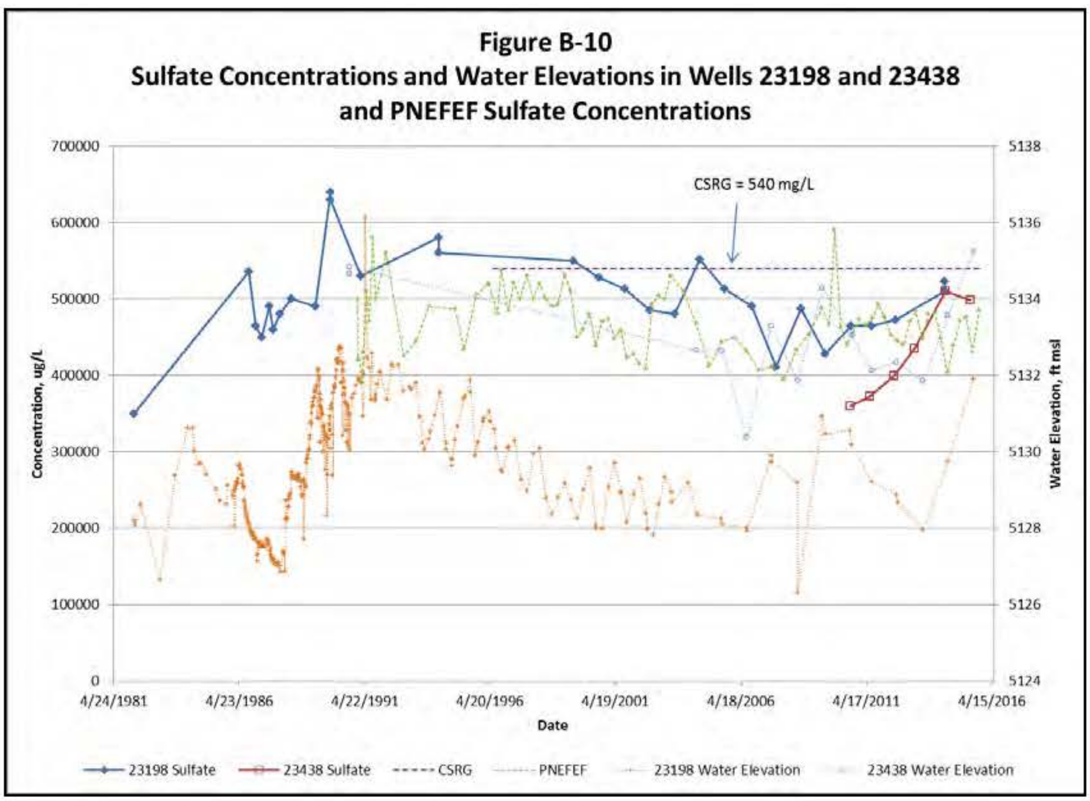


Figure B-10
Sulfate Concentrations and Water Elevations in Wells 23198 and 23438
and PNEFEF Sulfate Concentrations
Concentration, ug/L
Water Elevation, ft msl
Date
CSRG = 540 mg/L
23198 Sulfate
23438 Sulfate
CSRG
PNEFEF
23198 Water Elevation
23438 Water Elevation

Figure B-11
DIMP Concentrations and Water Elevations in Wells 23253 and 23405, and PNEFEF DIMP Concentrations

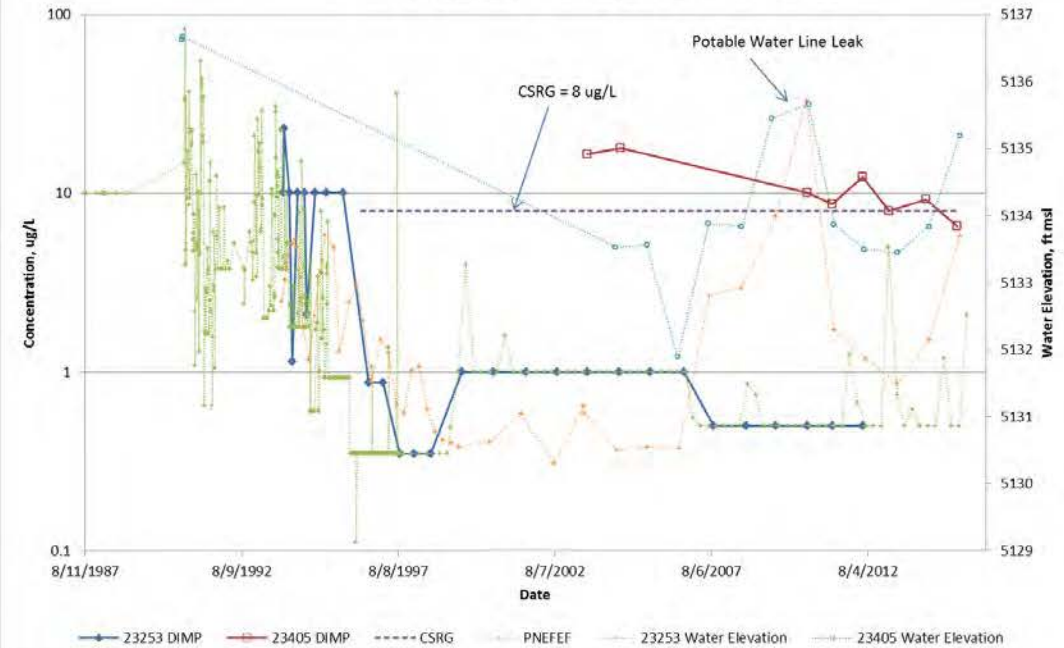
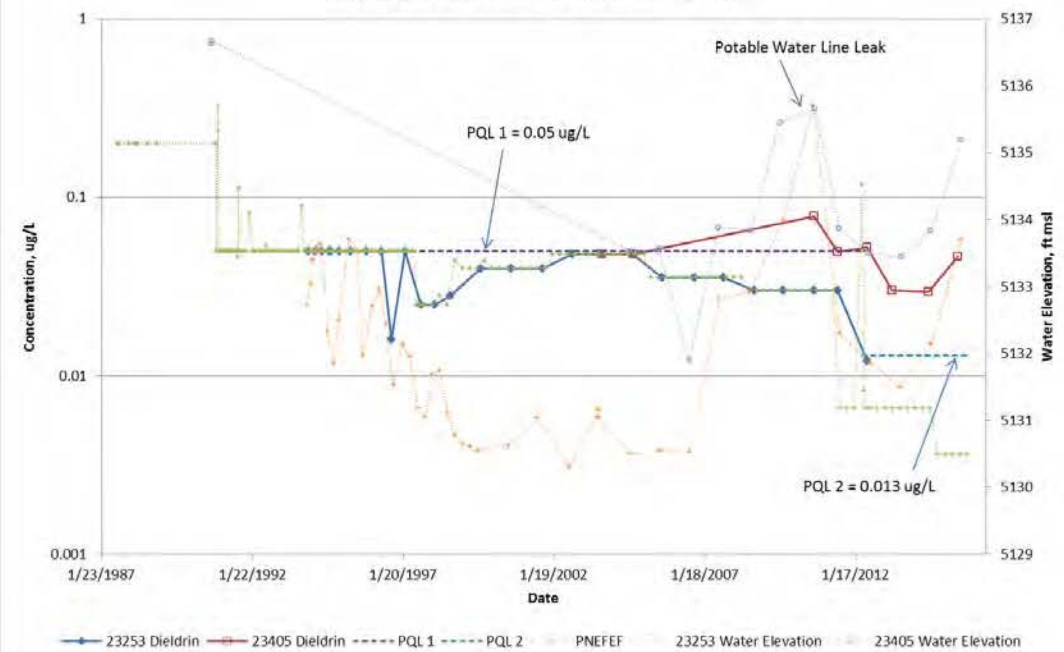


Figure B-12
Dieldrin Concentrations and Water Elevations in Wells 23253 and 23405 and PNEFEF Dieldrin Concentrations



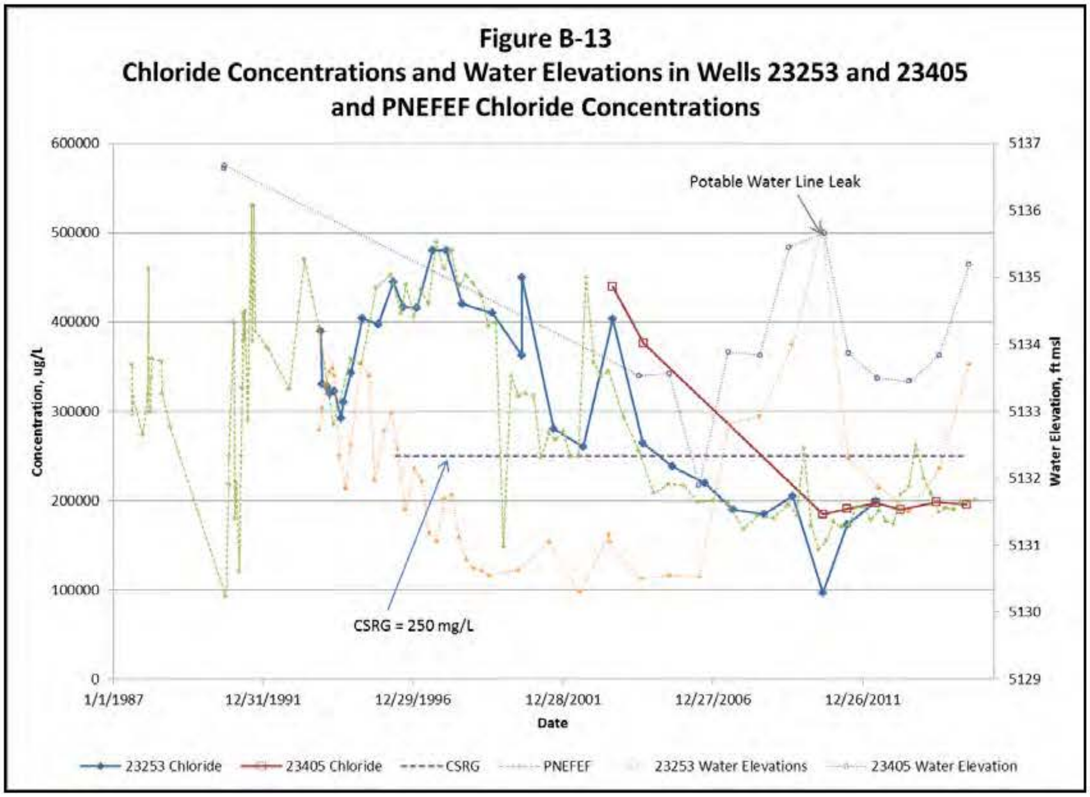


Figure B-13
Chloride Concentrations and Water Elevations in Wells 23253 and 23405
and PNEFEF Chloride Concentrations
Potable Water Line Leak
CSRG = 250 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
600000
500000
400000
300000
200000
100000
0
5137
5136
5135
5134
5133
5132
5131
5130
5129
1/1/1987
12/31/1991
12/29/1996
12/28/2001
12/27/2006
12/26/2011
23253 Chloride
23405 Chloride
CSRG
PNEFEF
23253 Water Elevations
23405 Water Elevation

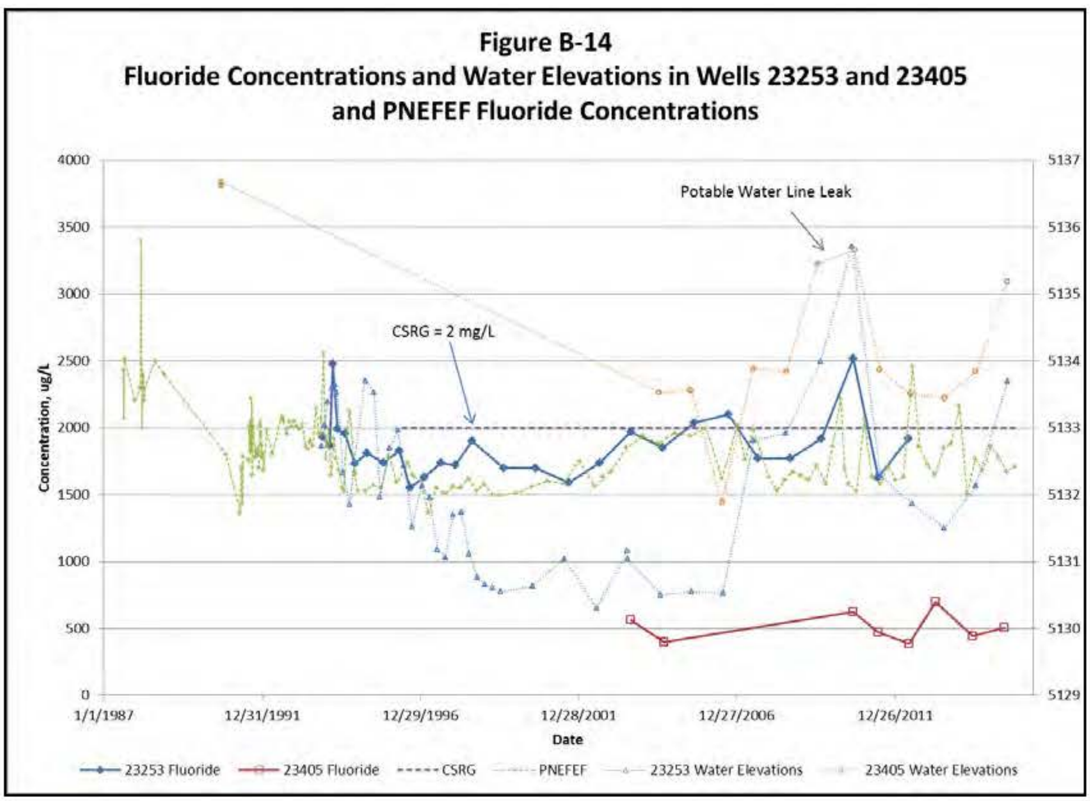


Figure B-14
Fluoride Concentrations and Water Elevations in Wells 23253 and 23405
and PNEFEF Fluoride Concentrations
Potable Water Line Leak
CSRG = 2 mg/L
Concentration, ug/L
Date
4000
3500
3000
2500
2000
1500
1000
500
0
5137
5136
5135
5134
5133
5132
5131
5130
5129
1/1/1987
12/31/1991
12/29/1996
12/28/2001
12/27/2006
12/26/2011
23253 Fluoride
23405 Fluoride
CSRG
PNEFEF
23253 Water Elevations
23405 Water Elevations

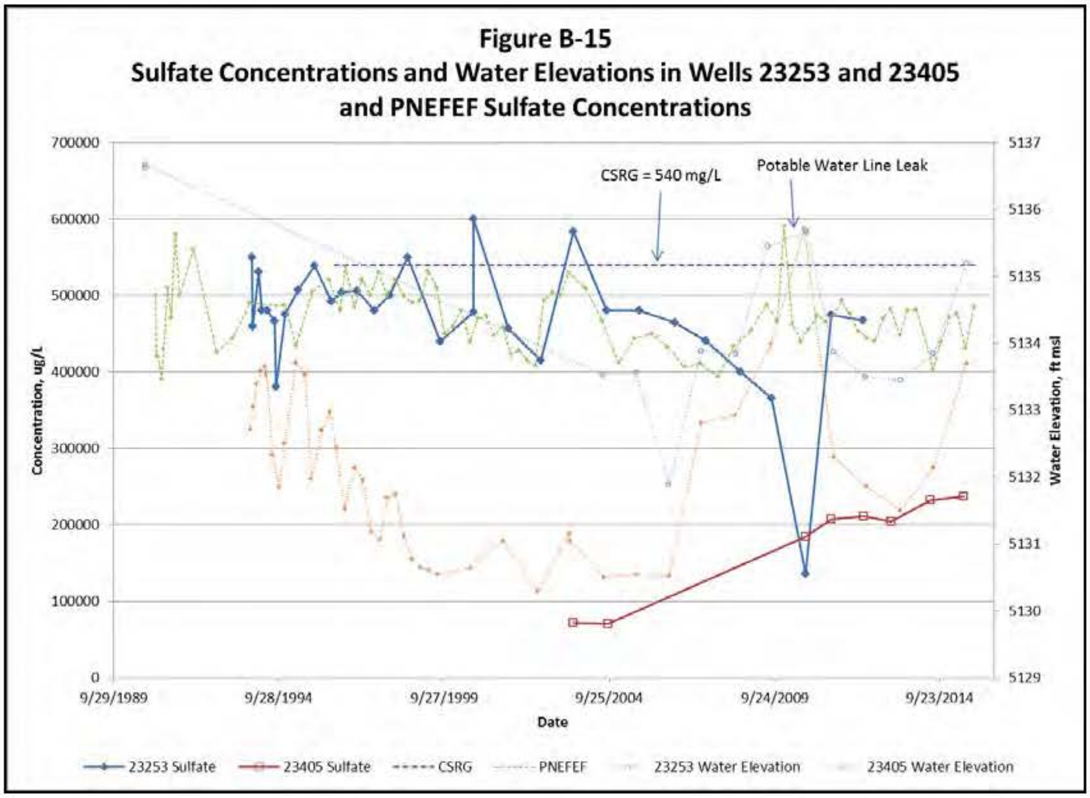


Figure B-15
Sulfate Concentrations and Water Elevations in Wells 23253 and 23405 and PNEFEF Sulfate Concentrations
CSRG = 540 mg/L
Potable Water Line Leak
Concentration, ug/L
Water Elevation, ft msl
Date
23253 Sulfate
23405 Sulfate
CSRG
PNEFEF
23253 Water Elevation
23405 Water Elevation

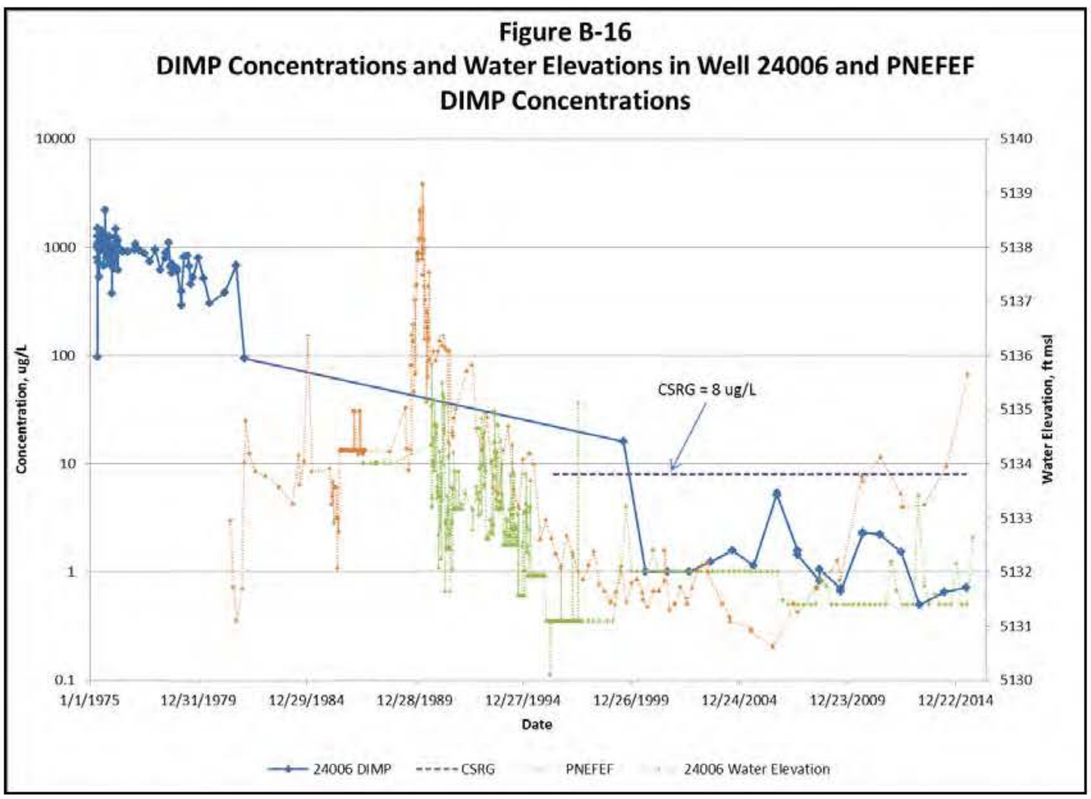


Figure B-16
DIMP Concentrations and Water Elevations in Well 24006 and PNEFEF DIMP Concentrations
CSRG = 8 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
24006 DIMP
CSRG
PNEFEF
24006 Water Elevation

Figure B-17
Dieldrin Concentrations and Water Elevations in Well 24006 and PNEFEF
Dieldrin Concentrations

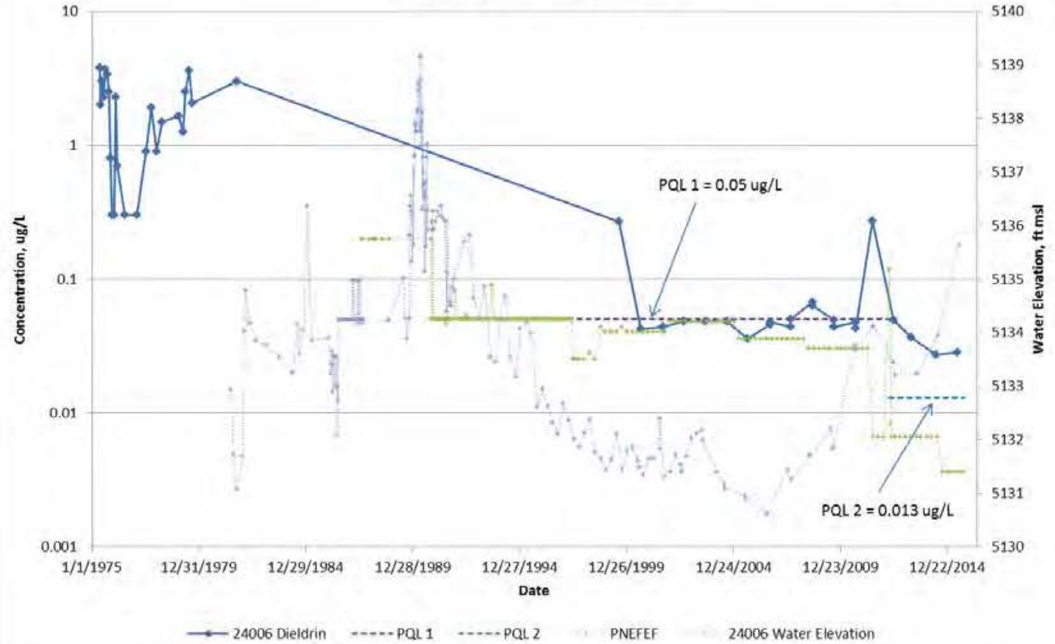
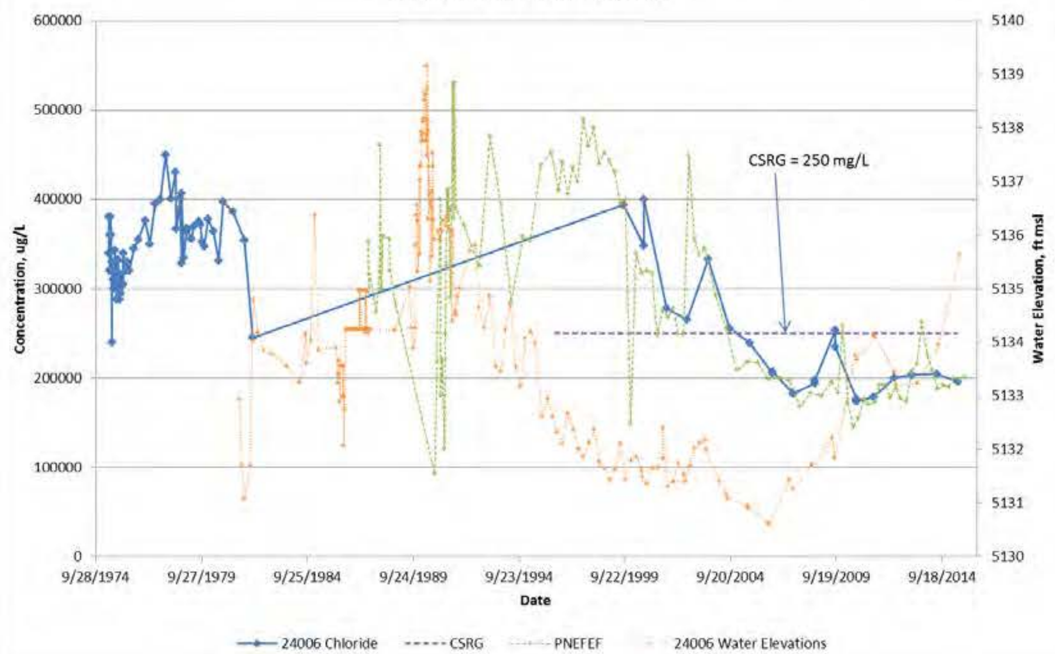


Figure B-18
Chloride Concentrations and Water Elevations in Well 24006 and PNEFEF
Chloride Concentrations



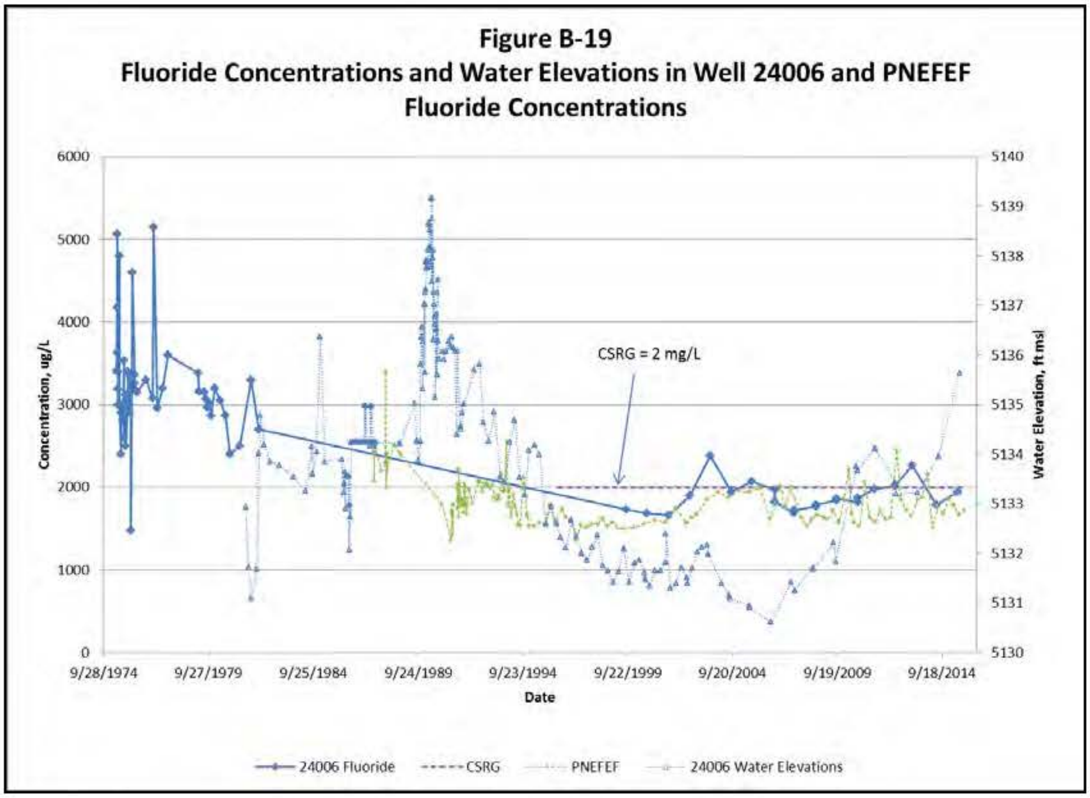


Figure B-19
Fluoride Concentrations and Water Elevations in Well 24006 and PNEFEF
Fluoride Concentrations
CSRG = 2 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
9/28/1974
9/27/1979
9/25/1984
9/24/1989
9/23/1994
9/22/1999
9/20/2004
9/19/2009
9/18/2014
24006 Fluoride
CSRG
PNEFEF
24006 Water Elevations

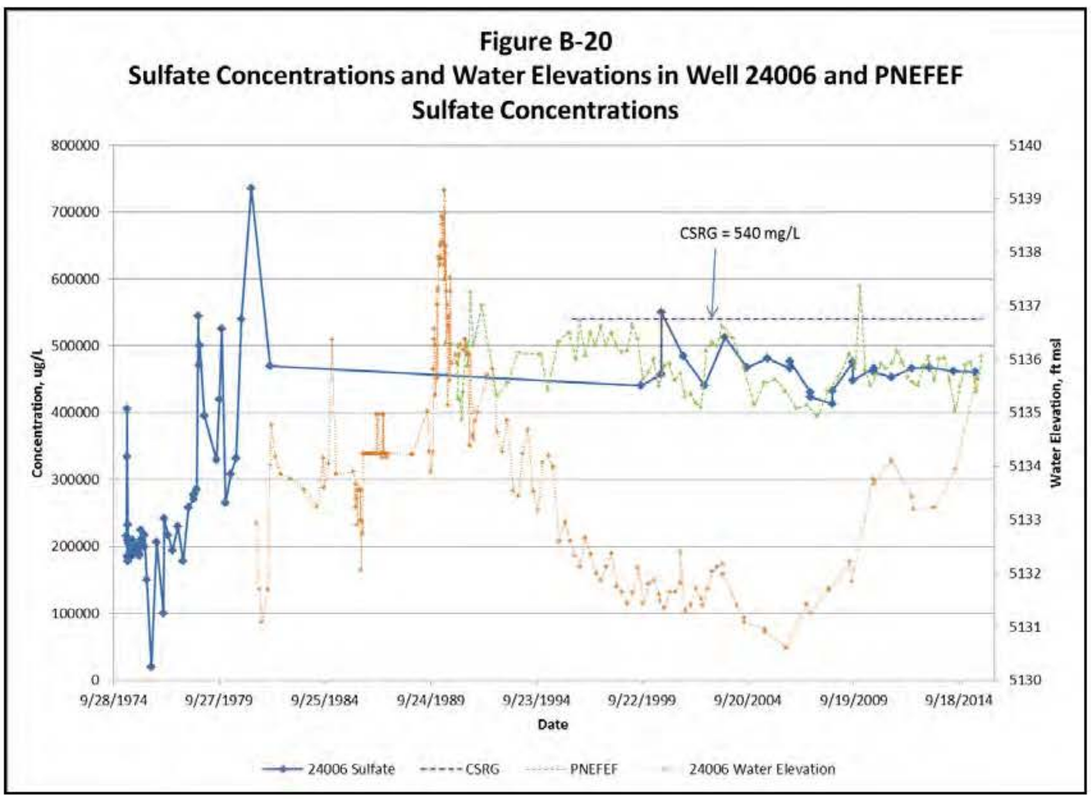


Figure B-20
Sulfate Concentrations and Water Elevations in Well 24006 and PNEFEF
Sulfate Concentrations
CSRG = 540 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
9/28/1974
9/27/1979
9/25/1984
9/24/1989
9/23/1994
9/22/1999
9/20/2004
9/19/2009
9/18/2014
24006 Sulfate
CSRG
PNEFEF
24006 Water Elevation

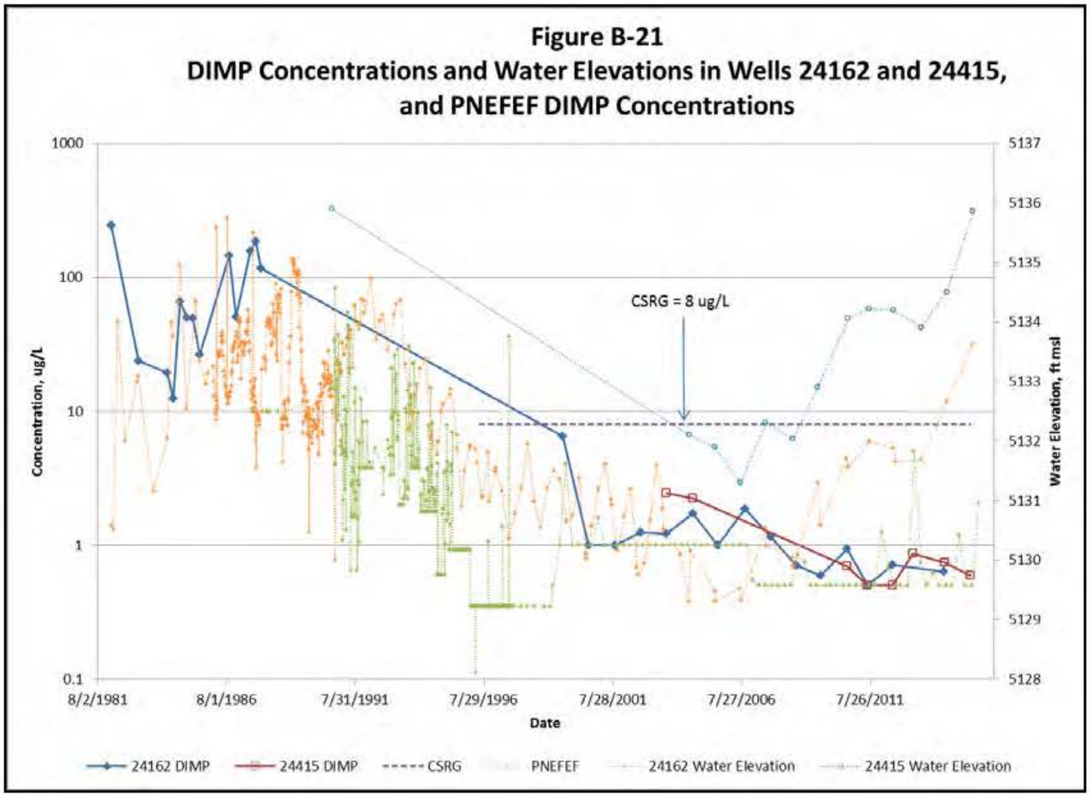


Figure B-21
DIMP Concentrations and Water Elevations in Wells 24162 and 24415, and PNEFEF DIMP Concentrations
Concentration, ug/L
Water Elevation, ft msl
CSRG = 8 ug/L
Date
24162 DIMP
24415 DIMP
CSRG
PNEFEF
24162 Water Elevation
24415 Water Elevation

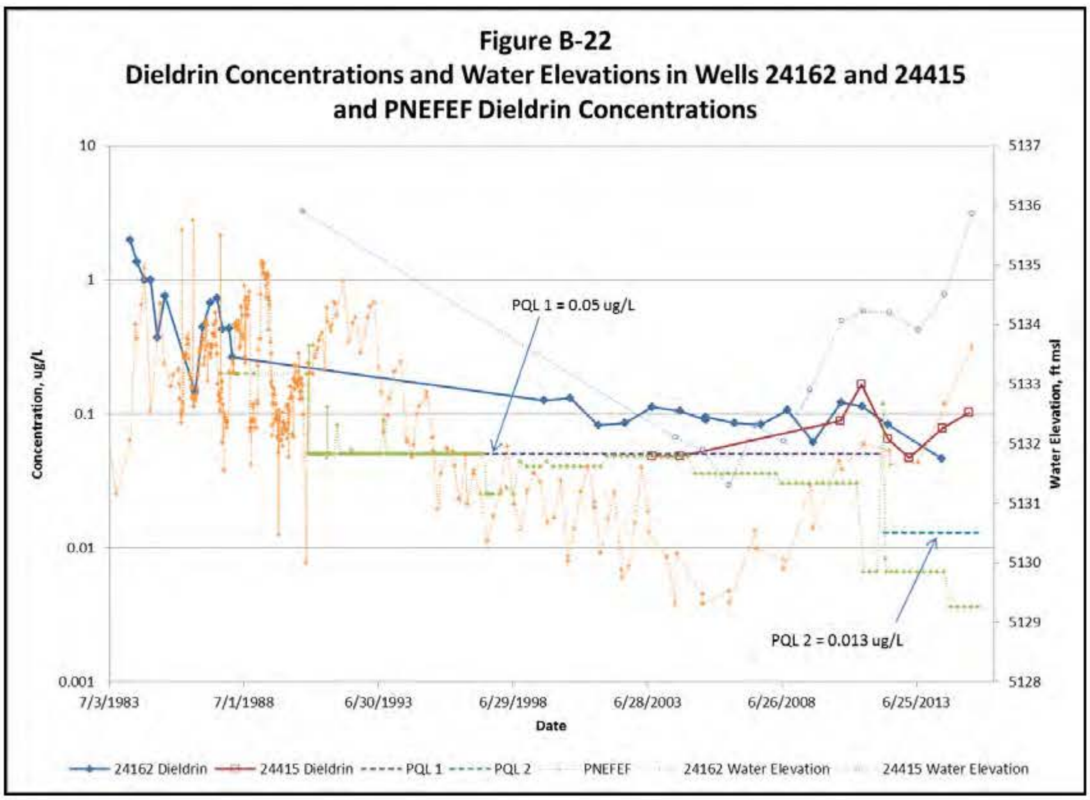


Figure B-22
Dieldrin Concentrations and Water Elevations in Wells 24162 and 24415 and PNEFEF Dieldrin Concentrations
Concentration, ug/L
Water Elevation, ft msl
PQL 1 = 0.05 ug/L
PQL 2 = 0.013 ug/L
Date
24162 Dieldrin
24415 Dieldrin
PQL 1
PQL 2
PNEFEF
24162 Water Elevation
24415 Water Elevation

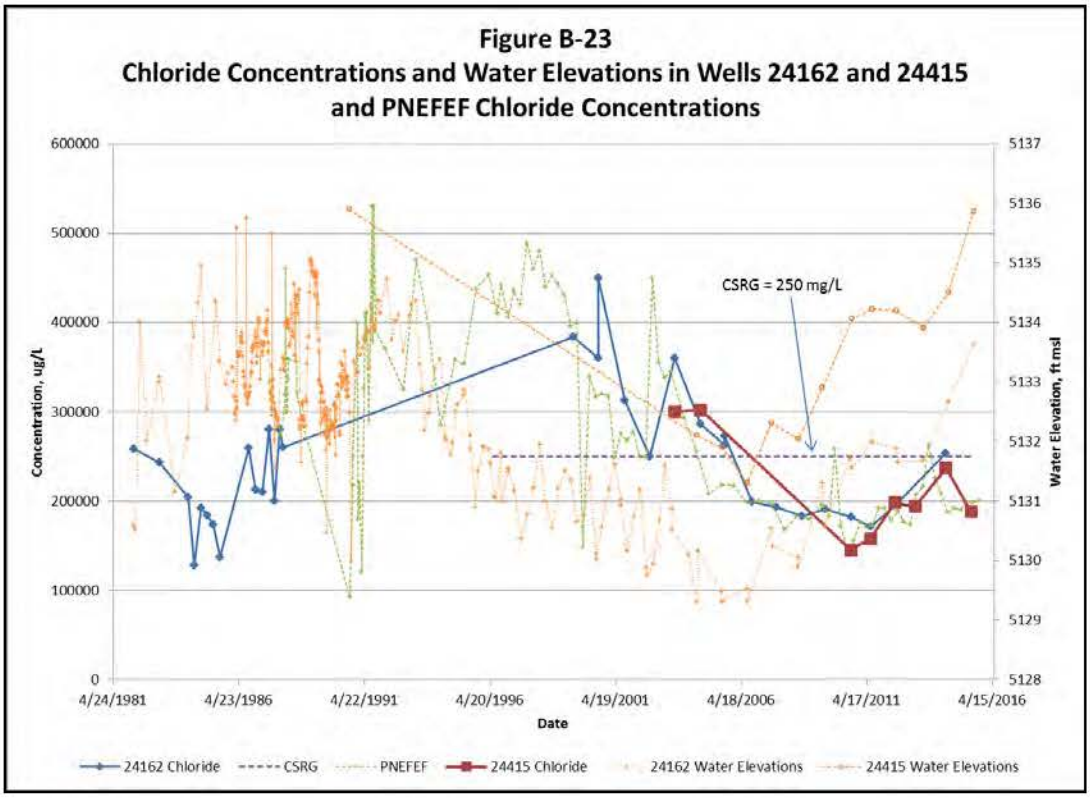


Figure B-23
Chloride Concentrations and Water Elevations in Wells 24162 and 24415
and PNEFEF Chloride Concentrations
Concentration, ug/L
Water Elevation, ft msl
CSRG = 250 mg/L
Date
4/24/1981
4/23/1986
4/22/1991
4/20/1996
4/19/2001
4/18/2006
4/17/2011
4/15/2016
24162 Chloride
CSRG
PNEFEF
24415 Chloride
24162 Water Elevations
24415 Water Elevations

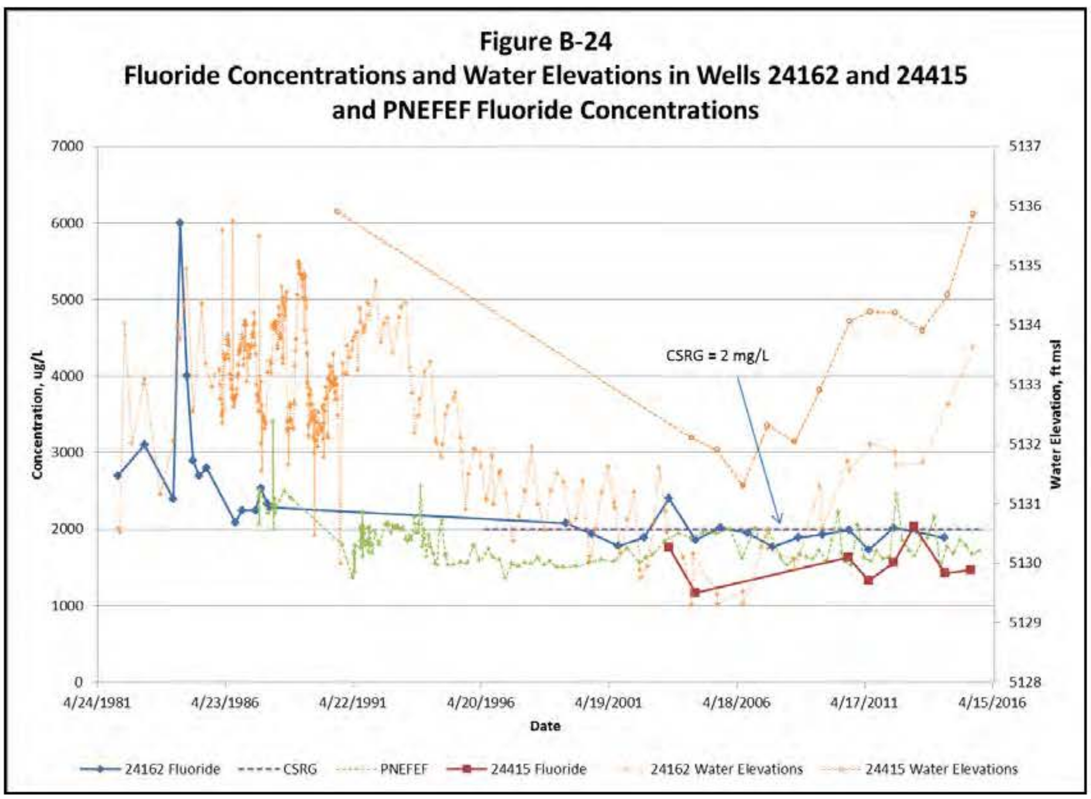


Figure B-24
Fluoride Concentrations and Water Elevations in Wells 24162 and 24415
and PNEFEF Fluoride Concentrations
Concentration, ug/L
Water Elevation, ft msl
CSRG = 2 mg/L
Date
4/24/1981
4/23/1986
4/22/1991
4/20/1996
4/19/2001
4/18/2006
4/17/2011
4/15/2016
24162 Fluoride
CSRG
PNEFEF
24415 Fluoride
24162 Water Elevations
24415 Water Elevations

Figure B-25
Sulfate Concentrations and Water Elevations in Wells 24162 and 24415 and PNEFEF Sulfate Concentrations

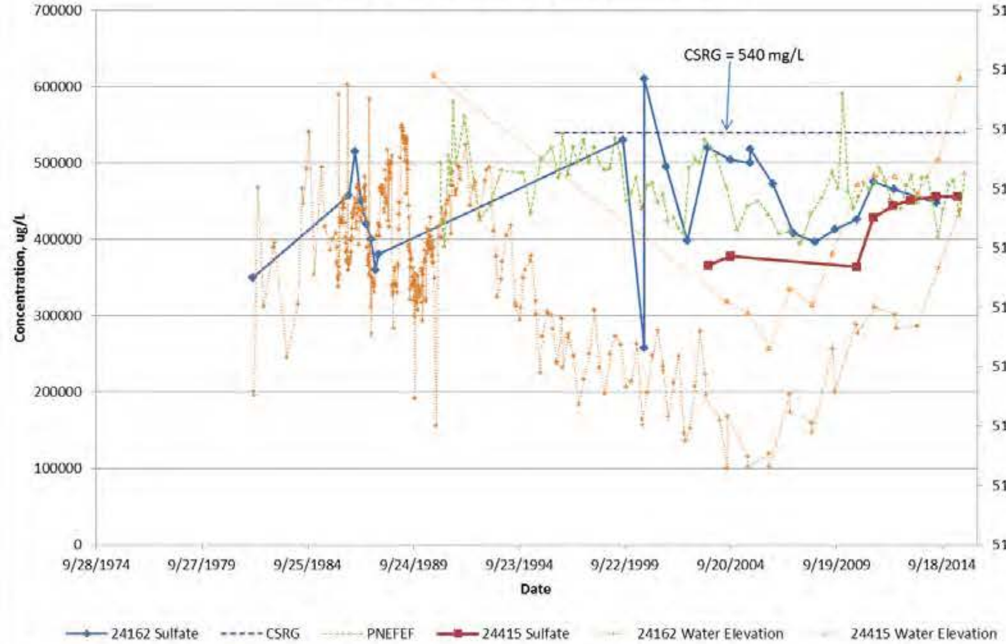
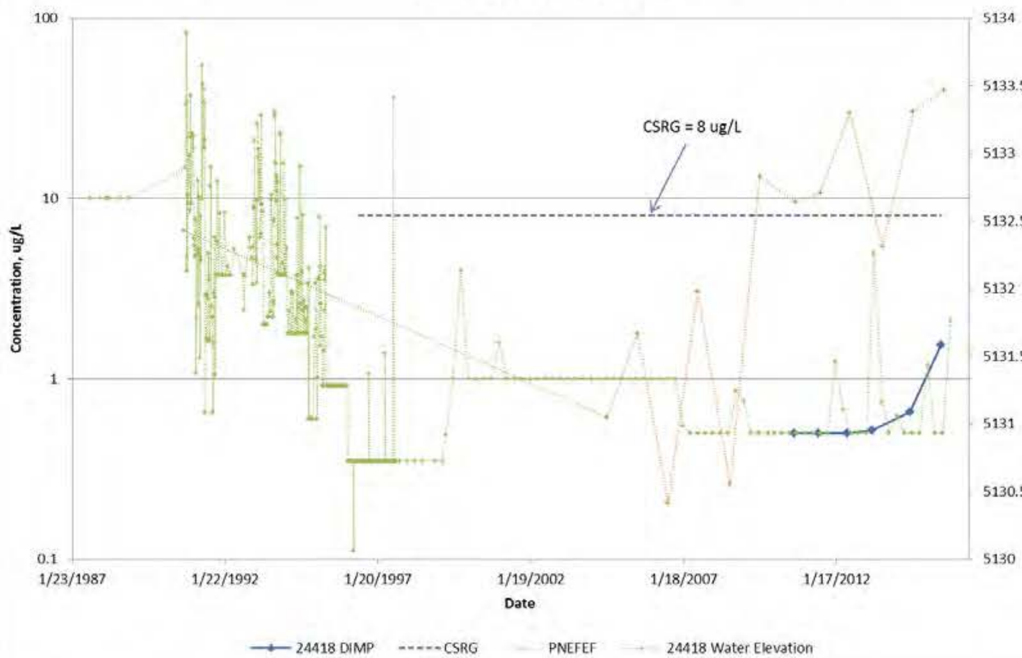


Figure B-26
DIMP Concentrations and Water Elevations in Well 24418 and PNEFEF DIMP Concentrations



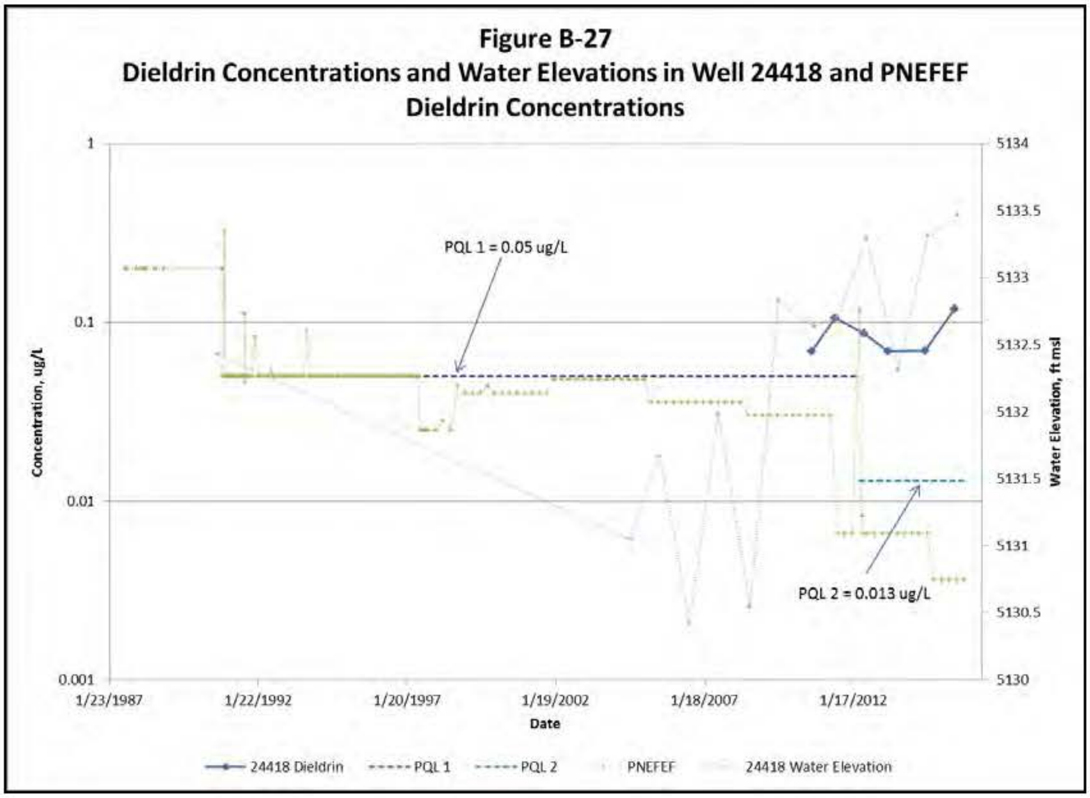


Figure B-27
Dieldrin Concentrations and Water Elevations in Well 24418 and PNEFEF
Dieldrin Concentrations
PQL 1 = 0.05 ug/L
PQL 2 = 0.013 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
24418 Dieldrin
PQL 1
PQL 2
PNEFEF
24418 Water Elevation

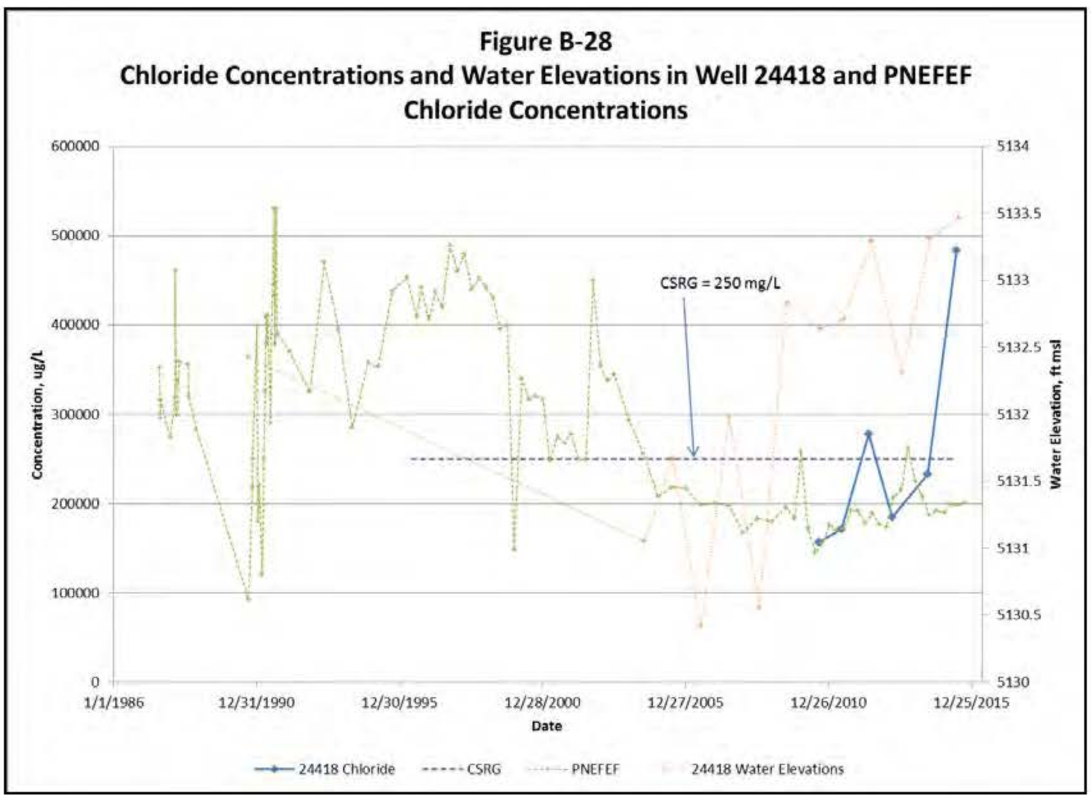


Figure B-28
Chloride Concentrations and Water Elevations in Well 24418 and PNEFEF
Chloride Concentrations
CSRG = 250 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
24418 Chloride
CSRG
PNEFEF
24418 Water Elevations

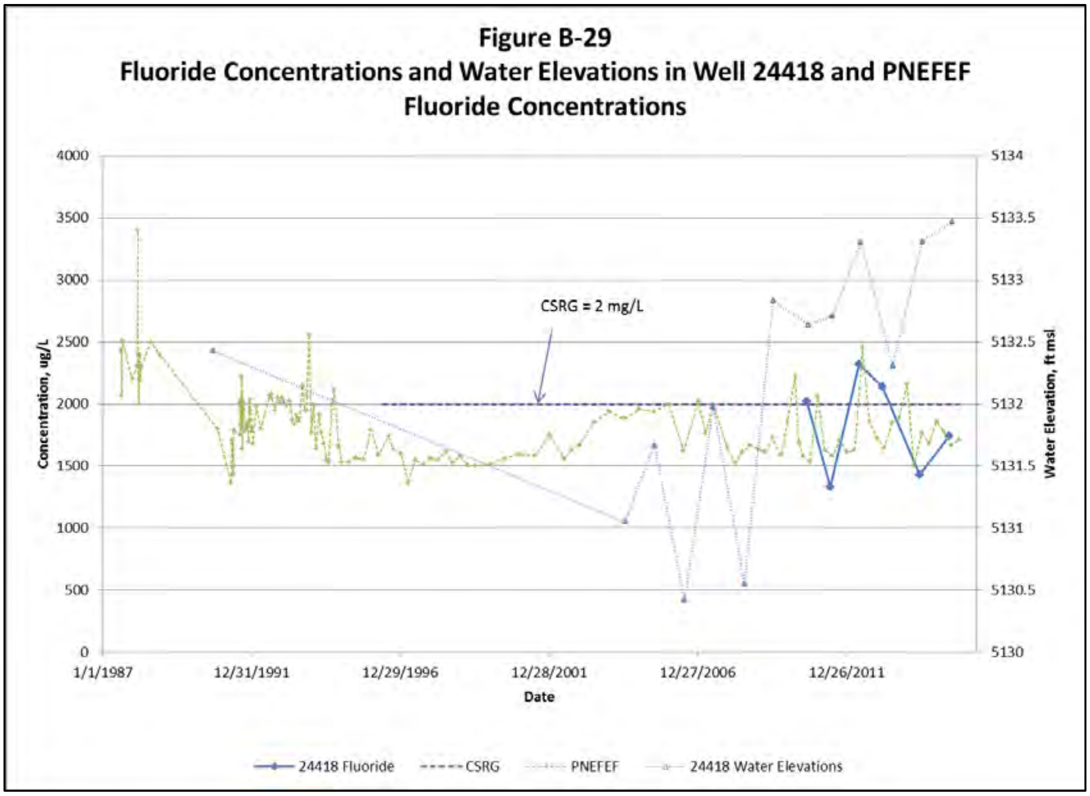


Figure B-29
Fluoride Concentrations and Water Elevations in Well 24418 and PNEFEF
Fluoride Concentrations
CSRG = 2 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
0
500
1000
1500
2000
2500
3000
3500
4000
5130
5130.5
5131
5131.5
5132
5132.5
5133
5133.5
5134
1/1/1987
12/31/1991
12/29/1996
12/28/2001
12/27/2006
12/26/2011
24418 Fluoride
CSRG
PNEFEF
24418 Water Elevations

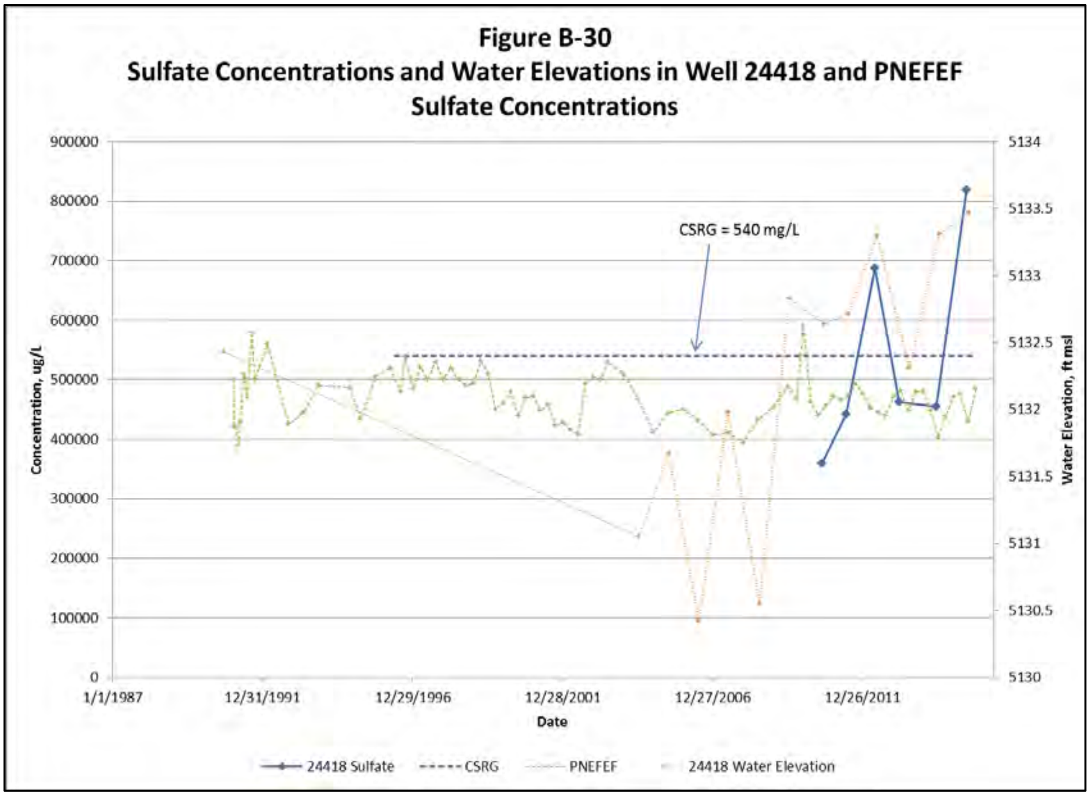


Figure B-30
Sulfate Concentrations and Water Elevations in Well 24418 and PNEFEF
Sulfate Concentrations
CSRG = 540 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
0
100000
200000
300000
400000
500000
600000
700000
800000
900000
5130
5130.5
5131
5131.5
5132
5132.5
5133
5133.5
5134
1/1/1987
12/31/1991
12/29/1996
12/28/2001
12/27/2006
12/26/2011
24418 Sulfate
CSRG
PNEFEF
24418 Water Elevation

Figure B-31
Dieldrin Concentrations and Water Elevations in Well 24163 and PNEFEF
Dieldrin Concentrations

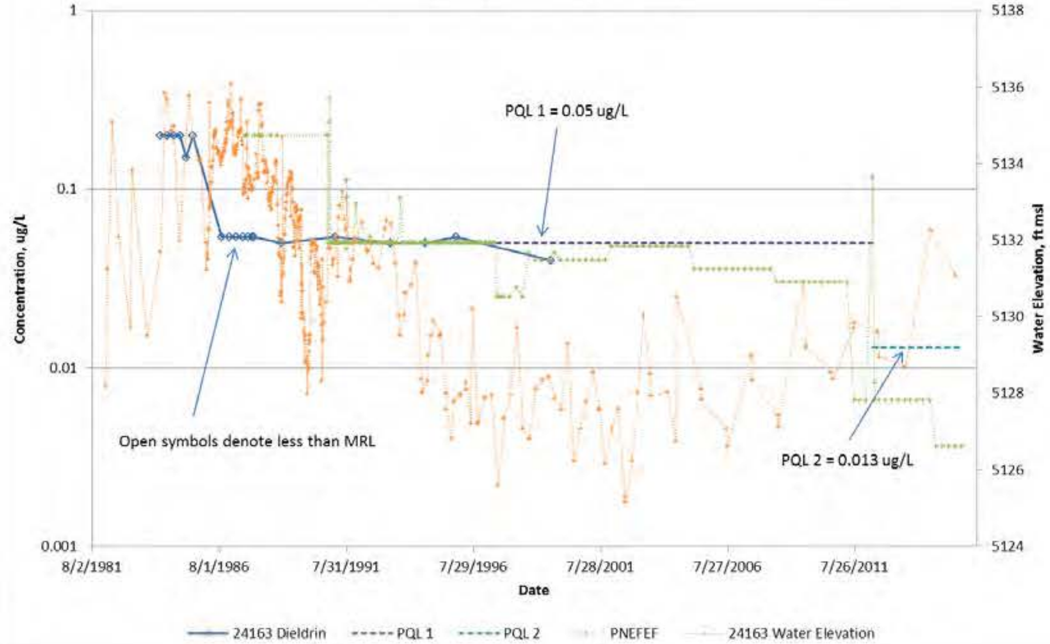
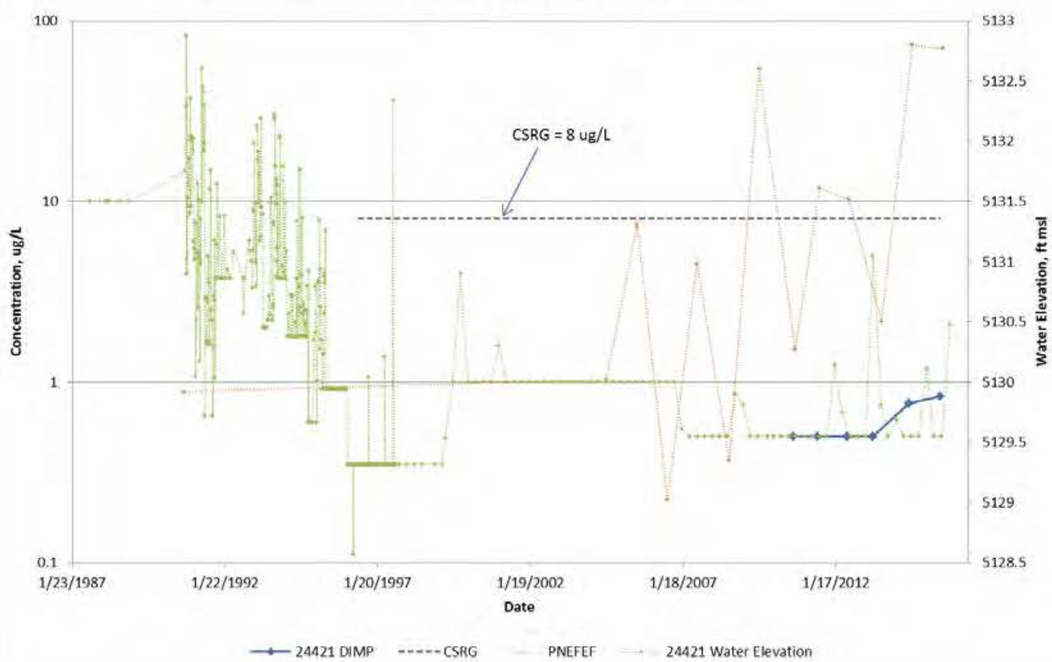


Figure B-32
DIMP Concentrations and Water Elevations in Well 24421 and PNEFEF
DIMP Concentrations



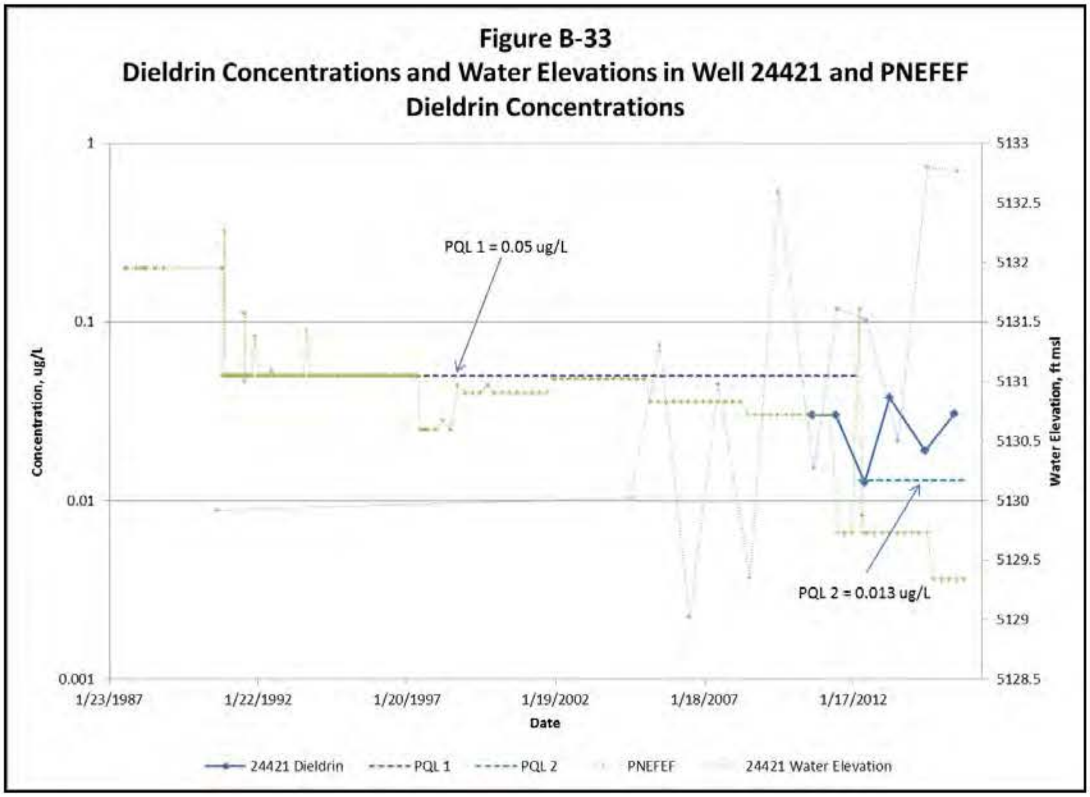


Figure B-33
Dieldrin Concentrations and Water Elevations in Well 24421 and PNEFEF
Dieldrin Concentrations
PQL 1 = 0.05 ug/L
PQL 2 = 0.013 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
1/23/1987
1/22/1992
1/20/1997
1/19/2002
1/18/2007
1/17/2012
24421 Dieldrin
PQL 1
PQL 2
PNEFEF
24421 Water Elevation

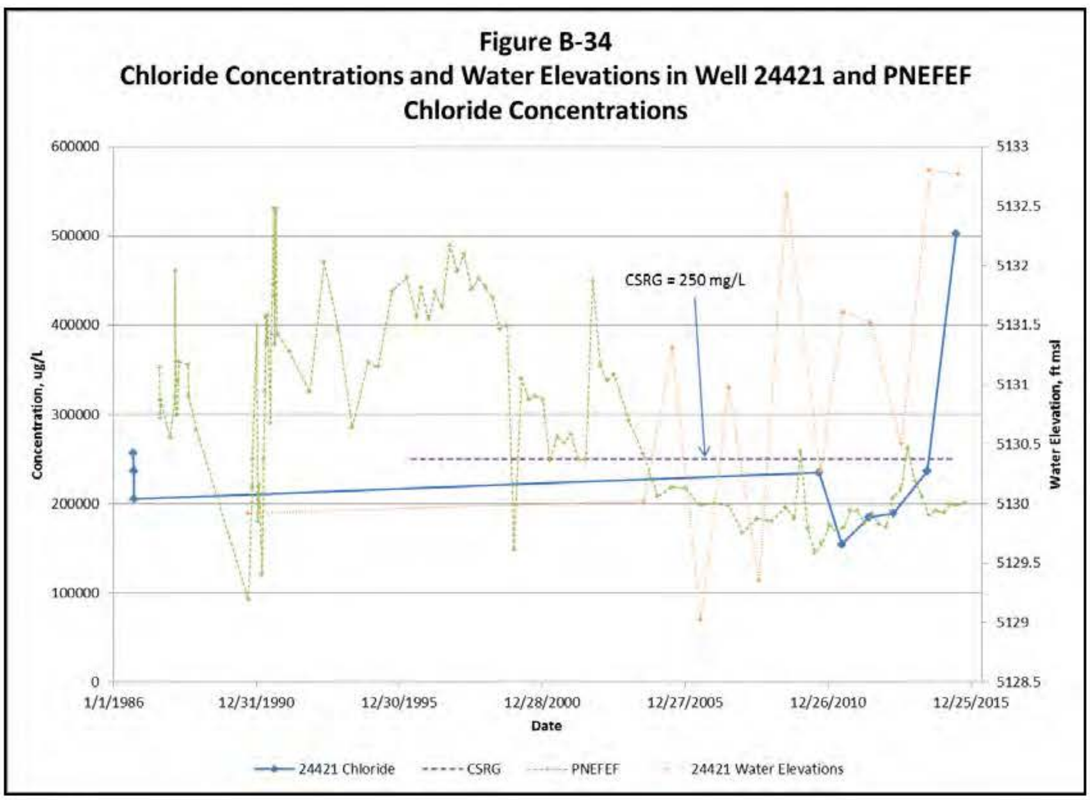


Figure B-34
Chloride Concentrations and Water Elevations in Well 24421 and PNEFEF
Chloride Concentrations
CSRG = 250 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
1/1/1986
12/31/1990
12/30/1995
12/28/2000
12/27/2005
12/26/2010
12/25/2015
24421 Chloride
CSRG
PNEFEF
24421 Water Elevations

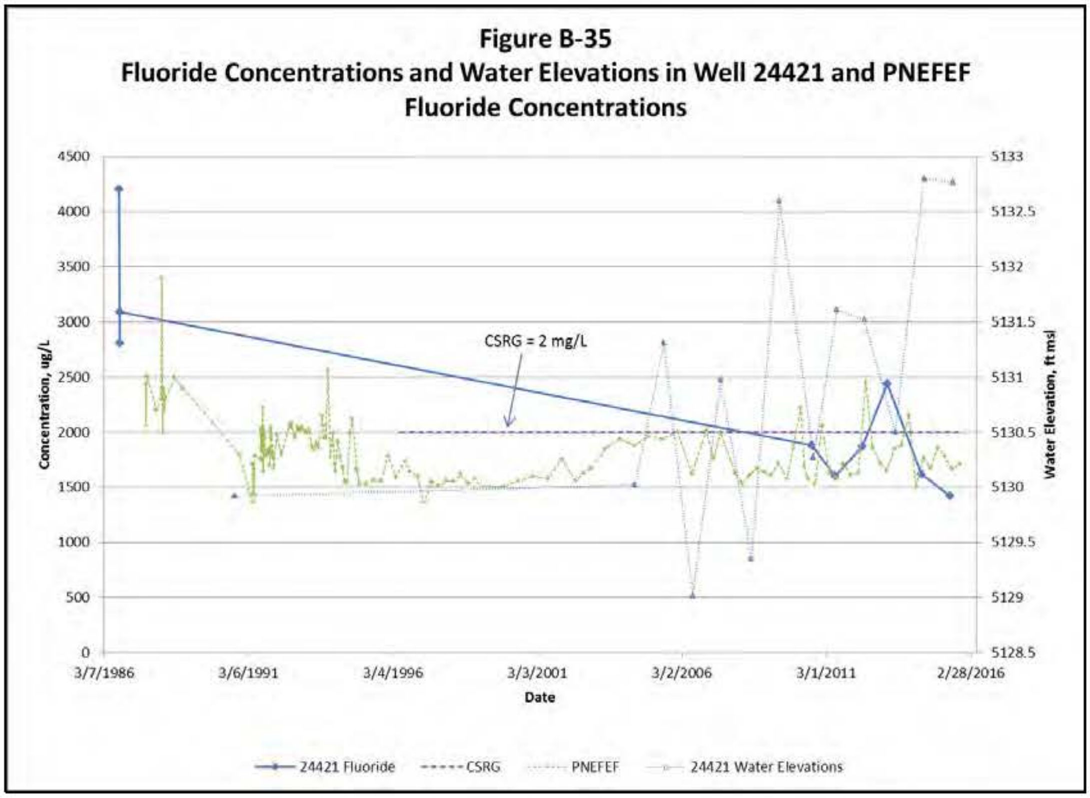


Figure B-35
Fluoride Concentrations and Water Elevations in Well 24421 and PNEFEF
Fluoride Concentrations
CSRG = 2 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5128.5
5129
5129.5
5130
5130.5
5131
5131.5
5132
5132.5
5133
3/7/1986
3/6/1991
3/4/1996
3/3/2001
3/2/2006
3/1/2011
2/28/2016
24421 Fluoride
CSRG
PNEFEF
24421 Water Elevations

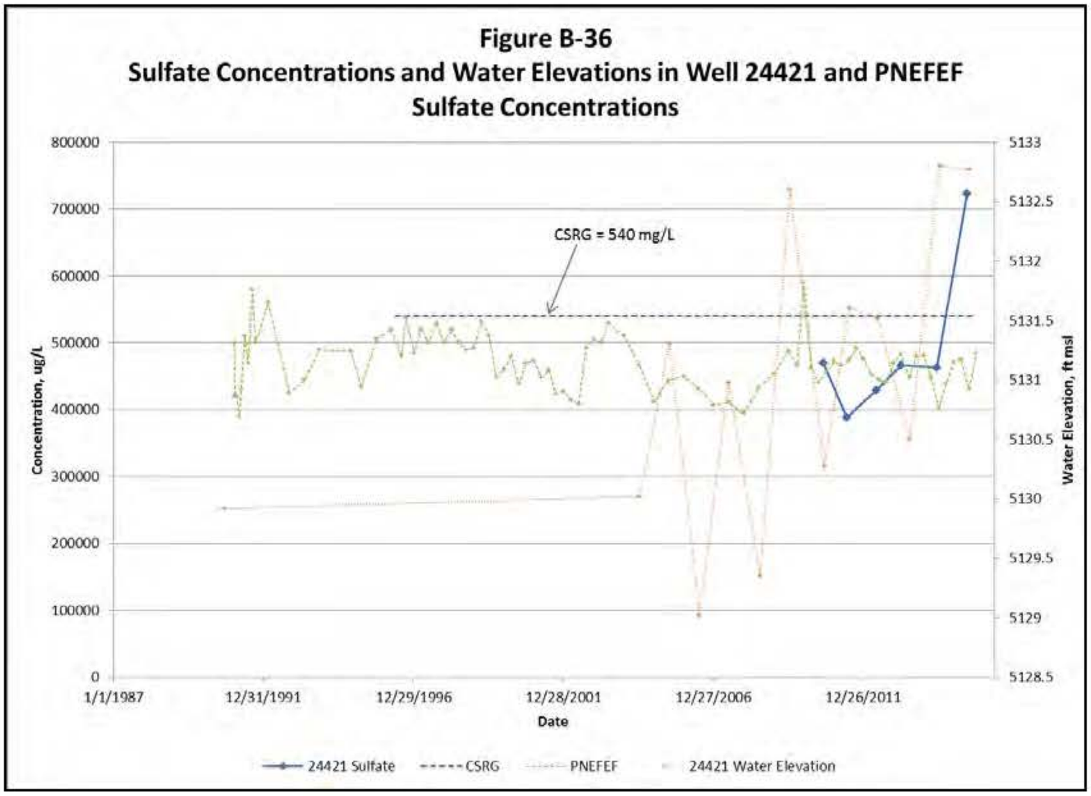


Figure B-36
Sulfate Concentrations and Water Elevations in Well 24421 and PNEFEF
Sulfate Concentrations
CSRG = 540 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
0
100000
200000
300000
400000
500000
600000
700000
800000
5128.5
5129
5129.5
5130
5130.5
5131
5131.5
5132
5132.5
5133
1/1/1987
12/31/1991
12/29/1996
12/28/2001
12/27/2006
12/26/2011
24421 Sulfate
CSRG
PNEFEF
24421 Water Elevation

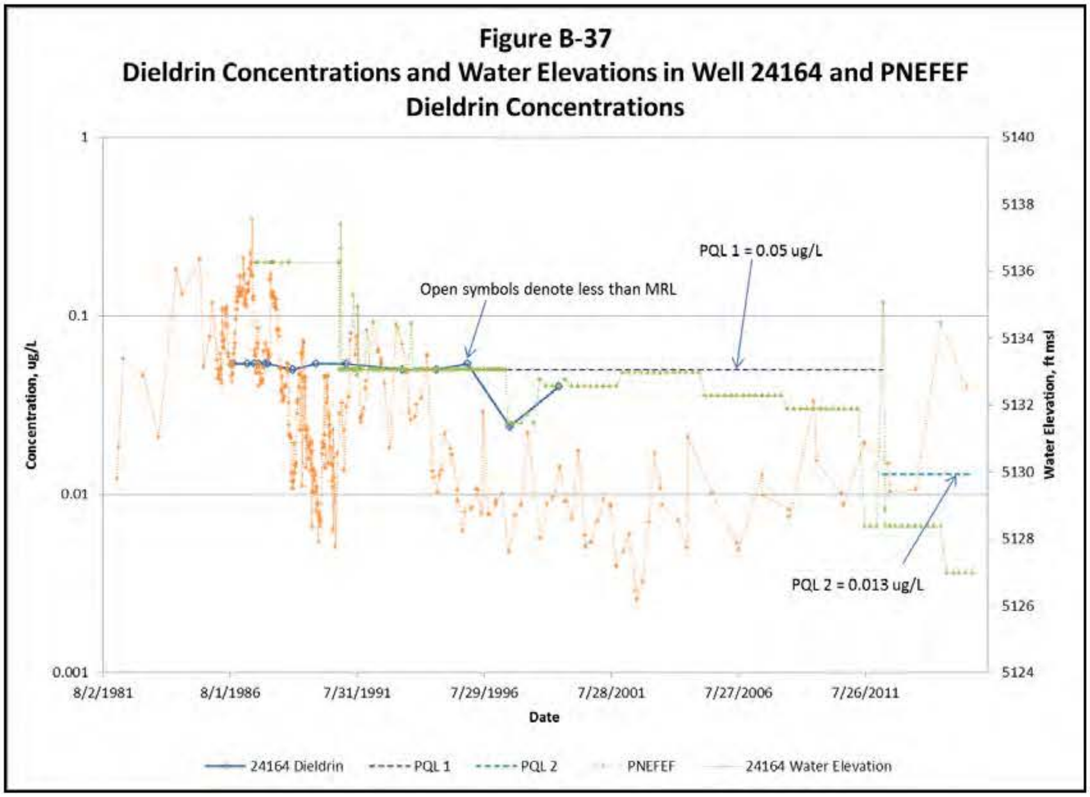


Figure B-37
Dieldrin Concentrations and Water Elevations in Well 24164 and PNEFEF
Dieldrin Concentrations
PQL 1 = 0.05 ug/L
Open symbols denote less than MRL
PQL 2 = 0.013 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
24164 Dieldrin
PQL 1
PQL 2
PNEFEF
24164 Water Elevation

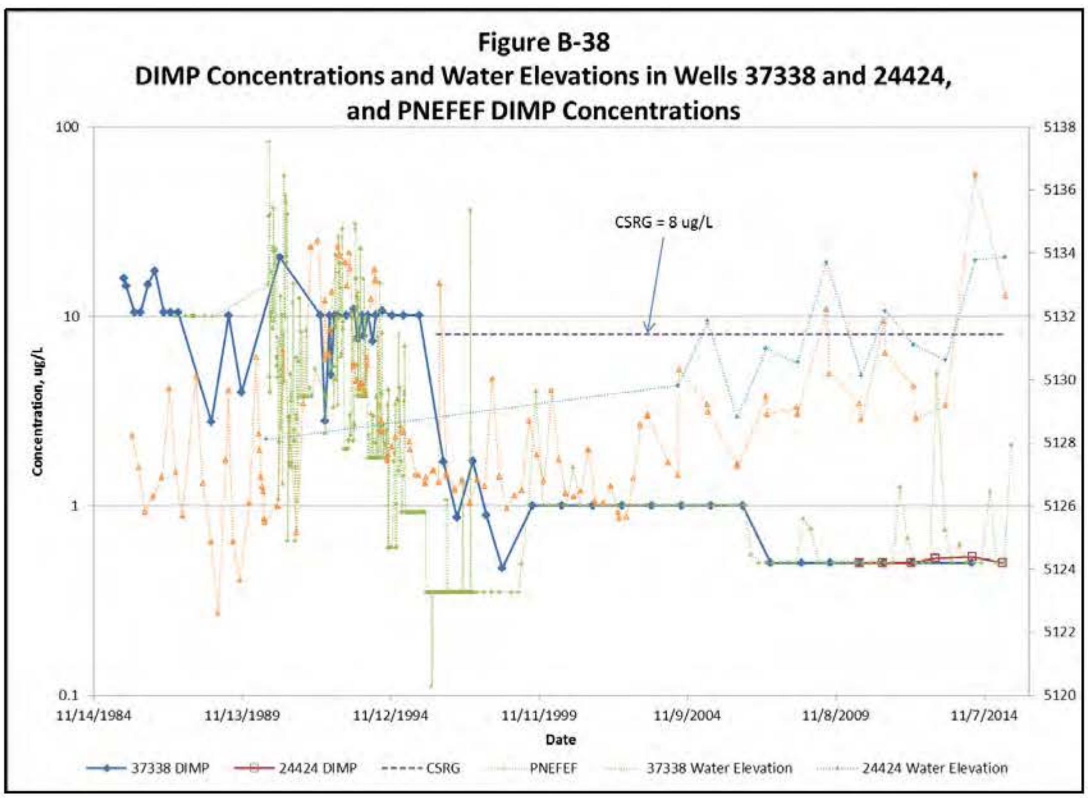


Figure B-38
DIMP Concentrations and Water Elevations in Wells 37338 and 24424,
and PNEFEF DIMP Concentrations
CSRG = 8 ug/L
Concentration, ug/L
Date
37338 DIMP
24424 DIMP
CSRG
PNEFEF
37338 Water Elevation
24424 Water Elevation

Figure B-39
Dieldrin Concentrations and Water Elevations in Wells 37338 and 24424 and PNEFEF Dieldrin Concentrations

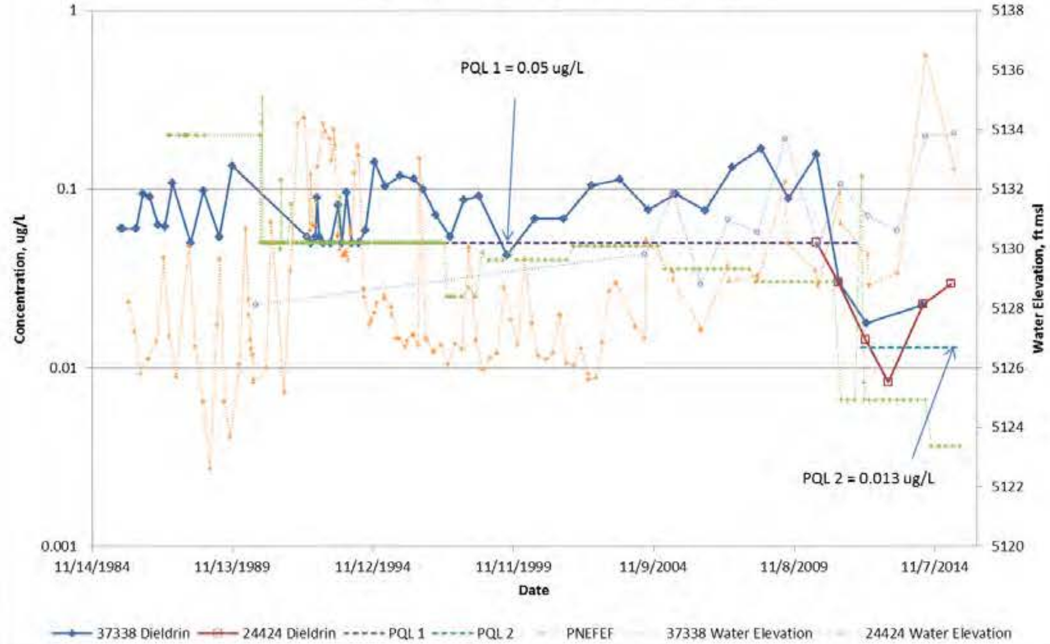
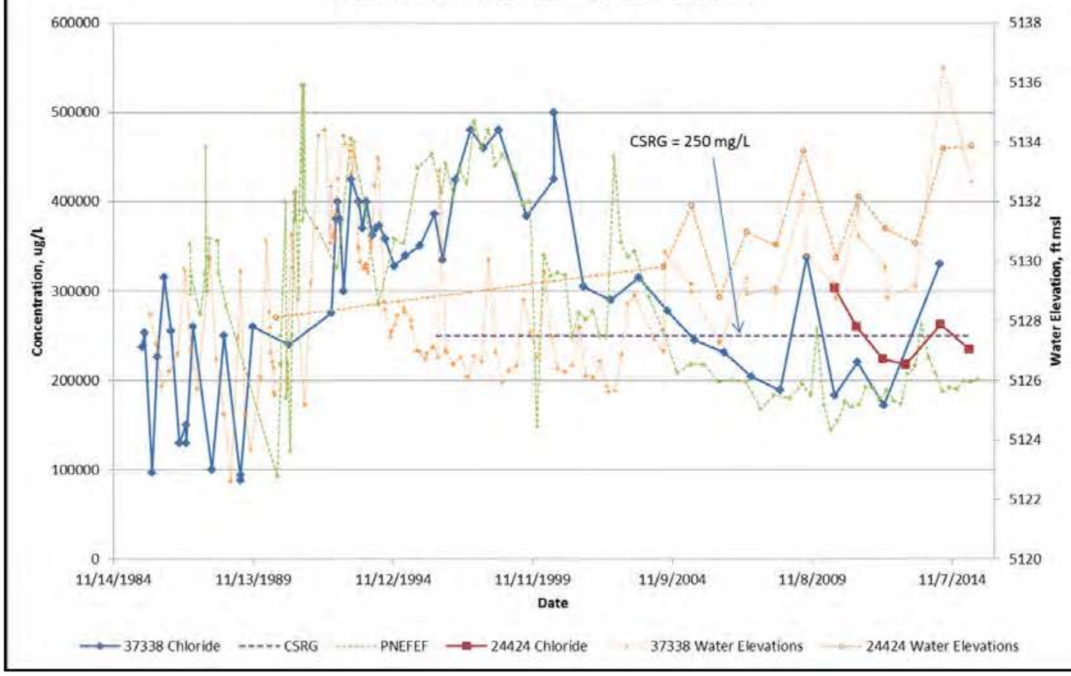


Figure B-40
Chloride Concentrations and Water Elevations in Wells 37338 and 24424 and PNEFEF Chloride Concentrations



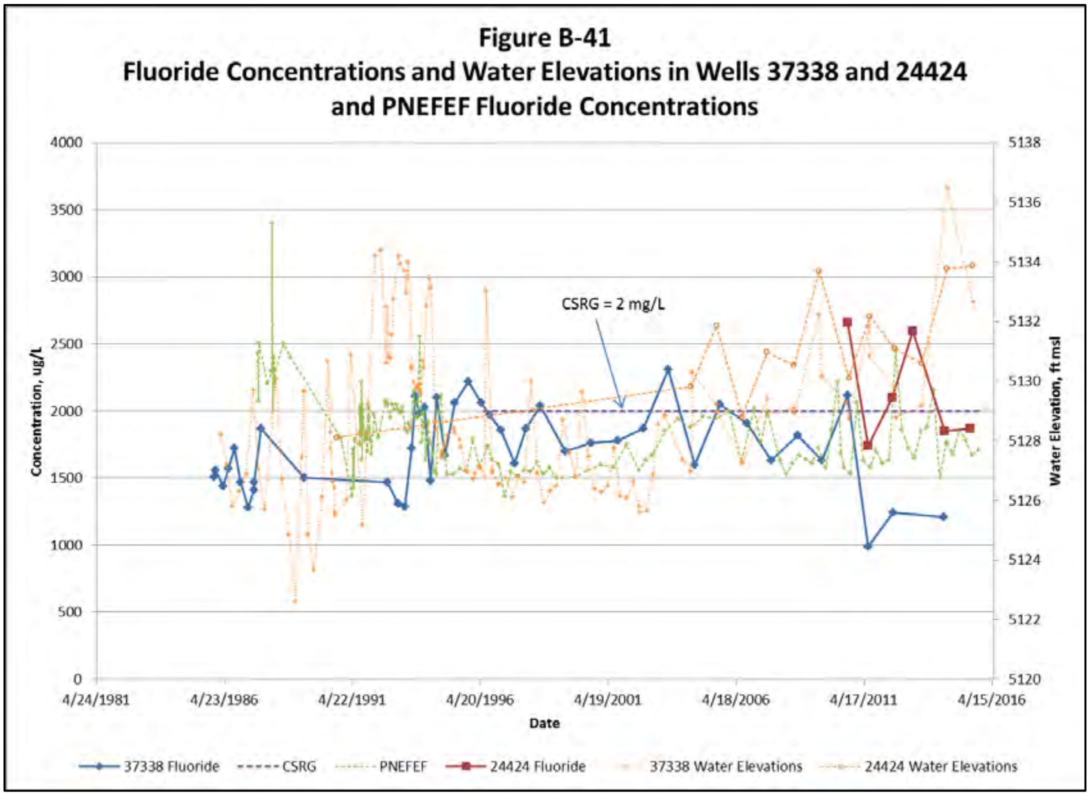


Figure B-41
Fluoride Concentrations and Water Elevations in Wells 37338 and 24424 and PNEFEF Fluoride Concentrations
CSRG = 2 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
4/24/1981
4/23/1986
4/22/1991
4/20/1996
4/19/2001
4/18/2006
4/17/2011
4/15/2016
37338 Fluoride
CSRG
PNEFEF
24424 Fluoride
37338 Water Elevations
24424 Water Elevations

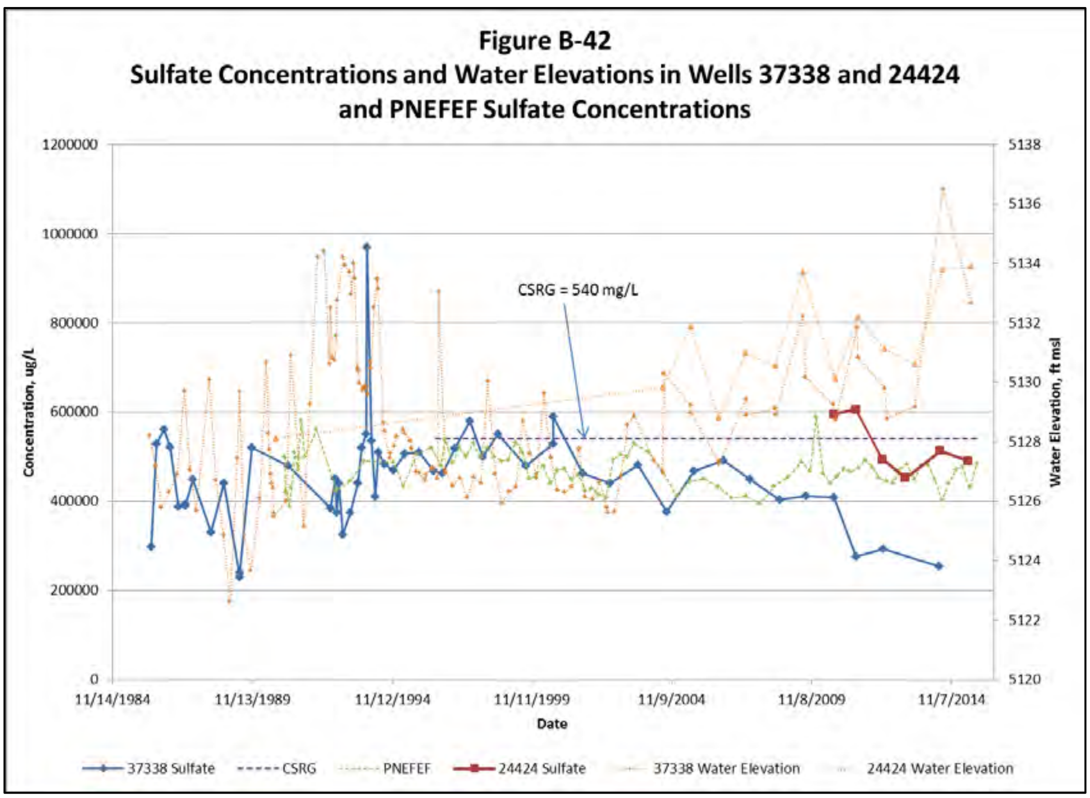


Figure B-42
Sulfate Concentrations and Water Elevations in Wells 37338 and 24424 and PNEFEF Sulfate Concentrations
CSRG = 540 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
11/14/1984
11/13/1989
11/12/1994
11/11/1999
11/9/2004
11/8/2009
11/7/2014
37338 Sulfate
CSRG
PNEFEF
24424 Sulfate
37338 Water Elevation
24424 Water Elevation

Figure B-43
DIMP Concentrations and Water Elevations in Wells 24166 and 24004, and PNEFEF DIMP Concentrations

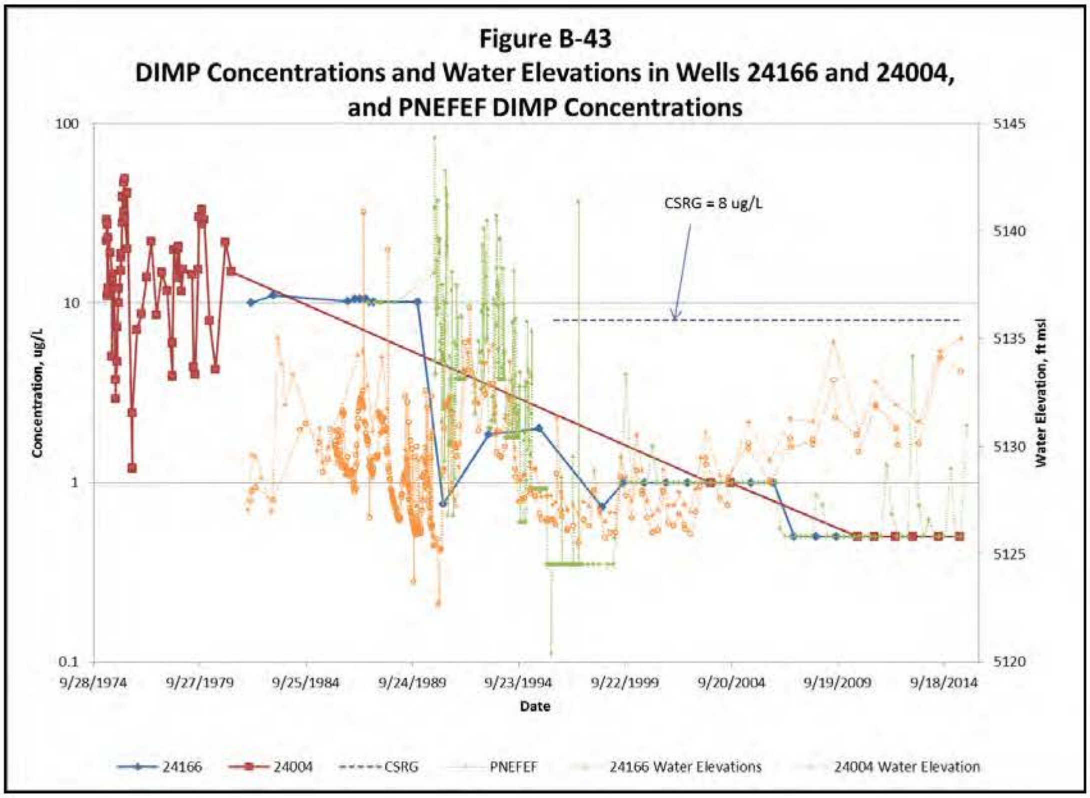


Figure B-44
Dieldrin Concentrations and Water Elevations in Wells 24166 and 24004 and PNEFEF Dieldrin Concentrations

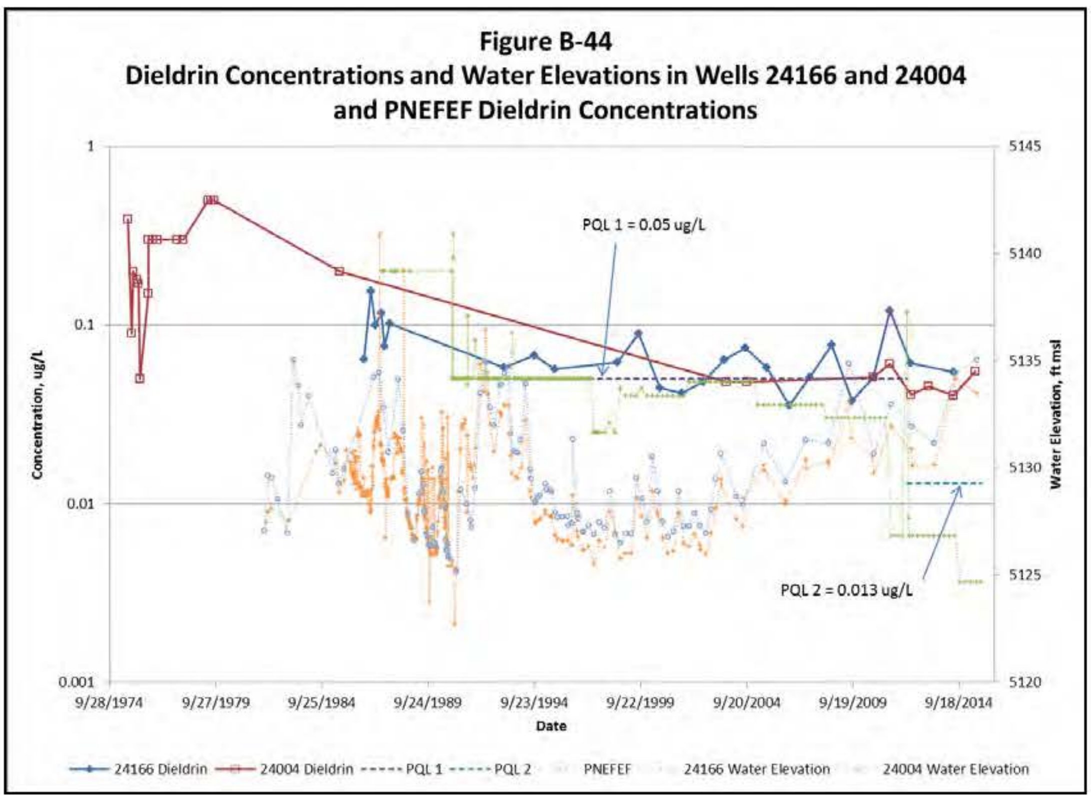


Figure B-45
Chloride Concentrations and Water Elevations in Wells 24166 and 24004 and PNEFEF Chloride Concentrations

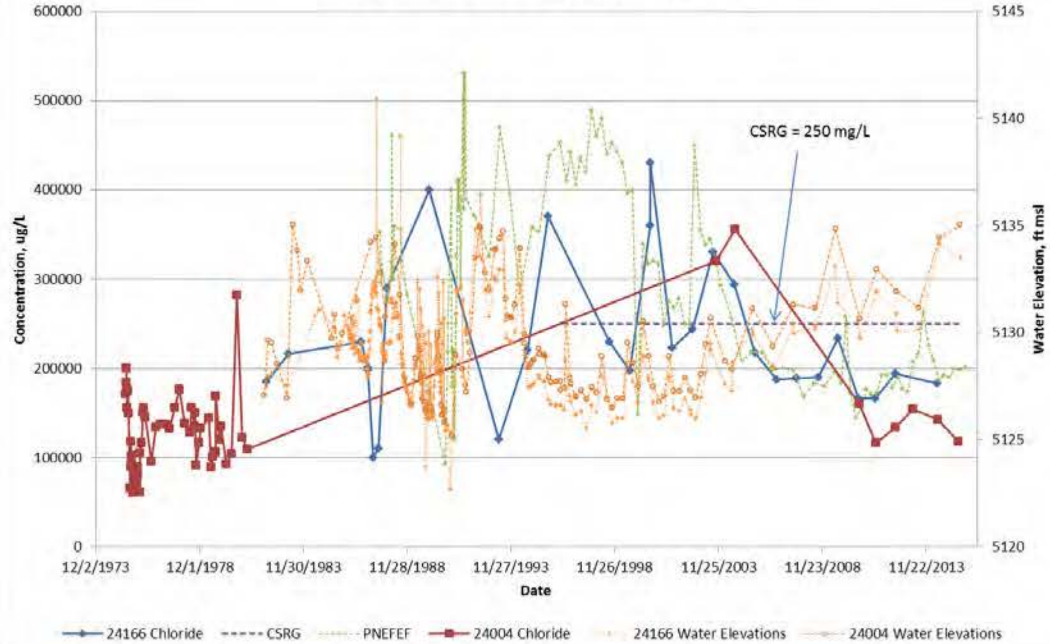
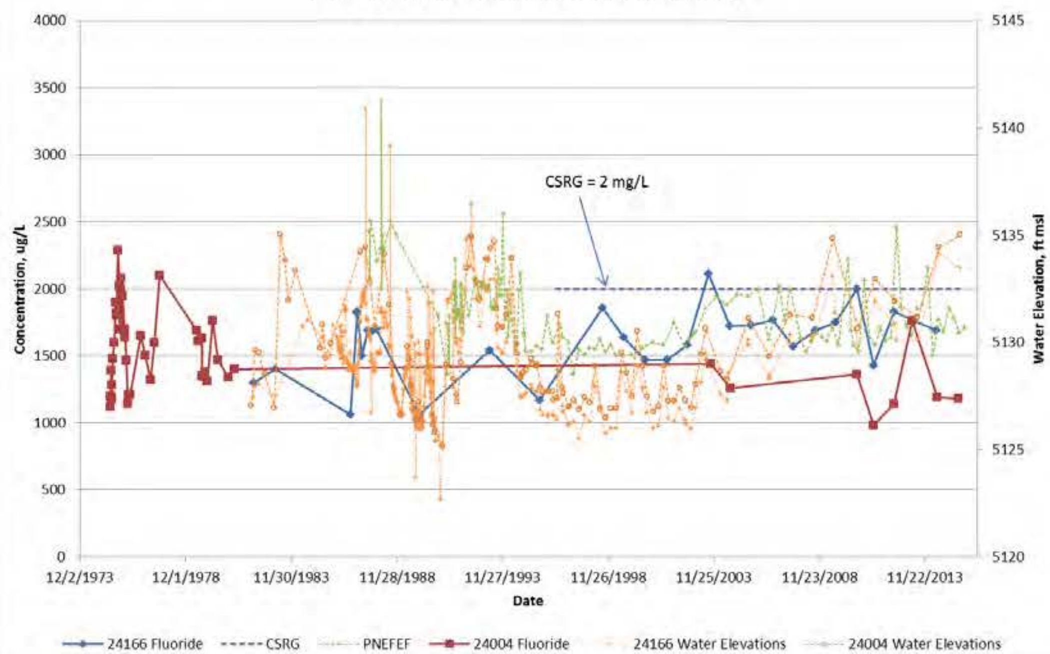


Figure B-46
Fluoride Concentrations and Water Elevations in Wells 24166 and 24004 and PNEFEF Fluoride Concentrations



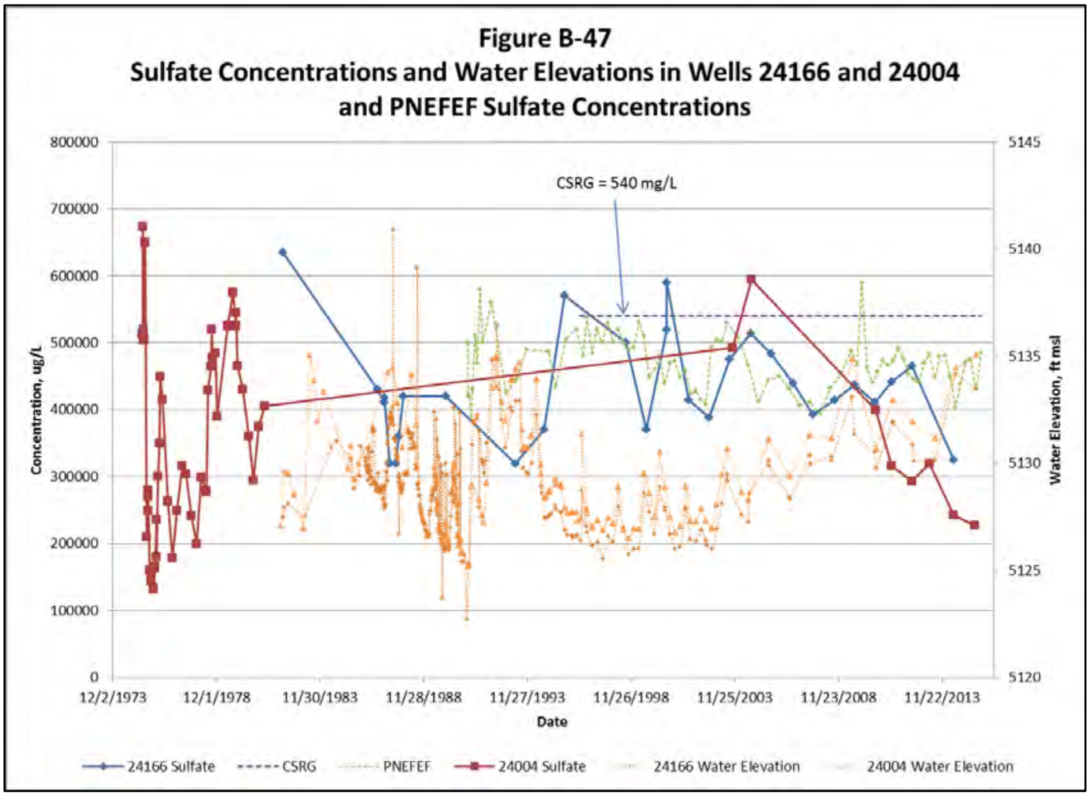


Figure B-47
Sulfate Concentrations and Water Elevations in Wells 24166 and 24004 and PNEFEF Sulfate Concentrations
CSRG = 540 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
800000
700000
600000
500000
400000
300000
200000
100000
0
5145
5140
5135
5130
5125
5120
12/2/1973
12/1/1978
11/30/1983
11/28/1988
11/27/1993
11/26/1998
11/25/2003
11/23/2008
11/22/2013
24166 Sulfate
CSRG
PNEFEF
24004 Sulfate
24166 Water Elevation
24004 Water Elevation

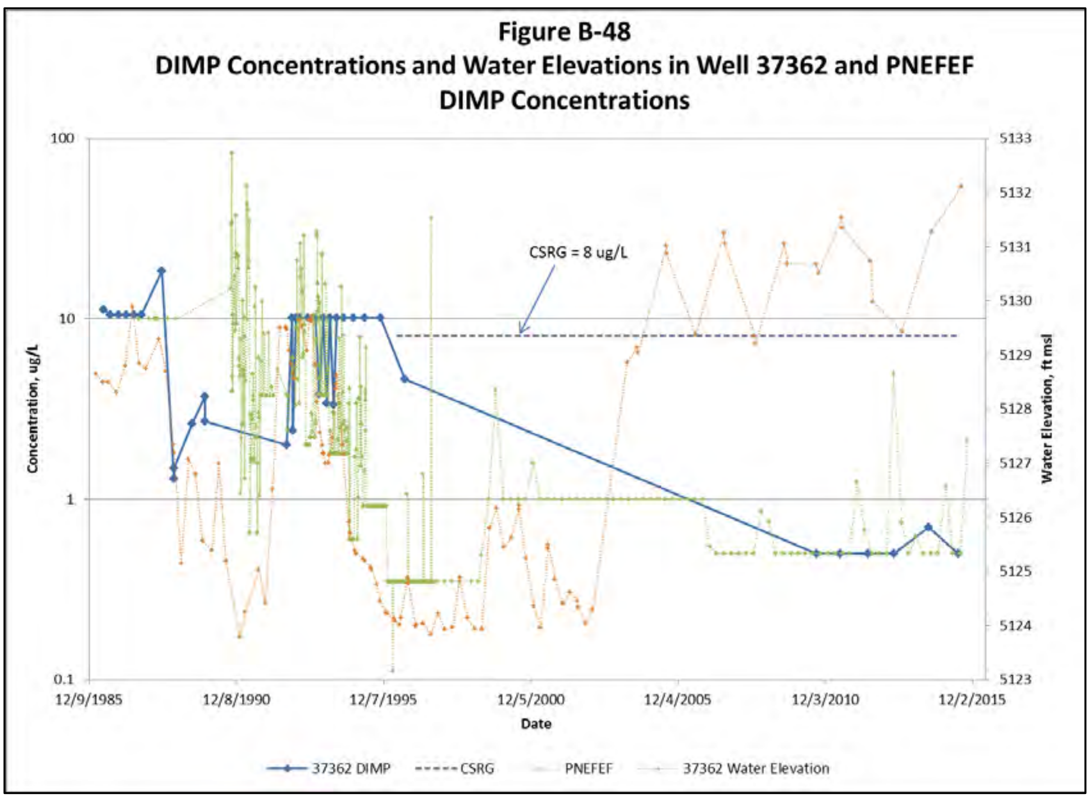


Figure B-48
DIMP Concentrations and Water Elevations in Well 37362 and PNEFEF DIMP Concentrations
CSRG = 8 ug/L
Concentration, ug/L
Water Elevation, ft msl
Date
100
10
1
0.1
5133
5132
5131
5130
5129
5128
5127
5126
5125
5124
5123
12/9/1985
12/8/1990
12/7/1995
12/5/2000
12/4/2005
12/3/2010
12/2/2015
37362 DIMP
CSRG
PNEFEF
37362 Water Elevation

Figure B-49
Dieldrin Concentrations and Water Elevations in Well 37362 and PNEFEF
Dieldrin Concentrations

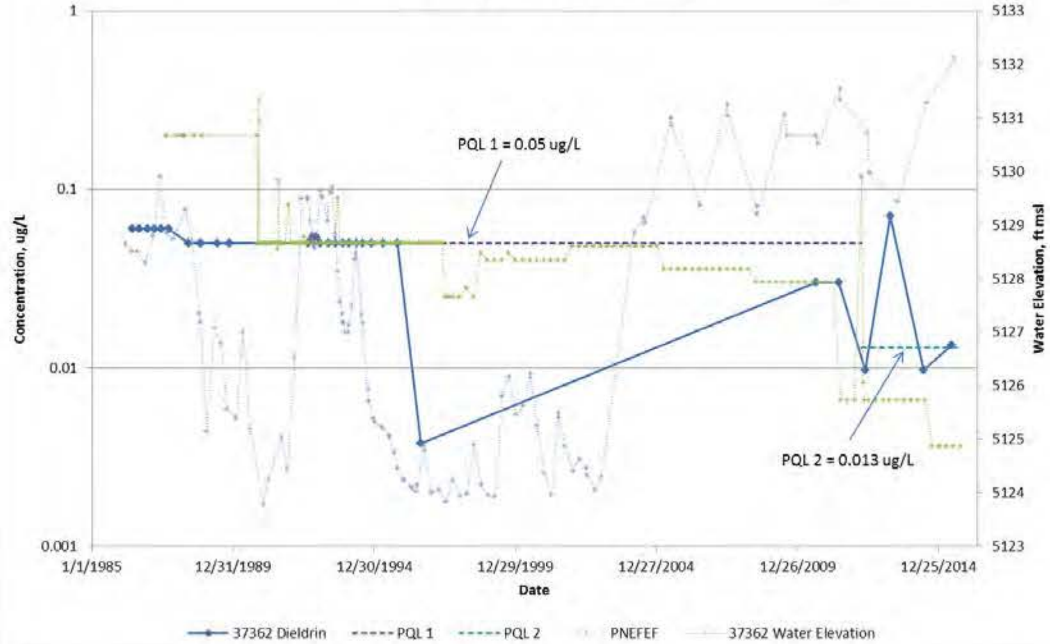
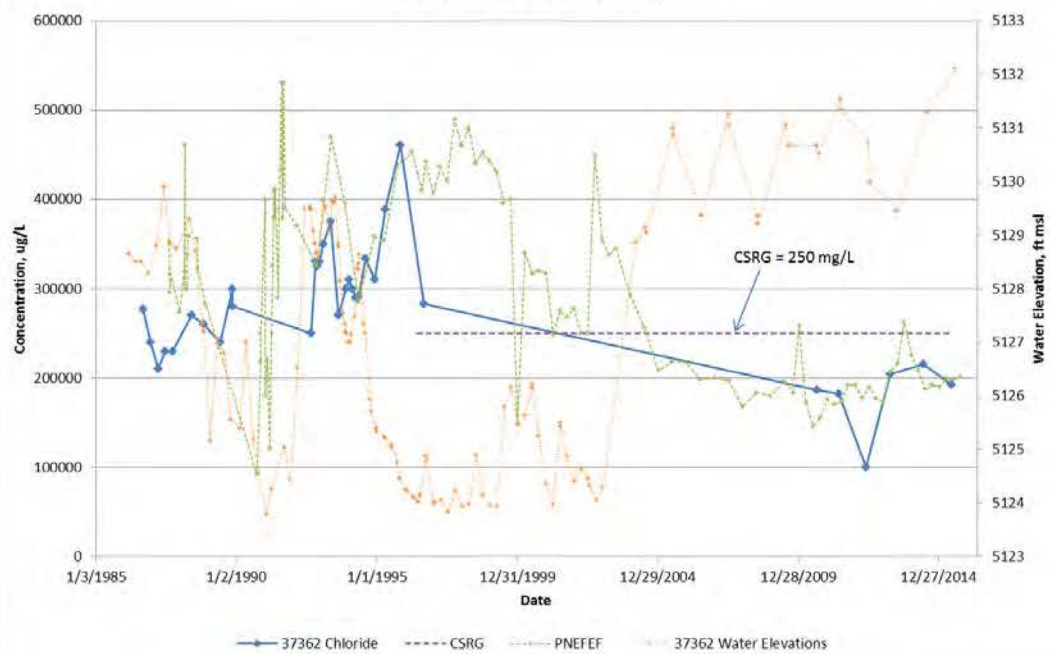


Figure B-50
Chloride Concentrations and Water Elevations in Well 37362 and PNEFEF
Chloride Concentrations



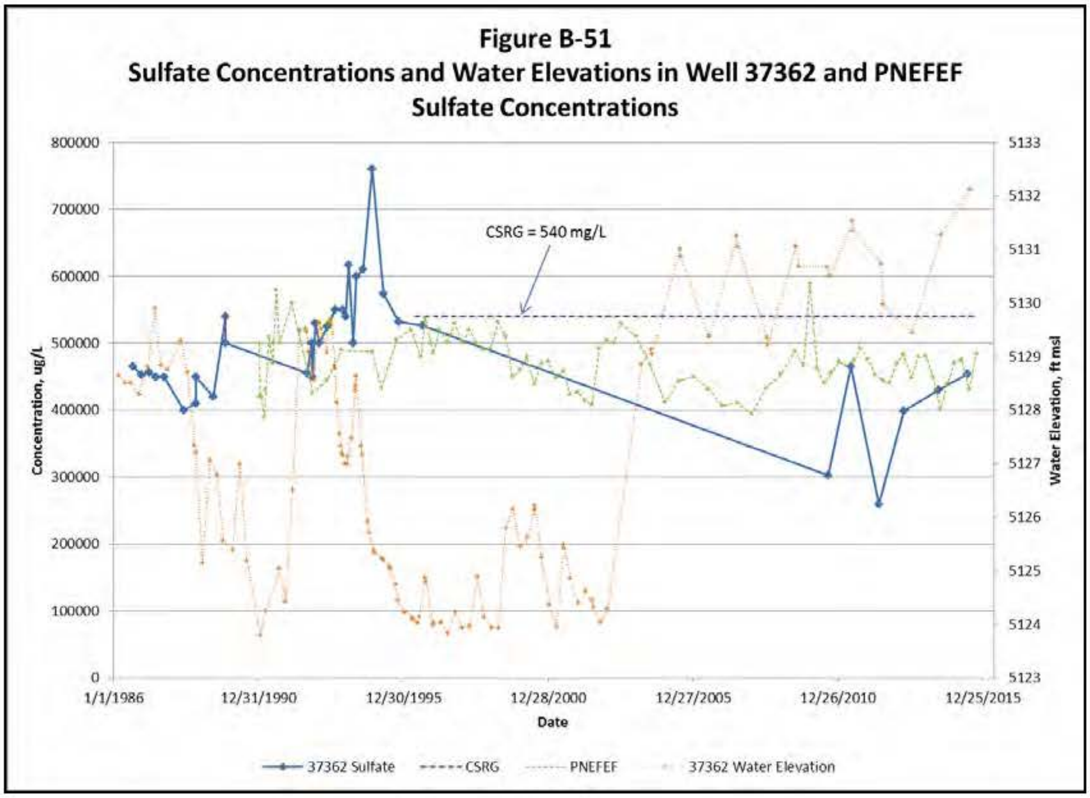


Figure B-51
Sulfate Concentrations and Water Elevations in Well 37362 and PNEFEF
Sulfate Concentrations
CSRG = 540 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
0
100000
200000
300000
400000
500000
600000
700000
800000
5123
5124
5125
5126
5127
5128
5129
5130
5131
5132
5133
1/1/1986
12/31/1990
12/30/1995
12/28/2000
12/27/2005
12/26/2010
12/25/2015
37362 Sulfate
CSRG
PNEFEF
37362 Water Elevation

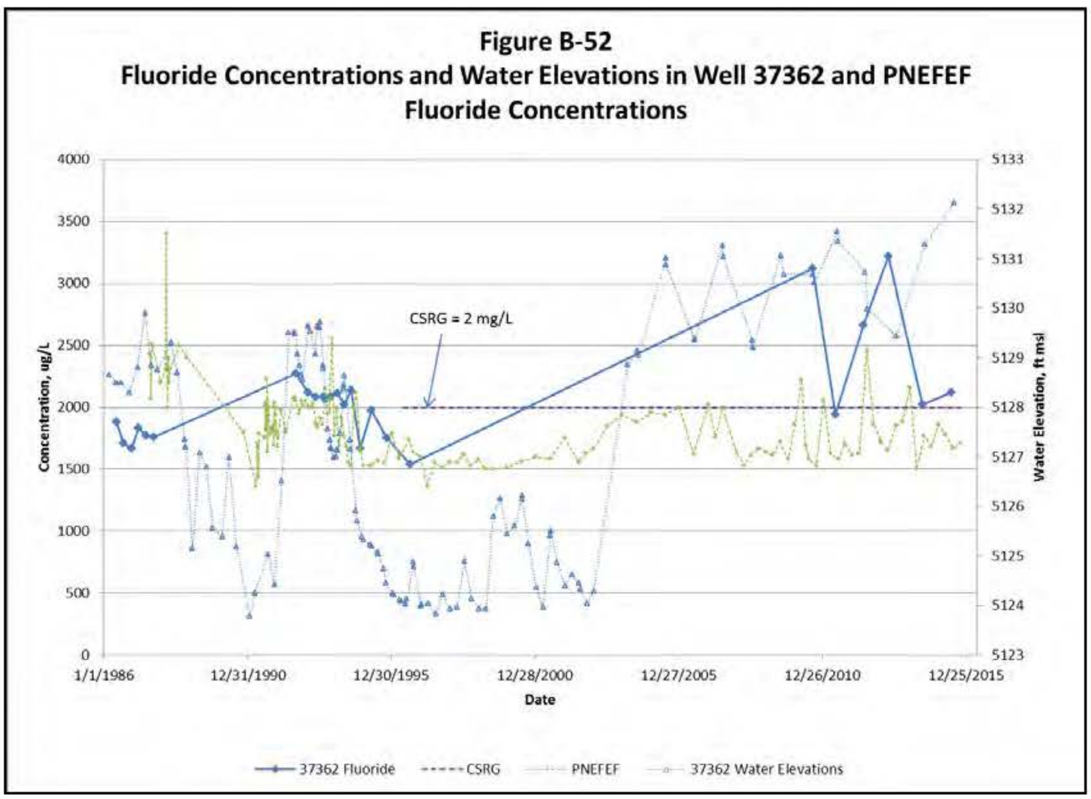


Figure B-52
Fluoride Concentrations and Water Elevations in Well 37362 and PNEFEF
Fluoride Concentrations
CSRG = 2 mg/L
Concentration, ug/L
Water Elevation, ft msl
Date
0
500
1000
1500
2000
2500
3000
3500
4000
5123
5124
5125
5126
5127
5128
5129
5130
5131
5132
5133
1/1/1986
12/31/1990
12/30/1995
12/28/2000
12/27/2005
12/26/2010
12/25/2015
37362 Fluoride
CSRG
PNEFEF
37362 Water Elevations

APPENDIX C

Bedrock Ridge Extraction System Evaluation

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FYSR Appendix C

Bedrock Ridge Extraction System Evaluation

Introduction

According to the 2010 Long-Term Monitoring Plan for Groundwater and Surface Water (LTMP) performance criteria for Bedrock Ridge Extraction System (BRES), the downgradient performance well concentrations should be below the Basin A Neck System (BANS) Containment System Remediation Goals (CSRGs)/Practical Quantitation Limits (PQLs) or have decreasing trends if the concentrations are above the CSRGs/PQLs, for the BRES to be functioning as intended.

BRES plume capture is indicated by quarterly water table maps and water quality data in cross-gradient wells. This is another LTMP criterion for demonstrating that the system is performing as expected. As discussed in the Five-Year Summary Review (FYSR) Section 5.1.1.5, the contaminant concentrations in one of the four downgradient performance wells show opposing trends, with concentrations of three analytes increasing and concentrations of three other analytes decreasing, which makes the performance evaluation of the system equivocal based on this well. The concentrations of three contaminants (1,2-dichloroethane [12DCLE], tetrachloroethylene [TCLEE], and trichloroethylene [TRCLE]) are increasing in downgradient performance well 36566 and the concentrations of three other contaminants (carbon tetrachloride, chloroform, and diisopropylmethyl phosphonate [DIMP]) are decreasing. The other three downgradient performance wells meet the performance criteria.

Due to limited downgradient well data and low permeability of the Denver Formation sandstones, it was uncertain in the LTMP whether the downgradient well water quality data would be representative of system effectiveness. Consequently, five years of water quality data were to be collected in the downgradient performance wells after the LTMP was issued in 2010 before drawing conclusions about the system performance, and determining whether the LTMP criteria should apply. The BRES performance wells are sampled annually. This five-year period ended in FY14, such that conclusions about the performance could be drawn in the FY14 Annual Summary Report (ASR) and 2015 FYSR.

Army and Shell's conclusion in the FY14 ASR and FYSR was that well 36566 is located in an area downgradient of one of the extraction wells where the hydraulic gradient is very flat, and the concentration trends in well 36566 may not be indicative of system performance. Thus, five years of data may not be a sufficient time period for determining system performance based on the concentration trends in this well. At the Regulatory Agencies' request, Army and Shell agreed to perform additional evaluation of the BRES in the FYSR to help resolve questions about the performance of the BRES. This appendix provides the additional evaluation of the BRES.

Background Information

The designers of the BRES chose not to include downgradient water quality monitoring of the BRES to evaluate system performance because the low permeability of the Denver sandstone aquifer might cause the wells to clean up very slowly downgradient of the extraction wells when plume capture is achieved, giving the erroneous impression that the system is not operating effectively. In revising the LTMP in 2010, additional performance criteria were included for the BRES so that all the groundwater systems would have similar performance criteria. Thus, downgradient performance well monitoring and performance criteria were included for the BRES in the 2010 LTMP. The five-year data collection period for the downgradient wells was included as a prerequisite for making performance conclusions to help address the concerns raised by the designers.

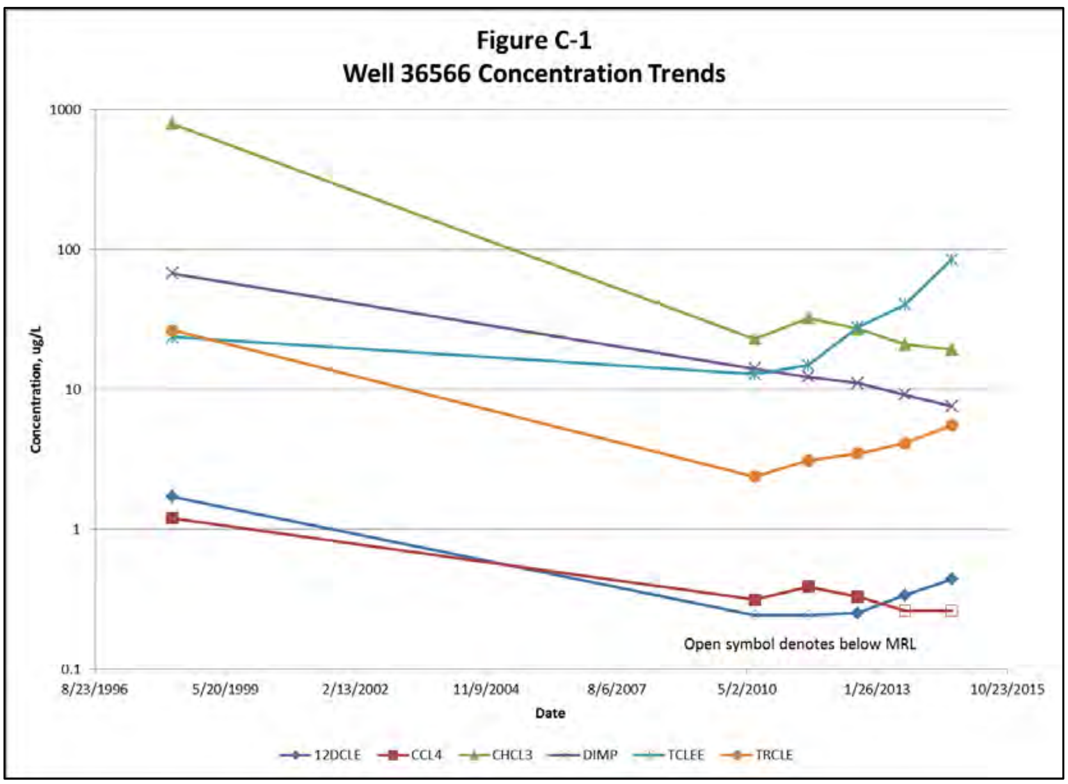
Methodology

Quarterly BRES water table maps are included in the ASRs and are used in the annual performance evaluations. The fourth quarter FY14 water table map from the FY14 ASR is provided in this appendix**.** The configuration of the water table contours is very consistent over time and has indicated that the contaminated flow paths upgradient of the system appear to be captured. Treatment of the BRES groundwater occurs at the BANS treatment plant.

The analytical data were reviewed to determine if a more complete analysis might provide useful information.

Results

Figure C-1 below shows the concentration trends for the six contaminants discussed previously for well 36566. Except for TCLEE, the FY14 concentrations are lower than the 1998 baseline concentrations.



The BRES well location map is FYSR Figure 5.1.1.5-1. The fourth quarter FY14 water table map from the FY14 ASR is provided in this appendix as Figure C-22. The configuration of the contours is similar to previous maps. The hydraulic gradient near downgradient well 36566 is extremely flat for a low-permeability aquifer (FY09 to FY14 average is 0.0018 ft/ft between wells 36569 and 36566), which might cause the increasing concentration trends of a few analytes to misrepresent system performance. In Army and Shell's opinion, this map indicates that plume capture appears to be achieved, and the increasing trends of three analytes in well 36566 are not representative of system performance.

In FY14, seven BANS CSRG analytes, plus DIMP, were present upgradient of the BRES at concentrations above the CSRGs/PQLs/Colorado Basic Standards for Groundwater (CBSGs) and only four of these analytes were above the CSRGs/PQLs/CBSGs in one of the four downgradient performance wells (36566). Of these four analytes, the concentrations of one (chloroform) are decreasing. The concentrations of three of the analytes are increasing, but two (12DCLE at 0.44 ug/L and TRCLE at 5.53 ug/L) are just above the CSRGs of 0.4 and 5 ug/L, respectively.

In FY14, a total of 22 organic contaminants were detected in the BRES upgradient performance wells. Of these 22 analytes, 19 either were not detected, below the CSRGs/PQLs/CBSGs, or the concentrations are decreasing in the downgradient performance wells. There were no CSRG/PQL/CBSG exceedances in three of the four downgradient performance wells. Again, only three analytes (12DCLE, TCLEE, and TRCLE) were above the CSRGs and not decreasing in only one of the four downgradient wells. It is uncertain whether the increasing trends for these three analytes are meaningful for system performance when the majority of a large group of contaminants show the system is effectively reducing the downgradient concentrations and the water table maps shows no indication of bypass.

Conclusions and Recommendations

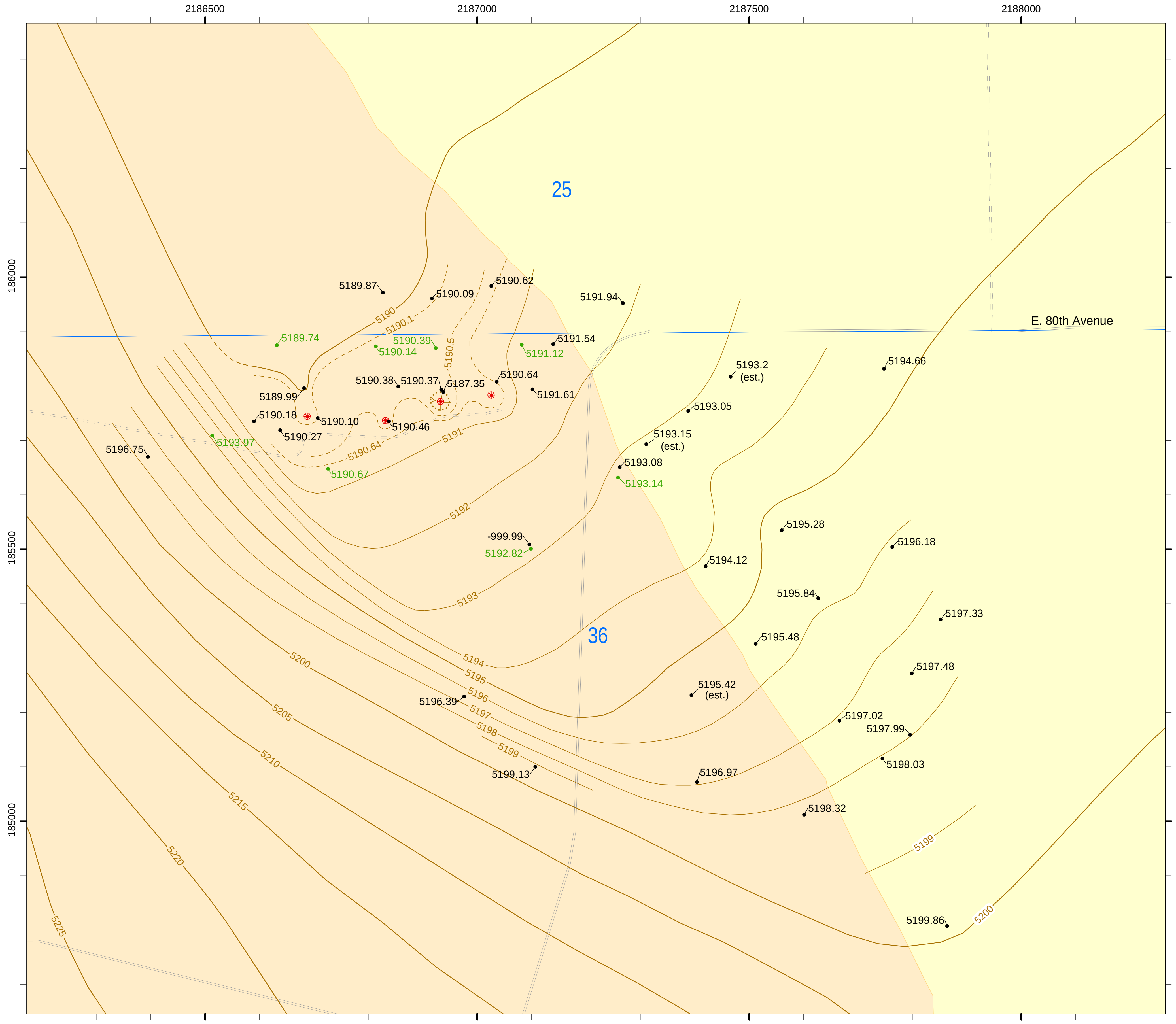
Based on the available data, it is premature to conclude that the BRES is not functioning as intended. The majority of the water level and water quality data indicate that the BRES is intercepting the plumes and effectively reducing the downgradient concentrations. For the three analytes that are present above the CSRGs and the concentrations are increasing, it is not possible to determine whether the increasing trends are due to bypass of the system or represent contamination that was present downgradient of the extraction wells when the system commenced operation and is slower to clean up than the other analytes.

Currently, the downgradient performance wells are sampled annually. Collecting additional water quality data may help resolve the performance question. Increased sampling frequency is listed as an option in LTMP Table 4.7-1 when the downgradient concentrations are increasing. Therefore, Army and Shell propose sampling wells 36569 and 36566 quarterly for one year to assess the contaminant concentration trends. Well 36569 is not currently in the downgradient performance well network and has not been sampled previously, but is included to provide additional data in the area immediately downgradient of extraction well 36302 and upgradient of well 36566. In addition, extraction well 36302 will be sampled semiannually to provide data for comparison to the concentration trends in the downgradient wells. If this proposal is acceptable to the Regulatory Agencies, an Operations and Maintenance Change Notice (OCN) will be issued to temporarily amend the LTMP. The one-year sampling period will commence after the OCN is approved.

The supplemental data will be evaluated in conjunction with the quarterly water level and annual water quality data collected according to the BRES monitoring schedule during the one-year period. A draft interpretation report will be issued within 90 days of the last quarter's water quality data being finalized. The report will evaluate system performance and determine whether the one-year supplemental monitoring period is sufficient or should be extended for one or both wells. The report will also identify any additional follow-up actions, if necessary. The analytical data review/QA and a summary of the results will be provided in the corresponding ASR.

FIGURE

FY14 4th Quarter Groundwater Elevation Contours of the Unconfined Aquifer Bedrock Ridge System



Legend

- Saturated Alluvium
- Unsaturated Alluvium (Developed using summer 2014 data)
- Section Lines
- Ditches
- Paved Roads
- Unimproved Roads
- Water elevation contour - 1 foot interval. Hachures indicate depression. Water elevations collected July 2014.
- Approximate water elevation contour
- Supplemental water elevation contour
- Approximate supplemental water elevation contour

Measured Wells Used for Contouring with Water Elevations (-999.99 indicates dry well - see remarks in water elevation listings included on CD)

- 5109.86 Monitoring Wells
- 5109.86 Performance Water Quality Wells

Wells Not Measured or Not Used for Contouring

- Depression in water table due to extraction well. May not match actual areal extent of depression.

N

0 100 200 Feet

NAD27-NGVD29 Datum, US Survey Feet, Colorado North Zone

Sources: U.S. Army, RMA GIS, PMC, OMC, Shell/URS Corp.

Figure C-22

Army/Shell GIS

8/26/2015 RMITS

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