Alabama Department of Transportation

Coliseum Boulevard Plume Analysis of TCE Trends Over Time Through January 2008

July 2008

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A. Trend Plots for TCE Concentrations
B. TCE Degradation Products and TCE Degradation Indicator Parameters

1. Introduction

Groundwater samples have been collected from monitoring wells and Continuous Multichannel Tubing (CMT) wells at the Coliseum Boulevard Plume (CBP) Site from 2001 through January 2008. Currently samples are collected at varying frequencies from 135 monitoring wells, of which 96 wells are evaluated for trend analysis. Sufficient analyses have been completed that the data can be evaluated by visual and statistical methods to determine:

- Temporal changes in TCE concentrations throughout the CBP Site.
- Groundwater level changes and effects on TCE movement throughout the CBP Site.
- Occurrences and distributions of compounds that result from the degradation of the TCE.

These topics are discussed in the following sections. The first section provides the results of trend analyses to determine temporal changes in TCE concentrations at the CBP Site. The subsequent section, "Degradation of TCE," includes discussions of the limited occurrences and distribution of compounds that result from the degradation of TCE.

2. Temporal Changes in TCE Concentrations

2.1. Methodology

Time-series plots and intrawell Shewhart-Cumulative Sum (CUSUM) control charts were used to evaluate the trends in TCE concentrations. Trends were evaluated only for wells where TCE concentrations were above the detection limit for a sufficient number of sampling events to develop valid trends. Wells with detectable levels of TCE are restricted to the Shallow Zone (above the first restrictive clay). As a consequence, trends for only 100- and 200- series wells are evaluated, as TCE has not been detected in a Deep Zone well (300- and 400- series). The 100- series wells are always the upper most well screened in the Shallow Zone (SZ), and at most locations correspond to the top of the aquifer. Where there is a cluster of three wells, the 200B- series is screened at an intermediate depth and the 200C- series is at the base of the Shallow zone.

The following monitoring locations were added to the trend analysis in 2007, for a total of 96 routine sample locations:

100 Series	200B Series	200C Series
	MW-243B	
MW-146A	MW-246B	
	MW-247B	
MW-149A	MW-249B	MW-249C
MW-150A	MW-250B	MW-250C
MW-151A	MW-251B	
MW-152A	MW-252B	
MW-153		
MW-156		

These wells were constructed within the past three years and previously did not have a sufficient number of samples to calculate trend statistics.

2.1.1. Time-series Plots

Time-series plots provide for visual interpretations of trends. The TCE data were plotted for each well for which there were more than 8 sets of samples with TCE concentrations above detectable levels (Appendix A).

2.1.2. Shewhart-CUSUM Statistical Analysis:

The Shewhart-CUSUM statistical analysis provides two statistics that are based on comparison of recent monitoring results to results from the first four sampling events for each well. The Shewhart statistic represents the "current" trend relative to baseline, whereas the CUSUM statistic represents the long-term trend relative to baseline (the CUSUM statistic retains a "memory" of previous values because it is a summed statistic). The numeric values that determine statistical significance for the Shewhart and CUSUM trend methods are provided on Table 2-1.

Table 2-1.
Shewhart-CUSUM Test for Significant Trend

Statistical Significance	Shewhart Statistic	CUSUM Statistic
Significant Increase (increase)	> 4.5	> 5
No Significant Trend	<= 4.5 and >= -4.5	<= 5 and >= -5
Significant Decrease (increase)	< -4.5	< -5

2.2. Results

Of the wells from which water samples contained detectable levels of TCE, approximately 60 percent are lower Shallow Zone wells. Recharge from precipitation to the top of the aquifer causes this stratification of TCE such that the higher concentrations are near the base of the aquifer. The well locations used for the trend analysis are presented on Figure 2-1. Table 2-1 provides a comparison of the Shewart and CUSUM statistics for data from the upper Shallow Zone and lower Shallow Zone monitoring wells. For long-term trends (CUSUM statistic) and the most recent trends (Shewhart statistic), relatively few wells had increasing trends in TCE concentrations, with 80 and 77 percent of all monitoring wells exhibiting either no trend or a decreasing trend for the Shewhart and CUSUM statistics. Currently, 18 percent of the upper Shallow Zone wells have increasing recent and long-term trends and 21 and 25 percent of the lower Shallow Zone wells have increasing recent and long-term trends.

Table 2-2.
Distribution of Time Trends between Upper and Lower Shallow Zone Wells

Well Screen Interval	Shewhart Statistics				CUSUM Statistics			
	Increase	No Trend	Decrease	Total	Increase	No Trend	Decrease	Total
SITE WIDE								
Upper SZ	18%	67%	15%	100%	18%	6%	76%	100%
Lower SZ	21%	63%	16%	100%	25%	13%	62%	100%
All Wells	20%	64%	16%	100%	23%	10%	67%	100%
PH12 AREA								
All Wells	7%	72%	21%	100%	11%	3%	86%	100%

Note: "Increase" and "decrease" are statistically significant trends.

Spatial distributions of the trends are presented on Figures 2-2 and 2-3. The recent trend for each well is presented on Figure 2-2 and the distribution of the CUSUM statistic for each well is presented in Figure 2-3. The values for the Shewhart statistics and CUSUM statistics are provided in Appendix A. Most of the wells with increasing trends are along the southwest-northeast axis of the plume (Figures 2-4 and 2-5). This axis coincides with the dominant directions of groundwater flow. Wells with no trend or decreasing trends are principally found in and close to the PH12 area and in areas around open fields where recharge from precipitation is greater (Figures 2-6 and 2-7).

2.3. Changes in TCE Trends from October 2006 to January 2008

The trend analysis has been carried out on an annual basis since 2005. The following summarizes changes in the trend analysis that have occurred since the previous report dated March 2007 documented TCE trends through October 2006.

Monitoring locations that exhibited a change in the most recent trends compared to the trends over the previous years can be grouped into the following categories:

A. Aligned along southwest or northeast axis of plume. All of these wells exhibited a change in an increasing direction:

100 Series			200B Series			200C Series		
Location	**SH**	**CU**	**Location**	**SH**	**CU**	**Location**	**SH**	**CU**
			MW-201	✓				
			MW-203	✓				
			MW-207		✓			
MW-111	✓	✓	MW-211		✓			
MW-125			MW-225	✓	✓			
			MW-226	✓				
MW-128	✓	✓	MW-228	✓				
MW-130								
						MW-236C		✓

Note: SH = Change in the Shewhart Statistic between October 2006 and January 2008
CU = Change in the CUSUM Statistic between October 2006 and January 2008

This change is attributable to a combination of the movement of higher upgradient TCE concentrations toward these monitoring locations plus effects of the drought conditions through 2007.

B. Located within the PH12 area. All of these locations were CMT ports that, except CMT 2-7, exhibited a change in a decreasing direction:

CMT 1			CMT 2			CMT 3			CMT 4		
Port	**SH**	**CU**	**Port**	**SH**	**CU**	**Port**	**SH**	**CU**	**Port**	**SH**	**CU**
CMT 1-5	✓		CMT 2-3	✓		CMT 3-5		✓	CMT 4-4	✓	
CMT 1-7	✓	✓	CMT 2-4	✓		CMT 3-6	✓		CMT 4-7	✓	
			CMT 2-5		✓						

Note: SH = Change in the Shewhart Statistic between October 2006 and January 2008
CU = Change in the CUSUM Statistic between October 2006 and January 2008

The change observed in these CMT sample ports is a result of biodegradation that is facilitated by the localized (less than 15 feet from each well location) higher pH created from grout used in construction of these wells. The change from *"no significant trend"* to *"significant increase"* for CMT 2-7 is attributable to slight changes in vertical groundwater flow caused by variation in precipitation. Over a vertical distance of less than 4 feet the TCE concentration increases from 242 ug/L in CMT 2-7 to 817 ug/L in the overlying port (CMT 2-6), masking any lateral temporal change observed in CMT 2-7.

C. Located near the Montgomery Zoo Pond: MW-215

With the increased reliance on the Zoo Pond as a source of water for irrigation and moat water coupled with the significant drought through 2007, the TCE concentration in the lower of two clustered wells, MW-215, has increased significantly. Use of the Zoo Pond has induced a local northward gradient toward the pond and the increase in concentration from less than 5 ug/L at MW-215 in 2006 to 44 ug/L in January 2008 is consistent with expected trends. TCE concentrations in the shallow well, MW-115, are either non-detect or only slightly above detectable levels.

D. North-central area of the Plume: MW-2A

The increase in TCE at this monitoring well is attributable to the drought conditions through 2007. TCE concentrations in MW-2A increased to levels observed during the drought experienced in 2002.

3. Degradation of TCE

In addition to TCE, analyses for other volatile organic compounds typically found as impurities in TCE (e.g., 1,1-dichloroethene) or degradation products of TCE (e.g., cis 1,2-dichloroethene and vinyl chloride) have been completed. Indicators of biodegradation (e.g., methane) also have been routinely measured. Few TCE degradation products have been detected in groundwater samples from within the CBP; where detected, they are predominately from within the PH12 area of the plume. Vinyl chloride has been detected only since October 2005 (see time trend graphs in Appendix B). The occurrences of these degradation products are largely restricted to two CMT wells within the PH12 area and results from highly localized elevated pH around the CMT wells. The higher pH occurs where the groundwater is in contact with grout used to seal the annular space around the CMT well and the area of influence is so localized that any effects are not seen at a distance of 15 feet from the CMT well. There is no evidence that significant biodegradation is occurring within the CBP (see Figures B-1 through B-5 in Appendix B).

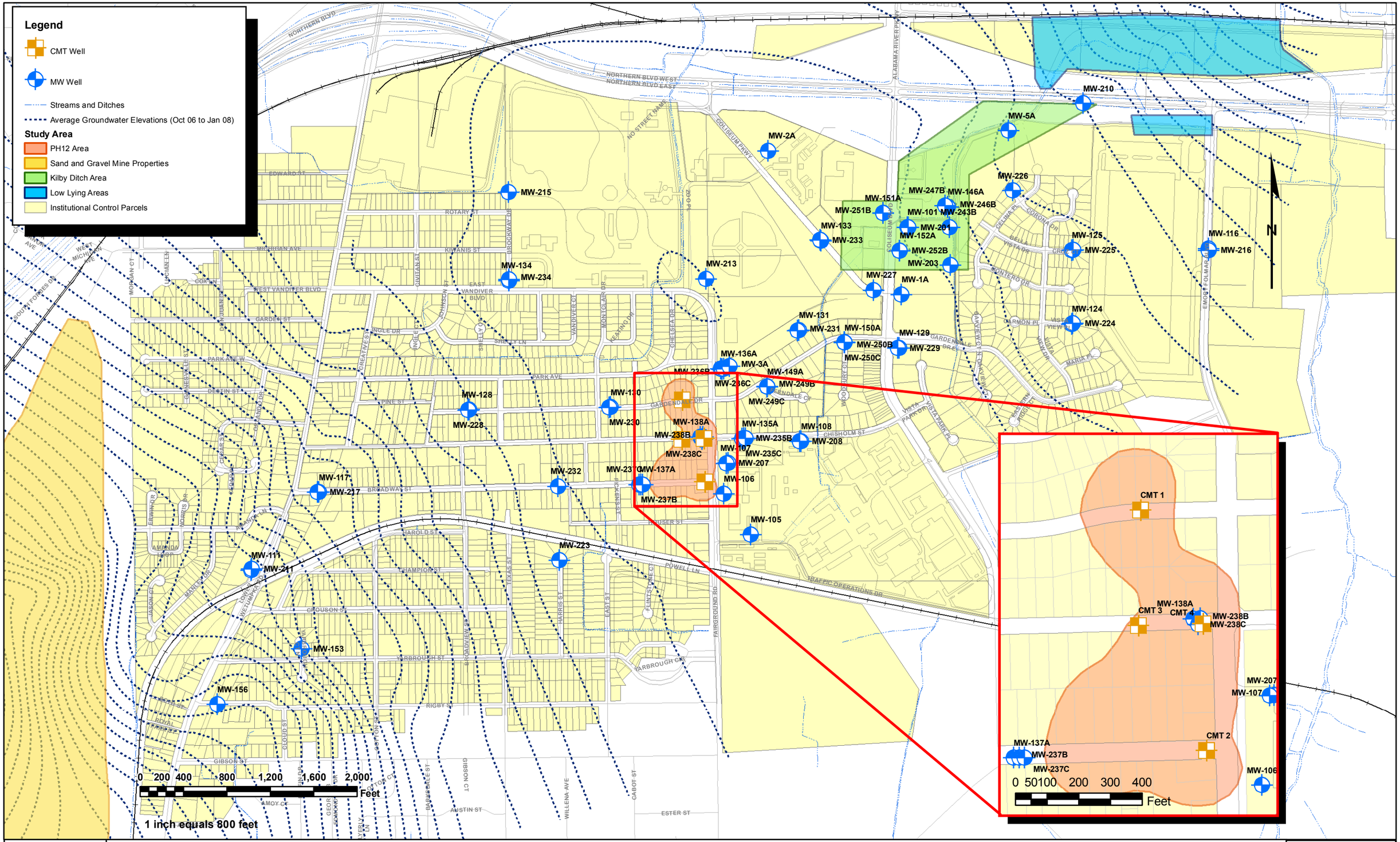
1,1-dichloroethene (1,1-DCE) is found as an impurity in TCE and as such, its concentration is directly proportional to the corresponding TCE concentration at a specific monitoring location (Figures B-1 and B-2).

Cis 1,2-dichloroethene (cis 1,2-DCE) is present as a biodegradation product of TCE and is found above detectable levels in the PH12 area and portions of the Kilby Ditch with highest concentrations associated with the CMT wells (Figure B-3).

Vinyl Chloride (VC) like cis 1,2-DCE, is a biodegradation product of TCE, but is found only in samples from the CMT wells (Figure B-4). The presence of vinyl chloride corresponds with the presence of dehalococcoides, which is controlled by the pH of the groundwater.

Methane above detectable levels has predominantly been measured in samples from the PH12, Kilby Ditch, and Low Lying areas. Highest concentrations are in samples from CMT-4 and directly correlate with vinyl chloride concentrations detected in samples from these wells (Figure B-5).

pH of the groundwater throughout the CBP is acidic (averaging 4.90). This low pH prevents growth of bacteria such as dehalococcoides. A higher pH in samples from the CMT wells (averaging 6.17) is a result of the grout used to construct these wells, and as a consequence, allows for highly localized growth of dehalococcoides. The effect of the grout extends less than 15 feet from the CMT wells.



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Wells Used in TCE Assessment

FIGURE 2-1

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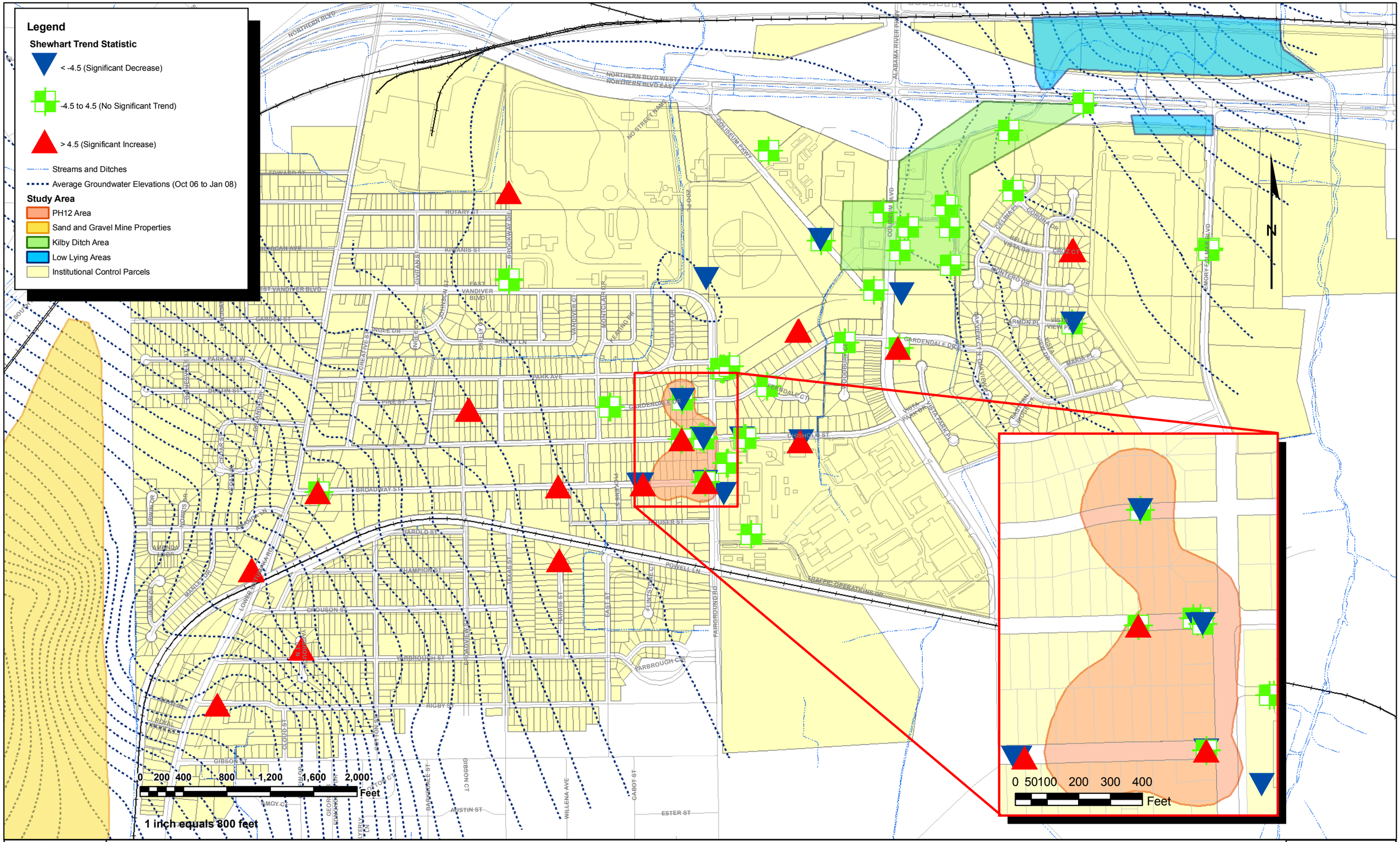

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Shewhart Trend Summary

FIGURE 2-2

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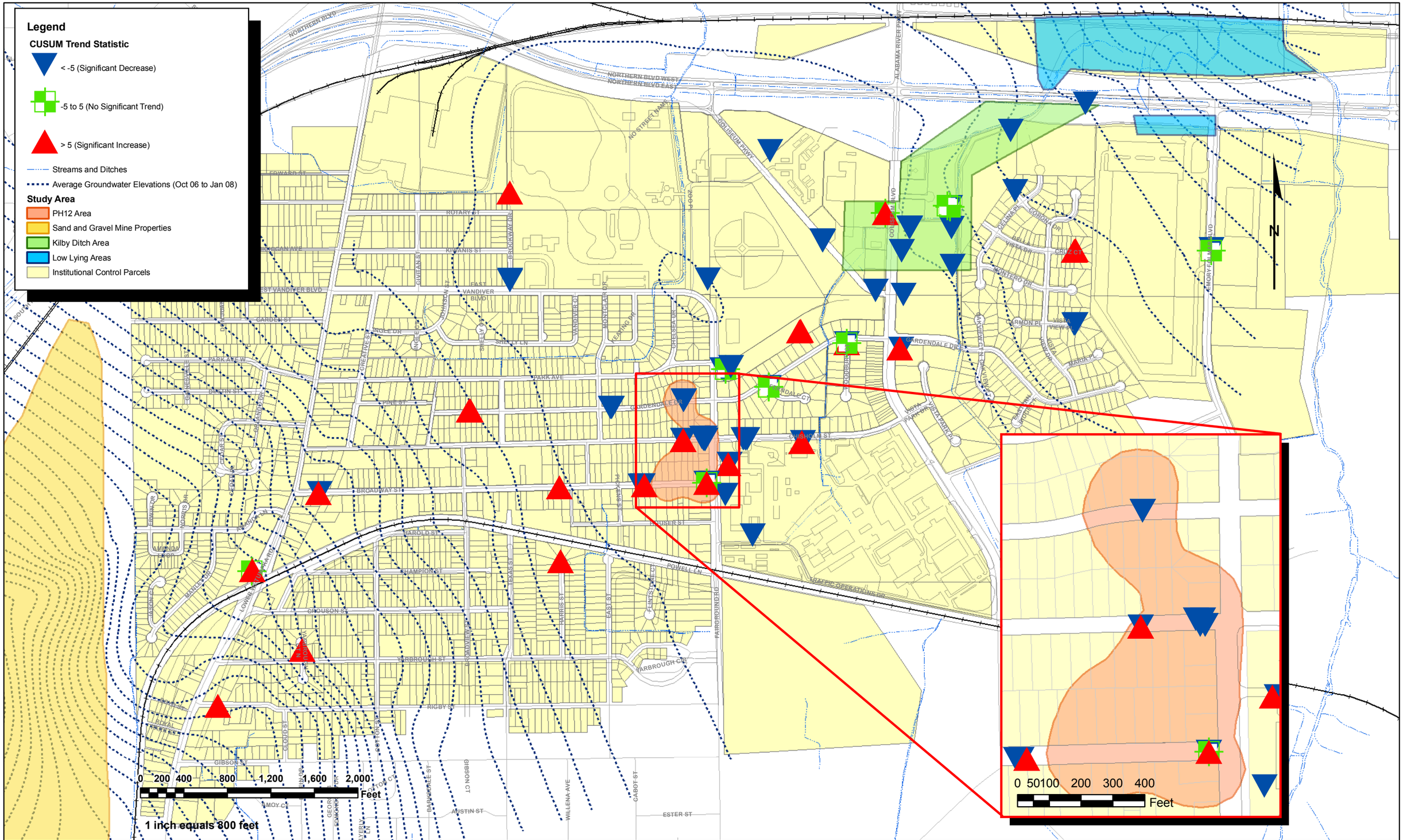

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CUSUM Trend Summary

FIGURE 2-3

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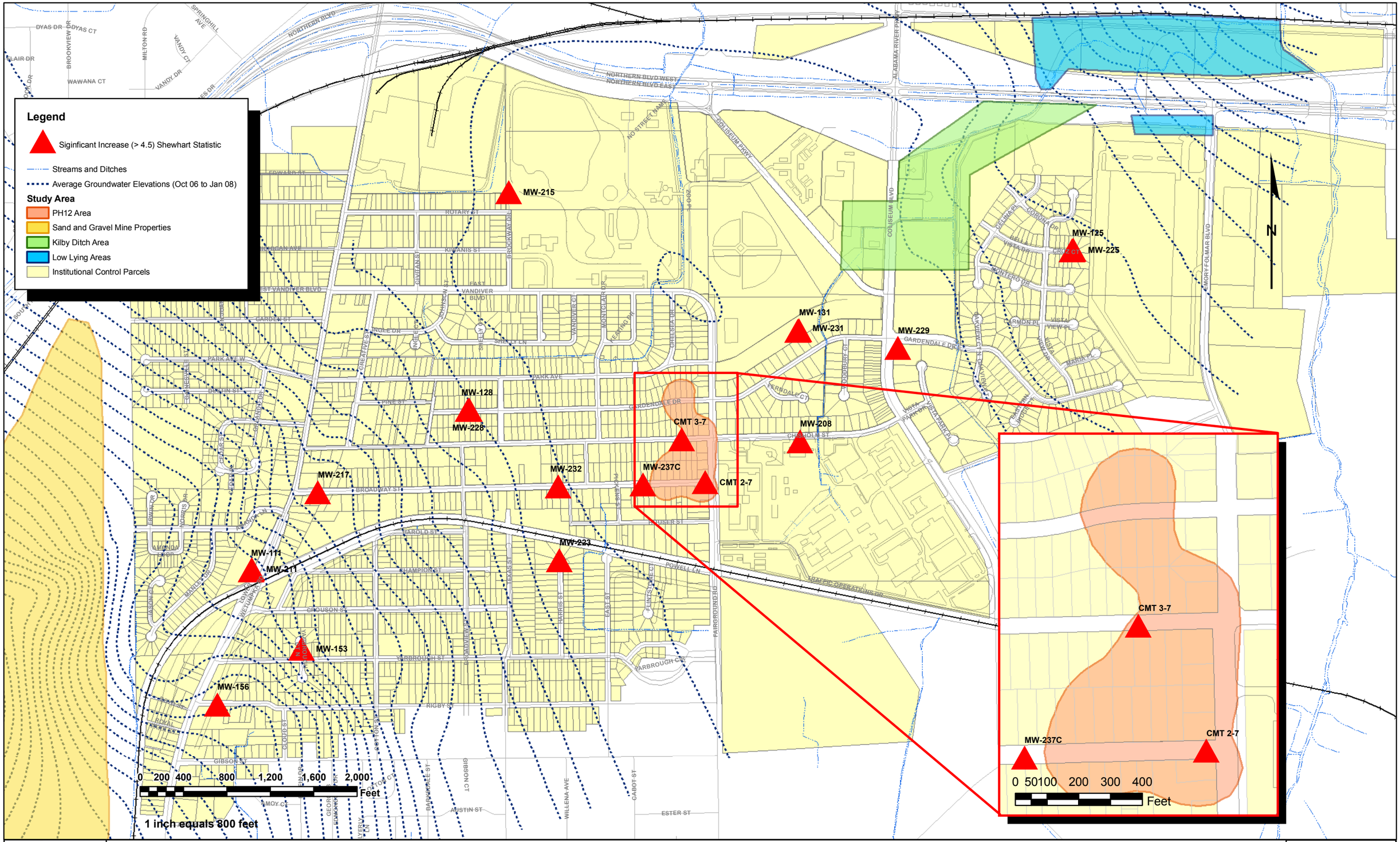

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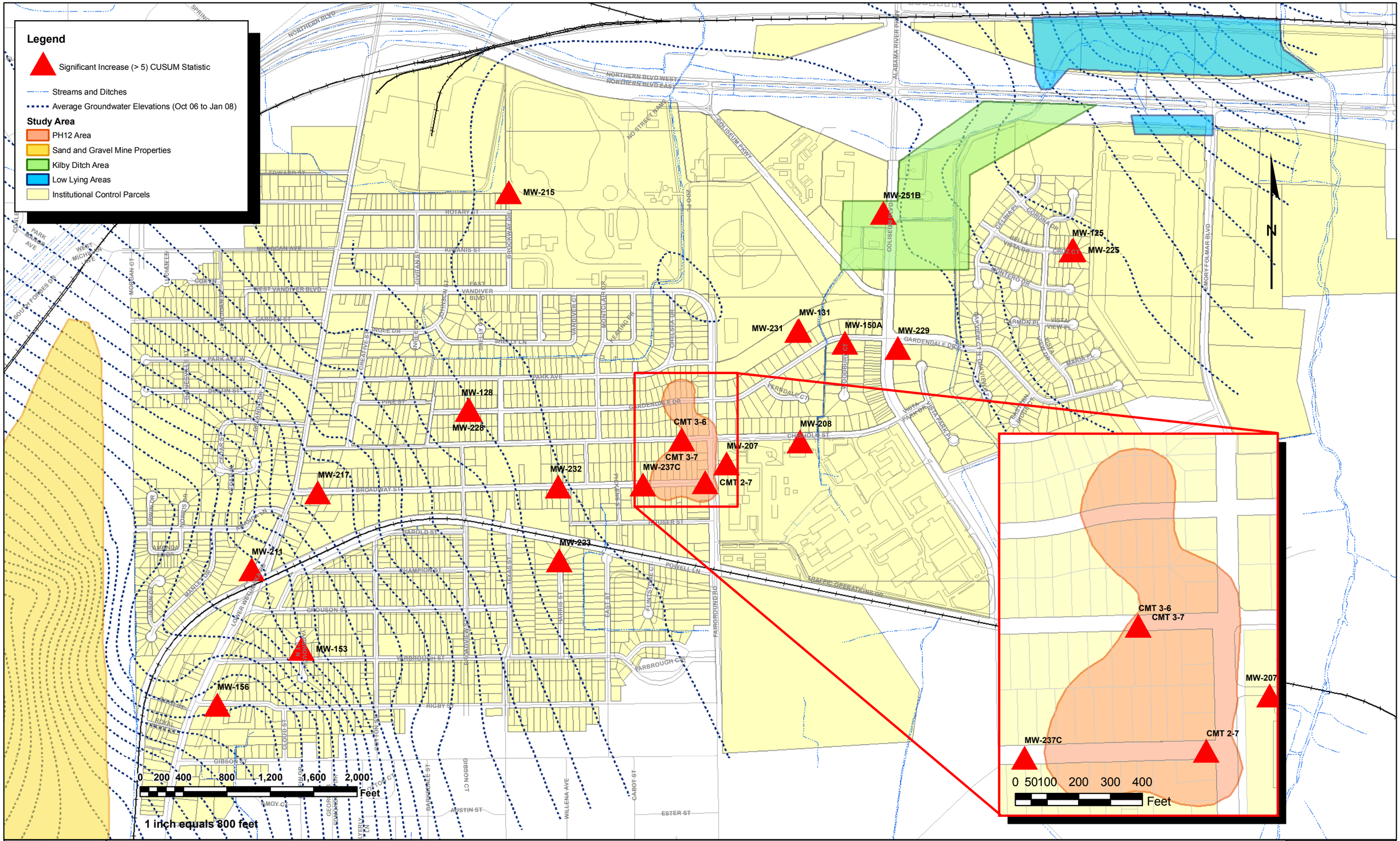
Wells With Significant Increasing TCE Trends - Shewhart Statistic

FIGURE 2-4

July 2008



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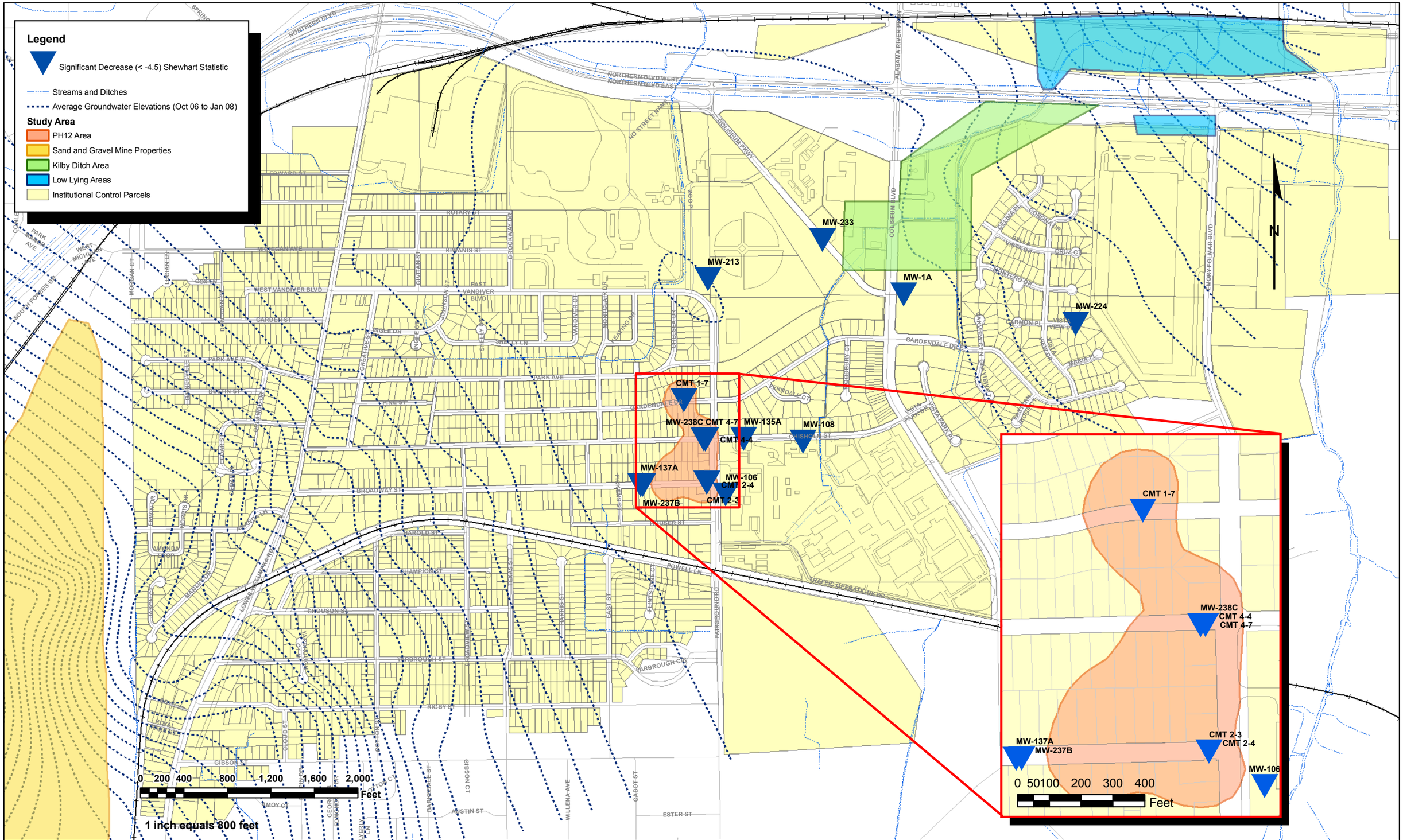
Wells With Significant Increasing TCE Trends - CUSUM Statistic

FIGURE 2-5

July 2008



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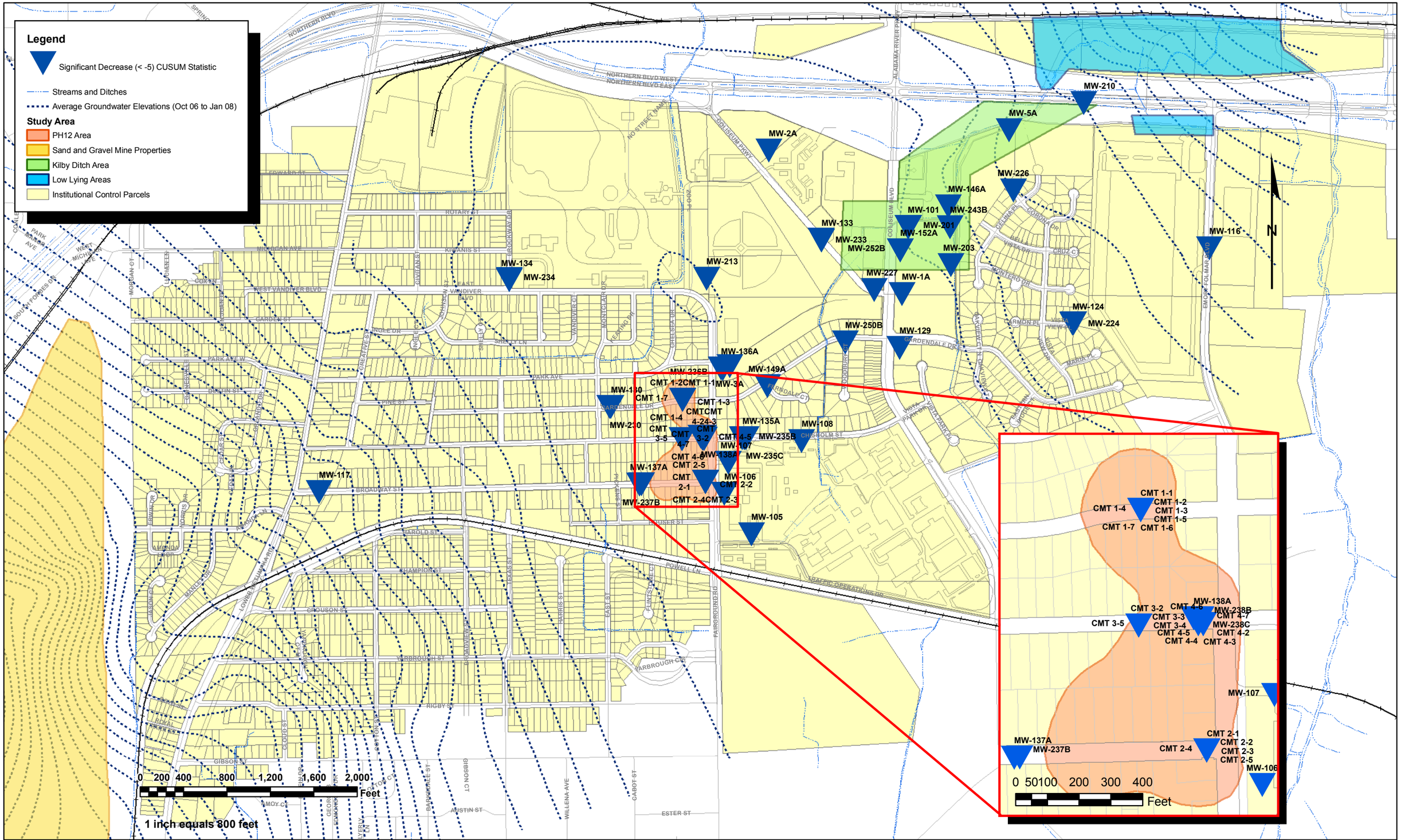
Wells With Significant Decreasing TCE Trends - Shewhart Statistic

FIGURE 2-6

July 2008



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Wells With Significant Decreasing TCE Trends - CUSUM Statistic

FIGURE 2-7

July 2008

APPENDIX A

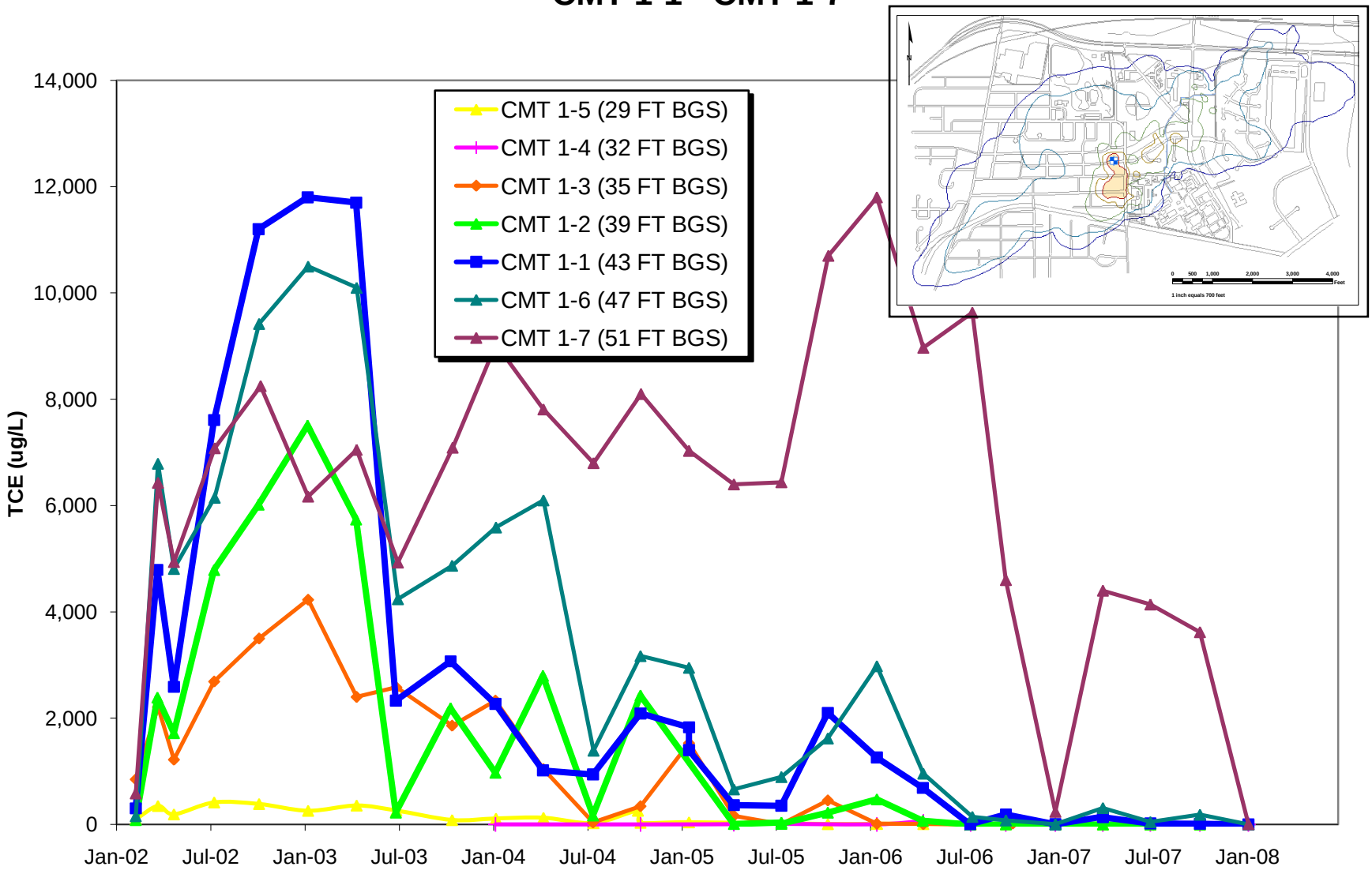
TREND PLOTS FOR TCE CONCENTRATIONS

SUMMARY OF TREND ANALYSIS METRICS FOR TCE

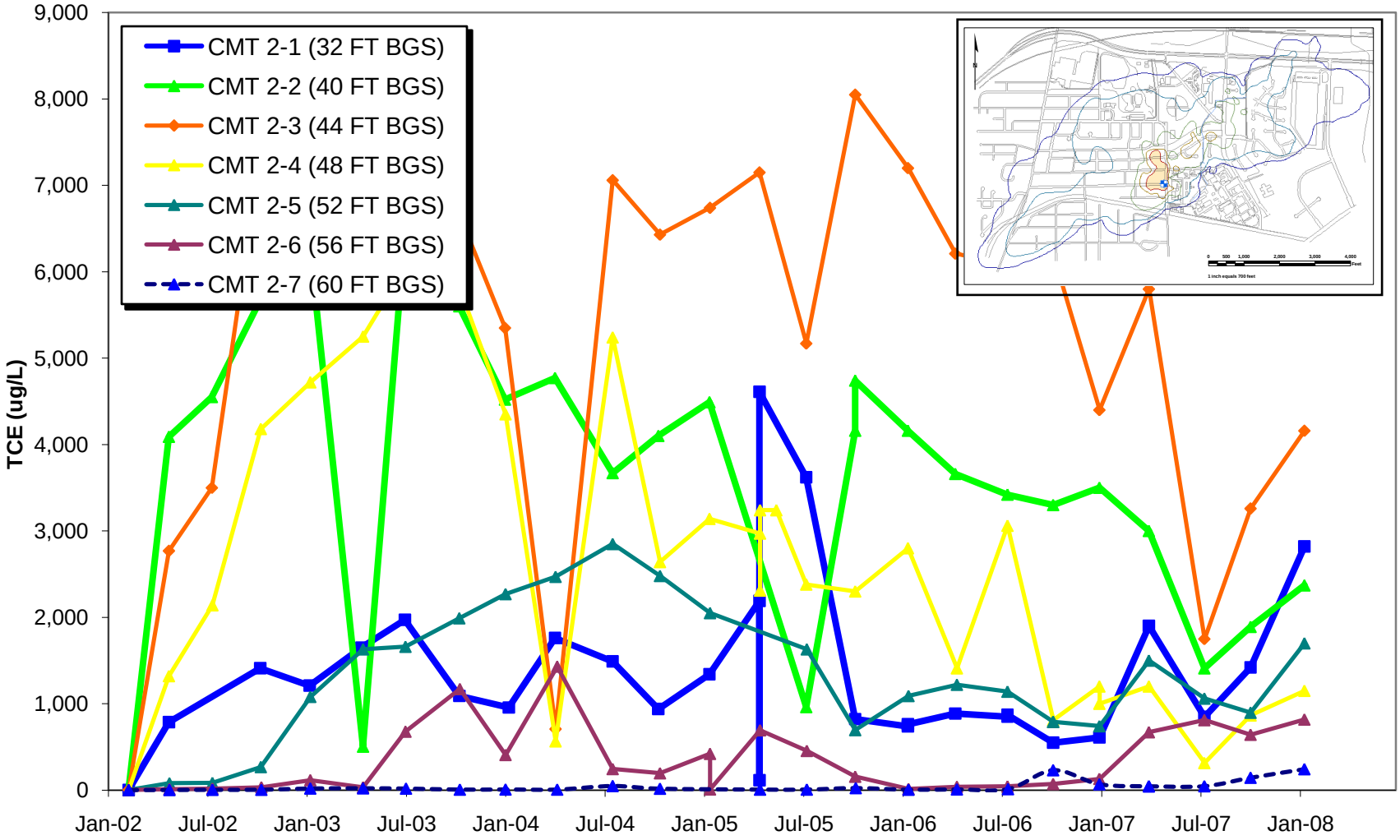
SHEWHART STATISTIC						CUSUM STATISTIC					
Significant Increase		No Trend		Significant Decrease		Significant Increase		No Trend		Significant Decrease	
Well	Statistic	Well	Statistic	Well	Statistic	Well	Statistic	Well	Statistic	Well	Statistic
MW-111	8.37	MW-117	3.76	MW-106	-15.26	MW-125	45.19	MW-111	3.85	MW-101	-49.05
MW-125	41.51	MW-129	1.34	MW-108	-8.12	MW-128	9.69	MW-216	4.81	MW-105	-24.94
MW-128	13.47	MW-150A	3.63	MW-135A	-6.53	MW-131	75.44	MW-247B	4.32	MW-106	-200.78
MW-131	9.34	MW-151A	0.64	MW-137A	-9.60	MW-150A	11.30	MW-250C	3.59	MW-107	-26.91
MW-153	5.48	MW-152A	0.33	MW-1A	-5.30	MW-153	14.44	MW-151A	-0.58	MW-108	-87.16
MW-156	5.41	MW-207	1.87	MW-213	-6.68	MW-156	14.71	MW-236C	-4.48	MW-116	-56.55
MW-208	52.10	MW-216	1.21	MW-224	-5.20	MW-207	12.68	MW-246B	-2.35	MW-117	-30.05
MW-211	22.57	MW-230	1.31	MW-233	-15.10	MW-208	305.51	MW-249B	-2.59	MW-124	-42.87
MW-215	35.79	MW-235C	0.75	MW-237B	-7.86	MW-211	60.65	MW-249C	-1.96	MW-129	-24.93
MW-217	26.02	MW-236B	0.63	**MW-238C**	**-8.66**	MW-215	29.52	**CMT 2-6**	**-3.39**	MW-130	-100.12
MW-223	53.04	MW-236C	2.21	CMT 1-7	-4.70	MW-217	265.55			MW-133	-74.92
MW-225	4.56	MW-246B	0.53	CMT 2-3	-8.02	MW-223	398.10			MW-134	-48.71
MW-228	6.01	MW-247B	4.03	CMT 2-4	-4.87	MW-225	15.81			MW-135A	-47.84
MW-229	27.77	MW-249C	0.35	CMT 4-4	-5.05	MW-228	9.62			MW-136A	-14.75
MW-231	17.63	MW-250C	1.13	CMT 4-7	-9.70	MW-229	259.29			MW-137A	-119.66
MW-232	48.40	MW-251B	3.39			MW-231	238.84			**MW-138A**	**-45.83**
MW-237C	10.66	MW-3A	0.73			MW-232	486.87			MW-146A	-8.36
CMT 2-7	**29.90**	**CMT 2-1**	**3.85**			MW-237C	79.46			MW-149A	-8.49
CMT 3-7	**109.18**	**CMT 2-5**	**0.83**			MW-251B	7.41			MW-152A	-5.06
		CMT 2-6	**1.94**			**CMT 2-7**	**69.24**			MW-1A	-47.59
		CMT 3-6	**1.95**			**CMT 3-6**	**14.44**			MW-201	-96.53
		MW-101	-0.51			**CMT 3-7**	**271.61**			MW-203	-140.59
		MW-105	-2.03							MW-210	-9.94
		MW-107	-1.01							MW-213	-72.03
		MW-116	-2.57							MW-224	-100.15
		MW-124	-1.81							MW-226	-41.33
		MW-130	-1.74							MW-227	-20.78
		MW-133	-4.39							MW-230	-25.72
		MW-134	-2.24							MW-233	-151.51
		MW-136A	-0.51							MW-234	-22.11
		MW-138A	**-2.55**							MW-235B	-17.43
		MW-146A	-0.35							MW-235C	-16.47
		MW-149A	-0.65							MW-236B	-6.27
		MW-201	-4.13							MW-237B	-130.52
		MW-203	-0.56							**MW-238B**	**-73.11**
		MW-210	-0.45							**MW-238C**	**-93.94**
		MW-226	-4.47							MW-243B	-7.30
		MW-227	-2.23							MW-250B	-10.54
		MW-234	-1.83							MW-252B	-9.28
		MW-235B	-0.62							MW-2A	-44.65
		MW-238B	**-4.21**							MW-3A	-13.57
		MW-243B	-1.30							MW-5A	-53.21
		MW-249B	-1.32							**CMT 1-1**	**-51.21**
		MW-250B	-0.69							**CMT 1-2**	**-40.62**
		MW-252B	-1.47							**CMT 1-3**	**-76.02**
		MW-2A	-0.94							**CMT 1-4**	**-7.44**
		MW-5A	-3.45							**CMT 1-5**	**-28.35**
		CMT 1-1	**-2.00**							**CMT 1-6**	**-59.89**
		CMT 1-2	**-1.53**							**CMT 1-7**	**-19.41**

	CMT 1-3 -3.73 CMT 1-4 -1.03 CMT 1-5 -0.94 CMT 1-6 -2.94 CMT 2-2 -0.83 CMT 3-2 -2.04 CMT 3-3 -2.01 CMT 3-4 -1.69 CMT 3-5 -1.81 CMT 4-2 -1.48 CMT 4-3 -1.28 CMT 4-5 -1.85 CMT 4-6 -1.38				CMT 2-1 -21.83 CMT 2-2 -24.58 CMT 2-3 -107.36 CMT 2-4 -84.50 CMT 2-5 -6.47 CMT 3-2 -24.72 CMT 3-3 -41.33 CMT 3-4 -37.07 CMT 3-5 -13.69 CMT 4-2 -31.99 CMT 4-3 -33.82 CMT 4-4 -83.95 CMT 4-5 -42.07 CMT 4-6 -29.24 CMT 4-7 -152.75

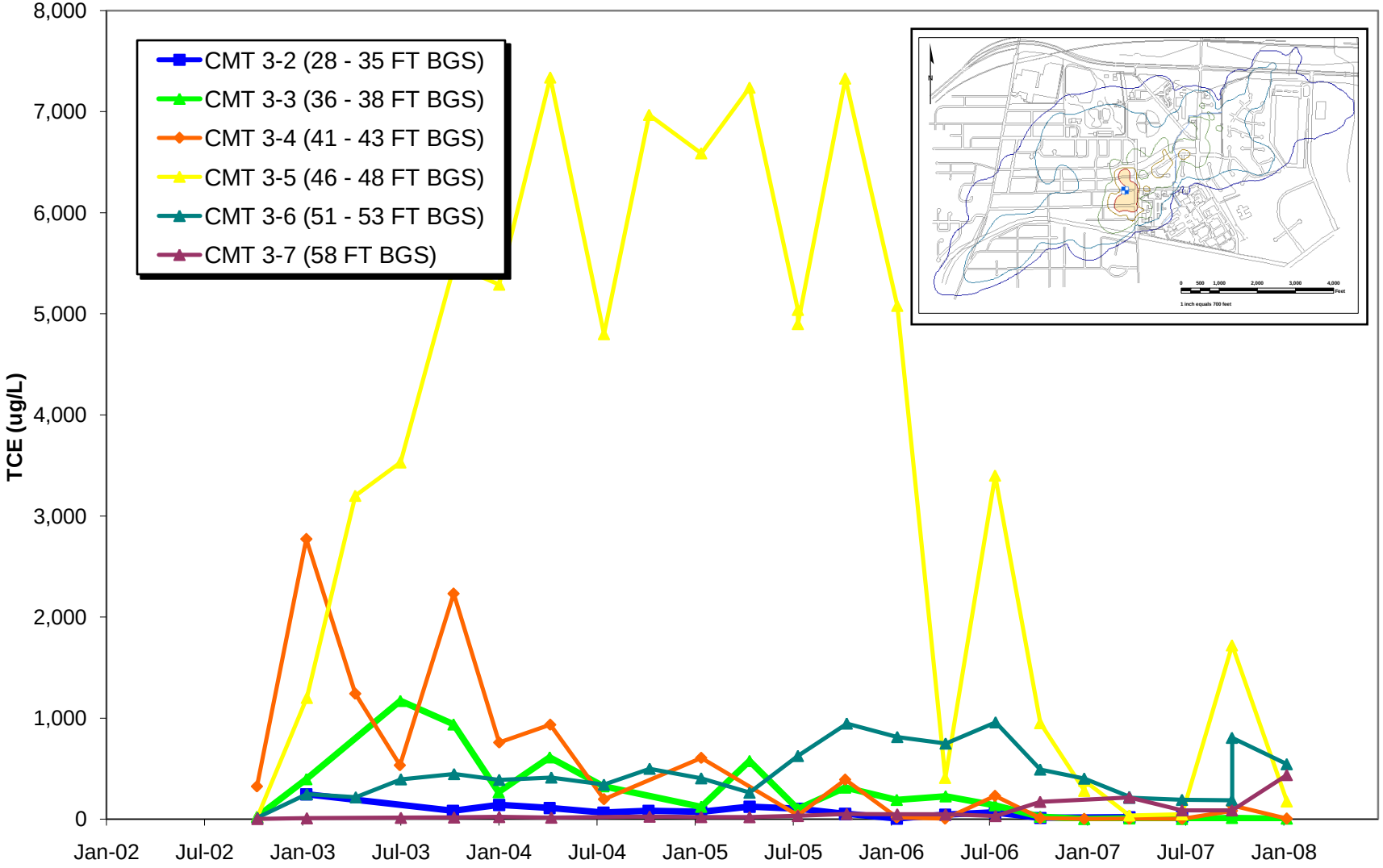
Time Series Plots
CMT 1-1 - CMT 1-7



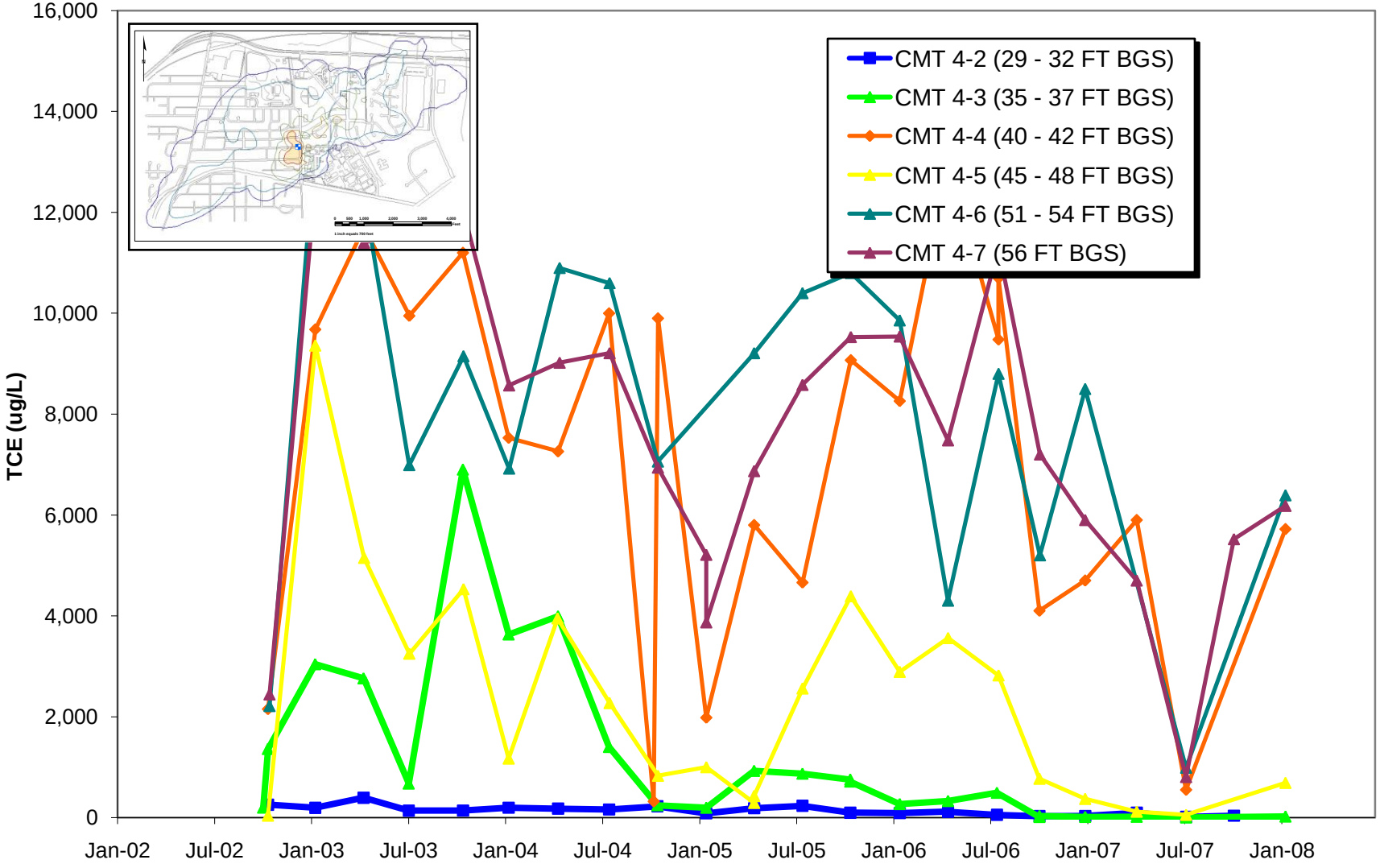
Intrawell Time Series PLots
CMT 2-1 - CMT 2-7



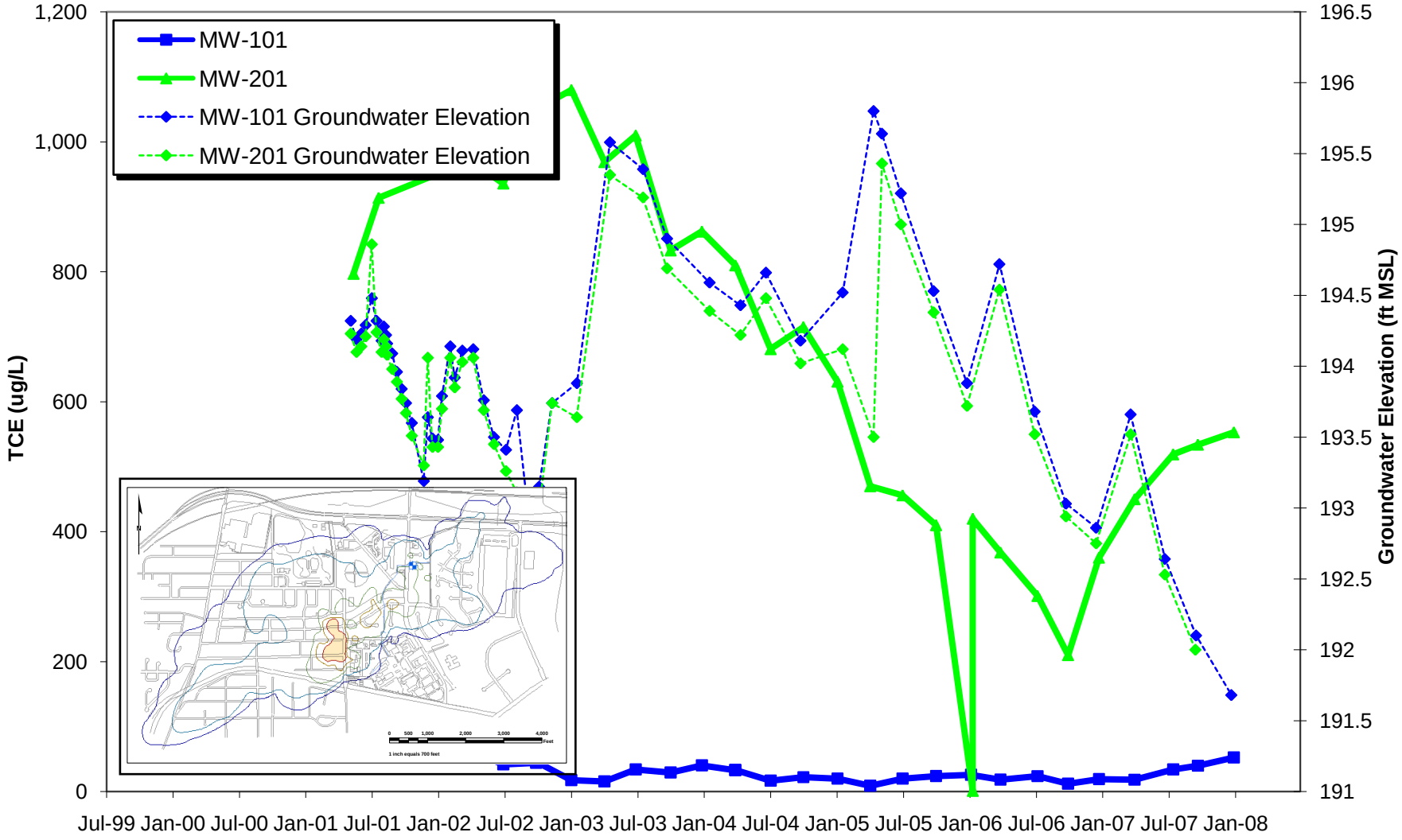
Intrawell Time Series Plots
CMT 3-2 - CMT 3-7



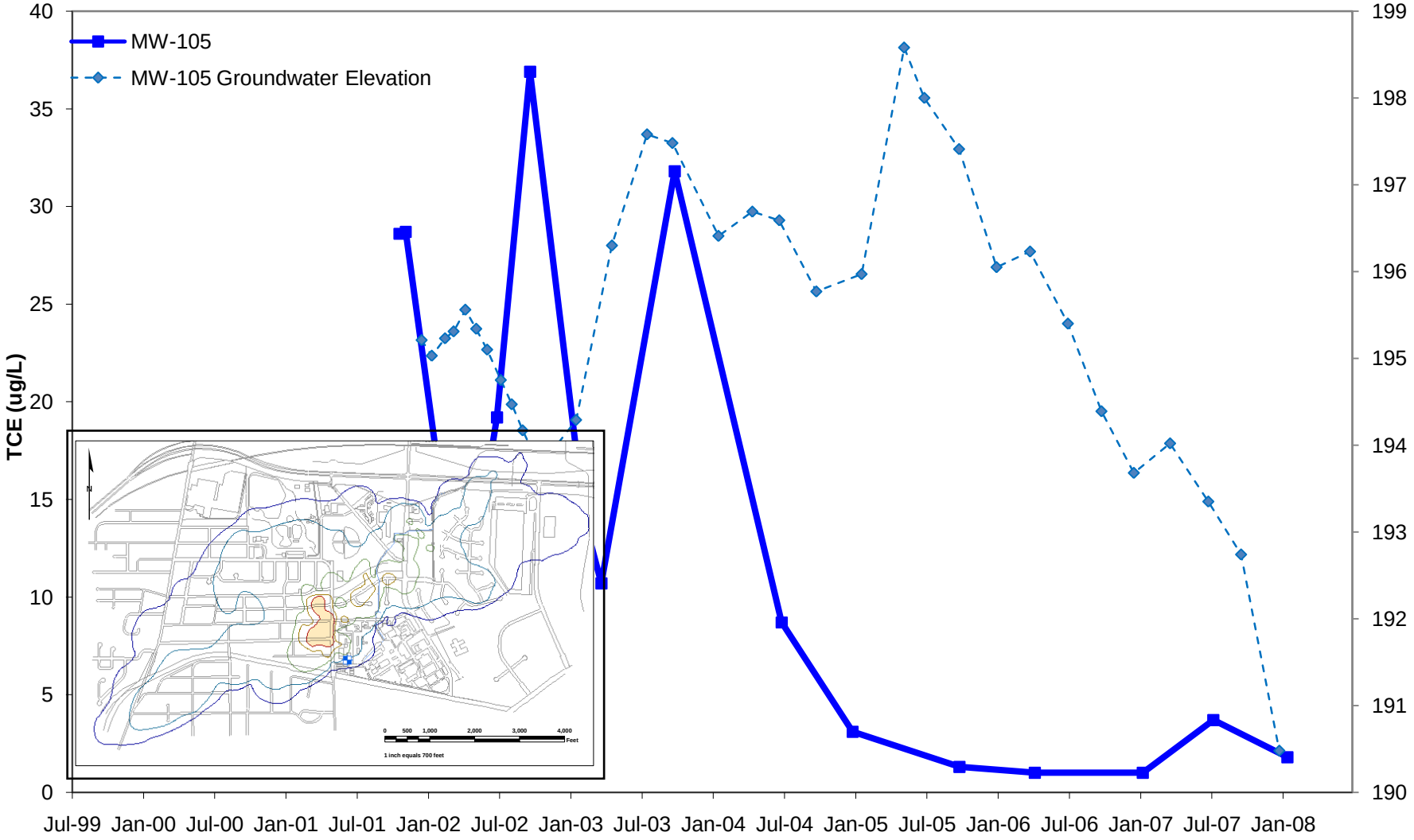
Intrawell Time Series Plots
CMT 4-2 - CMT 4-7



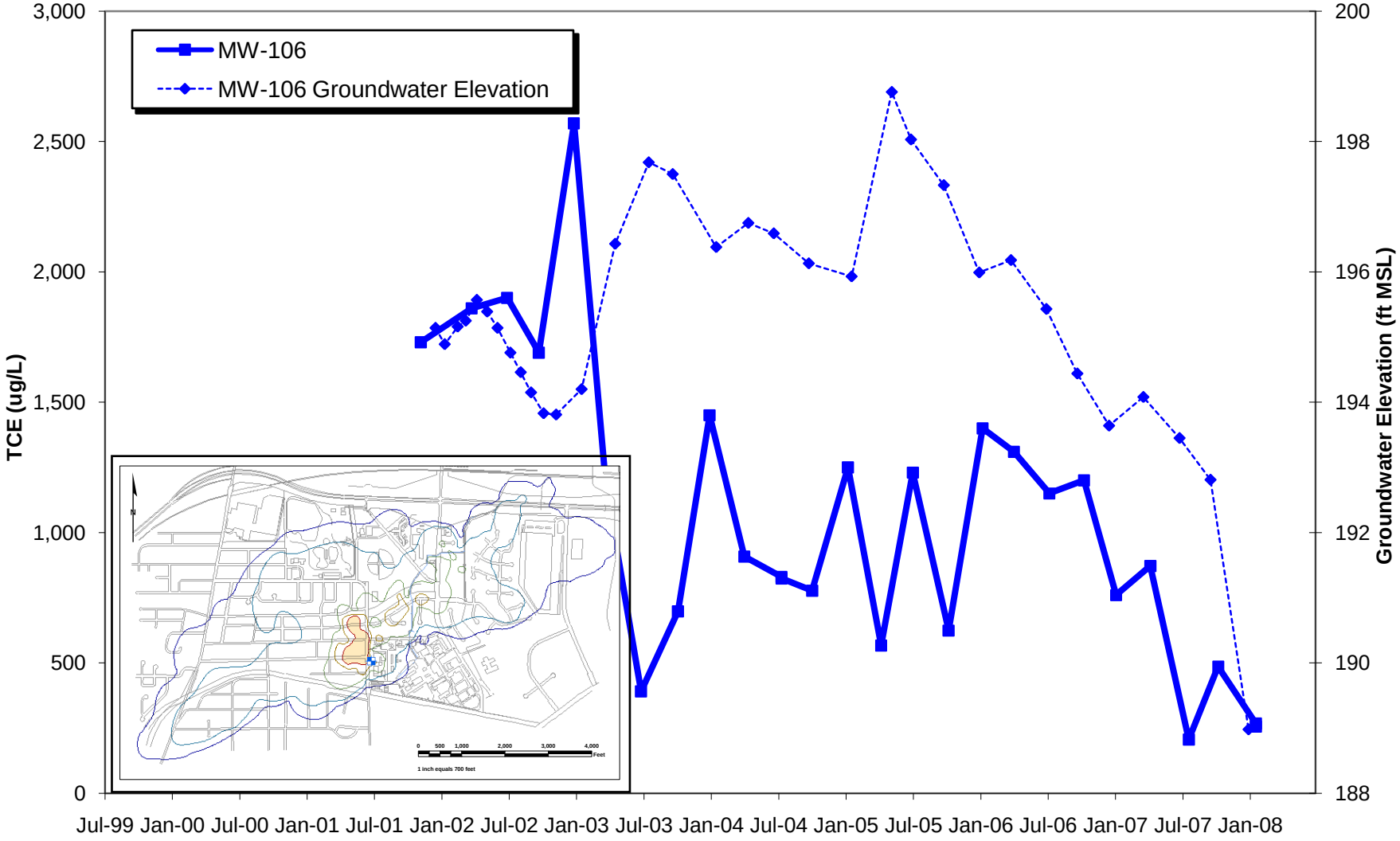
Intrawell Time Series Plots
MW-101 - MW-201



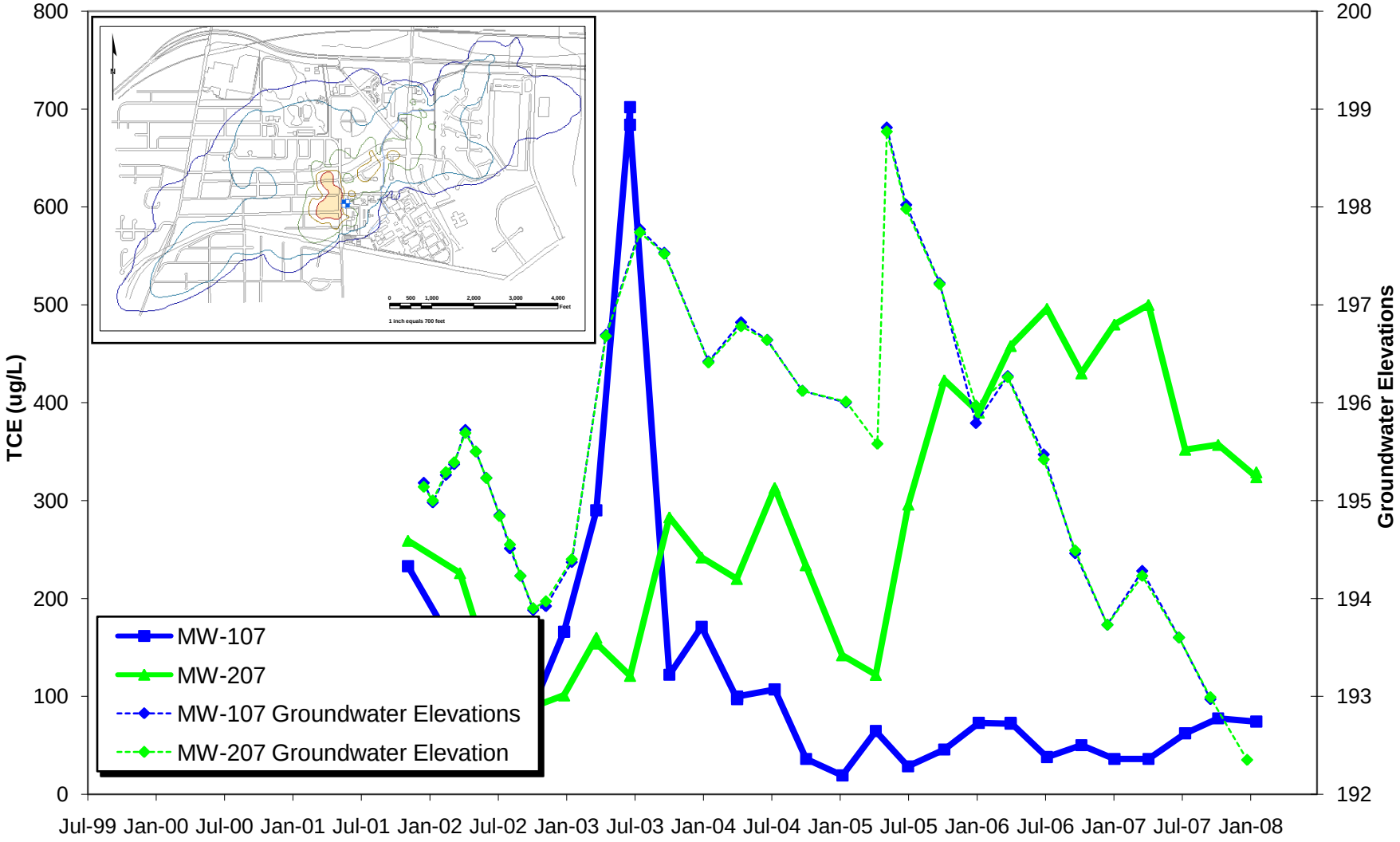
Intrawell Time Series Plots
MW-105



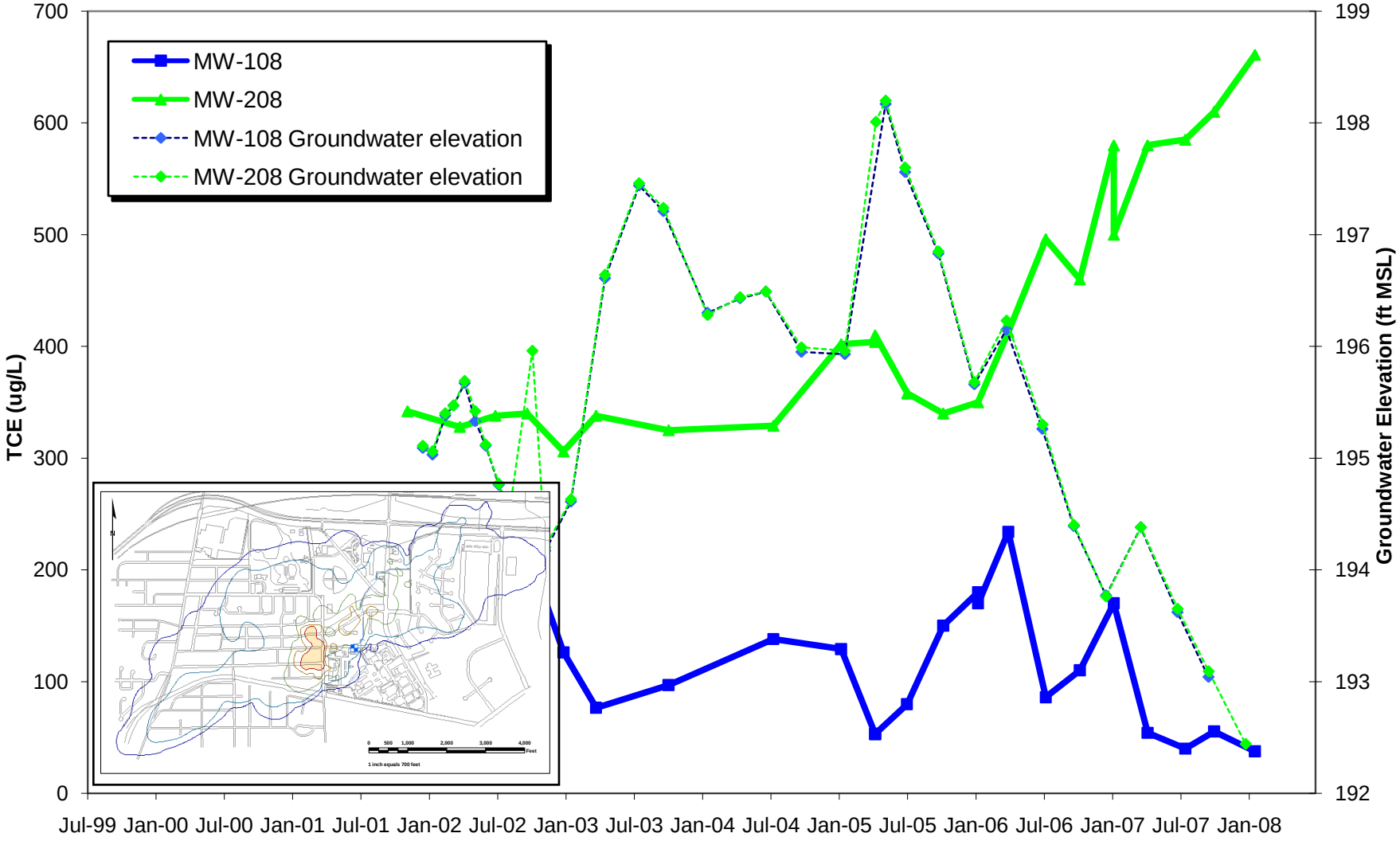
Intrawell Time Series Plots
MW-106



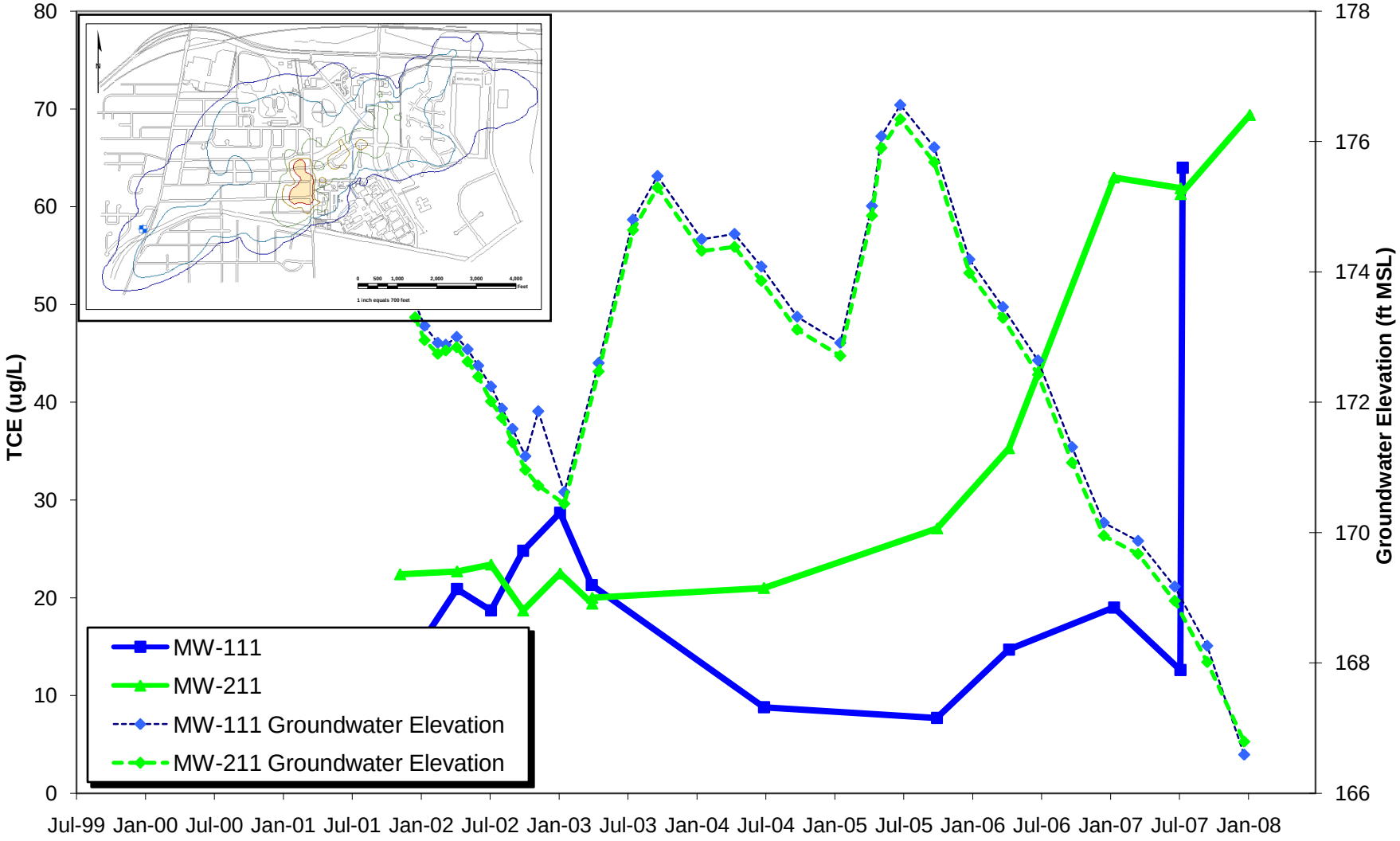
Intrawell Time Series Plots
MW-107 - MW-207



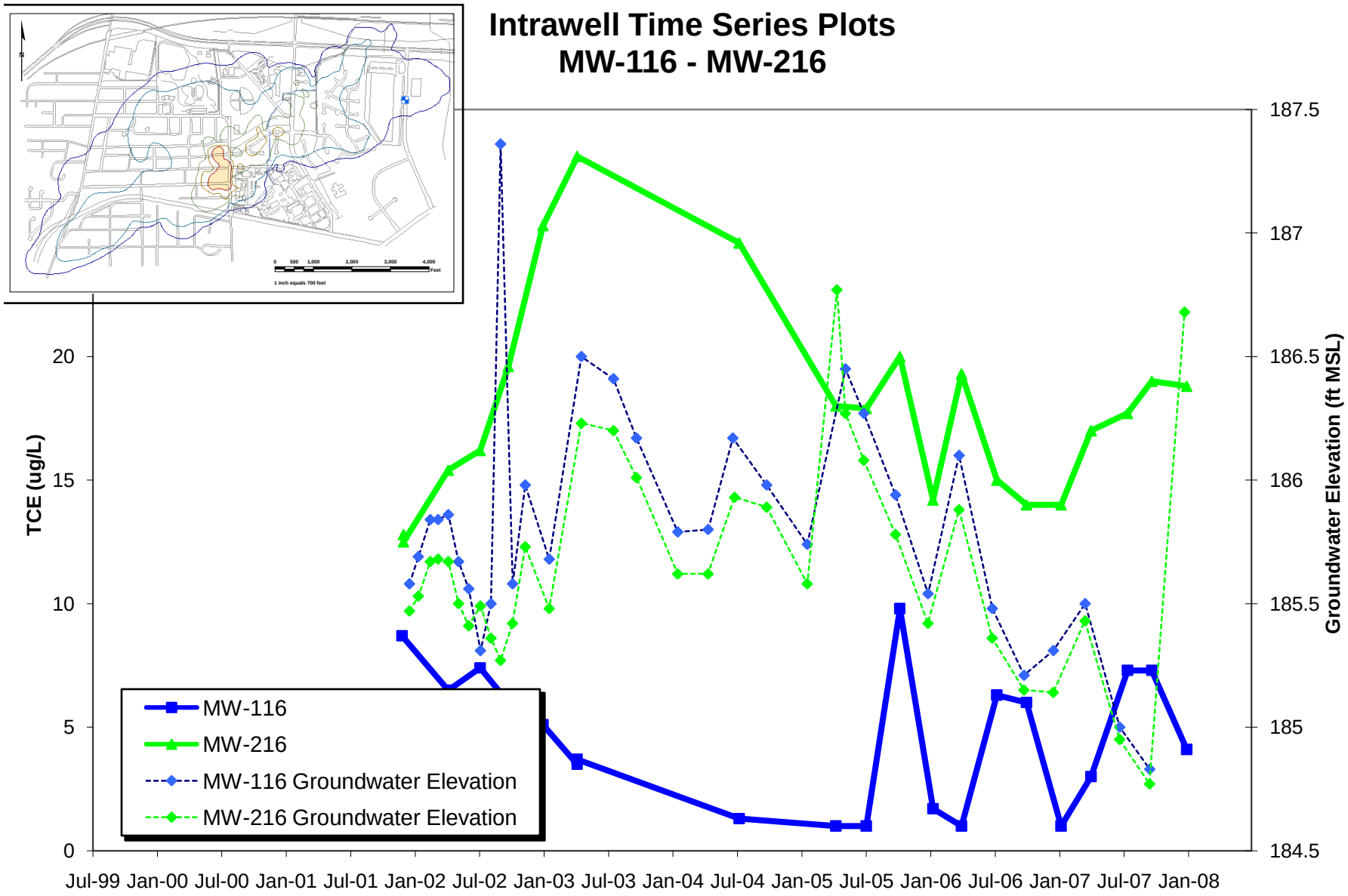
Intrawell Time Series Plots
MW-108 - MW-208



Intrawell Time Series Plots
MW-111 - MW-211



Intrawell Time Series Plots
MW-116 - MW-216



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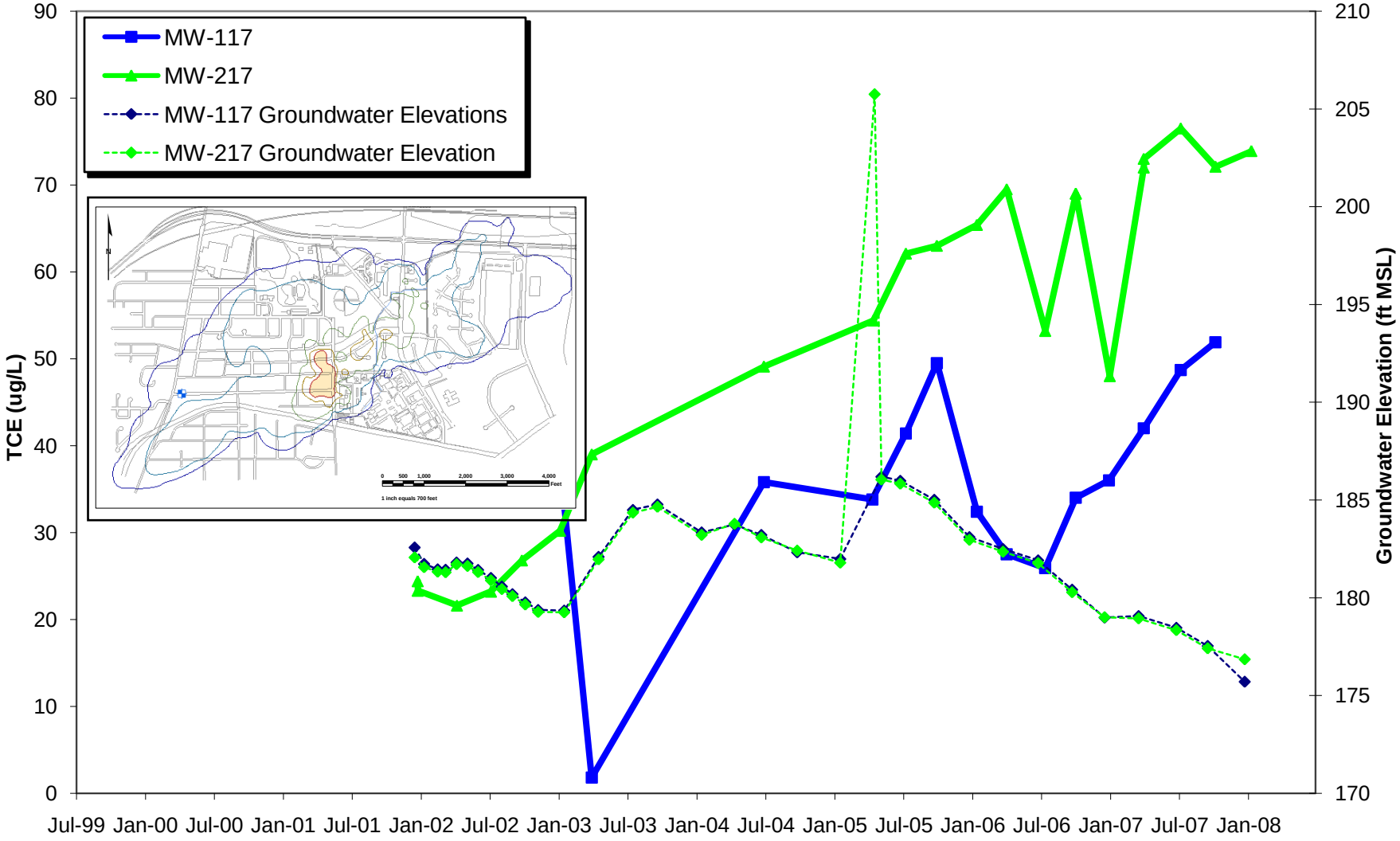

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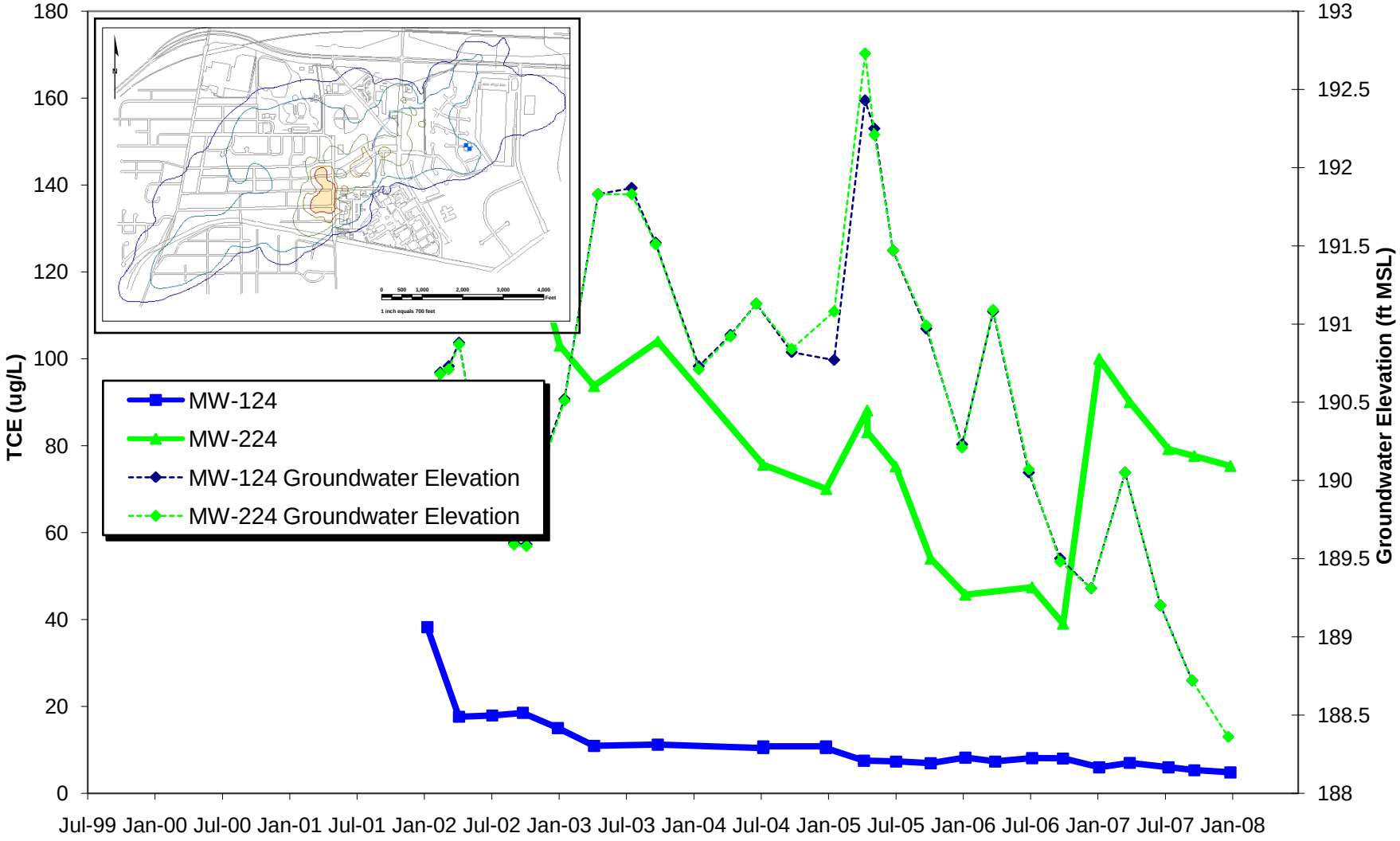

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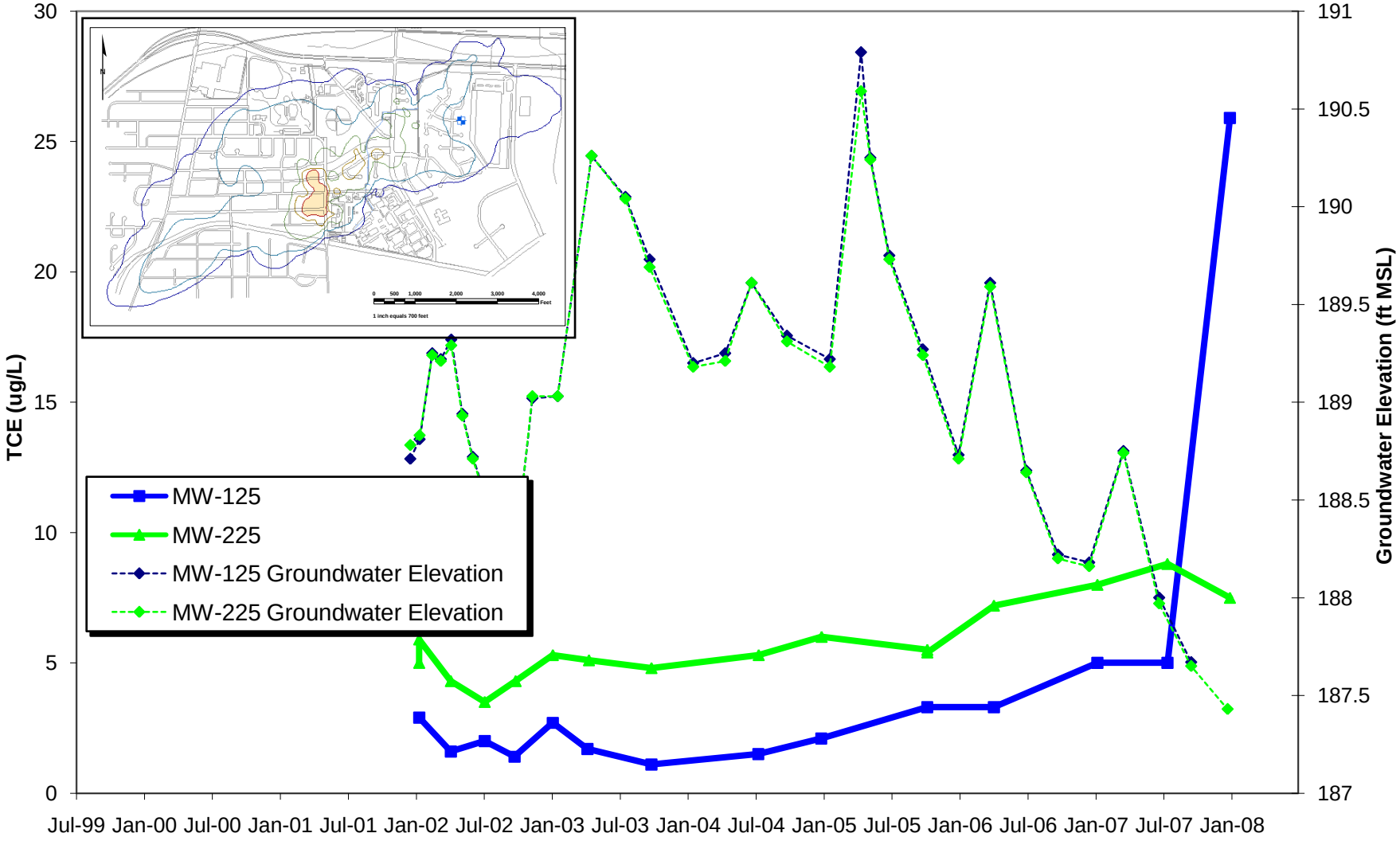

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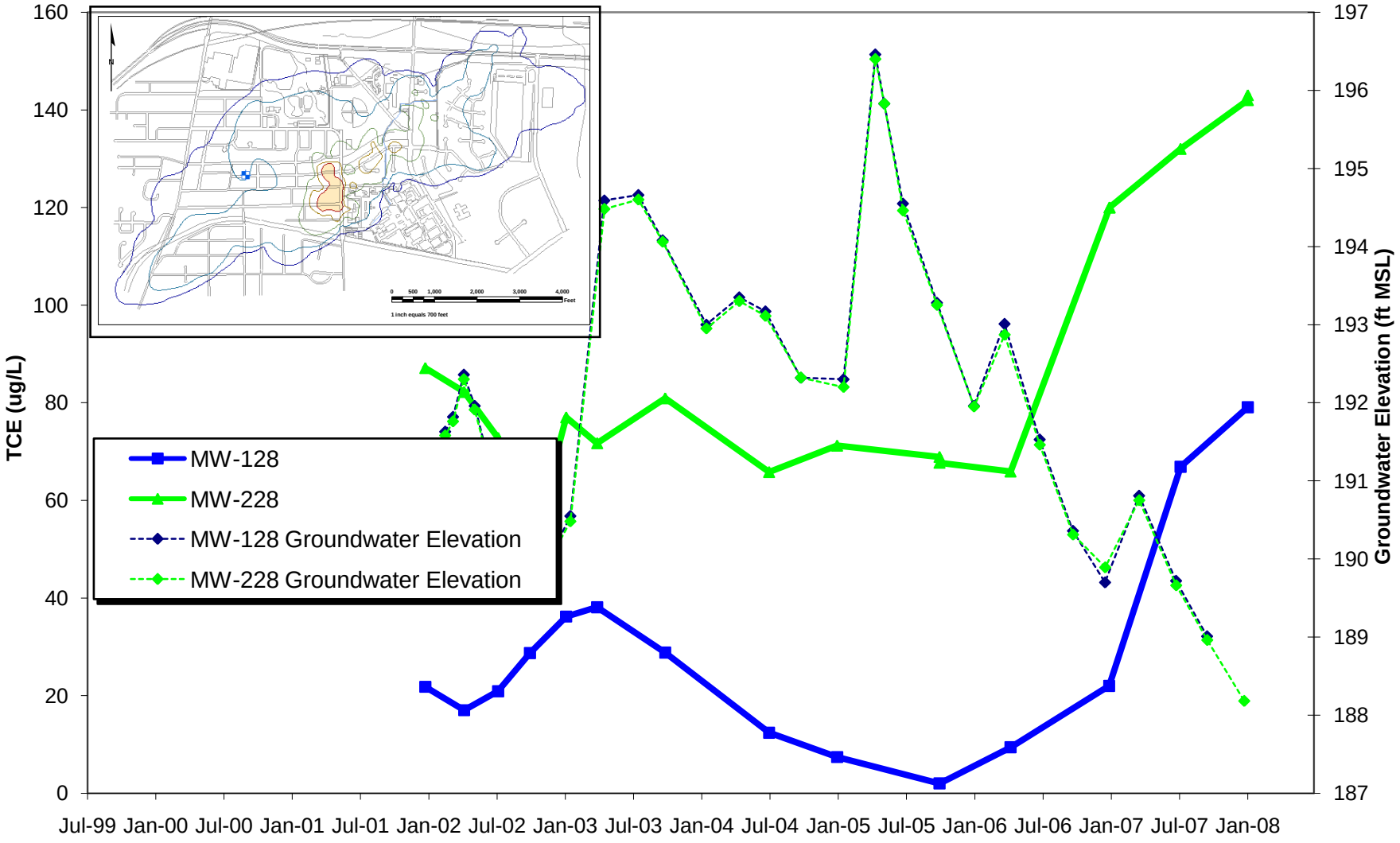

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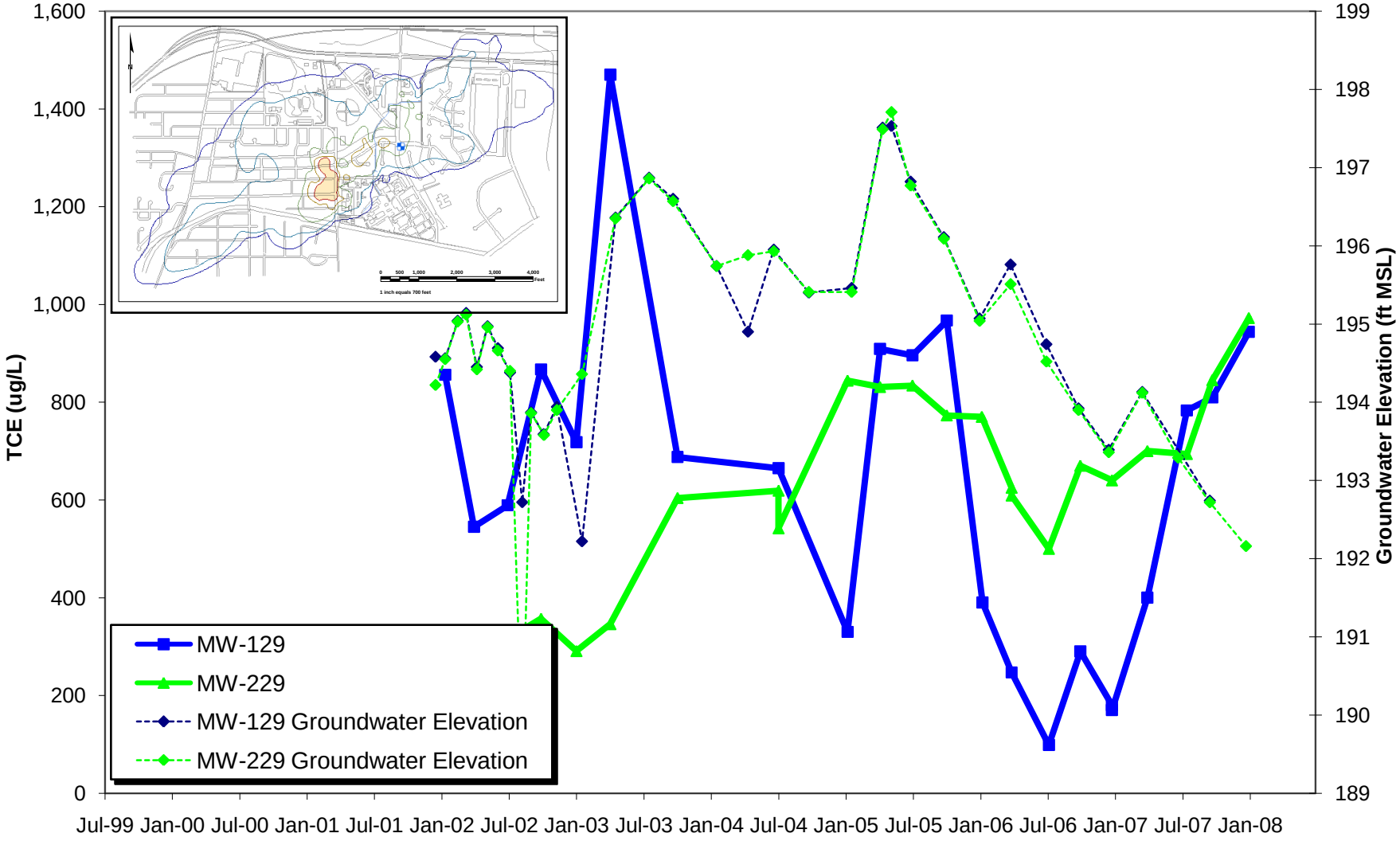
MW-129 - MW-229



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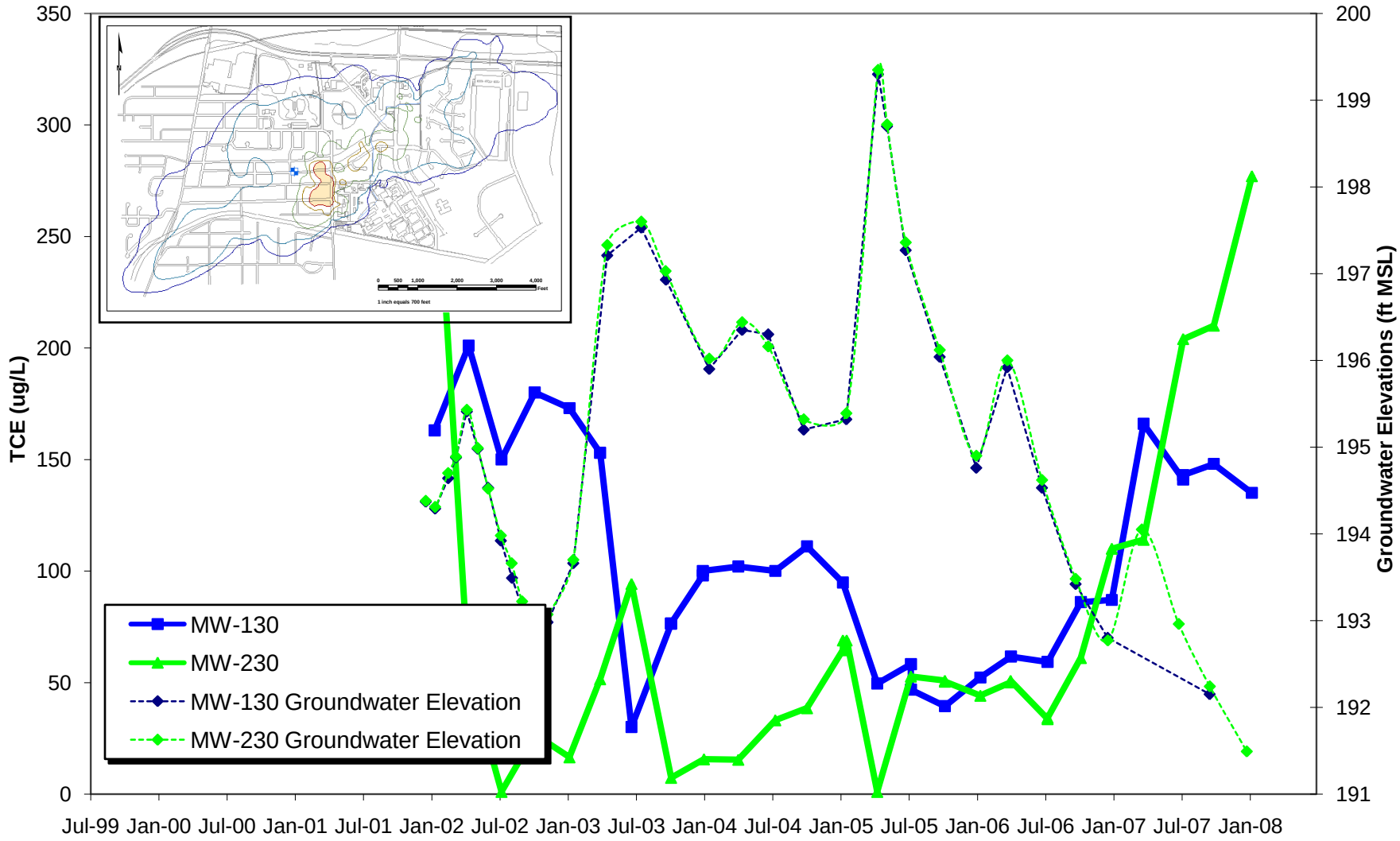

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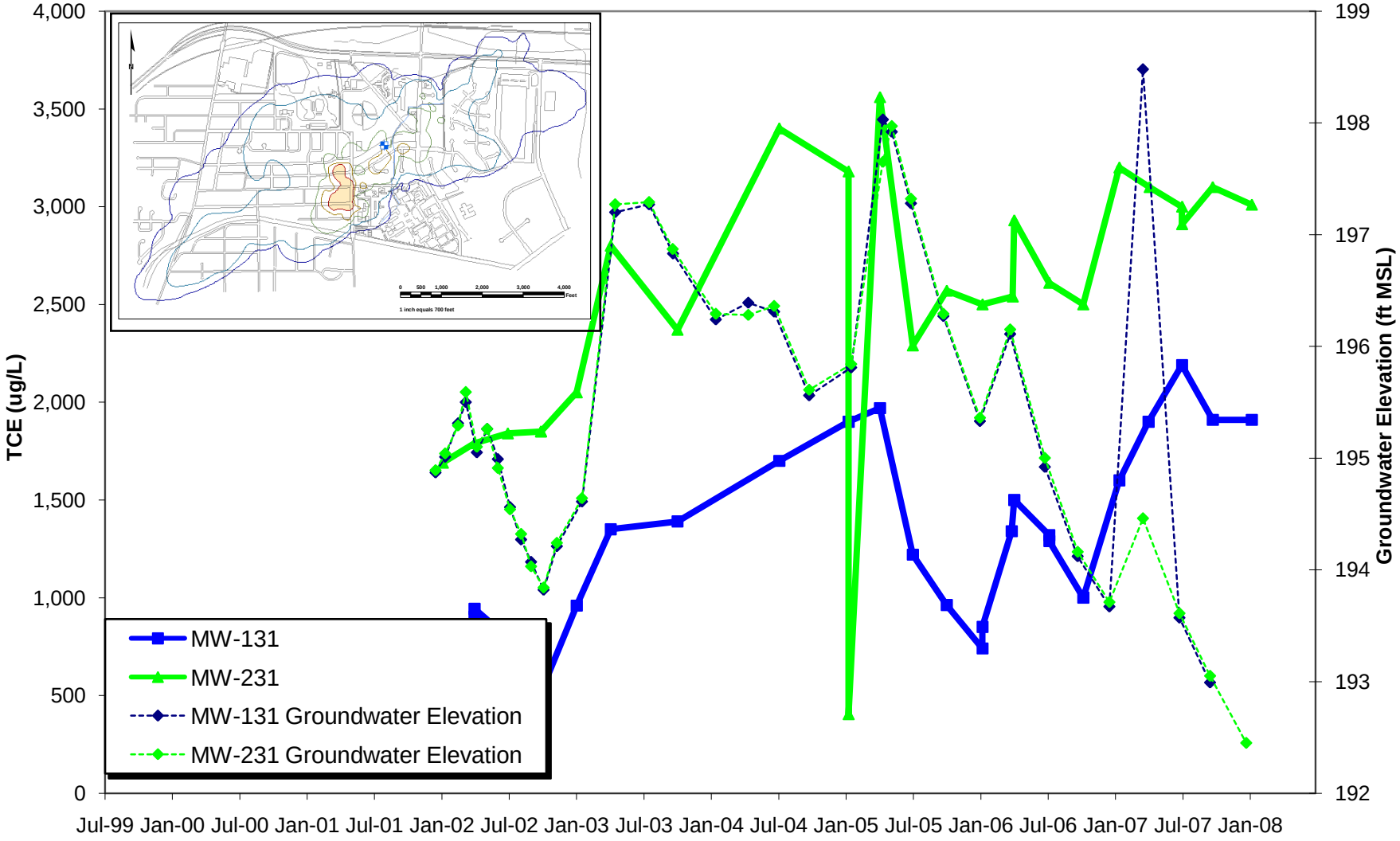

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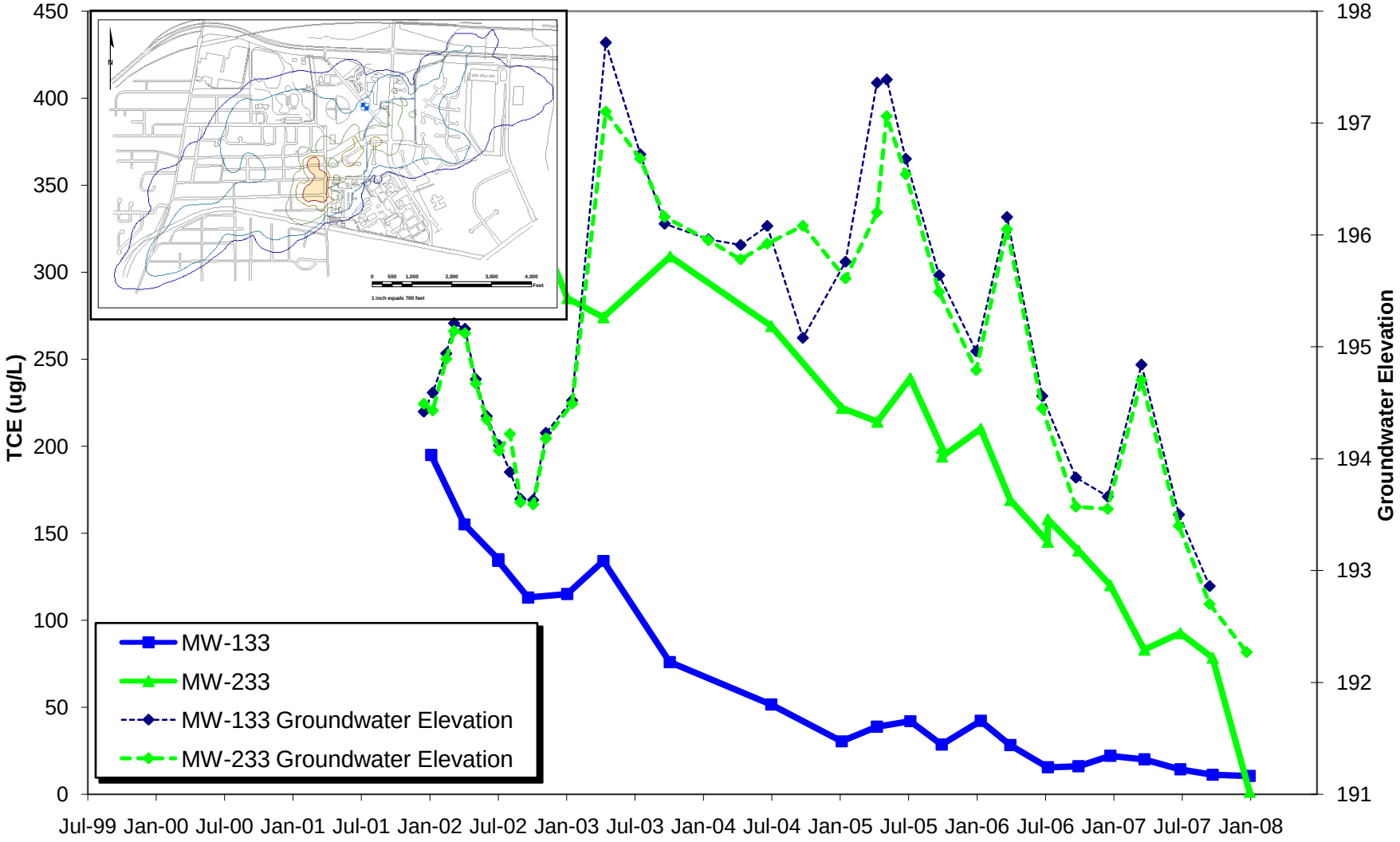

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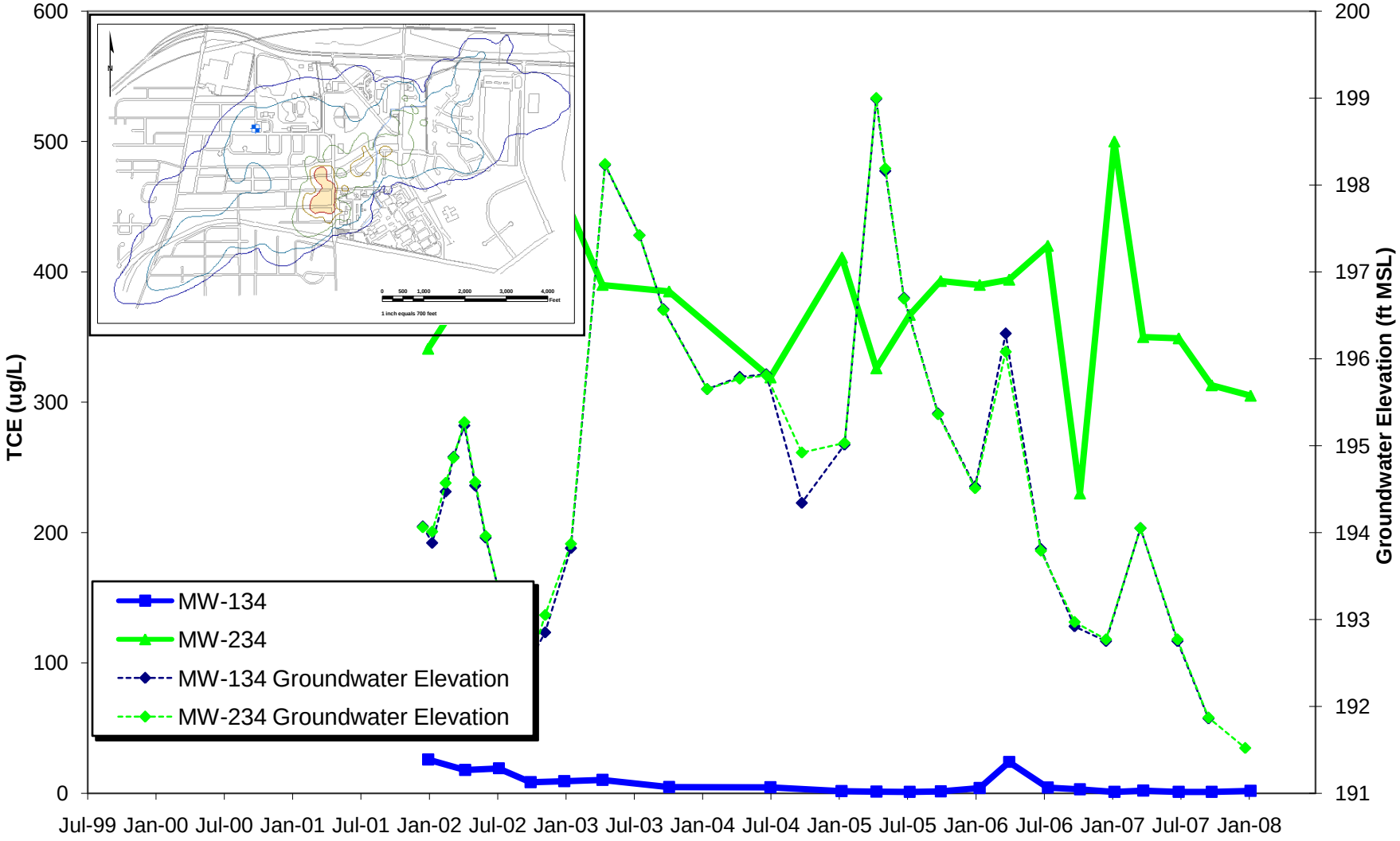

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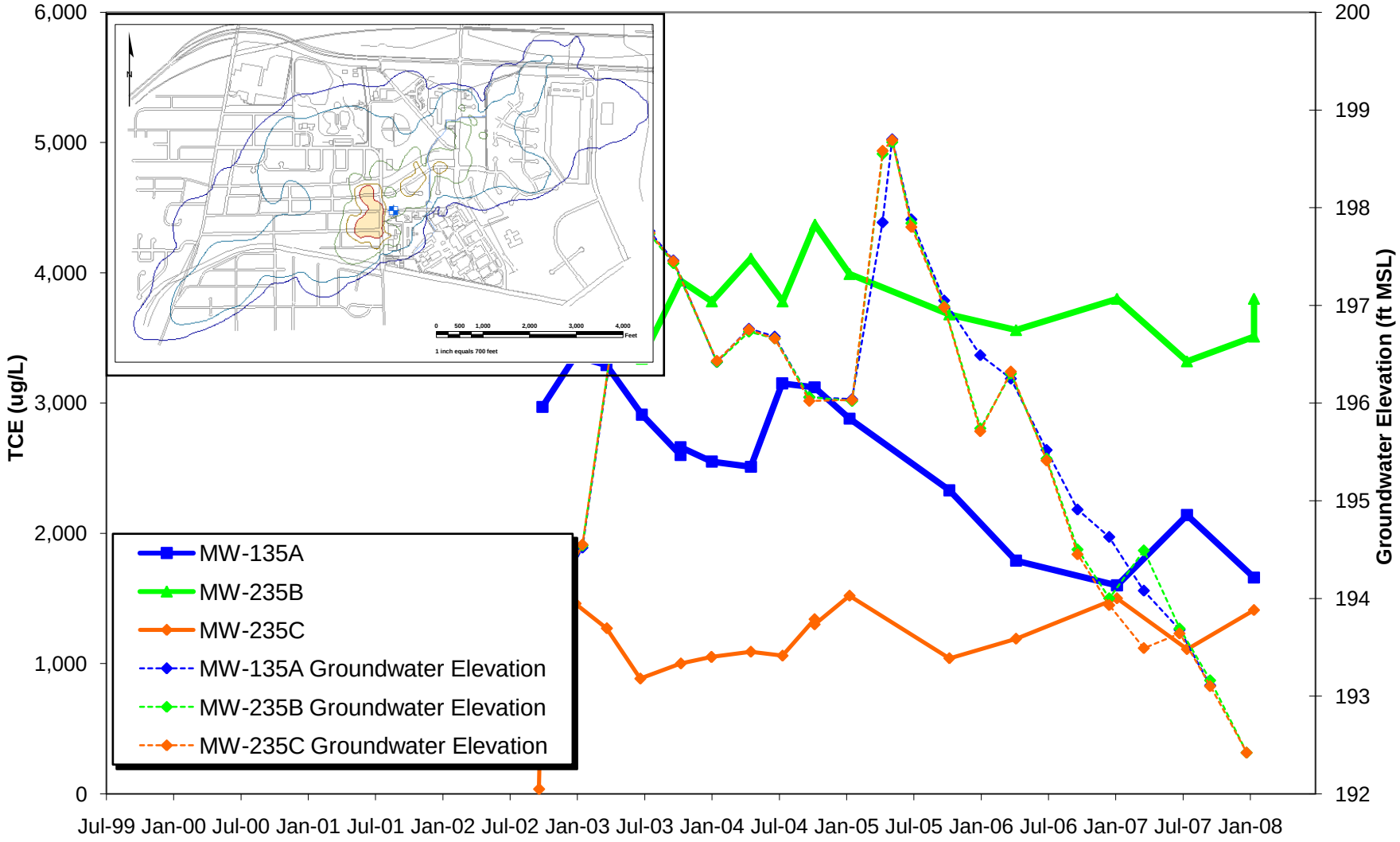

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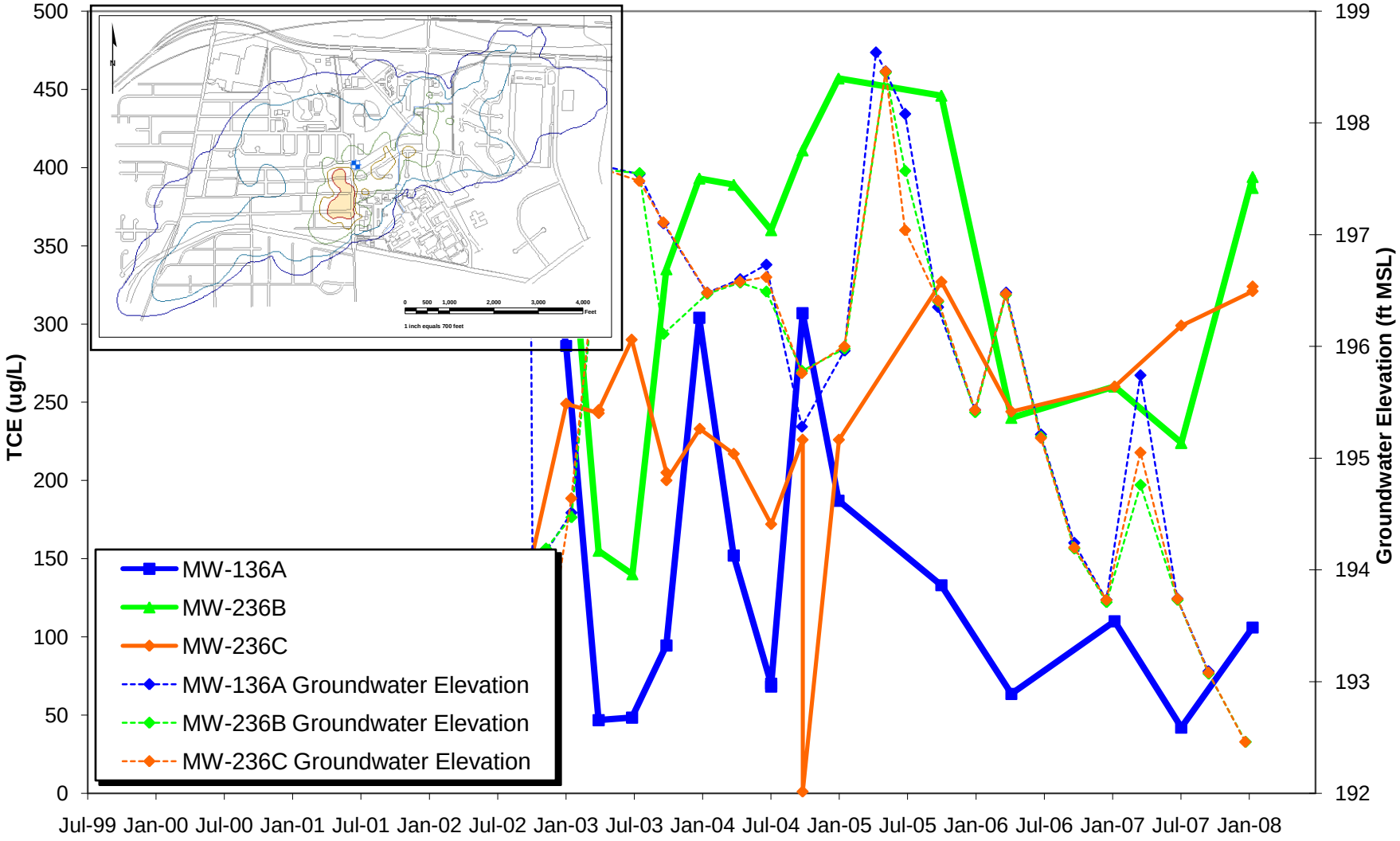

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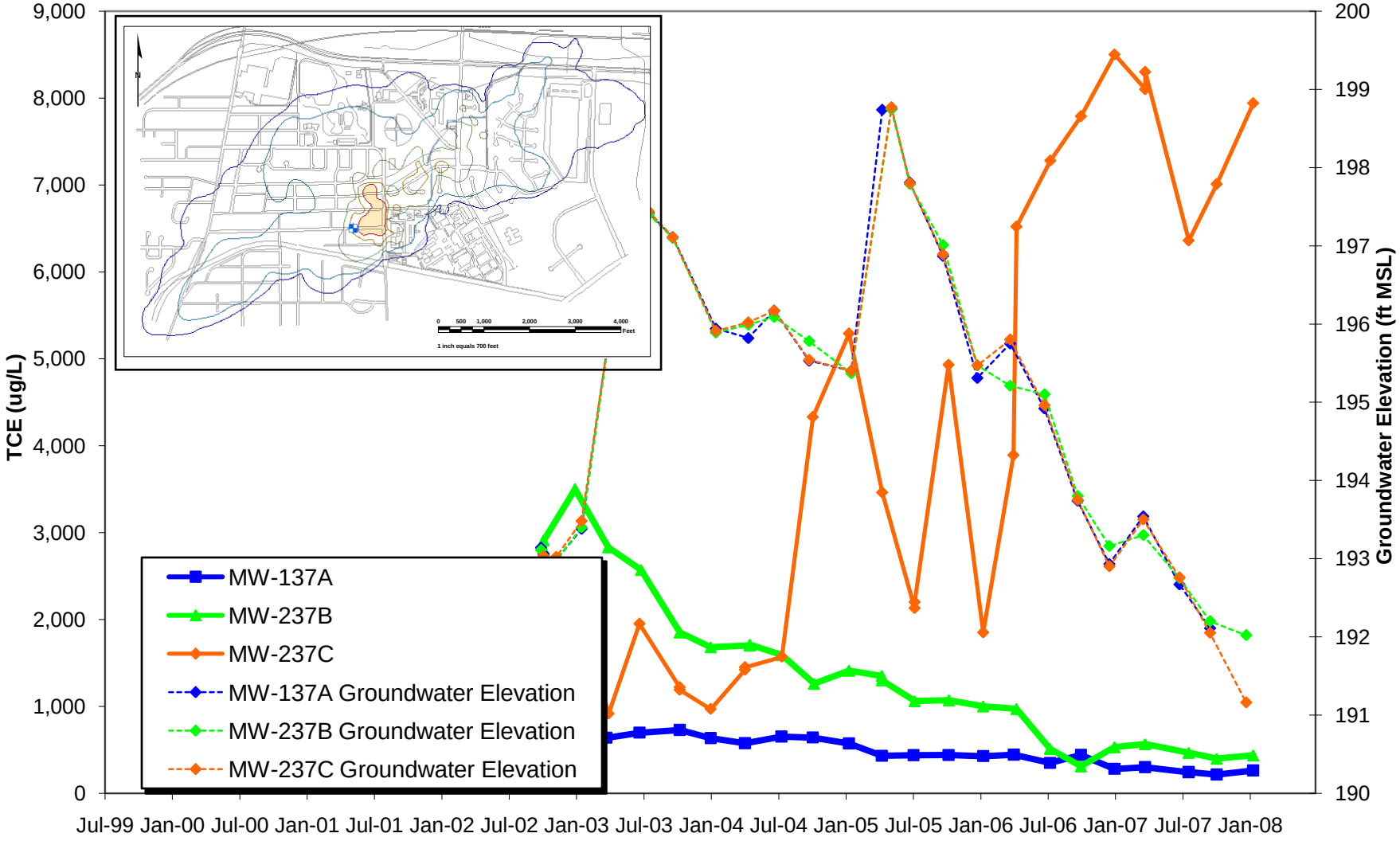

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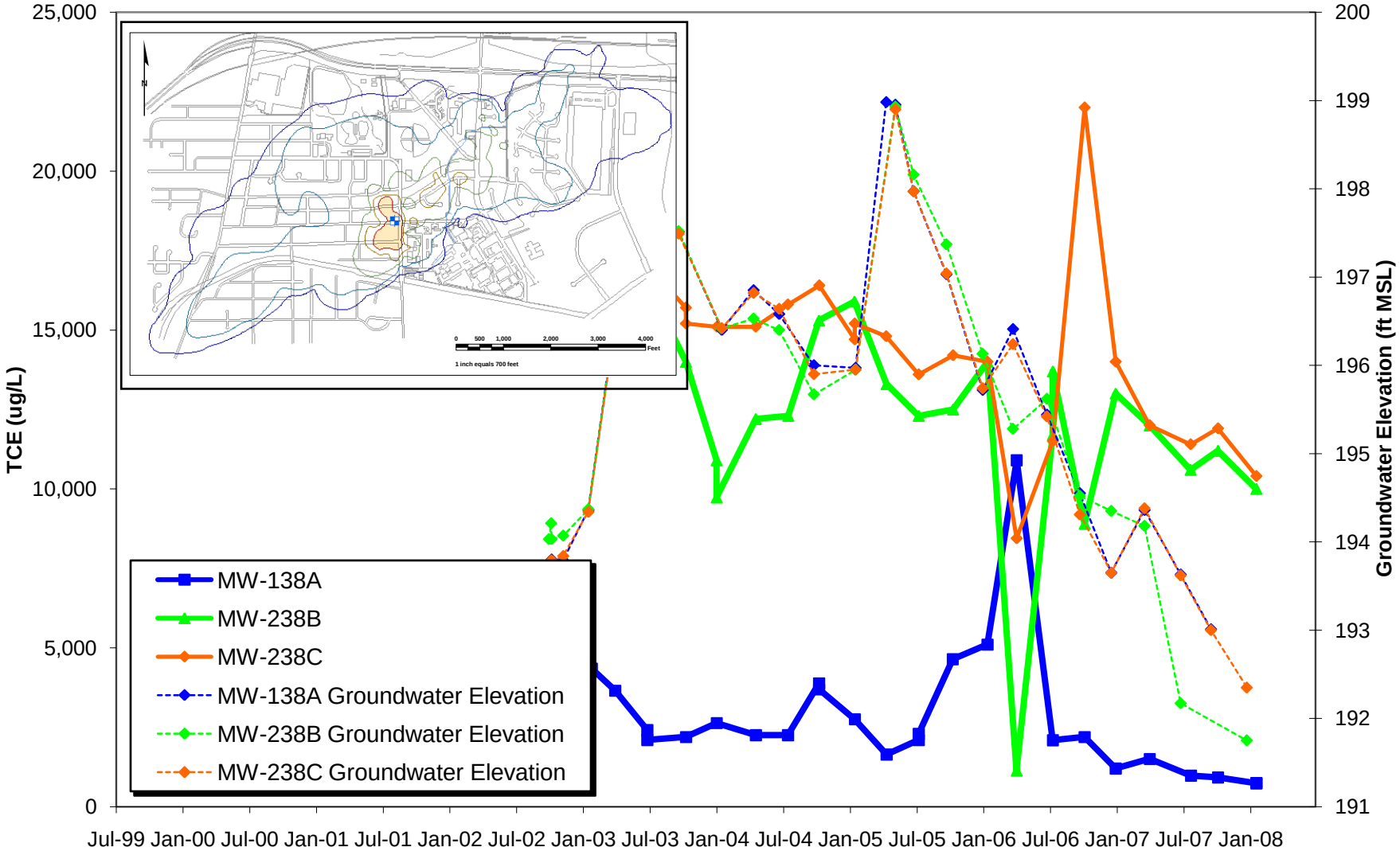

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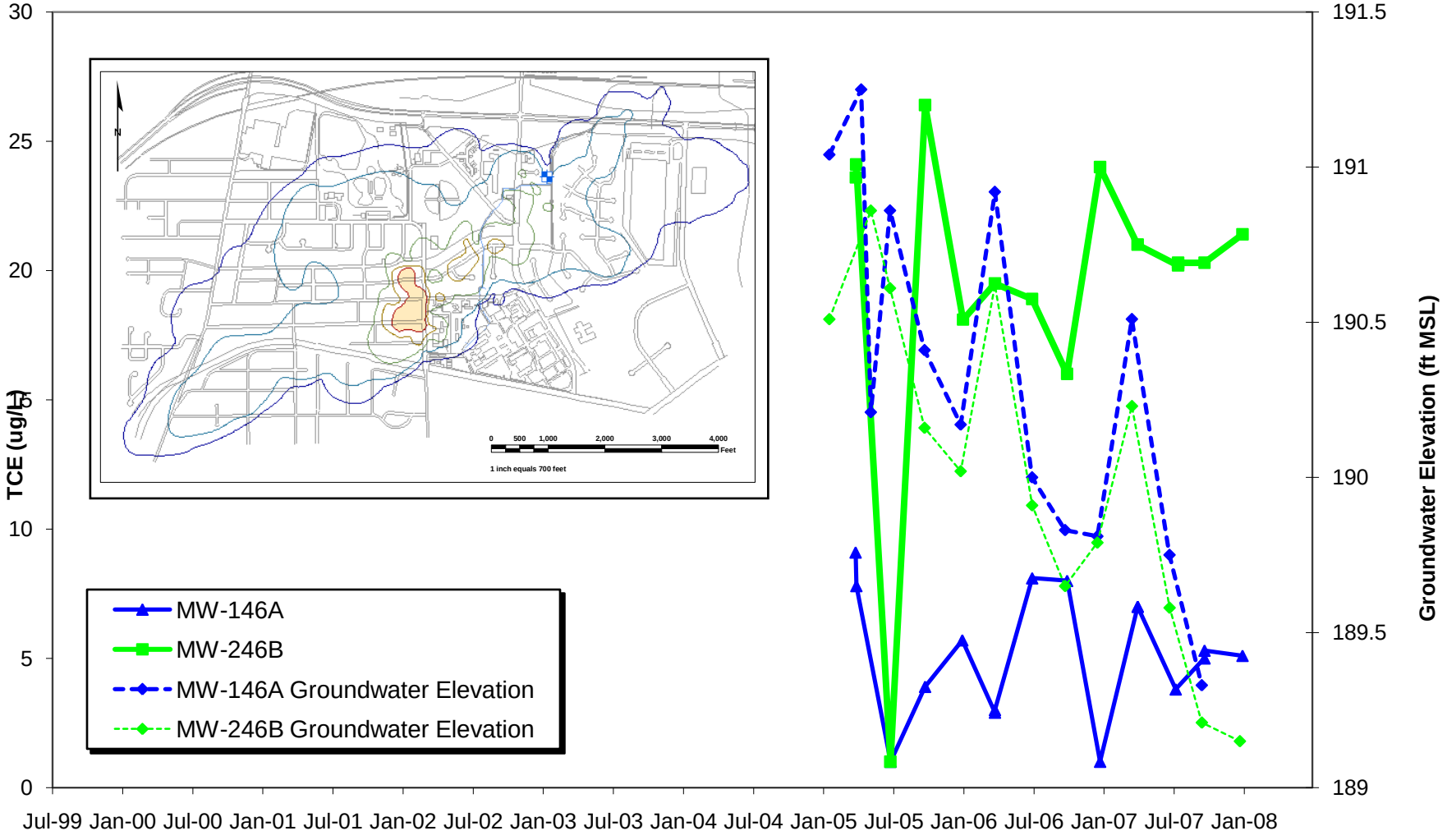
MW-146A - MW-246B



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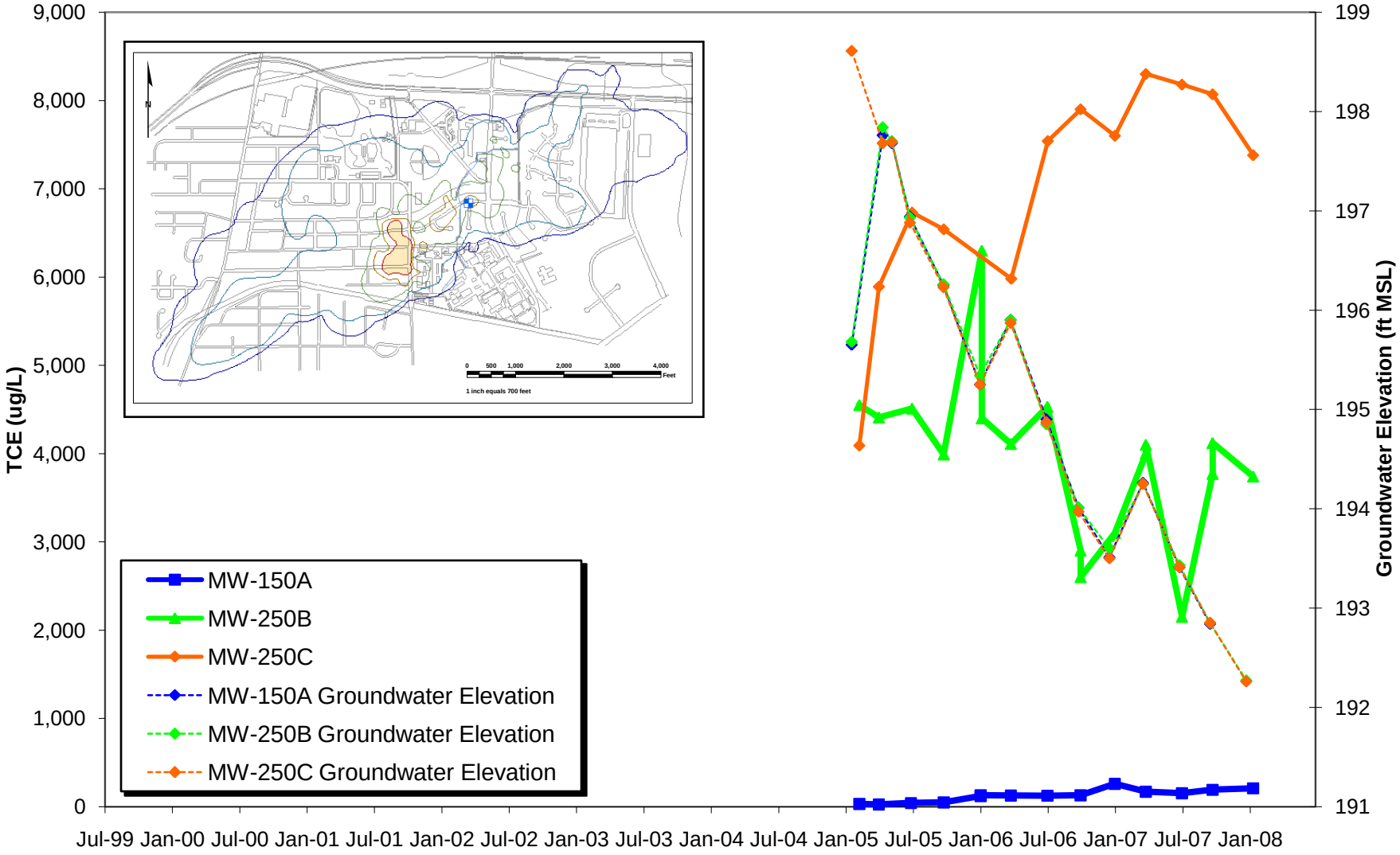

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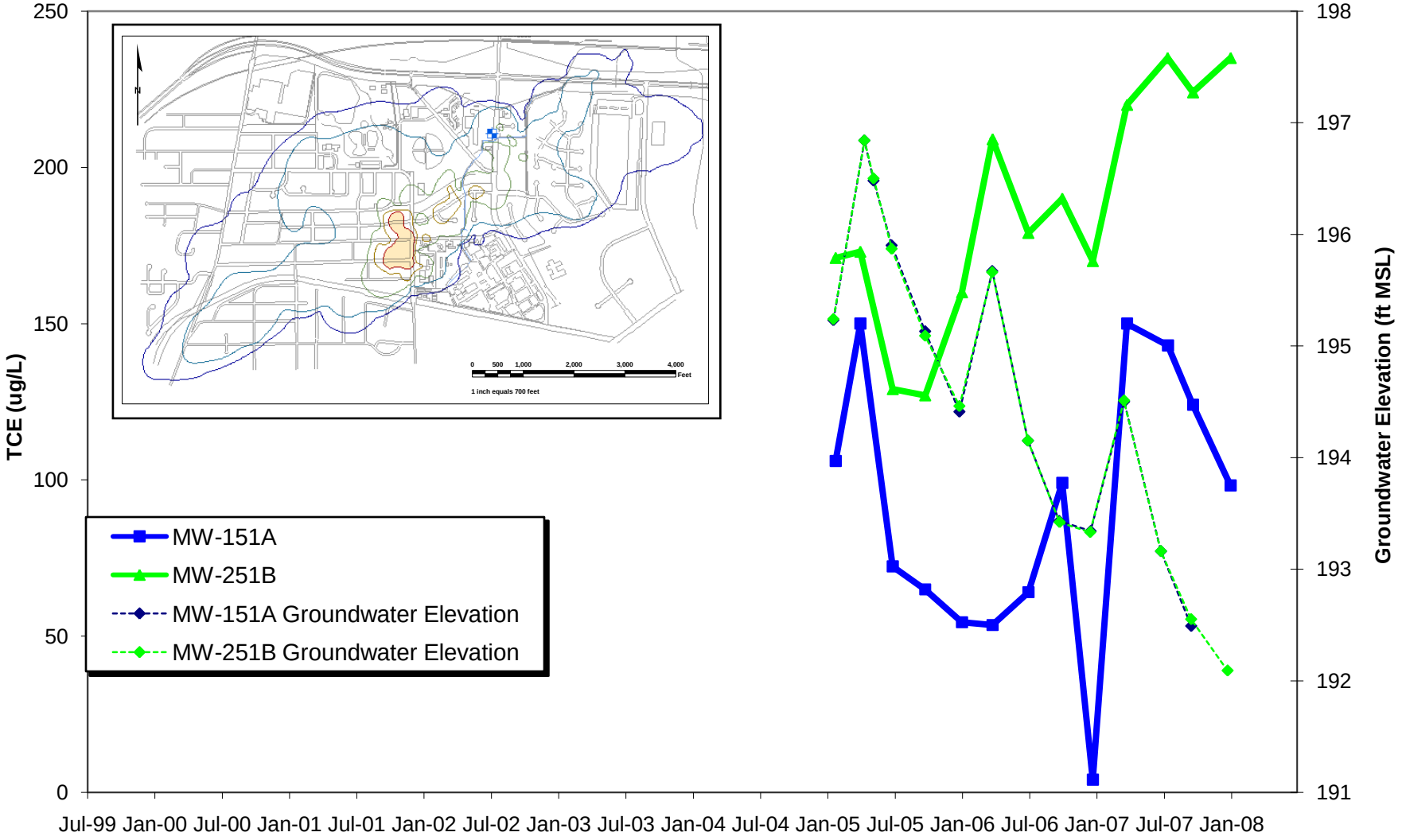

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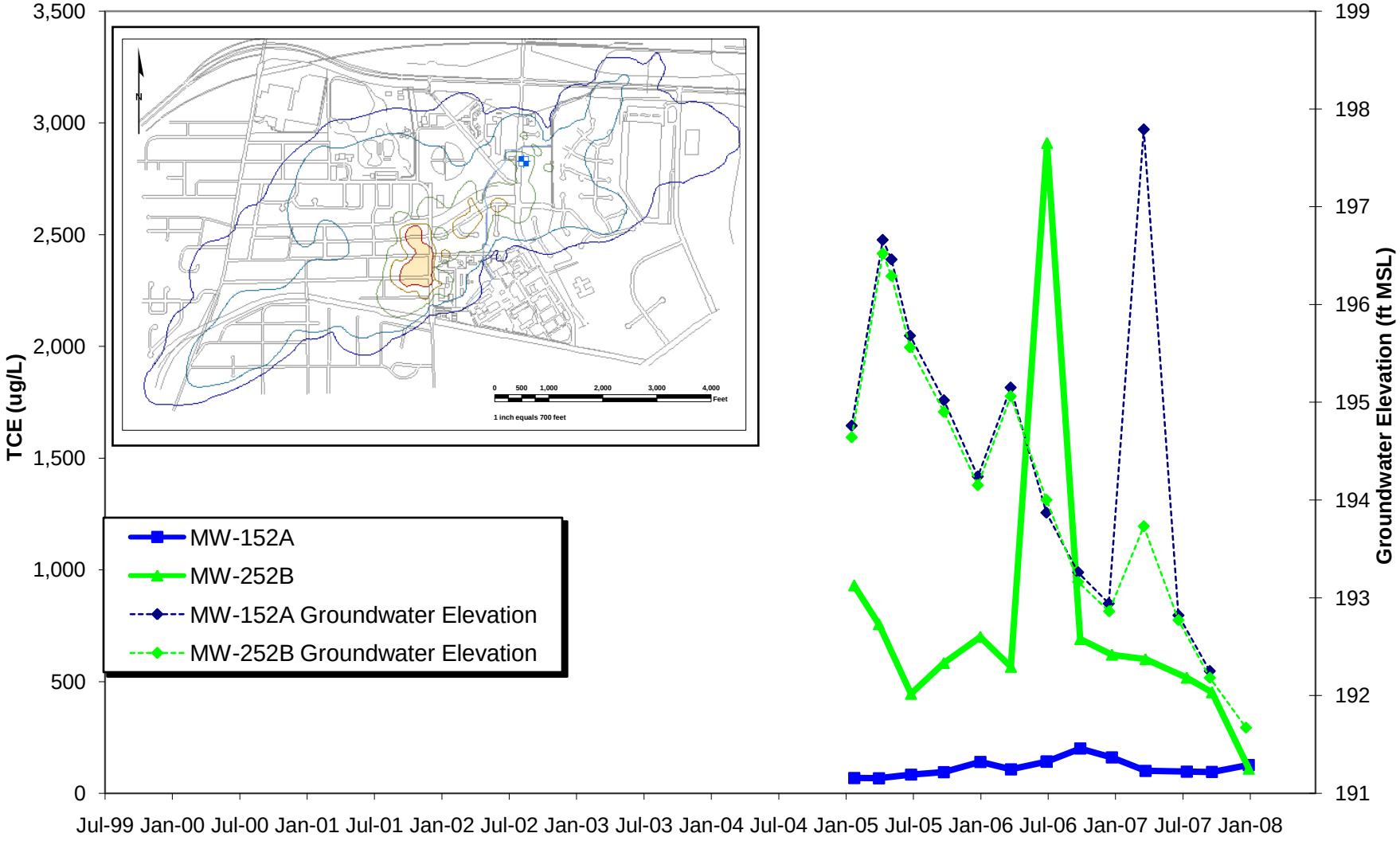

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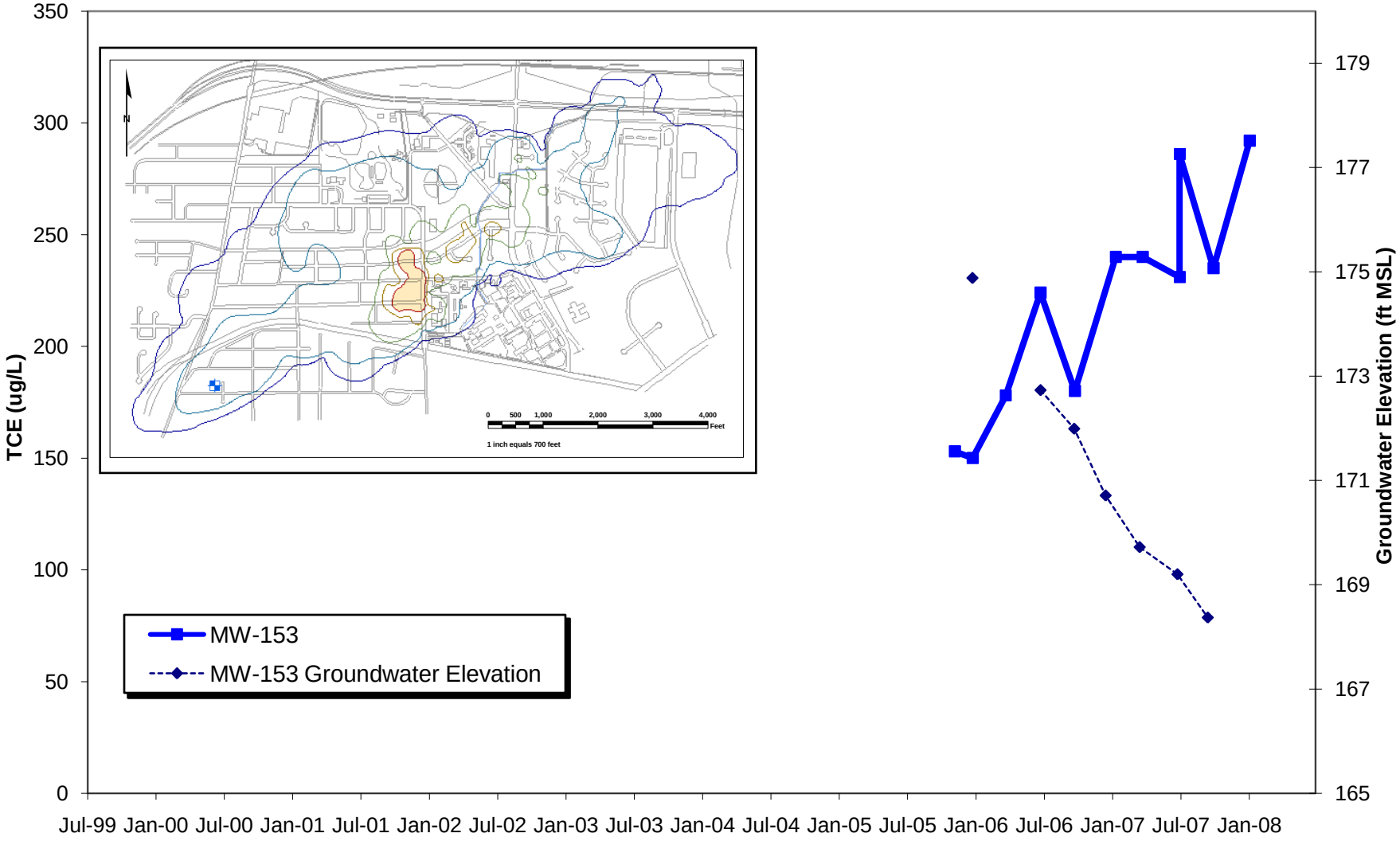

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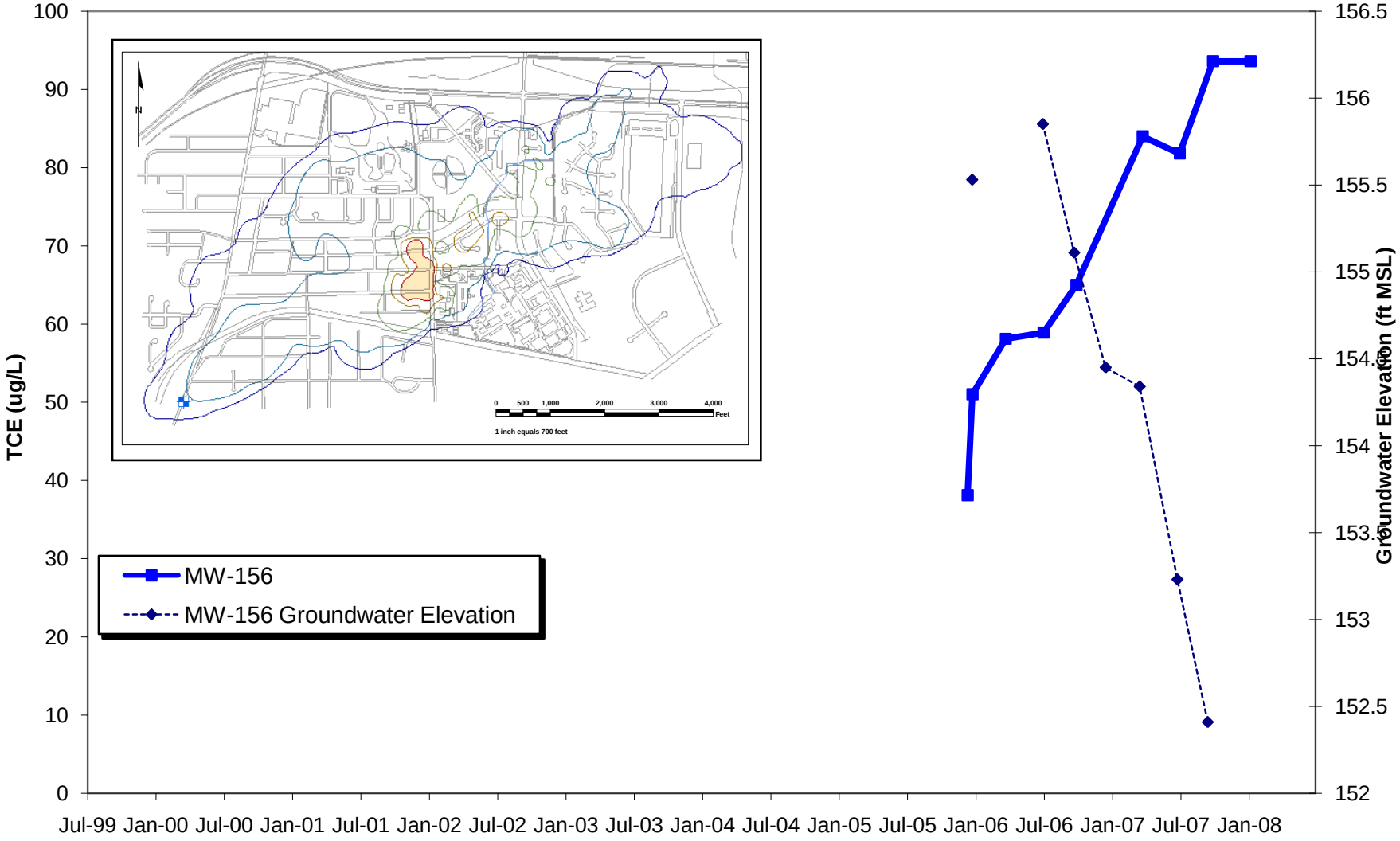

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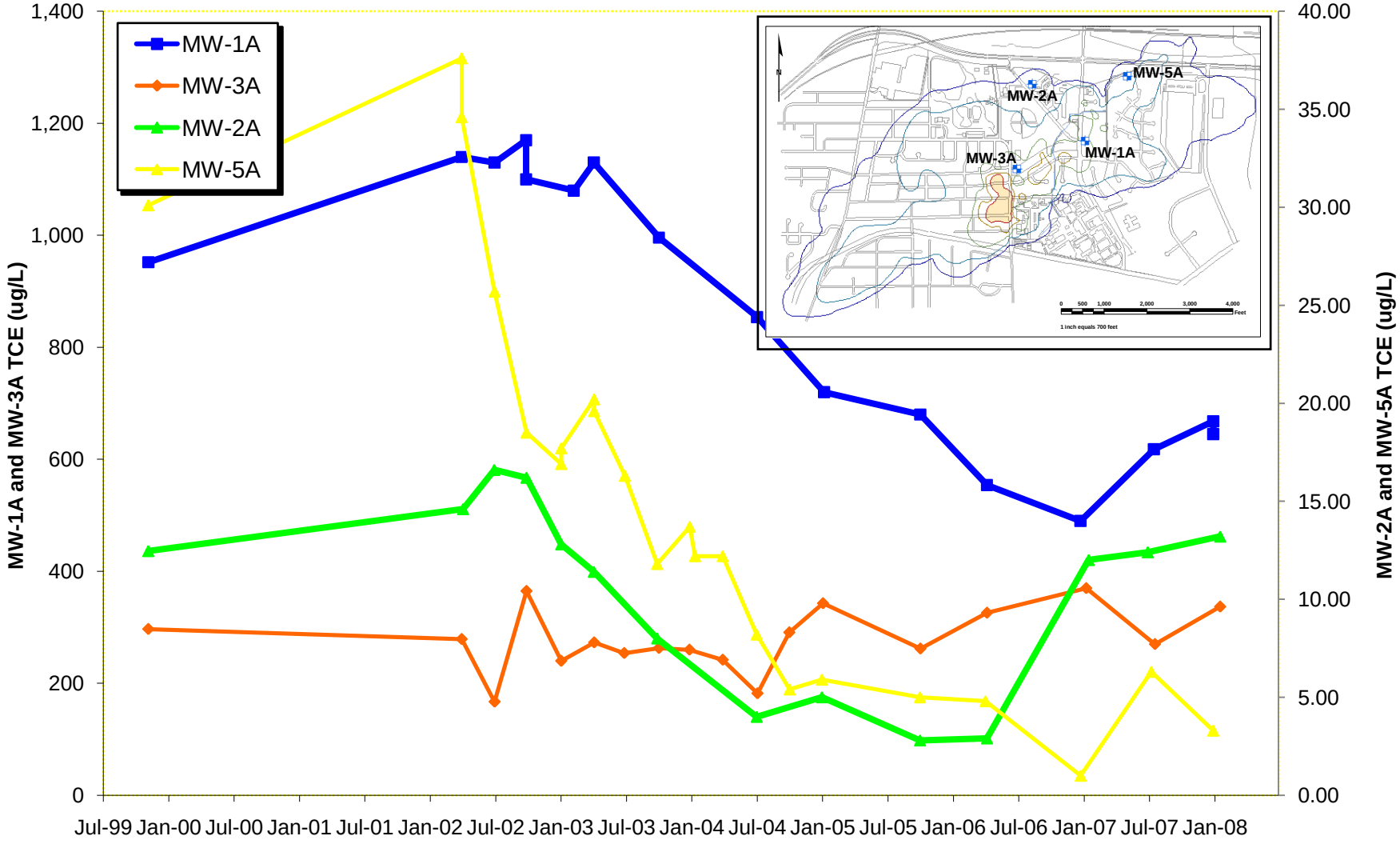
MW-1A - MW-5A



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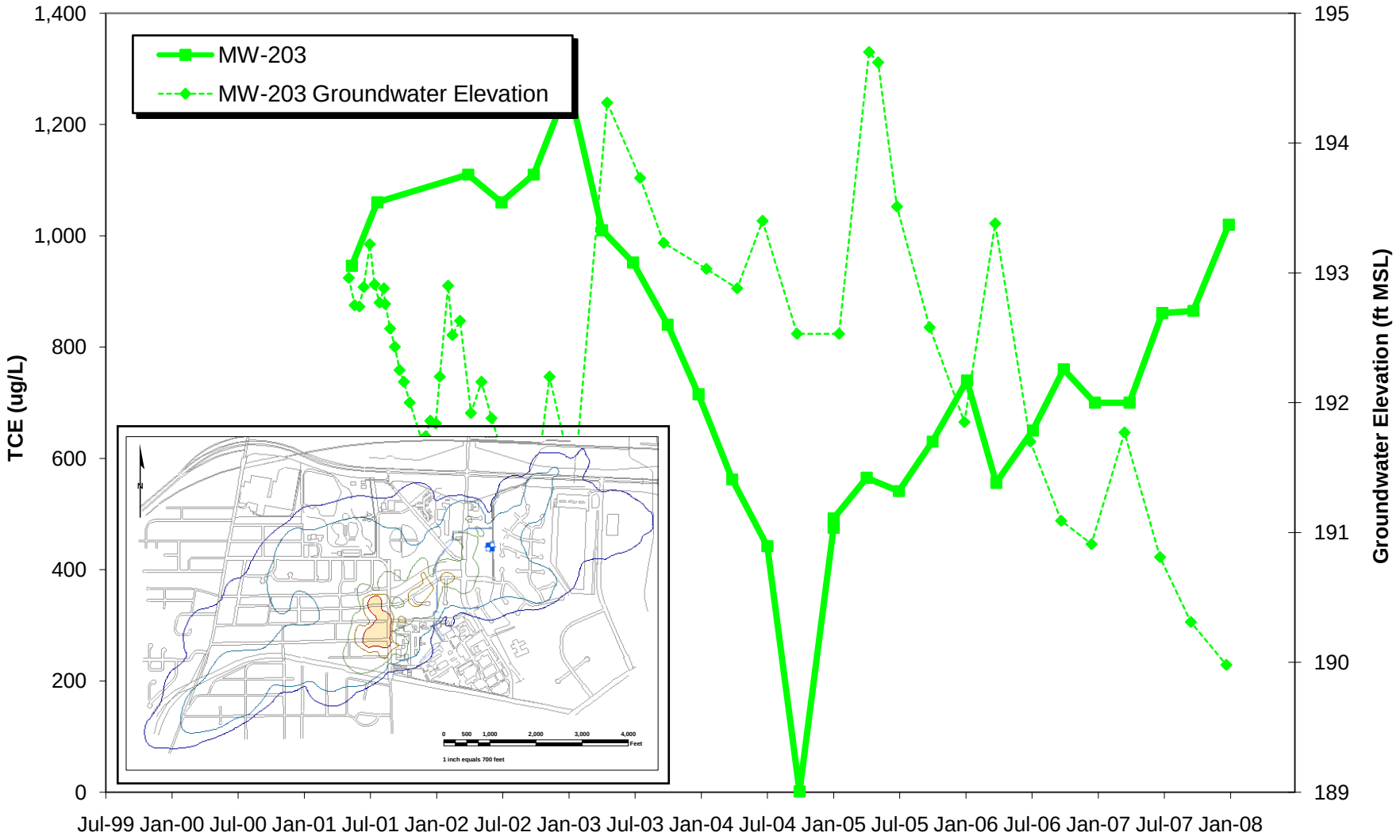
MW-203



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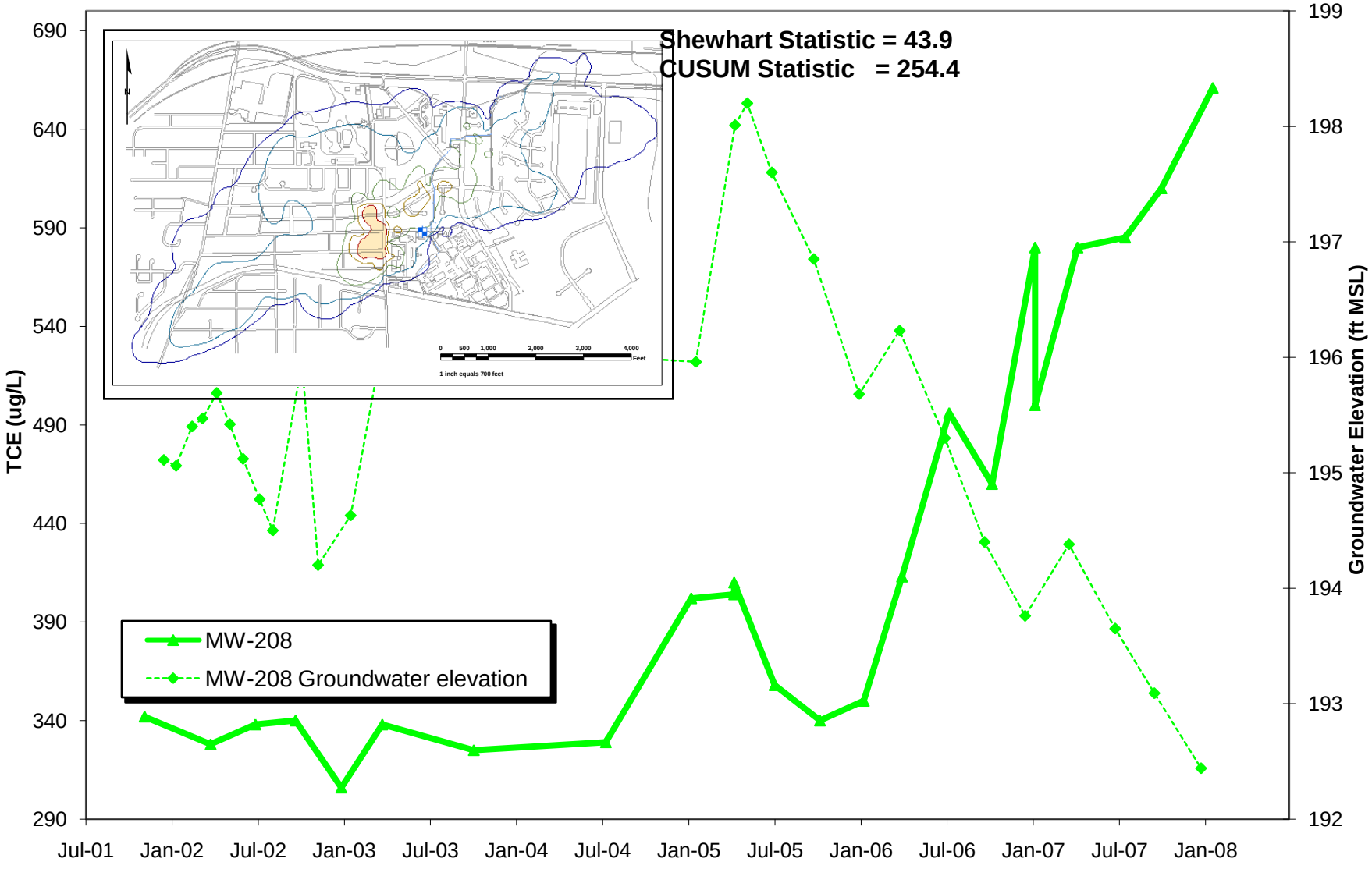

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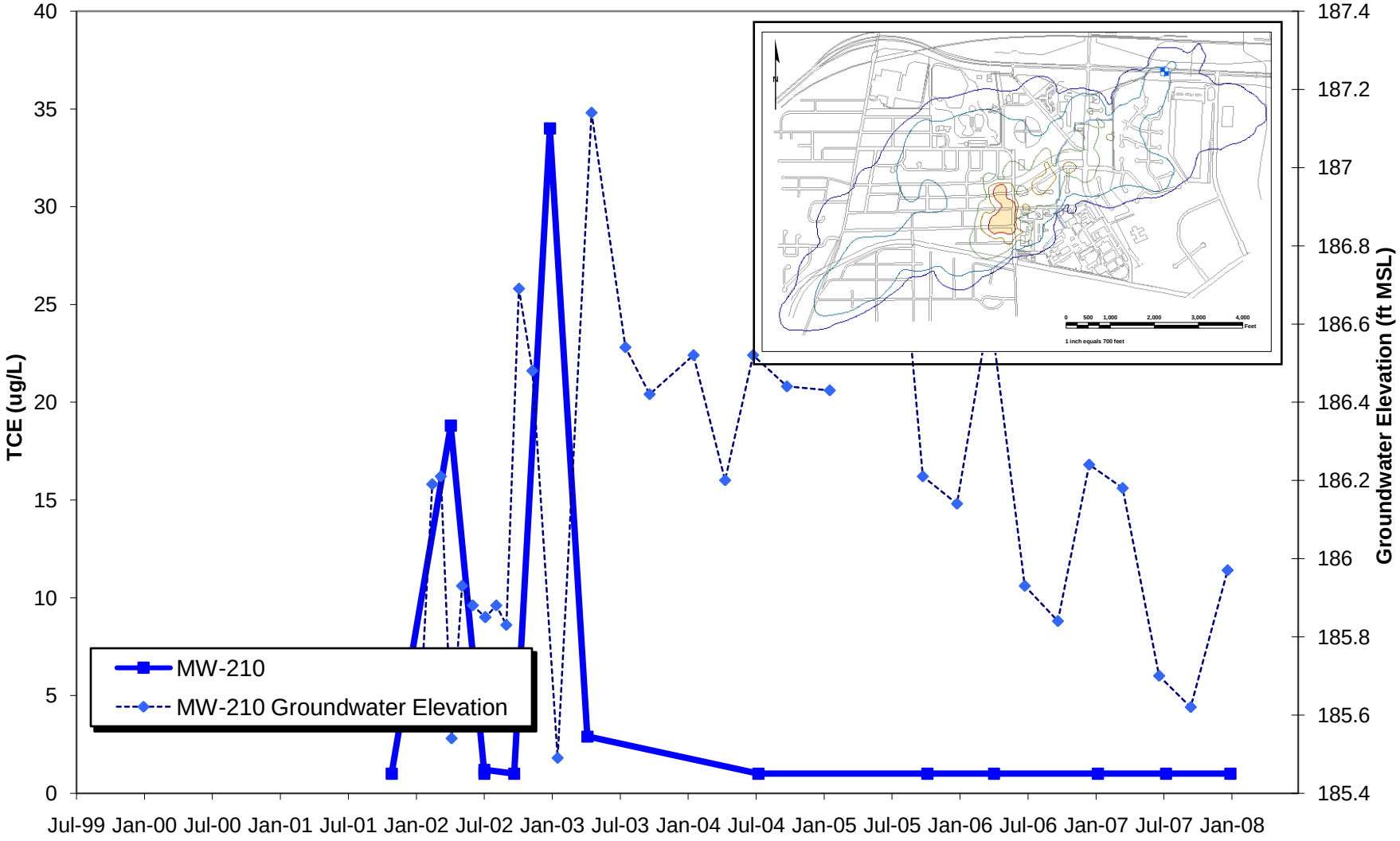

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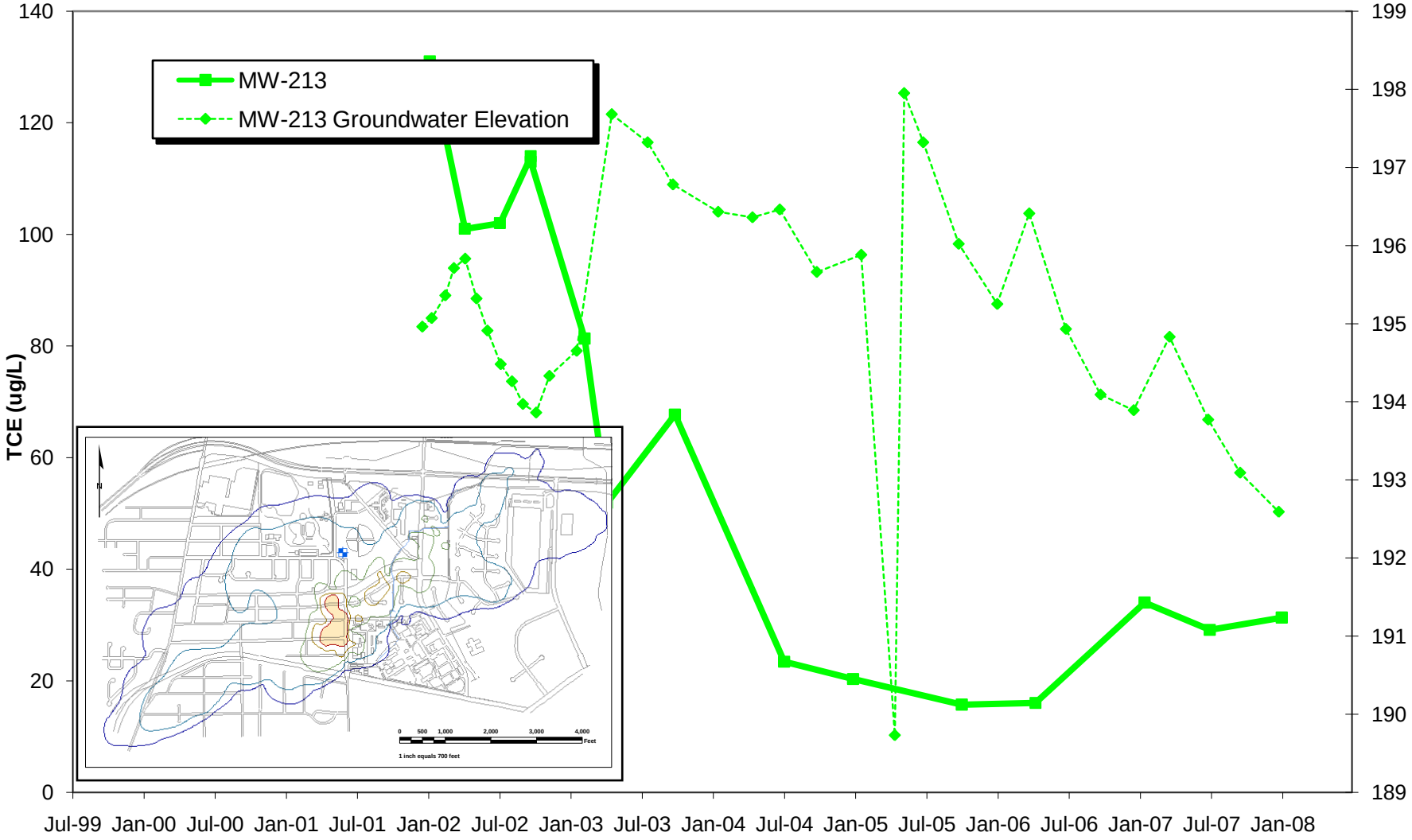

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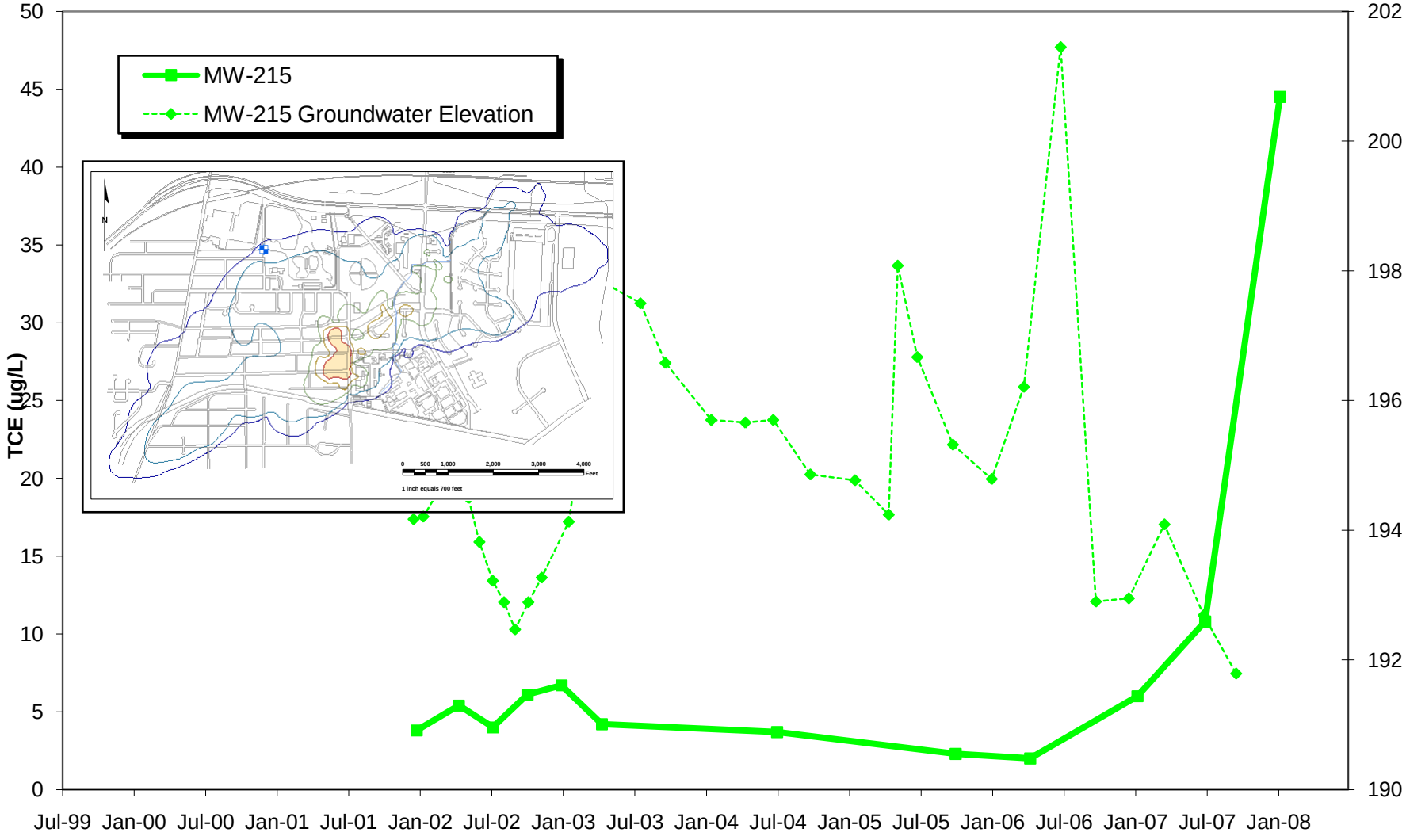

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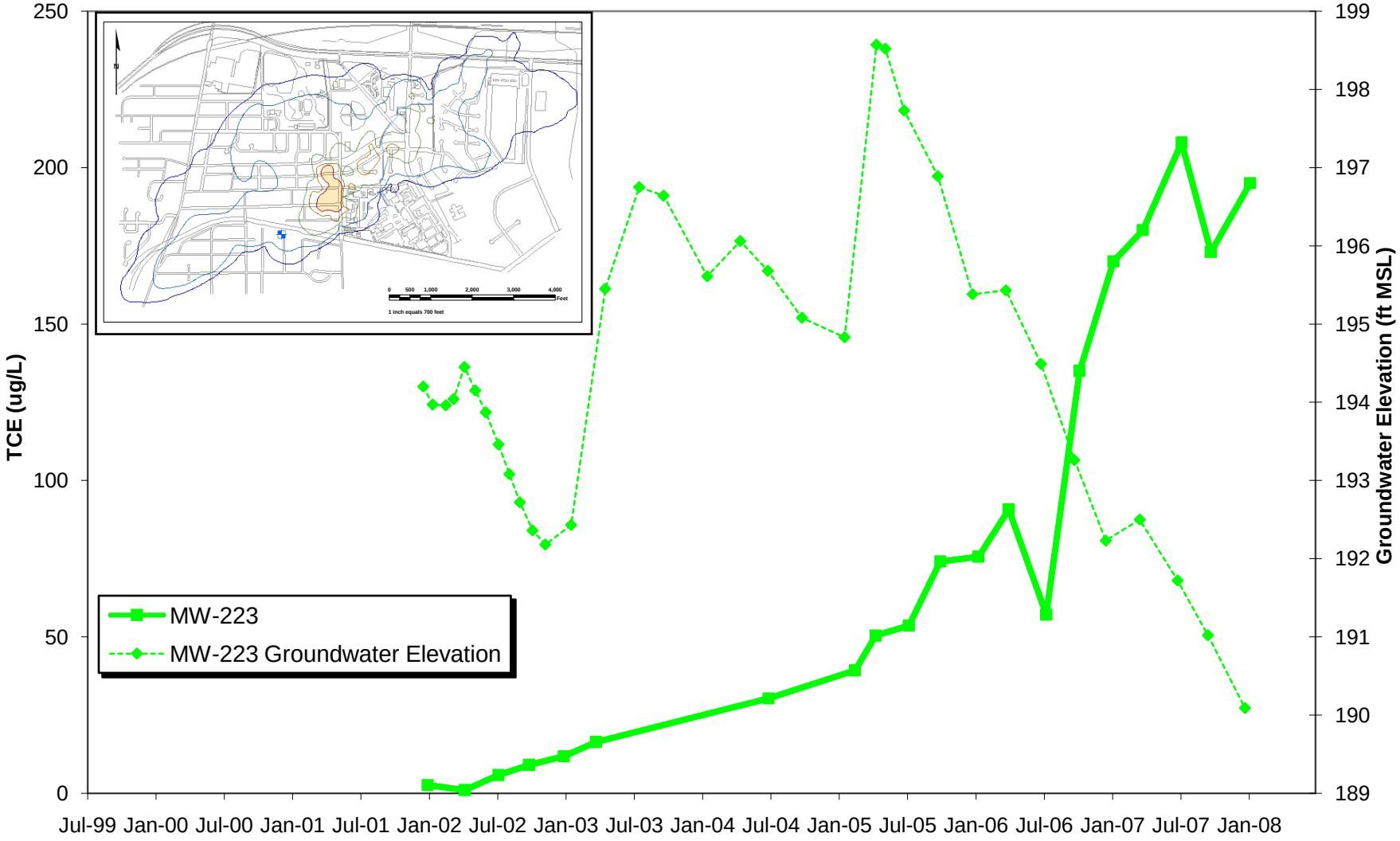

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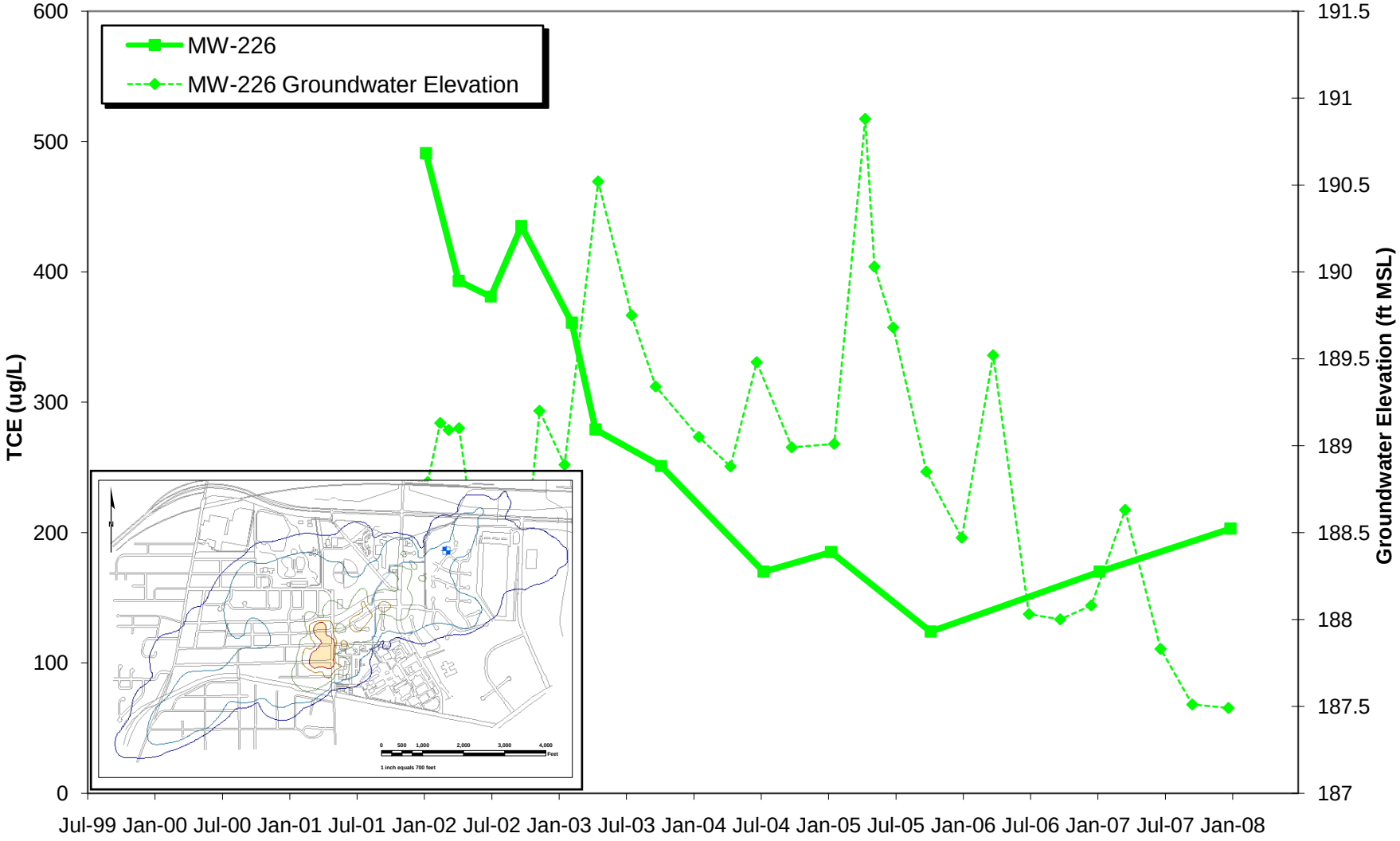

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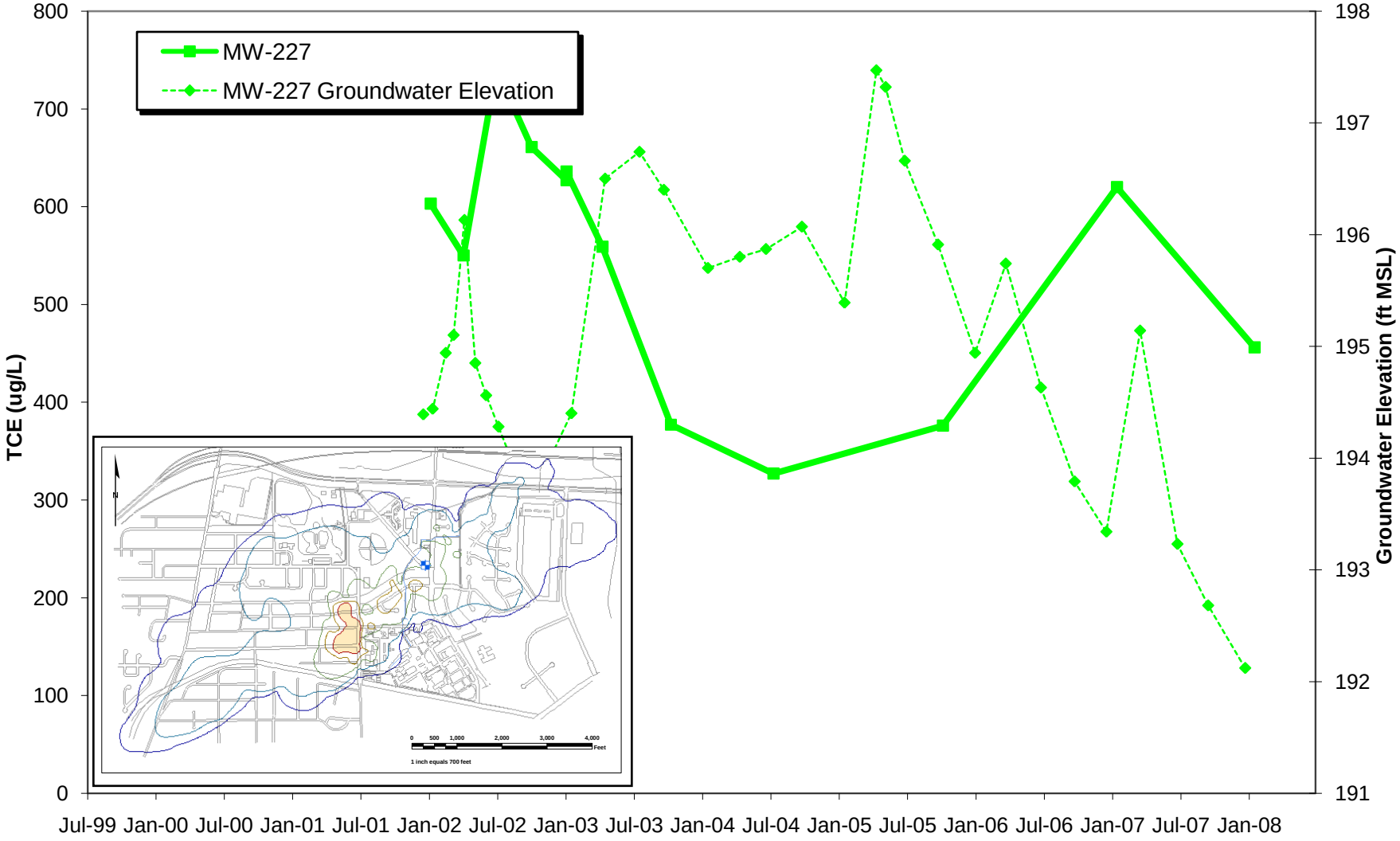

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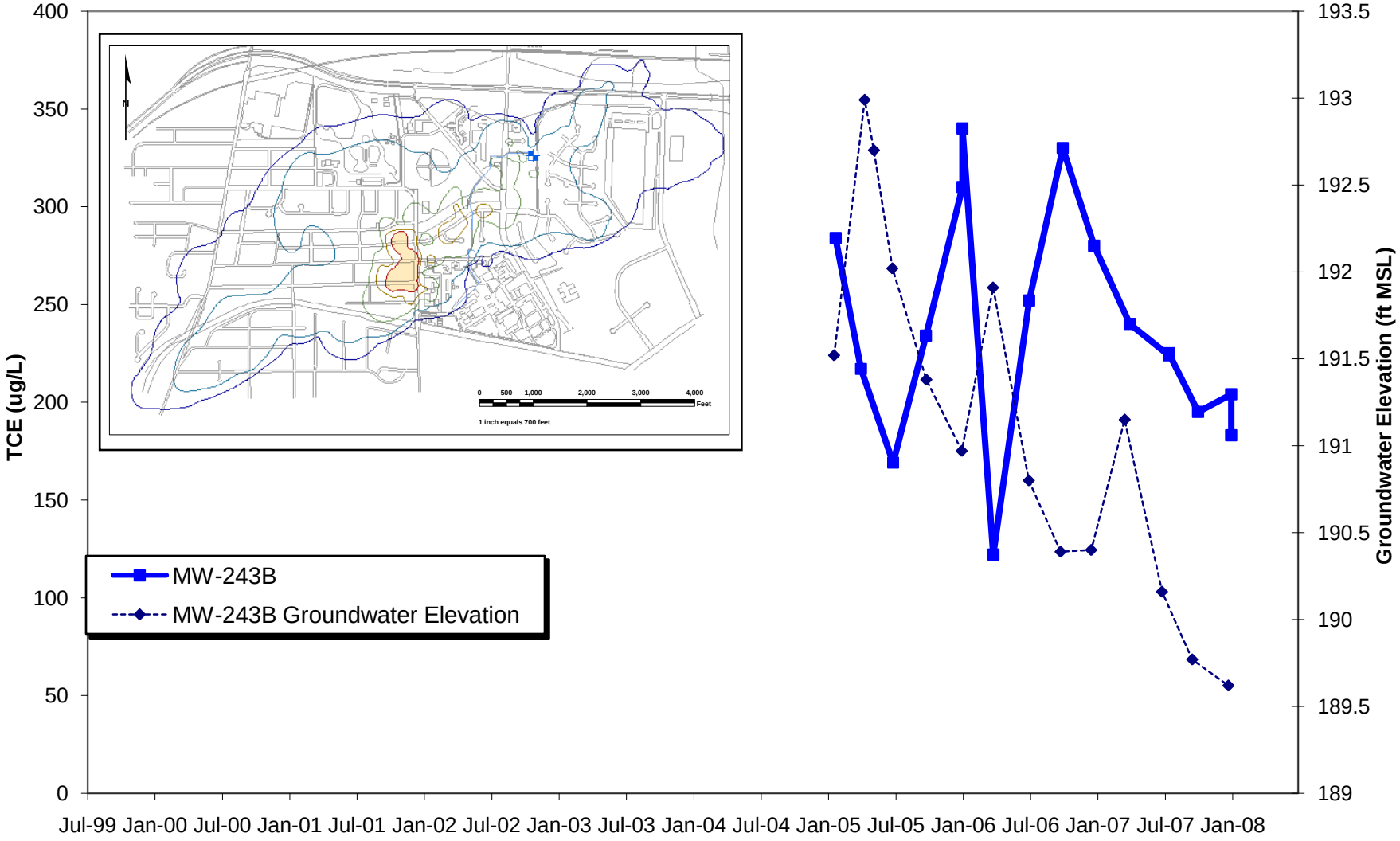
MW-243B



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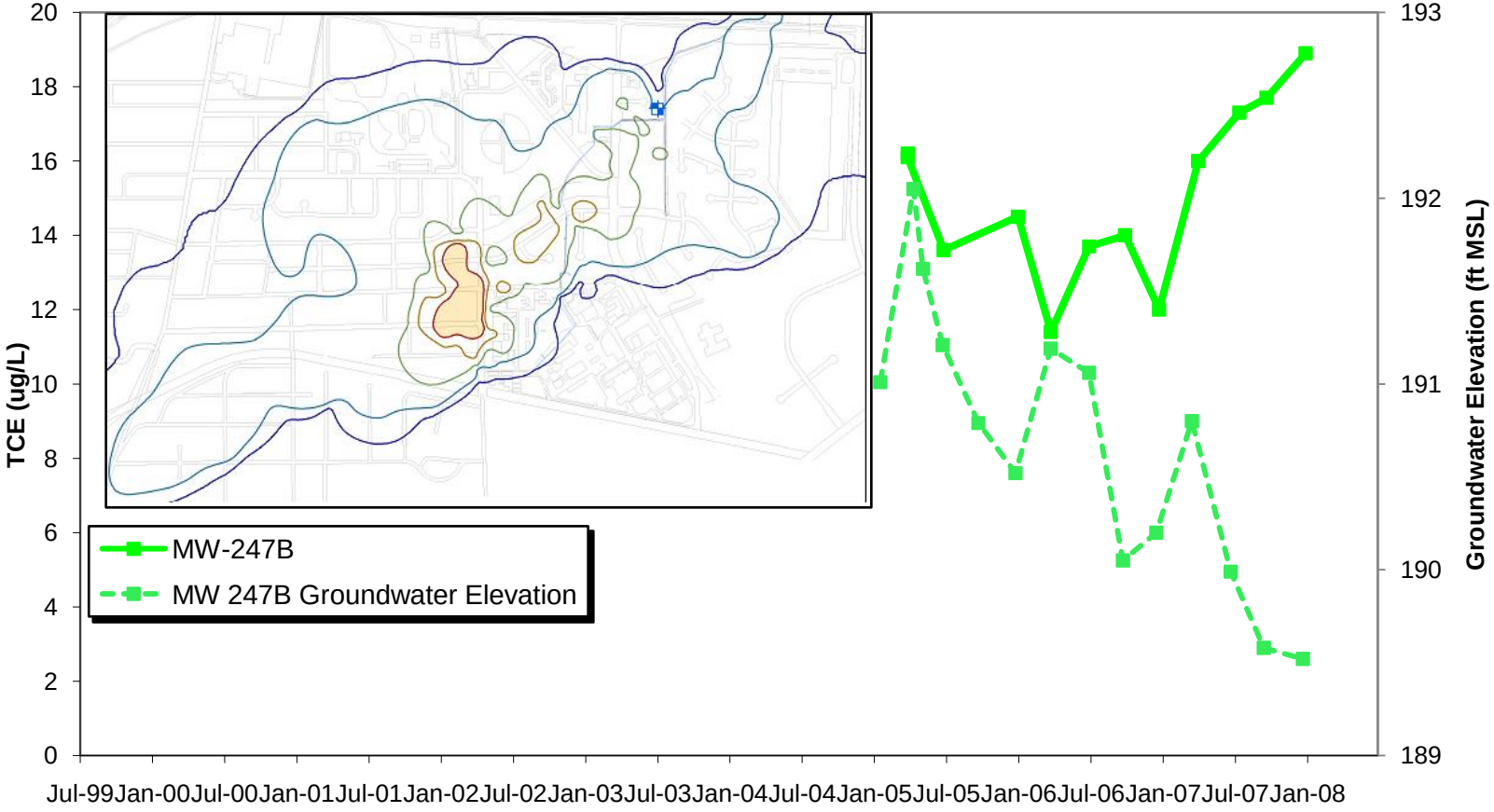
MW-247B



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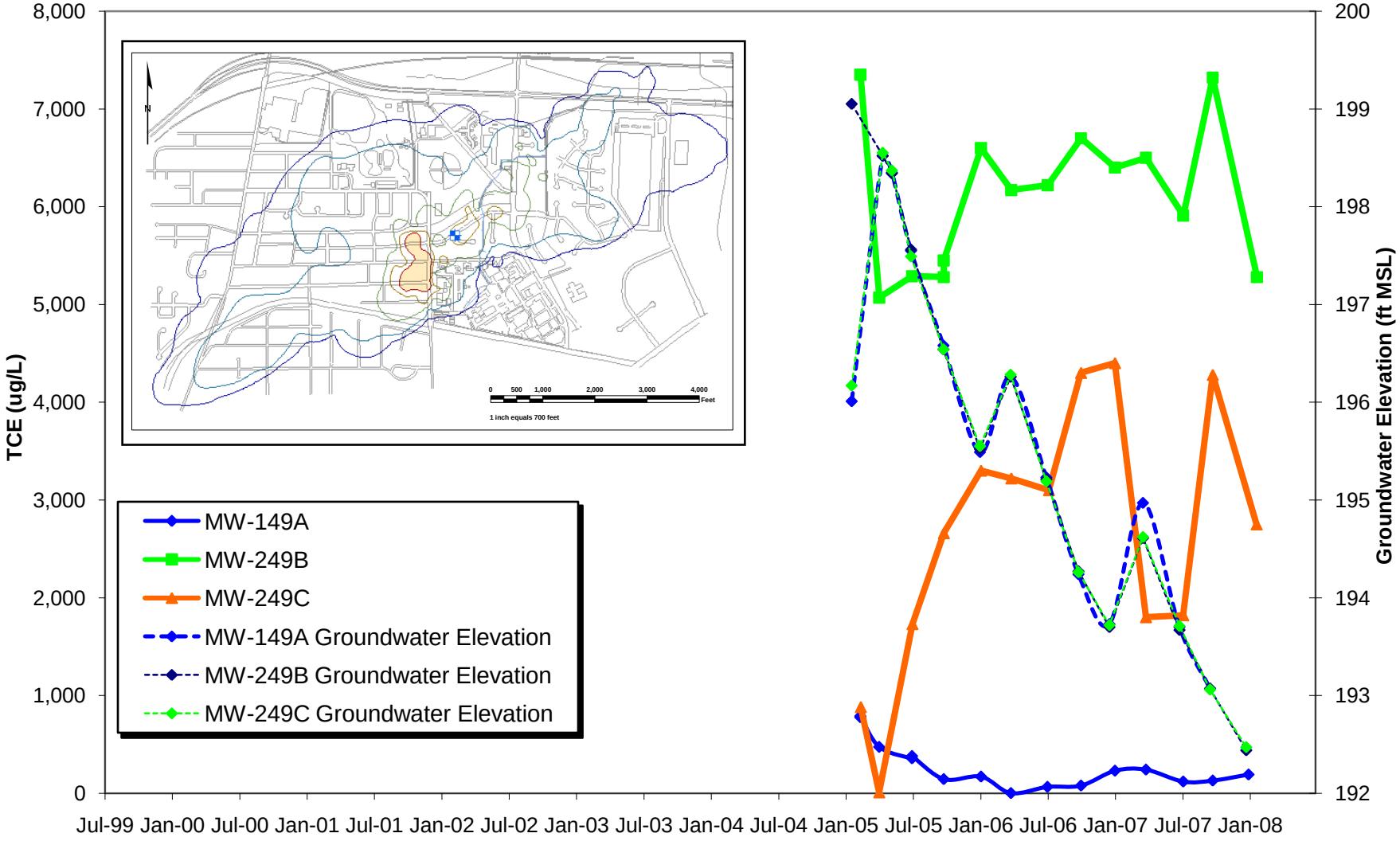
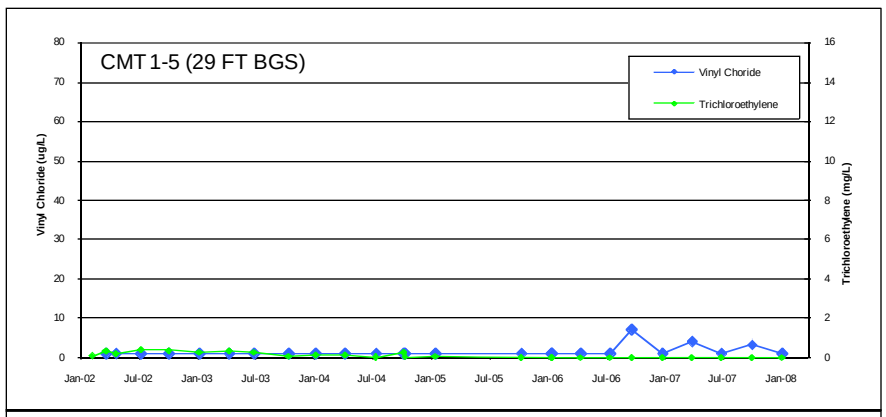
MW-249B - MW-249C

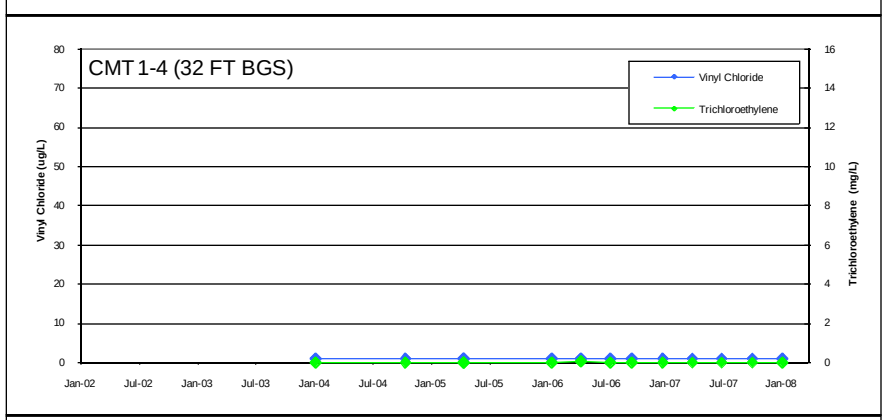


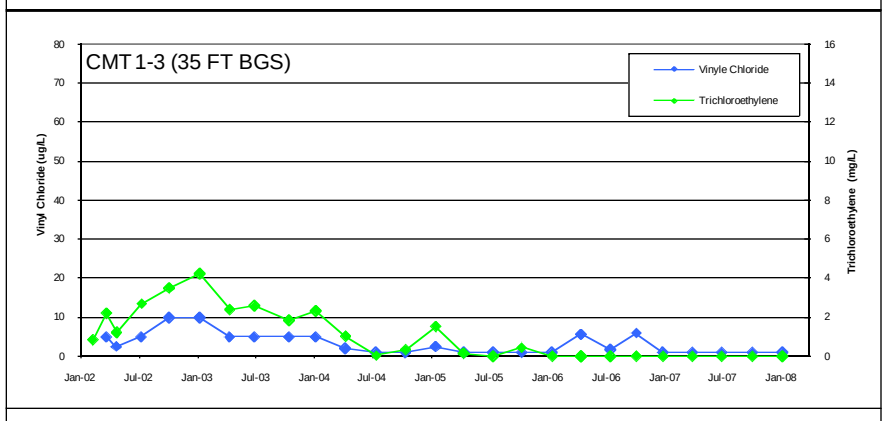
APPENDIX B

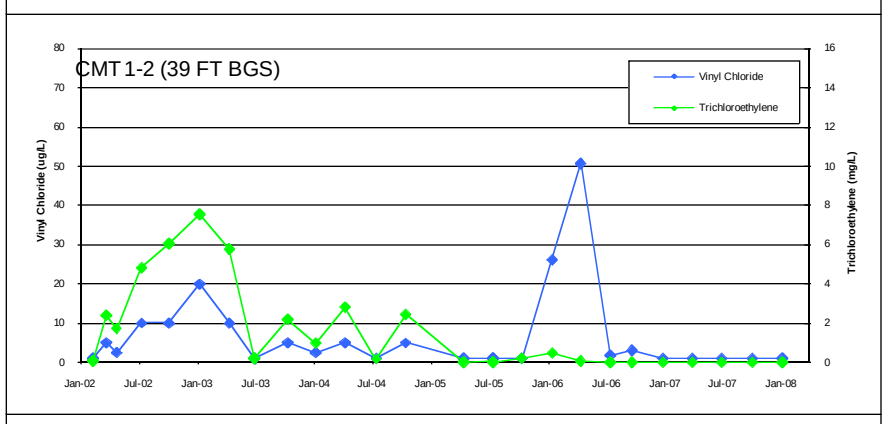
TCE DEGRADATION PRODUCTS
AND
TCE DEGRADATION INDICATOR PARAMETERS

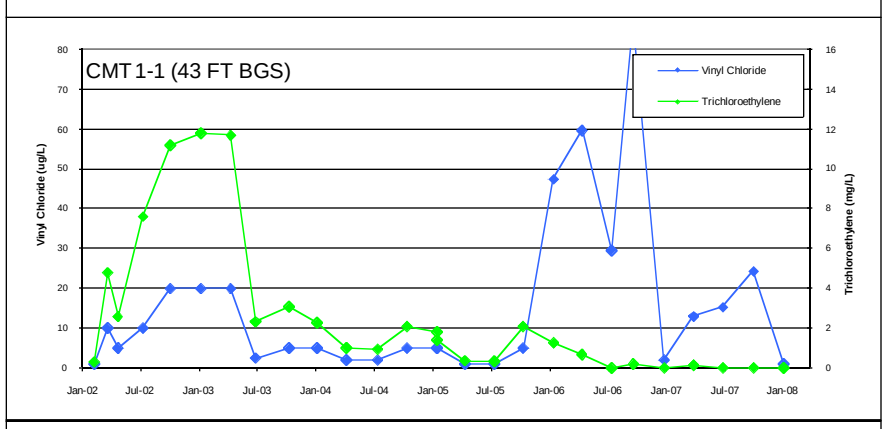
COLISEUM BOULEVARD PLUME
CMT 1 AND CMT 2 CONSTITUENT CONCENTRATION TRENDS

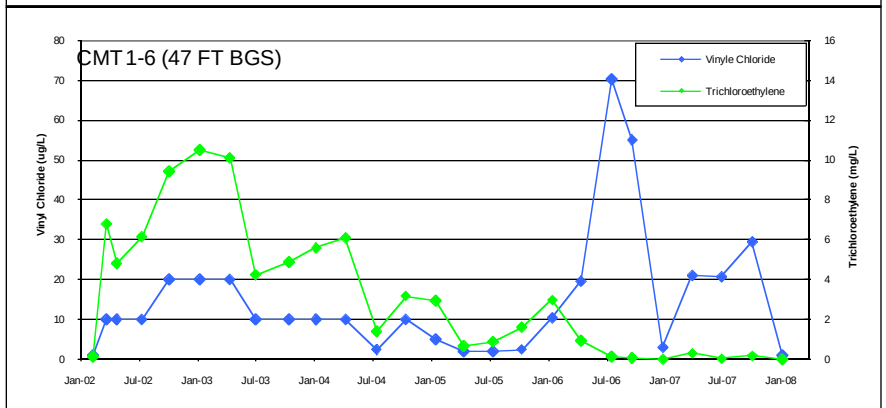


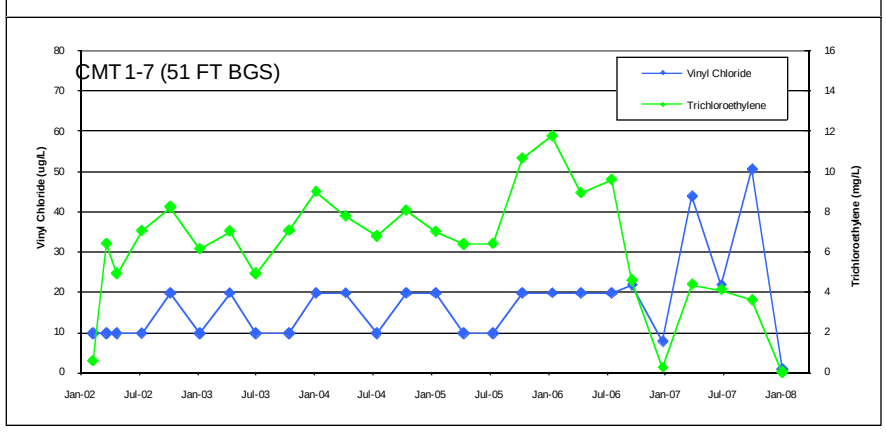


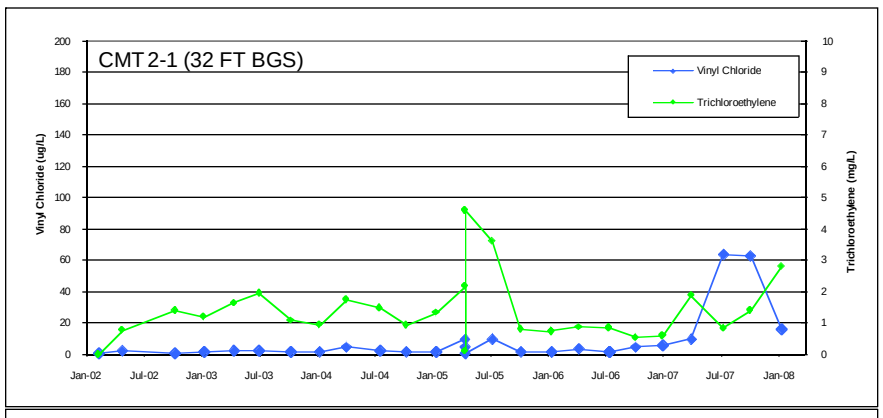


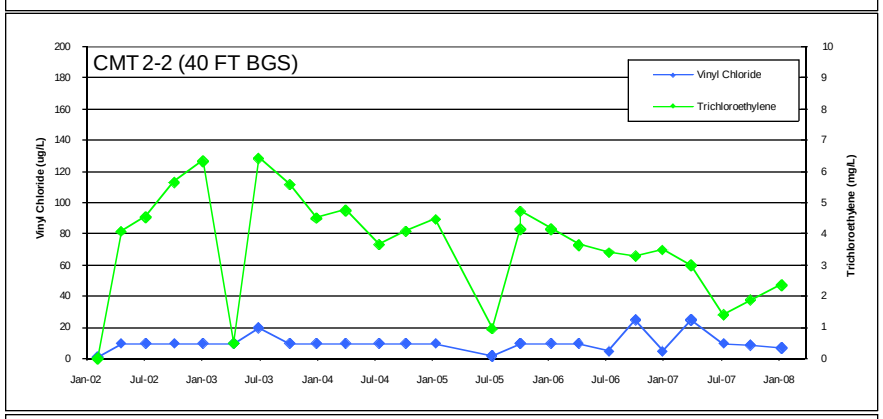


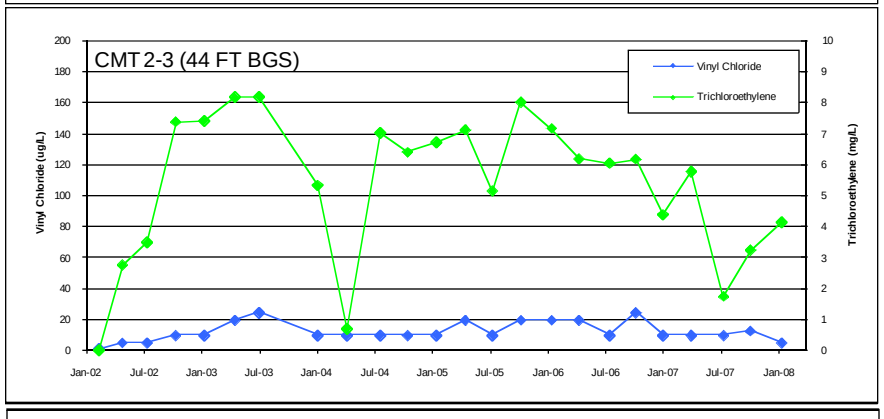


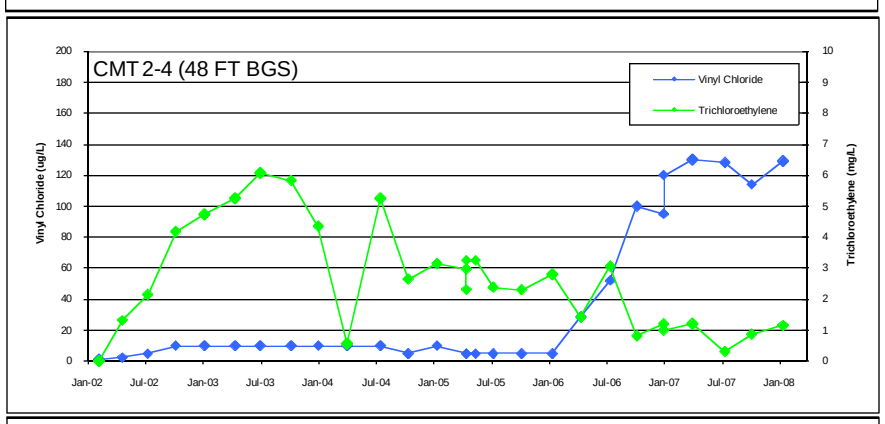


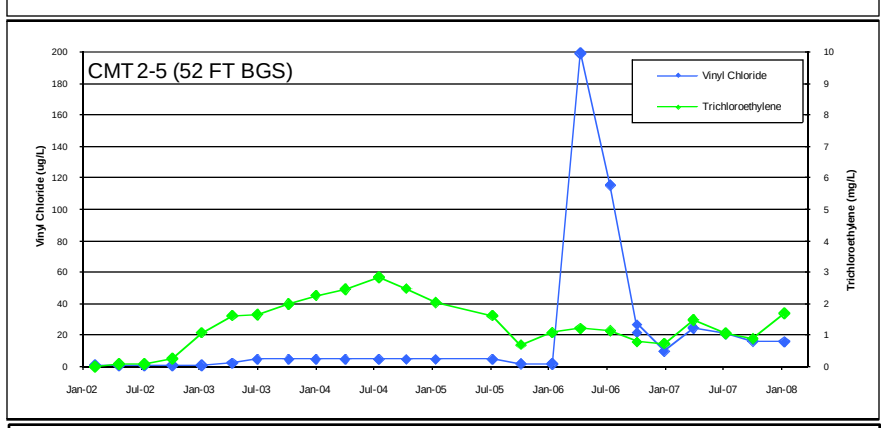


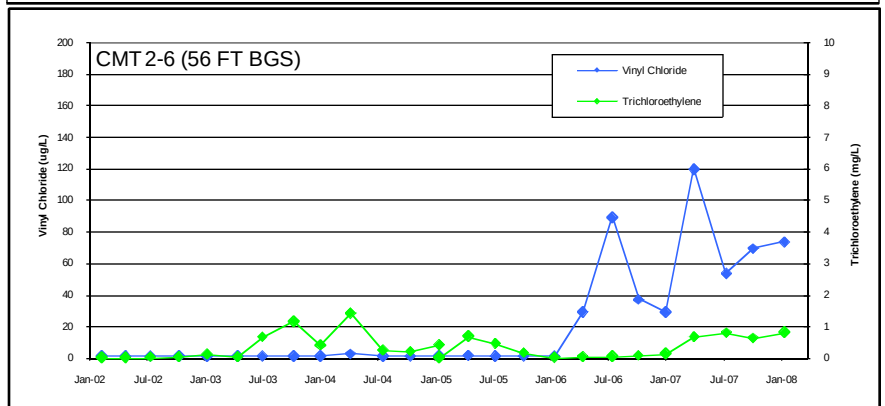


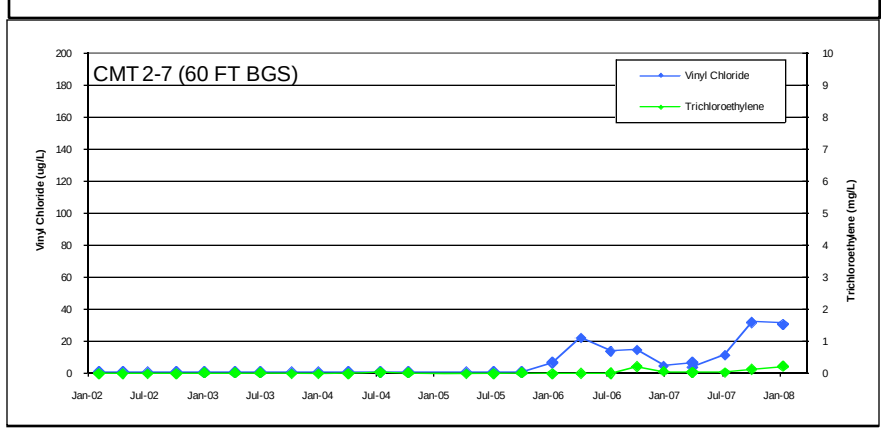




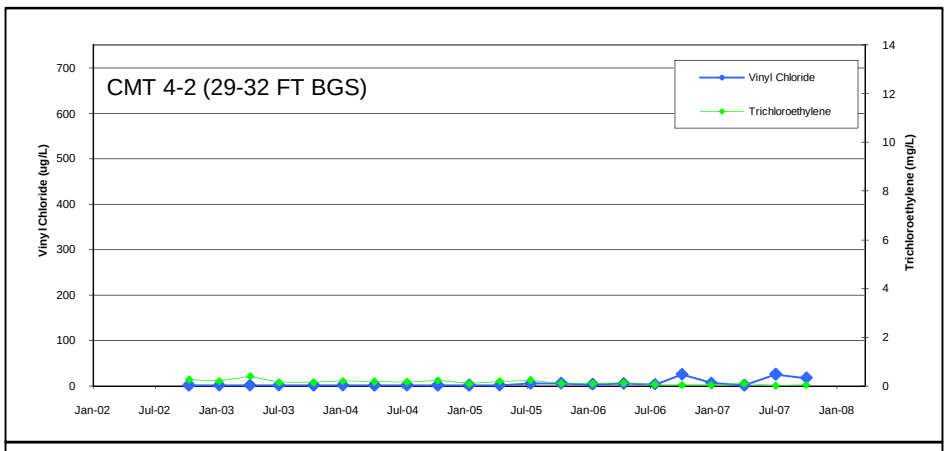


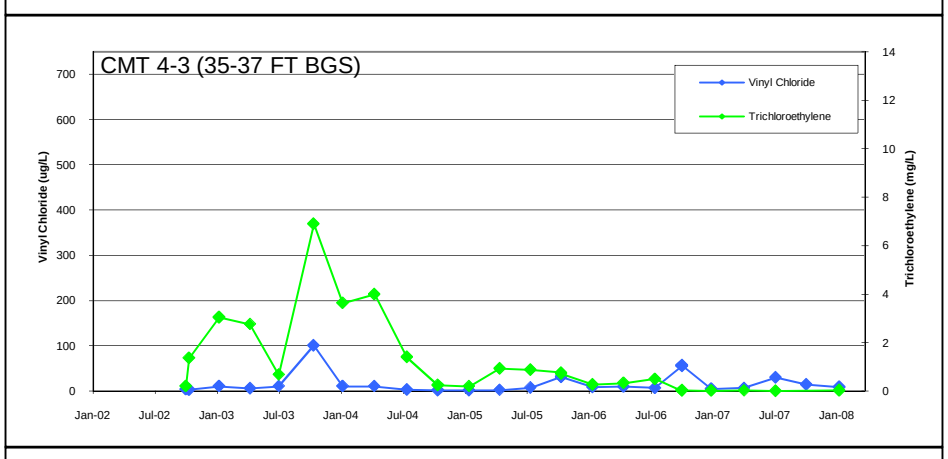


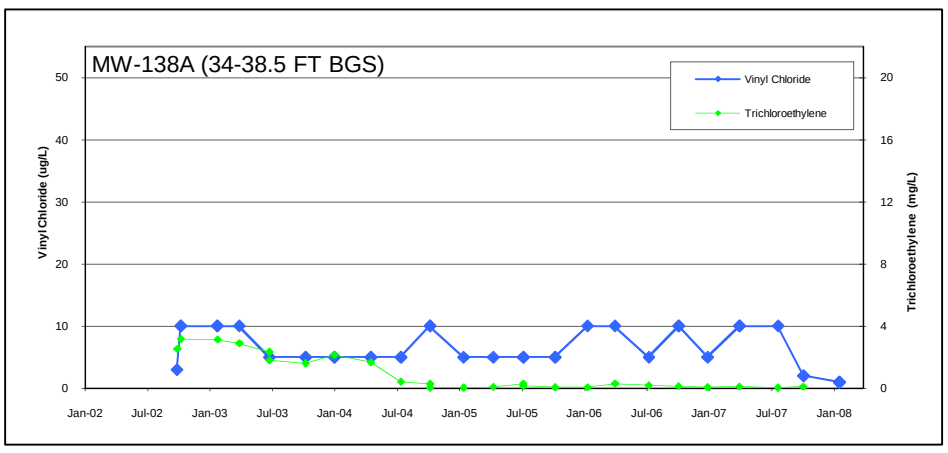


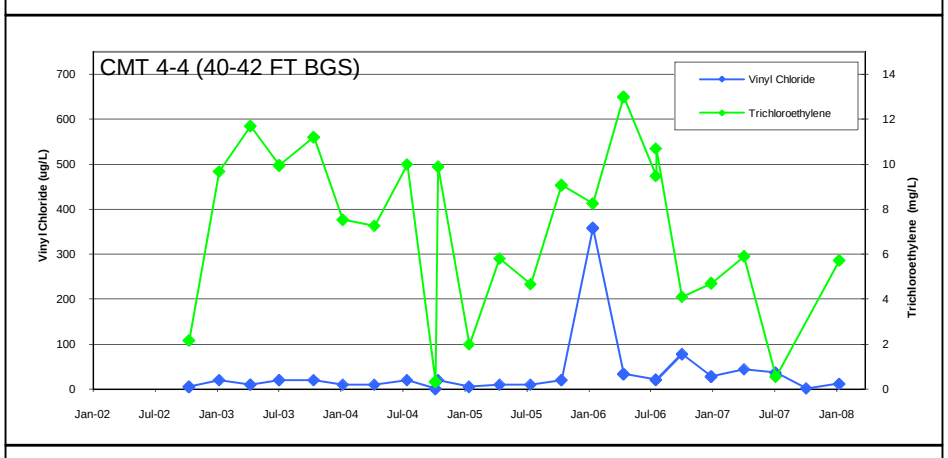


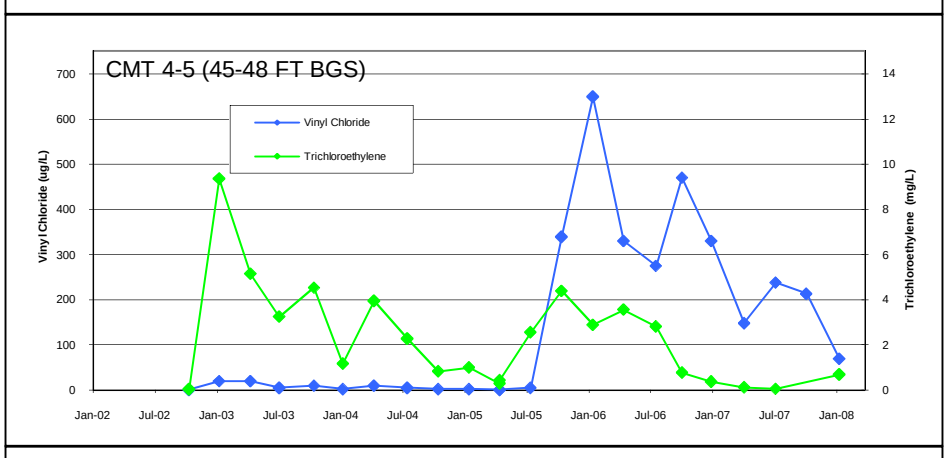
COLISEUM BOULEVARD PLUME
CMT 4 AND MW-138A/238B/238C CONSTITUENT CONCENTRATION TRENDS

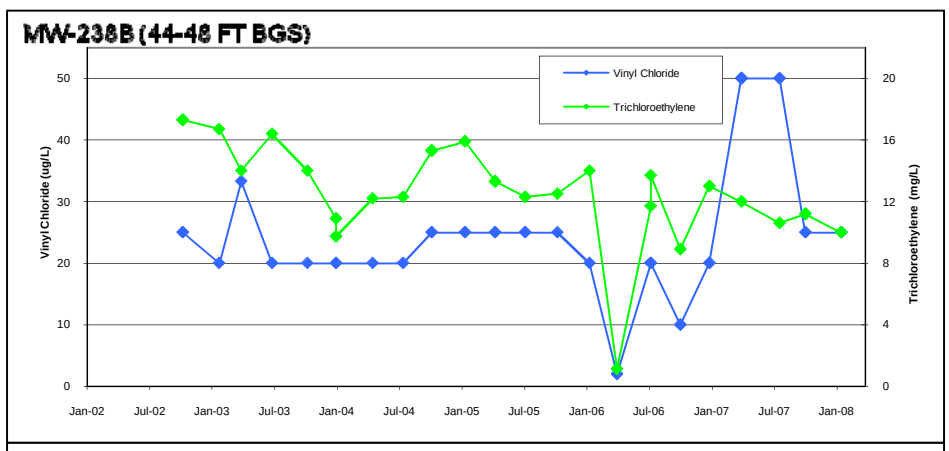


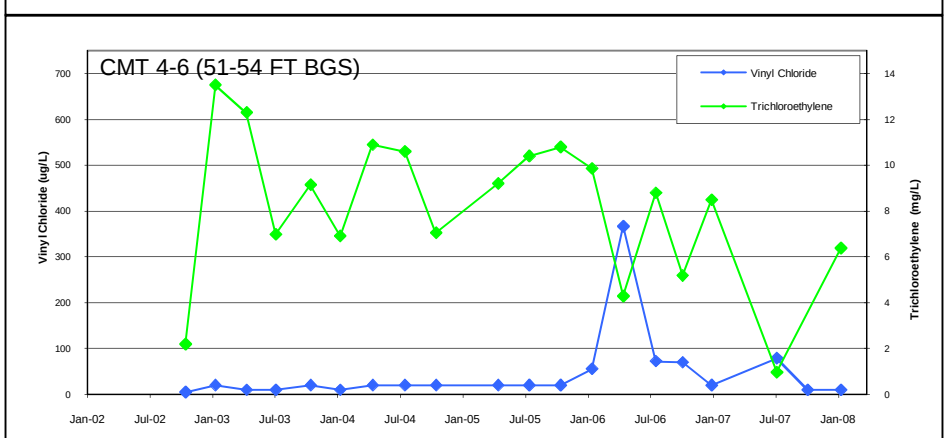


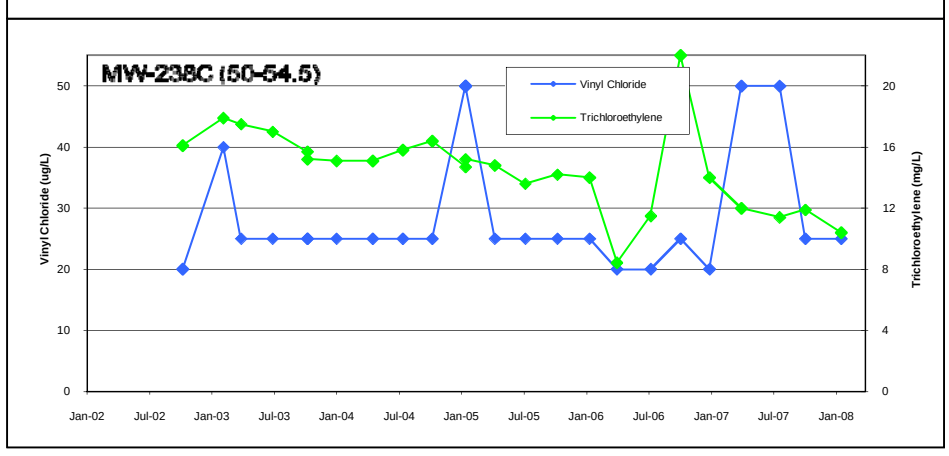


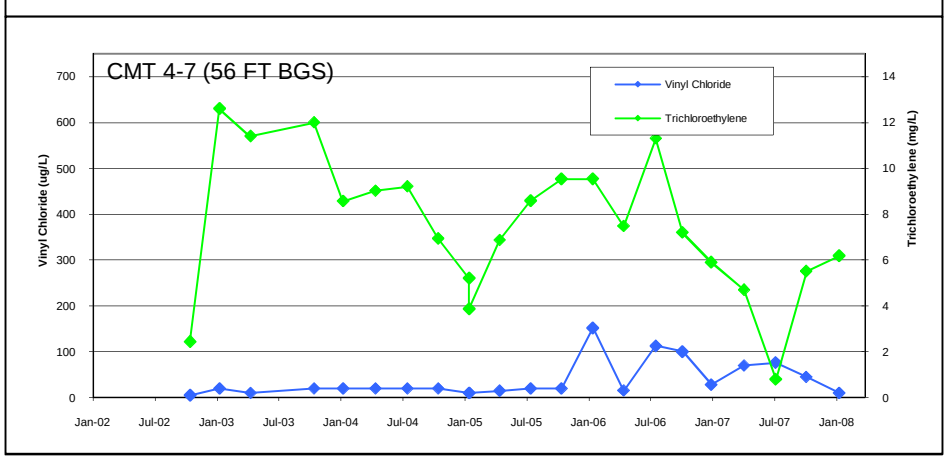


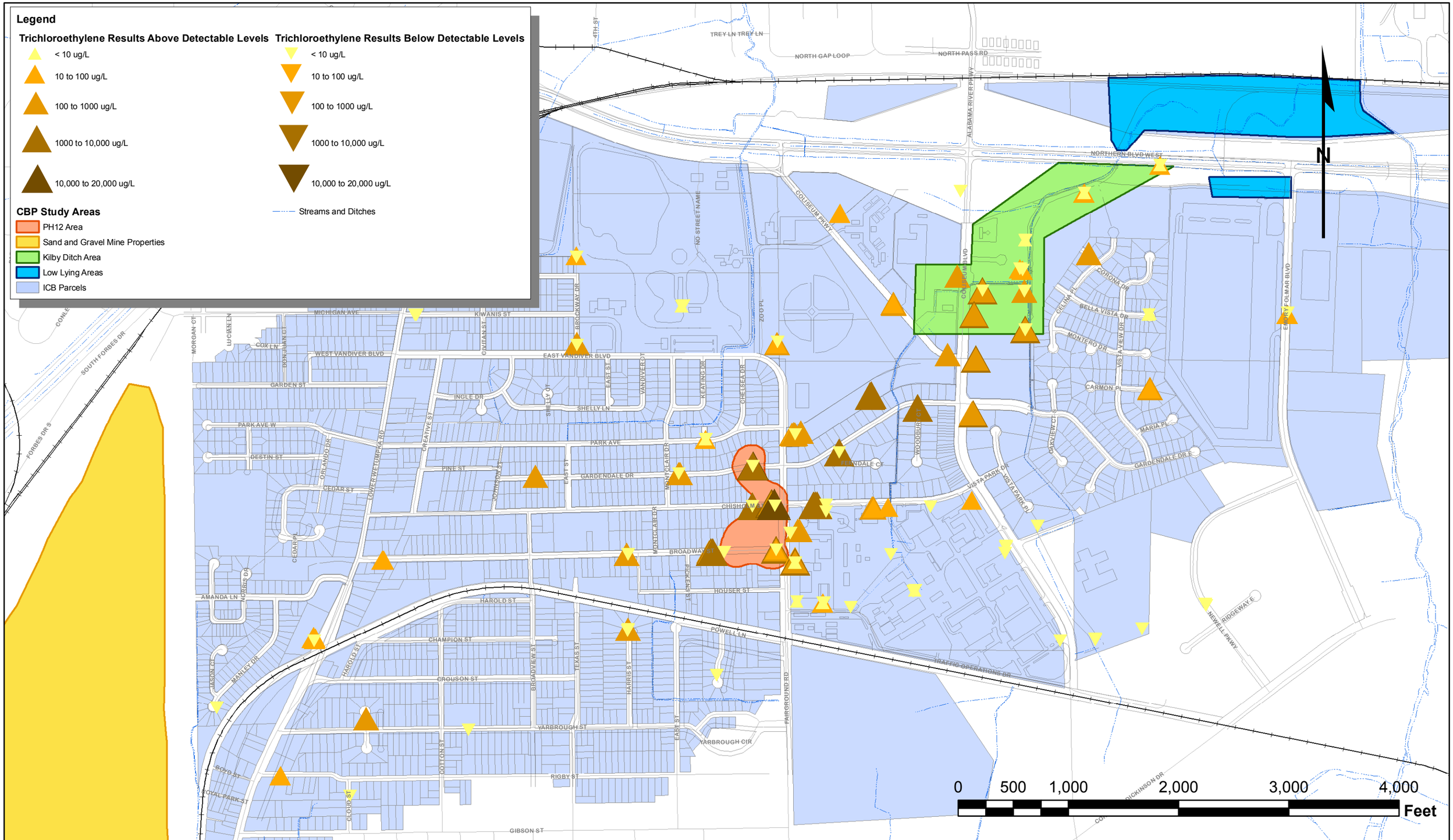










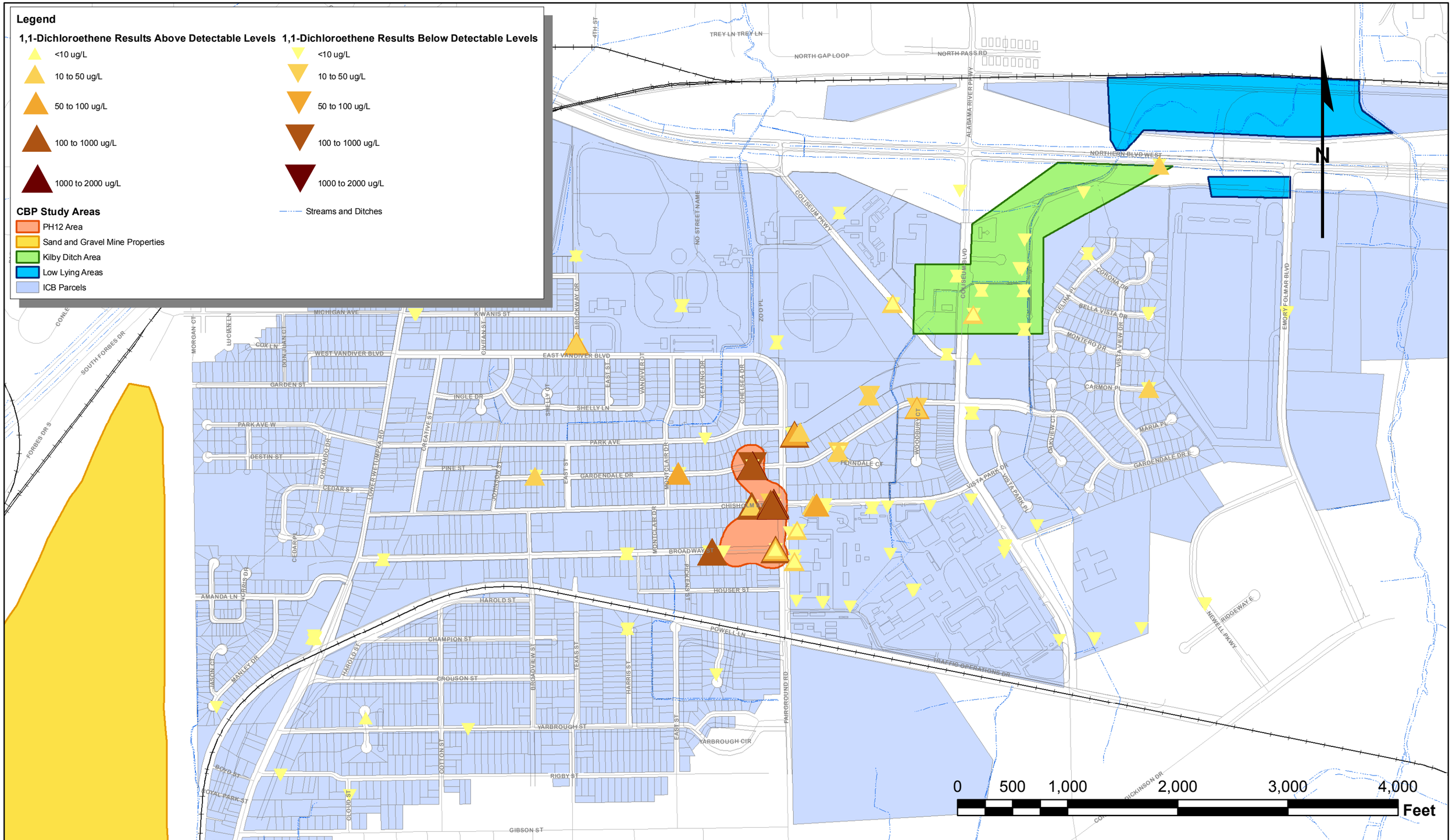


Alabama Department of Transportation
Coliseum Boulevard Project

Maximum TCE Concentration in Groundwater (May 2001 - Jan 2008)

FIGURE B-1

July 2008

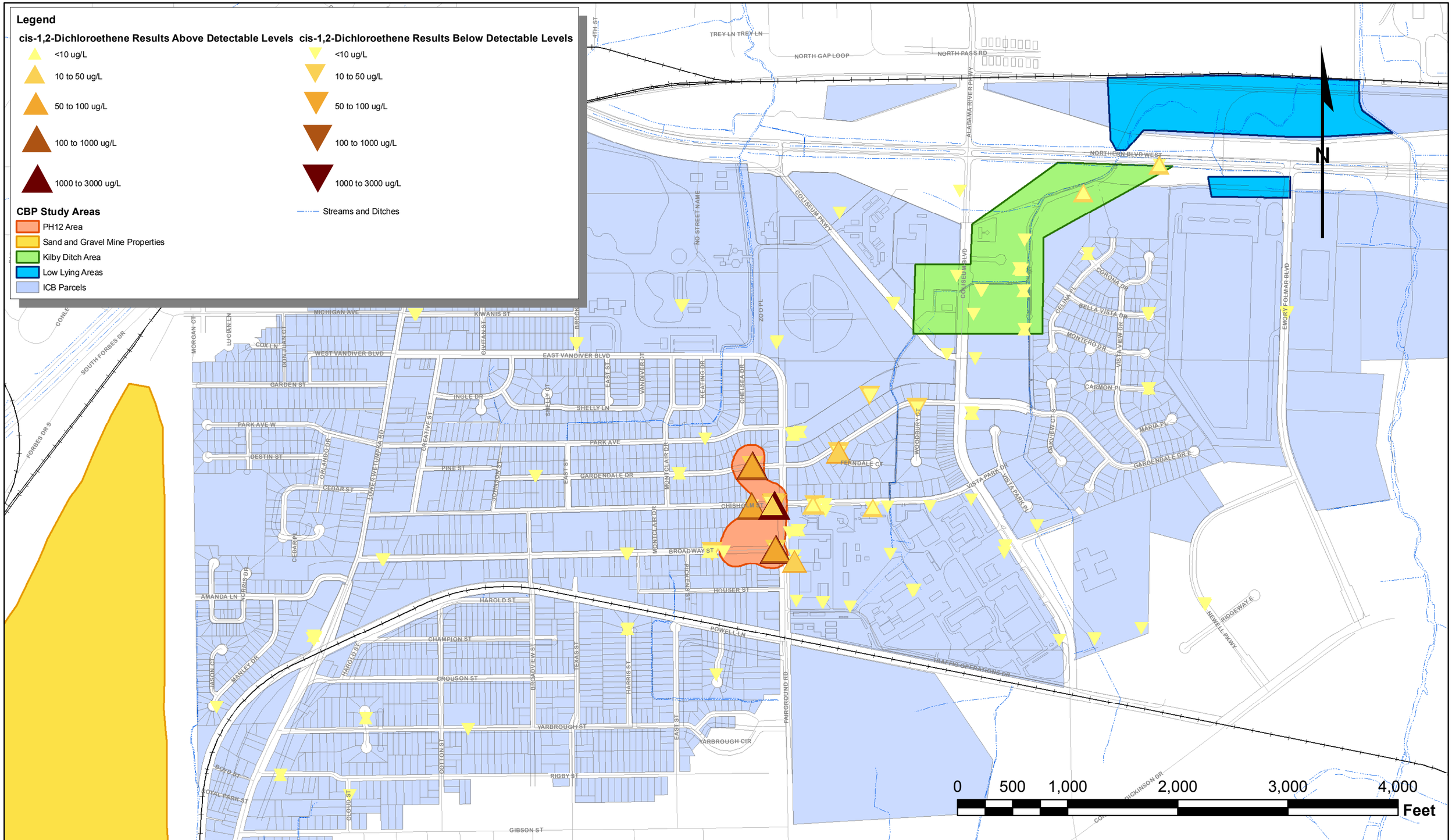


Alabama Department of Transportation
Coliseum Boulevard Project

Maximum 1,1-Dichloroethene Concentration in Groundwater (May 2001 - Jan 2008)

FIGURE B-2

July 2008

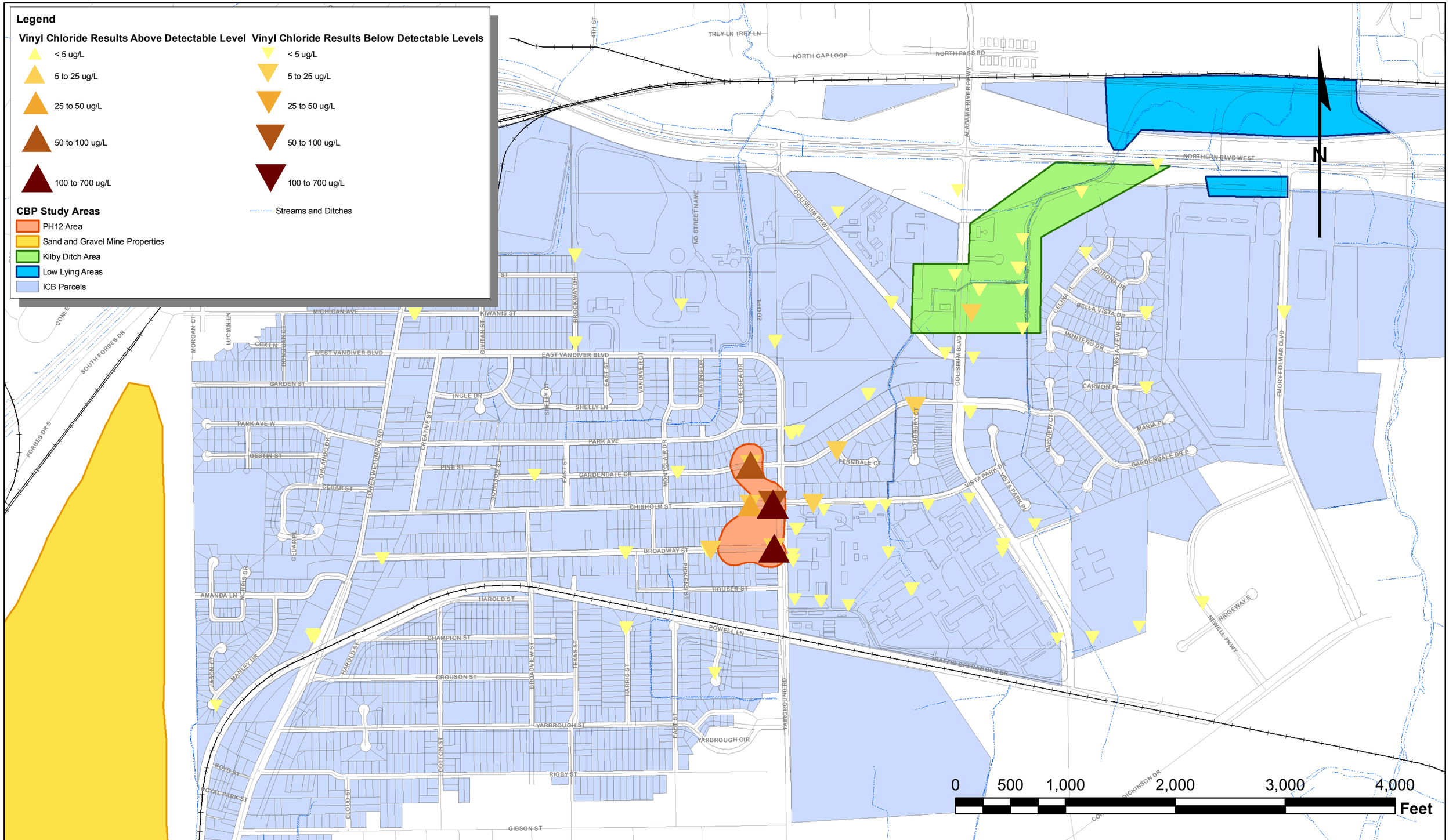


Alabama Department of Transportation
Coliseum Boulevard Project

Maximum Cis 1,2-Dichloroethene Concentration in Groundwater (May 2001 - Jan 2008)

FIGURE B-3

July 2008

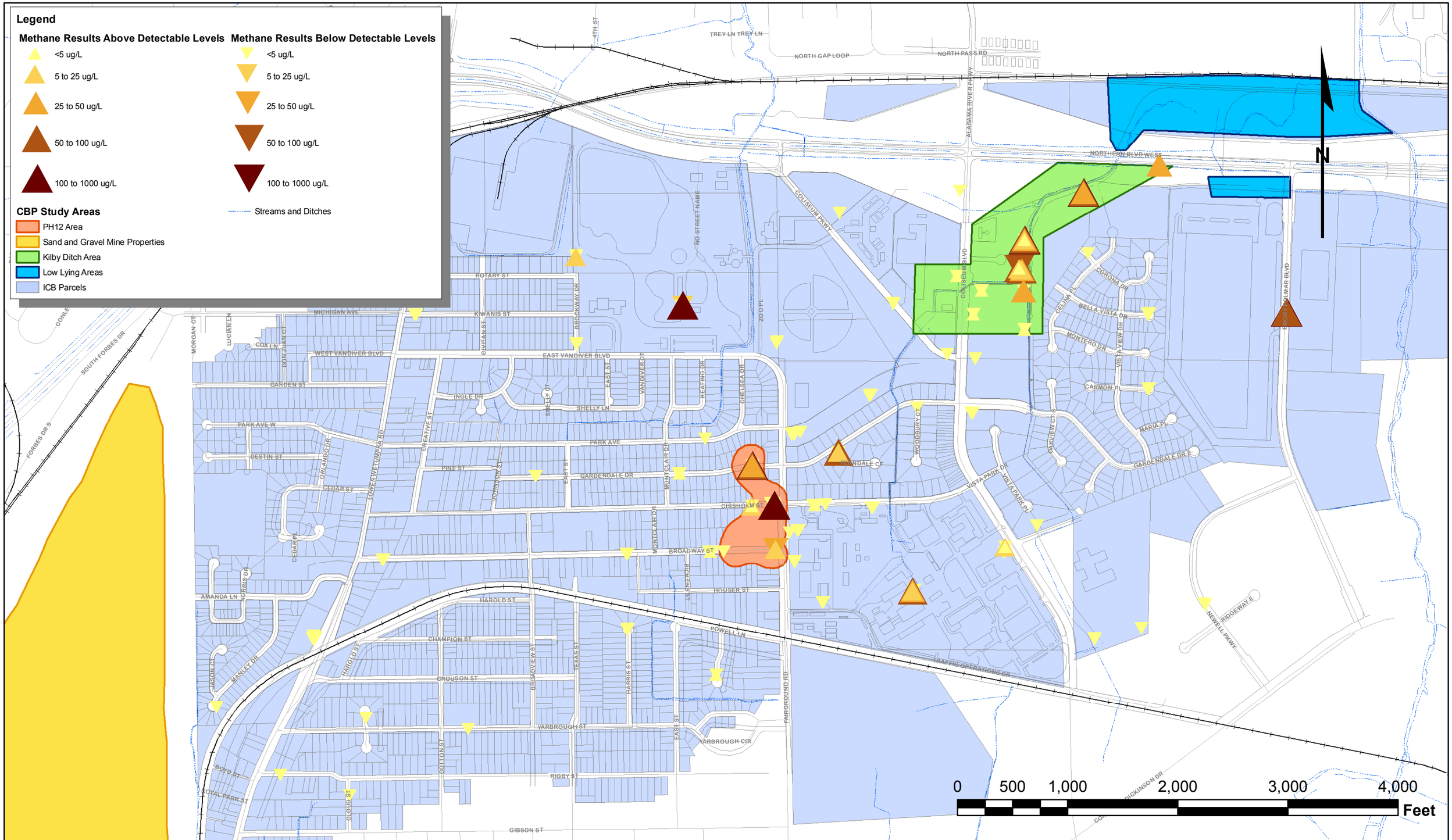


Alabama Department of Transportation
Coliseum Boulevard Project

Maximum Vinyl Chloride Concentration in Groundwater (May 2001 - Jan 2008)

FIGURE B-4

July 2008



Alabama Department of Transportation
Coliseum Boulevard Project

Maximum Methane Concentration in Groundwater (May 2001 - Jan 2008)

FIGURE B-5

July 2008