APPENDIX A

GROUNDWATER TRAVEL TIMES, AND AQUIFER TEST AND PROPERTY DATA

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A.1 INTRODUCTION

Section 3.1.2.1 in the Long-Term Monitoring Plan (LTMP) text discusses groundwater travel times for various contaminant migration pathways at Rocky Mountain Arsenal (RMA). Section A.2 in this appendix is included to provide more information on the input values and assumptions used to derive those estimates.

Extraction system area-of-influence groundwater travel times are calculated in Section A.3 to evaluate proposed shut-off monitoring frequencies when the extraction systems are turned off. The shut-off monitoring frequencies are quarterly during the first year and last year, and annual during the intervening years for the containment systems, and quarterly during the first year and semiannual during the second year for mass removal systems. Retardation of the contaminants representing the range of mobility of the contaminants present at each system is included in the analysis.

Aquifer test results and aquifer property data have been compiled from RMA documents and reports as a reference for hydrogeologic evaluations and are presented in Section A.4. These data are used to estimate groundwater velocities and travel times in the LTMP and include hydraulic conductivity, effective porosity, and aquifer sediment organic carbon.

References are listed in Section A.5.

A.2 GROUNDWATER TRAVEL TIMES FOR CONTAMINANT MIGRATION PATHWAYS

Groundwater velocities and travel times are estimated for contaminant migration pathways using hydraulic conductivity data compiled in Table A-19, which is attached at the end of Appendix A, and are compared to estimates in the Water Remedial Investigation (RI) (Ebasco 1989). Where available, hydraulic conductivity data from aquifer pumping or injection tests are preferred to slug or falling head tests because they are more representative of conditions in larger areas of the aquifer. The test types are indicated in Table A-19. Hydraulic gradients are from the 2006 regional water table map unless indicated otherwise. Effective porosity data are either measured or assumed values as discussed in Section A.3.

A.2.1 South Plants Pathways

Groundwater pathways in the former South Plants have historically radiated from the centrally located water table mound in this area. The primary pathways associated with contaminant migration include the north pathway from South Plants toward Basin A and a second pathway trending southwest toward Lake Ladora.

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Extraction system area-of-influence groundwater travel times are calculated in Section A.3 to evaluate proposed shut-off monitoring frequencies when the extraction systems are turned off. The shut-off monitoring frequencies are quarterly during the first year and last year, and annual during the intervening years for the containment systems, and quarterly during the first year and semiannual during the second year for mass removal systems. Retardation of the contaminants representing the range of mobility of the contaminants present at each system is included in the analysis.

Aquifer test results and aquifer property data have been compiled from RMA documents and reports as a reference for hydrogeologic evaluations and are presented in Section A.4. These data are used to estimate groundwater velocities and travel times in the LTMP and include hydraulic conductivity, effective porosity, and aquifer sediment organic carbon.

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A.2 GROUNDWATER TRAVEL TIMES FOR CONTAMINANT MIGRATION PATHWAYS

Groundwater velocities and travel times are estimated for contaminant migration pathways using hydraulic conductivity data compiled in Table A-19, which is attached at the end of Appendix A, and are compared to estimates in the Water Remedial Investigation (RI) (Ebasco 1989). Where available, hydraulic conductivity data from aquifer pumping or injection tests are preferred to slug or falling head tests because they are more representative of conditions in larger areas of the aquifer. The test types are indicated in Table A-19. Hydraulic gradients are from the 2006 regional water table map unless indicated otherwise. Effective porosity data are either measured or assumed values as discussed in Section A.3.

A.2.1 South Plants Pathways

Groundwater pathways in the former South Plants have historically radiated from the centrally located water table mound in this area. The primary pathways associated with contaminant migration include the north pathway from South Plants toward Basin A and a second pathway trending southwest toward Lake Ladora.

A.2.1.1 South Plants North

Groundwater in the north pathway flows primarily through saturated alluvium with lesser flow through the unconfined bedrock. The average linear velocity for alluvial flow is estimated to range from 0.3 to 9 feet per day (ft/day) (Ebasco 1989). Using the faster flow velocity, the travel time in the alluvial flow path from the center of the groundwater mound to the center of Basin A is approximately 1 year. This estimate using 1989 assumptions appears to be unrealistic under current conditions. The alluvium is unsaturated in South Plants and the hydraulic gradient is extremely flat (Segment 1 below). Within South Plants, the travel time in Segment 1 is estimated to be greater than 100 years, but the 2006 gradient probably is not representative due to transient conditions. From the north end of South Plants, where the alluvium is saturated, to the middle of Basin A, the travel time is estimated to be approximately 28 years (Segment 2). The water elevation in the middle of Basin A is estimated because it is based on contours derived from wells located at the edges of the basin. This calculation may be refined when monitoring commences in the Basin A wells, which were installed in 2008, and are inside the Basin A footprint.

Table A-1. South Plants North Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
Segment 1	
01515 (DEN)	1.73
01602 (DEN)	3.6
	Average = 2.7
Segment 2	
36058 (A/D)	11.4
36070 (ALL)	19.8
36300 (A/D)	4.25
	Average = 11.8

Segment 1

SV= Ki/n where:
Average K = 2.7 ft/day
2006 Hydraulic gradient, i = 0.0001 ft/ft
Porosity, n = 0.05 (assumed)
Seepage Velocity, SV = 0.005 ft/day
Distance, D = 600 ft (well 01078 to 01525)
Travel time, T = D/SV ≥100 years

Segment 2

SV= Ki/n where:
Average K = 11.8 ft/day
2006 Hydraulic gradient, i = 0.0055 ft/ft (estimate)
Porosity, n = 0.25 (assumed)
Seepage Velocity, SV = 0.26 ft/day
Distance, D = 2,700 ft (well 01525 to middle of Basin A)
Travel time, T = D/SV = 28 years

A.2.1.2 South Plants Southwest

Groundwater in the southwest pathway flows through both alluvium and bedrock. Average linear velocity in alluvium ranged from 0.017 to 2.1 ft/day (Ebasco 1989). The shortest travel time in the alluvial flow path from the center of the groundwater mound to Lake Ladora is estimated to be 2.8 years. Significantly less flow occurs in the unconfined bedrock. The

alluvium is unsaturated in most of this pathway; thus, the estimated alluvial travel time likely is not representative.

An estimate of the groundwater travel time between the South Tank Farm (STF) Groundwater Mass Removal (GWMR) System was made in the GWMR Design Analysis Report (Washington Group 2005). The average groundwater flow velocity was estimated to range from 95 to 162 ft/year (0.26 to 0.44 ft/day). Over a distance of 1,200 feet (ft) downgradient of the STF plume, the travel time was estimated to range from 12.6 to 7.4 years using hydraulic gradients in 2004 and 2005. Using the 2006 gradient and the information below, the travel time is estimated as 8.7 years.

Table A-2. South Plants Southwest Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
02029 (DEN)	1.0
02505 (DEN)	3.4
02598 (DEN)	1.26
	Average = 1.9

SV= Ki/n where:
Average K = 1.9 ft/day
2006 Hydraulic gradient, i = 0.01 ft/ft
Porosity, n = 0.05 (assumed)
Seepage Velocity, SV = 0.38 ft/day
Distance, D = 1,200 ft (well 02522 to 02505)
Travel time, T = D/SV = 8.7 years

A.2.2 Basin A to Basin A Neck System (BANS) Pathway

Groundwater in Section 36 flows through both the alluvium and bedrock. Average linear velocity in alluvium ranged from 0.04 to 11.7 ft/day in the Water RI. Corresponding travel times from the center of Basin A to the downgradient end of Basin D ranged from 1.5 to 44.5 years.

More recent data provided below indicate that the travel time from the south end of Basin A to the BANS is approximately 20 years. The water elevation at the south end of Basin A is estimated because it is based on contours derived from wells located at the edges of the basin. In the future, as remediation is completed and the Integrated Cover System is installed, local recharge feeding the Basin A aquifer will be significantly reduced, resulting in further flattening of the hydraulic gradient in the Basin A aquifer and further reducing the groundwater velocity and contaminant migration rates and increasing the travel times.

Table A-3. Basin A to BANS Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
26503 (ALL)	52.2
35509 (A/D)	27.8
36123 (A/D)	13.2
36300 (A/D)	4.25
36301 (ALL)	2.84
36599 (ALL)	11.9
	Average = 18.7

SV= Ki/n where:
Average K = 18.7 ft/day
2006 Hydraulic gradient, i = 0.009 ft/ft
Porosity, n = 0.25 (assumed)
Seepage Velocity, SV = 0.67 ft/day
Distance, D = 5,000 ft (from south end of Basin A to BANS)
Travel time, T = D/SV = 20 years

A.2.3 BANS to Northwest Boundary Containment System (NWBCS) Pathway

A continuation of the Basin A Neck pathway extends from beneath Basin D to the northwest boundary. Flow in this area is primarily through alluvial deposits. Saturated thickness typically is 10 ft or less; however, a north-trending channel with a saturated thickness of 20 to 30 ft is located in the western part of Section 27. Hydraulic conductivity estimates from aquifer tests near the NWBCS indicate much higher values than in the Basin A Neck channel as indicated in Table A-3 below. The average hydraulic conductivity in the Basin A Neck channel from two pumping tests at the BANS is estimated to be 40 ft/day. No representative aquifer tests are available in the Basin A Neck channel downgradient of the BANS. Similar hydraulic gradients in the Basin A Neck channel suggest that the hydraulic conductivity is similar to that estimated at the BANS. Travel times from the downgradient end of Basin D to the NWBCS were estimated in the Water RI to range from 0.2 to 41 years. Using the more recent data below to narrow the range in estimated travel times, the groundwater velocity in the Basin A Neck channel is estimated to be approximately 2 ft/day, and 4.9 ft/day in Section 27, upgradient of the NWBCS. Thus, the groundwater travel time from the BANS to the NWBCS is estimated to be approximately 11 years.

Table A-4. BANS to NWBCS Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
A-Neck	
26503 (ALL)	52.2
35509 (A/D)	27.8
	Average = 40
NWB	
22068 (ALL)	587
27067 (ALL)	1134
	Average = 861

A Neck channel
SV= Ki/n where:
Average K = 40 ft/day
2006 Hydraulic gradient, i = 0.013 ft/ft
Porosity, n = 0.25 (assumed)
Seepage Velocity, SV = 2.1 ft/day
Distance, D = 7,200 ft (35505 to 27079)
Travel time, T = D/SV = 9.4 years

Northwest Boundary (NWB) pathway
SV= Ki/n where:
Average K = 861 ft/day
2006 Hydraulic gradient, i = 0.002 ft/ft
Porosity, n = 0.35 (measured)
Seepage Velocity, SV = 4.9 ft/day
Distance, D = 2,500 ft (27079 to 22502)
Travel time, T = D/SV = 1.4 year

Total Travel Time = 10.8 years

A.2.4 Other NWBCS Pathways

Other contaminant migration pathways from sources upgradient of the NWBCS include the South Plants West plume (Original System) and South Plants Southwest plume (Southwest Extension [SWE]), and travel time calculations are provided below.

A.2.4.1 South Plants to NWBCS Original System (from Section 3 well 03005)

The travel time for the South Plants West plume from Section 3 to the NWBCS is estimated to be approximately 3.5 years. The flow path is divided into two segments with different hydraulic conductivities and gradients.

Table A-5. South Plants to NWBCS Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
Segment 1	
03505 (ALL)	130.4
03506 (A/D)	258
03510 (A/D)	723
	Average = 370.5
Segment 2	
22020 (ALL)	835
27067 (ALL)	1134
	Average = 985

Segment 1
SV= Ki/n where:
Average K = 370.5 ft/day
2006 Hydraulic gradient, i = 0.02 ft/ft
Porosity, n = 0.30
Seepage Velocity, SV = 24.7 ft/day
Distance, D = 2,000 ft (03005+2000 ft)
Travel time, T = D/SV = 0.2 years

Segment 2
SV= Ki/n where:
Average K = 985 ft/day
2006 Hydraulic gradient, i = 0.0036 ft/ft
Porosity, n = 0.35
Seepage Velocity, SV = 10.1 ft/day
Distance, D = 12,000 ft (+2000 ft to 22008)
Travel time, T = D/SV = 3.3 years

Total Travel Time = 3.5 years

A.2.4.2 Lake Mary to NWBCS SWE

The travel time for the South Plants Southwest plume downgradient of Lake Mary in Section 3 to the NWBCS is estimated to be approximately 2.4 years. The flow path is divided into two segments with different hydraulic conductivities and gradients.

Table A-6. Lake Mary to NWBCS SWE Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
Segment 1	
03505 (ALL)	130.4
03506 (A/D)	258
03510 (A/D)	723
	Average = 370.5
Segment 2	
27507 (A/D)	1134
27508 (A/D)	1672
27512 (A/D)	935
	Average = 1,247

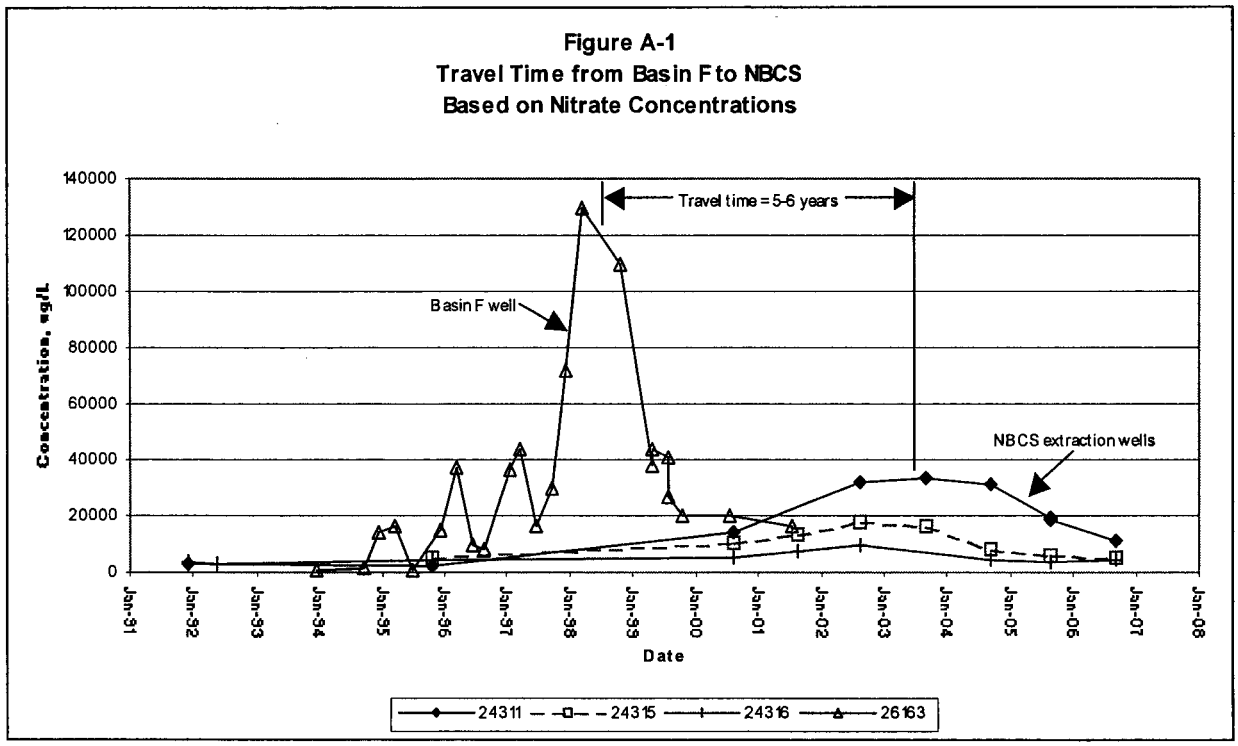
Segment 1
SV= Ki/n where:
Average K = 370.5 ft/day
2006 Hydraulic gradient, i = 0.017 ft/ft
Porosity, n = 0.30
Seepage Velocity, SV = 21 ft/day
Distance, D = 2,500 ft (03016 to 03015)
Travel time, T = D/SV = 0.3 years

Segment 2
SV= Ki/n where:
Average K = 1247 ft/day
2006 Hydraulic gradient, i = 0.0037 ft/ft
Porosity, n = 0.35
Seepage Velocity, SV = 13.2 ft/day
Distance, D = 10,350 ft (03015 to 27510)
Travel time, T = D/SV = 2.1 years

Total Travel Time = 2.4 years

A.2.5 Basin F Pathway

Contaminant migration from Basin C and Basin F occurs in alluvial material and weathered bedrock. The Basin F pathway extends north and northeast to the North Boundary Containment System (NBCS). Estimated average linear velocity ranged from 0.17 to 15.6 ft/day in the Water RI. Travel time from the northeast corner of Basin F to the NBCS ranged from 1.1 to 99 years. Based on more recent data and a short-term increase in nitrate concentrations that could be tracked in wells from the northeast corner of Basin F (well 26163) to the NBCS (extraction wells 24311, 24315, and 24316), the travel time from Basin F to the NBCS is estimated to be 5 to 6 years (Figure A-1). Nitrate is a conservative compound and migrates at a similar rate as the groundwater. The NBCS extraction wells are sampled annually, so it is not possible to narrow the estimate based on these wells. The NBCS influent is sampled more frequently and the peak in concentrations in the influent occurred in the second quarter of Fiscal Year 2003 (FY03). Thus, the travel time is estimated to be approximately 5 years based on these data.



Based on a seepage velocity calculation using the assumptions below, the travel time from Basin F to the NBCS is estimated to be about 6 years. These two estimates are very similar and the estimate based on nitrate concentrations may be more accurate because it is similar to a tracer test and is a more direct estimate with fewer assumptions.

Table A-7. Basin F Pathway Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
23049 (ALL)	964
23096 (ALL)	992
23237 (A/D)	244
24013 (ALL)	170
24025 (ALL)	224
24043 (ALL)	207
	Average = 467

SV= Ki/n where:
Average K = 467 ft/day
2006 Hydraulic gradient, i = 0.0019 ft/ft
Porosity, n = 0.25 (assumed)
Seepage Velocity, SV = 3.5 ft/day
Distance, D = 7,800 ft (well 26163 to 24316)
Travel time, T = D/SV = 6.1 years

A.2.6 North Plants Pathway

The travel time from North Plants to the NBCS is estimated to be approximately 6 years based on the assumptions below.

Table A-8. North Plants Pathway Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
24013 (ALL)	170.1
24025 (ALL)	224
24043 (ALL)	207
24092 (ALL)	177
25062 (A/D)	196
	Average = 195

SV= Ki/n where:
Average K = 195 ft/day
2006 Hydraulic gradient, i = 0.0059 ft/ft
Porosity, n = 0.30 (assumed)
Seepage Velocity, SV = 3.8 ft/day
Distance, D = 8,300 ft (well 25059 to 24130)
Travel time, T = D/SV = 6 years

A.2.7 Western Tier Pathway

Contaminant migration from the Railyard and Motor Pool occurs in coarse-grained alluvial sand and gravel. Average linear velocity along the Railyard and Motor Pool pathway was estimated to range from 3.0 to 60 ft/day in the Water RI. If the Railyard Containment System (RYCS) is shut down, the groundwater travel time from the Motor Pool/Railyard area to the former Irondale Containment System (ICS) was estimated between 0.44 and 8.6 years (Ebasco 1989). Using hydraulic conductivity data from more recent aquifer tests in wells located in or near the groundwater flow path (i.e., wells 03505, 03506, 03510, 04507, 33302, 33304, and 33305) (Table A-10), a July 2007 hydraulic gradient of 0.0037 ft/ft, and an effective porosity of 0.3, the travel time was calculated. The distance between the Railyard extraction system and the RMA boundary is approximately 7,800 ft. The travel time is estimated to be 2.5 years (Estimate 1).

The aquifer test for well 33302 was re-analyzed (WCC 1991) and the estimated hydraulic conductivity was reduced from 1,786 ft/day to 806 ft/day. Averaging the re-analyzed hydraulic conductivity for well 33302, the average groundwater velocity is estimated to be 6.8 ft/day, and the average groundwater travel time is 3.1 years (Estimate 2). Thus, the average groundwater travel time from the Railyard extraction system to the RMA boundary is estimated to range from 2.5 to 3.1 years.

Table A-9. Western Tier Pathway Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
Estimate 1	
03505 (ALL)	130.4
03506 (A/D)	258
03510 (A/D)	723
04507 (A/D)	194
33302 (A/D)	1786
33304 (A/D)	1145
33305 A/D)	587
	Average = 689
Estimate 2	
03505 (ALL)	130.4
03506 (A/D)	258
03510 (A/D)	723
04507 (A/D)	194
33302 (A/D)	806 (re-analyzed)
33304 (A/D)	1145
33305 (A/D)	587
	Average = 549

Estimate 1
SV= Ki/n where:
Average K = 689 ft/day
2007 Hydraulic gradient, i = 0.0037 ft/ft
Porosity, n = 0.30 (calculated)
Seepage Velocity, SV = 8.5 ft/day
Distance, D = 7,800 ft (RYCS to 33060)
Travel time, T = D/SV = 2.5 years

Estimate 2
SV= Ki/n where:
Average K = 549 ft/day
2007 Hydraulic gradient, i = 0.0037 ft/ft
Porosity, n = 0.30 (calculated)
Seepage Velocity, SV = 6.8 ft/day
Distance, D = 7,800 ft (RYCS to 33060)
Travel time, T = D/SV = 3.1 years

A.2.8 Off-Post First Creek and Northern Pathways

Contaminant migration in the Northern pathways occurs in fine- to coarse-grained sands that comprise most of the saturated alluvium, overlain by finer grained materials (silts or silty or clayey sands). Contaminant migration in the First Creek pathway occurs in coarser grained sands interfingered with lenses or layers of finer grained silts, silty sands, or clayey sands. The average linear velocity in the Northern pathway is estimated to be 3.3 ft/day with a travel time from the NBCS to the Northern pathway portion of Off-Site Groundwater Intercept and Treatment System (OGITS) of 5.2 years. Average linear velocity in the First Creek pathway is estimated to be 3 ft/day with a travel time from the NBCS to the First Creek portion of OGITS of 2.9 years.

A.2.8.1 Aquifer Tests

The focus of aquifer testing is to estimate aquifer characteristics to be used during the design of treatment systems, including transmissivity, hydraulic conductivity, and storage coefficient, and

to estimate well efficiency. These tests can be used to assist in the development of monitoring programs for treatment systems. The test methods used typically include (in order) a step-drawdown test, recovery, a 24-hour constant-rate pumping test, and recovery monitoring. The information obtained through the pumping and recovery stages of the test is analyzed by one of three standard methods to compute transmissivity and average hydraulic conductivity of the aquifer.

The First Creek and Northern pathway systems underwent aquifer testing in 1990 (HLA 1990), yielding the following estimates of hydraulic conductivity, hydraulic gradient, and aquifer cross-section area:

Parameter	First Creek Pathway	Northern Pathway
Hydraulic Conductivity (centimeters per second [cm/sec])	4.6×10^{-2}	6.2×10^{-2}
Hydraulic Gradient	0.005	0.005
Aquifer Cross-Section Area (square feet [ft^2])	39,000	43,600

The hydraulic conductivity values estimated from the test data fall within the range reported for unconsolidated silty sand to clean sand aquifers. Total groundwater flows through the First Creek and Northern pathways have been estimated at 130 and 200 gallons per minutes (gpm), respectively. As mentioned previously, aquifer test results are compiled in Appendix A.

A.2.9 Off-Post First Creek and Northern Pathway Systems to the South Platte River

Since contaminant plumes were present downgradient of the OGITS before it was installed in 1993, groundwater travel times from the FCS and NPS to the South Platte River are estimated. Except near OGITS, the hydraulic conductivity test data are sparse, and there are no test wells downgradient of the FCS and NPS within the respective flow paths (Figure A-1). Furthermore, there is a wide range in the available hydraulic conductivities used in the calculations (from 20 to 1300 feet/day). Consequently, it is uncertain whether the average hydraulic conductivities used in the estimates are representative for the flow paths. Therefore, two estimates are developed for each flow path to provide a range for the travel time estimates.

Development of gravel pits for surface water storage near the South Platte River has changed the hydraulic gradients and hydrology near the river. Slurry walls were installed around some of the gravel pits and some have systems to pump the groundwater into the gravel pit. The flow paths downgradient of the FCS and NPS either intersect or pass near these gravel pits. Consequently, the groundwater in these flow paths may no longer discharge into the river. Thus, a 1994 hydraulic gradient is used in the calculations, which pre-dates the gravel pit development.

For the FCS, the groundwater travel time for the flow path downgradient from the central portion of the FCS (well 37343) was estimated below. Two travel-time estimates are calculated to provide a range due to the uncertainty discussed above. Estimate 1 uses the average hydraulic conductivity for 4 aquifer tests; 2 wells in the FCS, and 2 private wells farther off-post. Estimate

2 uses the average hydraulic conductivity for the 2 FCS wells. The groundwater travel time from the FCS to the river is estimated to range from 2.6 to 10.7 years.

Table A-10. FCS Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
Estimate 1	
1213B (ALL)	1,040
490C (ALL)	1,300
37802 (A/D)	150
37422 (ALL)	173
	Average = 666
Estimate 2	
37802 (A/D)	150
37422 (ALL)	173
Estimate 2	Average = 162

Estimate 1
SV= Ki/n where:
Average K = 666 ft/day
1994 Hydraulic gradient, i = 0.0068 ft/ft
Porosity, n = 0.30 (assumed)
Seepage Velocity, SV = 15.1 ft/day
Distance, D = 14,500 ft (well 37343 to River)
Travel time, T = D/SV = 2.6 years

Estimate 2
SV= Ki/n where:
Average K = 162 ft/day
1994 Hydraulic gradient, i = 0.0068 ft/ft
Porosity, n = 0.30 (assumed)
Seepage Velocity, SV = 3.7 ft/day
Distance, D = 14,500 ft (well 37343 to River)
Travel time, T = D/SV = 10.7 years

For the NPS, the groundwater travel time for the flow path downgradient from the northeast end of the NPS (well 37009) was estimated below. Two travel-time estimates also are calculated for the NPS to provide a range. Estimate 1 uses the average hydraulic conductivity for 6 aquifer tests; 4 wells in the NPS, and 2 private wells farther off-post. Estimate 2 uses the average hydraulic conductivity for 2 of the NPS wells. The groundwater travel time from the NPS to the river is estimated to range from 3.3 to 9.2 years.

Table A-11 Northern Pathway Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
Estimate 1	
1213B (ALL)	1,040
490C (ALL)	1,300
37806 (A/D)	140
37807 (A/D)	190
37901 (A/D)	20
37902 (A/D)	46
	Average = 456
Estimate 2	

Well (aquifer)	Hydraulic Conductivity, K, ft/day
37806 (A/D)	140
37807 (A/D)	190
	Average = 165

Estimate 1
SV= Ki/n where:
Average K = 456 ft/day
1994 Hydraulic gradient, i = 0.0067 ft/ft
Porosity, n = 0.30 (assumed)
Seepage Velocity, SV = 10.2 ft/day
Distance, D = 12,400 ft (well 37009 to River)
Travel time, T = D/SV = 3.3 years

Estimate 2
SV= Ki/n where:
Average K = 165 ft/day
1994 Hydraulic gradient, i = 0.0067 ft/ft
Porosity, n = 0.30 (assumed)
Seepage Velocity, SV = 3.7 ft/day
Distance, D = 12,400 ft (well 37009 to River)
Travel time, T = D/SV = 9.2 years

A. 3 EXTRACTION SYSTEM AREA OF INFLUENCE TRAVEL TIMES

A.3.1 Shut-Off Monitoring Frequency

The Record of Decision (ROD) shut-off monitoring frequency of quarterly for 5 years is to be changed to quarterly during the first and last year, with annual monitoring during the intervening years. This section provides information on travel times within the areas of influence of the extraction system that would be most affected by potential rebound of contaminant concentrations after shut-off.

U.S. Environmental Protection Agency (EPA) (1996) described six stages of pump-and-treat remediation and the initial year of shut-off monitoring corresponds to EPA's Stage 4, Post-Termination Monitoring, when monitoring of water levels and contaminant concentrations is conducted to determine when the groundwater flow system is re-established. Potential causes of concentrations to increase after a pump-and-treat system is turned off include rebound and potential migration from continuing sources. Rebound is addressed below and migration from continuing sources will be addressed during the consultative approach for each system when the shut-off and post-shut-off monitoring programs are developed.

Rebound

The term "rebound" pertains to the potential increase in concentrations at an extraction system immediately after extraction wells are turned off. It is caused by the return to the natural flow conditions and gradient. Contaminant concentrations in higher permeability preferential flow pathways that contained a greater proportion of flow during pumping may have declined faster than in less permeable zones. After pumping ends, residual contamination at higher concentrations migrating in the less permeable zones may then be detected and cause the concentrations in monitoring wells to increase. Desorption of contaminants from the aquifer sediments may also cause concentrations to increase when pumping ends and the groundwater flow returns to the natural gradient. Thus, rebound primarily occurs in the area of influence of the system where steeper hydraulic gradients have been induced.

To address potential rebound, the following approach will be used:

- More frequent shut-off monitoring will be conducted during the initial, first year of the shutdown period to monitor rebound.
- Monitoring frequency will be quarterly as this is an accepted standard frequency that addresses seasonal variations in groundwater levels and conditions, and allows adequate time for normal analytical analysis, quality assurance (QA), and evaluation of the data.
- Groundwater velocity and travel time within the area of influence of each system or discrete portions of a system will be estimated to determine when the groundwater flow system is re-established and confirm that quarterly water quality monitoring for 1 year is adequate during the initial stage when rebound is most likely.
- The ranges of retardation factors for the contaminants present are also calculated to compare contaminant migration rates to the proposed sampling frequencies.

A.3.2 NWBCS

The NWBCS is divided into three components: the Original System, Northeast Extension (NEE), and SWE. Due to the thin saturated zone and low flows at the NEE, it is not included in this section.

A.3.2.1 NWBCS Original System

An upgradient area of influence of 150 ft is conservatively determined from the FY06 Operational Assessment Report (OAR) water table map. Upgradient of this distance, the hydraulic gradient returns to the regional gradient. This appears to be a representative distance for the hydraulic barrier portion of the system.

A pre-NWBCS gradient of 0.002 ft/ft from July–August 1981 (PMRMA 1987) is used to calculate the groundwater velocity after shut-off. The groundwater travel time is estimated as approximately 31 days. Chloroform and dieldrin are the most prevalent of the Containment System Remediation Goal (CSRG) analytes at the NWBCS. Chloroform and dieldrin retardation factors are estimated to be 1.02 and 3.5, respectively. These estimates are consistent with retardation factor ranges for the NWBCS in the Off-Post Endangerment Assessment/Feasibility Study (EA/FS) (HLA 1992b), which were 1 to 4 for chloroform 2 to 5 for dieldrin. The chloroform and dieldrin travel times within the area of influence are estimated to be 32 and 109 days, respectively. Thus, quarterly shut-off monitoring for the first year is appropriate.

Table A-12. NWBCS Hydraulic Conductivity and Fractional Organic Carbon

Well (aquifer)	Hydraulic Conductivity, K, ft/day
22068 (ALL)	587
27067 (ALL)	1134
	Average = 861
Well (aquifer)	Fractional Organic Carbon, foc
27088 (ALL)	0.000052
27090 (ALL)	0.00014
27091 (A/D)	0.00001
	Average = 0.000067

SV= Ki/n where:
Average K = 861 ft/day
Hydraulic gradient, i = 0.002 ft/ft
Porosity, n = 0.35 (measured, WCC 1991))
Seepage Velocity, SV = 4.9 ft/day
Distance, D = 150 ft (FY06 OAR water table)
Travel time, T = D/SV = 31 days

Chloroform Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, Db = 1.8 g/cm^3 (Ebasco 1992)
Koc = 44.7 L/mg (Ebasco 1992)
Average foc = 0.000067
Porosity, n = 0.35
$R_f = 1.02$

Chloroform Travel Time
Groundwater travel time, T_{GW} = 31 days
Chloroform retardation, R = 1.02
Chloroform travel time,
$T_{CHCL3} = T_{GW} \times R_f = 32$ days

Dieldrin Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, D_b = 1.8 g/cm^3 (Ebasco 1992)
Koc = 7244 L/mg (Ebasco 1992)
Average foc = 0.000067
Porosity, n = 0.35
$R_f = 3.5$

Dieldrin Travel Time
Groundwater travel time, T_{GW} = 31 days
Dieldrin retardation, $R_f = 3.5$
Dieldrin travel time,
$T_{DLDRN} = T_{GW} \times R_f = 109$ days

A.3.2.2 NWBCS SWE

An upgradient area of influence of 150 ft for the SWE was determined from the FY06 OAR water table map. The hydraulic gradient is steeper within this area. Upgradient of this distance, the hydraulic gradient returns to the regional gradient. A pre-SWE gradient of 0.0025 ft/ft from February 1990 (MKES 1990c) is used to calculate the groundwater velocity after shut-off. The groundwater travel time during shut-off is estimated as from 11 to 13 days. Dieldrin is the only Contaminant of Concern (COC) at the SWE. With dieldrin retardation estimated to be 3.5 to 3.9, the dieldrin travel time is estimated to be between 39 and 51 days within the area of influence. Thus, quarterly shut-off monitoring for the first year is more than adequate to monitor rebound.

Table A-13. NWBCS SWE Hydraulic Conductivity and Fractional Organic Carbon

Well (aquifer)	Hydraulic Conductivity, K, ft/day
27508 (A/D)	1672
Well	Fractional Organic Carbon, foc
27088 (ALL)	0.000052
27090 (ALL)	0.00014
27091 (A/D)	0.00001
	Average = 0.000067

Groundwater Travel Time
SV= Ki/n where:
K = 1672 ft/day
Hydraulic gradient, i = 0.0025 ft/ft (27044 to27505 in 1990)
Porosity, n = 0.35 (measured, WCC 1991)
Seepage Velocity, SV = 11.9 ft/day
Distance, D = 150 ft (FY06 OAR water table)
Travel time, T = D/SV = 13 days

Dieldrin Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8$ g/cm^3 (Ebasco 1992)
Koc = 7244 (Ebasco 1992)
Average foc = 0.000067
Porosity, n = 0.35
$R_f = 3.5$

Dieldrin Travel Time
Groundwater travel time, $T_{GW} = 13$ days
Dieldrin retardation, $R_f = 3.5$
Dieldrin travel time, $T_{DLDRN} = T_{GW} \times R_f = 46$ days

A.3.3 NBCS

For the purposes of this analysis, the pre-existing hydraulic gradient before the slurry wall was constructed will be used in the calculation. The highest concentrations for the largest number of contaminants occur at extraction wells 24311, 24315, and 24316. Therefore, the estimated travel time in the area of influence is for the area near these three wells. DIMP and dieldrin are selected to represent the range of contaminant mobility for NBCS CSRG analytes. Other compounds may have lower partition coefficients than diisopropylmethyl phosphonate (DIMP) (e.g., 1,2-dichloroethane, chloroform, and n-nitrosodimethylamine [NDMA]), but they are less widespread and would migrate at a rate similar to the groundwater. No aquifer sediment organic carbon data are available in this area. Consequently, an average of 14 alluvial wells, excluding Basin A (Section 36), was used for the calculation of retardation. Using the information below,

the retardation factors are 1.4 for DIMP and 2 to 5 for dieldrin. The associated average travel times within a 150-ft area of influence are 59 to 70 days for DIMP and 84 to 250 days for dieldrin. Quarterly shut-off monitoring for the first year therefore, is adequate.

Table A-14. NBCS Hydraulic Conductivity and Fractional Organic Carbon

Well (aquifer)	Hydraulic Conductivity, K, ft/day
24013 (ALL)	170
24025 (ALL)	224
24043 (ALL)	207
	Average = 200
Well	Fractional Organic Carbon, foc
14 wells	Average = 0.00048

SV= Ki/n where:
Average K = 200 ft/day
1979 Hydraulic gradient, i = 0.0045 ft/ft
Porosity, n = 0.25 to 0.30 (assumed)
Seepage Velocity, SV = 3.6 to 3 ft/day
Distance, D = 150 ft (FY06 OAR)
Travel time, T = D/SV = 42 to 50 days

DIMP Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8$ g/cm^3 (Ebasco 1992)
Koc = 123 (Ebasco 1992)
Average foc = 0.00048
Porosity, n = 0.25 to 0.30
R_f = 1.4 to 1.35 (R_f = 1 to 2 in Off-Post EA/FS, HLA 1992b)

Dieldrin Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8$ g/cm^3 (Ebasco 1992)
Koc = 7244 L/mg (Ebasco 1992)
Average foc = 0.00048
Porosity, n = 0.25 to 0.3
R_f = 25 to 22 (R_f = 2 to 5 in Off-Post EA/FS, HLA 1992b)

The retardation estimate for dieldrin appears too high based on observed migration. Since the total organic carbon concentration in Table A-12 is an average of wells in other areas, using foc of 0.00048 probably is not appropriate. The Off-Post EA/FS (HLA 1992b) used a range of retardation factors for dieldrin of 2 to 5. Since the aquifer sediments at NBCS and off post are similar, the Off-Post EA/FS retardation factors were used in the dieldrin calculations. The range of DIMP retardation factors of 1 to 2 in the Offpost EA/FS agree with the calculated values of 1.4 to 1.35. Thus, retardation of 1.4 for DIMP is used in the estimate of DIMP travel time.

DIMP Travel Time
Groundwater travel time, T_{GW} = 42 to 50 days
DIMP retardation, R = 1.4
DIMP travel time, $T_{DIMP} = T_{GW} \times R_f$ = 59 to 70 days

Dieldrin Travel Time
Groundwater travel time, T_{GW} = 42 to 50 days
Dieldrin retardation, R_f = 2 to 5 (Off-Post EA/FS, HLA 1992b)
Dieldrin travel time, $T_{DLDRN} = T_{GW} \times R_f$ = 84 to 250 days

A.3.4 RYCS

An upgradient area of influence of 180 feet for the RYCS was determined from the FY06 OAR water table map. The hydraulic gradient is steeper within this area and the hydraulic gradient upgradient of this distance returns to the regional gradient. A pre-RYCS gradient of 0.0078 ft/ft from July 1989 (MKE 1989) is used to calculate the groundwater velocity after shut-off. The groundwater travel time during shut-off is estimated as 19 to 22 days. Dibromochloropropane (DBCP) is the only COC at the RYCS. No aquifer sediment organic carbon data are available in this area. Consequently, an average of 14 alluvial wells, excluding Basin A (Section 36), was used for the calculation of retardation. Based on the coarse-grained sands and gravels and low fines contents in the Railyard, the organic carbon content likely is lower than the average used in the calculation. With DBCP retardation estimated to be 1.7 to 1.6, the DBCP travel time is estimated to be between 32 and 35 days within the area of influence. Thus, quarterly shut-off monitoring for the first year is more than adequate to monitor rebound.

Table A-15. RYCS Hydraulic Conductivity and Fractional Organic Carbon

Well (aquifer)	Hydraulic Conductivity, K, ft/day
03505 (ALL)	130.4
03506 (A/D)	258
03510 (A/D)	723
	Average = 370
Alluvial wells outside of Section 36	Fractional Organic Carbon, foc
14 wells	Average = 0.00048

SV= Ki/n where:
Average K = 370 ft/day
1989 Hydraulic gradient, i = 0.0078 ft/ft
Porosity, n = 0.30 to 0.35
Seepage Velocity, SV = 9.6 to 8.2 ft/day
Distance, D = 180 ft (2006 OAR)
Travel time, T = D/SV = 19 to 22 days

DBCP Retardation
$R = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8$ g/cm^3 (Ebasco 1992)
Koc = 257 (Ebasco 1992)
Average foc = 0.00048
Porosity, n = 0.30 to 0.35
$R_f = 1.7$ to 1.6

DBCP Travel Time
Groundwater travel time, $T_{GW} = 19$ to 22 days
DBCP retardation, $R_f = 1.7$ to 1.6
DBCP travel time, $T_{DBCP} = T_{GW} \times R_f = 32$ to 35 days

A.3.5 BANS

The area of influence upgradient of the extraction system is estimated to be 50 feet in FY06. For the purposes of this analysis, the pre-existing hydraulic gradient (i.e., in 1989) before the slurry wall was constructed will be assumed.

NDMA and dieldrin are selected to represent the range of contaminant mobility for BANS CSRG analytes. The alluvial aquifer foc was measured in two wells in Basin A (36163 and 36165). Well 36163 is located near the Shell Trenches and well 36165 is located in Basin A. The foc data for well 36165 will be used for this calculation; however, the average foc for both wells is similar (i.e., 0.0039 and 0.004). The retardation for NDMA is estimated to be 1 and dieldrin is estimated to be between 3 and 6. The corresponding travel times are estimated to be 21 days for NDMA and between 63 and 126 days for dieldrin.

Table A-16. BANS Hydraulic Conductivity and Fractional Organic Carbon

Well (aquifer)	Hydraulic Conductivity, K, ft/day
26503 (ALL)	52.2
35509 (A/D)	27.8
	Average = 40
Well (aquifer)	Fractional Organic Carbon, foc
36165 (ALL)	0.0054
	0.0059
	0.0007
	Average = 0.004

SV= Ki/n where:
Average K = 40 ft/day
1989 Hydraulic gradient, i = 0.015 ft/ft (35079 to 26154)
Porosity, n = 0.25 (assumed)
Seepage Velocity, SV = 2.4 ft/day
Distance, D = 50 ft (FY06 OAR)
Travel time, T = D/SV = 21 days

NDMA Retardation
$R = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8\ g/cm^3$ (Ebasco 1992)
Koc = 0.1 (Ebasco 1992)
Average foc = 0.004
Porosity, n = 0.25 (assumed)
$R_f = 1.0$

Dieldrin Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8\ g/cm^3$ (Ebasco 1992)
Koc = 7244 (Ebasco 1992)
Average foc = 0.004
Porosity, n = 0.25 (assumed)
$R_f = 210$

This retardation estimate for dieldrin appears too high based on observed migration. Dieldrin was first produced in 1951 and would have been disposed in Basin A. It was detected at the NWBCS via the Basin A Neck channel at least by 1985, which is 34 years. Using a 1979 hydraulic gradient, the groundwater travel time from the location of BANS to the NWB is estimated as approximately 11 years, which yields a retardation factor of approximately 3 (plume travel time/groundwater travel time). The gradients were probably higher when Basin A was used for waste disposal. If the gradient in Basin A Neck was twice that in 1979, the travel time to the NWB would have been about 6 years, which gives a retardation factor of 6. Hence dieldrin retardation of 3 to 6 will be assumed in the calculation below. The presence of dissolved organic carbon in the groundwater and colloidal transport have been hypothesized to facilitate the transport sorptive compounds such as dieldrin, and may explain the reduced retardation relative to the calculated value above.

NDMA Travel Time
Groundwater travel time, $T_{GW} = 21$ days
NDMA retardation, $R_f = 1$
NDMA travel time, $T_{NDMA} = T_{GW} \times R_f = 21$ days

Dieldrin Travel Time
Groundwater travel time, $T_{GW} = 21$ days
Dieldrin retardation, $R_f = 3$ to 6
Dieldrin travel time, $T_{DLDRN} = T_{GW} \times R_f = 63$ to 126 days

A.3.6 Bedrock Ridge

The area of influence upgradient of the extraction system is estimated to be 50 ft in FY06. The groundwater travel time is estimated to be 128 days. No foc data are available for Denver Formation sandstones at RMA and it would be speculative to assume retardation factors for the Bedrock Ridge Extraction System (BRES).

Table A-17. BRES Hydraulic Conductivity

Well (aquifer)	Hydraulic Conductivity, K, ft/day
36556 (DEN)	19.8
36560 (DEN)	11.1
	Average = 15.5

SV= Ki/n where:
Average K = 15.5 ft/day
1998 Hydraulic gradient, i = 0.005 ft/ft
Porosity, n = 0.20 (assumed)
Seepage Velocity, SV = 0.39 ft/day
Distance, D = 50 ft (FY06 OAR)
Travel time, T = D/SV = 128 days

A.3.7 OGITS

The areas of influence are estimated to be 200 ft for well 37802 in the First Creek System (FCS) and 100 feet in the Northern Pathway System (NPS) from the FY06 OAR water table map. A pre-OGITS regional gradient of 0.005 ft/ft is used to calculate the groundwater velocity after shut-off. The groundwater travel time in the FCS is estimated as approximately 68 days, and 34 days in the NPS. Contaminants representing the range of mobility of the CSRG analytes are 1,2-dichloroethylene (12DCLE) and DCPD at the FCS, and DIMP and dieldrin at the NPS. The retardation factors range from 1.1 to 5. The retardation factors for DCPD and dieldrin are calculated higher than 5 based on available information, but dieldrin, which is more sorptive than DCPD, was estimated to range from 2 to 5 in the Off-Post EA/FS, thus 5 is assumed to be the maximum value. The estimated contaminant travel times within the areas of influence range from 37 and 340 days.

Table A-18. OGITS Hydraulic Conductivity and Fractional Organic Carbon

System	Hydraulic Conductivity, K, ft/day
FCS	130
NPS	176
Well (aquifer)	Fractional Organic Carbon, foc
FCS	
37343 (ALL)	0.001
NPS	
37344 (ALL)	0.00018

A.3.7.1 First Creek System (FCS)

SV= Ki/n where:
Average K = 130 ft/day
1989 Hydraulic gradient, i = 0.005 ft/ft
Porosity, n = 0.30 (assumed)

Seepage Velocity, SV = 2.2 ft/day
Distance, D = 150 ft (FY06 OAR)
Travel time, T = D/SV = 68 days

1,2-Dichloroethylene Retardation
$R_f = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8\ g/cm^3$ (Ebasco 1992)
Koc = 15.8 (Ebasco 1992)
Average foc = 0.001
Porosity, n = 0.30 (assumed)
$R_f = 1.1$

DCPD Retardation
$R = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8\ g/cm^3$ (Ebasco 1992)
Koc = 977 (Ebasco 1992)
Average foc = 0.001
Porosity, n = 0.30 (assumed)
$R_f = 6.9$ (Dieldrin R = 2 to 5 in Offpost EA/FS)

1,2-Dichloroethylene Travel Time
Groundwater travel time, $T_{GW} = 68$ days
12DCLE retardation, $R_f = 1.1$
12DCLE travel time, $T_{12DCLE} = T_{GW} \times R_f = 75$ days

DCPD Travel Time
Groundwater travel time, $T_{GW} = 68$ days
DCPD retardation, $R_f = 2$ to 5 (assumed for dieldrin)
DCPD travel time, $T_{DCPD} = T_{GW} \times R_f = 136$ to 340 days

A.3.7.2 Northern Pathway System (NPS)

SV= Ki/n where:
Average K = 176 ft/day
1989 Hydraulic gradient, i = 0.005 ft/ft
Porosity, n = 0.30 (assumed)
Seepage Velocity, SV = 2.9 ft/day
Distance, D = 100 ft (FY06 OAR)
Travel time, T = D/SV = 34 days

DIMP Retardation
$R = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8\ g/cm^3$ (Ebasco 1992)
Koc = 123 (Ebasco 1992)
Average foc = 0.00018
Porosity, n = 0.30 (assumed)

$R_f = 1.1$ ($R_f = 1$ to 2 in Off-Post EA/FS HLA 1992b)

Dieldrin Retardation
$R = 1+D_b(Koc)(foc)/n$ where:
Bulk density, $D_b = 1.8$ g/cm^3 (Ebasco 1992)
Koc = 7244 (Ebasco 1992)
Average foc = 0.00018
Porosity, n = 0.30 (assumed)
$R_f = 8.8$ ($R_f = 2$ to 5 in Off-Post EA/FS HLA 1992b)

DIMP Travel Time
Groundwater travel time, $T_{GW} = 34$ days
DIMP retardation, $R_f = 1.1$
DIMP travel time, $T_{DIMP} = T_{GW} \times R_f = 37$ days

Dieldrin Travel Time
Groundwater travel time, $T_{GW} = 34$ days
DLDRN retardation, $R_f = 2$ to 5 (assumed)
DLDRN travel time, $T_{DLDRN} = T_{GW} \times R_f = 68$ to 170 days

A.4 AQUIFER TEST AND AQUIFER PROPERTY DATA

Data included in this section include hydraulic conductivity, effective porosity, and aquifer sediment organic carbon. Approximately 370 aquifer tests have been conducted on post and off post near RMA to determine the hydraulic conductivity of the aquifers. The results of these aquifer tests have been compiled from RMA documents and reports (Table A-19). Although Table A-19 is a comprehensive listing, the results of every aquifer test conducted at or near RMA may not be included. Hydraulic conductivity is one of the parameters used to estimate groundwater velocity and travel time. Other parameters used in the calculation are the hydraulic gradient and effective porosity of the aquifer sediments. The hydraulic gradient is determined from water level monitoring at RMA. Effective porosity of the aquifer sediments may be measured from soil samples or determined during groundwater tracer tests. Effective porosity may also be assumed based on literature values for different lithologies when borehole lithology descriptions are available. The organic carbon content data provided in Table A-20 are used to estimate retardation factors for the groundwater contaminants, which is a determination of the relative migration rate of the contaminants to the groundwater velocity.

Measurements of other parameters used to estimate groundwater velocity and retardation are more limited and are provided in Appendix E of the Remedial Investigation Summary Report (RISR) (Ebasco 1992). RISR Appendix E contains assumed bulk density and effective porosity, literature-derived partition coefficients, and calculated retardation factors for a range of measured organic carbon contents for the RMA COCs in saturated unconfined aquifer sediments and saturated lakebed sediments and soils. The organic carbon content data for aquifer sediments in RISR Appendix E are from wells in Basin A. As indicated in Table A-20, the organic carbon content of the alluvial aquifer is higher in Basin A than in other areas of RMA.

Consequently, the retardation factors in other areas of RMA may be lower than those listed in RISR Appendix E. In order to better estimate the retardation factors in other areas, the organic carbon content data for aquifer sediments have been compiled from RMA documents and reports and are provided in Table A-20.

A.4.1 Hydraulic Conductivity

Table A-19 contains a compilation of hydraulic conductivity data derived from well and packer tests and includes information such as test type, analysis method, test reference, and other pertinent information where possible. It is grouped by flow system (i.e., unconfined monitoring wells and private wells, questionable, and confined). Within flow system groups, the table is ordered by well ID. The test locations are shown on Figure A-2.

A.4.2 Effective Porosity

Effective porosity measurements in the alluvial aquifer are limited to the NWBCS and Irondale areas. In the coarse-grained sand and gravel of the alluvium in the western part of RMA, the effective porosity was estimated to range from 0.31 to 0.35 (WCC 1991). Elsewhere, the porosity likely is lower due to the finer grained nature of the alluvial sands, and may be assumed to range from 0.20 to 0.30 depending on the grain size and grading/sorting of the sands as described in the lithologic logs for wells and boreholes. Effective porosity in the Denver Formation is lower than in the alluvium with porosity of approximately 0.2 in the sandstones and 0.05 to 0.10 in the weathered claystones. In the STF plume area of South Plants, the porosity in the weathered Denver Formation was estimated to range from a total porosity of approximately 0.50 based on laboratory analyses of soil samples, to an effective porosity of 0.001 based on a field tracer test (Foster Wheeler 1996).

A.4.3 Organic Carbon

Table A-20 is a compilation of organic carbon concentration data for saturated zone alluvial and Denver sediment samples and is ordered by well ID. The test well locations are shown on Figure A-3.

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TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
UNCONFINED FLOW SYSTEM								
01008	FH	DEN	U	8.090E-04	2.293E+00	Broughton et al. 1979		CL
01014	FH	DEN	U	3.040E-04	8.617E-01	Broughton et al.1979		CL
01017	FH	A/D	U	7.410E-04	2.100E+00	Broughton et al. 1979		CL
01088	SLUG	DEN	U	2.000E-03	5.669E+00	HLA 1992a		
01089	PUMP	DEN	U	2.800E-03	7.937E+00	HLA 1992a		
01099	SLUG	DEN	U	7.700E-04	2.183E+00	HLA 1992a		
01100	SLUG	DEN	U	1.400E-03	3.969E+00	HLA 1992a		
01101	SLUG	DEN	U	5.600E-05	1.587E-01	HLA 1992a		
01104	PUMP	A/D	U	3.800E-03	1.077E+01	HLA 1992a		
01515	SLUG	DEN	U	6.100E-04	1.729E+00	HLA 1992a		
01516	SLUG	DEN	U	5.200E-04	1.474E+00	HLA 1992a		
01521	SLUG	DEN	U	2.300E-03	6.520E+00	HLA 1992a		
01523	SLUG	DEN	U	1.600E-03	4.535E+00	HLA 1992a		
01530	SLUG	DEN	U	4.000E-03	1.134E+01	HLA 1992a		
01569	SLUG	DEN	U	1.500E-03	4.252E+00	HLA 1992a		
01580	INJ	A/D	U	3.700E-04	1.049E+00	MKES 1990a		
01601	PUMP	A/D	U	6.100E-03	1.729E+01	Knaus 1982		
01602	PUMP	DEN	U	1.270E-03	3.600E+00	Knaus 1982		
01603	PUMP	DEN	U	1.200E-03	3.402E+00	Knaus 1982		
02003	FH	DEN	U	2.150E-04	6.094E-01	Broughton et al. 1979		CL
02029	PUMP	DEN	U	3.493E-04	9.900E-01	Foster Wheeler 1996		
02065	PUMP	DEN	U	5.700E-03	1.616E+01	HLA 1992a		
02068	SLUG	DEN	U	1.300E-03	3.685E+00	HLA 1992a		
02505	INJ	DEN	U	1.200E-03	3.402E+00	MKES 1990a		
02562	SLUG	DEN	U	4.800E-04	1.361E+00	HLA 1992a		
02573	SLUG	DEN	U	1.800E-03	5.102E+00	HLA 1992a		
02582	SLUG	DEN	U	3.800E-04	1.077E+00	HLA 1992a		
02583	SLUG	DEN	U	1.200E-04	3.402E-01	HLA 1992a		
02598	INJ	DEN	U	4.450E-04	1.261E+00	MKES 1990a		
03505	INJ	ALL	U	4.600E-02	1.304E+02	MKES 1990b		
03506	INJ	A/D	U	9.100E-02	2.580E+02	MKES 1990b		
03510	INJ	A/D	U	2.550E-01	7.228E+02	MKES 1990b		
04304	PUMP	ALL	U	1.370E-01	3.883E+02	USACE 1953		
04507	INJ	A/D	U	6.840E-02	1.939E+02	MKES 1990		
19001	FH/RH	DEN	U	1.910E-03	5.414E+00	Ertec 1981		SM
19002	FH/RH	DEN	U	1.740E-04	4.932E-01	Ertec 1981		SM
19004	FH/RH	A/D	U	2.820E-03	7.994E+00	Ertec 1981		SP
19005	FH/RH	DEN	U	6.020E-04	1.706E+00	Ertec 1981		CH & CL

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
19006	FH/RH	DEN	U	1.230E-03	3.487E+00	Ertec 1981		CL
19007	FH/RH	A/D	U	1.620E-04	4.592E-01	Ertec 1981		SM & CH
22020	PUMP	ALL	U	7.986E-01	2.264E+03	May 1982	Jacob	NW-11, SW to SP
22020	PUMP	ALL	U	2.946E-01	8.350E+02	WCC 1991	Neuman	NW-11 Reanalyzed using Neuman method
22068	PUMP	ALL	U	2.071E-01	5.870E+02	WCC 1982/USACE 1986	Boulton	W-5
22301	PUMP	ALL	U	4.727E-02	1.340E+02	WCC 1991	Neuman	Tracer Test
23024	PUMP	A/D	U			Mitchell 1976		
23024	PUMP	A/D	U	4.200E-02	1.191E+02	ESE 1990		Mitchel test reanalyzed
23049	PUMP	ALL	U	4.660E-01	1.321E+03	Vispi 1978	Theis/Jacob/Chow	SP-GP. Use 23237 instead (falling WLs)
23049	PUMP	ALL	U	3.400E-01	9.638E+02	ESE et al. 1990		Vispi test reanalyzed
23067	PUMP	A/D	U	7.920E-02	2.245E+02	Vispi 1978	Theis/Jacob/Chow	SP-GP
23067	PUMP	A/D	U	9.400E-02	2.665E+02	ESE et al. 1990		Vispi test reanalyzed
23096	PUMP	ALL	U	4.240E-01	1.202E+03	Vispi 1978	Theis/Jacob/Chow	SP-GP
23096	PUMP	ALL	U	3.500E-01	9.921E+02	ESE et al. 1990		Vispi test reanalyzed
23142	FH/RH	A/D	U	4.500E-04	1.276E+00	Ertec 1981		CH & CL
23144	FH/RH	A/D	U	5.460E-05	1.548E-01	Ertec 1981		CH
23145	FH/RH	A/D	U	1.330E-03	3.770E+00	Ertec 1981		SP&CH
23146	FH/RH	A/D	U	3.950E-03	1.120E+01	Ertec 1981		SP&CH
23147	FH/RH	A/D	U	1.400E-05	3.969E-02	Ertec 1981		SP
23160	FH/RH	A/D	U	1.570E-04	4.450E-01	Ertec 1981		SM & CH
23167	SLUG	DEN	U	1.330E-05	3.770E-02	May et al. 1980		
23176	PUMP	DEN	U	1.200E-04	3.402E-01	Black and Veatch 1980		
23226	SLUG	DEN	U	2.220E-04	6.293E-01	ESE 1988a		
23227	SLUG	DEN	U	2.000E-06	5.669E-03	ESE 1988a		Silty sand
23237	INJ	A/D	U	8.600E-02	2.438E+02	MKE 1989		
23548	PUMP	DEN	U	6.700E-03	1.899E+01	Chadwick 2005		
24013	PUMP	ALL	U			Mitchell 1976		
24013	PUMP	ALL	U	6.000E-02	1.701E+02	ESE et al. 1990		Mitchel test reanalyzed
24025	PUMP	ALL	U			Mitchell 1976		
24025	PUMP	ALL	U	7.900E-02	2.239E+02	ESE et al. 1990		Mitchel test reanalyzed
24029	PUMP	ALL	U	1.540E-01	4.365E+02	Vispi 1978		SM-SP
24029	PUMP	ALL	U	1.400E-01	3.969E+02	ESE et al. 1990		SM-SP, Vispi test reanalyzed
24030	FH/RH	ALL	U	3.860E-05	1.094E-01	Ertec 1981		SP
24031	FH/RH	ALL	U	3.990E-02	1.131E+02	Ertec 1981		CL
24040	PUMP	ALL	U	1.700E-01	4.819E+02	Vispi 1978		
24043	PUMP	ALL	U	3.800E-02	1.077E+02	Vispi 1978		
24043	PUMP	ALL	U	3.800E-02	1.077E+02	May 1982		
24043	PUMP	ALL	U	7.300E-02	2.069E+02	ESE et al. 1990		Vispi test reanalyzed

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
24048	SLUG	ALL	U	2.484E-01	7.041E+02	ESE 1988a		SP
24049	SLUG	ALL	U	1.113E-01	3.155E+02	ESE 1988a		SP-GP
24080	FH/RH	DEN	U	4.920E-04	1.395E+00	Ertec 1981		SM & CH
24081	FH/RH	A/D	U	3.560E-03	1.009E+01	Ertec 1981		SM & CH
24082	FH/RH	DEN	U	1.620E-02	4.592E+01	Ertec 1981		SM
24083	FH/RH	DEN	U	6.370E-03	1.806E+01	Ertec 1981		SM & CL
24084	SLUG	ALL	U	9.910E-03	2.809E+01	ESE 1988a		SM
24086	FH/RH	DEN	U	1.850E-02	5.244E+01	Ertec 1981		SM. May be well 26015 based on screen interval
24087	FH/RH	DEN	U	8.680E-03	2.460E+01	Ertec 1981		SM
24088	FH/RH	A/D	U	4.820E-02	1.366E+02	Ertec 1981		Range average, SW
24092	SLUG	ALL	U	6.230E-02	1.766E+02	ESE 1988a		SM
24093	FH/RH	A/D	U	7.840E-04	2.222E+00	Ertec 1981		GC
24094	FH/RH	A/D	U	3.530E-02	1.001E+02	Ertec 1981		SM & CH
24096	FH/RH	A/D	U	9.900E-02	2.806E+02	Ertec 1981		SM & CH
24097	FH/RH	A/D	U	3.000E-02	8.504E+01	Ertec 1981		GM & CL
24098	FH/RH	A/D	U	8.240E-04	2.336E+00	Ertec 1981		SM
24099	FH/RH	A/D	U	6.430E-03	1.823E+01	Ertec 1981		SM & CH
24100	FH/RH	A/D	U	4.880E-03	1.383E+01	Ertec 1981		CL
24101	FH/RH	A/D	U	4.880E-04	1.383E+00	Ertec 1981		GP & CH
24102	FH/RH	A/D	U	1.420E-02	4.025E+01	Ertec 1981		SM & CH
24103	FH/RH	A/D	U	7.000E-07	1.984E-03	Ertec 1981		GH & CH
24105	FH/RH	A/D	U	2.220E-02	6.293E+01	Ertec 1981		CL
24106	FH/RH	A/D	U	1.530E-03	4.337E+00	Ertec 1981		SP & CL
24112	FH/RH	DEN	U	4.420E-03	1.253E+01	Ertec 1981		SM & CL
24113	FH/RH	A/D	U	4.000E-03	1.134E+01	Ertec 1981		SM & CL
24114	FH/RH	A/D	U	1.510E-05	4.280E-02	Ertec 1981		SM-SP
24115	SLUG	A/D	U	1.060E-02	3.005E+01	ESE 1988a		SM & CH
24126	SLUG	A/D	U	1.300E-02	3.685E+01	ESE 1988a		
24127	FH/RH	DEN	U	6.730E-04	1.908E+00	Ertec 1981		SM & CH
24129	SLUG	A/D	U	1.670E-02	4.734E+01	ESE 1988a		SM & CH
24130	FH/RH	DEN	U	4.650E-04	1.318E+00	Ertec 1981		CL
24135	SLUG	DEN	U	1.410E-02	3.997E+01	May et al. 1980		Fine to medium grained sand
24136	SLUG	DEN	U	1.710E-05	4.847E-02	May et al. 1980		
24140	SLUG	DEN	U	1.530E-04	4.337E-01	May et al. 1980		
24150	PUMP	A/D	U	5.856E-02	1.660E+02	Black and Veatch 1980		
24150	PUMP	A/D	U	8.300E-02	2.353E+02	ESE et al. 1990		B&V test reanalyzed
24153	PUMP	A/D	U	8.043E-02	2.280E+02	Black and Veatch 1980		
24153	PUMP	A/D	U	8.300E-02	2.353E+02	ESE et al.1990		B&V test reanalyzed
25022	SLUG	DEN	U	4.000E-04	1.134E+00	HLA 1999		sandstone

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
25027	SLUG	DEN	U	1.700E-03	4.819E+00	HLA 1999		sandstone
25028	SLUG	DEN	U	4.900E-06	1.389E-02	HLA 1999		claystone
25062	PUMP	A/D	U	6.900E-02	1.956E+02	HLA 1992a		
25065	SLUG	DEN	U	1.900E-05	5.386E-02	HLA 1999		claystone
25066	SLUG	DEN	U	3.300E-06	9.354E-03	HLA 1999		claystone
25082	SLUG	DEN	U	5.100E-04	1.446E+00	HLA 1999		sandstone
25087	SLUG	DEN	U	3.200E-03	9.071E+00	HLA 1999		sandstone
25089	SLUG	DEN	U	1.700E-03	4.819E+00	HLA 1999		sandstone
26014	FH/RH	ALL	U	3.750E-04	1.063E+00	Ertec 1981		SP-GP
26016	FH/RH	A/D	U	5.990E-03	1.698E+01	Ertec 1981		SP-GP
26017	FH/RH	ALL	U	1.130E-02	3.203E+01	Ertec 1981		SP-GP
26018	FH/RH	ALL	U	7.700E-05	2.183E-01	Ertec 1981		SP-GP
26039	FH/RH	DEN	U	1.790E-03	5.074E+00	Ertec 1981		CH
26063	FH	DEN	U	4.150E-04	1.176E+00	Broughton1979 et al.	Cooper	CH & SP
26066	SLUG	DEN	U	3.497E-04	9.913E-01	Bopp and Kolmer 1979	Cooper	
26070	FH	ALL	U	1.134E-04	3.214E-01	Bopp and Kolmer 1979	Bouwer and Rice	
26071	SLUG	DEN	U	1.153E-03	3.268E+00	Bopp and Kolmer 1979	Cooper	
26073	FH	DEN	U	4.199E-03	1.190E+01	Bopp and Kolmer 1979	Bouwer and Rice	
26081	FH	ALL	U	2.277E-04	6.454E-01	Bopp and Kolmer 1979	Bouwer and Rice	
26083	FH	A/D	U	2.441E-04	6.919E-01	Bopp and Kolmer 1979	Cooper	
26085	FH	ALL	U	9.735E-04	2.760E+00	Bopp and Kolmer 1979	Cooper	
26087	FH	ALL	U	9.735E-04	2.760E+00	Bopp and Kolmer 1979	Cooper	
26088	FH	A/D	U	4.380E-05	1.242E-01	Bopp and Kolmer 1979	Bouwer and Rice	
26089	SLUG	DEN	U	2.280E-03	6.463E+00	Bopp and Kolmer 1979	Cooper	
26090	SLUG	DEN	U	2.132E-03	6.043E+00	Bopp and Kolmer 1979	Cooper	Loosely cemented sand
26092	SLUG	DEN	U	5.509E-04	1.562E+00	Bopp and Kolmer 1979	Cooper	
26093	FH	ALL	U	8.300E-06	2.353E-02	Bopp and Kolmer 1979	Bouwer and Rice	
26094	SLUG	DEN	U	3.866E-04	1.096E+00	Bopp and Kolmer 1979	Cooper	
26123	FH/RH	DEN	U	5.080E-05	1.440E-01	Ertec 1981		CH & CL
26124	FH/RH	DEN	U	3.120E-04	8.844E-01	Ertec 1981		CH
26128	SLUG	DEN	U	1.215E-03	3.444E+00	Bopp and Kolmer 1979	Cooper	
26129	SLUG	DEN	U	1.832E-03	5.193E+00	Bopp and Kolmer 1979	Cooper	
26133	FH/RH	DEN	U	2.040E-05	5.783E-02	Ertec 1981		SM
26140	SLUG	DEN	U	7.100E-03	2.013E+01	WES 1979	Cooper	Medium-coarse grained sand
26166	SLUG	A/D	U	8.150E-03	2.310E+01	HLA 1994		
26168	SLUG	A/D	U	2.300E-04	6.520E-01	HLA 1994		
26169	SLUG	A/D	U	1.450E-02	4.110E+01	HLA 1994		
26171	SLUG	A/D	U	1.450E-02	4.110E+01	HLA 1994		
26501	SLUG	ALL	U	6.710E-03	1.902E+01	MKE 1989		
26503	INJ	ALL	U	1.840E-02	5.216E+01	MKE 1989		

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
27067	PUMP	ALL	U	3.965E-01	1.124E+03	WCC 1982	Boulton	W-4
27067	PUMP	ALL	U	4.036E-01	1.144E+03	USACE 1986	Boulton	W-4
27507	PUMP	A/D	U	4.000E-01	1.134E+03	MKES 1990c		
27508	PUMP	A/D	U	5.900E-01	1.672E+03	MKES 1990d		
27512	PUMP	A/D	U	3.300E-01	9.354E+02	MKES 1990d		
31003	FH	A/D	U	1.120E-03	3.175E+00	Broughton et al. 1979		CL
31522	PUMP	A/D	U	7.260E-02	2.058E+02	Finch and Mathews 1971		
33302	PUMP	A/D	U	6.299E-01	1.786E+03	May 1982	Jacob	W-2
33302	PUMP	A/D	U	2.843E-01	8.060E+02	WCC 1991	Neuman	W-2 Reanalyzed using Neuman method
33304	PUMP	A/D	U	4.040E-01	1.145E+03	USACE 1975		
33305	PUMP	A/D	U	2.070E-01	5.868E+02	USACE 1975		
35016	SLUG	DEN	U	9.850E-04	2.792E+00	Broughton et al. 1979	Cooper	SC
35018	FH	ALL	U	1.600E-04	4.535E-01	Broughton et al. 1979	Cooper	CL & SM
35020	FH	ALL	U	2.080E-04	5.896E-01	Broughton et al. 1979		CL & SM
35023	FH	A/D	U	5.880E-04	1.667E+00	Broughton et al. 1979		CL
35024	SLUG	DEN	U	7.980E-03	2.262E+01	Broughton et al. 1979		SM
35026	FH	ALL	U	7.780E-04	2.205E+00	Broughton et al. 1979		CL
35032	SLUG	DEN	U	7.733E-04	2.192E+00	Bopp and Kolmer 1979	Cooper	
35036	SLUG	DEN	U	3.495E-04	9.907E-01	Bopp and Kolmer 1979	Cooper	
35038	SLUG	DEN	U	2.450E-04	6.945E-01	Bopp and Kolmer 1979	Cooper	
35042	FH	A/D	U	1.190E-03	3.373E+00	Bopp and Kolmer 1979	Cooper	
35049	FH	DEN	U	1.571E-04	4.453E-01	Bopp and Kolmer 1979	Bouwer and Rice	
35506	SLUG	A/D	U	3.000E-05	8.504E-02	MKE 1989		
35509	INJ	A/D	U	9.810E-03	2.781E+01	MKE 1989		
36058	SLUG	A/D	U	4.020E-03	1.140E+01	Broughton et al. 1979		CL
36063	SLUG	A/D	U	3.010E-03	8.532E+00	Broughton et al. 1979		CH
36065	SLUG	ALL	U	1.250E-04	3.543E-01	Broughton et al. 1979		CL
36070	SLUG	ALL	U	7.000E-03	1.984E+01	Broughton et al. 1979		SM
36071	SLUG	DEN	U	5.370E-03	1.522E+01	Broughton et al. 1979		SM
36072	SLUG	DEN	U	3.330E-04	9.439E-01	Broughton et al. 1979		SM
36077	FH	ALL	U	5.510E-04	1.562E+00	Broughton et al. 1979		ML
36082	SLUG	ALL	U	4.450E-03	1.261E+01	Broughton et al. 1979		
36115	PUMP	A/D	U	6.700E-03	1.899E+01	MK 1999	Theis	Bedrock Ridge
36123	PUMP	A/D	U	4.650E-03	1.318E+01	May 1982		
36187	SLUG	ALL	U	2.0E-4 to 3.0E-3		WCC 1991		
36201	SLUG	DEN	U	3.0E-6 to 3.0E-5		WCC 1991		
36300	PUMP	A/D	U	1.500E-03	4.252E+00	HLA 1992a		
36301	PUMP	ALL	U	1.000E-03	2.835E+00	RVO 1997		Army Trenches Design
36544	SLUG	DEN	U	1.400E-05	3.969E-02	RVO 1997		Army Trenches Design

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
36545	SLUG	DEN	U	6.800E-05	1.928E-01	RVO 1997		Army Trenches Design
36554	PUMP	ALL	U	4.800E-03	1.361E+01	MK 1999	Theis	Bedrock Ridge
36555	PUMP	DEN	U	1.150E-01	3.260E+02	MK 1999	Theis	Bedrock Ridge
36556	PUMP	DEN	U	7.000E-03	1.984E+01	MK 1999	Theis	Bedrock Ridge
36560	PUMP	DEN	U	3.900E-03	1.106E+01	MK 1999	Theis	Bedrock Ridge
36595	PUMP	DEN	U	9.000E-06	2.551E-02	HLA 1992a		Claystone
36599	PUMP	ALL	U	4.200E-03	1.191E+01	HLA 1992a		
36702	PUMP	DEN	U	2.700E-03	7.654E+00	May et al. 1983	Jacob	Denver sandstone (SP), Test well APT-0 (between 36137 and 36150)
37376	SLUG	DEN	U	1.200E-04	3.402E-01	ESE 1988a		
37379	SLUG	DEN	U	2.220E-04	6.293E-01	ESE 1988a		
37380	SLUG	DEN	U	4.300E-05	1.219E-01	ESE 1988a		
37390	SLUG	DEN	U	2.200E-04	6.236E-01	ESE 1988a		
37408	PUMP	A/D	U	6.400E-02	1.814E+02	HLA and Pirnie 1990	Theis Recovery	
37409	PUMP	A/D	U	5.200E-02	1.474E+02	HLA and Pirnie 1990	Theis Recovery	
37410	PUMP	A/D	U	2.000E-01	5.669E+02	HLA and Pirnie 1990	Jacob Method	
37411	PUMP	A/D	U	6.300E-02	1.786E+02	HLA and Pirnie 1990	Theis	
37412	PUMP	ALL	U	5.300E-02	1.502E+02	HLA and Pirnie 1990	Theis	
37413	PUMP	A/D	U	7.200E-02	2.041E+02	HLA and Pirnie 1990	Theis	
37414	PUMP	A/D	U	3.900E-02	1.106E+02	HLA and Pirnie 1990	Theis	
37415	PUMP	A/D	U	7.400E-02	2.098E+02	HLA and Pirnie 1990	Theis	
37416	PUMP	ALL	U	8.800E-02	2.494E+02	HLA and Pirnie 1990	Theis	
37418	PUMP	A/D	U	3.200E-02	9.071E+01	HLA and Pirnie 1990	Theis Recovery	
37419	PUMP	A/D	U	3.900E-02	1.106E+02	HLA and Pirnie 1990	Theis Recovery	
37420	PUMP	A/D	U	2.600E-02	7.370E+01	HLA and Pirnie 1990	Theis Recovery	
37421	PUMP	A/D	U	5.300E-02	1.502E+02	HLA and Pirnie 1990	Theis	
37422	PUMP	ALL	U	6.100E-02	1.729E+02	HLA and Pirnie 1990	Theis	
37423	PUMP	A/D	U	4.800E-02	1.361E+02	HLA and Pirnie 1990	Theis	
37424	PUMP	A/D	U	5.300E-02	1.502E+02	HLA and Pirnie 1990	Theis	
37425	PUMP	A/D	U	3.000E-02	8.504E+01	HLA and Pirnie 1990	Theis	
37426	PUMP	ALL	U	3.500E-02	9.921E+01	HLA and Pirnie 1990	Theis	
37427	PUMP	A/D	U	5.500E-02	1.559E+02	HLA and Pirnie 1990	Theis	
37800	PUMP	A/D	U	2.858E-02	8.10E+01	HLA 1994	Theis Recovery	
37801	PUMP	A/D	U	2.999E-02	8.50E+01	HLA 1994	Theis	Renumbered from 37420
37802	PUMP	A/D	U	5.292E-02	1.50E+02	HLA 1994	Theis	Renumbered from 37418
37803	PUMP	A/D	U	1.940E-02	5.50E+01	HLA 1994	Theis Recovery	
37804	PUMP	A/D	U	2.505E-02	7.10E+01	HLA 1994	Theis Recovery	
37805	PUMP	A/D	U	3.881E-03	1.10E+01	HLA 1994	Theis Recovery	
37806	PUMP	A/D	U	4.939E-02	1.40E+02	HLA 1994	Theis Recovery	
37807	PUMP	A/D	U	6.703E-02	1.90E+02	HLA 1994	Theis Recovery	

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
37808	PUMP	A/D	U	1.411E-03	4.00E+00	HLA 1994	Theis Recovery	
37809	PUMP	A/D	U	1.305E-02	3.70E+01	HLA 1994	Theis Recovery	
37810	PUMP	A/D	U	8.114E-02	2.30E+02	HLA 1994	Theis Recovery	
37811	PUMP	A/D	U	1.094E-01	3.10E+02	HLA 1994	Theis Recovery	
37812	PUMP	DEN	U	1.446E-01	4.10E+02	HLA 1994	Theis Recovery	
37813	PUMP	A/D	U	9.172E-02	2.60E+02	HLA 1994	Theis Recovery	
37814	PUMP	A/D	U	1.552E-01	4.40E+02	HLA 1994	Theis Recovery	
37815	PUMP	A/D	U	1.482E-01	4.20E+02	HLA 1994	Theis Recovery	
37816	PUMP	A/D	U	1.446E-02	4.10E+01	HLA 1994	Theis Recovery	
37900	SLUG	A/D	U	3.528E-05	1.00E-01	HLA 1994	Bouwer Method	
37901	PUMP	A/D	U	7.056E-03	2.00E+01	HLA 1994	Theis Recovery	
37902	PUMP	A/D	U	1.623E-02	4.60E+01	HLA 1994	Theis Recovery	
37903	PUMP	A/D	U	6.350E-02	1.80E+02	HLA 1994	Theis Recovery	
37904	PUMP	A/D	U	4.233E-02	1.20E+02	HLA 1994	Theis Recovery	
37905	PUMP	A/D	U	4.233E-02	1.20E+02	HLA 1994	Theis Recovery	
37906	PUMP	A/D	U	1.446E-02	4.10E+01	HLA 1994	Theis Recovery	
37907	PUMP	A/D	U	5.997E-03	1.70E+01	HLA 1994	Theis Recovery	
37908	PUMP	A/D	U	1.517E-02	4.30E+01	HLA 1994	Theis Recovery	
37909	PUMP	A/D	U	1.693E-02	4.80E+01	HLA 1994	Theis Recovery	
37910	PUMP	A/D	U	8.819E-02	2.50E+02	HLA 1994	Theis Recovery	
37911	PUMP	A/D	U	1.235E-02	3.50E+01	HLA 1994	Theis Recovery	
37912	PUMP	A/D	U	5.997E-02	1.70E+02	HLA 1994	Theis Recovery	
37913	PUMP	A/D	U	1.870E-01	5.30E+02	HLA 1994	Theis Recovery	
37914	PUMP	A/D	U	6.703E-02	1.90E+02	HLA 1994	Theis Recovery	
37915	PUMP	A/D	U	1.058E-01	3.00E+02	HLA 1994	Theis Recovery	
37916	PUMP	A/D	U	1.094E-01	3.10E+02	HLA 1994	Theis Recovery	
37917	PUMP	A/D	U	8.819E-02	2.50E+02	HLA 1994	Theis Recovery	
37918	PUMP	A/D	U	1.305E-01	3.70E+02	HLA 1994	Theis Recovery	
37919	PUMP	A/D	U	6.350E-02	1.80E+02	HLA 1994	Theis Recovery	
37920	PUMP	A/D	U	3.881E-02	1.10E+02	HLA 1994	Theis Recovery	
37921	PUMP	A/D	U	1.129E-02	3.20E+01	HLA 1994	Theis Recovery	
37922	PUMP	A/D	U	2.469E-02	7.00E+01	HLA 1994	Theis Recovery	
37923	PUMP	A/D	U	1.976E-01	5.60E+02	HLA 1994	Theis Recovery	
Offpost Private Wells (See Comments for USGS locations)								Owner, Location (USGS system)
TCHD # (Site Type = TAPW)								
1190C	PUMP	ALL	U	4.692E-01	1.33E+03	USATHAMA 1961	Jacob/Theis	Aden well, T2S-R67W Sec. 9daa

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
1189A	PUMP	ALL	U	4.198E-01	1.19E+03	USATHAMA 1961	Jacob/Theis	Dobbs well, T2S-R67W Sec. 9ddb
1380C	PUMP	ALL	U	1.058E+00	3.00E+03	USATHAMA 1961	Jacob/Theis	Marty well, T2S-R67W Sec. 21add
1213B	PUMP	ALL	U	3.669E-01	1.04E+03	USATHAMA 1961	Jacob/Theis	Masunaga well, T2S-R67W Sec. 10dcc
641C	PUMP	ALL	U	9.313E-01	2.64E+03	USATHAMA 1961	Jacob/Theis	Matsumoto well, T2S-R67W Sec. 16ddc
641D	PUMP	ALL	U	9.596E-01	2.72E+03	USATHAMA 1961	Jacob/Theis	Matsumoto well, T2S-R67W Sec. 16ddd2
309B	PUMP	ALL	U	7.691E-01	2.18E+03	USATHAMA 1961	Jacob/Theis	Monson well, T2W-R67W Sec. 15badd
490C	PUMP	ALL	U	4.586E-01	1.30E+03	USATHAMA 1961	Jacob/Theis	Myers well, T2S-R67W Sec. 10bdcd
296D	PUMP	ALL	U	3.669E-01	1.04E+03	USATHAMA 1961	Jacob/Theis	Powers well, T2S-R67W Sec. 15ccd
Unknown	PUMP	ALL	U	4.022E-01	1.14E+03	USATHAMA 1961	Jacob/Theis	Wolpert well, T2S-R67W Sec. 4adb
SAC-17	PUMP	ALL	U	1.660E-01	4.706E+02	May 1982	Jacob	Commerce City Well, 77th and Quebec
SAC-17	PUMP	ALL	U	1.386E-01	3.930E+02	WCC 1991	Neuman	Commerce City Well, reanalyzed using Neuman method
Unknown	PUMP	ALL	U	3.828E-01	1.09E+03	RMA records 1955		Neson Well, T2S-R67W Sec. 22bcc
QUESTIONABLE FLOW SYSTEM								
23218	SLUG	DEN	V	2.400E-06	6.803E-03	ESE 1988a		
23219	SLUG	DEN	Q	2.370E-05	6.718E-02	ESE 1988a		
24032	FH/RH	DEN	Q	2.970E-05	8.419E-02	Ertec 1981		CH
24089	FH/RH	DEN	V	2.560E-03	7.257E+00	Ertec 1981		CH
24137	SLUG	DEN	Q	5.600E-06	1.587E-02	May et al. 1980		
24138	SLUG	DEN	Q	3.340E-05	9.468E-02	May et al. 1980		
24142	SLUG	DEN	Q	6.900E-05	1.956E-01	May et al. 1980		Clayey sand
24145	SLUG	DEN	Q	1.920E-05	5.443E-02	May et al. 1980		jointed clay
24154	PUMP	DEN	Q	3.900E-04	1.106E+00	Black and Veatch 1980		
24154	PUMP	DEN	Q	9.100E-08	2.580E-04	Ertec 1981		Obs. wells 24144 and 24155
24191	SLUG	DEN	V	7.000E-05	1.984E-01	ESE 1988a		
26069	SLUG	DEN	V	7.281E-04	2.064E+00	Bopp and Kolmer 1979	Cooper	
26086	SLUG	DEN	Q	6.766E-04	1.918E+00	Bopp and Kolmer 1979	Cooper	

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
35028	SLUG	DEN	Q	3.710E-05	1.052E-01	Broughton et al. 1979		CH
36078	SLUG	DEN	Q	5.660E-03	1.604E+01	Broughton et al. 1979		OH
36206	SLUG	DEN	Q	1.900E-04	5.386E-01	HLA 1992a		
37372	SLUG	DEN	Q	1.235E-04	3.500E-01	ESE 1988a		Medium grained sandstone
37387	SLUG	DEN	V	2.100E-04	5.953E-01	ESE 1988a		
CONFINED FLOW SYSTEM								
01015	SLUG	DEN	C	1.150E-04	3.260E-01	Broughton et al. 1979		SM
01079	SLUG	DEN	C	3.200E-05	9.071E-02	HLA 1992a		
01103	SLUG	DEN	C	3.400E-05	9.638E-02	HLA 1992a		
01109	SLUG	DEN	C	6.800E-06	1.928E-02	HLA 1992a		
01300	PUMP	DEN	C	4.800E-05	1.361E-01	HLA 1992a		
02004	SLUG	DEN	C	1.780E-03	5.046E+00	Broughton et al. 1979		SM
02064	SLUG	DEN	C	3.300E-06	9.354E-03	HLA 1992a		
02300	PUMP	DEN	C	1.000E-07	2.835E-04	HLA 1992a		Claystone
23161	SLUG	DEN	C	1.420E-05	4.025E-02	May 1980		
23162	SLUG	DEN	C	1.080E-05	3.061E-02	May 1980		
23163	SLUG	DEN	C	7.920E-05	2.245E-01	May 1980		
23164	SLUG	DEN	C	7.900E-07	2.239E-03	May 1980		
23168	SLUG	DEN	C	7.610E-05	2.157E-01	May 1980		
23169	SLUG	DEN	C	3.550E-05	1.006E-01	May 1980		
24131	SLUG	DEN	C	7.890E-05	2.237E-01	May 1980		
24132	SLUG	DEN	C	2.880E-05	8.164E-02	May 1980		
24133	SLUG	DEN	C	1.910E-05	5.414E-02	May 1980		
24134	SLUG	DEN	C	1.150E-05	3.260E-02	May 1980		
24139	SLUG	DEN	C	7.360E-05	2.086E-01	May 1980		
24141	SLUG	DEN	C	8.900E-06	2.523E-02	May 1980		
24143	SLUG	DEN	C	2.080E-05	5.896E-02	May 1980		
24144	SLUG	DEN	C	4.940E-04	1.400E+00	May 1980		
24146	SLUG	DEN	C	1.670E-05	4.734E-02	May 1980		
24147	SLUG	DEN	C	2.210E-04	6.265E-01	May 1980		
25009	PUMP	DEN	C	7.790E-04	2.208E+00	HLA 1999		sandstone
25063	PUMP	DEN	C	7.540E-04	2.137E+00	HLA 1999		sandstone
25064	PUMP	DEN	C	7.600E-04	2.154E+00	HLA 1999		sandstone
25081	SLUG	DEN	C	1.500E-04	4.252E-01	HLA 1999		sandstone
25083	SLUG	DEN	C	4.200E-05	1.191E-01	HLA 1999		sandstone
25085	SLUG	DEN	C	3.500E-04	9.921E-01	HLA 1999		sandstone
26064	SLUG	DEN	C	1.950E-03	5.528E+00	Broughton et al. 1979	Cooper	SM
26067	SLUG	DEN	C	7.238E-04	2.052E+00	Bopp and Kolmer 1979	Cooper	

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
26072	SLUG	DEN	C	1.903E-03	5.394E+00	Bopp and Kolmer 1979		
26075	SLUG	DEN	C	7.232E-04	2.050E+00	Bopp and Kolmer 1979	Cooper	
26080	SLUG	DEN	C	2.020E-05	5.726E-02	Bopp and Kolmer 1979	Cooper	
26134	SLUG	DEN	C	2.200E-03	6.236E+00	WES 1979	Cooper	
26135	SLUG	DEN	C	1.300E-06	3.685E-03	WES 1979	Cooper	Siltstone
26136	SLUG	DEN	C	5.100E-05	1.446E-01	WES 1979		
26137	SLUG	DEN	C	1.900E-07	5.386E-04	WES 1979		Buffer zone
26138	SLUG	DEN	C	2.100E-05	5.953E-02	WES 1979		
26139	SLUG	DEN	C	1.500E-05	4.252E-02	WES 1979		Average of 2 tests
26141	SLUG	DEN	C	1.900E-03	5.386E+00	WES 1979	Cooper	
26142	SLUG	DEN	C	7.600E-06	2.154E-02	WES 1979		
31004	SLUG	DEN	C	3.040E-05	8.617E-02	Broughton et al. 1979		SM
35017	SLUG	DEN	C	1.370E-05	3.883E-02	Broughton et al. 1979	Cooper	SC
35019	SLUG	DEN	C	5.460E-04	1.548E+00	Broughton et al. 1979	Cooper	SM
35021	SLUG	DEN	C	1.710E-04	4.847E-01	Broughton et al. 1979		CH
35039	SLUG	DEN	C	1.289E-04	3.654E-01	Bopp and Kolmer 1979	Cooper	
35041	SLUG	DEN	C	1.297E-04	3.677E-01	Bopp and Kolmer 1979	Cooper	
36059	SLUG	DEN	C	3.120E-05	8.844E-02	Broughton et al. 1979		ML, CH, & SM
36064	SLUG	DEN	C	2.490E-05	7.058E-02	Broughton et al. 1979		SM
36066	SLUG	DEN	C	4.150E-05	1.176E-01	Broughton et al. 1979		OH
36079	SLUG	DEN	C	1.000E-03	2.835E+00	Broughton et al. 1979		CH
36083	SLUG	DEN	C	4.120E-05	1.168E-01	Broughton et al. 1979		OH
36598	SLUG	DEN	C	1.800E-05	5.102E-02	HLA 1992a		Sandstone
36598	PACKER	DEN	C	2.000E-07	5.669E-04	HLA 1992a		45 to 48.3 ft, siltstone, carbonaceous clay
36598	PACKER	DEN	C	2.000E-06	5.669E-03	HLA 1992a		49.5 to 54.5 ft, carbonaceous clay, sandstone
36602	SLUG	DEN	C	8.500E-06	2.409E-02	HLA 1992a		50.5 to 58 ft, claystone
36602	PACKER	DEN	C	2.000E-06	5.669E-03	HLA 1992a		36 to 41 ft, sandy siltstone, fractures
36602	PACKER	DEN	C	2.000E-07	5.669E-04	HLA 1992a		48 to 60 ft, claystone, coal, sandstone lens
Lime Basins Borings (Section 36) Packer Tests								
LB-03	PACKER	DEN		9.300E-07	2.636E-03	Tetra Tech 2007		52 to 60 ft, sandstone and claystone
LB-03	PACKER	DEN		3.900E-07	1.106E-03	Tetra Tech 2007		62 to 70 ft, claystone
LB-05	PACKER	DEN		3.000E-06	8.504E-03	Tetra Tech 2007		47 to 55 ft, sandstone and claystone

TABLE A-19. RMA Aquifer Tests

WELLID	TEST TYPE	AQUIFER	FLOW SYSTEM	K, cm/sec	K, ft/day	REFERENCE	ANALYSIS METHOD	COMMENTS Lithology, SSCS, etc.
LB-05	PACKER	DEN		7.600E-07	2.154E-03	Tetra Tech 2007		57 to 65 ft, claystone and sandstone
LB-08	PACKER	DEN		3.100E-07	8.787E-04	Tetra Tech 2007		47 to 55 ft, claystone and sandstone
LB-10	PACKER	DEN		4.000E-07	1.134E-03	Tetra Tech 2007		47 to 55 ft, claystone
LB-12	PACKER	DEN		1.200E-07	3.402E-04	Tetra Tech 2007		47 to 55 ft, claystone
LB-14	PACKER	DEN		5.100E-07	1.446E-03	Tetra Tech 2007		47 to 55 ft, claystone
LB-17	PACKER	DEN		6.100E-07	1.729E-03	Tetra Tech 2007		47 to 55 ft, claystone

TABLE A-20. RMA Aquifer Sediment Organic Carbon Data

WELL	AQUIFER	FLOW SYSTEM	DEPTH (cm)	DEPTH (ft)	MEDIAN GRAIN SIZE (mm)	ORGANIC CARBON (%)	FRACTIONAL ORGANIC CARBON, foc	REFERENCE	FORMATION	LITHOLOGY
22081	A/D	U		47.5		0.0022	0.000022	WCC 1991	Denver	claystone
22082	A/D	U		49		0.0042	0.000042	WCC 1991	Denver	claystone
27088	ALL	U		55		0.0052	0.000052	WCC 1991	alluvium	GW
27090	ALL	U		35.5		0.014	0.00014	WCC 1991	alluvium	SP/GP
27091	A/D	U		37.5		0.001	0.00001	WCC 1991	alluvium	SP/GP
36163	ALL	U		10.5-11.5		0.45	0.0045	ESE 1988b	alluvium	SM
36163	ALL	U		10.5-11.5		0.22	0.0022	ESE 1988b	alluvium	SM
36163	ALL	U		10.5-11.5		0.43	0.0043	ESE 1988b	alluvium	SM
36163	ALL	U		10.5-11.5		0.29	0.0029	ESE 1988b	alluvium	SM
36163	ALL	U		13.5-14.5		0.39	0.0039	ESE 1988b	alluvium	SM
36163	ALL	U		13.5-14.5		0.17	0.0017	ESE 1988b	alluvium	SM
36163	ALL	U		13.5-14.5		0.66	0.0066	ESE 1988b	alluvium	SM
36163	ALL	U		13.5-14.5		0.35	0.0035	ESE 1988b	alluvium	SM
36163	ALL	U		14.5-15.5		0.53	0.0053	ESE 1988b	alluvium	SC
36163	ALL	U		14.5-15.5		0.3	0.003	ESE 1988b	alluvium	SC
36163	ALL	U		14.5-15.5		0.68	0.0068	ESE 1988b	alluvium	SC
36163	ALL	U		14.5-15.5		0.26	0.0026	ESE 1988b	alluvium	SC
36165	ALL	U		3-8.5		0.54	0.0054	ESE 1988b	alluvium	SC
36165	ALL	U		3-8.5		0.59	0.0059	ESE 1988b	alluvium	SC
36165	ALL	U		3-8.5		0.07	0.0007	ESE 1988b	alluvium	SC
36598	DEN	C		44-44.5		0.7	0.007	MKES 1994	Denver	claystone
36598	DEN	C		62.5-63		0.74	0.0074	MKES 1994	Denver	claystone
36602	DEN	C		52.5-53		1.2	0.012	MKES 1994	Denver	claystone
36602	DEN	C		60-60.5		1.7	0.017	MKES 1994	Denver	claystone
37338	A/D	U	97	3.18	0.23	0.1	0.001	ESE 1987	alluvium	
37338	A/D	U	99	3.25	0.002	0.4	0.004	ESE 1987	Denver	
37342	A/D	U	104	3.41	0.3	0.05	0.0005	ESE 1987	alluvium	
37342	A/D	U	105	3.44	0.52	0.01	0.0001	ESE 1987	alluvium	
37342	A/D	U	106	3.48	0.003	0.05	0.0005	ESE 1987	alluvium	
37343	ALL	U	112	3.67	0.39	0.3	0.003	ESE 1987	alluvium	
37343	ALL	U	113	3.71	0.39	0.1	0.001	ESE 1987	alluvium	
37343	ALL	U	114	3.74	0.41	0.01	0.0001	ESE 1987	alluvium	
37343	ALL	U	116	3.81	0.51	0.02	0.0002	ESE 1987	alluvium	
37343	ALL	U	118	3.87	0.0035	0.2	0.002	ESE 1987	Denver	
37343	ALL	U	118	3.87	0.0035	0.25	0.0025	ESE 1987	Denver	
37344	ALL	U	402	13.19	0.01	0.03	0.0003	ESE 1987	alluvium	

TABLE A-20. RMA Aquifer Sediment Organic Carbon Data

WELL	AQUIFER	FLOW SYSTEM	DEPTH (cm)	DEPTH (ft)	MEDIAN GRAIN SIZE (mm)	ORGANIC CARBON (%)	FRACTIONAL ORGANIC CARBON, foc	REFERENCE	FORMATION	LITHOLOGY
37344	ALL	U	403	13.22	0.066	0.03	0.0003	ESE 1987	alluvium	
37344	ALL	U	404	13.25	0.38	0.008	0.00008	ESE 1987	alluvium	
37344	ALL	U	405	13.29	0.81	0.005	0.00005	ESE 1987	alluvium	
37344	ALL	U	406	13.32	0.3	0.006	0.00006	ESE 1987	Denver	
37345	A/D	U	50	1.64	0.88	0.007	0.00007	ESE 1987	alluvium	
37345	A/D	U	51	1.67	1.5	0.003	0.00003	ESE 1987	alluvium	
37345	A/D	U	52	1.71	0.1	0.05	0.0005	ESE 1987	alluvium	
37351	A/D	U	222	7.28	0.37	0.03	0.0003	ESE 1987	alluvium	
37351	A/D	U	223	7.32	0.3	0.4	0.004	ESE 1987	alluvium	
37351	A/D	U	224	7.35	0.32	0.02	0.0002	ESE 1987	alluvium	
37351	A/D	U	225	7.38	0.28	0.03	0.0003	ESE 1987	Denver	
37352	A/D	U	384	12.60	0.25	0.05	0.0005	ESE 1987	alluvium	
37352	A/D	U	386	12.66	1.5	0.002	0.00002	ESE 1987	alluvium	
37352	A/D	U	388	12.73	NA	0.08	0.0008	ESE 1987	Denver	
37353	ALL	U	141	4.63	2.1	0.002	0.00002	ESE 1987	alluvium	
37353	ALL	U	142	4.66	0.23	0.15	0.0015	ESE 1987	alluvium	
37354	ALL	U	171	5.61	3.9	0.002	0.00002	ESE 1987	alluvium	
37354	ALL	U	369	12.11	1.5	0.002	0.00002	ESE 1987	alluvium	
37354	ALL	U	369	12.11	1.5	0.002	0.00002	ESE 1987	alluvium	
37354	ALL	U	373	12.24	2.9	0.004	0.00004	ESE 1987	alluvium	
37354	ALL	U	374	12.27	NA	0.04	0.0004	ESE 1987	Denver	
37358	ALL	U	203	6.66	0.28	0.009	0.00009	ESE 1987	alluvium	
37358	ALL	U	204	6.69	NA	0.08	0.0008	ESE 1987	Denver	
37361	ALL	U	179	5.87	0.46	0.008	0.00008	ESE 1987	alluvium	
37361	ALL	U	180	5.91	2.4	0.002	0.00002	ESE 1987	alluvium	
37361	ALL	U	182	5.97	2.5	0.001	0.00001	ESE 1987	alluvium	
37361	ALL	U	184	6.04	1.9	0.003	0.00003	ESE 1987	alluvium	
37361	ALL	U	185	6.07	2.5	0.2	0.002	ESE 1987	alluvium	

Legend

- RMA National Wildlife Refuge
- Rocky Mountain Arsenal
- Section Lines
- Hazardous Waste Landfill, Enhanced Hazardous Waste Landfill, and Landfill Wastewater Treatment System
- Detention Basin Area
- CAMU Boundary
- Lakes, Ponds, and Rivers
- Wetlands
- Dry Lake Areas
- Ditch or Canal
- Intermittent stream
- Slurry Walls
- Recharge Trenches
- Local Roads
- Secondary Roads
- Primary Roads
- Unimproved Roads
- Aquifer Test Wells

N

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

Sources: USGS, DPRA, Inc., Washington Group, RMA Environmental Database, U.S. Army, Shell Chemical

0 1,000 2,000 4,000

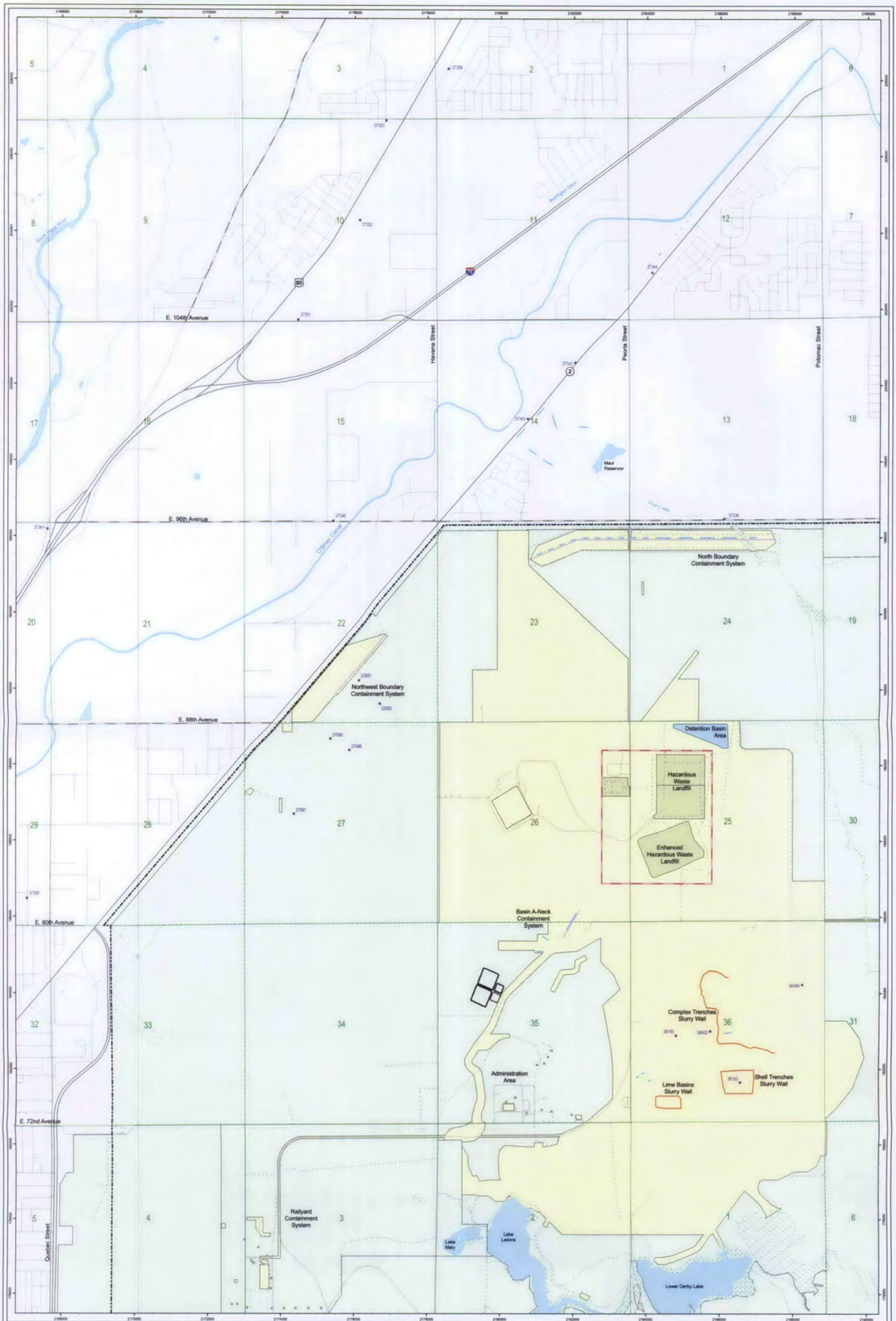
Feet

Aquifer Test Wells

Figure A-2

Remediation Venture Office GIS

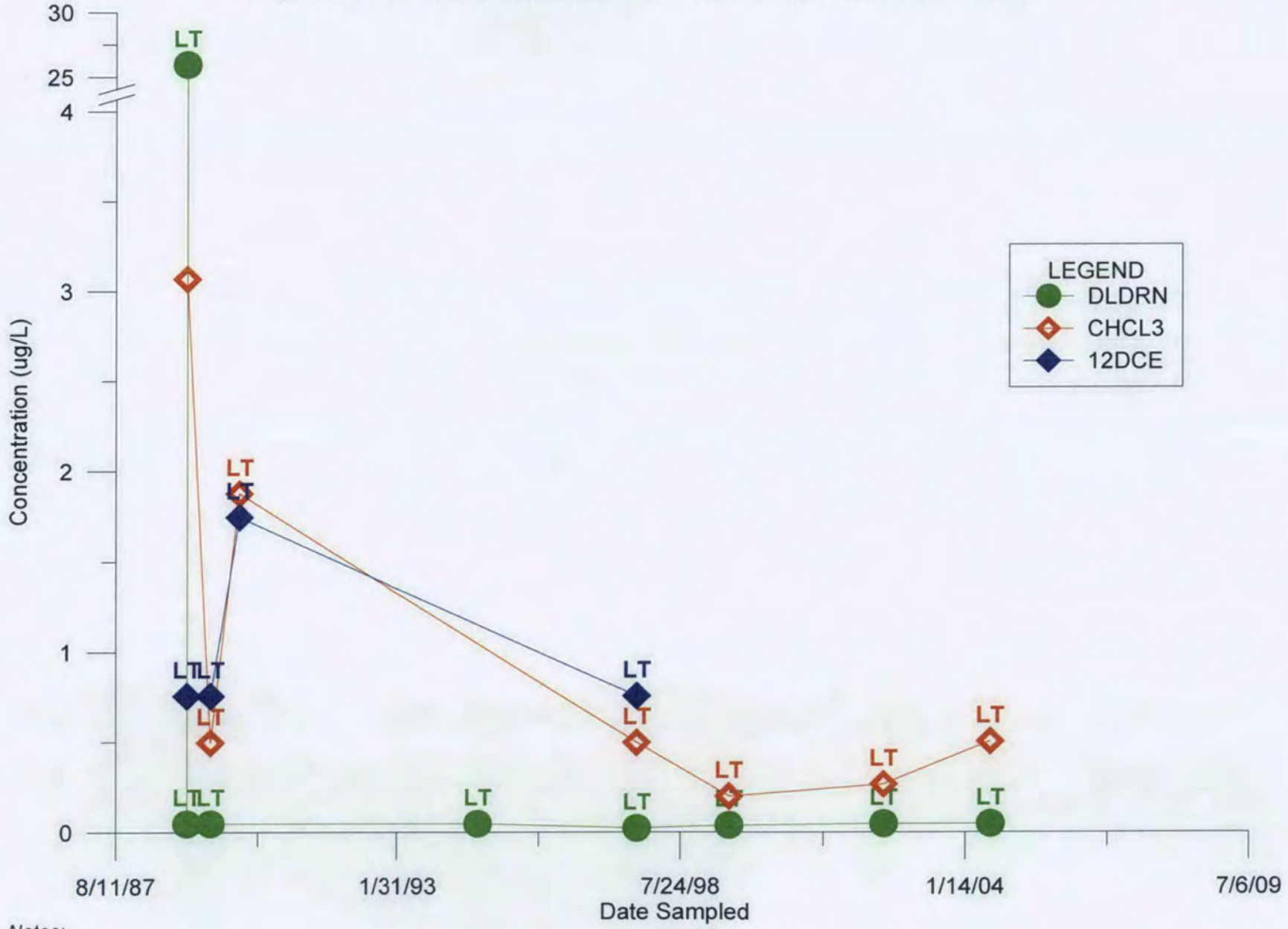
10/30/2007 DPRA, Inc. Q:\projects\ltmp_06_07\mxds\aquifer_test_wells08.mxd


E. 104th Avenue
E. 96th Avenue
E. 88th Avenue
E. 80th Avenue
E. 72nd Avenue
Havana Street
Peoria Street
Potomac Street
Quebec Street
South Platte River
Burlington Ditch
O'Brian Canal
First Creek
Maul Reservoir
North Boundary Containment System
Northwest Boundary Containment System
Detention Basin Area
Hazardous Waste Landfill
Enhanced Hazardous Waste Landfill
Basin A-Neck Containment System
Complex Trenches Slurry Wall
Shell Trenches Slurry Wall
Lime Basins Slurry Wall
Administration Area
Railyard Containment System
Lake Mary
Lake Ladora
Lower Derby Lake
Legend
RMA National Wildlife Refuge
Rocky Mountain Arsenal
Section Lines
Hazardous Waste Landfill, Enhanced Hazardous Waste Landfill, and Landfill Wastewater Treatment System
Detention Basin Area
CAMU Boundary
Lakes, Ponds, and Rivers
Wetlands
Dry Lake Areas
Ditch or Canal
Intermittent stream
Slurry Walls
Recharge Trenches
Local Roads
Secondary Roads
Primary Roads
Unimproved Roads
Test Wells
N
NAD27-NGVD29 Datum, US Survey Feet, Colorado North Zone
Sources: USGS, DPRA, Inc., Washington Group, RMA Environmental Database, U.S. Army, Shell Chemical
0 1,000 2,000 4,000
Feet
Aquifer Sediment Organic Carbon Test Wells
Figure A-3
Remediation Venture Office GIS
10/28/2008 DPRA, Inc.

APPENDIX B

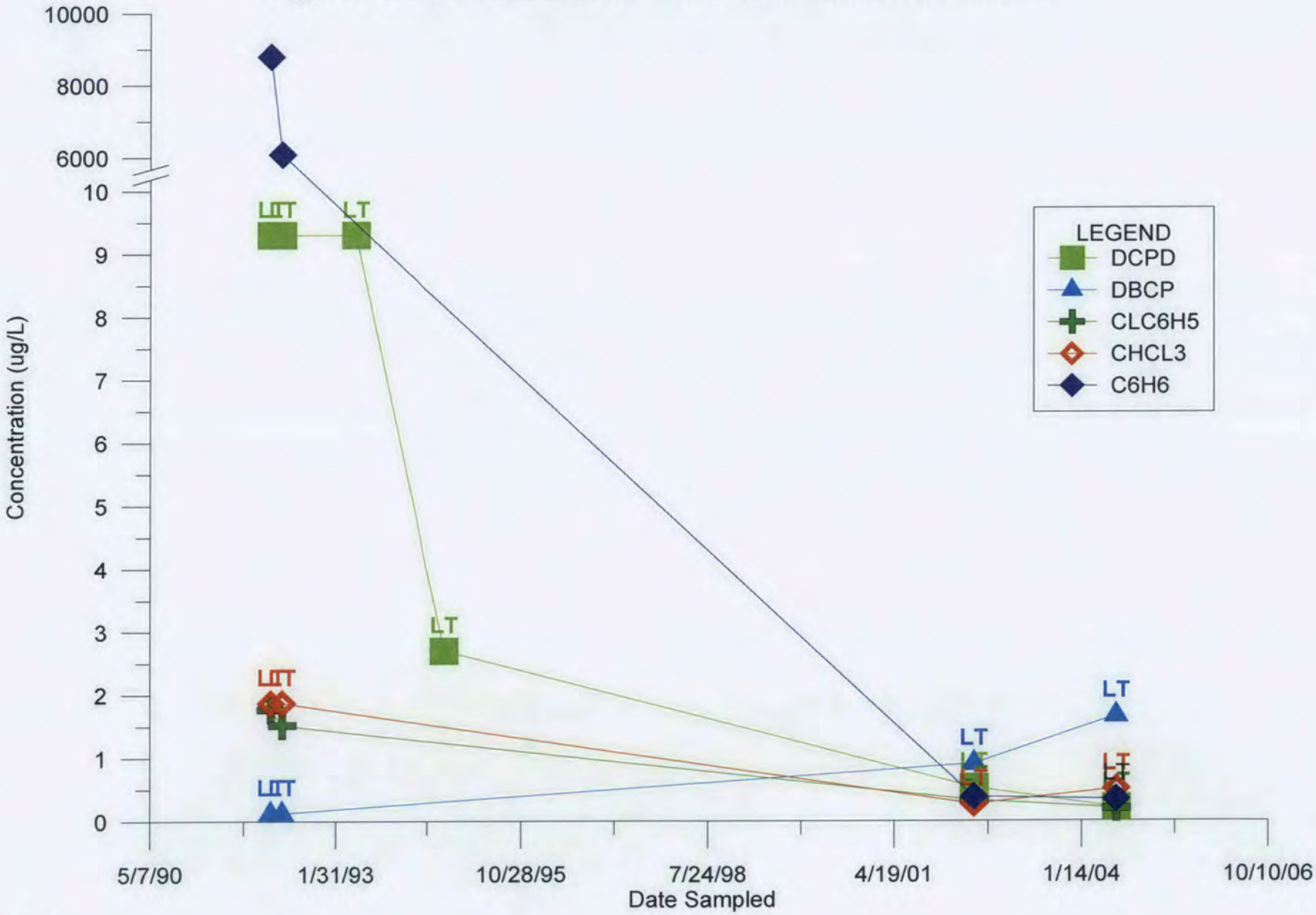
CONCENTRATION TIME-TREND GRAPHS FOR CONFINED FLOW SYSTEM

Figure B-1 Concentration vs. Time Plot of Well 01067



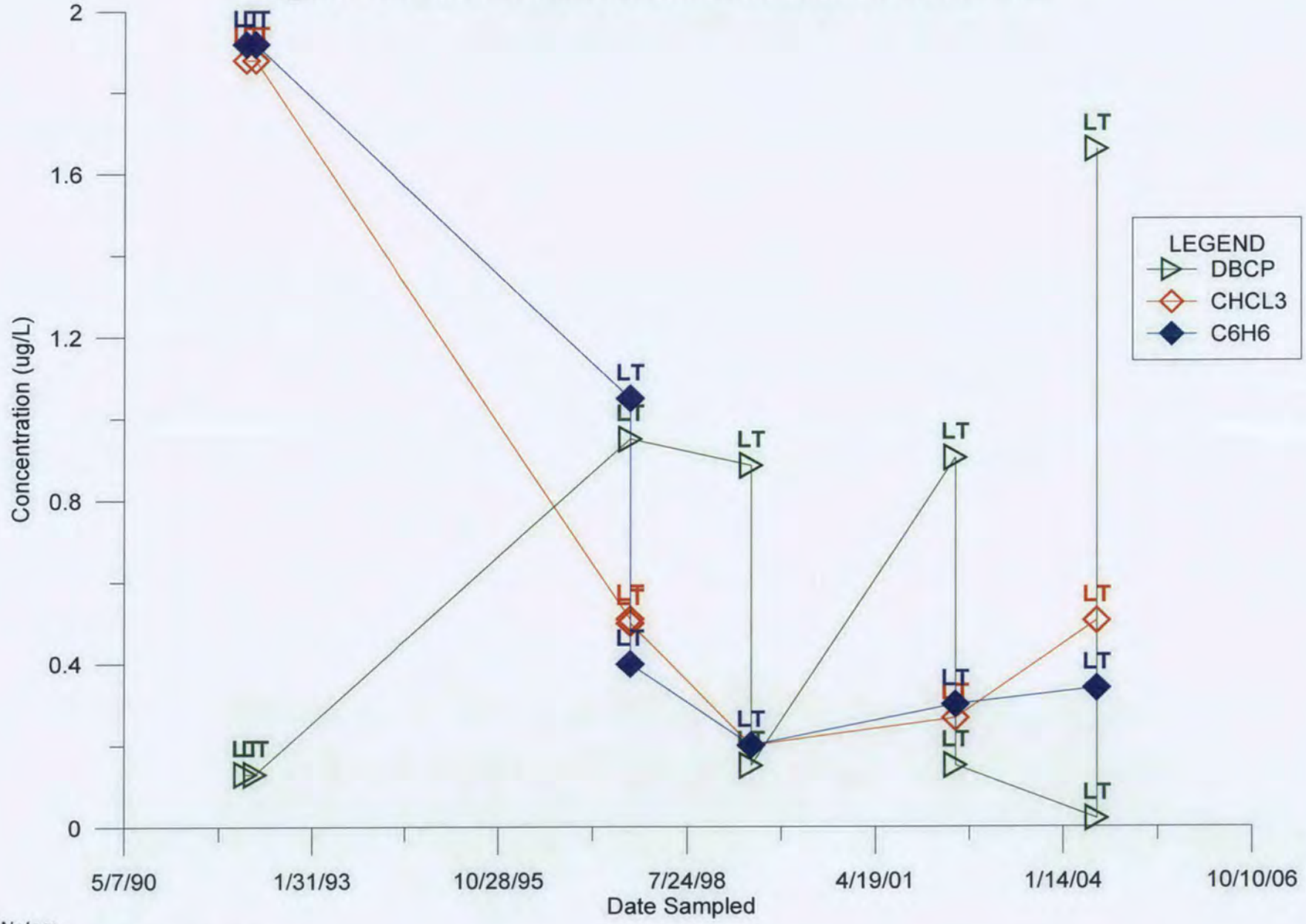
Notes:
LT - Less than detection limit

Figure B-2 Concentration vs. Time Plot of Well 01102



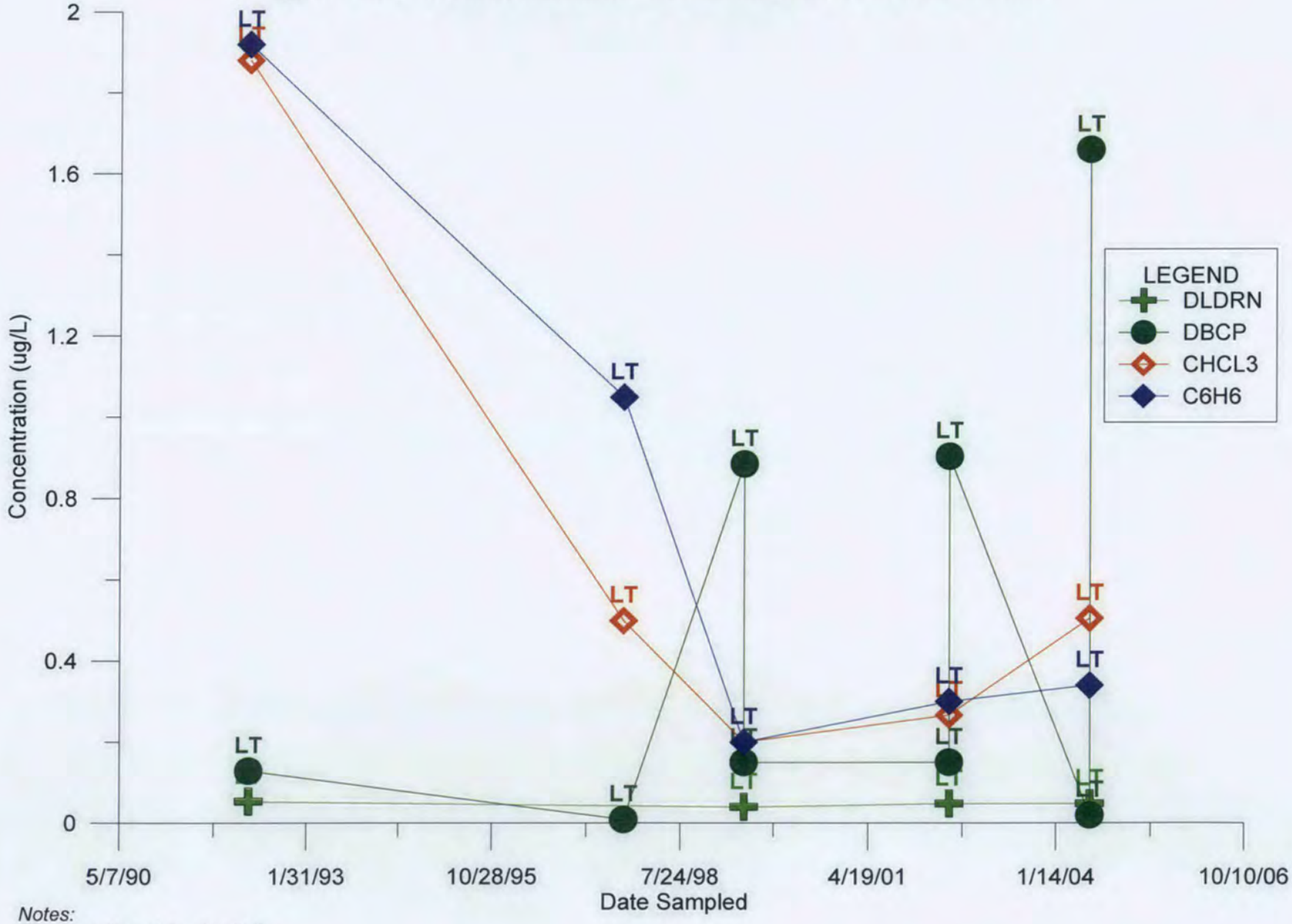
Notes:
LT - Less than detection limit

Figure B-3 Concentration vs. Time Plot of Well 01109



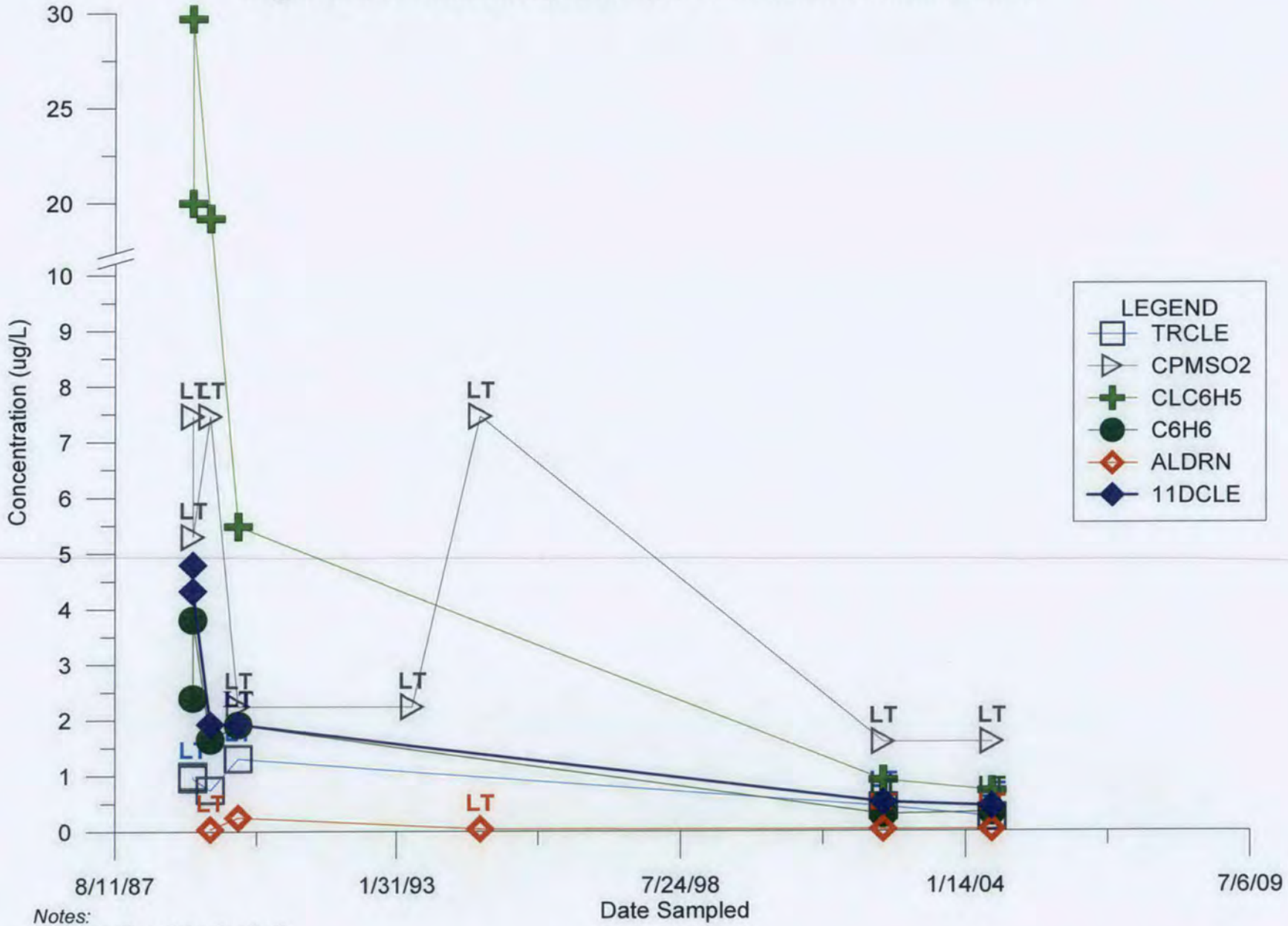
Notes:
LT - Less than detection limit

Figure B-4 Concentration vs. Time Plot of Well 01300



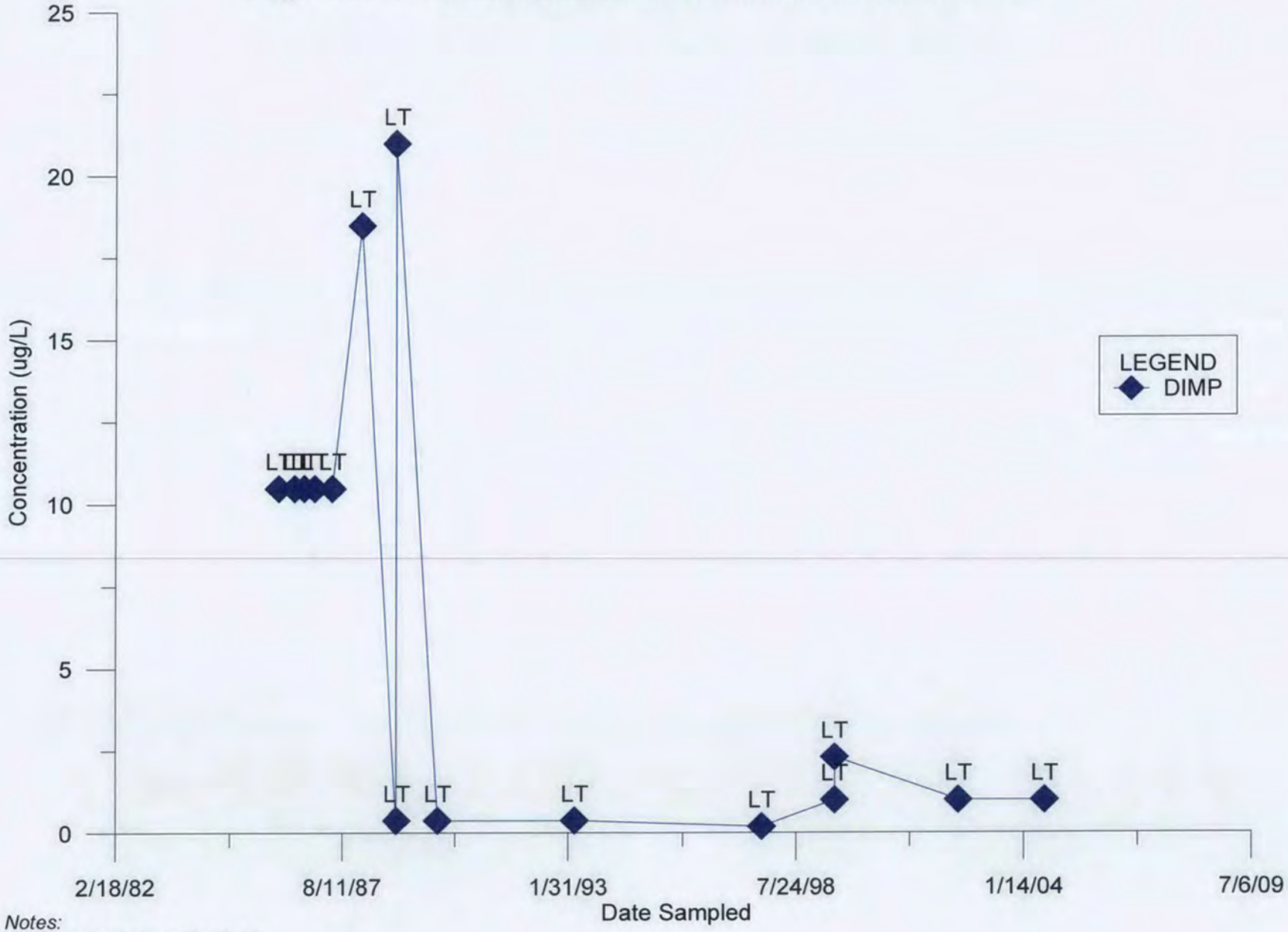
Notes:
LT - Less than detection limit

Figure B-5 Concentration vs. Time Plot of Well 02057



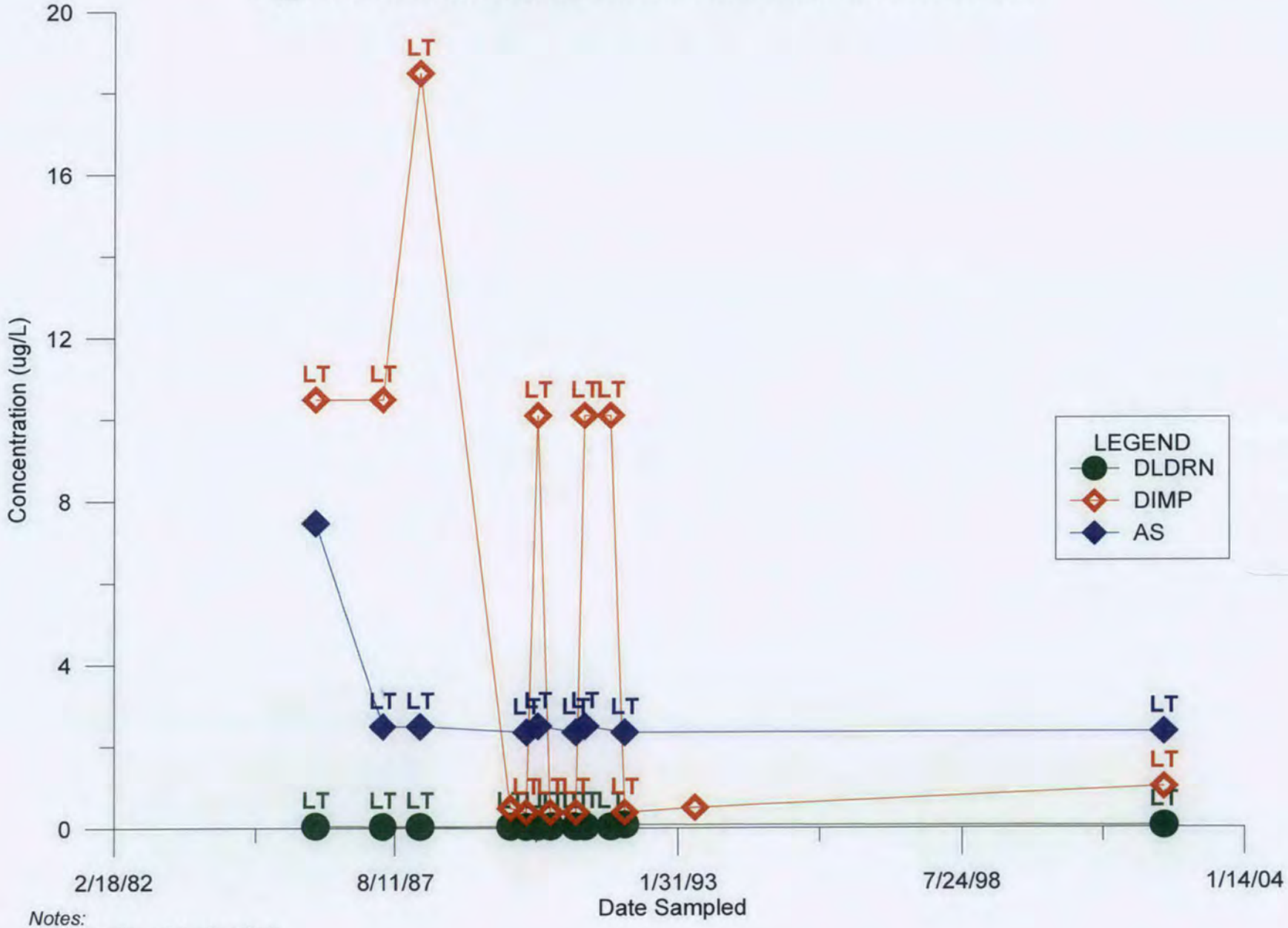
Notes:
LT - Less than detection limit

Figure B-6 Concentration vs. Time Plot of Well 23187



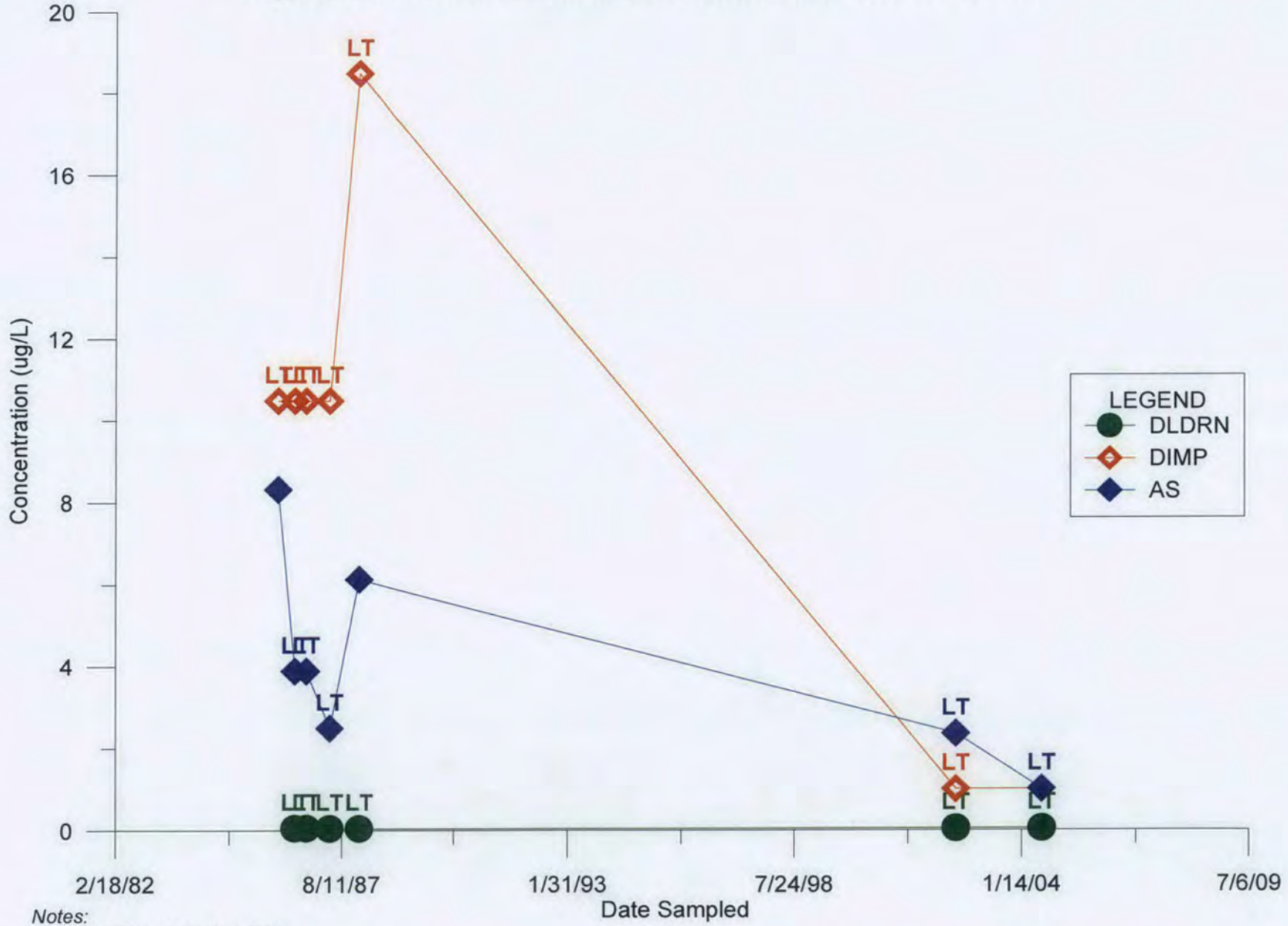
Notes:
LT - Less than detection limit

Figure B-7 Concentration vs. Time Plot of Well 23193



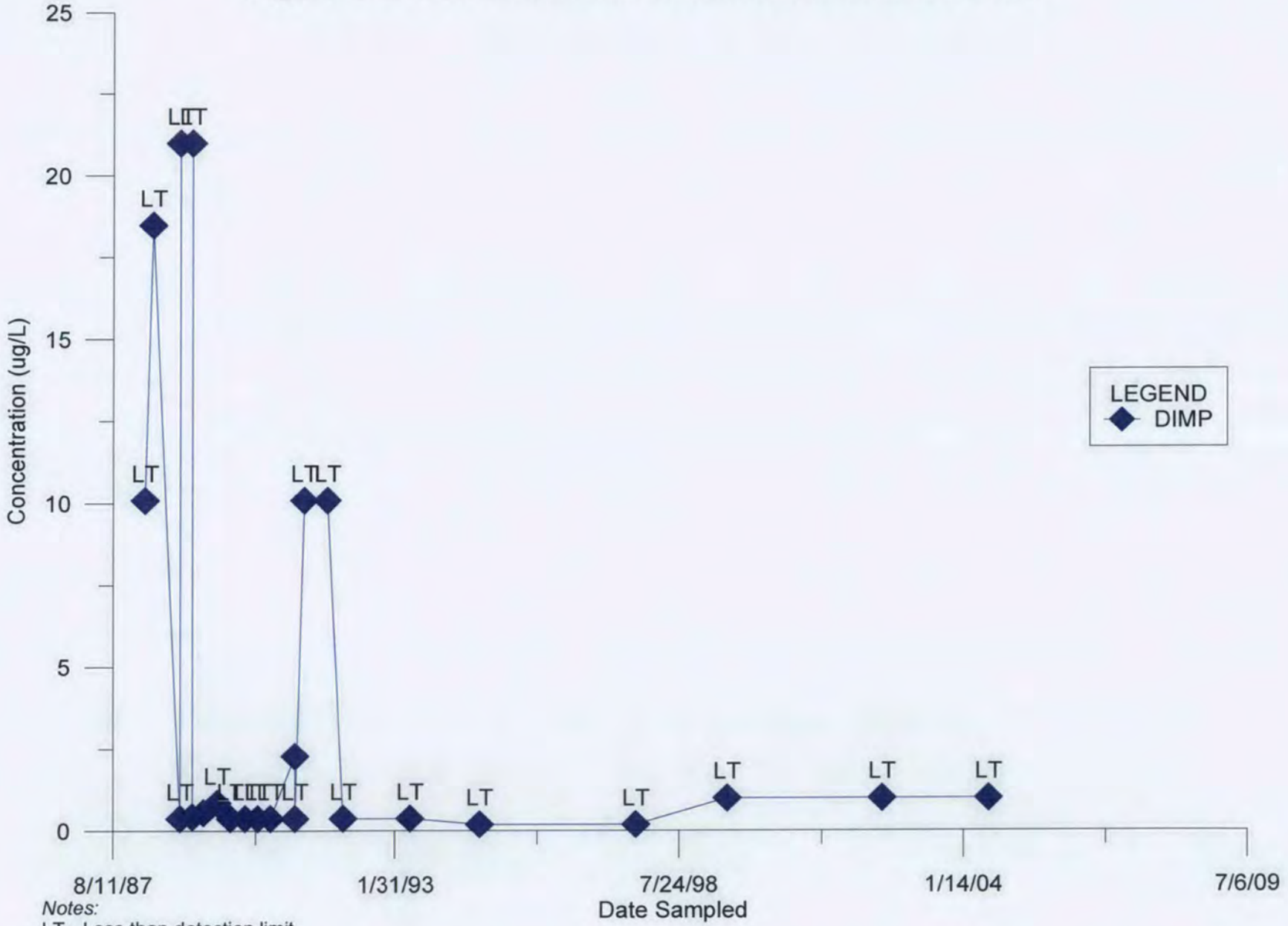
Notes:
LT - Less than detection limit

Figure B-8 Concentration vs. Time Plot of Well 26147



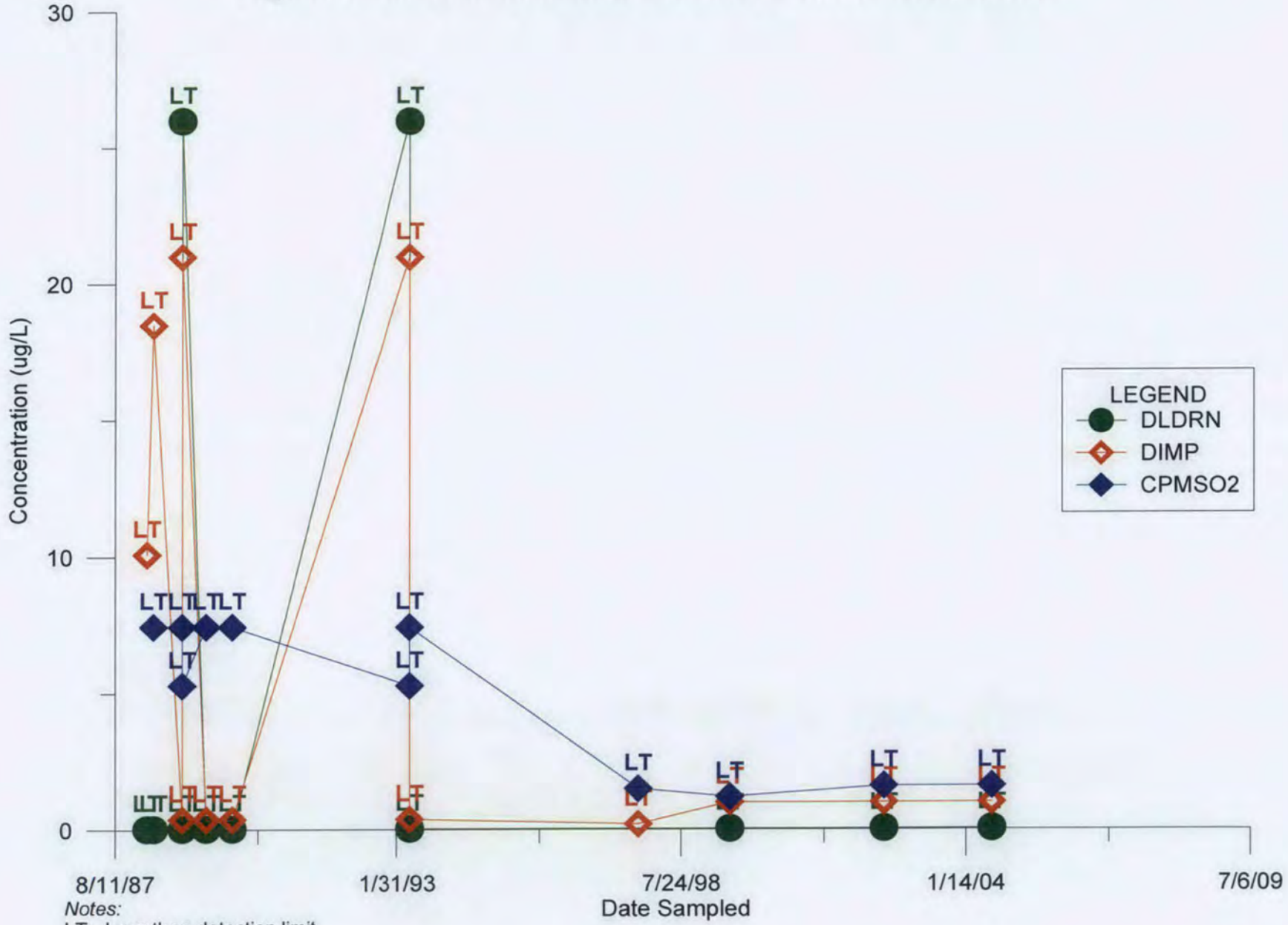
Notes:
LT - Less than detection limit

Figure B-9 Concentration vs. Time Plot of Well 26150



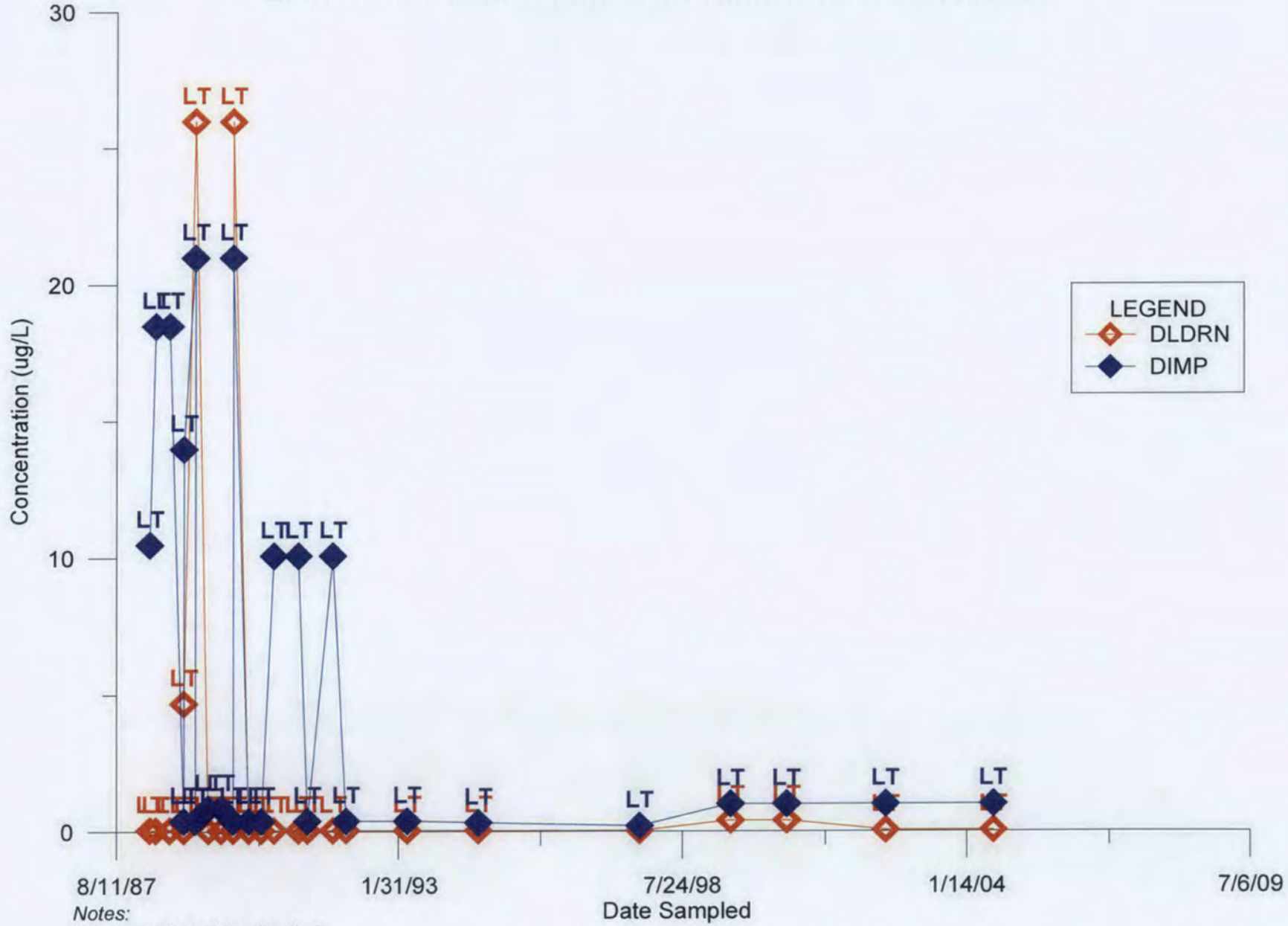
Notes:
LT - Less than detection limit

Figure B-10 Concentration vs. Time Plot of Well 26152



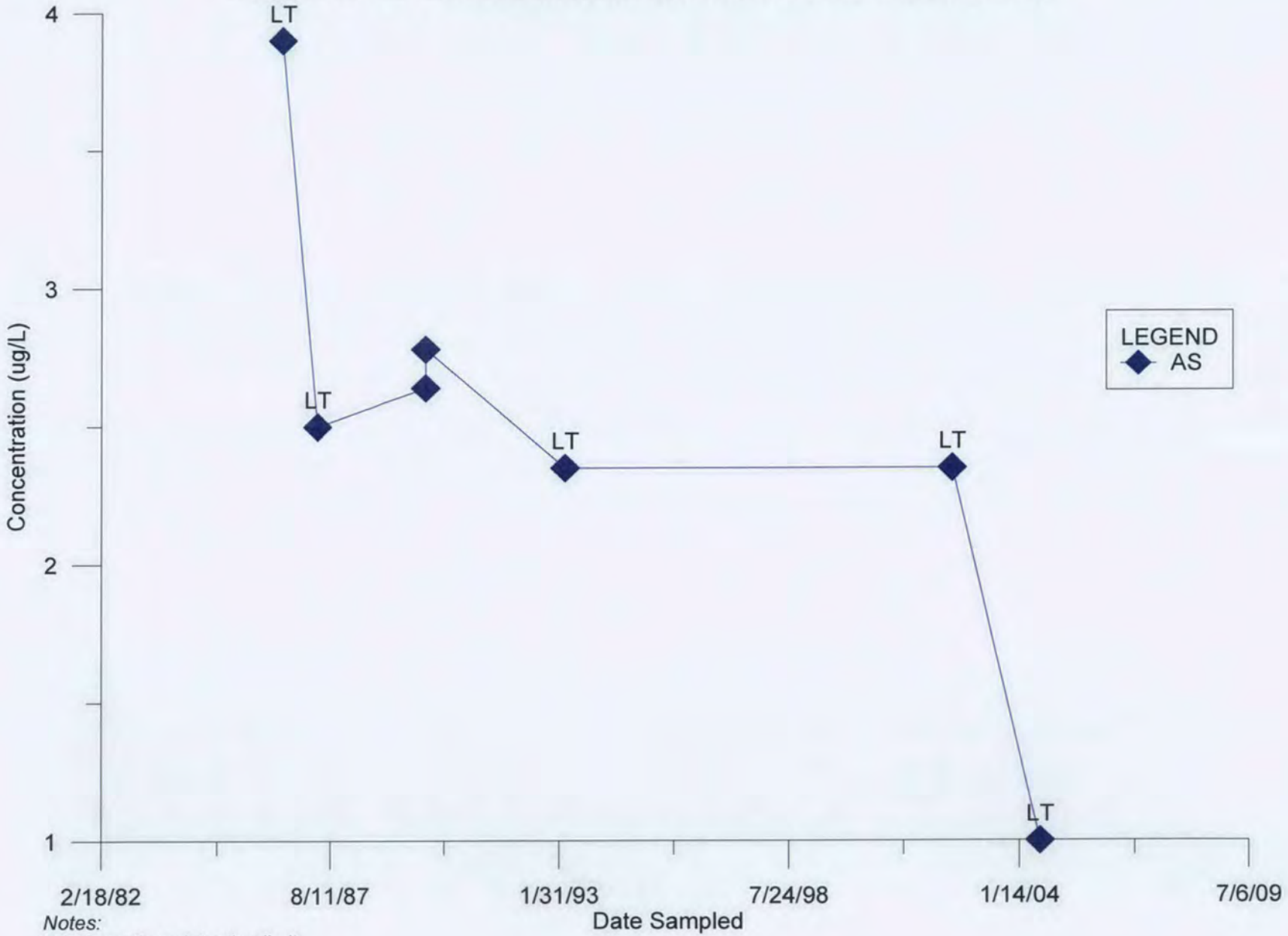
Notes:
LT - Less than detection limit

Figure B-11 Concentration vs. Time Plot of Well 26153



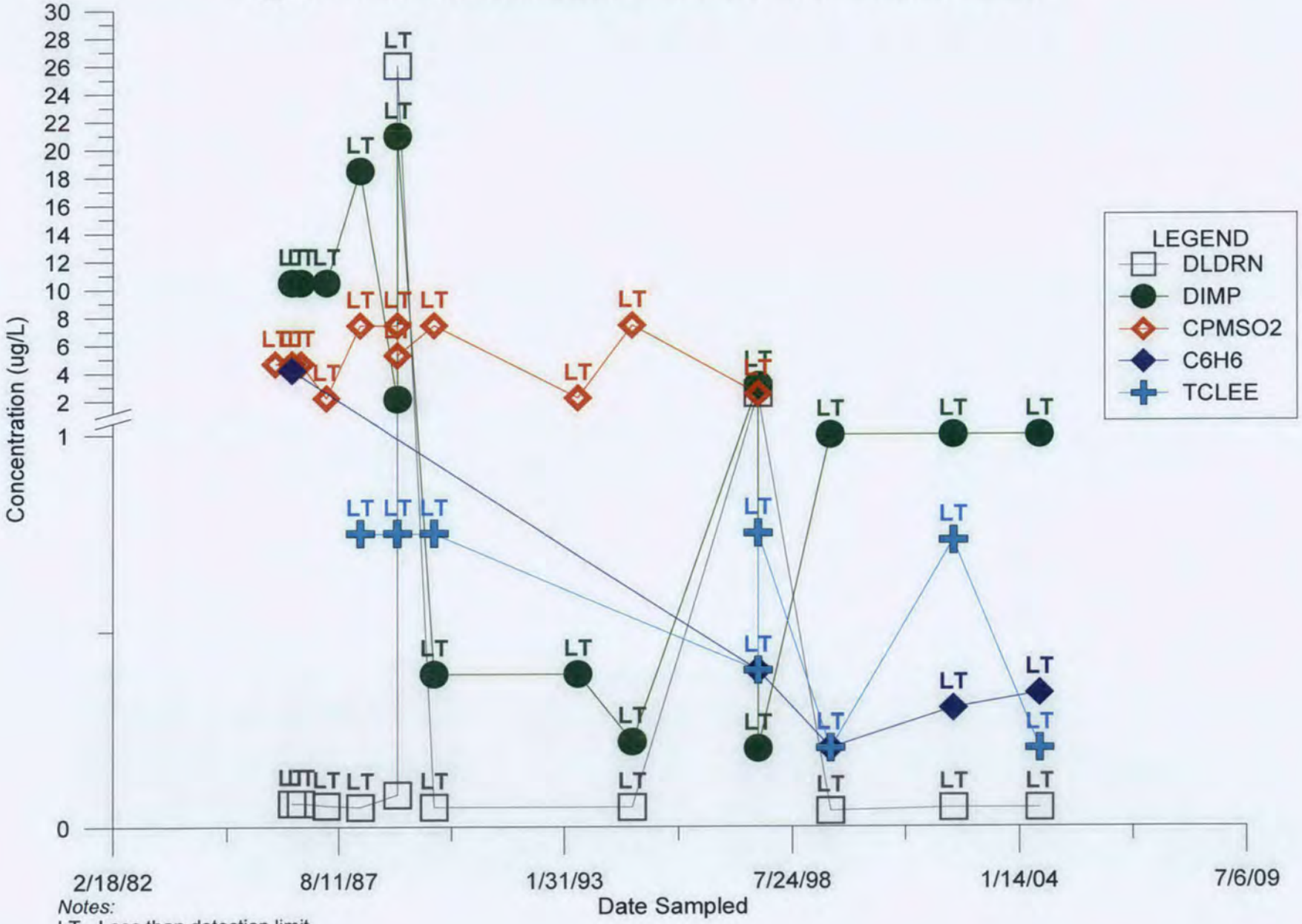
Notes:
LT - Less than detection limit

Figure B-12 Concentration vs. Time Plot of Well 35063



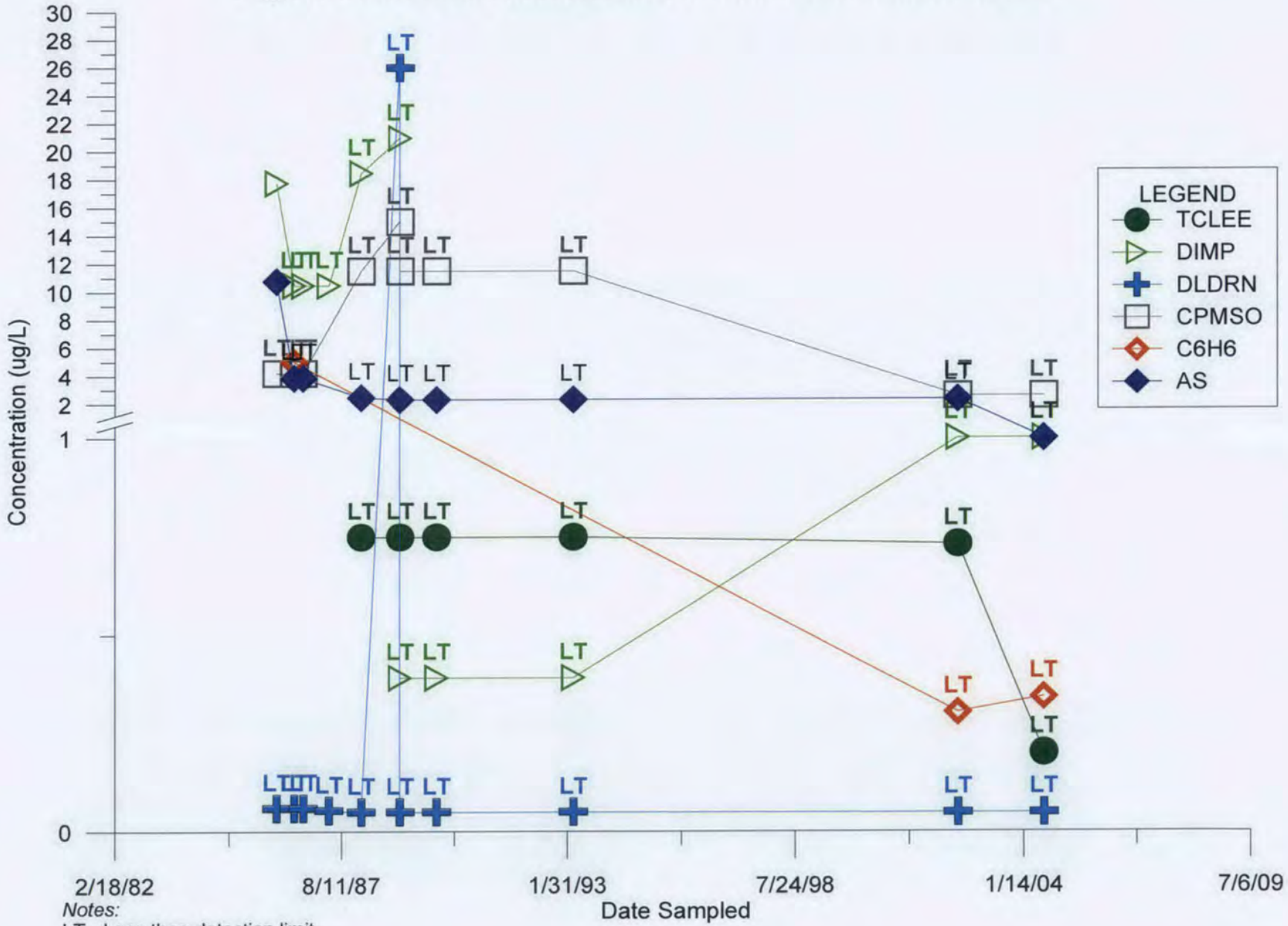
Notes:
LT - Less than detection limit

Figure B-13 Concentration vs. Time Plot of Well 35067



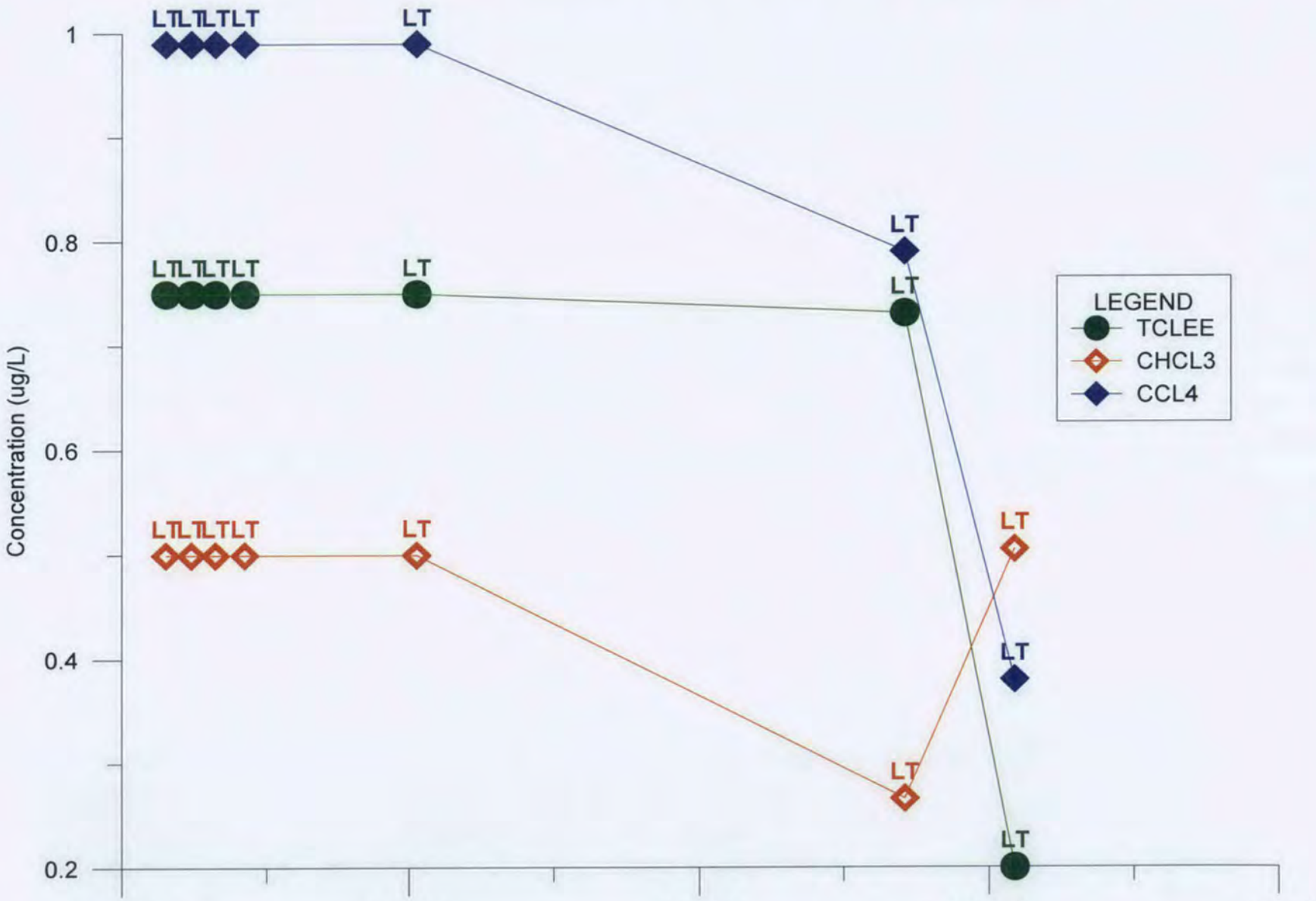
Notes:
LT - Less than detection limit

Figure B-14 Concentration vs. Time Plot of Well 35068



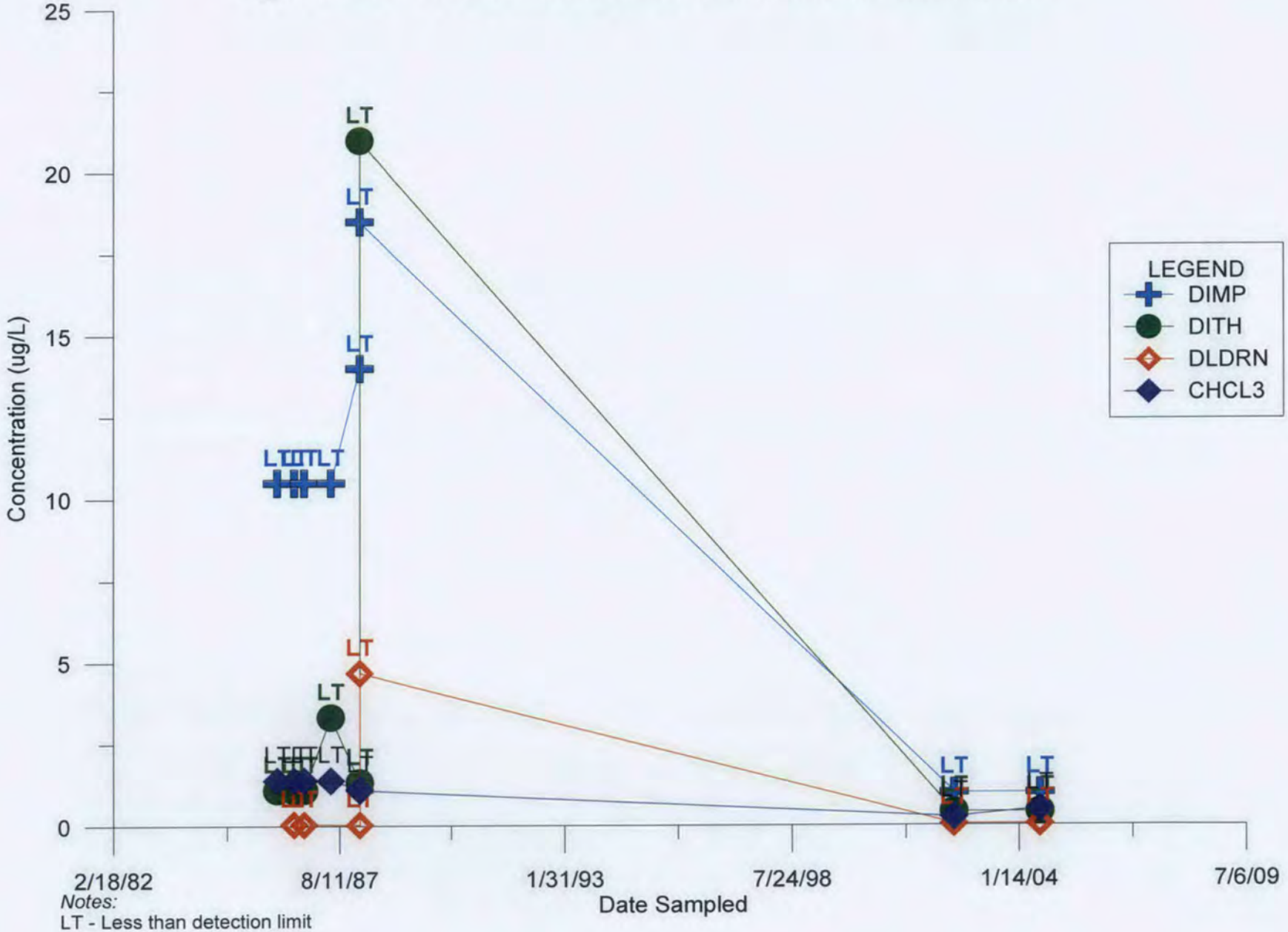
Notes:
LT - Less than detection limit

Figure B-15 Concentration vs. Time Plot of Well 35083



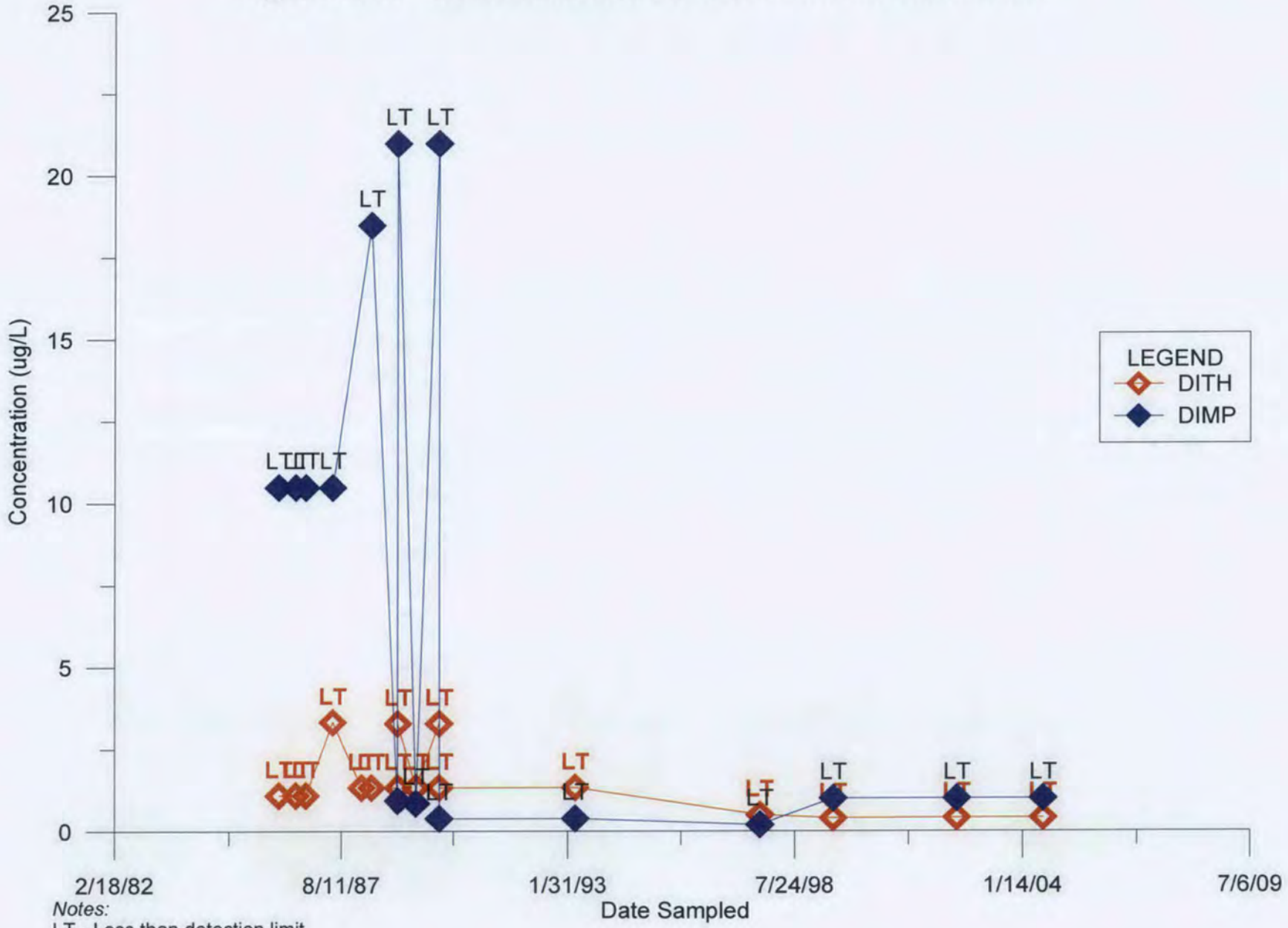
Notes:
LT - Less than detection limit

Figure B-16 Concentration vs. Time Plot of Well 36113



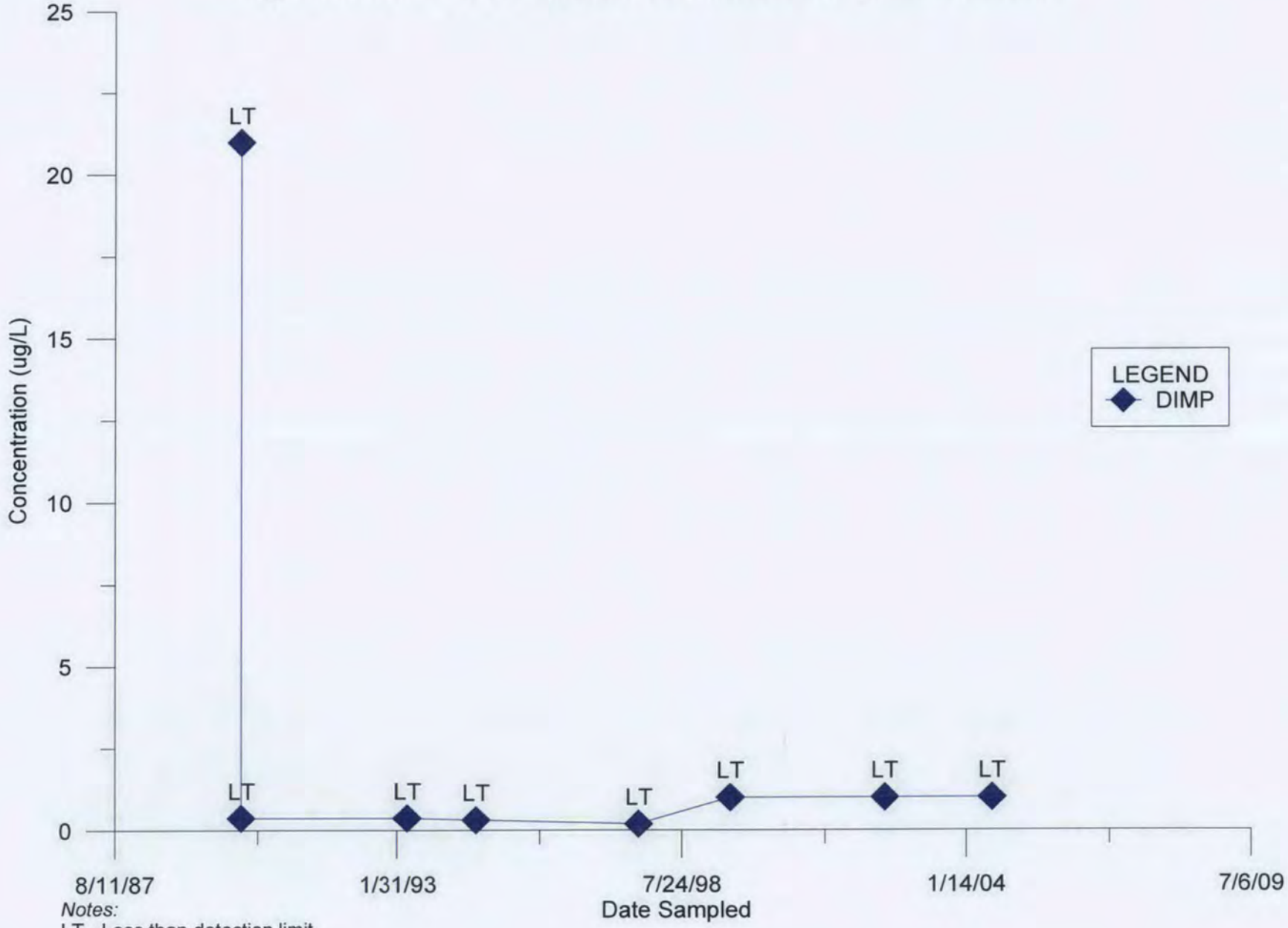
Notes:
LT - Less than detection limit

Figure B-17 Concentration vs. Time Plot of Well 36114



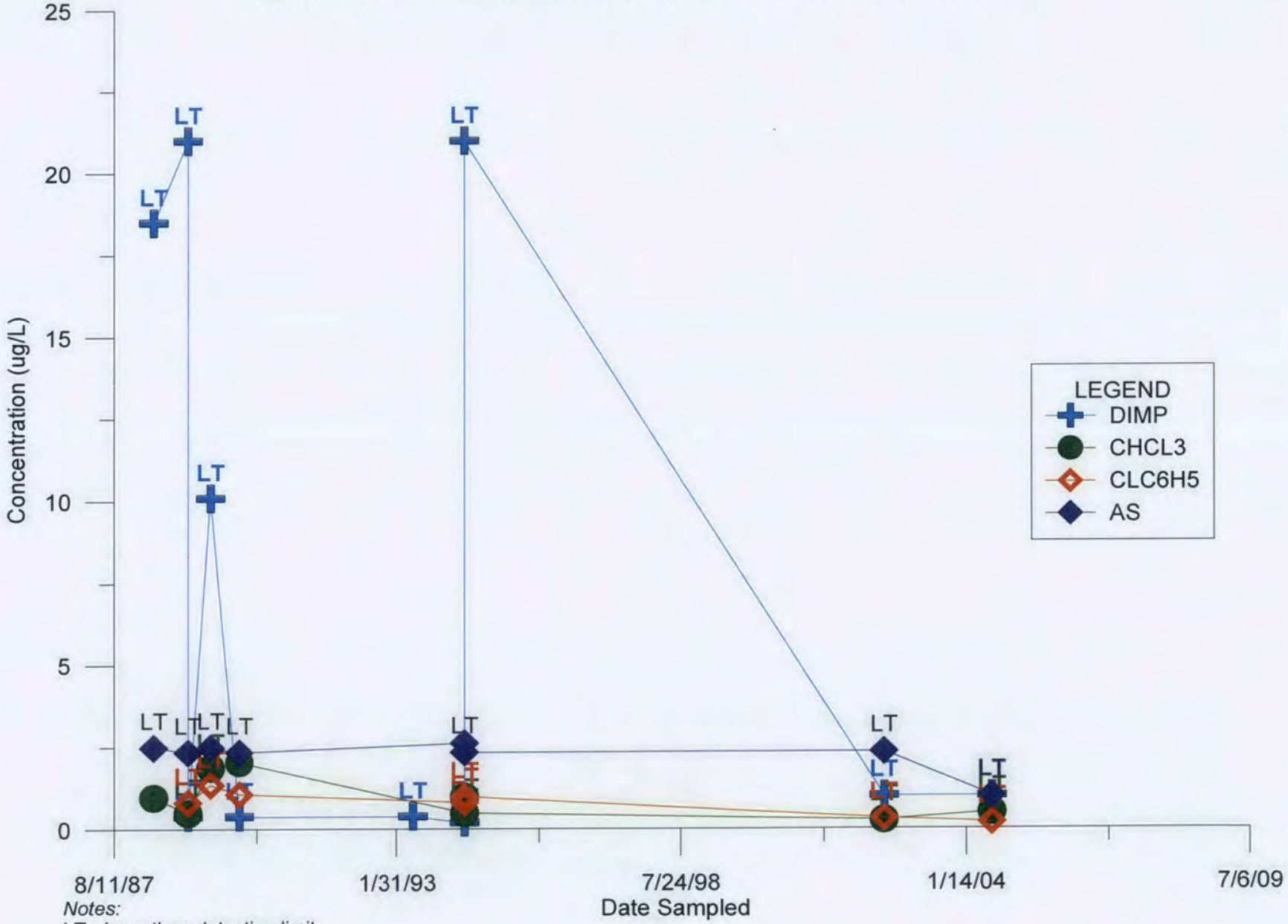
Notes:
LT - Less than detection limit

Figure B-18 Concentration vs. Time Plot of Well 36159



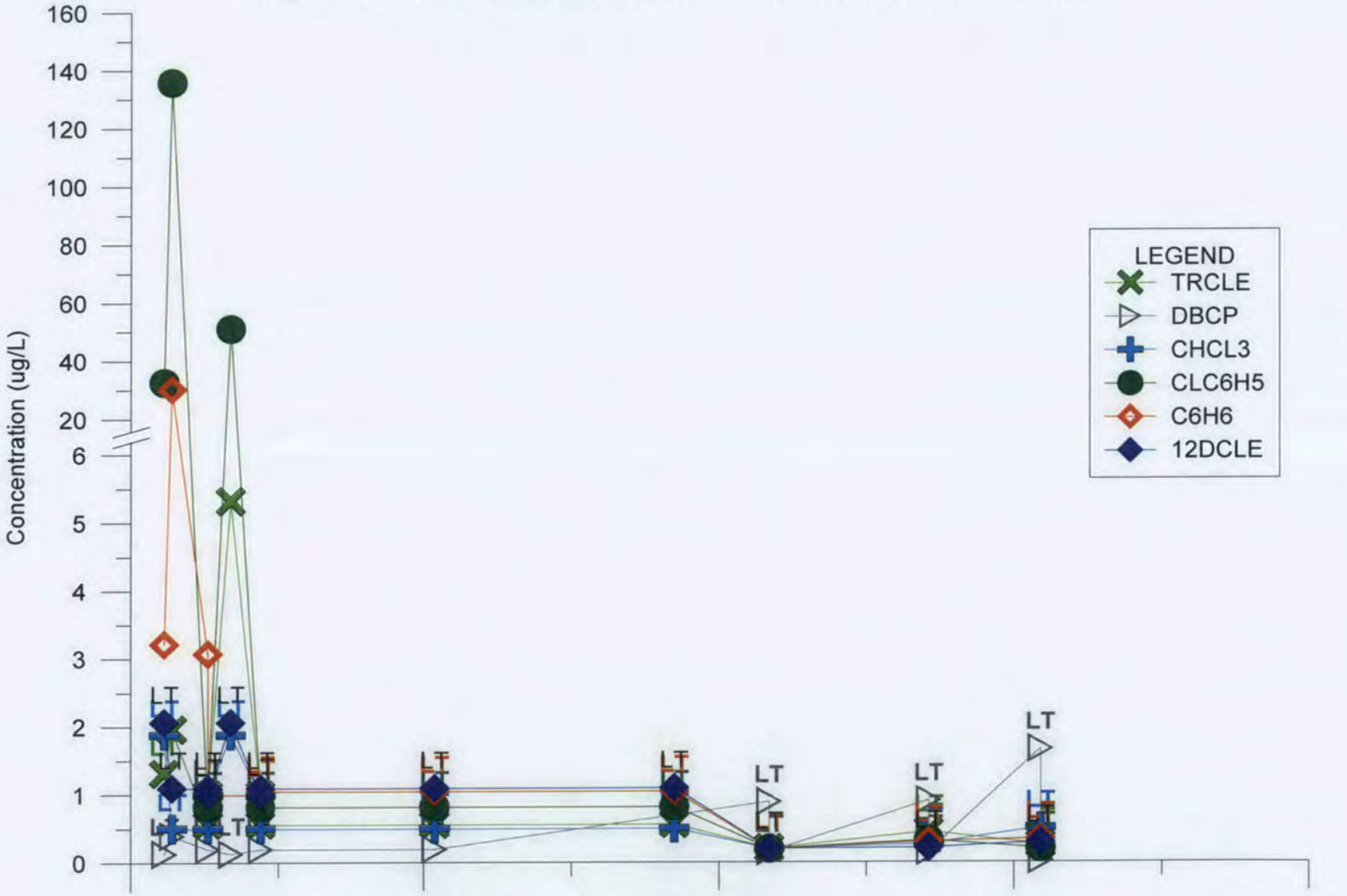
Notes:
LT - Less than detection limit

Figure B-19 Concentration vs. Time Plot of Well 36171



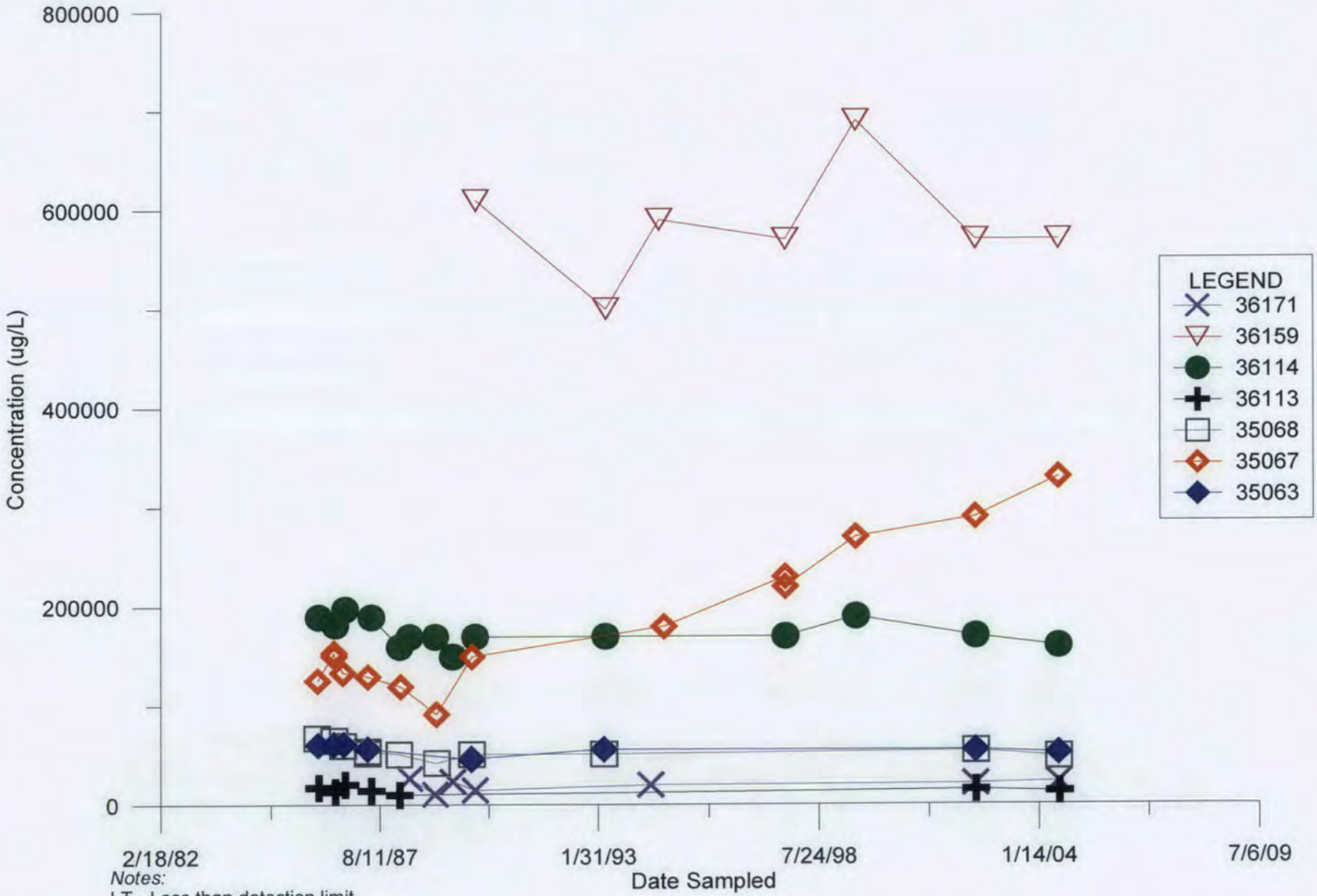
Notes:
LT - Less than detection limit

Figure B-20 Concentration vs. Time Plot of Well 36183



Notes:
LT - Less than detection limit

Figure B-21 Concentration of Chloride vs. Time Plot of Basin A Confined Flow System Wells

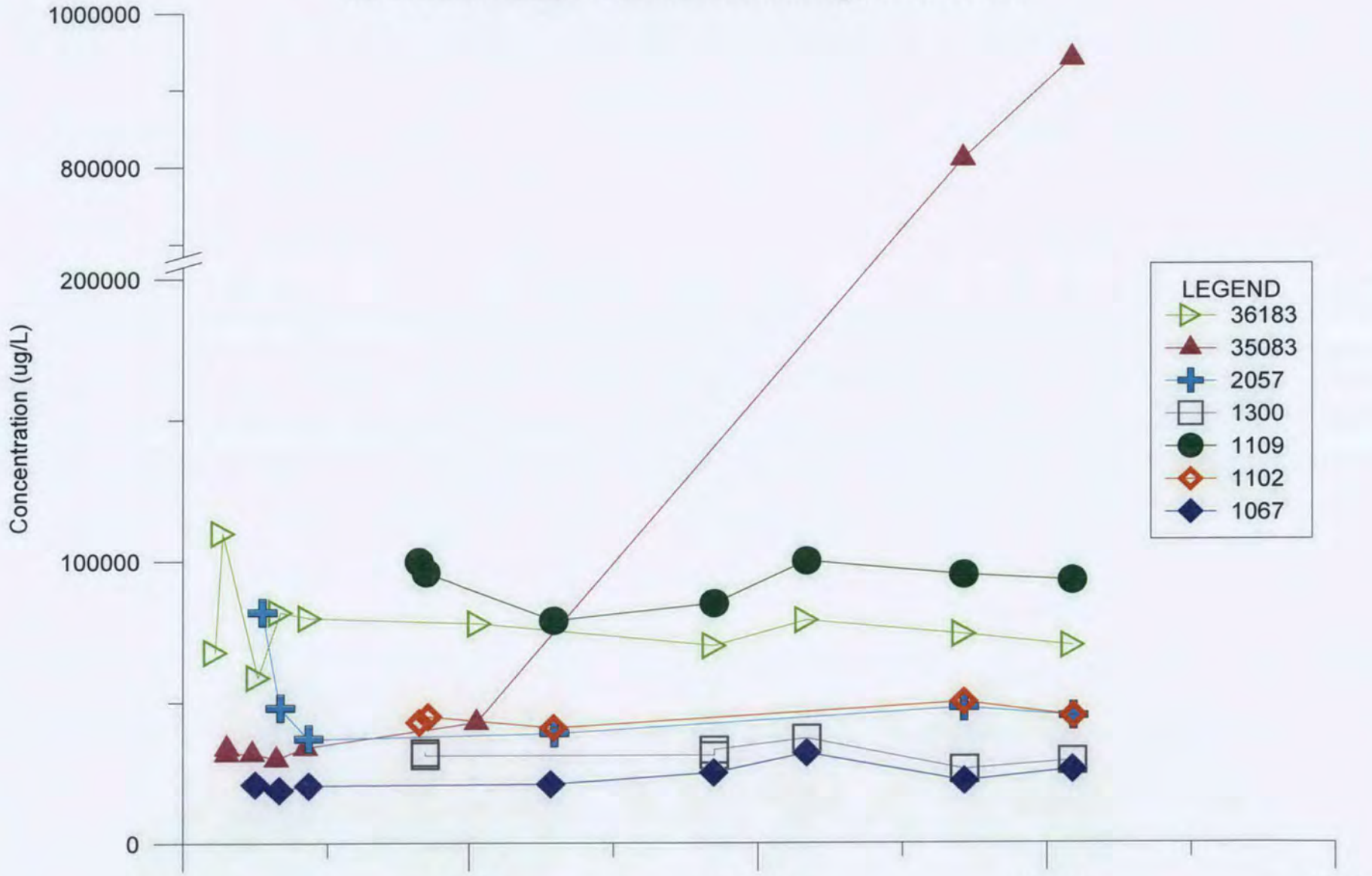


Notes:
LT - Less than detection limit

Figure B-22 Concentration of Chloride vs. Time Plot of Basin F Confined Flow System Wells

Notes:
LT - Less than detection limit

Figure B-23 Concentration of Chloride vs. Time Plot of South Plants Confined Flow System Wells



Notes:
LT - Less than detection limit

APPENDIX C

PRIVATE WELL MONITORING PROGRAM

APPENDIX C

PRIVATE WELL MONITORING PROGRAM

Introduction

The Private Well Monitoring Program is administered by Tri-County Health Department (TCHD) via a Memorandum of Agreement with the Army (PMRMA 1997). Under this program, TCHD samples private wells and surface water sources in the off-post study area. The program is separate and independent from the Army-administered and conducted off-post monitoring program. The primary purpose of private well monitoring is to provide water quality data to address community health concerns related to off-post groundwater contamination. The private well monitoring program will be included in the Off-Post Institutional Control Program.

Data from TCHD's private well monitoring program will be used to help delineate the CSRG Exceedance area. The Offpost OU Remediation Scope and Schedule (RS/S) (HLA 1996) stated that Offpost private wells will be selected for sampling based on the following criteria:

- Available well construction data indicate the well is properly completed within one aquifer
- The well is used for domestic use
- The well is not located near other similarly completed wells that are scheduled to be sampled
- One or more of the following:
    - The well aids in defining the CSRG exceedance area
    - The well has been requested for sampling by the owner
    - The well has indicated detections above the CSRG limit in recent sampling events.

In addition, newly installed private wells within the 1996 DIMP plume footprint are sampled. A selected group of Arapahoe Formation confined flow system (CFS) wells are sampled for well integrity and potential cross contamination from the overlying unconfined aquifer (See Section 2.8.2).

TCHD samples surface water discharges from gravel operations into the South Platte River, which are analyzed for DIMP, and maintains a database with demographic information regarding private wells in the CSRG exceedance area.

TCHD prepares and provides a candidate sampling list based on historical data for RVO, EPA, and CDPHE to review annually. In the past, sampling of up to 50 private wells took place each summer with the permission of the well owners. The list is reviewed by RVO and the other Regulatory Agencies before implementation. Currently, approximately 25 to 35 wells are sampled each year.

As new demographic information and the water quality data become available in the area of interest, they are entered into TCHD and RVO Environmental Databases. The results of the program are provided annually by TCHD to the RVO, EPA, and CDPHE.

The off-post ROD (HLA 1995) included the requirement for sampling and closing CFS wells that exceed CSRGs. The CFS well sampling requirements were amended in the 2000 Five-Year Review Report (FYRR) (RVO 2000) and a 2001 Fact Sheet (RVO 2001). The 1999 LTMP (FWENC 1999) included nine shallow unconfined flow system (UFS) private wells in the off-post CSRG Exceedance network that were to be sampled if possible. As documented in the 2005 FYRR (RVO 2007), the off-post groundwater contaminant concentrations and CSRG exceedance plume areas have decreased significantly since the 1999 LTMP was developed. More private wells were sampled in 2007 and 2009 to confirm these trends and better delineate the CSRG exceedance areas. The additional private-well data collected since 1999 have demonstrated the overall decreasing trends in concentrations such that sampling fewer private wells in the future is appropriate. For example, no private wells had DIMP concentrations above the CSRG in FY2007 and FY2008, and only one private well had a DIMP concentration at the CSRG in FY2009. Additionally, many of the private wells no longer are available for sampling due to a variety of factors, including rapid development of the off-post area, closing of wells, and water rights restrictions.

Arapahoe CFS Wells

Eight Arapahoe CFS wells were identified for continued annual monitoring in the 2000 FYRR and 2001 Fact Sheet. The report recommended that wells 1070B, 343A, 359A, 486C, 588A, 589A, 848A, and 914B should be monitored for DIMP and that wells 1070B and 914B should also be monitored for chloroform. Of these eight wells, six met the criteria established in the 2000 FYRR and 2001 Fact Sheet for discontinuing sampling or they cannot be sampled. The criteria are provided below.

- CFS Well Sampling Criteria
    - Sampling should continue annually until the contaminant concentration falls below analytical reporting limits, or until the well has been sampled at least five times and the mean concentration plus two standard deviations is less than the CSRG.

Wells 343A and 486C are not in use. Only wells 588A and 589A had not met the criteria for discontinuing sampling, but permission was not given for sampling them. The DIMP concentrations were consistently below the CSRG.

In 2004, CFS wells 1171A, 376A, 544A, 545A, 548A, 848A, and 986B were added to TCHD's CFS sampling program. Wells 544A, 545A, 548A, and 848A met the criteria for discontinuing monitoring during the 2000 - 2005 FYR period. Table C-1 is an evaluation of the DIMP and chloroform data applying the above CFS well sampling criteria for the wells specified in the 2000 FYRR and wells subsequently added to TCHD'CFS well monitoring program. Wells 359A, 376A, 914B, 986B, 1070B, and 1171A met the criteria during the 2005 - 2010 FYR period. Thus, all the CFS wells specified in the 2001 Fact Sheet, and the wells added to TCHD's monitoring program in 2004 have met the criteria and the annual CFS monitoring may be

discontinued. TCHD may still sample CFS wells at their discretion or if requested by the well owner, or if permission is granted to sample wells 588A or 589A. As stated previously, the private well monitoring program will be included in the Off-Post Institutional Control Program.

References

FWENC (Foster Wheeler Environmental Corporation)

1999 (Dec.) *Rocky Mountain Arsenal Long-Term Monitoring Plan for Groundwater.* Final.

HLA (Harding Lawson Associates)

1995 (Dec. 19) *Rocky Mountain Arsenal Offpost Operable Unit, Final Record of Decision.*

1996 (Sep. 25) *Remediation Scope and Schedule for the Offpost Operable Unit, Rocky Mountain Arsenal, Commerce City, Colorado.*

PMRMA (Program Manager for Rocky Mountain Arsenal)

1997 (Aug. 13) Memorandum *of Agreement Between Tri-County Health Department and Program Manager for Rocky Mountain Arsenal.*

RVO (Remediation Venture Office)

2000 *2000 Five-Year Review Report*, Final.

2001 (Mar. 25) *Letter to EPA confirming finalization of the Documentation of Non-Significant or Minor Off-post ROD Change at RMA of the CFS Well Evaluation Criteria*

2007 *2005 Five-Year Review Report*, Final.

Table C-1. Offpost Private CFS Well Data Evaluation

Well	Analyte	Sample Date	Boolean	Value	Units	
DIMP						
1070B	DIMP	1999-05-25		7.36	UGL	
1070B	DIMP	1999-06-24		6.59	UGL	
1070B	DIMP	2000-06-14		4.91	UGL	
1070B	DIMP	2001-07-10		3.53	UGL	
1070B	DIMP	2002-07-02		3.54	UGL	
1070B	DIMP	2003-06-09		2.7	UGL	
1070B	DIMP	2003-07-30		2.88	UGL	
1070B	DIMP	2004-07-07		1.86	UGL	
1070B	DIMP	2005-06-24		2.43	UGL	
1070B	DIMP	2006-06-12		2.25	UGL	
1070B	DIMP	2007-06-20		2.48	UGL	
1070B	DIMP	2008-06-18		2.16	UGL	
1070B	DIMP	2009-06-11		1.82	UGL	
			Average	3.42		
			STD	1.79		
			Avg. + 2 STD	7.0		
1171A	DIMP	1990-10-30		1.8	UGL	
1171A	DIMP	1993-12-10		6.5	UGL	
1171A	DIMP	1994-07-18		5.6	UGL	
1171A	DIMP	1994-10-05		5.86	UGL	
1171A	DIMP	1995-01-23		5.43	UGL	
1171A	DIMP	1995-05-04		4.86	UGL	
1171A	DIMP	1995-07-25		7.07	UGL	
1171A	DIMP	1996-01-26		5.08	UGL	
1171A	DIMP	1997-09-18		4.53	UGL	
1171A	DIMP	1998-05-18		4.44	UGL	
1171A	DIMP	1999-07-29		3.41	UGL	
1171A	DIMP	2000-07-18		3.65	UGL	
1171A	DIMP	2001-09-24		2.53	UGL	
1171A	DIMP	2002-09-10	LT	0.35	UGL	
1171A	DIMP	2004-07-13		1.14	UGL	
1171A	DIMP	2005-06-16		1.56	UGL	
1171A	DIMP	2006-06-15		1.47	UGL	
1171A	DIMP	2007-06-18		0.932	UGL	
1171A	DIMP	2009-06-10		0.735	UGL	
			Average	3.52		
			STD	2.15		
			Avg. + 2 STD	7.8		

Table C-1. Offpost Private CFS Well Data Evaluation

Well	Analyte	Sample Date	Boolean	Value	Units	
343A	DIMP	1993-09-30		0.411	UGL	
343A	DIMP	1995-08-02	LT	0.92	UGL	
343A	DIMP	1996-01-22	LT	0.35	UGL	
343A	DIMP	1998-05-20		0.48	UGL	
			Average	0.54		
			STD	0.26		
			Avg. + 2 STD	1.06		
359A	DIMP	1991-11-19		3.25	UGL	
359A	DIMP	1994-07-19	LT	1.78	UGL	
359A	DIMP	1995-01-24		3.4	UGL	
359A	DIMP	1995-07-31		6.49	UGL	
359A	DIMP	1996-01-25		4.8	UGL	
359A	DIMP	1998-05-19		4.77	UGL	
359A	DIMP	1998-09-29		3.12	UGL	
359A	DIMP	1999-07-29		5.68	UGL	
359A	DIMP	2000-06-28		4.02	UGL	
359A	DIMP	2001-06-06		4.24	UGL	
359A	DIMP	2002-07-09		3.69	UGL	
359A	DIMP	2003-07-14		1.01	UGL	
359A	DIMP	2004-06-29		2.72	UGL	
359A	DIMP	2005-08-25		4.96	UGL	
359A	DIMP	2006-07-05		4.1	UGL	
359A	DIMP	2007-06-14		4.04	UGL	
359A	DIMP	2008-06-11		2.58	UGL	
359A	DIMP	2009-06-16		3.77	UGL	
			Average	3.8		
			STD	1.33		
			Avg. + 2 STD	6.45		
376A	DIMP	1992-02-06	LT	0.392	UGL	
	DIMP	1996-03-27	LT	0.35	UGL	
	DIMP	1998-09-18	LT	0.35	UGL	
	DIMP	2003-06-24	LT	0.35	UGL	
	DIMP	2004-06-15	LT	0.35	UGL	
	DIMP	2005-06-17	LT	0.4	UGL	
	DIMP	2006-06-15	LT	0.4	UGL	
	DIMP	2007-06-18	LT	0.4	UGL	
	DIMP	2009-06-09	LT	0.5	UGL	
486C	DIMP	1998-03-10		0.624	UGL	
544A	DIMP	1992-01-28	LT	0.392	UGL	
	DIMP	1994-10-07	LT	0.6	UGL	
	DIMP	2002-07-10	LT	0.35	UGL	
	DIMP	2004-08-18	LT	0.35	UGL	
545A	DIMP	1991-01-31	LT	0.392	UGL	
	DIMP	1995-07-28	LT	0.92	UGL	
	DIMP	1997-05-12	LT	0.35	UGL	

Table C-1. Offpost Private CFS Well Data Evaluation

Well	Analyte	Sample Date	Boolean	Value	Units	
	DIMP	1998-05-20	LT	0.35	UGL	
	DIMP	2004-06-15	LT	0.35	UGL	
548A	DIMP	1992-07-16	LT	0.392	UGL	
	DIMP	1993-11-17	LT	0.2	UGL	
	DIMP	1997-05-12	LT	0.35	UGL	
	DIMP	1998-05-21	LT	0.35	UGL	
	DIMP	2002-07-09	LT	0.35	UGL	
	DIMP	2004-07-14	LT	0.35	UGL	
588A	DIMP	1991-10-15		8.44	UGL	
588A	DIMP	1993-11-18		5.5	UGL	
588A	DIMP	1994-09-22		5.01	UGL	
588A	DIMP	1994-09-22		4.81	UGL	
588A	DIMP	1995-05-04		4.33	UGL	
588A	DIMP	1995-08-01	LT	0.92	UGL	
588A	DIMP	1996-02-14		3.33	UGL	
			Average	4.62		
			STD	2.27		
			Avg. + 2 STD	9.17		
589A	DIMP	1992-01-28		3.49	UGL	
589A	DIMP	1993-11-16		9.9	UGL	
589A	DIMP	1994-07-22		4.71	UGL	
589A	DIMP	1994-10-06		5.01	UGL	
589A	DIMP	1995-01-26		3.87	UGL	
589A	DIMP	1995-05-02		4.69	UGL	
589A	DIMP	1995-07-25		5.22	UGL	
589A	DIMP	1995-10-05		4.6	UGL	
589A	DIMP	1996-01-26		2.13	UGL	
589A	DIMP	1998-05-18		4.69	UGL	
589A	DIMP	1999-07-29		1.91	UGL	
			Average	4.57		
			STD	2.09		
			Avg. + 2 STD	8.75		
848A	DIMP	1996-06-11		0.906	UGL	
848A	DIMP	1996-09-09		0.974	UGL	
848A	DIMP	1998-05-21		1.28	UGL	
848A	DIMP	1999-05-26		1.32	UGL	
848A	DIMP	2000-06-29		1.74	UGL	
848A	DIMP	2001-06-13	LT	0.35	UGL	
848A	DIMP	2001-08-03		1.11	UGL	
848A	DIMP	2002-07-16		0.708	UGL	
848A	DIMP	2003-06-10	LT	0.35	UGL	
848A	DIMP	2004-06-30	LT	0.35	UGL	
			Average	0.91		
			STD	0.47		
			Avg. + 2 STD	1.86		

Table C-1. Offpost Private CFS Well Data Evaluation

Well	Analyte	Sample Date	Boolean	Value	Units	
914B	DIMP	1999-05-26		1.02	UGL	
914B	DIMP	1999-06-24		1.07	UGL	
914B	DIMP	2000-05-25		1.75	UGL	
914B	DIMP	2001-07-10		3.6	UGL	
914B	DIMP	2002-07-16		3.11	UGL	
914B	DIMP	2003-06-16		2.51	UGL	
914B	DIMP	2004-07-06		2.67	UGL	
914B	DIMP	2005-06-15	LT	0.4	UGL	
914B	DIMP	2006-06-12		1.6	UGL	
914B	DIMP	2007-06-20		0.888	UGL	
914B	DIMP	2008-07-02		1.78	UGL	
914B	DIMP	2008-07-02	LT	0.5	UGL	
			Average	1.74		
			STD	1.04		
			Avg. + 2 STD	3.82		
986B	DIMP	1991-10-16	LT	0.392	UGL	
986B	DIMP	1993-06-17	LT	0.392	UGL	
986B	DIMP	1994-10-04	LT	0.6	UGL	
986B	DIMP	1996-02-13	LT	0.35	UGL	
986B	DIMP	1998-06-02	LT	0.35	UGL	
986B	DIMP	1998-09-24	LT	0.35	UGL	
986B	DIMP	2002-07-18	LT	0.35	UGL	
986B	DIMP	2004-06-17	LT	0.35	UGL	
986B	DIMP	2005-06-14	LT	0.4	UGL	
986B	DIMP	2006-06-13	LT	0.4	UGL	
986B	DIMP	2007-06-04	LT	0.4	UGL	
986B	DIMP	2009-05-18	LT	0.5	UGL	
Chloroform						
1070B	CHCL3	1999-06-24		8.86	UGL	
1070B	CHCL3	2000-06-14		0.209	UGL	
1070B	CHCL3	2001-07-10		0.447	UGL	
1070B	CHCL3	2003-07-30	LT	0.2	UGL	
914B	CHCL3	1999-06-24		1.09	UGL	
914B	CHCL3	2001-07-10	LT	0.2	UGL	

Table C-1. Offpost Private CFS Well Data Evaluation

		Sample				
Well	Analyte	Date	Boolean	Value	Units	
Notes:						
STD = Standard Deviation						
LT = Less Than						
UGL = Micrograms per liter						
DIMP = Diisopropylmethyl phosphonate						
CHCL3 = Chloroform						