MWH

BUILDING A BETTER WORLD

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SUBJECT: Wasatch Chemical Site
Progress Report No. 99

Dear Sam and Tony:

This semiannual report was prepared by MWH to summarize environmental remediation activities at the Wasatch Chemical Site (Site) in Salt Lake City, Utah from January through June 2013. Primary activities conducted during this reporting period include routine semiannual groundwater monitoring, focused shallow soil and deeper groundwater investigation, and shallow groundwater sentry well installation.

A number of remedial actions have been implemented at the Site since 1985, for both soils and groundwater. A brief summary of background information and highlights of groundwater remediation history at the Site are provided; however, for a more thorough presentation of Site history refer to historical documents such as the *Record of Decision* (USEPA, 1991), the *Fourth Five-Year Review Report* (USEPA, 2012), the *Remedial Action Completion Report* (Interstate Land Company, 1998) and the *Draft Wasatch Chemical Site Natural Attenuation Evaluation* (MWH, 2011b).

This progress report includes the following sections:

1.0 Background (includes a brief summary of groundwater remediation history and progress)
2.0 Activities Conducted During Current Reporting Period
3.0 Routine Groundwater Monitoring Results
4.0 Shallow Groundwater Data Analyses
5.0 Natural Attenuation Assessment
6.0 Recommendations
7.0 Deliverables Submitted During Current Reporting Period
8.0 Actions to be Completed During Next Reporting Period

April 2013 groundwater data verification, time series groundwater data, and statistical analyses of groundwater data are appended.

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1.0 BACKGROUND

1.1 History

Beginning in 1957 the Site was used for producing, packaging, and distributing industrial chemical products such as pesticides, herbicides, fertilizers, industrial chemicals, and cleaners. A remedial investigation was conducted in the late 1980s and a feasibility study for both soil and groundwater remediation alternatives was completed in August 1990 (Harding Lawson, 1990). Selected remedies included in-situ vitrification of soils and sludges, land farming of hydrocarbon contaminated soils, and extraction and treatment of contaminated groundwater. A Record of Decision (ROD) (USEPA, 1991) and Consent Decree (U.S. District Court, 1991) were completed and signed in 1991. The Site was added to the National Priorities List in 1991 and continues to be federally regulated under the Comprehensive Environmental Response, Compensation, and Liability Act. United States Environmental Protection Agency (USEPA) and Utah Department of Environmental Quality (UDEQ) certified completion of the land farm remedy for soils in January 1994 and the in-situ vitrification remedial action work in May 1996 (Interstate Land, 1991), and groundwater remediation has been ongoing since 1995.

Performance standards for groundwater remediation at the Site are outlined in the Consent Decree (U.S. District Court, 1991) and state that "indicator chemical" concentrations are to be reduced to maximum contaminant levels (MCLs), or proposed Alternative Performance Standards. Additionally, concentrations were to be reduced within the first five years of remediation by at least 50 percent of baseline concentrations established at the beginning of the remedial action (March 1995). Groundwater remediation "indicator chemicals" identified in the ROD (USEPA, 1991) as performance monitoring parameters include tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), pentachlorophenol (PCP), and 2,4-dichlorophenoxyacetic acid (2,4-D).

1.2 Shallow Groundwater Remediation Progress

Concentrations of indicator chemicals in shallow groundwater (the interval of the shallow aquifer up to 25 feet below ground surface) have decreased by two and three orders of magnitude since 1995 as more than 99 percent of the estimated dissolved contaminant mass in the shallow groundwater was estimated to have been removed by 2011. The 50 percent reduction requirement for shallow groundwater has consistently been met for all monitoring locations and indicator chemicals established in the ROD except for TCE in EX-02 which has been below the 50 percent reduction value of 110 µg/l for three of the eight most recent monitoring rounds. TCE concentrations in EX-02 have historically fluctuated both above and below the 50 percent reduction value. However, the TCE baseline concentration for EX-02 (220 µg/l, March 1995) is relatively low compared to concentrations detected at this monitoring location during the initial years of monitoring (e.g., 1,000 µg/l of TCE was detected in September 1995).

Groundwater concentrations of 2,4-D reached the performance standard (MCL) across the Site by 1996, and since 2004 2,4-D is no longer monitored. Concentrations of the remaining groundwater remediation indicator chemicals across the Site are currently either below MCLs, decreasing, or may be approaching an asymptotic value above the MCL (see Section 4.0 of this report).

As outlined in the Consent Decree, "best efforts" to attain MCLs have been made to "maximize the performance of the shallow groundwater Remedial Action to attain the performance standards" (U.S. District Court, 1991). At the Site, "best efforts" have included implementation of three different groundwater remediation technologies:

- Groundwater extraction and treatment (including operation of extraction wells and trenches and modified system operations such as pulse pumping)
- Monitored natural attenuation (MNA)
- Enhanced biodegradation.

An active pump-and-treat remedy was implemented for eight years until the change in groundwater concentrations over time was very small and significant mass removal was no longer occurring, and a period of MNA was approved. MNA was implemented at the Site beginning in 2003 to assess whether natural biodegradation processes could successfully decrease remaining contaminant mass in the groundwater. Data collected since the groundwater extraction and treatment system was shut down in 2003, and the presence of degradation products that were not released at the Site (e.g., DCE isomers and VC), indicate natural attenuation of chlorinated solvents has occurred and continues to occur at the Site. Since 2003, all indicator chemicals established in the ROD plus VC have been monitored and time series data tracked. This list of chemicals (PCE, TCE, 1,1-DCE, VC, and PCP) is referred to as the primary constituents of concern (COCs) hereafter in this document.

In an effort to accelerate the degradation of chlorinated hydrocarbons at the Site, biodegradation enhancing products were injected near monitoring points within the core of the plume in 2004 and 2006, and monitoring was conducted to assess whether biodegradation was impacted as a result. Results from these pilot tests indicate substantial mass reductions in portions of the aquifer with higher permeability (such as the two gravel-filled extraction trenches), but very limited impact in the prevalent native silts and clays of the Site.

Due to the demonstrated limitations of the pump-and-treat remedy at the Site, a *Draft Groundwater Remediation Focused Feasibility Study* (FFS) (MWH, 2010) was prepared and submitted in February 2010 to evaluate alternative groundwater remediation technologies to remediate the remaining contaminants in the shallow groundwater at the Site. MNA along with maintenance of the environmental covenant is one of the alternatives considered in this FFS. The potential to move to a MNA remedy prompted the development of the *Draft Natural Attenuation Evaluation* in October 2011 (MWH, 2011b). The USEPA reviewed this report and provided comments to Questar in February 2013, and Questar submitted responses to their comments in May 2013. Finalization of this evaluation report is currently on hold as MNA is reassessed as a potential alternative remedy for shallow groundwater at the Site.

1.3 Summary of Recent Findings and Activities

Formal comments on the draft FFS for shallow groundwater remediation and subsequent discussions between Questar and the regulatory agencies spurred additional focused investigation in 2011 and 2012. Additional monitoring points were requested to better define the horizontal extent of contamination present on the west side of the Site. During subsequent conversations, USEPA and UDEQ requested installation of additional deeper monitoring wells to determine whether dense non-aqueous phase liquid (DNAPL) was present along or beneath potential preferential pathways

(inferred subsurface sand channels), to assess the competency of the underlying clayey confining layer identified during the additional studies conducted in the early 1990s (Harding Lawson, 1993), and to provide deeper groundwater monitoring points at the Site. A shallow groundwater monitoring well was requested in the southwest area of the Site to aid in shallow groundwater plume and potentiometric surface delineation. In response to these requests, four monitoring wells (MW-30, MW-31D, MW-32D, and MW-33D) were installed in October 2011, at locations requested by the USEPA. The three deeper wells were completed between 45 and 56 feet below ground surface (bgs) and the new shallow well was completed at 24 feet bgs. Details of the monitoring wells' installation are included in *Progress Report No. 96* (MWH, 2012) and the *Draft Final Groundwater Monitoring Well Installation Documentation* technical memorandum (MWH, 2011a).

Data collected from these new monitoring points indicate shallow soil (3.5 feet bgs) and deeper groundwater contamination (35 to 45 feet bgs) at one of the four locations (MW-33D). Therefore, additional investigation was warranted in the southeast area of the Site. Additional investigative steps to delineate the lateral extent of the soil contamination and the extent of deeper groundwater contamination discovered during October 2011 drilling activities in the southeast area of the Site began in May 2013 (*Final Revision 2 Focused Shallow Soil and Deeper Groundwater Investigation and Sentry Well Installation Work Plan* [MWH, 2012b]). Additionally, groundwater monitoring data from the new shallow monitoring well installed in the southwest area of the Site (MW-30) indicate presence of volatile organic compounds (VOCs), therefore a new shallow groundwater sentry well downgradient of this location was installed in June 2013 to better define the edge of the VOC plume boundaries in this area. A shallow soil and deeper groundwater investigation report will be prepared and submitted in draft form to the regulatory agencies for comment. Regulatory agency comments on the draft report will be discussed and conclusions and recommendations will be agreed upon at an on-board review meeting between Questar and representatives of the regulatory agencies.

Due to shallow groundwater VOC contamination near occupied buildings the potential for vapor intrusion and potential risk to workers was evaluated in the spring of 2012. Primary contaminants of concern for indoor air (TCE, DCE isomers, and VC) were not detected in whole air samples collected with SUMMA® canisters in the three occupied buildings on the Site (**Figure 1**); thus, significant risk to worker health was not concluded. A description of the investigation methods, results, and conclusions are presented in the *Draft Indoor Air Investigation Summary Report* (MWH, 2012a). One additional round of sampling is planned to verify the absence of risk to human health from potential vapor intrusion in the three buildings.

2.0 ACTIVITIES CONDUCTED DURING CURRENT REPORTING PERIOD

2.1 Groundwater Treatment System Operation

The groundwater extraction and treatment system was not operated during the reporting period. Operation of the groundwater extraction and treatment system was discontinued in January 2003 in accordance with the USEPA's approval letter dated January 9, 2003.

2.2 Groundwater Monitoring Activities

Routine semiannual groundwater monitoring was conducted at 16 monitoring locations for the shallow groundwater (screened up to 25 feet bgs) and three deeper monitoring points (screened up to 56 feet bgs) in April 2013. The monitoring program is designed to provide data to assess natural

attenuation processes of contaminants in the shallow groundwater as described in the *Monitored Natural Attenuation Work Plan* (MWH, 2002) and to assess potential groundwater contaminant migration. Both hydrogeologic and constituent concentration data were collected and evaluated.

Though not included in the compliance monitoring network for the shallow groundwater, one additional monitoring well (MW-02) was sampled in April 2013 to provide a downgradient monitoring point on the southwest plume boundary for this sampling round. Groundwater monitoring results are discussed in the "Summary of Results" section of this report.

2.3 Focused Shallow Soil Investigation

A focused shallow soil investigation was conducted in May 2013 to assess the nature and extent of impacted shallow subsurface soils in the vicinity of monitoring well MW-33D where concentrations above EPA industrial screening levels were detected in samples collected during drilling activities at 3.5 feet bgs in October 2011 (**Figure 1**). Shallow soil sampling activities began on May 6, 2013 and were completed on May 22, 2013. Direct-push soil borings were completed at a total of 53 locations, beginning at the MW-33D location and moving outward from locations where sampling results were above screening levels. Borings were advanced up to approximately five feet bgs; and one to two samples were collected from each core. Dynamic work strategies were implemented to allow for adaptation based on new/updated information. Rushed laboratory results were received one to three days after sample collection and compared to EPA Region's 3, 6, and 9 2011 screening levels for industrial soil, and additional samples were collected at locations as indicated in the *Focused Shallow Soil and Deeper Groundwater Investigation and Sentry Well Installation Work Plan* (MW, 2012b). PCE, TCE, ethylbenzene, xylenes, and PCP were detected at concentrations above screening levels in 18 of the 53 boring locations, most located along the north-south trending corridor east of Peterson Plumbing warehouse and northward along the historical industrial process wastewater pipeline (process drain line) alignment.

All shallow soil data will be presented and evaluated in the focused investigation report to be submitted to the regulatory agencies and discussed during a subsequent on-board review meeting between Questar and the regulatory agencies.

2.4 Focused Deeper Groundwater Investigation

A focused deeper groundwater investigation began on May 20, 2013, to assess the nature and extent of groundwater contamination identified at monitoring well MW-33D where VOCs and PCP have been detected above MCLs in a deeper interval (35-45 feet bgs). Cone penetration testing (CPT) has been used to profile subsurface characteristics and to collect direct-push groundwater samples at even deeper depths. CPT and direct-push groundwater sampling were conducted May 20 through 24, 2013, at five locations to total depths ranging from 87 to 106 feet bgs. Direct-push groundwater samples were collected at the more conductive intervals (interpreted as silts and sands) at four to five different depths at each CPT boring. Results indicate deeper groundwater has been impacted up to 106 feet bgs adjacent to MW-33D at levels above MCLs for a number of VOCs and PCP. Additionally, two constituents of concern were detected at concentrations just slightly above their MCLs (VC [2.3 µg/l] and PCP [1.1 µg/l]) approximately 70 feet northwest of MW-33D.

Additional data will be collected in July 2013 at three additional locations, stepping out to the northeast, northwest, and southwest. Once the laboratory analytical data are received for these three

additional locations, an on-board discussion will be held between Questar and regulatory agencies to determine next steps. All lithological, groundwater, and pore dissipation test data will be presented and evaluated in the focused investigation report to be submitted to the regulatory agencies and discussed during a subsequent on-board review meeting between Questar and the regulatory agencies.

2.5 New Shallow Sentry Well Installation

A new shallow sentry well, MW-34, was installed downgradient of MW-30 on June 3, 2013. Groundwater data from this new sentry well will better define the extent of shallow groundwater contamination on the southwest side of the Site. (See **Figure 1** for new well location.) CPT and direct-push groundwater sampling were conducted prior to well construction to aid in screen interval selection and to ensure that the proposed new sentry well would be located downgradient of the shallow groundwater plume. The new well is screened from 9.5 to 19.5 feet bgs, across the most permeable interval up to a 30 feet bgs at this location. The well was installed as outlined in the *Focused Shallow Soil and Deeper Groundwater Investigation and Sentry Well Installation Work Plan* (MWH, 2012b). Additional details, including well construction and lithological data, will be included in the investigation report to be submitted to the regulatory agencies.

3.0 ROUTINE GROUNDWATER MONITORING RESULTS

3.1 Shallow Groundwater Level Monitoring Results

Shallow groundwater wells and piezometers are completed to depths of 25 feet bgs or less. Groundwater elevation contours drawn from shallow groundwater monitoring data collected on April 22, 2013 are illustrated in **Figure 2**. In general, groundwater elevations continue to indicate an overall groundwater flow direction in the shallow aquifer of west to northwest. The average depth to shallow groundwater across the Site for those wells completed in the shallower zones was approximately 3.2 feet bgs, with shallower depths on the upgradient side of the Site (southeast) and greater depths further downgradient. The average change in shallow groundwater elevation from November 2012 to April 2013 was an increase of 0.29 feet. The average change in groundwater elevation between April 2012 and April 2013 was a very slight decrease of 0.08 feet.

3.2 Deeper Groundwater Level Monitoring Results

Groundwater level data for the deeper wells (MW-31D, MW-32D, and MW-33D completed to depths between 45 and 56 feet bgs) were collected on June 13, 2013. The average depth to water measured in the three deeper wells was approximately 2.2 feet bgs, 1.4 feet higher than the average depth to water measured in November 2012. Water-level data from these three points indicate an overall direction of horizontal flow towards the northwest in the deeper zones. Groundwater level elevations for the deeper wells are shown in **Figure 3**.

Each deep well is located close to a shallow well, providing three well pairs where the vertical component of groundwater flow can be assessed. Vertical hydraulic gradients and resulting directions of the vertical component of groundwater flow are tabulated in **Table 1** for data collected since the new deeper wells were installed. Overall, the data indicate that groundwater in the deeper zones is under pressure, inducing an upward flow, as shown by the hydraulic gradients presented in **Table 1**.

3.3 Shallow Groundwater Sampling Results

Shallow groundwater samples were collected from the 16 routine monitoring locations from April 23 through 26 for the first semiannual monitoring round of 2013. Two additional shallow groundwater monitoring wells were sampled this round: MW-02 located immediately west of the Peterson Plumbing warehouse, and a new shallow sentry well (installed on June 3, 2013), sampled on April 26, 2013 and June 13, 2013, respectively. The samples were analyzed for the primary COCs PCE, TCE, DCE isomers, VC, PCP, plus geochemical parameters pertinent to the assessment of biotransformation of chlorinated solvents (sulfate, sulfide, nitrate, nitrite, and ferrous iron). Dissolved oxygen (DO), pH, and oxidation-reduction potential (ORP) were measured in the field during sampling activities. Laboratory analytical methods and sampling results for wells completed in the shallow zones for this sampling round are presented in **Table 2**. (Data for the three deeper wells are shown in **Table 3**, see discussion in following subsection.) A detailed data verification report is included as **Appendix A**.

April 2013 shallow groundwater results for PCE, TCE, 1,1-DCE, VC, and PCP are presented on Site maps shown in **Figures 4 through 8**. Isoconcentration contours outline areas where concentrations were detected above regulatory drinking water MCLs. In general, the April 2013 data and interpreted contaminant plume areas are similar to those reported for April 2012 (presented in *Progress Report No. 97*), though with the addition of monitoring data for the new sentry well (MW-34) and monitoring well MW-02 for the April 2013 monitoring round, plume contours on the southwest side of the Site have been drawn with solid, rather than dashed lines (indicating an inferred interpretation). The DCE isomers cis-1,2-DCE and trans-1,2-DCE are not considered primary Site COCs and are not presented on Site maps because they are not designated as "indicator chemicals" in the ROD (USEPA, 1991), nor are they included in the analyte list in the *Final Groundwater Monitoring Well Installation and Sampling Plan* (MWH, 2011c). However, the 1,2-DCE isomers have been monitored and reported in Site progress reports since April 2009 to aid in natural attenuation evaluations. Laboratory results for the primary COCs are discussed below.

PCE. As illustrated in **Figure 4**, PCE was not detected above its MCL of 5 µg/l in the shallow groundwater during this sampling round.

TCE. TCE was detected above its MCL of 5 µg/l at four shallow groundwater monitoring locations, ES-01, EX-02, EX-04, and EX-11 in April 2013. In addition, TCE was detected at concentrations below the MCL in eight additional monitoring points as listed in **Table 2** and illustrated in **Figure 5**, though six of these were reported as trace concentrations (below laboratory reporting limit of 1 µg/l). The maximum TCE concentration detected for this monitoring round was 300 µg/l at EX-02. As illustrated in **Figure 5**, the footprint of the TCE plume remains centered around EX-02 in the southern portion of the site and around EX-04 in the northern portion of the site.

1,1-DCE. Shallow 1,1-DCE concentrations above the MCL of 7 µg/l ranged between 9.3 to 15 µg/l for the April 2013 monitoring round and continue to be detected in two areas, one to the north, near monitoring point EX-05, and the other in the vicinity of EX-02 and EX-11 located further south as shown in **Figure 6**. The interpreted plume footprint in this area has not changed significantly over recent monitoring rounds.

VC. The April 2013 shallow groundwater VC plume is illustrated in **Figure 7**, and is just slightly larger than the plume drawn for November 2012 data, primarily because the VC concentration in ES-01 increased from 0.4 µg/l in November 2012 to 13 µg/l in April 2013. The maximum VC concentration continues to be detected at EX-11, where VC was detected at 460 µg/l in April 2013. VC was detected above its MCL at 6.5 µg/l in the MW-30, located along the western edge of the Site, though VC was not detected at the new sentry well, MW-34, located off the Site directly downgradient of MW-30.

PCP. The April 2013 PCP plume is limited to the southern area of the Site where PCP was detected at just three of the shallow groundwater monitoring locations (ES-01, EX-02 and EX-08). Results from ES-01 and EX-02 exceed the PCP MCL of 1.0 µg/l (refer to **Figure 8**.) The maximum PCP concentration for this round was 6.3 µg/l at EX-02. PCP has not been detected in the new shallow monitoring well, MW-30 located west of EX-02 (**Table 3**) to date, nor was it detected in the new sentry well, MW-34, located off the Site directly downgradient of MW-30.

The current PCP monitoring network includes the following monitoring locations: ES-01, EX-02, EX-07, EX-08, and EX-11. Monitoring wells EX-04, EX-05, and EX-09 were removed from the PCP semiannual monitoring network beginning May 2012 in concurrence with USEPA's approval documented in February 2012 written comments on *Progress Report No. 95*. However, as requested by the USEPA, these three wells will be monitored once every five years for PCP beginning in 2016.

Geochemical parameters including pH, ORP, DO, nitrate, nitrite, ferrous iron, sulfate, and sulfide were collected to assess whether conditions in the aquifer are conducive to biotransformation processes. April 2013 results for these parameters for shallow groundwater monitoring points are listed in **Table 2**. Overall, the geochemical parameters of pH, ORP, DO, nitrate, and ferrous iron throughout the Site indicate mostly favorable conditions for anaerobic reductive dechlorination. Generally, DO results are within the anaerobic range (< 0.5 mg/l) at monitoring locations where primary Site COCs were detected above MCLs, suggesting that DO concentrations are conducive to biodegradation. The exceptions were at EX-02 and EX-04 where DO was measured at 0.7 and 1.0 mg/l. Ferrous iron and nitrate results indicate favorable conditions in all wells with detections of TCE, 1,1-DCE and VC above MCLs with exceptions of a ferrous iron concentration of 0.2 mg/l at ES-01 and a concentration of nitrate at 1.2 mg/l at EX-02. ORP values measured in the field are consistent with historical results and are generally within the expected range of values given the measured DO and ferrous iron concentrations.

3.4 Deeper Groundwater Sampling Results. Groundwater samples were collected from the three new wells completed in deeper zones (MW-31D, MW-32D, and MW-33D) on April 24 and 25, 2013. The samples were analyzed for VOCs, herbicides (e.g., PCP), and geochemical parameters pertinent to the assessment of biotransformation of chlorinated solvents (sulfate, sulfide, nitrate, nitrite, and ferrous iron). No herbicide compounds have been detected during any of the quarterly sampling rounds. DO, pH, and ORP were measured in the field during sampling activities. Laboratory analytical methods used and results from all six sampling rounds conducted to date for wells completed in the deeper zones are presented in **Table 3**. Detailed sampling and data validation information are included in **Appendix A**. A full suite of VOC analytes is reported for

groundwater samples collected from MW-33D in Table A-2 due to the detection of additional VOCs in the soil samples collected from the MW-33D boring during October 2011 drilling activities. Those VOCs detected are included in **Table 3**.

As shown in **Table 3**, of the three deeper wells, VOCs have been detected only in samples collected from MW-33D since monitoring began in December 2011. Though PCE, TCE, and cis-1,2-DCE were detected in MW-33D above MCLs across the first three monitoring rounds (December 2011, February 2012, and April 2012), over the past three monitoring rounds (August 2012, November 2012, and April 2013) PCE and VC were the only VOCs detected above MCLs. TCE and 1,1-DCE were below their laboratory reporting limits in MW-33D over the past three monitoring rounds. Hydrocarbon concentrations continued to be detected at MW-33D, though all are significantly below Utah Leaking Underground Storage Tank Program (LUST) initial screening levels, as listed below:

April 2013 Hydrocarbon Groundwater Concentrations Detected in MW-33D and Utah Leaking Underground Storage Tank Regulatory Limits

Hydrocarbon	MW-33D April 2013 Concentration (µg/l)	Utah LUST Screening Level (µg/l)
Ethylbenzene	5.1	700
m,p,o-Xylene (sum of isomers)	57	10,000
Toluene	1.6	1,000

Geochemical parameters measured in April 2013 for all three deeper wells illustrate conditions conducive to natural attenuation with consistently negative ORP readings, low DO concentrations, and neutral pH readings. Laboratory analytical results for nitrate, ferrous iron, and sulfate in MW-33D also fall in the biodegradation indicator ranges presented in USEPA natural attenuation guidance (USEPA, 1998).

4.0 SHALLOW GROUNDWATER DATA ANALYSES

Foreseeing potential difficulties in meeting performance standards with pump-and-treat technology, the Site Consent Decree (U.S. District Court, 1991, Section VII, part 17) provides an avenue to "waive or modify" groundwater treatment performance standards (equivalent to MCLs as defined in the ROD) that are demonstrated to be "technically impracticable from an engineering perspective" to achieve, as reflected in "asymptotic conditions" at the Site. To provide justification for a performance standard waiver or modification, the Consent Decree requires a demonstration for each contaminant for which a wavier or modification is sought that illustrates contaminant concentrations remain "at statistically significant asymptotic values above MCLs" for at least the eight most recent data points.

As mass removal rates diminished substantially after the first years of groundwater extraction and treatment at the Site, statistical methods have been applied to assess whether "asymptotic conditions" exist at various shallow groundwater monitoring points where contaminant

concentrations remain above MCLs. Since 2001, linear regression analyses have been used to evaluate current trends at the Site in accordance with the *Extraction System Performance Standards, Milestones, and Shutdown Procedures* document (Montgomery Watson, 2001). These trends illustrate groundwater remediation progress and help guide remediation strategy at the Site and have been presented in Progress Reports since 2001. Results and discussion for the linear regression evaluation using data through April 2013 are presented below. Additionally, in an effort to look more closely at overall plume stability, shallow groundwater data have been assessed with additional methods, including Mann-Kendall and Theil-Sen statistical tests. Results for both linear regression and the combination of Mann-Kendall and Theil-Sen statistical analyses, using a confidence level of 99 percent in accordance with the Consent Decree, are summarized below in Sections 4.1 and 4.2, respectively. Results of the additional statistical procedures, Mann-Kendall and Theil-Sen, reinforce the linear regression analysis results which characterize areas of the plume as trending or stable according to the wells' concentrations.

This section provides a summary of findings based on current trends at individual wells (using the eight most recent data points), as well as historical trends for data extending back to 1995. Overall plume stability was evaluated for monitoring locations where trend analyses did not indicate significant or apparent trends. Results of these evaluations are presented below.

4.1 Current Trend Evaluation using Linear Regression Analysis

To assess current VOC and PCP trends for wells with contaminants detected above MCLs, regression analyses were conducted using data from the eight most recent sampling rounds. The current trends identified were either decreasing or not statistically different from a slope of zero. A tabulated summary of current trends is presented in Table B1-1 and data plots for constituents determined to be significantly above the MCL over the past eight monitoring rounds are presented in Exhibits B1-1 through B1-7 in **Appendix B**.

To evaluate whether the last eight points are considered above or below performance standards, confidence intervals were calculated for each data set, and lower 95-percent confidence interval limits were compared to the MCLs. Using the eight most recent points to compare constituent concentrations to performance standards provides a more statistically relevant result than if only the single most recent point is used. Those determined to be statistically above the performance standard were evaluated for trends using the linear regression method.

Regression analyses for the following monitoring locations and contaminants suggest that during the last eight monitoring rounds an asymptote above the MCL may have been reached (the slope of the regression line is not statistically different from zero):

- EX-02: TCE, 1,1-DCE, VC, PCP
- EX-04: 1,1-DCE
- EX-05: 1,1-DCE
- EX-08: PCP
- EX-11: VC
- MW-20: VC
- MW-30: VC

Decreasing trends were identified for the following locations and contaminants over the last eight monitoring rounds:

- EX-04: TCE
- EX-05: VC

No increasing trends were identified.

4.2 Contaminant Trend Evaluation using Mann-Kendall and Theil-Sen Trend Analyses

To assess shallow groundwater data trends and plume stability at the Site with more detail than previous reports, shallow groundwater data were evaluated for trends over the past eight monitoring points using Mann-Kendall and Theil-Sen analyses for locations with current concentrations above and below the MCLs. These additional data analyses were conducted in accordance with EPA Unified Guidance (EPA, 2009) to assess overall plume stability at the Site, evaluate the current shallow groundwater monitoring program, and identify locations with constituent concentrations that have stabilized above MCLs such that petitioning for Alternative Performance Standards may be justified as outlined in the Site Consent Decree (U.S. District Court, 1991).

The Mann-Kendall method is preferred over linear regression (USEPA, 2009) because the validity of linear regression results is based on a number of underlying assumptions that are not always met consistently for all Site shallow monitoring well data). These assumptions include: 1) regression residuals are normally distributed, 2) regression residuals are homoscedastic (i.e., variance is homogeneous, 3) there is not significant skewness or any outliers in the data, and 4) there are few if any results below laboratory method detection limits. The Mann-Kendall test was used to test for a statistically significant slope (i.e., trend) in concentration values over time. The Theil-Sen method was used in conjunction with the Mann-Kendall method to determine a slope, or rate of change, of the trending data (Helsel, 2005). More in-depth discussion of these methods is included in **Appendix C**.

A broader set of data were evaluated with the Mann-Kendall and Theil-Sen methods than was evaluated with linear regression, including data for constituents that are consistently detected below MCLs, to assess stable concentrations below MCLs and/or declining constituent concentrations that may be trending towards MCLs. Furthermore, the last eight data points were used to construct confidence intervals for non-trending data and confidence bands for trending data to determine whether constituent concentrations are statistically above or below MCLs. A detailed discussion of methods, results, and conclusions are presented in the attached technical memorandum included in **Appendix C**. A summary of results for data sets that are statistically above the MCLs is presented in **Table 4**.

The Mann-Kendall test discussed above produced results for COCs that are comparable to results produced by the linear regression analyses discussed in the previous subsection of this report. Trend analysis results are illustrated in **Figure 9** for stable and decreasing trends, indicating areas of plume stability and plume attenuation, respectively. Decreasing trends were identified for TCE at EX-04 and VC at EX-05, and no increasing trends were identified. In summary, the Mann Kendall and Theil-Sen methods reinforced results of regression analyses.

4.3 Shallow Groundwater Plume Stability Evaluation Conclusions

The statistical analyses performed for the eight most recent data points for shallow groundwater across the Site (linear regression and Mann-Kendall/Theil-Sen) demonstrate that shallow groundwater concentrations currently above MCLs have stabilized or are decreasing at a 99 percent confidence level. See **Figure 9** and **Table 4** for monitoring locations/COCs that indicate plume stability based on these statistical results.

4.4 Historical Trends

Tables and graphs of all historical data for the current monitoring network are included in Section B2 of **Appendix B**. Decreases in concentrations over time are significant as illustrated in Exhibits B2-1 through B2-16. Since 1995, contaminant concentrations have decreased two to four orders of magnitude for the original VOC indicator chemicals designated in the ROD (i.e., PCE, TCE, and 1,1-DCE). For example, TCE concentrations have decreased by more than four orders of magnitude in EX-05 and by three orders of magnitude in EX-07, EX-09, and MW-20. Also, concentrations of PCE have decreased by four orders of magnitude in EX-11 and by two orders of magnitude in ES-01, EX-05, EX-07, and MW-20. Concentrations at most wells have decreased exponentially over time, as shown in the B2 Exhibits (**Appendix B**).

5.0 NATURAL ATTENUATION ASSESSMENT

5.1 Shallow Groundwater

Numerous data evaluation techniques were employed in the *Draft Natural Attenuation Evaluation* (MWH, 2011b) to evaluate natural attenuation processes in the shallow groundwater and determine if natural attenuation rates establish plume stability and remediate the Site. Historical shallow groundwater concentrations, soil chemistry, hydrogeological, and geochemical data were evaluated. Results support a natural attenuation degradation pathway in most wells located within the groundwater plume.

Geochemical parameters indicative of anaerobic microbial growth and reductive dechlorination of PCE and TCE are presented in **Table 2** as biodegradation indicators. Values shown in bold indicate conditions conducive to reductive dechlorination. As discussed in the Groundwater Sampling Results section of this report, April 2013 values for ORP, nitrate, and to a lesser extent, DO, were generally low and ferrous iron elevated in most areas of contamination, indicating generally favorable conditions for reductive dechlorination at the Site. Additionally, dehalococcoides have been identified in several monitoring wells at the Site supporting another line of evidence.

Though shallow groundwater data indicate that natural attenuation has been occurring at the Site and has contributed to overall shallow groundwater plume stability, MNA as an alternative remedy is currently being reassessed due to the presence of residual contamination in shallow soils at and near the water table northeast of the Peterson Plumbing warehouse. Matrix diffusion of residual contamination can lengthen the remediation time frame for MNA, particularly for contaminated aquifers with inter-bedded low-permeability zones. Therefore, an evaluation of plume stability based on statistical analyses has been conducted, and the practicability of MNA as an alternative remedy

given the discovery of residual soil contamination is being evaluated for those areas of the plume where contaminant concentrations are continuing to decline.

5.2 Deeper Groundwater

Deeper groundwater data from MW-33D including detections of TCE, cis-1,2-DCE, and VC (MW-33D) also are indicative of reductive dechlorination. The generally anoxic environment, negative ORP conditions, nitrate, ferrous iron, and sulfate concentrations, and the presence of daughter products TCE, cis-1,2-DCE, and VC indicate natural attenuation is occurring in the deeper zone at MW-33D (35 to 45 feet bgs).

6.0 RECOMMENDATIONS

1. **Conduct Indoor Air Sampling.** To verify the absence of a vapor intrusion risk in occupied Site buildings, one additional round of indoor air sampling is recommended. This additional round should include collection of whole indoor air samples in the occupied areas of the KEPCO+ and Intsel office buildings and in the Peterson Plumbing warehouse, both the office area and warehouse sections. (See **Figure 1** of this report for building locations.) The validated data from these air samples will be used to confirm the conclusion from the March 2012 indoor air investigation, namely the absence of unacceptable human health risks in occupied areas of the on-site buildings due to vapor intrusion. This recommendation is presented in the *Draft Indoor Air Sampling Work Plan* (MWH, 2013) and discussed further in responses to USEPA comments on the draft work plan. This indoor air sampling round is currently scheduled to be conducted in December 2013.

2. **Complete Focused Shallow Soil and Deeper Groundwater Investigation**. Additional investigation is warranted based on the contamination identified at the location of monitoring well MW-33D in shallow soil and in deeper groundwater. As outlined in the *Final Revision 2 Focused Shallow Soil and Deeper Groundwater Investigation and Sentry Well Installation Work Plan* (MWH, 2012b), a dynamic approach to further characterize the shallow soils and deeper groundwater will be completed to determine the lateral extent of shallow soil contamination as well as the vertical and horizontal boundaries of deeper groundwater contamination in the southeast area of the Site. The field activities for this investigation began in May 2013 and are expected to be completed in July or August 2013. A focused investigation report will be prepared for regulatory agency review this fall, and an on-board review meeting is planned to discuss and agree on next steps.

3. **Discontinue sampling for PCP in Monitoring Wells Installed in 2011.** The three deeper wells (MW-31D, MW-32D, and MW-33D) and shallow monitoring well MW-30 have been sampled and analyzed for PCP for six monitoring rounds since their installation in 2011 (four quarterly and two semiannual sampling events), and PCP has not been detected in any of these wells. Because PCP has not been detected in these wells and because the compliance monitoring network for PCP sampling is a subset of the larger VOC sampling network, it is recommended these wells be removed from the routine semiannual sampling network.

4. **Use Mann-Kendall and Theil-Sen Methods in lieu of Linear Regression for Trend Analyses.** As explained in this progress report, the validity of linear regression results is based on a number of underlying assumptions that are not met consistently for all shallow groundwater monitoring data at the Site. The Mann-Kendall test is not subject to the underlying assumptions that apply to linear regression analyses and can be applied to both parametric and non-parametric data sets that contain undetected concentrations (non-detects). The Theil-Sen test, which calculates a rate of change for parametric and non-parametric trending data, is also not subject to the underlying assumptions that apply to linear regression analyses of environmental data. These methods are supported by the EPA Unified Guidance (EPA, 2009). Therefore, the use of Mann-Kendall and Theil-Sen methods in lieu of linear regression for trend analyses is recommended for future trend analyses.

7.0 DELIVERABLES SUBMITTED DURING CURRENT REPORTING PERIOD

- *Wasatch Chemical Site Progress Report No. 98* was submitted on January 29, 2013
- The *Draft Indoor Air Sampling Work Plan*, was submitted March 25, 2013.
- The *Final Wasatch Chemical Site Quality Assurance Project Plan Rev 3.0* was submitted March 25, 2013.

8.0 ACTIONS TO BE COMPLETED DURING NEXT REPORTING PERIOD

The following project activities are scheduled to be conducted within the next six-month reporting period.

1. **Routine Groundwater Monitoring.** Groundwater contaminant concentrations and water levels will continue to be monitored for the remainder of 2013. Routine monitoring activities will include semiannual groundwater monitoring and sampling of both shallow and deeper compliance monitoring points in November in accordance with the *Monitored Natural Attenuation Work Plan* (MWH, 2002) and the *Final Quality Assurance Project Plan Revision 2.0, Wasatch Chemical Site* (MWH, 2012d). Additionally, the new shallow sentry well, MW-34, will be sampled on a quarterly basis, in August and November 2013.

2. **Focused Investigation.** Shallow soil and deeper groundwater investigation field work to define the nature and extent of contamination near MW-33D is expected to be completed in July or August 2013. A resulting draft investigation report, to include recommendations for installation of additional monitoring wells, will be prepared after the investigation work is complete. Final new well depths and locations will be selected and agreed upon at an on-board review meeting with the regulatory agencies, and the investigation report will be finalized accordingly. New deeper wells are expected to be installed later in 2013 based on decisions made during the on-board review meeting.

3. **New Deeper Well Installation.** New deeper monitoring well(s) will be installed as agreed upon by Questar and the regulatory agencies based on the deeper groundwater investigation results. Locations and depths will be determined during a focused investigation report on-board review meeting to be conducted approximately 30 days after submittal of the draft focused investigation report to the regulatory agencies.

4. **Indoor Air Monitoring.** Indoor air monitoring at the three occupied buildings on the Site is currently scheduled for December 2013. Whole air sample(s) will be collected in each of the occupied buildings located above shallow groundwater contamination, including KEPCO+, Intsel, and Peterson Plumbing. The *Indoor Air Sampling Work Plan* will be finalized and signed by Questar, MWH, and the regulatory agencies prior to the sampling event.

5. **Progress Reports.** Site Progress reports will continue to be submitted semiannually. The second semiannual progress report for 2013 is scheduled to be submitted in January 2014.

If you have any questions or concerns, please do not hesitate to contact me at (801) 617-3200.

Sincerely,

MWH

Susan Eyzaguirre, P.E., P.G.
Project Manager

cc: K. Heimsath
H. Pos

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TABLE 1
VERTICAL HYDRAULIC GRADIENT ASSESSMENT
USING DATA FROM NESTED SHALLOW AND DEEPER WELL PAIRS
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH

Well Pair	Date	Well	Well Screen Interval (ft bgs)	Groundwater Elevation (ft)	Groundwater Elevation Difference[(a)] (ft)	Vertical Hydraulic Gradient[(b)] (ft/ft)	Direction of Vertical Component of Groundwater Flow
Western (MW-06 and MW-31D)	11/8/2011	MW-06 MW-31D	5 - 25 46 - 56	4225.54 4227.17	1.63	0.048	Upward
	4/30/2012	MW-06 MW-31D	5 - 25 46 - 56	4225.96 4227.60	1.64	0.048	Upward
	8/28/2012	MW-06 MW-31D	5 - 25 46 - 56	4224.71 4226.38	1.67	0.069	Upward
	11/12/2012	MW-06 MW-31D	5 - 25 46 - 56	4225.88 4226.87	0.99	0.041	Upward
	12/21/2012	MW-06 MW-31D	5 - 25 46 - 56	4225.84 4226.53	0.69	0.028	Upward
	6/13/2013	MW-06 MW-31D	5 - 25 46 - 56	4225.84 4227.89	2.05	0.080	Upward
Northern (PZ-3 and MW-32D)	11/8/2011	PZ-3 MW-32D	14 - 24 38 - 48	4226.35 4227.01	0.66	0.018	Upward
	4/30/2012	PZ-3 MW-32D	14 - 24 38 - 48	4228.02 4227.03	-0.99	-0.270	Downward
	8/28/2012	PZ-3 MW-32D	14 - 24 38 - 48	NA 4225.95	NA	NA	NA
	11/12/2012	PZ-3 MW-32D	14 - 24 38 - 48	4226.51 4227.10	0.60	0.017	Upward
	12/21/2012	PZ-3 MW-32D	14 - 24 38 - 48	4226.45 4225.52	-0.92	-0.026	Downward
	6/13/2013	PZ-3 MW-32D	5 - 25 46 - 56	4226.88 4227.53	0.65	0.020	Upward
Southeastern (EX-01 and MW-33D)	11/8/2011	EX-01 MW-33D	5 - 15 35 - 45	4228.01 4228.18	0.17	0.005	Upward
	4/30/2012	EX-01 MW-33D	5 - 15 35 - 45	4228.68 4228.61	-0.07	-0.002	Downward
	8/28/2012	EX-01 MW-33D	5 - 15 35 - 45	4226.95 4227.78	0.84	0.028	Upward
	11/12/2012	EX-01 MW-33D	5 - 15 35 - 45	4228.23 4227.60	-0.62	-0.021	Downward
	12/21/2012	EX-01 MW-33D	5 - 15 35 - 45	4228.04 4228.05	0.02	0.000	Upward
	6/13/2013	EX-01 MW-33D	5 - 25 46 - 56	4228.20 4228.80	0.60	0.020	Upward

(a) Calculated by subtracting the water level elevation of the shallow well from the that of the deeper well.

(b) Calculated by dividing the difference in water level elevations by the distance between the middle of each screened interval. Vertical distances between screened intervals are 35, 24, and 30 ft for the Western, Northern, and Southeastern well pairs, respectively.

bgs - below ground surface
NA - data not available
ft - feet

TABLE 2
SHALLOW GROUNDWATER SAMPLING RESULTS AND NATURAL ATTENUATION INDICATORS
APRIL 2013
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH

		Analytical Results																		*Natural Attenuation Assessment*	
	Sample Identification	**ES-01**	**EX-02**	**EX-04**	**EX-05**	**EX-07**	**EX-08**	**EX-09**	**EX-11**	**MW-02[d]**	**MW-06**	**MW-20**	**MW-23**	**MW-30**	**MW-34**	**PZ-1**	**MW-24A**	**MW-25**	**PZ-3[b]**	**Biodegradation**	
	Date Collected	**4/23/13**	**4/23/13**	**4/23/13**	**4/23/13**	**4/23/13**	**4/25/13**	**4/23/13**	**4/24/13**	**4/26/13**	**4/25/13**	**4/23/13**	**4/25/13**	**8/28/12**	**6/13/13**	**4/24/13**	**4/24/13**	**4/25/13**	**4/24/13**	**Indicator**	**Purpose and/or Interpretation**
Volatile Organic Compounds (µg/l)	**Analytical Method**																				
Tetrachloroethene (PCE)	SW8260B	5	0.87 T	<1	<1	1.1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	Not Applicable	Original indicator chemical; MCL is 5 µg/l.
Trichloroethene (TCE)	SW8260B	**29**	**300 D**	**7.1**	**0.51 T**	**3.1**	<1	**0.23 T**	**69**	**0.21 T**	**0.25 T**	**1.4**	<1	**0.63 T**	**0.24 T**	<1	<1	<1	<1	detection	Original indicator chemical; degradation product of PCE; MCL is 5 µg/l.
1,1-Dichloroethene (1,1-DCE)	SW8260B	**2.9**	**10**	**4.9**	**9.3**	<1	<1	**2**	**15**	<1	**5.7**	**1.3**	<1	**5.6**	<1	<1	<1	<1	<1	detection	Original indicator chemical; degradation product of trichloroethene; MCL is 7 µg/l.
cis-1,2-Dichloroethene (cis-1,2-DCE)	SW8260B	**26**	**320 D**	**66**	**150 D**	**3.9**	<1	**25**	**670 D**	**0.37 T**	**28**	**20**	<1	**30**	**1.7**	<1	<1	<1	<1	detection	Degradation product of trichloroethene; MCL is 70 µg/l.
trans-1,2-Dichloroethene (trans-1,2-DCE)	SW8260B	**0.42 T**	**8.3**	**12**	**160 D**	**0.73 T**	<1	**7.5**	**84**	<1	**5.1**	**18**	<1	**0.93 T**	**0.48 T**	<1	<1	<1	<1	detection	Degradation product of trichloroethene; MCL is 100 µg/l.
Vinyl chloride (VC)	SW8260B	**13**	**55 D**	**0.84 T**	**11**	**1.4**	<1	<1	**460 D**	<1	**1.9**	**2.7**	<1	**6.5**	<1	<1	<1	<1	<1	detection	Degradation product of dichloroethenes; MCL is 2 µg/l.
Pesticides (µg/l)																					
Pentachlorophenol (PCP)	SW8151A	4 D	6.3 D	NA	NA	<0.5	0.87	NA	<0.5	<0.5	NA	NA	NA	<0.5	<0.5	NA	NA	<0.5	NA	Not Applicable	Original indicator chemical; MCL is 1 µg/l.
Geochemical Parameters																					
pH (standard units)	field measurement	**7.6**	**6.5**	**6.9**	**6.8**	**7.3**	**6.9**	**6.8**	**6.8**	**6.6**	**6.9**	**6.9**	**7.0**	**6.7**	**6.6**	**6.7**	**6.8**	**6.9**	**6.8**	5 to 9[a]	Optimal range for reductive pathway.
Oxidation-reduction Potential (mV)	field measurement	**-138**	62	**-44**	**-85**	**-65**	**40**	**1**	**-142**	123	**-101**	**-100**	**-141**	**-122**	**-193**	**-143**	**-74**	**-114**	**-69**	<50[a]	Reductive pathway possible.
Dissolved Oxygen (mg/l)	field measurement	**0.1**	0.7	1.0	**0.0**	**0.4**	**0.2**	2.6	**0.0**	1.2	**0.0**	**0.2**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	0.8	<0.5[a]	Reductive pathway possible.
Nitrate (mg/l)	E300.0	**0.105**	1.2	**0.397**	**<0.1**	1.2 D	2.8 D	**0.982**	**<0.1**	56.5 D	**<0.1**	0.567	**<0.5 D**	**<0.1**	<0.1	**0.0606 T**	**<0.1**	**<0.1**	**<0.1**	<1[a]	Reductive pathway possible.
Nitrite (mg/l)	E300.0	<0.1	<0.1	0.0729 T	<0.1	<0.1	<0.5 D	<0.1	<0.1	<1 D	0.25 D	<0.1	<0.5 D	<0.2 D	<0.1	<0.1	<0.1	<0.1	<0.1	>1	Evidence of nitrate reduction.
Iron II (mg/l)	Hach 8146	0.2	**3.1**	**3.3**	**3.3**	**1.7**	0.1	0.8	**2.9**	0.0	**1.2**	**1.6**	0.6	**1.2**	**>9.99**	**1.7**	**1.1**	**2.3**	**3.3**	>1[a]	Reductive pathway possible.
Sulfate (mg/l)	E300.0	70.2	1030 D	679 D	1460 D	78.6 D	493 D	1130 D	1040 D	2580 D	693 D	904 D	215 D	640 D	720 D	362 D	91.2 D	742 D	2160 D	<20[a]	At higher concentrations may compete with reductive pathway.
Sulfide, total (mg/l)	E376.2	0.201	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.051 T	<0.1	0.0433 T	<0.1	0.169	0.282	<0.1	0.0293 T	<0.1	<0.1	0.021 T	>1[a]	Evidence of sulfate reduction.

[a] From *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* , USEPA, 1998.

[b] Replacement monitoring point for MW-26A which was destroyed during construction activities on the SteelCo property in October 2004. Data for piezometer PZ-3, located approximately 100 ft south of the location of former monitoring well MW-26A, is reported in place of data for MW-26A.

[c] New monitoring well installed in October 2011.

[d] MW-02 is not part of the compliance monitoring network; it was sampled in April 2012 to provide an additional downgradient monitoring point southwest of the shallow groundwater plume boundary for this round.

MCL	maximum contaminant level (regulatory limit)
mg/l	milligrams per liter
mV	millivolts
µg/l	micrograms per liter
Bold	Values in bold suggest biodegradation is possible
NA	Not analyzed
D	Sample dilution required for analysis; reported values reflect the dilution.
J-	Data are estimated; potentially biased low
T	Analyte was positively identified but the reported concentration is estimated; reported concentration is less than the reporting limit, but greater than the method detection limit.
UJ	Possible false negative.

TABLE 3
GROUNDWATER SAMPLING RESULTS FOR DEEPER WELLS INSTALLED IN 2011
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH

		Deeper Monitoring Wells																	
	Sample Identification	**MW-31D**						**MW-32D**						**MW-33D**					
	Screened Interval (feet bgs)	**38 - 48**						**46 - 56**						**35 - 45**					
	Date Collected	**12/20/2011**	**2/7/2012**	**5/3/2012**	**8/28/2012**	**11/14/2012**	**4/25/2013**	**12/20/2011**	**2/7/2012**	**5/3/2012**	**8/28/2012**	**11/14/2012**	**4/24/2013**	**12/28/2011**	**2/7/2012**	**5/3/2012**	**8/28/2012**	**11/15/2012**	**4/24/2013**
Volatile Organic Compounds (µg/l)	**Analytical Method**																		
Tetrachloroethene (PCE)	SW8260B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	**46**	**19**	4.4	**5.2**	**6.2**	**8.8**
Trichloroethene (TCE)	SW8260B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	**31 J**	**48**	2.9	1.5	1.8	1.6
1,1-Dichloroethene (1,1-DCE)	SW8260B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	0.3 T	0.3 T	<1	<1	<1
cis-1,2-Dichloroethene (cis-1,2-DCE)	SW8260B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	4.7	**140 D**	**110 D**	17	15	17
trans-1,2-Dichloroethene (trans-1,2-DCE)	SW8260B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Vinyl chloride (VC)	SW8260B	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	**8.9**	**2.1**	**7.4**
Ethylbenzene	SW8260B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	27 J	52	3.6	<1	10	5.1
m,p-Xylene (Sum of Isomers)	SW8260B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	83 D	150 D	36	7.5	33	39
o-Xylene	SW8260B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	46	33	9.6	12	13	18
Toluene	SW8260B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10	5.2	2.8	0.7 T	2.8	1.6
Pesticides (µg/l)																			
Pentachlorophenol (PCP)	SW8151A	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Geochemical parameters																			
pH (standard units)	field measurement	8.3	8.2	8.2	7.8	8.0	8.0	8.2	8.1	7.8	7.6	7.9	7.6	8.3	8.1	8.1	7.8	8.0	7.8
Oxidation-reduction Potential (mV)	field measurement	-8	-199	-203	-178	-175	-244	70	-167	-186	-139	-139	-173	-17	-158	-180	-227	-150	-244
Dissolved Oxygen (mg/l)	field measurement	0.1	0.0	0.1	0.1	0.2	0.0	0.3	0.3	0.4	0.1	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.0
Nitrate (mg/l)	E300.0	NA	NA	<0.1	<0.1	<0.1	0.0539 T	NA	NA	<0.1	<0.1	0.05 T	<0.1	NA	NA	<0.1	0.0	<0.1	<0.1
Nitrite (mg/l)	E300.0	NA	NA	<0.1	<0.1	<0.1	<0.1	NA	NA	<0.1	<0.1	<0.1	<0.1	NA	NA	<0.1	<0.1	<0.1	<0.1
Iron II (mg/l)	Hach 8146	NA	NA	0.4	0.5	>3.33[(a)]	1.36	NA	NA	0.6	0.8	1.27	0.8	NA	NA	0.3	1.8	3.65	1.2
Sulfate (mg/l)	E300.0	NA	NA	0.3 T	<0.5	0.3 T	0.348T	NA	NA	0.5 T	<0.5	0.4 T	0.552	NA	NA	12.7	1.8	1.7	1.3
Sulfide, total (mg/l)	E376.2	NA	NA	0.2	0.1 T	0.07 T	0.0752 T	NA	NA	0.2	0.1 T	0.09 T	0.0826 T	NA	NA	0.2	0.2	0.1	0.151

(a) Greater than the maximum reading on the field instrument.

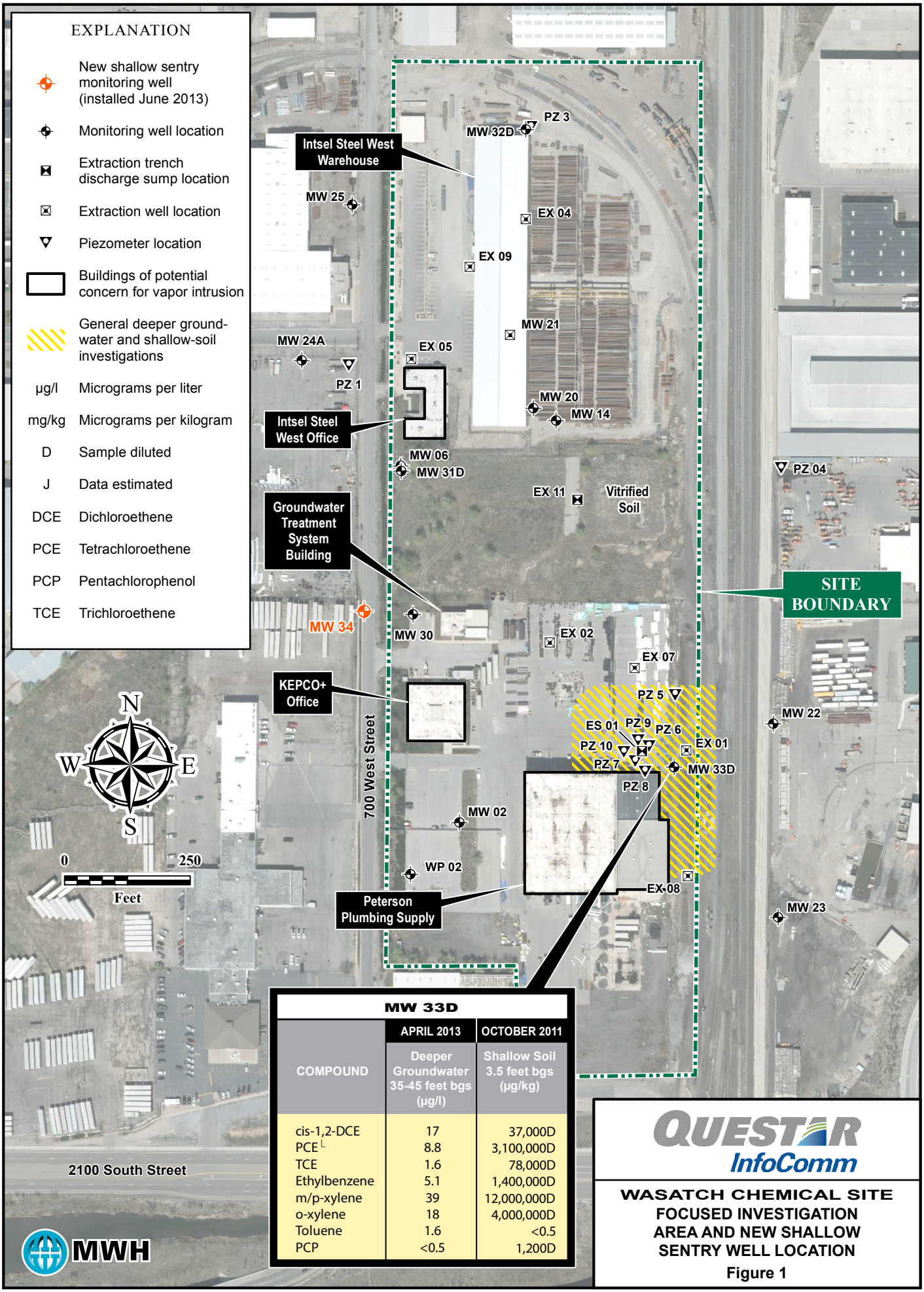
bgs below ground surface
µg/l micrograms per liter
MCL maximum contaminant level (regulatory limit)
mg/l milligrams per liter
mV millivolts
Bold Values in underlined bold exceed their MCL
NA Not analyzed
D Sample dilution required for analysis; reported values reflect the dilution.
T Analyte was positively identified but reported concentration is estimated; reported concentration is less than the reporting limit, but greater than the method detection limit.
J Data estimated

TABLE 4
SHALLOW GROUNDWATER STATISTICAL ANALYSIS RESULTS FOR DATA SETS ABOVE MCLs
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH

Monitoring Location	Constituent of Concern	Mean[(a)] (µg/l)	Trend[(b)]	Upper Confidence Limit[(c)]	Lower Confidence Limit[(c)]	Exceeds MCL[(d)]	Indication
EX-02	TCE	126.6	No	152.3	91.0	Yes	Stability
	1,1-DCE	9.0	No	9.8	8.3	Yes	Stability
	VC	117.8	No	160.1	75.6	Yes	Stability
	PCP	7.6	No	9.4	5.8	Yes	Stability
EX-04	TCE	31.6	Yes	44.7	18.6	Yes	Decreasing Trend
	1,1-DCE	10.3	No	12.9	7.8	Yes	Stability
EX-05	1,1-DCE	8.6	No	9.4	7.9	Yes	Stability
	VC	15.9	Yes	19.6	12.3	Yes	Decreasing Trend
EX-08	PCP	2.2	No	2.7	1.6	Yes	Stability
EX-11	VC	519.4	No	669.5	369.2	Yes	Stability
MW-20	VC	3.6	No	4.3	2.4	Yes	Stability
MW-30[(e)]	VC	13.1	No	18.7	7.5	Yes	Stability

Notes:
[(a)] Analyses conducted for the eight most recent data points.
[(b)] Mann-Kendall method with 99% confidence level used to test for presence of a significant trend (slope).
[(c)] Confidence limits determined using a 95% confidence level.
[(d)] MCL exceedances determined by comparing the lower confidence limit to the MCL.
[(e)] Seven data points were used for MW-30 (installed in October 2011).

MCL maximum contaminant level
α The percentage of cases for which a false conclusion is reached (1-confidence level)
µg/l micrograms per liter



MW 33D

COMPOUND	APRIL 2013 Deeper Groundwater 35-45 feet bgs (µg/l)	OCTOBER 2011 Shallow Soil 3.5 feet bgs (µg/kg)
cis-1,2-DCE	17	37,000D
PCE	8.8	3,100,000D
TCE	1.6	78,000D
Ethylbenzene	5.1	1,400,000D
m/p-xylene	39	12,000,000D
o-xylene	18	4,000,000D
Toluene	1.6	<0.5
PCP	<0.5	1,200D

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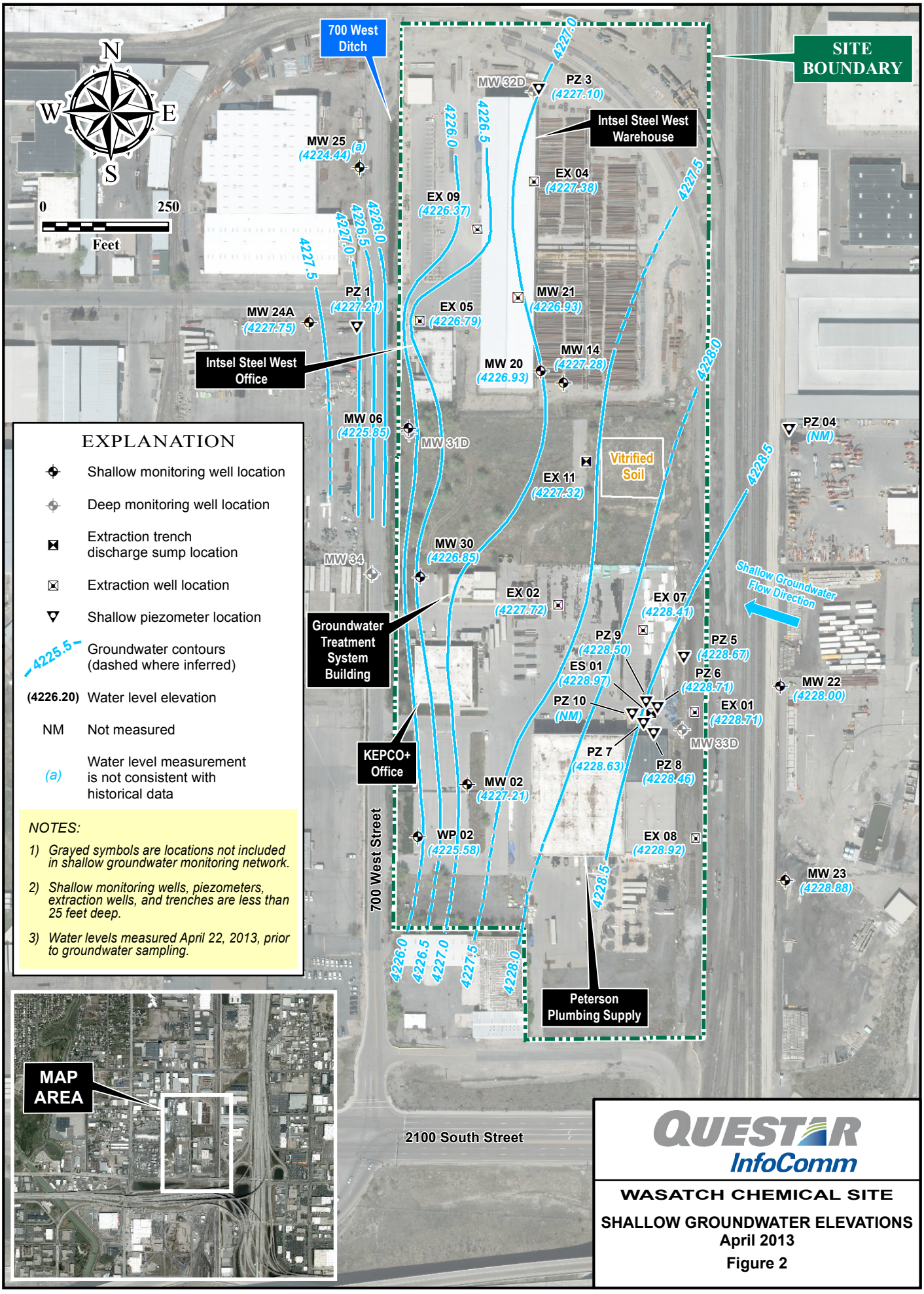
WASATCH CHEMICAL SITE FOCUSED INVESTIGATION AREA AND NEW SHALLOW SENTRY WELL LOCATION

Figure 1

MWH

DATE: 9 July 2013

FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 1_Focused Invest Area and New Sentry Well.mxd



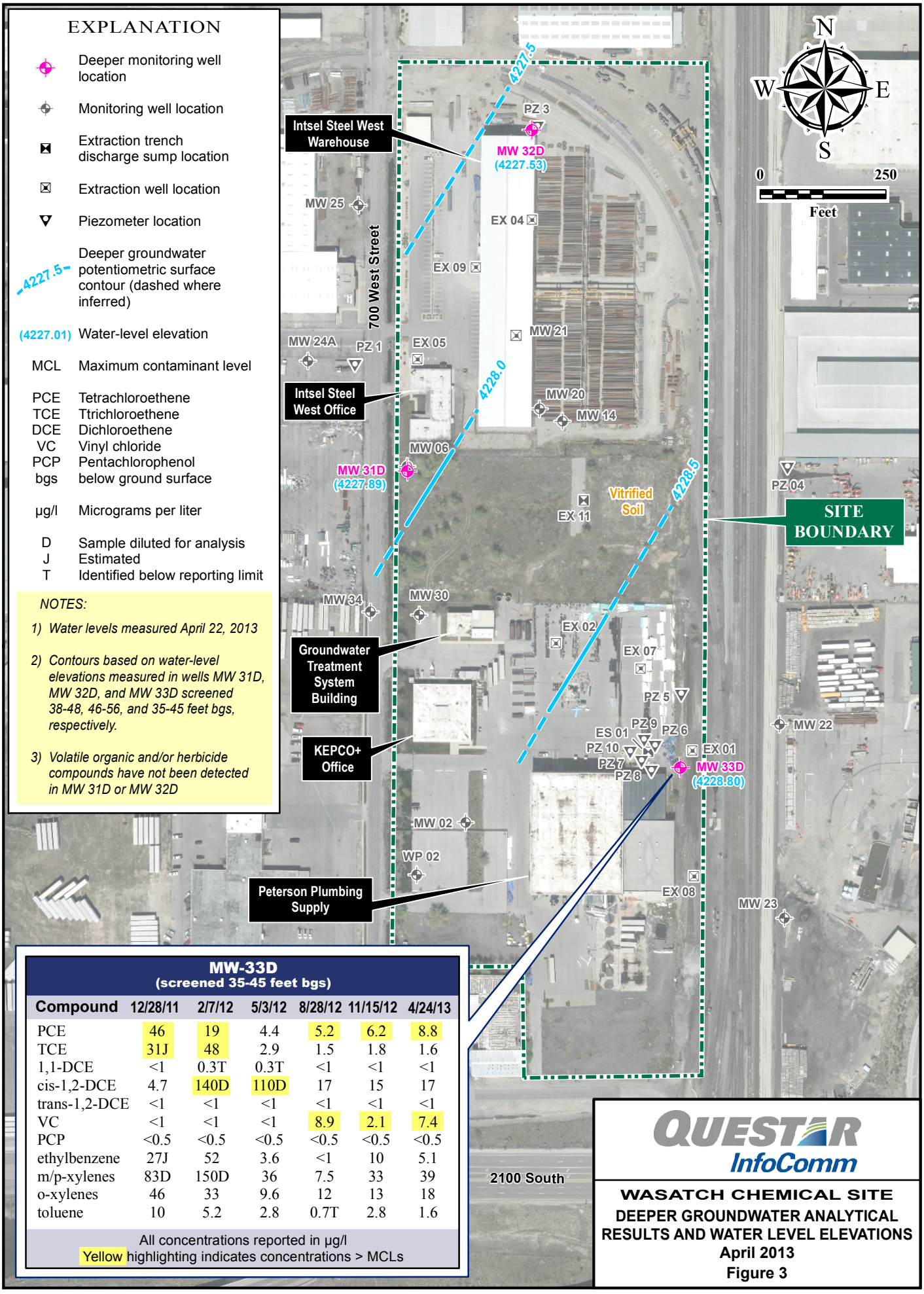
QUESTAR InfoComm

WASATCH CHEMICAL SITE

SHALLOW GROUNDWATER ELEVATIONS
April 2013
Figure 2

DATE: 9 July 2013

FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 2_Shallow_GW_Elev_Apr2013.mxd



MW-33D
(screened 35-45 feet bgs)

Compound	12/28/11	2/7/12	5/3/12	8/28/12	11/15/12	4/24/13
PCE	46	19	4.4	5.2	6.2	8.8
TCE	31J	48	2.9	1.5	1.8	1.6
1,1-DCE	<1	0.3T	0.3T	<1	<1	<1
cis-1,2-DCE	4.7	140D	110D	17	15	17
trans-1,2-DCE	<1	<1	<1	<1	<1	<1
VC	<1	<1	<1	8.9	2.1	7.4
PCP	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
ethylbenzene	27J	52	3.6	<1	10	5.1
m/p-xylenes	83D	150D	36	7.5	33	39
o-xylenes	46	33	9.6	12	13	18
toluene	10	5.2	2.8	0.7T	2.8	1.6

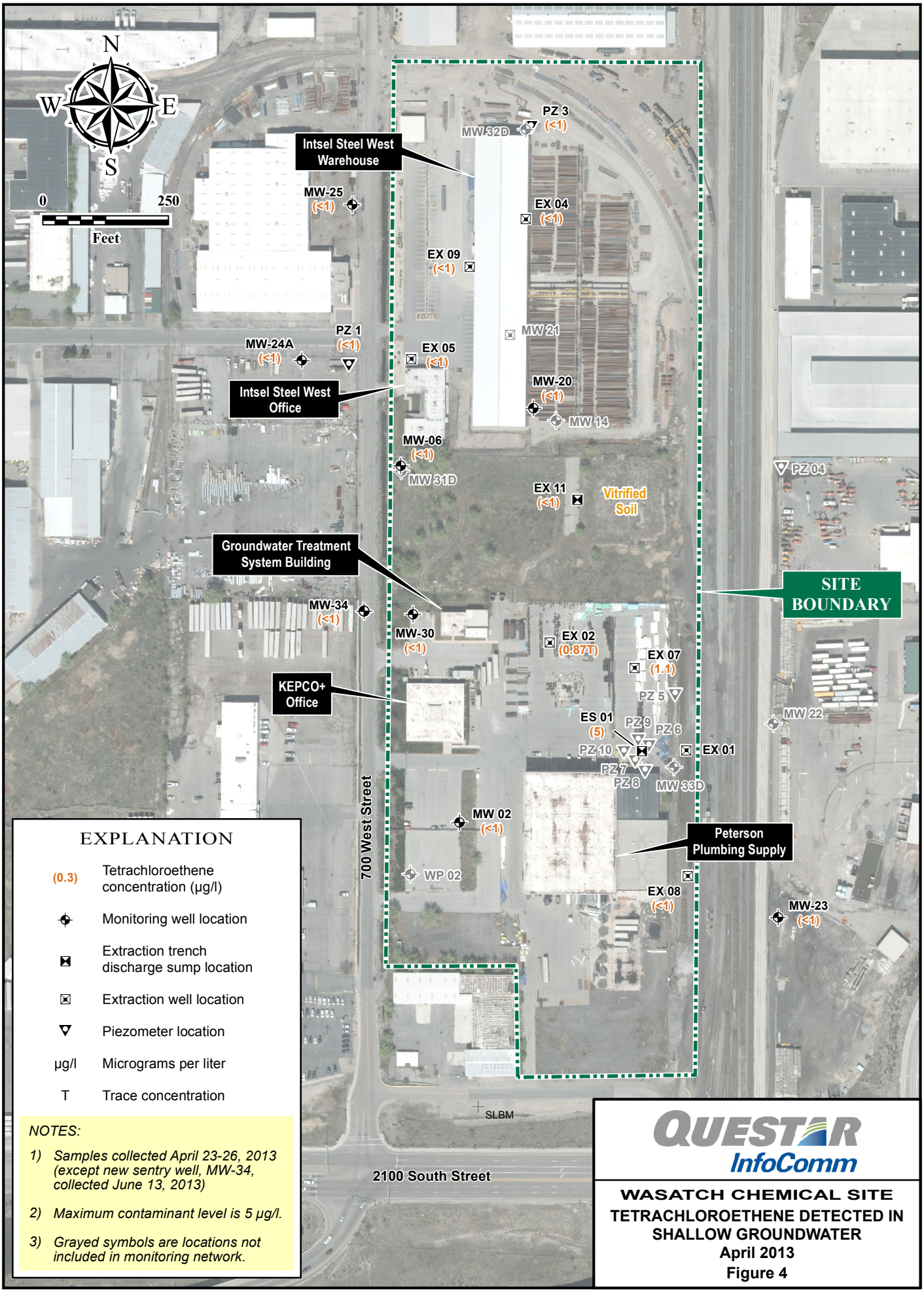
All concentrations reported in µg/l
Yellow highlighting indicates concentrations > MCLs

QUESTAR InfoComm

WASATCH CHEMICAL SITE
DEEPER GROUNDWATER ANALYTICAL RESULTS AND WATER LEVEL ELEVATIONS
April 2013
Figure 3

DATE: 9 July 2013

FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 3_Deep_Groundwater_April2013.mxd



QUESTAR InfoComm

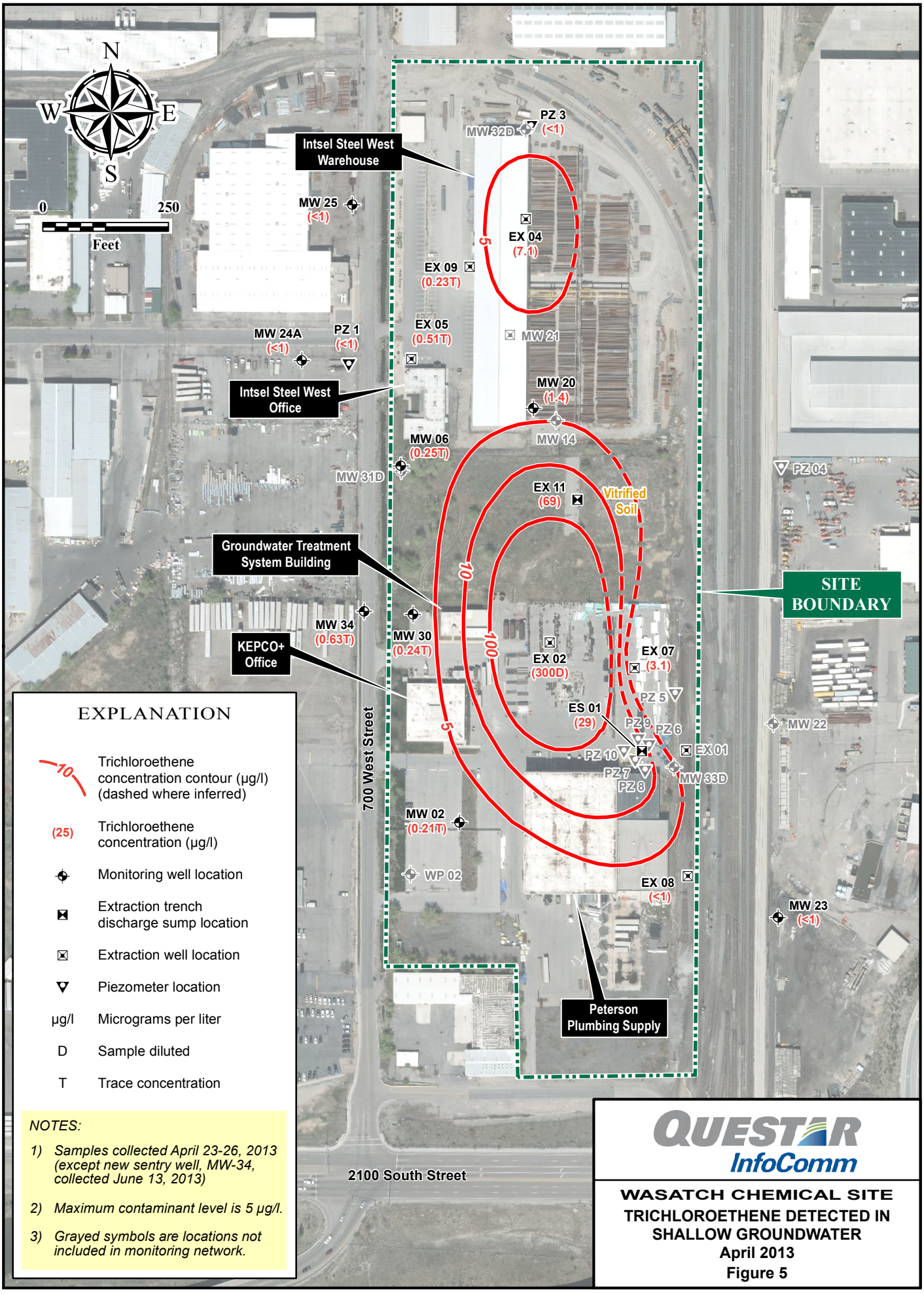
WASATCH CHEMICAL SITE

TETRACHLOROETHENE DETECTED IN SHALLOW GROUNDWATER

April 2013

Figure 4

FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 4_Tetrachlor_April2013.mxd DATE: 2 August 2013



EXPLANATION

10	Trichloroethene concentration contour (µg/l) (dashed where inferred)
(25)	Trichloroethene concentration (µg/l)
⊕	Monitoring well location
⊠	Extraction trench discharge sump location
⊠	Extraction well location
▽	Piezometer location
µg/l	Micrograms per liter
D	Sample diluted
T	Trace concentration

NOTES:

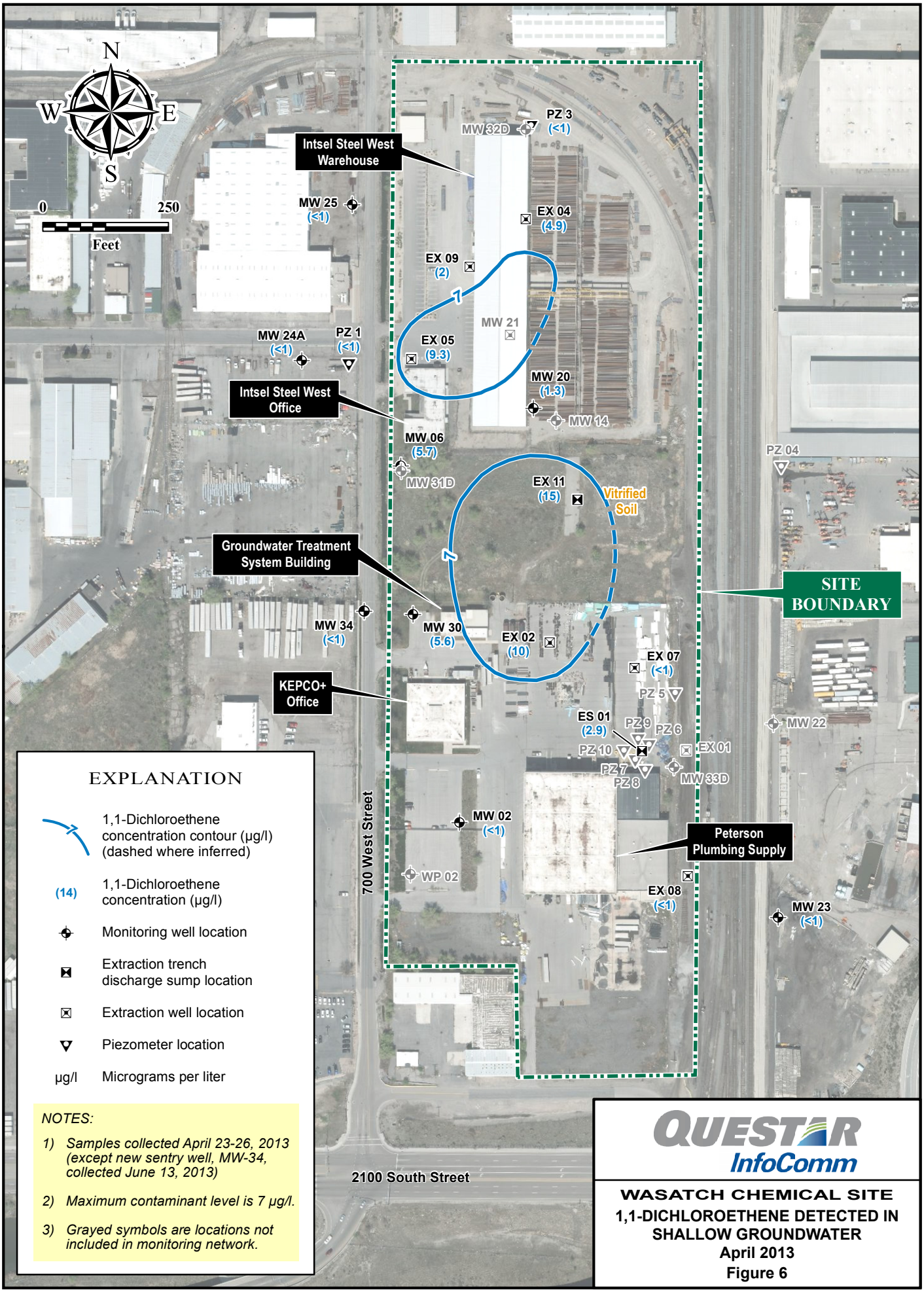
1) *Samples collected April 23-26, 2013 (except new sentry well, MW-34, collected June 13, 2013)*
2) *Maximum contaminant level is 5 µg/l.*
3) *Grayed symbols are locations not included in monitoring network.*

QUESTAR InfoComm

WASATCH CHEMICAL SITE
TRICHLOROETHENE DETECTED IN SHALLOW GROUNDWATER
April 2013
Figure 5

DATE: 2 August 2013

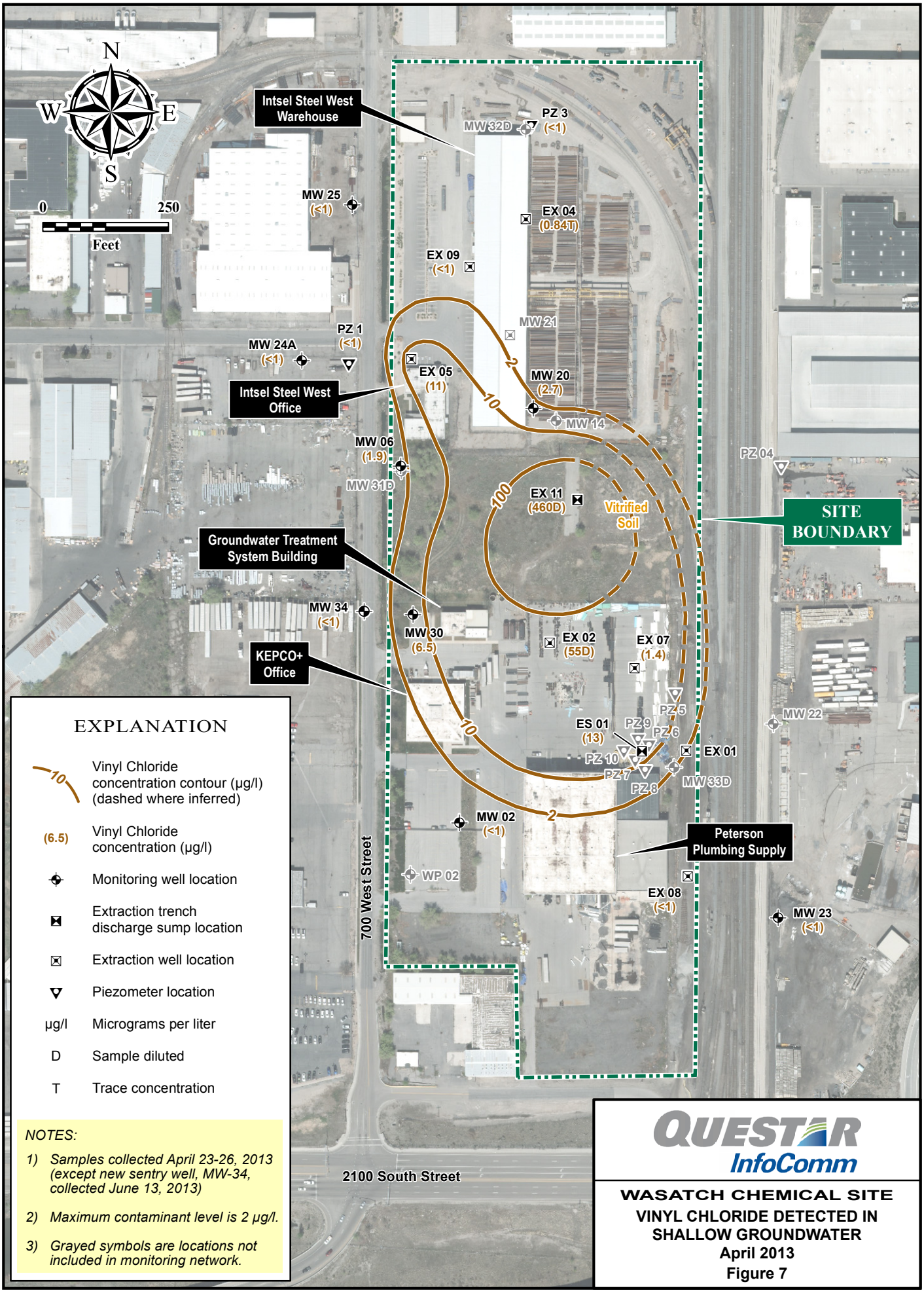
FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 5_Trichloro_April2013.mxd



QUESTAR InfoComm

WASATCH CHEMICAL SITE
1,1-DICHLOROETHENE DETECTED IN SHALLOW GROUNDWATER
April 2013
Figure 6

FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 6_Dichl_April2013.mxd DATE: 2 August 2013



EXPLANATION

10	Vinyl Chloride concentration contour (µg/l) (dashed where inferred)
(6.5)	Vinyl Chloride concentration (µg/l)
⊕	Monitoring well location
⊠	Extraction trench discharge sump location
⊠	Extraction well location
▽	Piezometer location
µg/l	Micrograms per liter
D	Sample diluted
T	Trace concentration

NOTES:

1) *Samples collected April 23-26, 2013 (except new sentry well, MW-34, collected June 13, 2013)*
2) *Maximum contaminant level is 2 µg/l.*
3) *Grayed symbols are locations not included in monitoring network.*

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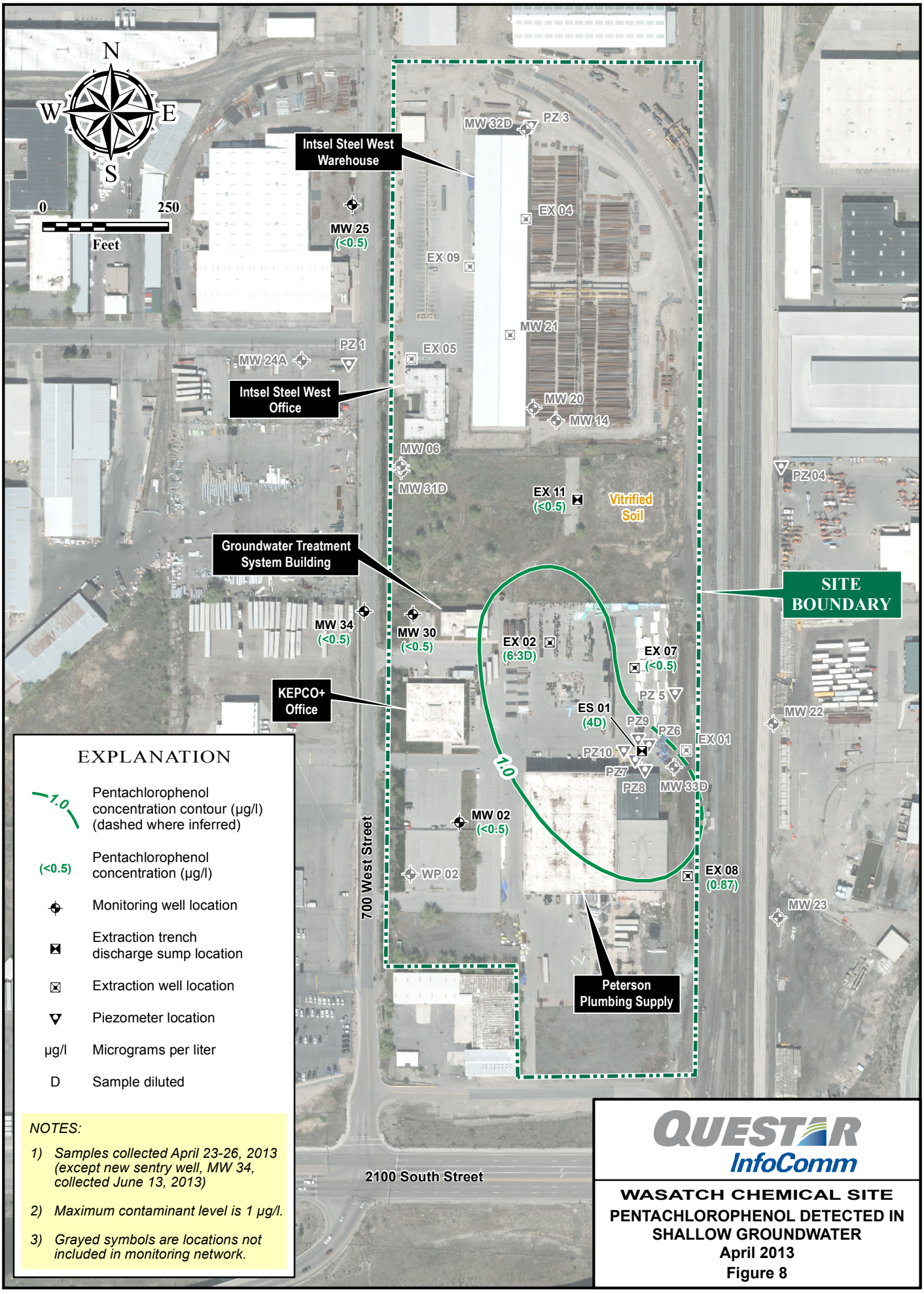
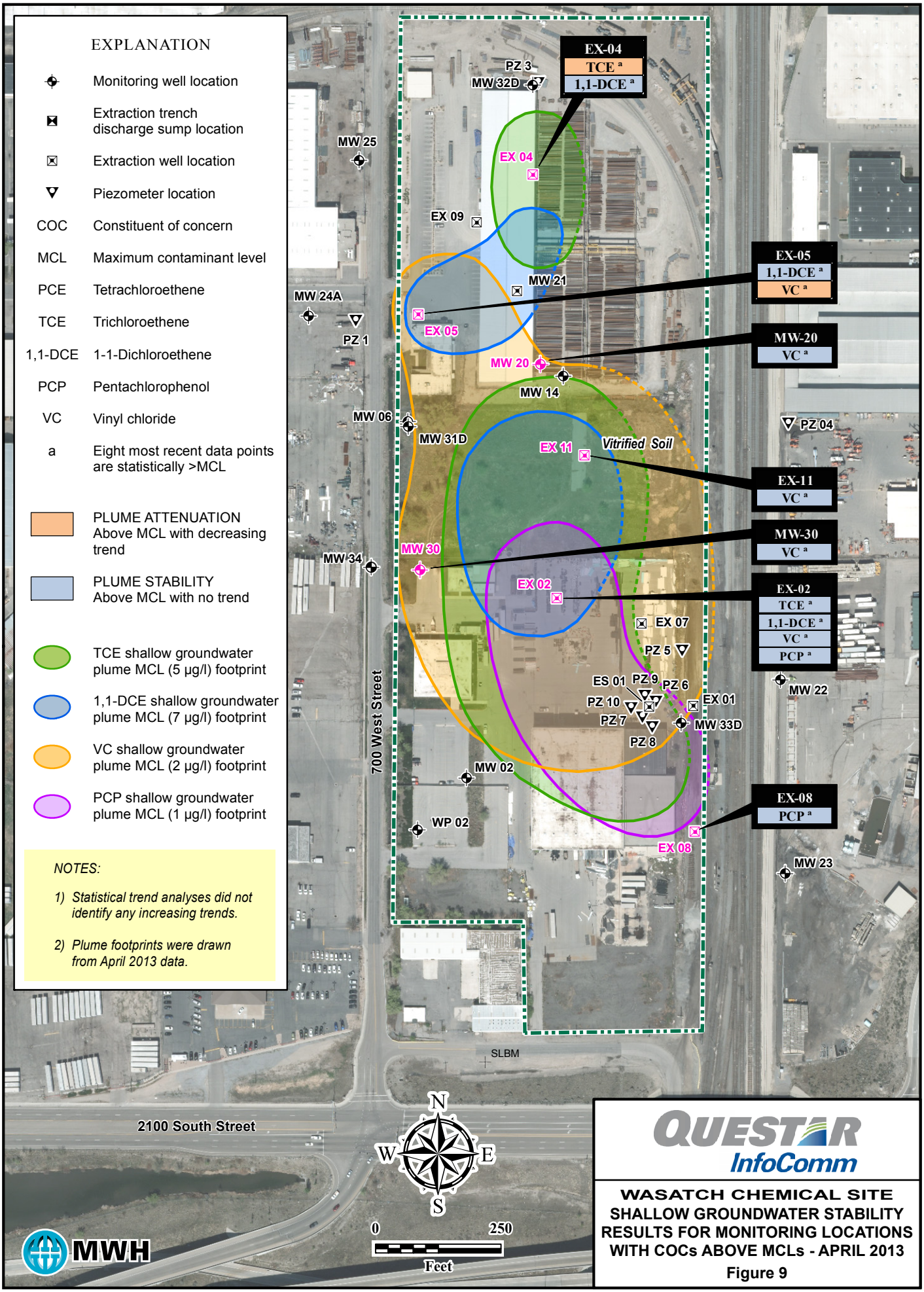
WASATCH CHEMICAL SITE
VINYL CHLORIDE DETECTED IN SHALLOW GROUNDWATER
April 2013
Figure 7

DATE: 2 August 2013

FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 7_Vinyl Chloride_April 2013.mxd


N
W
E
S
0
250
Feet
Intsel Steel West Warehouse
Intsel Steel West Office
Groundwater Treatment System Building
KEPCO+ Office
SITE BOUNDARY
Vitrified Soil
Peterson Plumbing Supply
700 West Street
2100 South Street
MW 32D
PZ 3
EX 04
MW 25 (<0.5)
EX 09
MW 21
PZ 1
MW 24A
EX 05
MW 20
MW 14
MW 06
MW 31D
EX 11 (<0.5)
PZ 04
MW 34 (<0.5)
MW 30 (<0.5)
EX 02 (6.3D)
EX 07 (<0.5)
PZ 5
ES 01 (4D)
PZ9
PZ6
EX 01
PZ10
PZ7
PZ8
MW 33D
MW 22
1.0
MW 02 (<0.5)
WP 02
EX 08 (0.87)
MW 23
EXPLANATION
1.0
Pentachlorophenol concentration contour (µg/l) (dashed where inferred)
(<0.5)
Pentachlorophenol concentration (µg/l)
Monitoring well location
Extraction trench discharge sump location
Extraction well location
Piezometer location
µg/l
Micrograms per liter
D
Sample diluted
NOTES:
1) Samples collected April 23-26, 2013 (except new sentry well, MW 34, collected June 13, 2013)
2) Maximum contaminant level is 1 µg/l.
3) Grayed symbols are locations not included in monitoring network.
QUESTAR InfoComm
WASATCH CHEMICAL SITE
PENTACHLOROPHENOL DETECTED IN SHALLOW GROUNDWATER
April 2013
Figure 8
DATE: 2 August 2013
FILE: I:\projects\QuestarWasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 8_Pentachl_April 2013.mxd


EXPLANATION
Monitoring well location
Extraction trench discharge sump location
Extraction well location
Piezometer location
COC Constituent of concern
MCL Maximum contaminant level
PCE Tetrachloroethene
TCE Trichloroethene
1,1-DCE 1-1-Dichloroethene
PCP Pentachlorophenol
VC Vinyl chloride
a Eight most recent data points are statistically >MCL
PLUME ATTENUATION Above MCL with decreasing trend
PLUME STABILITY Above MCL with no trend
TCE shallow groundwater plume MCL (5 µg/l) footprint
1,1-DCE shallow groundwater plume MCL (7 µg/l) footprint
VC shallow groundwater plume MCL (2 µg/l) footprint
PCP shallow groundwater plume MCL (1 µg/l) footprint
NOTES:
1) Statistical trend analyses did not identify any increasing trends.
2) Plume footprints were drawn from April 2013 data.
EX-04 TCE a 1,1-DCE a
EX-05 1,1-DCE a VC a
MW-20 VC a
EX-11 VC a
MW-30 VC a
EX-02 TCE a 1,1-DCE a VC a PCP a
EX-08 PCP a
PZ 3
MW 32D
MW 25
EX 04
EX 09
MW 21
MW 24A
PZ 1
EX 05
MW 20
MW 14
MW 06
MW 31D
EX 11
Vitrified Soil
PZ 04
MW 34
MW 30
EX 02
EX 07
PZ 5
ES 01
PZ 9
PZ 6
PZ 10
PZ 7
PZ 8
EX 01
MW 33D
MW 22
700 West Street
MW 02
WP 02
EX 08
MW 23
SLBM
2100 South Street
N
W
E
S
0
250
Feet
MWH
QUESTAR InfoComm
WASATCH CHEMICAL SITE
SHALLOW GROUNDWATER STABILITY RESULTS FOR MONITORING LOCATIONS WITH COCs ABOVE MCLs - APRIL 2013
Figure 9
DATE: 19 July 2013
FILE: I:\projects\Questar\Wasatch Chemical\PROGRESS REPORT_APR2013_No99\FIGURES\Fig 9_Shallow GW Stability Results for Mon Locs w COCs above MCL.mxd

APPENDIX A

DATA VERIFICATION

APPENDIX A

DATA VERIFICATION
SPRING 2013 GROUNDWATER SAMPLING

Introduction. Groundwater samples were collected as listed in Table A-1 at the Wasatch Chemical Site on April 23, 24, 25, 26 and June 13, 2013, during the seventy third quarter (Q-73) since groundwater remediation began in 1995. A summary of the analytical data is presented in Table A-2. The following paragraphs summarize the results of the data validation for Q-73.

Sampling Procedures. All groundwater samples were collected as scheduled and in accordance with the *Ground-water Monitoring Plan* (GWMP; MWH, 1996), the *Monitored Natural Attenuation Work Plan* (MWH, 2002), and the *Groundwater Monitoring Well Installation and Sampling Plan* (MWH, 2011).

Analytical Procedures and Detection Limits. All samples were analyzed in accordance with the methodology, detection limits, and quality control (QC) criteria specified in the project *Quality Assurance Project Plan, Revision 2* (QAPP; MWH, 2012). EMAX Laboratories, Inc. (EMAX) of Torrance, California provided analytical services for Q-73.

Three field duplicate (FD) samples were collected from monitoring well MW-34 and extraction wells ES-01 and EX-05 for Q-73. A summary of the field duplicate results as compared with the normal sample results for these locations is presented in Table C-4. Requested matrix spike (MS) and/or matrix spike duplicate (MSD) analyses were performed on groundwater sample collected at EX-11 (EX-11-73).

The following occurred during sample analysis resulting in flagged or qualified data; however, there was no impact to data usability:

- Dilutions were required during analysis due to the high concentrations of sulfate in all the groundwater samples except MW-31D, MW-32D and MW-33D. The affected sample results are flagged with a "D" to indicate sample dilution.

Data Verification Process. The data from Q-73 were validated based on the criteria specified in the project QAPP (MWH, 2012). The results of the data verification are summarized in the following tables:

- Table A-1, Summary of Groundwater Samples
- Table A-2, Groundwater Sample Data Summary
- Table A-3, Holding Time Summary
- Table A-4, Field Duplicate Data Summary

All holding times, reporting limits, accuracy, precision, and representativeness criteria, as specified in the QAPP, were met.

Conclusions. Based on the results of the data verification, the Q-73 data are considered precise, accurate, and representative, as qualified. Sampling completeness for this project is 100 percent, and analytical completeness for this sampling round is 100 percent, which meets the completeness goal of 85 percent.

REFERENCES

MWH, 1996. Final Ground-water Monitoring Plan, Wasatch Chemical Site. August 1996.

MWH, 2002. Monitored Natural Attenuation Work Plan, Wasatch Chemical Site Addendum to the Final Extraction and Treatment System Performance Standards, Milestones, and Shutdown Procedures document. November 14, 2002.

MWH, 2011. Final Groundwater Monitoring Well Installation and Sampling Plan, Wasatch Chemical Site. October 2011.

MWH, 2012. Quality Assurance Project Plan, Revision 2, Wasatch Chemical Site. March 2012.

TABLE A-1

SUMMARY OF GROUNDWATER SAMPLES
Q-73, APRIL and JUNE 2013
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH

Location Identification	Field Sample Identification	Date Collected	Sample Matrix	Sampling Technique	Sample Type	VOCs SW-846 8260B	PCP SW-846 8151A	Anions E300	Sulfide E376.2
ES-01	MW-35-73	23-Apr-13	WG	SP	FD	X	X	X	X
	ES-01-73	23-Apr-13	WG	SP	N	X	X	X	X
EX-02	EX-02-73	23-Apr-13	WG	SP	N	X	X	X	X
EX-04	EX-04-73	23-Apr-13	WG	SP	N	X	NS	X	X
EX-05	EX-05-73	23-Apr-13	WG	SP	N	X	NS	X	X
	MW-36-73	23-Apr-13	WG	SP	FD	X	NS	X	X
EX-07	EX-07-73	23-Apr-13	WG	SP	N	X	X	X	X
	EX-07-73DUP	23-Apr-13	WG	SP	LR	NS	NS	X	NS
	EX-07-73MS	23-Apr-13	WG	SP	MS	NS	NS	X	NS
	EX-07-73MSD	23-Apr-13	WG	SP	SD	NS	NS	X	NS
EX-08	EX-08-73	25-Apr-13	WG	SP	N	X	X	X	X
	EX-08-73DUP	25-Apr-13	WG	SP	LR	NS	NS	X	NS
	EX-08-73MS	25-Apr-13	WG	SP	MS	NS	NS	X	NS
	EX-08-73MSD	25-Apr-13	WG	SP	SD	NS	NS	X	NS
EX-09	EX-09-73	23-Apr-13	WG	SP	N	X	NS	X	X
EX-11	EX-11-73	24-Apr-13	WG	SP	N	X	X	X	X
	EX-11-73DUP	24-Apr-13	WG	SP	LR	NS	NS	X	X
	EX-11-73MS	24-Apr-13	WG	SP	MS	X	X	X	X
	EX-11-73MSD	24-Apr-13	WG	SP	SD	X	X	X	NS
MW-02	MW-02-73	26-Apr-13	WG	SP	N	X	X	X	X
	MW-02-73DUP	26-Apr-13	WG	SP	LR	NS	NS	X	NS
	MW-02-73MS	26-Apr-13	WG	SP	MS	NS	NS	X	NS
	MW-02-73MSD	26-Apr-13	WG	SP	SD	NS	NS	X	NS
MW-06	MW-06-73	25-Apr-13	WG	SP	N	X	NS	X	X
MW-20	MW-20-73	23-Apr-13	WG	SP	N	X	NS	X	X
MW-23	MW-23-73	25-Apr-13	WG	SP	N	X	NS	X	X
	MW-23-73DUP	25-Apr-13	WG	SP	LR	NS	NS	NS	X
	MW-23-73MS	25-Apr-13	WG	SP	MS	NS	NS	NS	X
MW-24A	MW-24A-73	24-Apr-13	WG	SP	N	X	NS	X	X
MW-25	MW-25-73	25-Apr-13	WG	SP	N	X	X	X	X
MW-30	MW-30-73	25-Apr-13	WG	SP	N	X	X	X	X
MW-31D	MW-31D-73	25-Apr-13	WG	SP	N	X	X	X	X
MW-32D	MW-32D-73	24-Apr-13	WG	SP	N	X	X	X	X
MW-33D	MW-33D-73	24-Apr-13	WG	SP	N	X	X	X	X
MW-34	MW-34	13-Jun-13	WG	SP	N	X	X	X	X
	SMW-934	13-Jun-13	WG	SP	FD	X	X	X	X
					LR	NS	NS	X	X
					MS	NS	NS	X	X
					SD	NS	NS	X	NS
PZ-1	PZ-1-73	24-Apr-13	WG	SP	N	X	NS	X	X
PZ-3	PZ-3-73	24-Apr-13	WG	SP	N	X	NS	X	X
FIELDQC	FB-4-23-13	23-Apr-13	WQ	NA	AB	X	X	X	X
	TB-4-24-13	24-Apr-13	WQ	NA	TB	X	NS	NS	NS
	EB-4-25-13	25-Apr-13	WQ	NA	EB	X	NS	NS	NS
	TB-4-26-13	26-Apr-13	WQ	NA	TB	X	NS	NS	NS
	TRIP BLANK	13-Jun-13	WQ	NA	TB	X	NS	NS	NS

AB or FB	Ambient blank	N	Compliance sample	TB	Trip blank
EB	Equipment rinseate blank	NS	Not sampled	VOCs	Volatile organic compounds
FD	Field Duplicate	PCP	Pentachlorophenol	WG	Groundwater
G	Grab sample	SD	Matrix spike duplicate	WQ	Reagent Grade water or distilled water
LR	Laboratory replicate	SP	Submersible pump	X	Sampled
MS	Matrix spike				

TABLE A-2

GROUNDWATER SAMPLE DATA SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Analyte/Methods (Units)	Location Identification	ES-01	ES-01 Dup	EX-02	EX-04	EX-05	EX-05 Dup	EX-07
	Field Sample Identification	ES-01-73	MW-35-73	EX-02-73	EX-04-73	EX-05-73	MW-36-73	EX-07-73
	Date Collected	4/23/2013	4/23/2013	4/23/2013	4/23/2013	4/23/2013	4/23/2013	4/23/2013
	Matrix	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
Water Quality Parameters (mg/l)								
Nitrogen, Nitrate (as N)		**0.105**	**0.105**	**1.2**	**0.397**	<0.1	<0.1	**1.2 D**
Nitrogen, Nitrite		<0.1	<0.1	<0.1	**0.0729 T**	<0.1	<0.1	<0.1
Sulfate (as SO_4)		**70.2 D**	**71 D**	**1030 D**	**679 D**	**1460 D**	**1430 D**	**78.6 D**
Sulfide		**0.201**	**0.216**	<0.1	<0.1	<0.1	<0.1	<0.1
Herbicides/SW8151A (µg/l)								
Pentachlorophenol		**4 D**	**4.1 D**	**6.3 D**	--	--	--	<0.5
Volatile Organic Compounds/SW8260B (µg/l)								
1,1-Dichloroethene		**2.9**	**3.7**	**10**	**4.9**	**9.3**	**9.6**	<1
Benzene		--	--	--	--	--	--	--
cis-1,2-Dichloroethene		**26**	**27**	**320 D**	**66**	**150 D**	**140 D**	**3.9**
Ethylbenzene		--	--	--	--	--	--	--
m,p-Xylene (Sum of isomers)		--	--	--	--	--	--	--
Naphthalene		--	--	--	--	--	--	--
o-Xylene (1,2-Dimethylbenzene)		--	--	--	--	--	--	--
Tetrachloroethene (PCE)		**5**	**5.3**	**0.87 T**	<1	<1	<1	**1.1**
Toluene		--	--	--	--	--	--	--
trans-1,2-Dichloroethene		**0.42 T**	**0.45 T**	**8.3**	**12**	**160 D**	**150 D**	**0.73 T**
Trichloroethene (TCE)		**29**	**31**	**300 D**	**7.1**	**0.51 T**	**0.53 T**	**3.1**
Vinyl chloride		**13**	**14**	**55 D**	**0.84 T**	**11**	**11**	**1.4**

µg/l micrograms per liter.
mg/l milligrams per liter.
Bold Bolded result indicates positively identified compound.
-- Not scheduled.
D Sample dilution required for analysis; reported values reflect the dilution.
T Analyte was positively identified but the reported concentration is estimated; reported concentration is less than the reporting limit, but greater than the method detection limit.

TABLE A-2

GROUNDWATER SAMPLE DATA SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	EX-08	EX-09	EX-11	MW-02	MW-06	MW-20	MW-23
Field Sample Identification	EX-08-73	EX-09-73	EX-11-73	MW-02-73	MW-06-73	MW-20-73	MW-23-73
Date Collected	4/25/2013	4/23/2013	4/24/2013	4/26/2013	4/25/2013	4/23/2013	4/25/2013
Matrix	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
Analyte/Methods (Units)							
Water Quality Parameters (mg/l)							
Nitrogen, Nitrate (as N)	**2.8 D**	**0.982**	<0.1	**56.5 D**	<0.1	**0.567**	<0.5 D
Nitrogen, Nitrite	<0.5 D	<0.1	<0.1	<1 D	<0.25 D	<0.1	<0.5 D
Sulfate (as SO_4)	**493 D**	**1130 D**	**1040 D**	**2580 D**	**693 D**	**904 D**	**215 D**
Sulfide	<0.1	<0.1	**0.051 T**	<0.1	**0.0433 T**	<0.1	**0.169**
Herbicides/SW8151A (µg/l)							
Pentachlorophenol	**0.87**	--	<0.5	<0.5	--	--	--
Volatile Organic Compounds/SW8260B (µg/l)							
1,1-Dichloroethene	<1	**2**	**15**	<1	**5.7**	**1.3**	<1
Benzene	--	--	--	--	--	--	--
cis-1,2-Dichloroethene	<1	**25**	**670 D**	**0.37 T**	**28**	**20**	<1
Ethylbenzene	--	--	--	--	--	--	--
m,p-Xylene (Sum of isomers)	--	--	--	--	--	--	--
Naphthalene	--	--	--	--	--	--	--
o-Xylene (1,2-Dimethylbenzene)	--	--	--	--	--	--	--
Tetrachloroethene (PCE)	<1	<1	<1	<1	<1	<1	<1
Toluene	--	--	--	--	--	--	--
trans-1,2-Dichloroethene	<1	**7.5**	**84**	<1	**5.1**	**18**	<1
Trichloroethene (TCE)	<1	**0.23 T**	**69**	**0.21 T**	**0.25 T**	**1.4**	<1
Vinyl chloride	<1	<1	**460 D**	<1	**1.9**	**2.7**	<1

µg/l micrograms per liter.
mg/l milligrams per liter.
Bold Bolded result indicates positively identified compound.
-- Not scheduled.
D Sample dilution required for analysis; reported values reflect the dilution.
T Analyte was positively identified but the reported concentration is estimated; reported concentration is less than the reporting limit, but greater than the method detection limit.

TABLE A-2

GROUNDWATER SAMPLE DATA SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH
(Page 3 of 4)

Location Identification	MW-24A	MW-25	MW-30	MW-31D	MW-32D	MW-33D	MW-34
Field Sample Identification	MW-24A-73	MW-25-73	MW-30-73	MW-31D-73	MW-32D-73	MW-33D-73	MW-34
Date Collected	4/24/2013	4/25/2013	4/25/2013	4/25/2013	4/24/2013	4/24/2013	6/13/2013
Matrix	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater	Groundwater
Analyte/Methods (Units)							
Water Quality Parameters (mg/l)							
Nitrogen, Nitrate (as N)	<0.1	<0.1	<0.1	**0.0539 T**	<0.1	<0.1	<0.1
Nitrogen, Nitrite	<0.1	<0.1	<0.2 D	<0.1	<0.1	<0.1	<0.1
Sulfate (as SO_4)	**91.2 D**	**742 D**	**640 D**	**0.348 T**	**0.552**	**1.29**	**720 D**
Sulfide	<0.1	<0.1	**0.282**	**0.0752 T**	**0.0826 T**	**0.151**	<0.1
Herbicides/SW8151A (µg/l)							
Pentachlorophenol	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Volatile Organic Compounds/SW8260B (µg/l)							
1,1-Dichloroethene	<1	<1	**5.6**	<1	<1	<1	<1
Benzene	--	--	--	--	--	<0.5	--
cis-1,2-Dichloroethene	<1	<1	**30**	<1	<1	**17**	**1.7**
Ethylbenzene	--	--	--	--	--	**5.1**	--
m,p-Xylene (Sum of isomers)	--	--	--	--	--	**39**	--
Naphthalene	--	--	--	--	--	<1	--
o-Xylene (1,2-Dimethylbenzene)	--	--	--	--	--	**18**	--
Tetrachloroethene (PCE)	<1	<1	<1	<1	<1	**8.8**	<1
Toluene	--	--	--	--	--	**1.6**	--
trans-1,2-Dichloroethene	<1	<1	**0.93 T**	<1	<1	<1	**0.48 T**
Trichloroethene (TCE)	<1	<1	**0.63 T**	<1	<1	**1.6**	**0.24 T**
Vinyl chloride	<1	<1	**6.5**	<1	<1	**7.4**	<1

µg/l micrograms per liter.
mg/l milligrams per liter.
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TABLE A-2

GROUNDWATER SAMPLE DATA SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	MW-34 Dup	PZ-1	PZ-3
Field Sample Identification	SMW-934	PZ-1-73	PZ-3-73
Date Collected	6/13/2013	4/24/2013	4/24/2013
Matrix	Groundwater	Groundwater	Groundwater
Analyte/Methods (Units)			
Water Quality Parameters (mg/l)			
Nitrogen, Nitrate (as N)	<0.1	**0.0606 T**	<0.1
Nitrogen, Nitrite	<0.1	<0.1	<0.1
Sulfate (as SO_4)	**708 D**	**362 D**	**2160 D**
Sulfide	<0.1	**0.0293 T**	**0.021 T**
Herbicides/SW8151A (µg/l)			
Pentachlorophenol	<0.5	--	--
Volatile Organic Compounds/SW8260B (µg/l)			
1,1-Dichloroethene	<1	<1	<1
Benzene	--	--	--
cis-1,2-Dichloroethene	**1.4**	<1	<1
Ethylbenzene	--	--	--
m,p-Xylene (Sum of isomers)	--	--	--
Naphthalene	--	--	--
o-Xylene (1,2-Dimethylbenzene)	--	--	--
Tetrachloroethene (PCE)	<1	<1	<1
Toluene	--	--	--
trans-1,2-Dichloroethene	**0.46 T**	<1	<1
Trichloroethene (TCE)	**0.25 T**	<1	<1
Vinyl chloride	<1	<1	<1

µg/l micrograms per liter.
mg/l milligrams per liter.
Bold Bolded result indicates positively identified compound.
-- Not scheduled.
D Sample dilution required for analysis; reported values reflect the dilution.
T Analyte was positively identified but the reported concentration is estimated; reported concentration is less than the reporting limit, but greater than the method detection limit.

TABLE A-3

HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
ES-01	ES-01-73	23-Apr-13	930	E300	N/A	N/A	N/A	24-Apr-13	1116	1	28
					N/A	N/A	N/A	24-Apr-13	1850	1	28
	MW-35-73	23-Apr-13	930	E300	N/A	N/A	N/A	24-Apr-13	1132	1	28
					N/A	N/A	N/A	24-Apr-13	1906	1	28
	ES-01-73	23-Apr-13	930	E376.2	N/A	N/A	N/A	25-Apr-13	1528	2	7
	MW-35-73	23-Apr-13	930	E376.2	N/A	N/A	N/A	25-Apr-13	1528	2	7
	ES-01-73	23-Apr-13	930	SW8151A	26-Apr-13	3	7	2-May-13	1738	9	14
	MW-35-73	23-Apr-13	930	SW8151A	26-Apr-13	3	7	6-May-13	1415	13	14
	ES-01-73	23-Apr-13	930	SW8260B	25-Apr-13	2	14	25-Apr-13	1357	2	14
	MW-35-73	23-Apr-13	930	SW8260B	25-Apr-13	2	14	25-Apr-13	1428	2	14
EX-02	EX-02-73	23-Apr-13	1116	E300	N/A	N/A	N/A	24-Apr-13	2043	1	28
					N/A	N/A	N/A	24-Apr-13	1149	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1529	2	7
				SW8151A	26-Apr-13	3	7	2-May-13	2118	9	14
				SW8260B	25-Apr-13	2	14	25-Apr-13	1901	2	14
					25-Apr-13	2	14	25-Apr-13	1458	2	14

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HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
EX-04	EX-04-73	23-Apr-13	1215	E300	N/A	N/A	N/A	24-Apr-13	1205	1	28
					N/A	N/A	N/A	24-Apr-13	2059	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1529	2	7
				SW8260B	25-Apr-13	2	14	25-Apr-13	1528	2	14
EX-05	EX-05-73	23-Apr-13	1547	E300	N/A	N/A	N/A	24-Apr-13	1358	1	28
					N/A	N/A	N/A	24-Apr-13	2131	1	28
	MW-36-73	23-Apr-13	1547	E300	N/A	N/A	N/A	24-Apr-13	2115	1	28
					N/A	N/A	N/A	24-Apr-13	1221	1	28
	EX-05-73	23-Apr-13	1547	E376.2	N/A	N/A	N/A	25-Apr-13	1531	2	7
	MW-36-73	23-Apr-13	1547	E376.2	N/A	N/A	N/A	25-Apr-13	1530	2	7
	EX-05-73	23-Apr-13	1547	SW8260B	25-Apr-13	2	14	25-Apr-13	1659	2	14
					25-Apr-13	2	14	25-Apr-13	2002	2	14
	MW-36-73	23-Apr-13	1547	SW8260B	25-Apr-13	2	14	25-Apr-13	1629	2	14
					25-Apr-13	2	14	25-Apr-13	1931	2	14

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HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
EX-07	EX-07-73	23-Apr-13	1413	E300	N/A	N/A	N/A	24-Apr-13	1745	1	28
					N/A	N/A	N/A	24-Apr-13	2252	1	28
					N/A	N/A	N/A	24-Apr-13	1446	1	28
	EX-07-73DUP	23-Apr-13	1413	E300	N/A	N/A	N/A	24-Apr-13	2308	1	28
					N/A	N/A	N/A	24-Apr-13	1502	1	28
					N/A	N/A	N/A	24-Apr-13	1801	1	28
	EX-07-73MS	23-Apr-13	1413	E300	N/A	N/A	N/A	24-Apr-13	1817	1	28
					N/A	N/A	N/A	24-Apr-13	1519	1	28
					N/A	N/A	N/A	24-Apr-13	2324	1	28
	EX-07-73MSD	23-Apr-13	1413	E300	N/A	N/A	N/A	24-Apr-13	1535	1	28
					N/A	N/A	N/A	24-Apr-13	2341	1	28
					N/A	N/A	N/A	24-Apr-13	1833	1	28
	EX-07-73	23-Apr-13	1413	E376.2	N/A	N/A	N/A	25-Apr-13	1530	2	7
				SW8151A	26-Apr-13	3	7	29-Apr-13	2103	6	14
				SW8260B	25-Apr-13	2	14	25-Apr-13	1558	2	14
EX-08	EX-08-73	25-Apr-13	1345	E300	N/A	N/A	N/A	26-Apr-13	1427	1	28
					N/A	N/A	N/A	26-Apr-13	1741	1	28
	EX-08-73DUP	25-Apr-13	1345	E300	N/A	N/A	N/A	26-Apr-13	1444	1	28
					N/A	N/A	N/A	26-Apr-13	1757	1	28
	EX-08-73MS	25-Apr-13	1345	E300	N/A	N/A	N/A	26-Apr-13	1814	1	28
	EX-08-73MSD	25-Apr-13	1345	E300	N/A	N/A	N/A	26-Apr-13	1516	1	28
					N/A	N/A	N/A	26-Apr-13	1830	1	28
	EX-08-73MS	25-Apr-13	1345	E300	N/A	N/A	N/A	26-Apr-13	1500	1	28
	EX-08-73	25-Apr-13	1345	E376.2	N/A	N/A	N/A	1-May-13	1706	6	7
				SW8151A	26-Apr-13	1	7	30-Apr-13	410	5	14
				SW8260B	29-Apr-13	4	14	29-Apr-13	1423	4	14

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HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
EX-09	EX-09-73	23-Apr-13	1621	E300	N/A	N/A	N/A	24-Apr-13	1414	1	28
					N/A	N/A	N/A	24-Apr-13	2147	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1532	2	7
				SW8260B	25-Apr-13	2	14	25-Apr-13	1730	2	14
EX-11	EX-11-73	24-Apr-13	655	E300	N/A	N/A	N/A	25-Apr-13	1125	1	28
					N/A	N/A	N/A	25-Apr-13	1738	1	28
	EX-11-73DUP	24-Apr-13	655	E300	N/A	N/A	N/A	25-Apr-13	1141	1	28
					N/A	N/A	N/A	25-Apr-13	1754	1	28
	EX-11-73MS	24-Apr-13	655	E300	N/A	N/A	N/A	25-Apr-13	1157	1	28
					N/A	N/A	N/A	25-Apr-13	1810	1	28
	EX-11-73MSD	24-Apr-13	655	E300	N/A	N/A	N/A	25-Apr-13	1213	1	28
					N/A	N/A	N/A	25-Apr-13	1826	1	28
	EX-11-73	24-Apr-13	655	E376.2	N/A	N/A	N/A	25-Apr-13	1539	1	7
	EX-11-73DUP	24-Apr-13	655	E376.2	N/A	N/A	N/A	25-Apr-13	1539	1	7
	EX-11-73MS	24-Apr-13	655	E376.2	N/A	N/A	N/A	25-Apr-13	1540	1	7
	EX-11-73	24-Apr-13	655	SW8260B	26-Apr-13	2	14	26-Apr-13	1712	2	14
				SW8151A	26-Apr-13	2	7	29-Apr-13	2347	5	14
	EX-11-73MS	24-Apr-13	655	SW8151A	26-Apr-13	2	7	30-Apr-13	20	6	14
	EX-11-73MSD	24-Apr-13	655	SW8151A	26-Apr-13	2	7	30-Apr-13	53	6	14
	EX-11-73	24-Apr-13	655	SW8260B	29-Apr-13	5	14	29-Apr-13	1520	5	14
	EX-11-73MS	24-Apr-13	655	SW8260B	26-Apr-13	2	14	26-Apr-13	1742	2	14
	EX-11-73MSD	24-Apr-13	655	SW8260B	26-Apr-13	2	14	26-Apr-13	1810	2	14

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HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
MW-02	MW-02-73	26-Apr-13	857	E300	N/A	N/A	N/A	27-Apr-13	1309	1	28
					N/A	N/A	N/A	27-Apr-13	1607	1	28
					N/A	N/A	N/A	27-Apr-13	1744	1	28
	MW-02-73DUP	26-Apr-13	857	E300	N/A	N/A	N/A	27-Apr-13	1325	1	28
					N/A	N/A	N/A	27-Apr-13	1800	1	28
					N/A	N/A	N/A	27-Apr-13	1623	1	28
	MW-02-73MS	26-Apr-13	857	E300	N/A	N/A	N/A	27-Apr-13	1341	1	28
					N/A	N/A	N/A	27-Apr-13	1639	1	28
	MW-02-73MSD	26-Apr-13	857	E300	N/A	N/A	N/A	27-Apr-13	1655	1	28
					N/A	N/A	N/A	27-Apr-13	1832	1	28
					N/A	N/A	N/A	27-Apr-13	1357	1	28
	MW-02-73MS	26-Apr-13	857	E300	N/A	N/A	N/A	27-Apr-13	1816	1	28
	MW-02-73	26-Apr-13	857	E376.2	N/A	N/A	N/A	1-May-13	1709	5	7
				SW8151A	30-Apr-13	4	7	1-May-13	126	5	14
				SW8260B	29-Apr-13	3	14	29-Apr-13	2213	3	14
MW-06	MW-06-73	25-Apr-13	816	E300	N/A	N/A	N/A	26-Apr-13	1146	1	28
					N/A	N/A	N/A	26-Apr-13	1250	1	28
					N/A	N/A	N/A	26-Apr-13	1323	1	28
				E376.2	N/A	N/A	N/A	1-May-13	1703	6	7
				SW8260B	26-Apr-13	1	14	26-Apr-13	2107	1	14
MW-20	MW-20-73	23-Apr-13	1653	E300	N/A	N/A	N/A	24-Apr-13	1430	1	28
					N/A	N/A	N/A	24-Apr-13	2204	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1532	2	7
				SW8260B	25-Apr-13	2	14	25-Apr-13	1759	2	14

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HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
MW-23	MW-23-73	25-Apr-13	1501	E300	N/A	N/A	N/A	26-Apr-13	1411	1	28
					N/A	N/A	N/A	26-Apr-13	1637	1	28
				E376.2	N/A	N/A	N/A	1-May-13	1707	6	7
	MW-23-73MS	25-Apr-13	1501	E376.2	N/A	N/A	N/A	1-May-13	1708	6	7
	MW-23-73DUP	25-Apr-13	1501	E376.2	N/A	N/A	N/A	1-May-13	1707	6	7
	MW-23-73	25-Apr-13	1501	SW8260B	29-Apr-13	4	14	29-Apr-13	1451	4	14
MW-24A	MW-24A-73	24-Apr-13	1136	E300	N/A	N/A	N/A	25-Apr-13	1302	1	28
					N/A	N/A	N/A	25-Apr-13	1617	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1535	1	7
				SW8260B	26-Apr-13	2	14	26-Apr-13	1909	2	14
MW-25	MW-25-73	25-Apr-13	1115	E300	N/A	N/A	N/A	26-Apr-13	1234	1	28
					N/A	N/A	N/A	26-Apr-13	1902	1	28
				E376.2	N/A	N/A	N/A	1-May-13	1705	6	7
				SW8151A	26-Apr-13	1	7	30-Apr-13	337	5	14
				SW8260B	29-Apr-13	4	14	29-Apr-13	1354	4	14
MW-30	MW-30-73	25-Apr-13	957	E300	N/A	N/A	N/A	26-Apr-13	1307	1	28
					N/A	N/A	N/A	26-Apr-13	1846	1	28
					N/A	N/A	N/A	26-Apr-13	1218	1	28
				E376.2	N/A	N/A	N/A	1-May-13	1704	6	7
				SW8151A	26-Apr-13	1	7	30-Apr-13	304	5	14
				SW8260B	26-Apr-13	1	14	26-Apr-13	2206	1	14
MW-31D	MW-31D-73	25-Apr-13	835	E300	N/A	N/A	N/A	26-Apr-13	1202	1	28
				E376.2	N/A	N/A	N/A	1-May-13	1703	6	7
				SW8151A	26-Apr-13	1	7	30-Apr-13	231	5	14
				SW8260B	26-Apr-13	1	14	26-Apr-13	2137	1	14

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HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH
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Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
MW-32D	MW-32D-73	24-Apr-13	1356	E300	N/A	N/A	N/A	25-Apr-13	1407	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1537	1	7
				SW8151A	26-Apr-13	2	7	30-Apr-13	126	6	14
				SW8260B	26-Apr-13	2	14	26-Apr-13	2006	2	14
MW-33D	MW-33D-73	24-Apr-13	1430	E300	N/A	N/A	N/A	25-Apr-13	1424	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1538	1	7
				SW8151A	26-Apr-13	2	7	30-Apr-13	158	6	14
				SW8260B	26-Apr-13	2	14	26-Apr-13	2035	2	14
MW-34	SMW-934	13-Jun-13	1050	E300	N/A	N/A	N/A	14-Jun-13	1127	1	28
					N/A	N/A	N/A	14-Jun-13	1159	1	28
	MW-34	13-Jun-13	1050	E300	N/A	N/A	N/A	14-Jun-13	1602	1	28
					N/A	N/A	N/A	14-Jun-13	1111	1	28
	SMW-934	13-Jun-13	1050	E300	N/A	N/A	N/A	14-Jun-13	1513	1	28
					N/A	N/A	N/A	14-Jun-13	1143	1	28
					N/A	N/A	N/A	14-Jun-13	1546	1	28
					N/A	N/A	N/A	14-Jun-13	1216	1	28
					N/A	N/A	N/A	14-Jun-13	1530	1	28
					N/A	N/A	N/A	14-Jun-13	1457	1	28
	MW-34	13-Jun-13	1050	E376.2	N/A	N/A	N/A	14-Jun-13	1634	1	7
	SMW-934	13-Jun-13	1050	E376.2	N/A	N/A	N/A	14-Jun-13	1634	1	7
	MW-34	13-Jun-13	1050	SW8151A	18-Jun-13	5	7	19-Jun-13	1316	6	14
	SMW-934	13-Jun-13	1050	SW8151A	18-Jun-13	5	7	19-Jun-13	1347	6	14
	MW-34	13-Jun-13	1050	SW8260B	17-Jun-13	4	14	17-Jun-13	1837	4	14
	SMW-934	13-Jun-13	1050	SW8260B	17-Jun-13	4	14	17-Jun-13	1909	4	14

TABLE A-3

HOLDING TIME SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH

Location Identification	Field Identification	Sample Date	Sample Time	Analysis Code	Preparation Date	Preparation Holding Time (Days)	Method Holding Time (Days)	Analysis Date	Analysis Time	Analysis Holding Time (Days)	Method Holding Time (Days)
PZ-1	PZ-1-73	24-Apr-13	1025	E300	N/A	N/A	N/A	25-Apr-13	1601	1	28
					N/A	N/A	N/A	25-Apr-13	1229	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1533	1	7
				SW8260B	26-Apr-13	2	14	26-Apr-13	1840	2	14
PZ-3	PZ-3-73	24-Apr-13	1345	E300	N/A	N/A	N/A	25-Apr-13	1246	1	28
					N/A	N/A	N/A	25-Apr-13	1633	1	28
				E376.2	N/A	N/A	N/A	25-Apr-13	1536	1	7
				SW8260B	26-Apr-13	2	14	26-Apr-13	1938	2	14

N/A Not applicable.

TABLE A-4

FIELD DUPLICATE DATA SUMMARY
Q-73, APRIL AND JUNE 2013
WASATCH CHEMICAL COMPANY, SALT LAKE CITY, UTAH
(Page 1 of 1)

Location Identification	ES-01	ES-01 Dup		EX-05	EX-05 Dup		MW-34	MW-34 Dup	
Field Sample Identification	ES-01-73	MW-35-73		EX-05-73	MW-36-73		MW-34	SMW-934	
Sample Type	Normal	Field Duplicate		Normal	Field Duplicate		Normal	Field Duplicate	
Date Collected	4/23/2013	4/23/2013		4/23/2013	4/23/2013		6/13/2013	6/13/2013	
Analyte/Methods (Units)			RPD			RPD			RPD
Water Quality Parameters (mg/l)									
Nitrogen, Nitrate (as N)	**0.105**	**0.105**	0	<0.1	<0.1	NC	<0.1	<0.1	NC
Nitrogen, Nitrite	<0.1	<0.1	NC	<0.1	<0.1	NC	<0.1	<0.1	NC
Sulfate (as SO_4)	**70.2 D**	**71 D**	1.13	**1460 D**	**1430 D**	2.08	**720 D**	**708 D**	1.68
Sulfide	**0.201**	**0.216**	7.19	<0.1	<0.1	NC	<0.1	<0.1	NC
Herbicides/SW8151A (µg/l)									
Pentachlorophenol	**4 D**	**4.1 D**	2.47	--	--	--	<0.5	<0.5	NC
Volatile Organic Compounds (µg/l)									
1,1-Dichloroethene	**2.9**	**3.7**	24.24	**9.3**	**9.6**	3.17	<1	<1	NC
cis-1,2-Dichloroethene	**26**	**27**	3.77	**150 D**	**140 D**	6.90	**1.7**	**1.4**	19.35
Tetrachloroethene (PCE)	**5**	**5.3**	5.83	<1	<1	NC	<1	<1	NC
trans-1,2-Dichloroethene	**0.42**	**0.45**	6.90	**160 D**	**150 D**	6.45	**0.48 T**	**0.46 T**	4.26
Trichloroethene (TCE)	**29**	**31**	6.67	**0.51**	**0.53**	3.85	**0.24 T**	**0.25 T**	4.008
Vinyl chloride	**13**	**14**	7.41	**11**	**11**	0	<1	<1	NC

µg/l micrograms per liter.
mg/l milligrams per liter.
Bold Bolded result indicates positively identified compound.
-- Not scheduled.
NC Not calculated.
D Sample dilution required for analysis; reported values reflect the dilution.
RPD relative percent difference.
T Analyte was positively identified but the reported concentration is estimated; reported concentration is less than the reporting limit, but greater than the method detection limit.

APPENDIX B

DATA TRENDS

APPENDIX B

WASATCH CHEMICAL SITE

SECTION B1: CURRENT TRENDS

List of Tables

List of Exhibits

SECTION B2: COMPREHENSIVE DATA AND HISTORICAL TRENDS

List of Exhibits

Section B1

Linear Regression Analyses and Assessment of Current Trends

TABLE B1-1

EVALUATION OF CONTAMINANT CONCENTRATION TRENDS FOR THE EIGHT MOST RECENT DATA POINTS
WASATCH CHEMICAL SITE
(Page 1 of 3)

Well ID	Chemical Constituent	Current Trend[a]	Lower Confidence Limit Relative to MCL	Reduced by at least 50% of Initial Baseline?	Comments
ES-01	PCE	NA (below MCL)	below	yes	PCE concentrations were less than the MCL for six of the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	yes	Concentrations ranged between 0.37 T and 47 µg/l over the past eight sampling rounds.
	1,1-DCE	NA (below MCL)	below	yes	1,1-DCE concentrations were below the MCL for seven of the eight most recent sampling rounds.
	PCP	NA (below MCL)	below	yes	Concentrations ranged between <0.5 and 26 µg/l for the past eight sampling rounds.
	VC[b]	NA (below MCL)	below	NA	Concentrations ranged between 0.35 T and 60 µg/l over the past eight sampling rounds.
EX-02	PCE	NA (below MCL)	below	yes	PCE was detected only at trace concentrations (below reporting limit) over the eight most recent sampling rounds.
	TCE	**Asymptotic**	**above**	no	Concentrations ranged between 74 and 300 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
	1,1-DCE	**Asymptotic**	**above**	yes	Concentrations ranged between 7.2 and 10 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
	PCP	**Asymptotic**	**above**	yes	Concentrations ranged between 3.5 and 13 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
	VC[b]	**Asymptotic**	**above**	NA	Concentrations ranged between 68 and 210 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
EX-04	PCE	NA (below MCL)	below	yes	PCE was not detected for the past eight sampling rounds.
	TCE	**Decreasing**	**above**	yes	TCE concentrations ranged between 7.1 to 58 µg/l over the past 8 sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is decreasing.
	1,1-DCE	**Asymptotic**	**above**	yes	1,1-DCE concentrations ranged between 4.9 and 17 µg/l over the past 8 sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
	VC[b]	NA (below MCL)	below	NA	VC concentrations ranged between 0.74 T to 2.9 µg/l over the past 8 sampling rounds. VC concentrations were below the MCL for six of the last eight sampling rounds.
EX-05	PCE	NA (below MCL)	below	yes	PCE was not detected over the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	yes	TCE was detected only at trace concentrations (below reporting limit) over the eight most recent sampling rounds.
	1,1-DCE	**Asymptotic**	**above**	yes	Concentrations ranged between 5.8 and 9.9 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
	VC[b]	**Decreasing**	**above**	NA	Concentrations ranged between 11 and 27 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is decreasing.
EX-07	PCE	NA (below MCL)	below	yes	PCE was detected only twice, and at trace concentrations (below reporting limit), over the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	yes	TCE concentrations ranged between 0.93 T and 3.1 µg/l over the past eight sampling rounds, all below the MCL.
	1,1-DCE	NA (below MCL)	below	yes	1,1-DCE concentrations were less than the MCL and the laboratory reporting limit over the past eight sampling rounds.
	PCP	NA (below MCL)	below	yes	PCP was not detected over the eight most recent sampling rounds.
	VC[b]	NA (below MCL)	below	NA	VC concentrations ranged between 1.4 and 6.5 µg/l over the past 8 sampling rounds.

TABLE B1-1

EVALUATION OF CONTAMINANT CONCENTRATION TRENDS FOR THE EIGHT MOST RECENT DATA POINTS
WASATCH CHEMICAL SITE
(Page 2 of 3)

Well ID	Chemical Constituent	Current Trend[a]	Lower Confidence Limit Relative to MCL	Reduced by at least 50% of Initial Baseline?	Comments
EX-08	PCE	NA (below MCL)	below	NA	PCE was not detected over the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	NA	All eight most recent data points are less than the MCL and the laboratory reporting limit; six are reported as trace concentrations, two are ND.
	1,1-DCE	NA (below MCL)	below	NA	1,1-DCE was not detected over the eight most recent sampling rounds.
	PCP	**Asymptotic**	**above**	yes	Concentrations ranged between 0.87 and 3.4 µg/l over the past eight sampling rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
	VC[b]	NA (below MCL)	below	NA	VC was either ND or reported as a trace concentration (below reporting limit) over the past eight sampling rounds.
EX-09	PCE	NA (below MCL)	below	NA	PCE was not detected over the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	yes	All eight most recent samples were detected at trace concentrations (below the reporting limit).
	1,1-DCE	NA (below MCL)	below	yes	Concentrations ranged between 1.2 and 2.8 µg/l over the past eight sampling rounds, all below the MCL.
	VC[b]	NA (below MCL)	below	NA	Six of the eight most recent data points are ND, two were reported as trace concentrations (below reporting limit).
EX-11	PCE	NA (below MCL)	below	yes	PCE was detected in just one of the eight most recent samples at a concentration of 1.7 µg/l.
	TCE	NA (below MCL)	below	yes	TCE concentrations ranged between 2 and 69 µg/l over the past eight sampling rounds; four data points are below the MCL.
	1,1-DCE	NA (below MCL)	below	yes	1,1-DCE concentrations ranged between 1.2 and 20 µg/l over the past eight sampling rounds.
	PCP	NA (below MCL)	below	NA	PCP was not detected over the eight most recent sampling rounds.
	VC[b]	**Asymptotic**	**above**	NA	VC concentrations ranged between 230 and 840 µg/l over the past eight monitoring rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
MW-06	PCE	NA (below MCL)	below	NA	PCE was not detected during the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	NA	Six of the eight most recent data points are ND; two are reported as trace concentrations (below reporting limit).
	1,1-DCE	NA (below MCL)	below	NA	Three of the eight most recent data points are below the laboratory reporting limit, and the most recent five data points range between 3 and 5.7 µg/l.
	VC[b]	NA (below MCL)	below	NA	All eight most recent data points are below the MCL, with two reported as ND and two at trace concentrations (below reporting limit).
MW-20	PCE	NA (below MCL)	below	yes	PCE was not detected during the eight most recent sampling rounds.
	TCE	NA (below MCL)	below	yes	The eight most recent data points are below the MCL.
	1,1-DCE	NA (below MCL)	below	yes	All eight of the most recent data points are below the MCLs, with three reported as trace concentrations (below reporting limit).
	VC[b]	**Asymptotic**	**above**	NA	VC concentrations range between 1.9 and 8.1 µg/l over the past eight monitoring rounds. A regression analysis for the eight most recent data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
MW-23	PCE	NA (below MCL)	below	NA	Upgradient well.
	TCE	NA (below MCL)	below	NA	Upgradient well.
	1,1-DCE	NA (below MCL)	below	NA	Upgradient well.
	VC[b]	NA (below MCL)	below	NA	Upgradient well.
MW-24A	PCE	NA (below MCL)	below	NA	Downgradient well.
	TCE	NA (below MCL)	below	NA	Downgradient well.
	1,1-DCE	NA (below MCL)	below	NA	Downgradient well.
	VC[b]	NA (below MCL)	below	NA	Downgradient well.

TABLE B1-1

EVALUATION OF CONTAMINANT CONCENTRATION TRENDS FOR THE EIGHT MOST RECENT DATA POINTS
WASATCH CHEMICAL SITE
(Page 3 of 3)

Well ID	Chemical Constituent	Current Trend[a]	Lower Confidence Limit Relative to MCL Relative to MCL	Reduced by at least 50% of Initial Baseline?	Comments
MW-25	PCE	NA (below MCL)	below	NA	Downgradient well.
	TCE	NA (below MCL)	below	NA	Downgradient well.
	1,1-DCE	NA (below MCL)	below	NA	Downgradient well.
	VC[b]	NA (below MCL)	below	NA	Downgradient well.
MW-30[c]	PCE	NA (below MCL)	below	NA	PCE has not been detected at MW-30 (seven sampling rounds conducted to date).
	TCE	NA (below MCL)	below	NA	All seven TCE data points are below the MCL, and six are reported as trace concentrations (below reporting limit).
	1,1-DCE	NA (below MCL)	below	NA	1,1-DCE concentrations range between 4.3 and 9 µg/l; four of the seven most recent data points are below the MCL.
	PCP	NA (below MCL)	below	NA	PCP has not been detected at MW-30 (seven sampling rounds conducted to date).
	VC[b]	**Asymptotic**	**above**	NA	VC concentrations range between 5.5 and 25 µg/l. A regression analysis for these seven data points indicates the slope of the regression line is not statistically different from zero (no significant change in concentration), therefore an asymptote may have been reached.
PZ-1	PCE	NA (below MCL)	below	NA	Downgradient well.
	TCE	NA (below MCL)	below	NA	Downgradient well.
	1,1-DCE	NA (below MCL)	below	NA	Downgradient well.
	VC[b]	NA (below MCL)	below	NA	Downgradient well.
PZ-3	PCE	NA (below MCL)	below	NA	Downgradient well.
	TCE	NA (below MCL)	below	NA	Downgradient well.
	1,1-DCE	NA (below MCL)	below	NA	Downgradient well.
	VC[b]	NA (below MCL)	below	NA	Downgradient well.

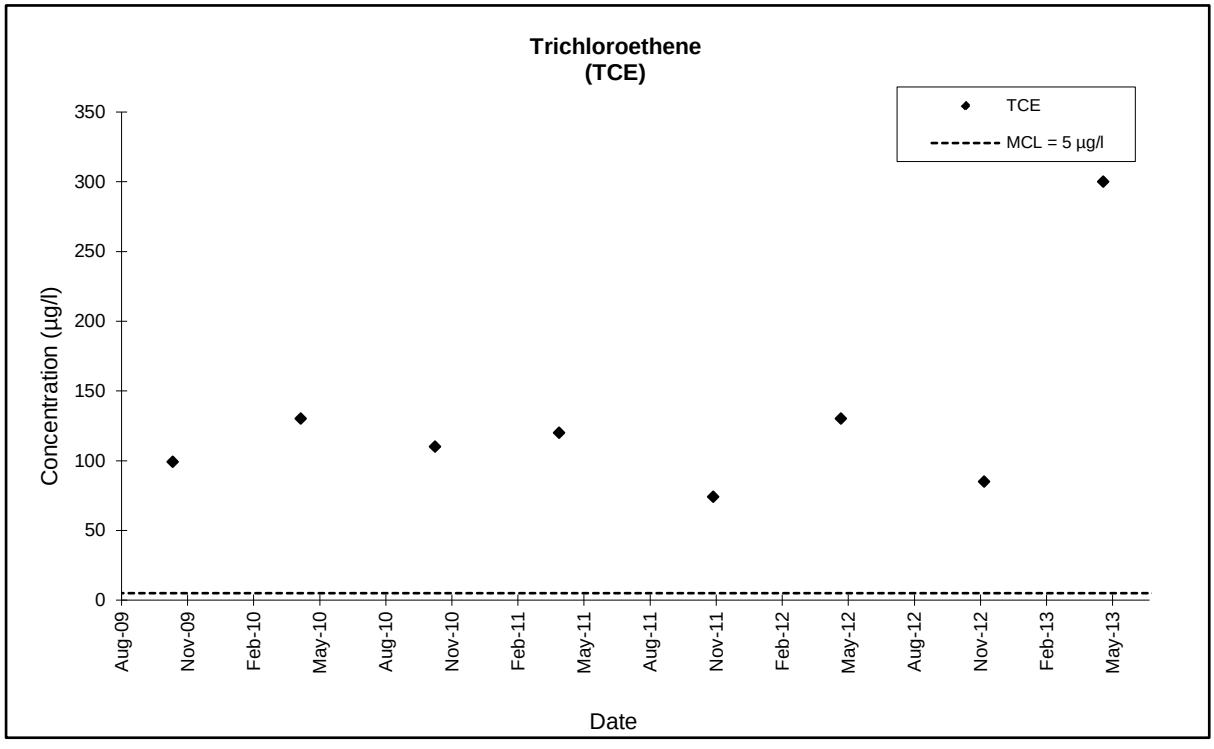
[a] To assess current trends, linear regression analyses were conducted using the eight most recent data points.
For data points where a constituent was not detected, the laboratory reporting limit was used.

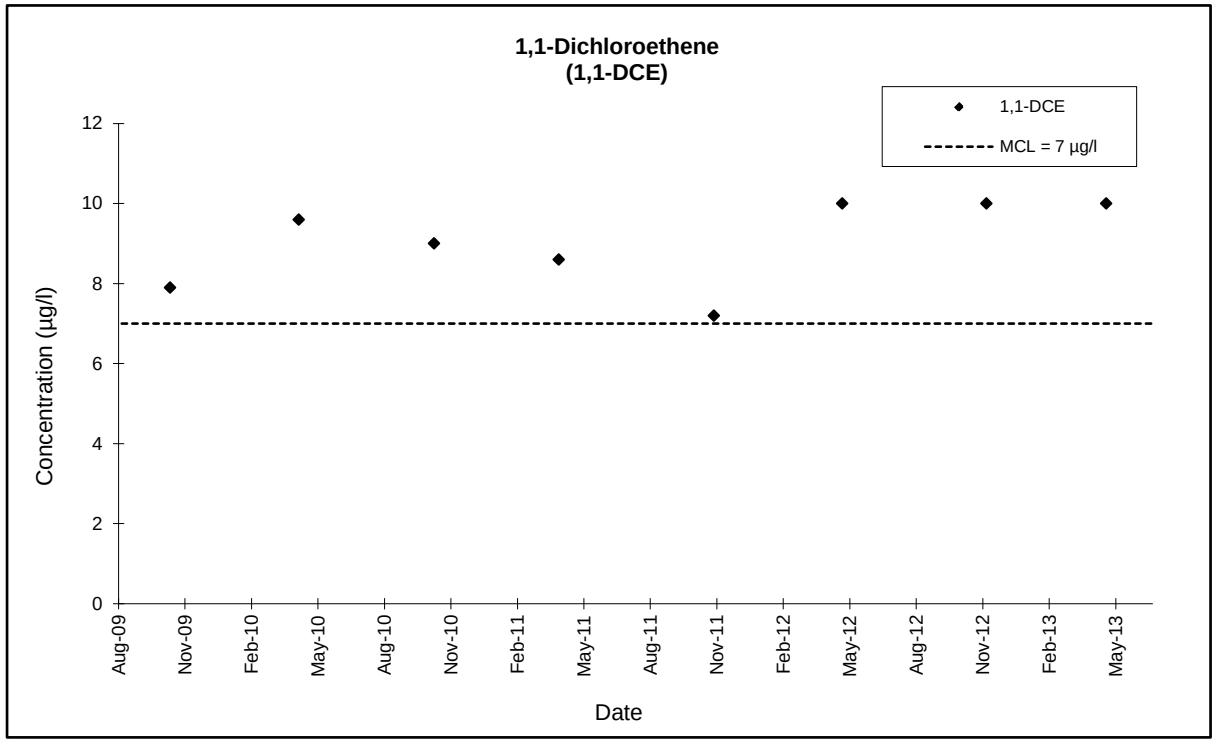
[b] VC was added as an analyte in January 2003 to aid in monitoring of natural attenuation at the site, and is not included in the Record of Decision as an indicator chemical.

[c] MW-30 was installed in October 2011, and has been sampled seven times to date.

µg/l	micrograms per liter
MCL	maximum contaminant level
NA	not applicable
ND	non-detect (constituent not detected by the laboratory instrument, but may be present at a value below the reporting limit)
PCE	tetrachloroethene
PCP	pentachlorophenol
T	Analyte was positively identified, but the reported concentration is estimated; reported concentration is less than the reporting limit but greater than the method detection limit.
TCE	trichloroethene
VC	vinyl chloride
1,1-DCE	1,1-dichloroethene

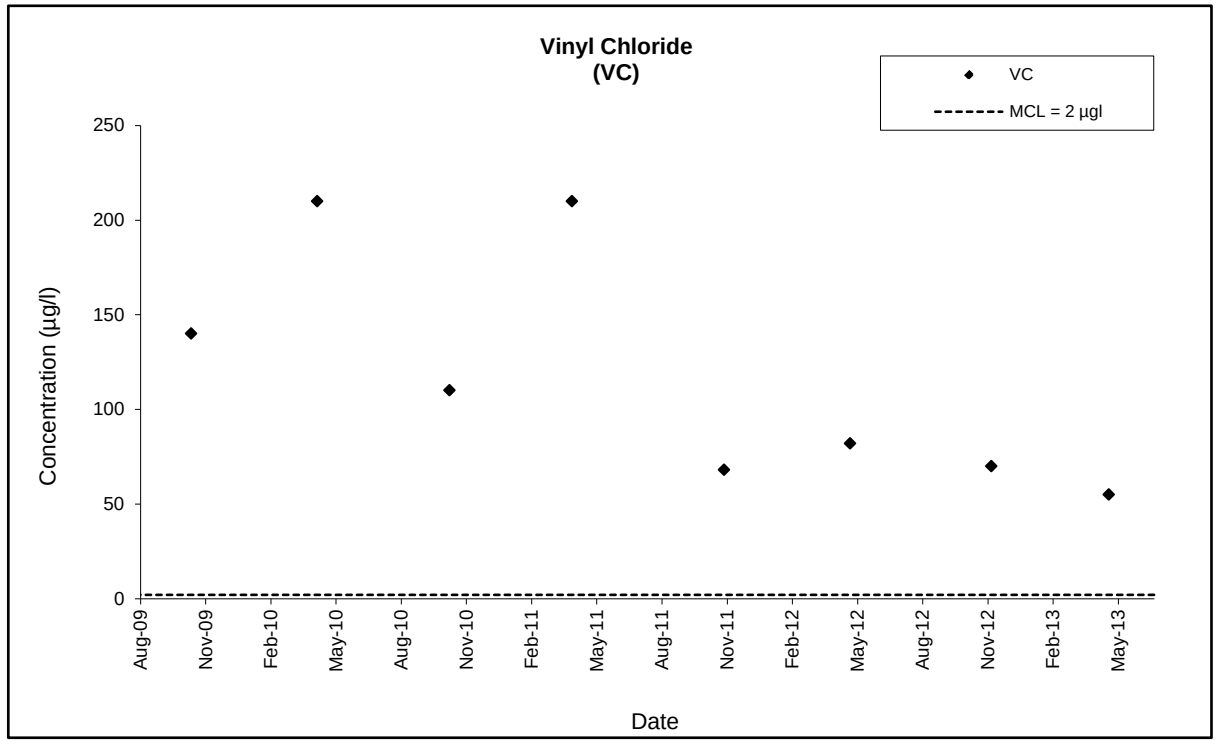
EXHIBIT B1-1
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL EX-02

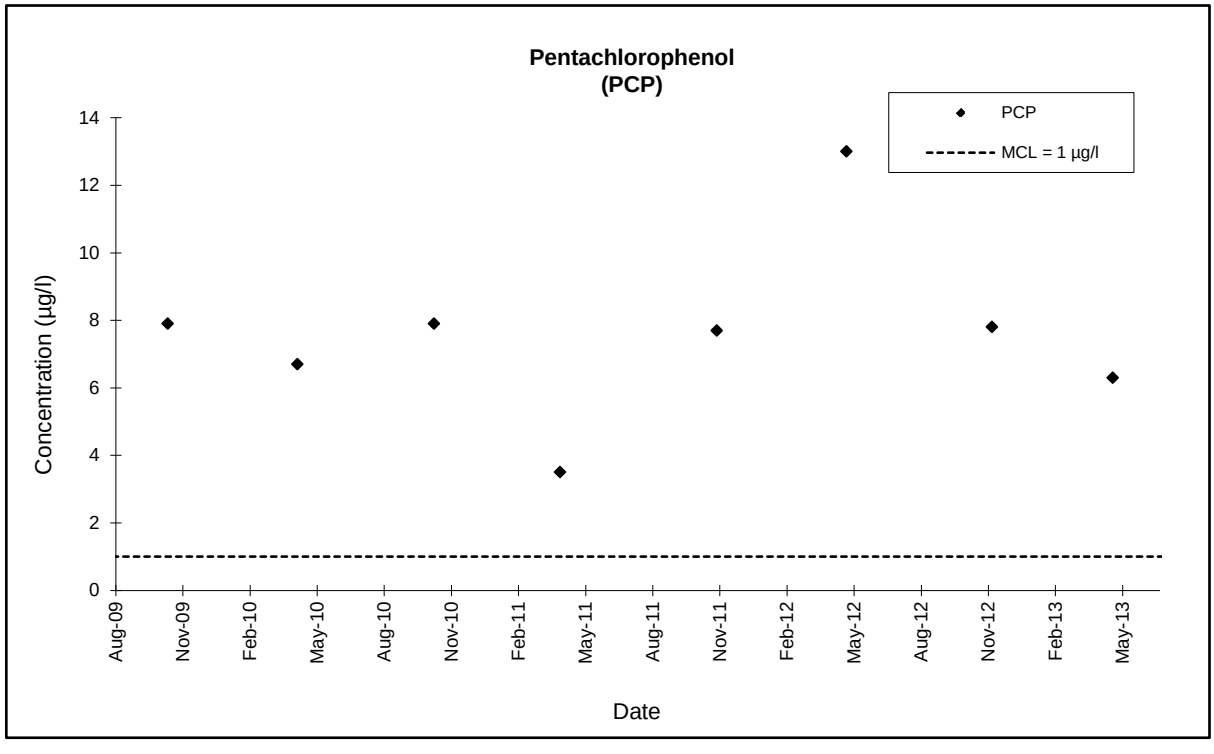




[(a)] Data for the eight most recent sampling rounds are shown.

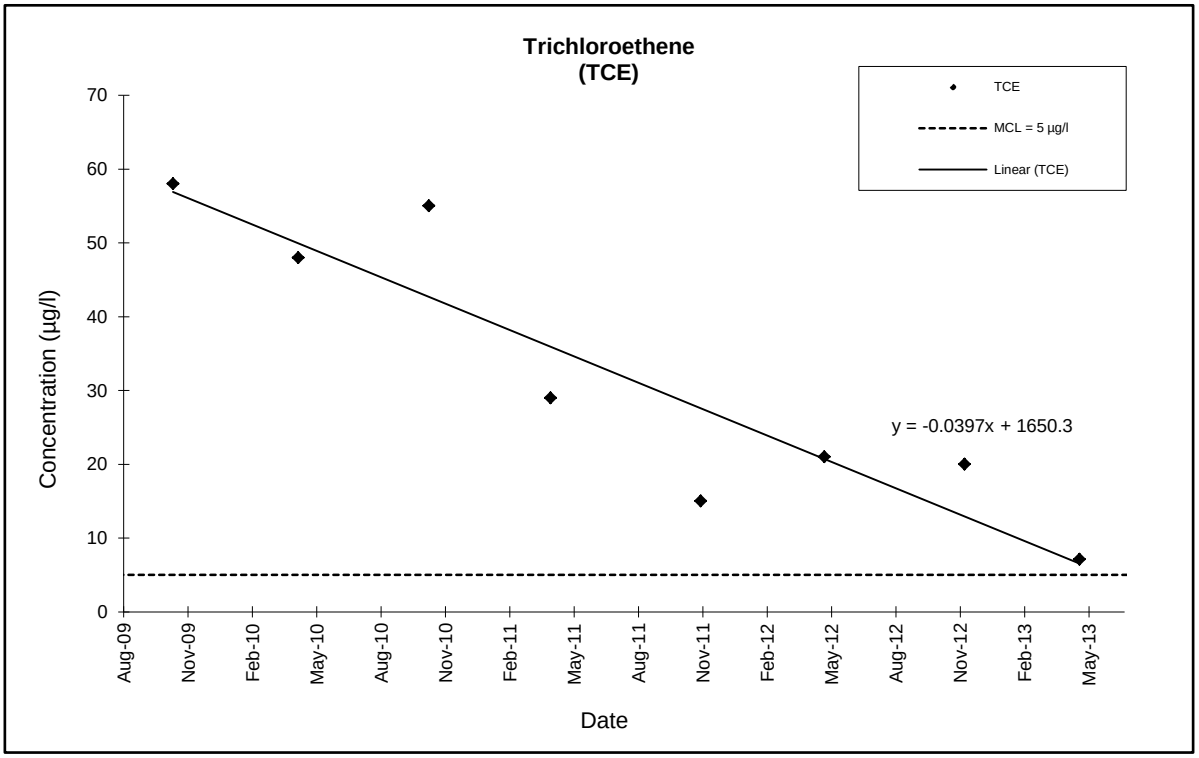
EXHIBIT B1-1
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL EX-02
(Page 2 of 2)

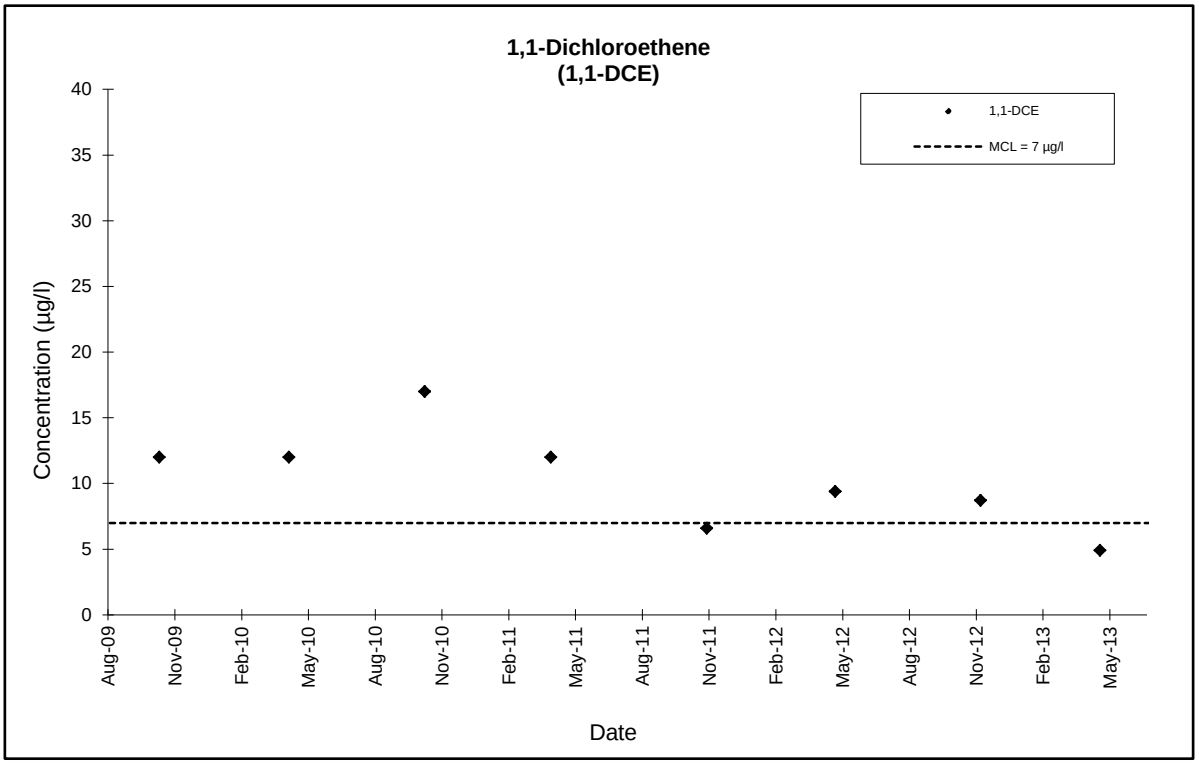




[(a)] Data for the eight most recent sampling rounds are shown.

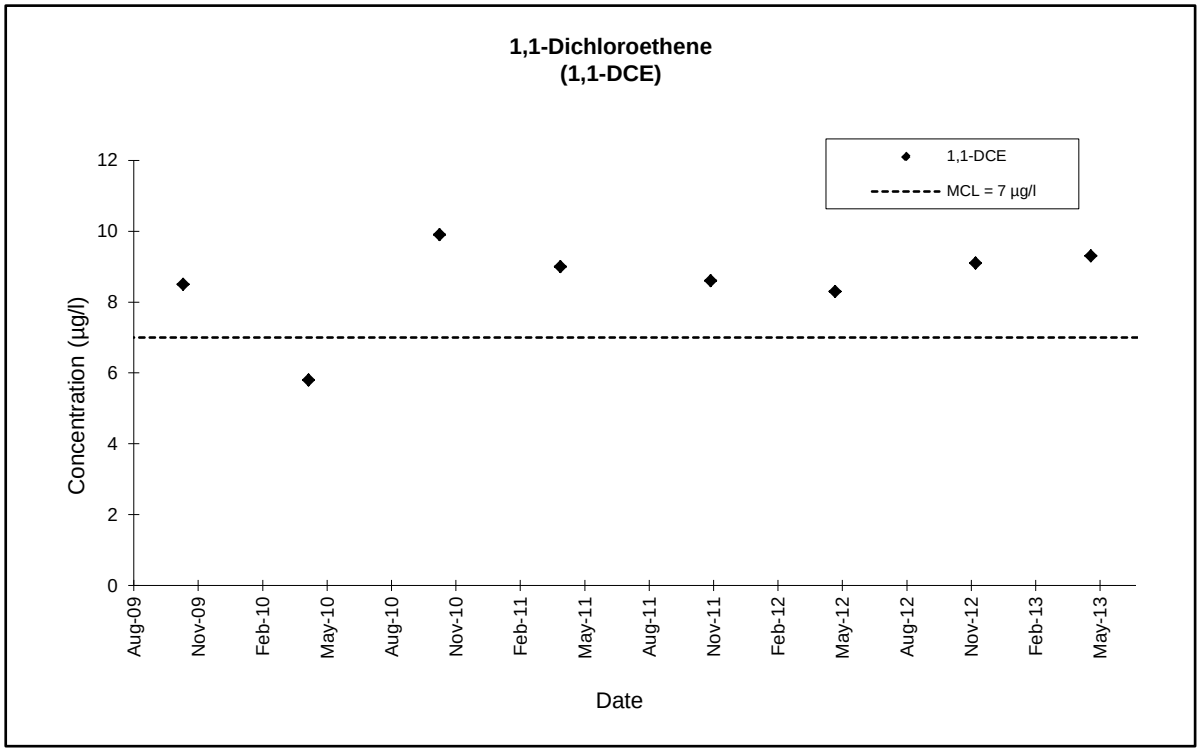
EXHIBIT B1-2
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL EX-04

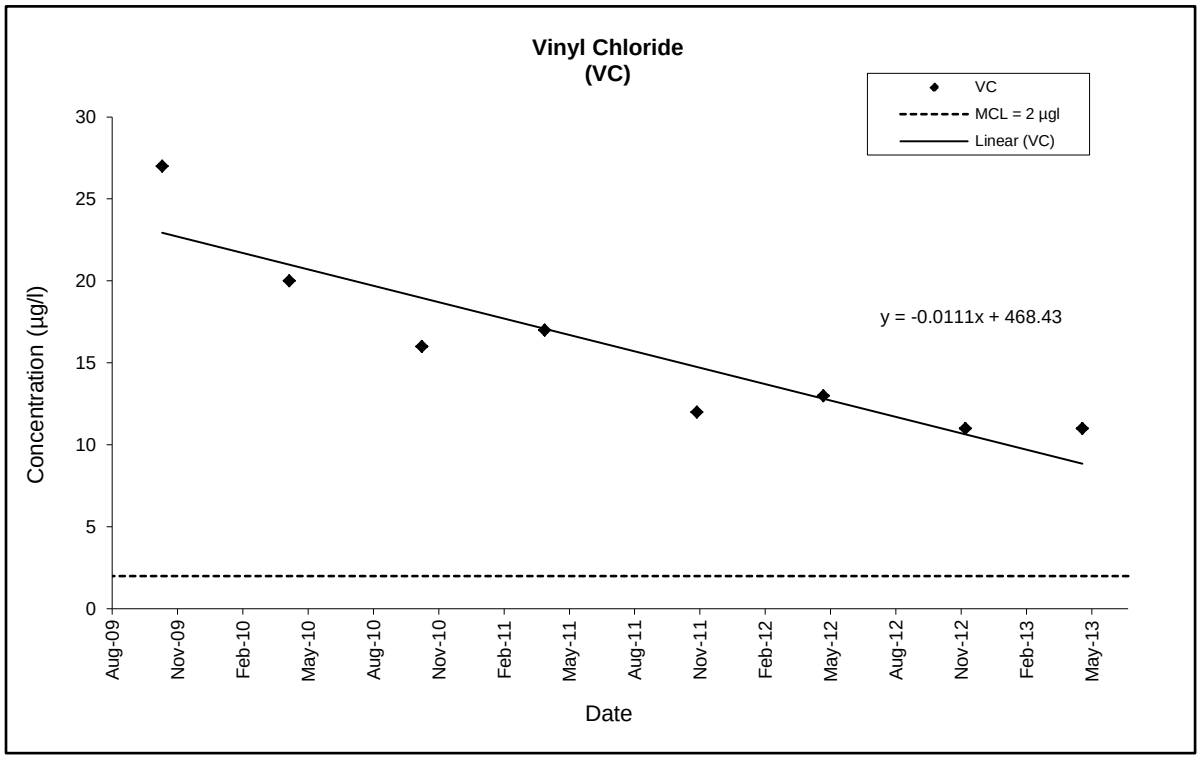




[(a)] Data for the eight most recent sampling rounds are shown.

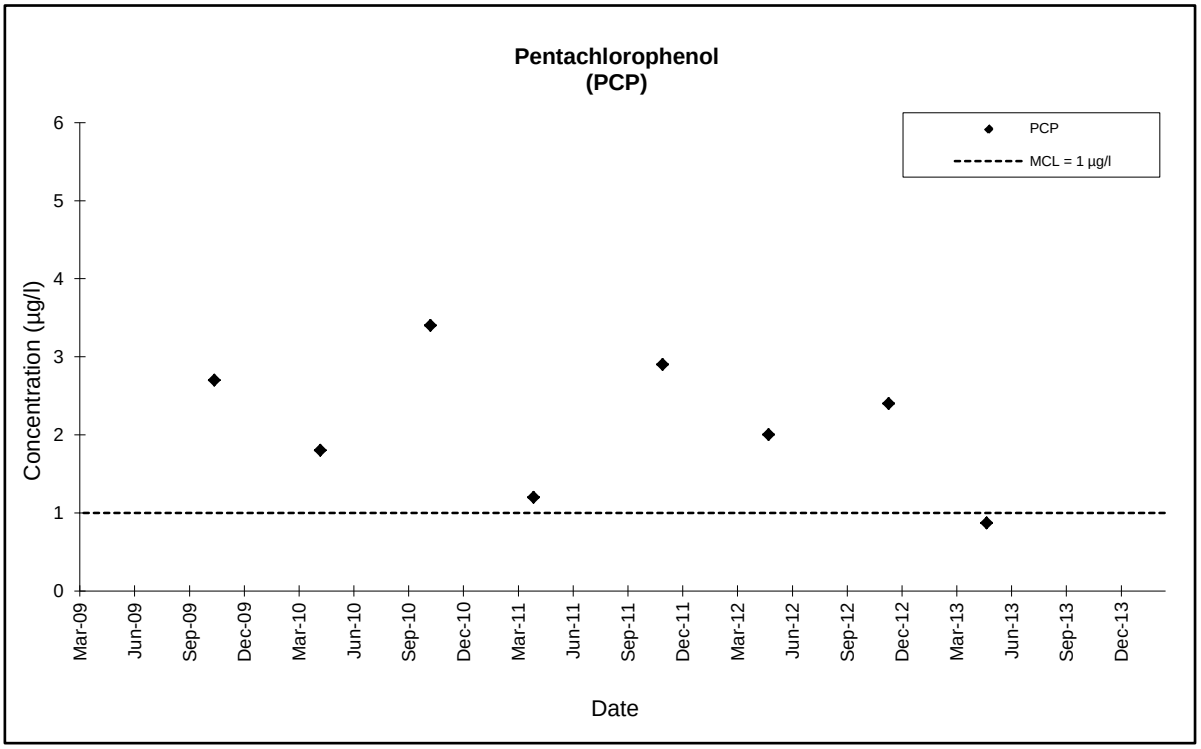
EXHIBIT B1-3
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL EX-05





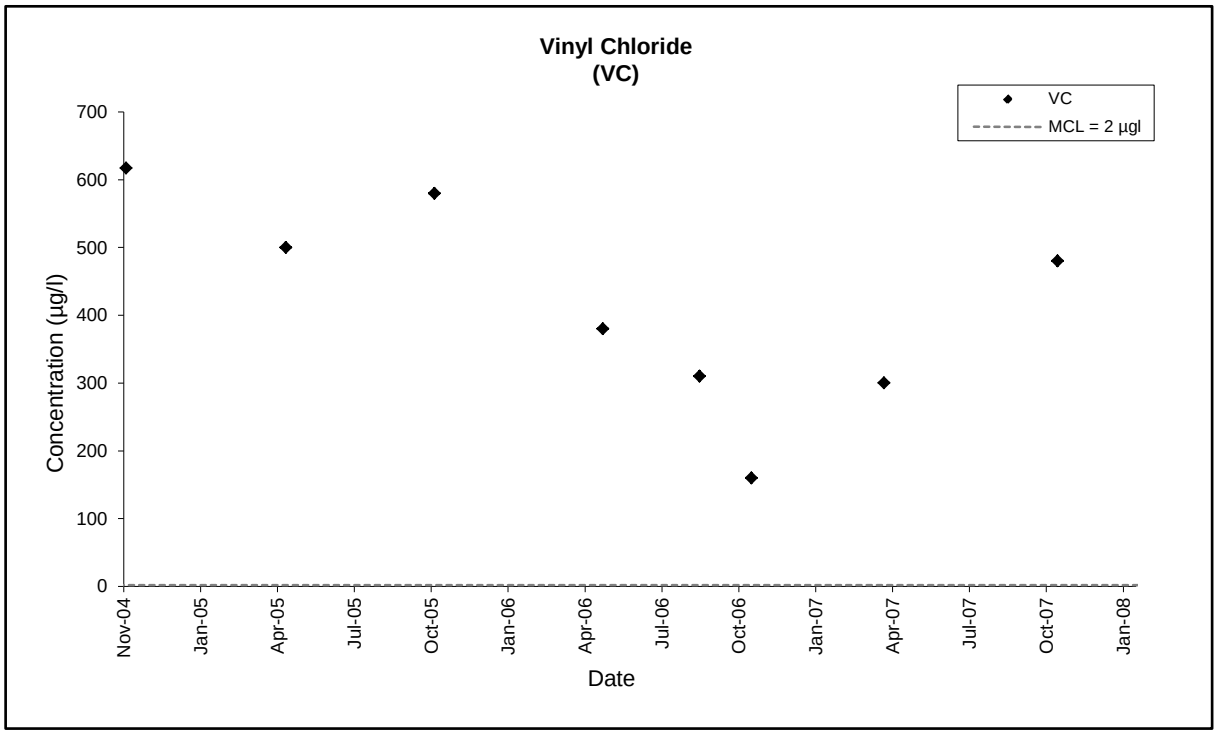
[(a)] Data for the eight most recent sampling rounds are shown.

EXHIBIT B1-4
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL EX-08



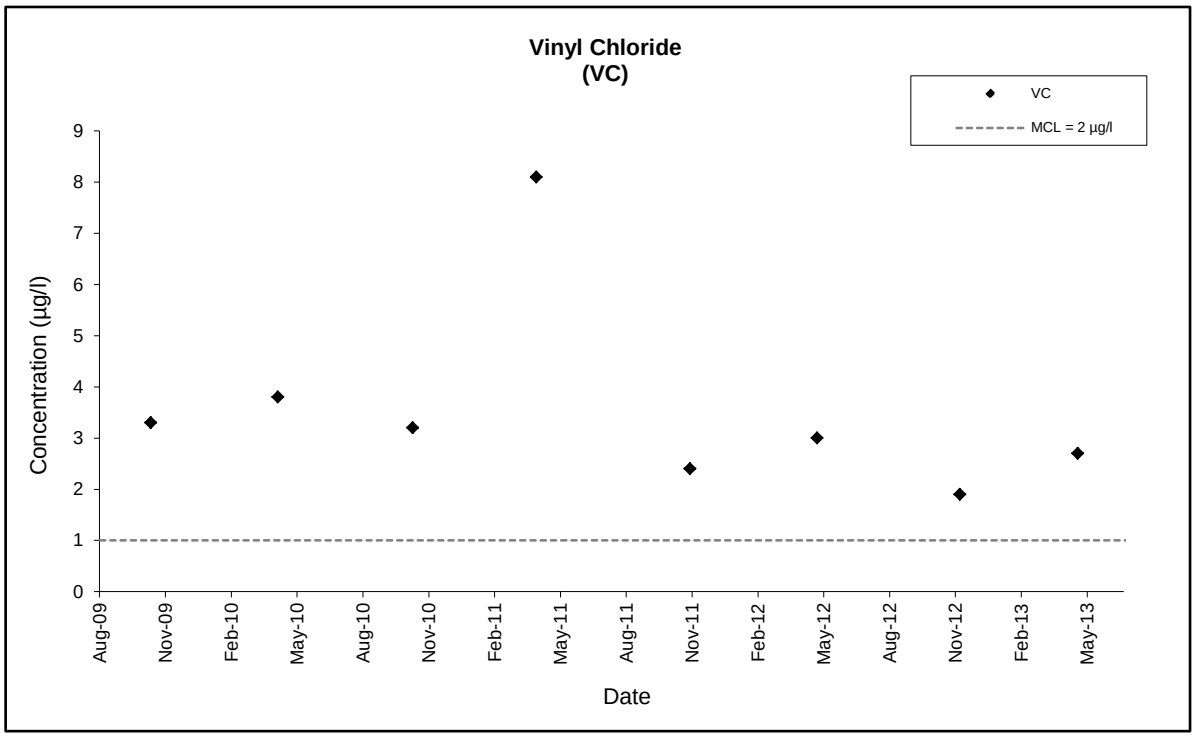
[(a)] Data for the eight most recent sampling rounds are shown.

EXHIBIT B1-5
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL EX-11



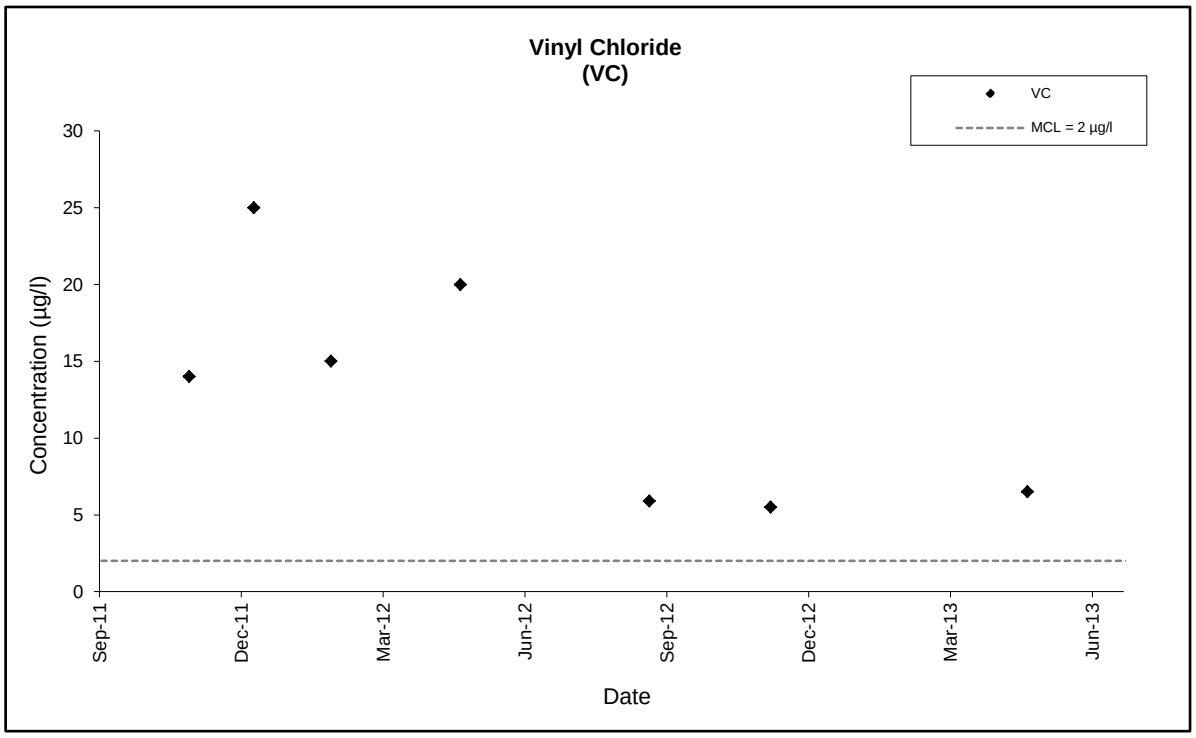
[(a)] Data for the eight most recent sampling rounds are shown.

EXHIBIT B1-6
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL MW-20



[(a)] Data for the eight most recent sampling rounds are shown.

EXHIBIT B1-7
WASATCH CHEMICAL SITE
TIME SERIES PLOTS[(a)] FOR INDICATOR CHEMICALS ABOVE MCLs
EXTRACTION WELL MW-30



[(a)] Data for the eight most recent sampling rounds are shown.

Section B2

Comprehensive Data and Historical Trends

EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01

Sample Date	LABORATORY PARAMETERS							
	PCE (µg/l)	TCE (µg/l)	1,1-DCE (µg/l)	cis-1,2-DCE (µg/l)	trans-1,2-DCE (µg/l)	VC (µg/l)	2,4-D (µg/l)	PCP (µg/l)
6-Nov-97	2200	890	270	--	--	--	260	4700
12-Feb-98	850 B	310 B	53	--	--	--	33	870 JG
19-May-98	1300	620	140	--	--	--	38	1100
12-Aug-98	2000	770	100	--	--	--	65	980
17-Nov-98	2000	690	87	--	--	--	48	1000
23-Feb-99	1600 J	750 J	82 J	--	--	--	30	670
26-May-99	1200	660	< 500 G	--	--	--	55	640
25-Aug-99	1200	410	33 T	--	--	--	35	240
17-Nov-99	1000	590	36 T	--	--	--	16	380
22-Feb-00	730	270	18 T	--	--	--	11.4	79
23-May-00	690	570	28 T	--	--	--	14.2	210
6-Oct-00	670 D	460 D	36 D	--	--	--	25 J	120 D
23-May-01	450 D	410 D	30 D	--	--	--	13	360 D
19-Nov-01	603 D	555 D	33 D	--	--	--	10	130
15-May-02	907 D	524 D	33 D	--	--	--	7.9	100
20-Nov-02	280 D	100 D	< 50 D	--	--	--	8.6	43 T
25-Feb-03	30	59	3.5	--	--	64	1.6	8 T
6-May-03	130 D	100 D	3 TD	--	--	31 D	1.7	1.3
12-Aug-03	5.7	14	2.2	--	--	505 D	< 0.5	0.3 TJ
5-Nov-03	4 TD	6 TD	< 10 D	--	--	51 D	< 2.4	0.07 TJ
14-May-04	80 DJ	106 D	9.7	--	--	80 D	--	21 D
3-Nov-04	18	19	0.7 T	--	--	6.1	--	3.2
10-May-05	< 50 D	35 TD	< 50 D	--	--	70 D	--	5.1 J
31-Oct-05	< 25 D	< 25 D	< 25 D	--	--	< 25 D	--	< 0.5
16-May-06	3.6	24	5.7	--	--	60 D	--	8 D
6-Nov-06	2	4.5	0.55 T	--	--	10 J-	--	< 0.5
9-Apr-07	23	39	1.9	--	--	11	--	1.5
29-Oct-07	1.4	2	< 1	--	--	2.4	--	0.11 T
28-Apr-08	13	62 D	6.1	--	--	85 D	--	16 D
14-Oct-08	1.2	2.4	< 1	--	--	1.6	--	< 0.5
7-Apr-09	70 D	150 D	10 J	210 D	1.8 J	75 D	--	42 TDJ
3-Nov-09	0.37 T	1.7	< 1	0.81 T	0.5 T	0.73 T	--	< 0.5
26-Apr-10	14	47	6.7	78	0.77 T	30 J	--	26 D
26-Oct-10	0.21 T	0.44 T	< 1	0.45 T	< 1	0.35 T	--	< 0.5
11-Apr-11	4.7	19	2.6	48	0.64 T	18	--	8.6 D
9-Nov-11	0.29 T	2.3	< 1	1.4	0.39 T	1.2	--	< 0.5
1-May-12	1.6	10	1.5	64	0.8 T	60 D	--	10 D
12-Nov-12	0.31 T	1.4	< 1	0.6 T	< 1	0.44 T	--	< 0.5
23-Apr-13	5	29	2.9	26	0.42 T	13	--	4 D

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01

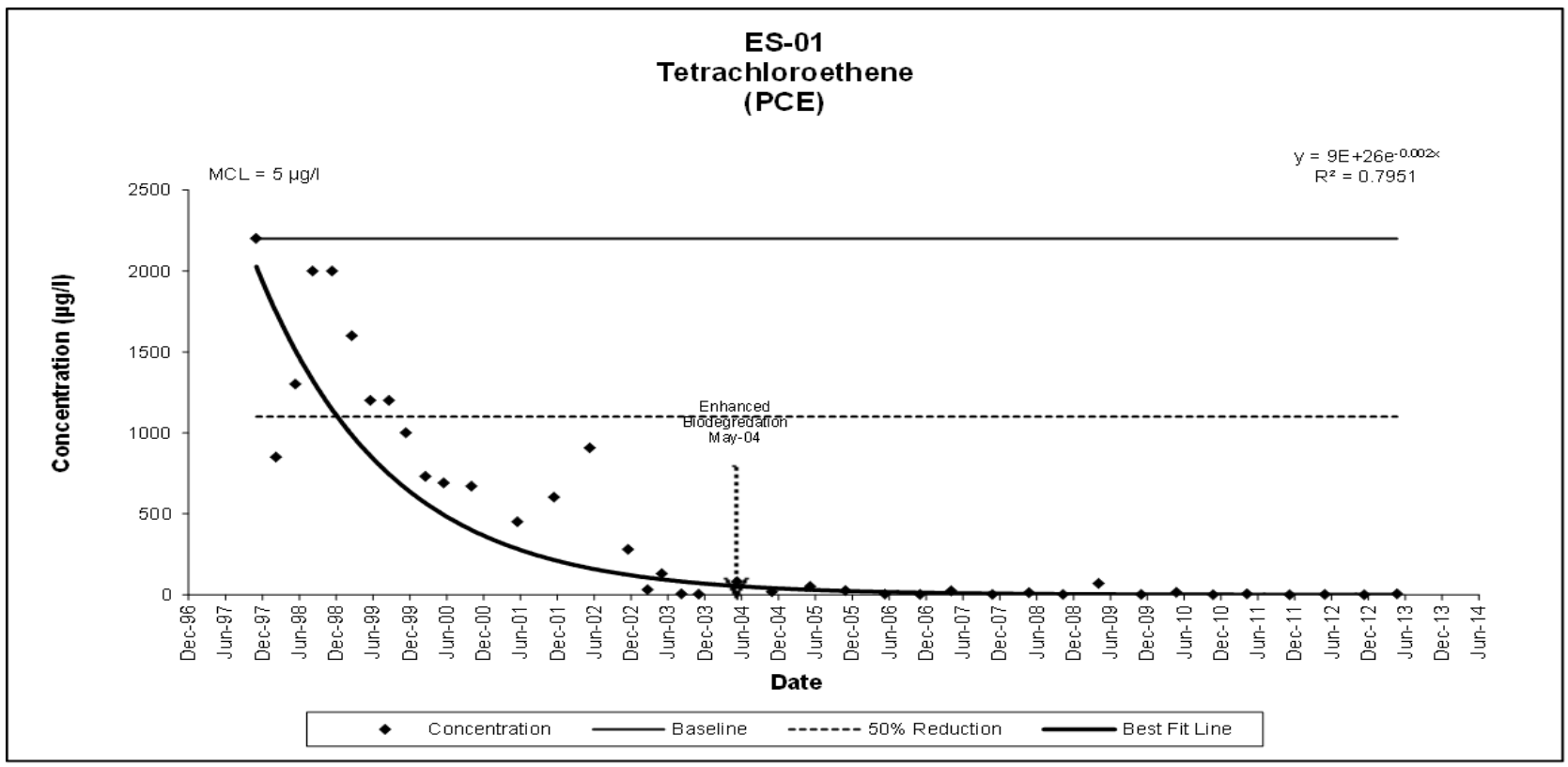
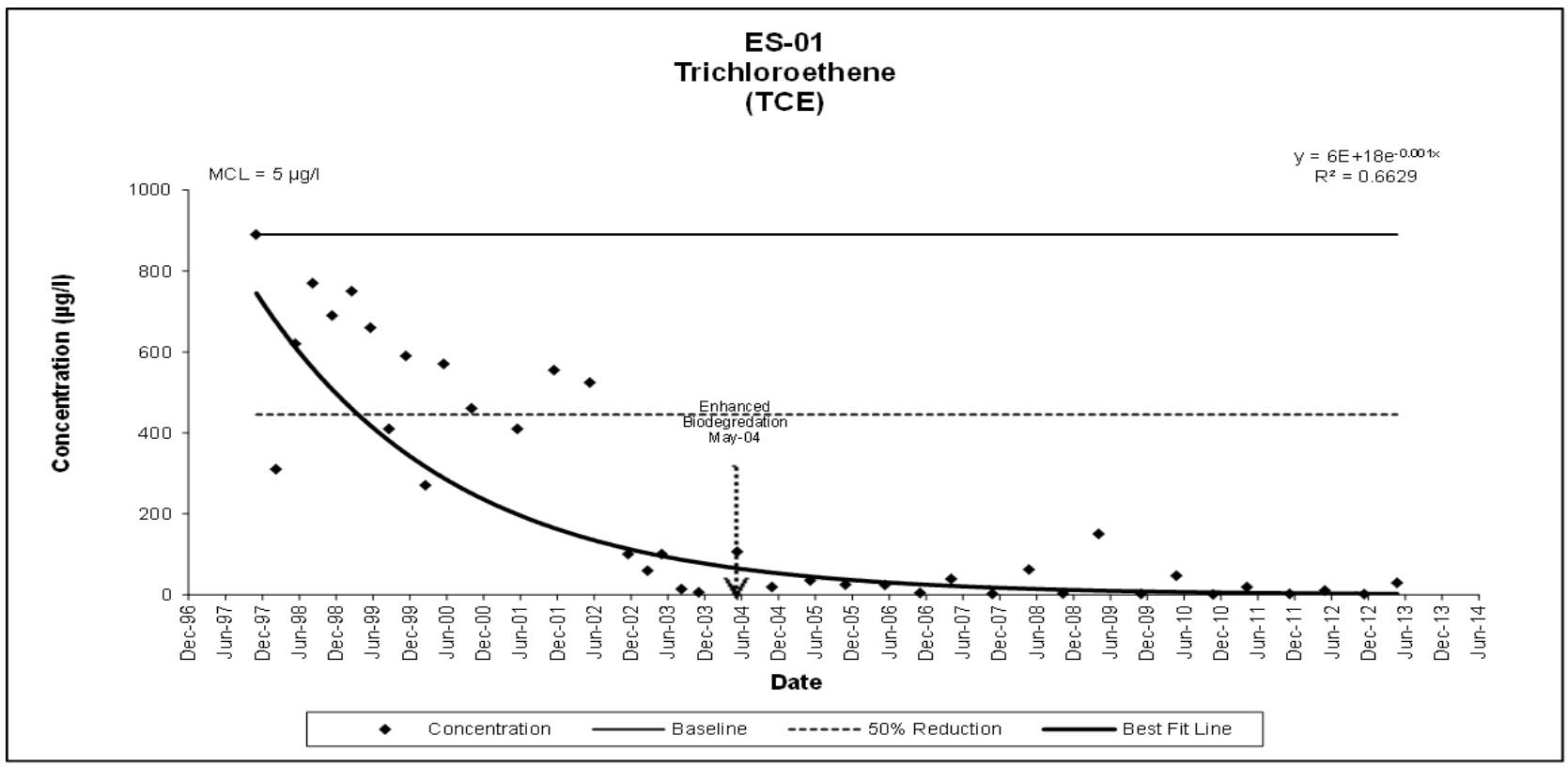


EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01



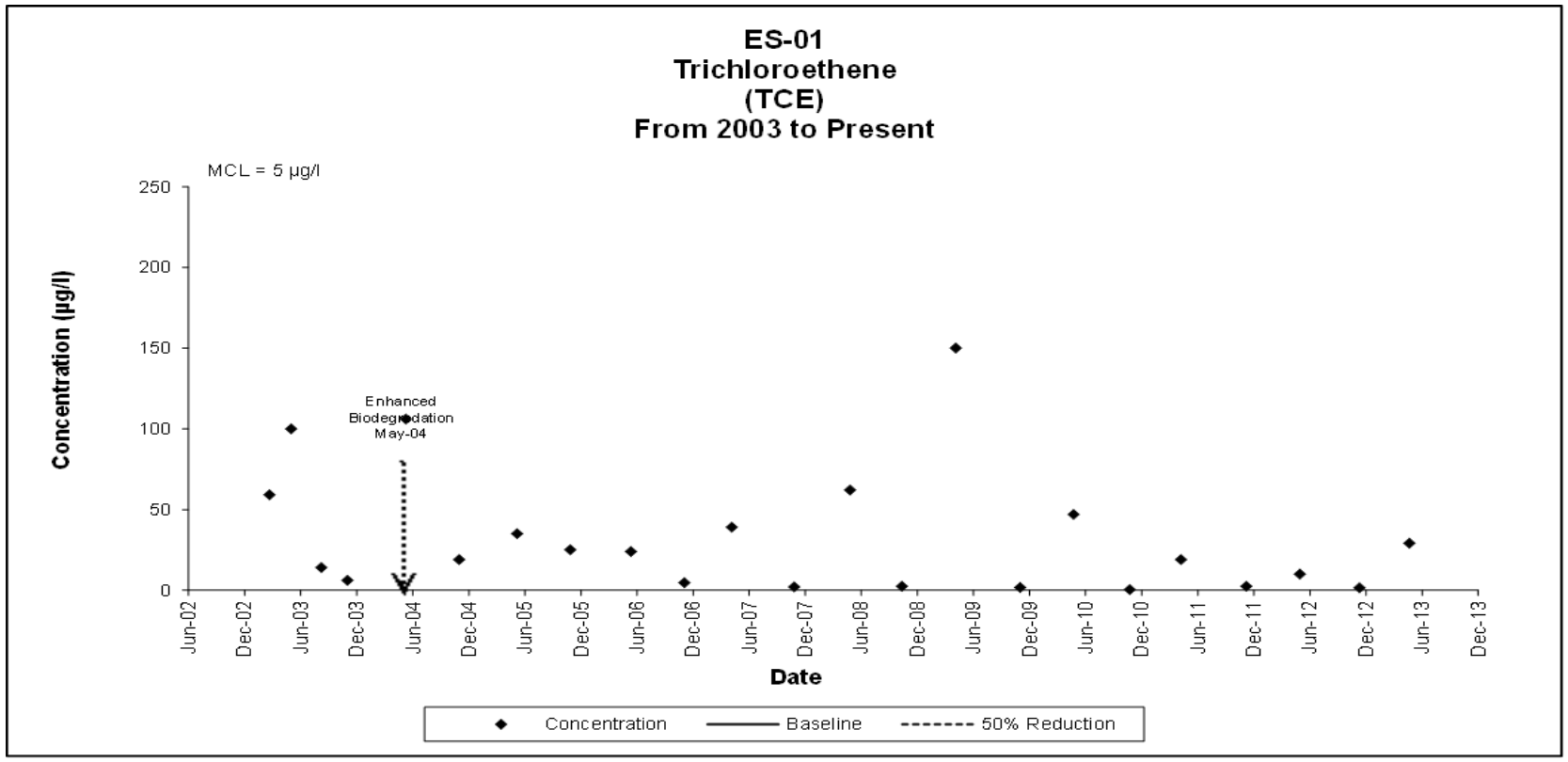
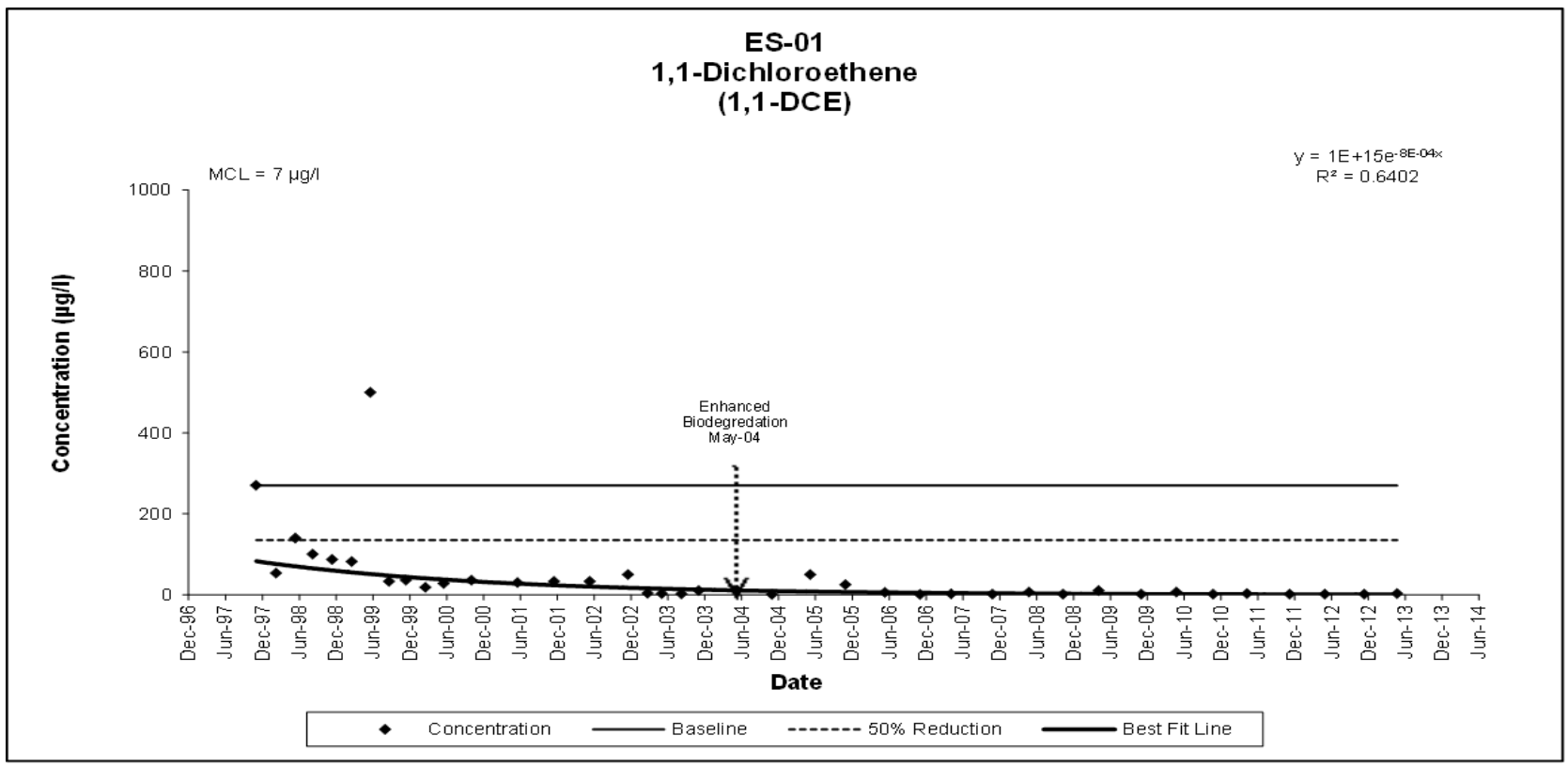


EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01



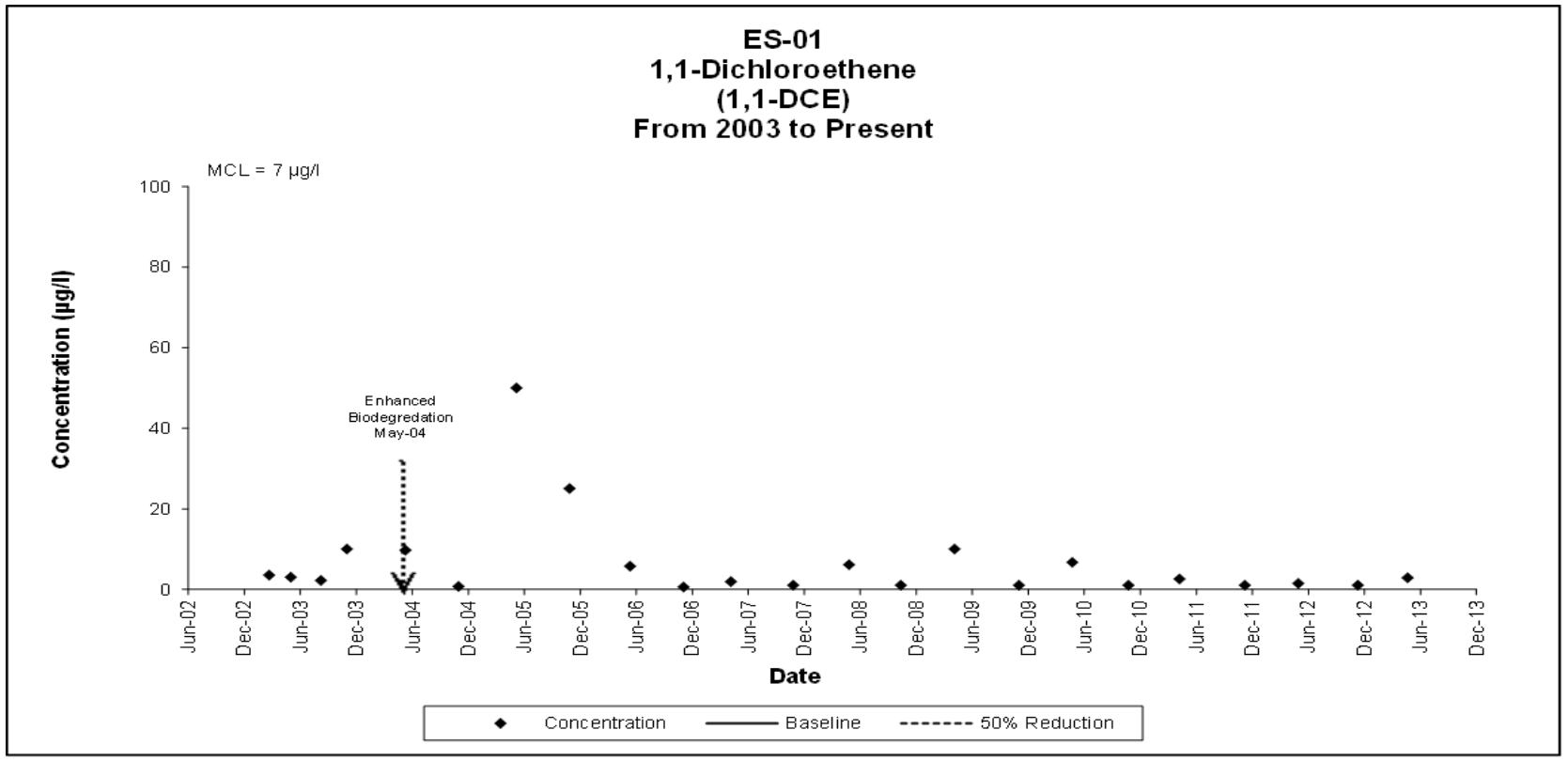
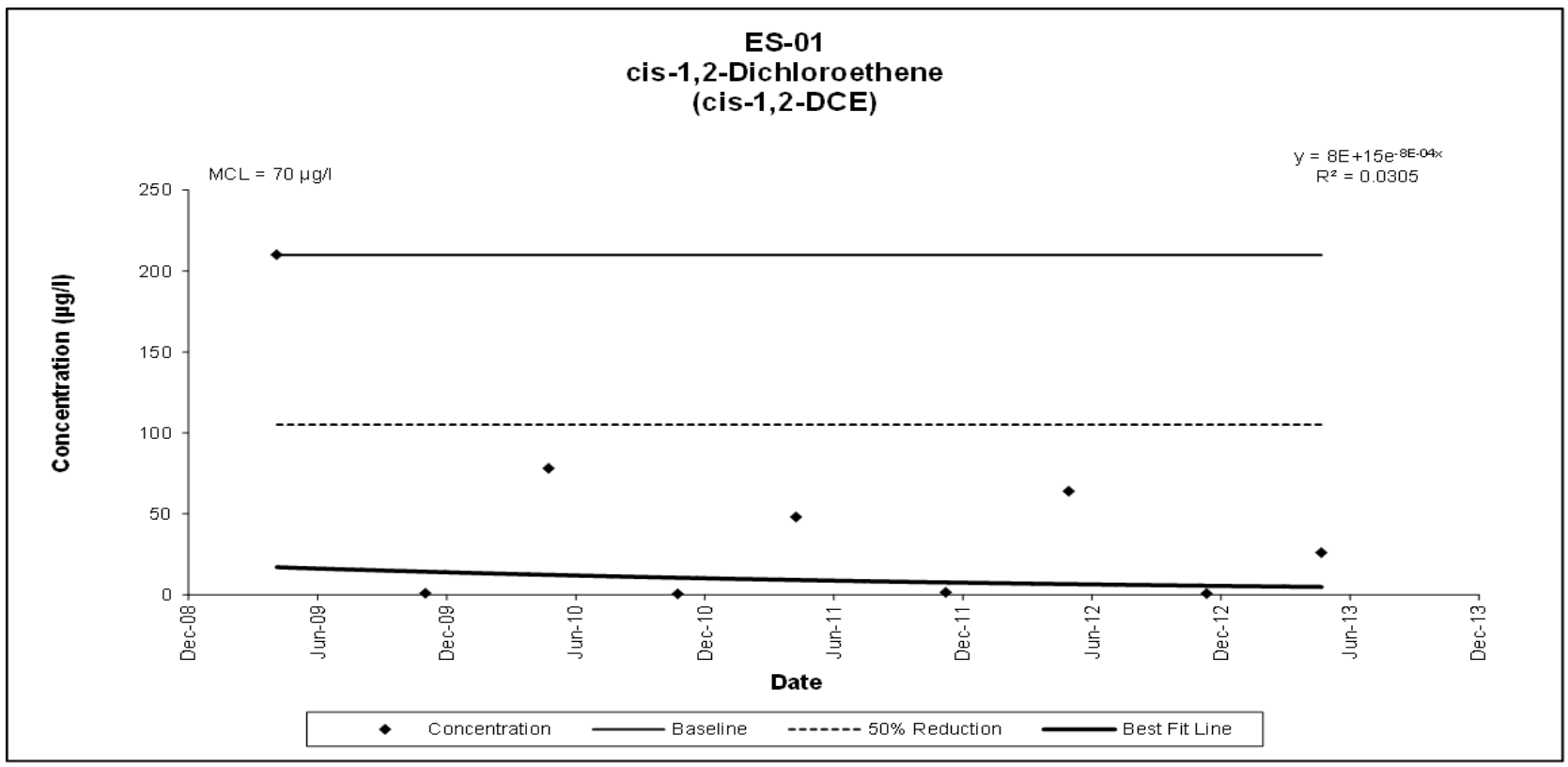


EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01



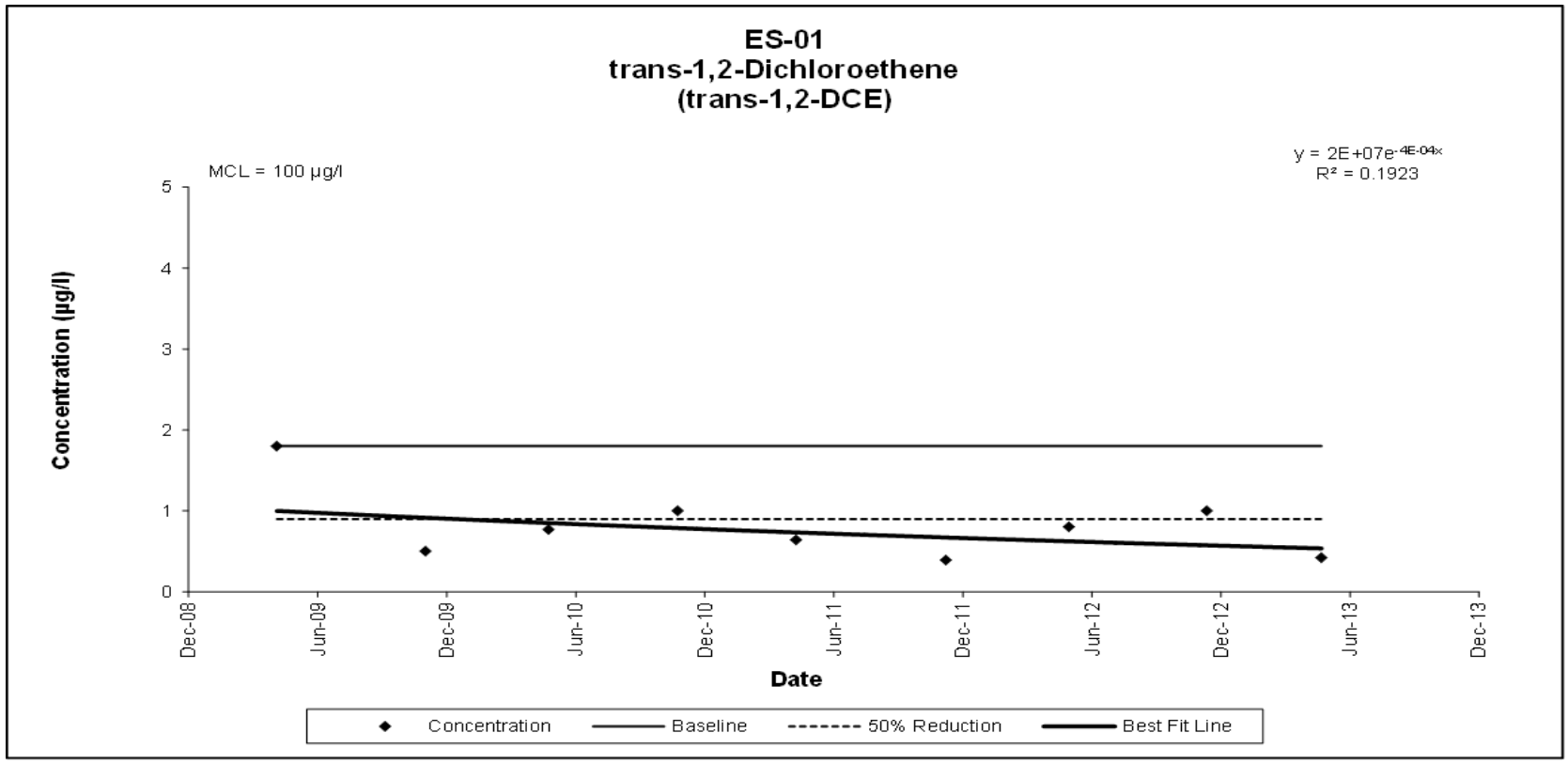
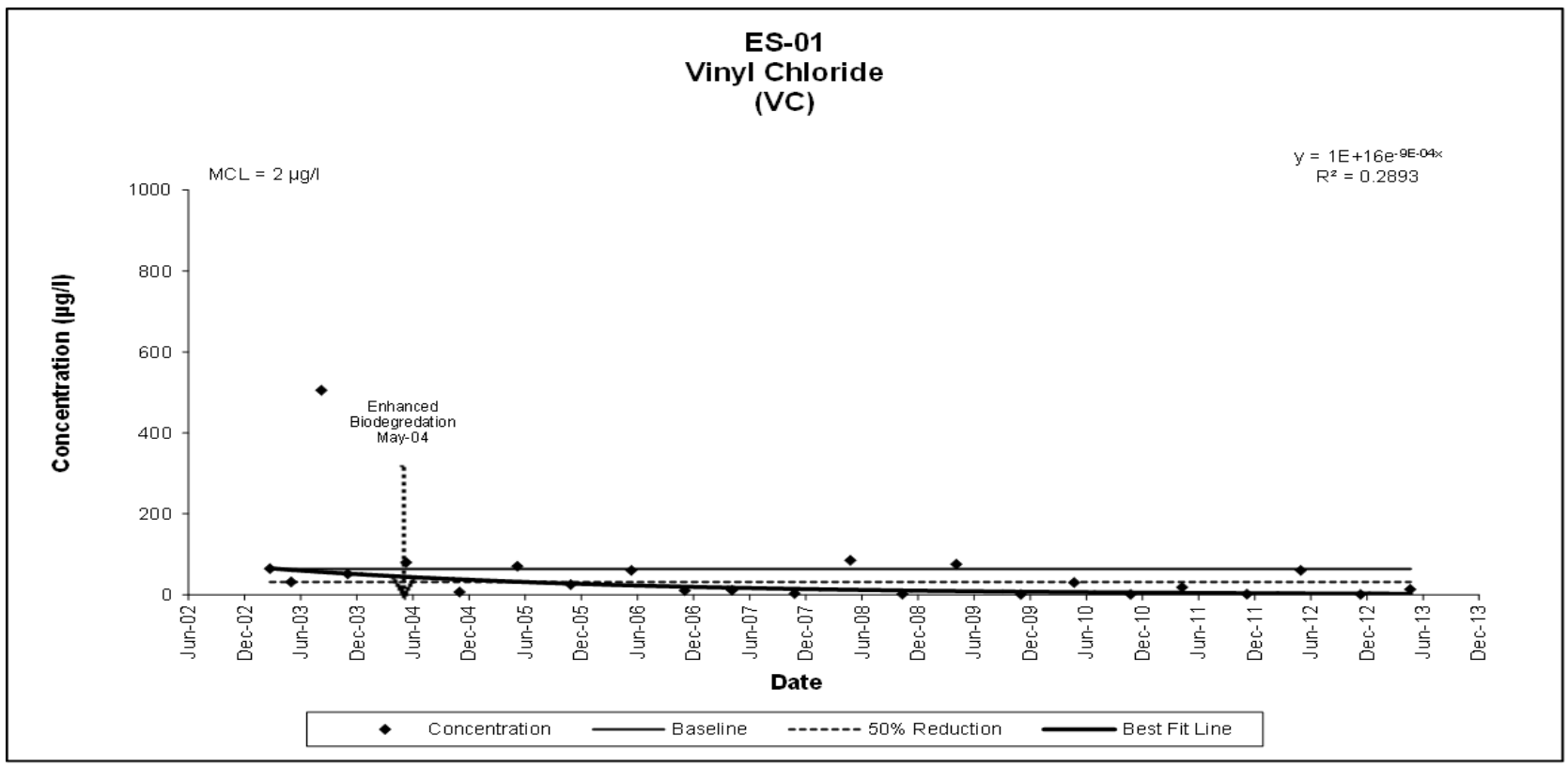


EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01



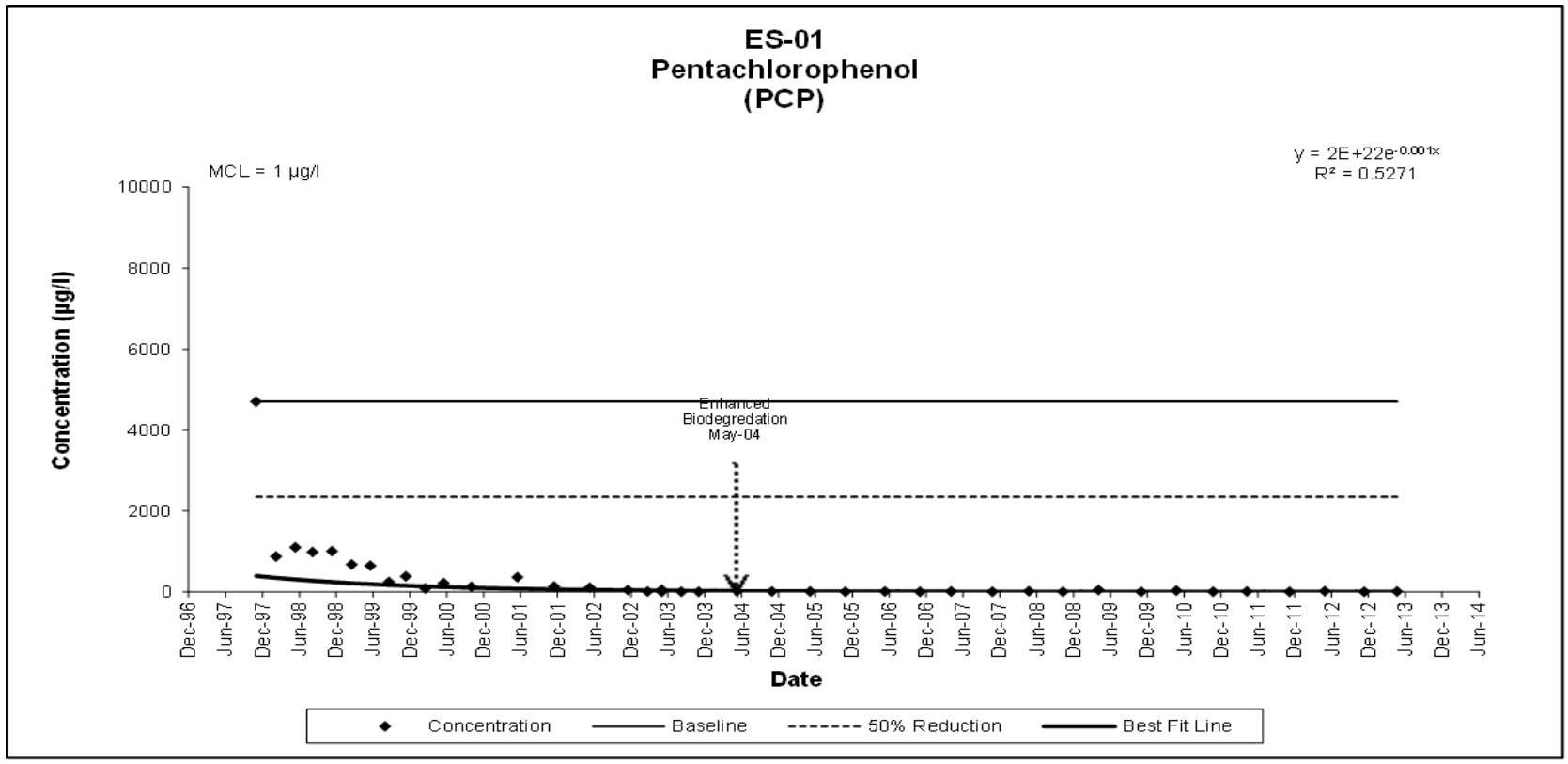


EXHIBIT B2-1
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL ES-01

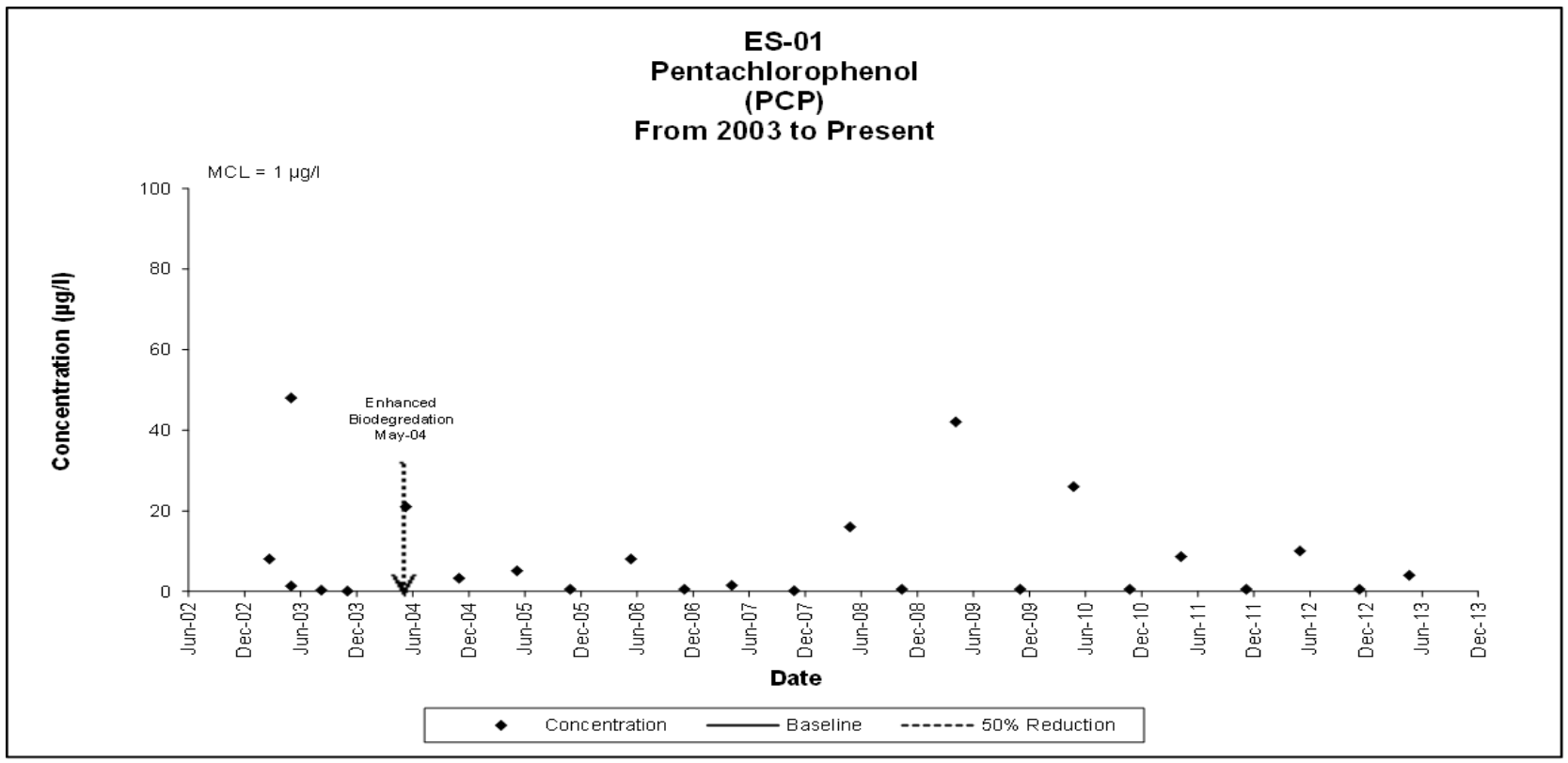


EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	4.8	220	27	--	--	--	3.73	139 J
6-Jul-95	8	360	35	--	--	--	< 2 J	< 400 J
27-Sep-95	11	1000	140	--	--	--	< 2	< 20
27-Dec-95	240 J	22 J	7.8 J	--	--	--	< 2	32
28-Mar-96	5.2	170	8.7	--	--	--	< 2	2.5
28-Aug-96	8.4	530	43	--	--	--	< 10	3.6 J
21-Nov-96	9.9 T	420	25	--	--	34	3.1 J	7 J
26-Feb-97	5.5	290	14	--	--	--	3.2	5.1
21-May-97	3.4 T	200	11	--	--	--	< 2.5 G	4.5
26-Aug-97	3	130	7.7	--	--	--	< 2.5 G	3.8 B
6-Nov-97	5.7 B	260	15	--	--	--	< 2.5 G	9.4 J
12-Feb-98	4 B	150 B	8.2	--	--	--	0.77 J	3.2
19-May-98	7.5	300	21	--	--	--	< 1.5 G	3.8
12-Aug-98	6.5	350	23	--	--	--	2.9 J	4.3 J
17-Nov-98	5.7	330	26 J	--	--	--	< 2.5 G	4.3
24-Feb-99	6.2 JB	260 J	15 J	--	--	--	3.9	6.1
26-May-99	< 12 G	190	12	--	--	--	< 4 UJ	9.2
25-Aug-99	< 25 G	440	14 T	--	--	--	1.94	12.1
17-Nov-99	4.6 T	130	8.1	--	--	--	< 0.2	9.48 J
22-Feb-00	2.1 T	89	5.2	--	--	--	1.01	10.1
24-May-00	2.8 T	54	3.1 T	--	--	--	1.36 J	5.08 J
23-Aug-00	0.83 D	0.34 D	0.58 D	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	< 0.5	8.59 J
23-May-01	1	61	4.2	--	--	--	< 0.5	3.3
19-Nov-01	6.2 D	99 D	11 D	--	--	--	< 0.5	0.8
15-May-02	2.6	114 D	11	--	--	--	< 0.5	2.1
20-Nov-02	3.9	83 D	8.2	--	--	--	< 0.48	0.4 T
25-Feb-03	1	127	12	--	--	74	< 0.48	1.1
6-May-03	2 TD	145 D	12 D	--	--	78 D	< 0.5	1.1
12-Aug-03	2	136 D	10	--	--	48	< 0.5	1.8
6-Nov-03	2	197 D	16	--	--	74 D	< 2.4	1.1
14-May-04	3	390 D	32	--	--	201 D	--	0.7 B
3-Nov-04	2 TD	181 D	14 D	--	--	80 D	--	2.0 J
10-May-05	4 TD	251 D	20 D	--	--	110 D	--	< 0.5 UJ
31-Oct-05	3.7	201 D	15	--	--	87 D	--	1.1 JJJ
16-May-06	5.7	200 D	14	--	--	65 D	--	2.4 D
6-Sep-06	3.1	170 D	14	--	--	82 D	--	--
6-Nov-06	2.5	190 D	14	--	--	95 D	--	0.39 T
10-Apr-07	2.1	130 D	14	--	--	120 D	--	3 D
30-Oct-07	0.62 T	120 D	11	--	--	170 DJ	--	1.5
30-Apr-08	--	--	--	--	--	--	--	1
13-May-08	1	200 D	12	--	--	180 D	--	2
14-Oct-08	1	140 D	12	--	--	180 D	--	--
7-Apr-09	0.81 T	140 D	13	96 D	11	220 D	--	8.3 D
3-Nov-09	0.51 T	99 D	7.9	73 D	7.6	140 D	--	7.9 D
26-Apr-10	0.89 T	130 D	9.6	94	11	210 D	--	6.7 D
26-Oct-10	0.39 T	110 D	9	100 D	11	110 D	--	7.9 D
13-Apr-11	0.35 T	120 D	8.6	84	11	210 D	--	3.5 D
9-Nov-11	0.23 T	74	7.2	110 D	8.8	68	--	7.7 D
1-May-12	0.37 T	130 D	10	170 D	8.6	82 D	--	13 D
12-Nov-12	0.21 T	85	10	220 D	11	70	--	7.8 D
23-Apr-13	0.87 T	300 D	10	320 D	8.3	55 D	--	6.3 D

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02

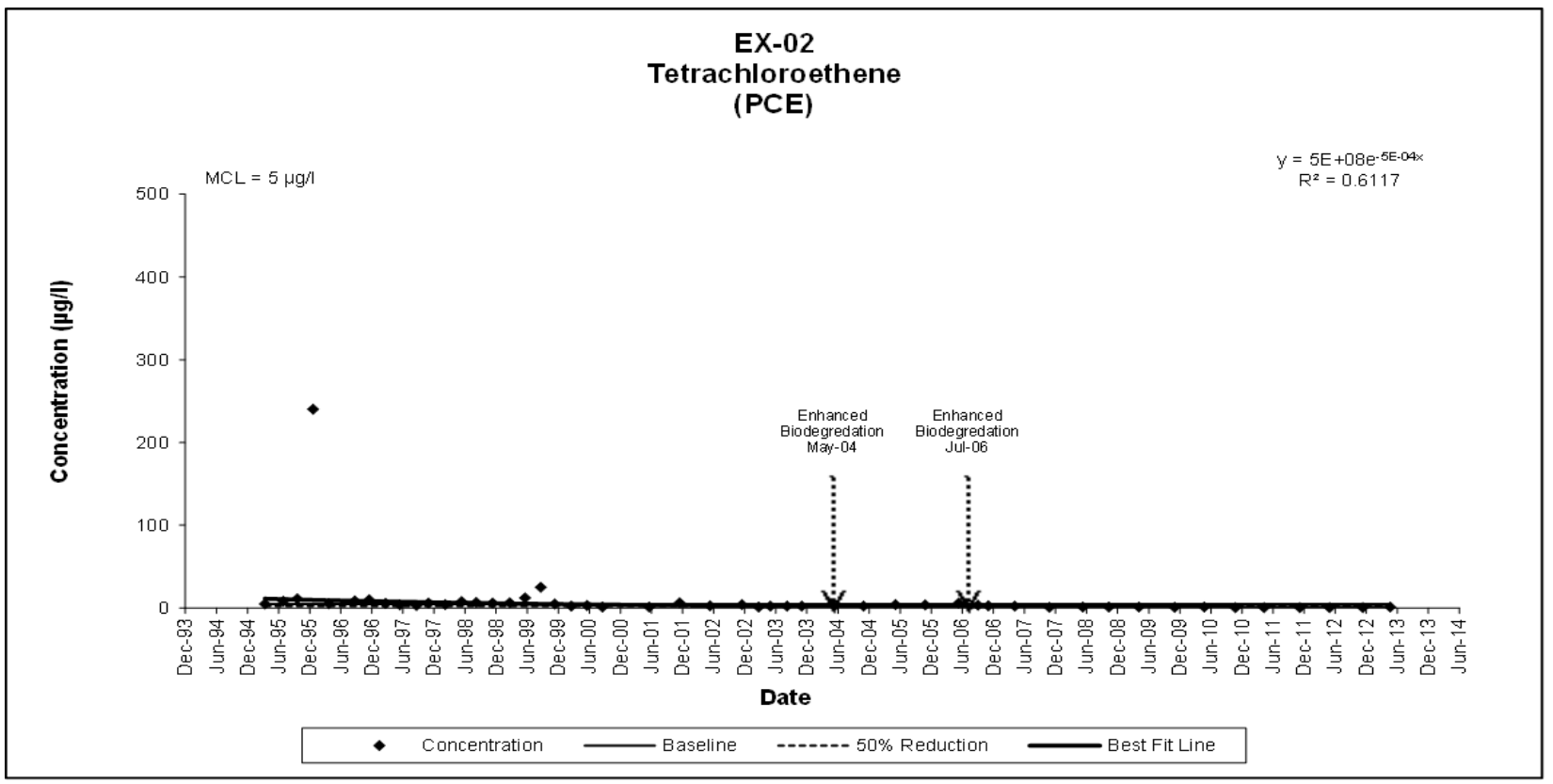


EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02

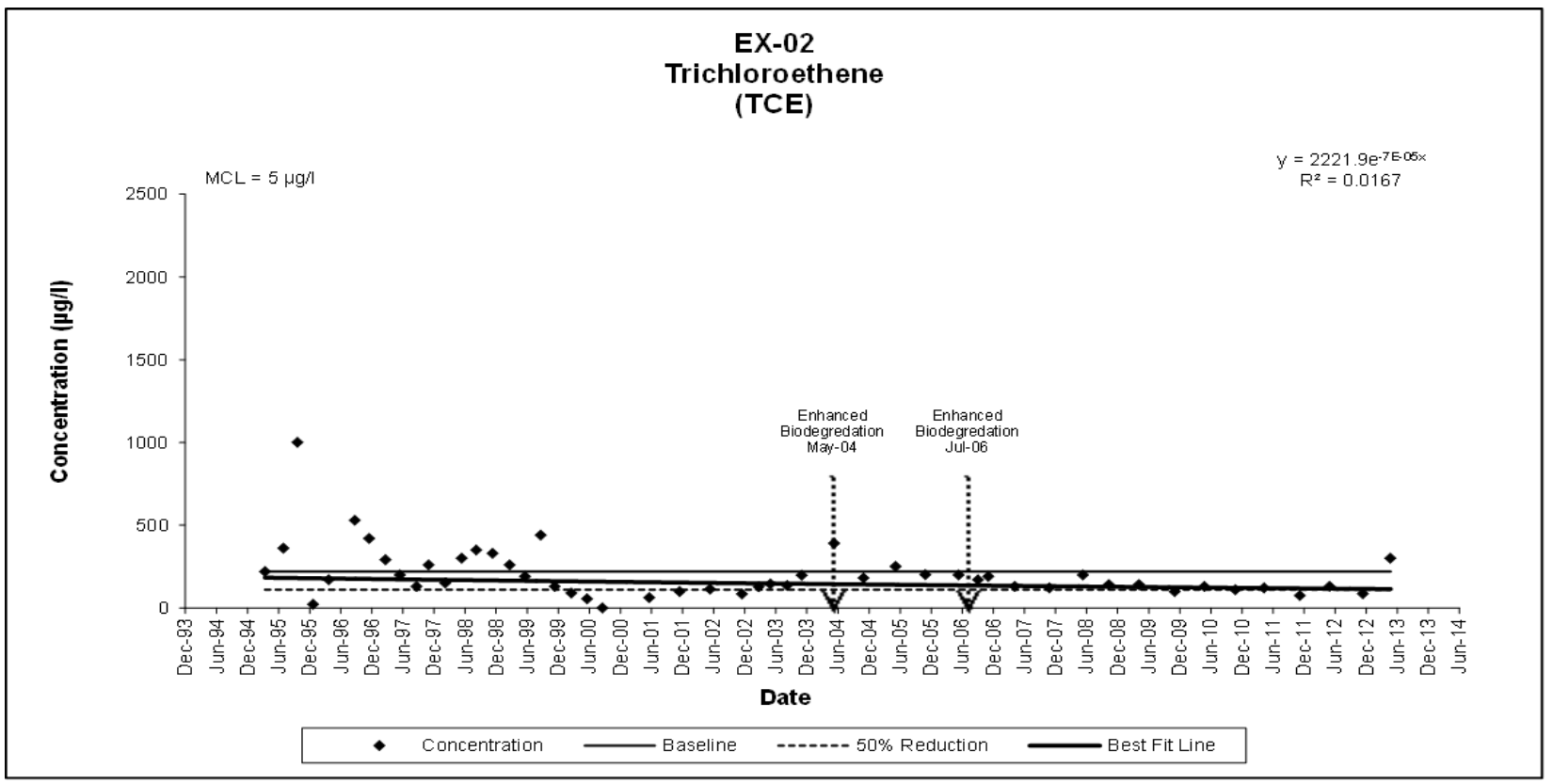
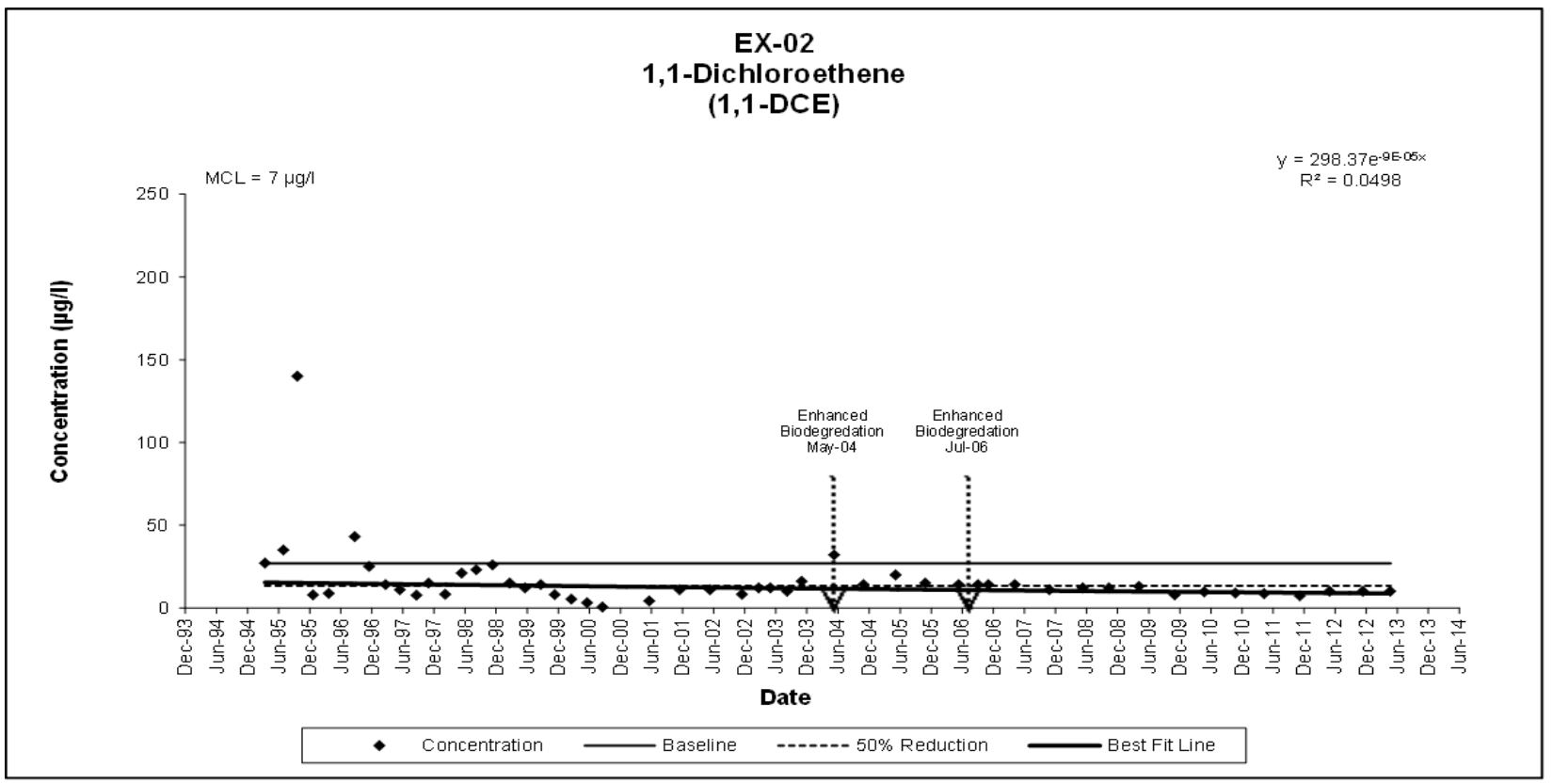


EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02



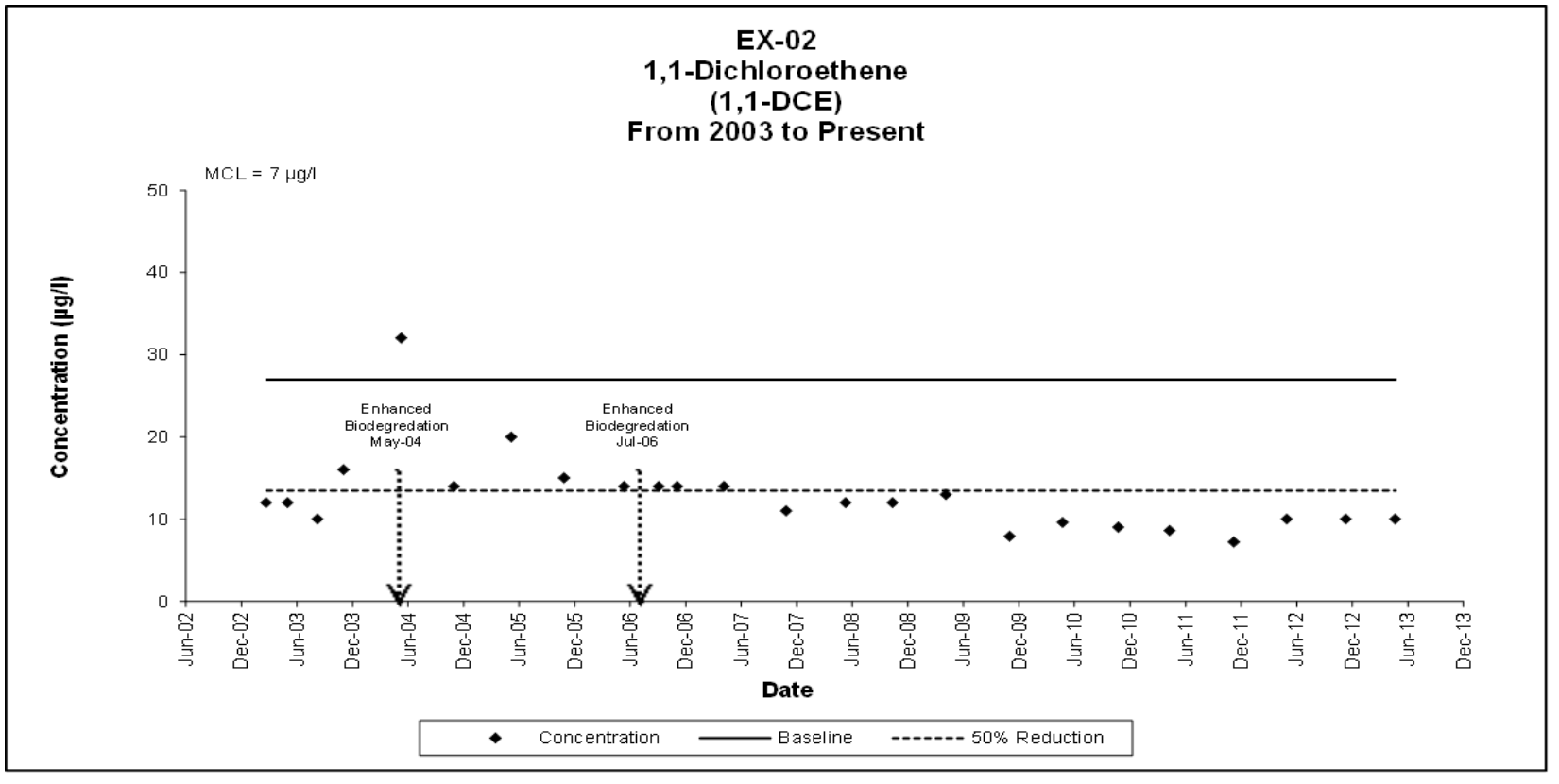
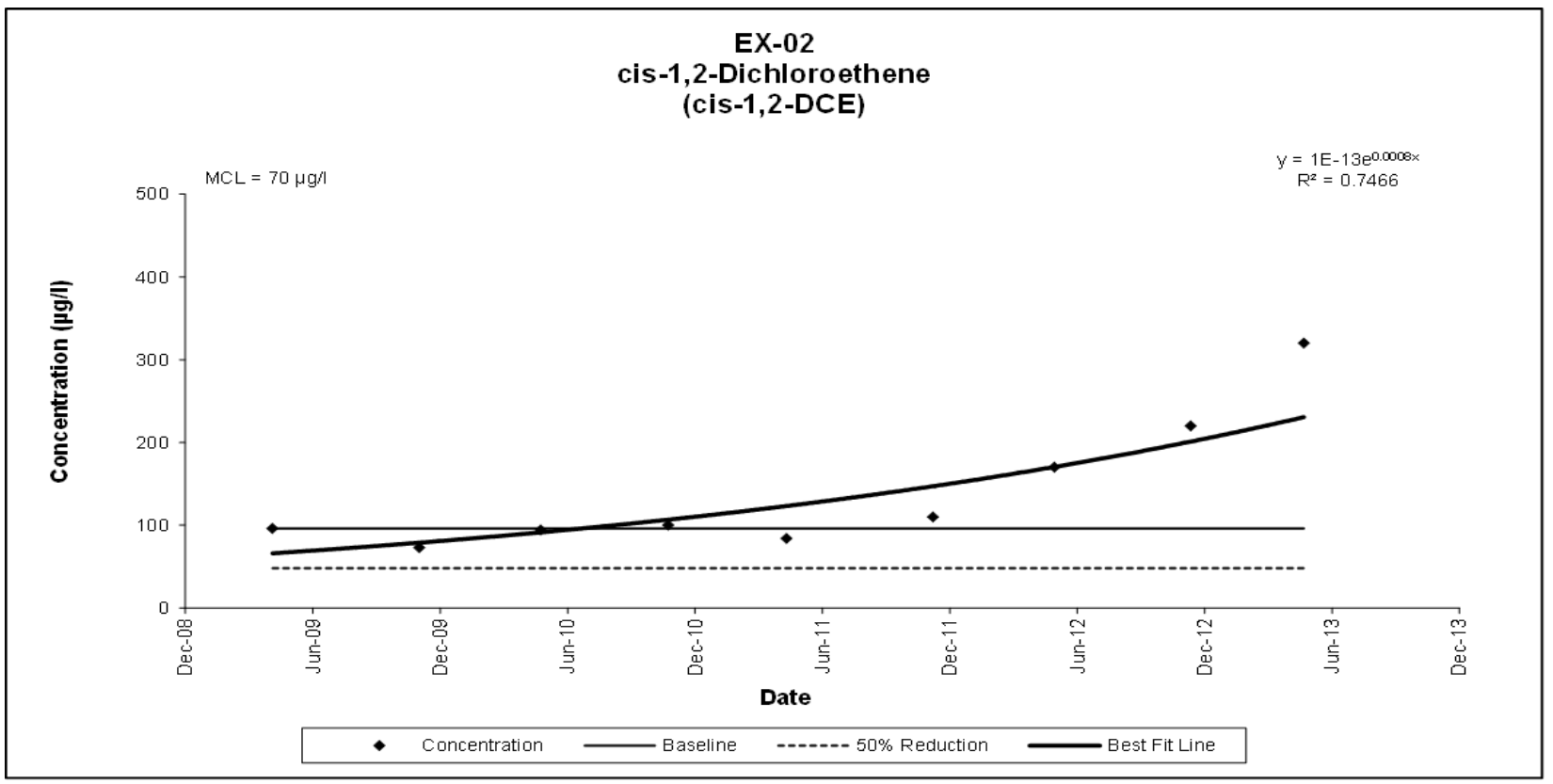


EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02



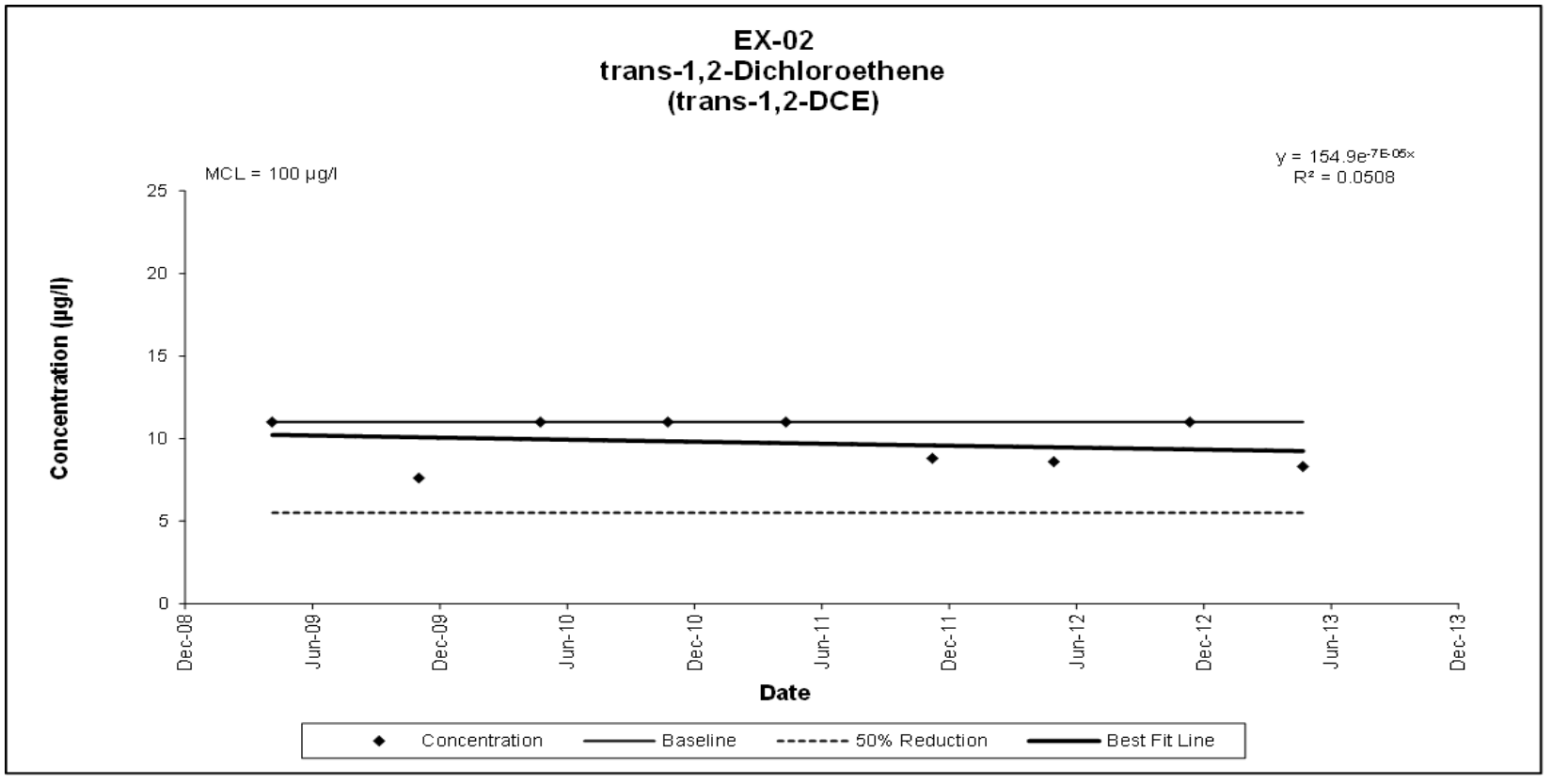


EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02

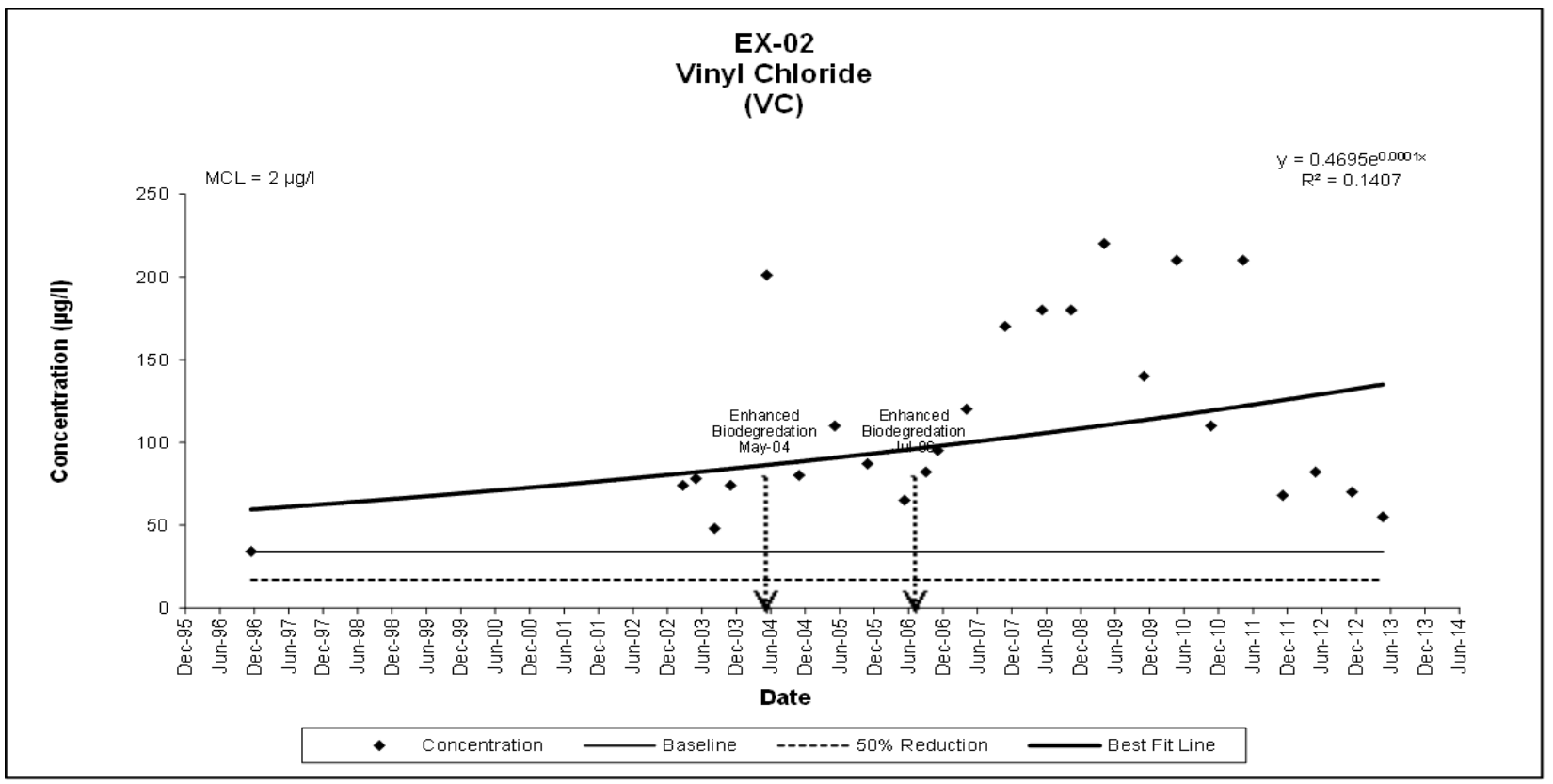


EXHIBIT B2-2
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-02

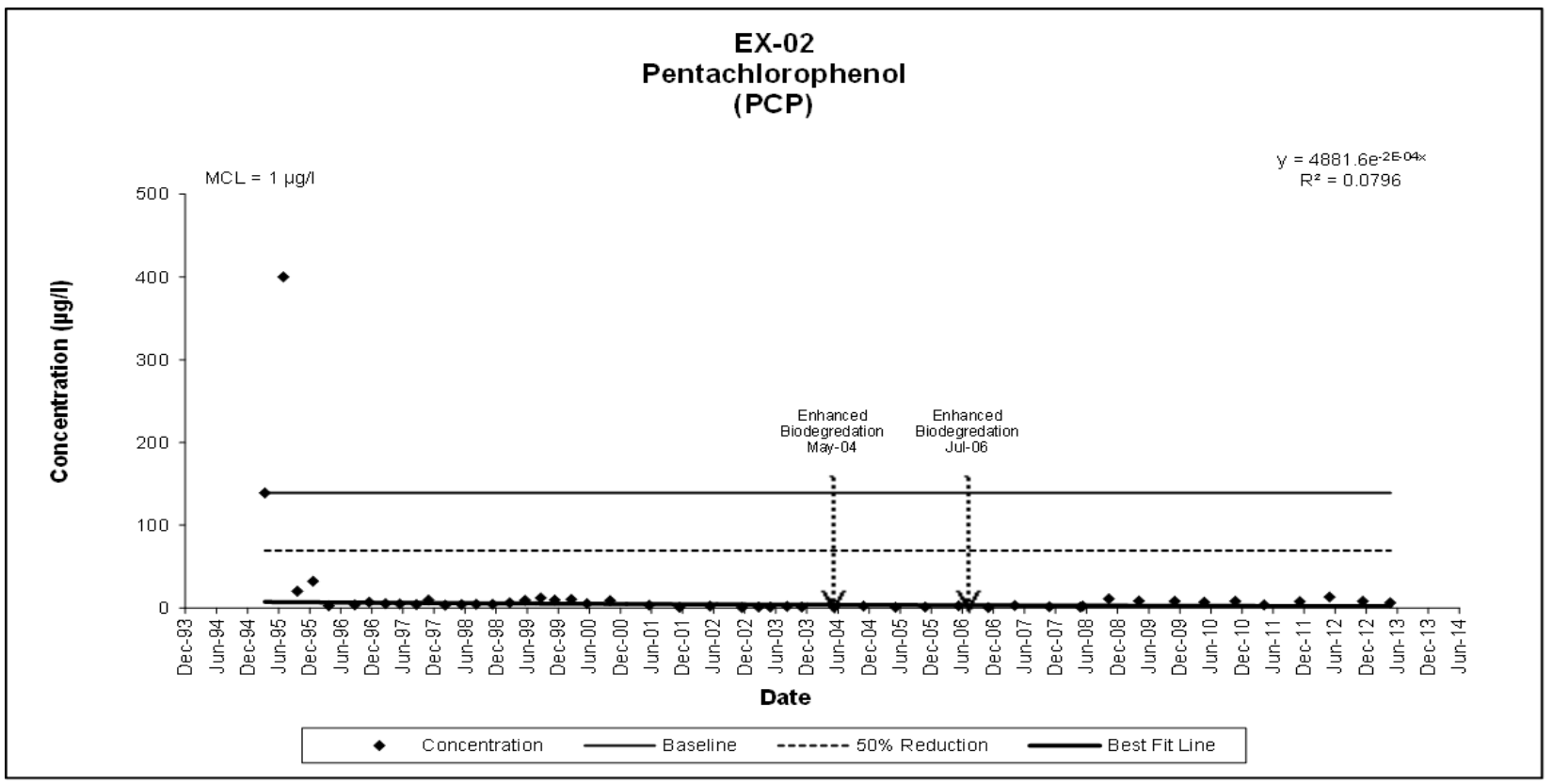


EXHIBIT B2-3
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-04

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	< 2 J	680	130	--	--	--	< 2	< 0.2 J
6-Jul-95	< 2	180	21	--	--	--	< 2 J	< 0.2 J
27-Sep-95	< 2	190	48	--	--	--	< 2	< 0.2
27-Dec-95	130	390	49	--	--	--	2.1	8.4
28-Mar-96	< 2	360	23	--	--	--	< 2	< 0.2
28-Aug-96	2.2	330	38	--	--	--	1.2 T	0.063 TJ
21-Nov-96	< 2.2 T	290	21	--	--	--	< 0.25	< 1 UJ
26-Feb-97	0.33 T	54	3.2	--	--	--	< 0.25	< 1
27-May-97	0.31 T	91	6.1	--	--	--	< 0.25	< 1
26-Aug-97	< 5	280	17	--	--	--	< 0.25	< 1
6-Nov-97	0.99	140	9	--	--	--	< 0.25	< 1
12-Feb-98	< 1	51	4	--	--	--	< 0.25	< 1
19-May-98	< 1	75	4.8	--	--	--	0.03 J	< 1
12-Aug-98	1.8 J	190	11	--	--	--	< 0.25	< 1
17-Nov-98	< 2.5	170	14	--	--	--	< 0.25	< 0.5
24-Feb-99	< 2	140	8.5	--	--	--	< 0.25	< 0.5
26-May-99	< 2	110	5.5 Q	--	--	--	< 4	< 0.5
25-Aug-99	< 25 G	120	7.6 T	--	--	--	< 0.2	< 0.1
17-Nov-99	7.5	200	11	--	--	--	< 0.2	0.5
22-Feb-00	< 5	110	8.8	--	--	--	< 0.2	< 0.1
24-May-00	< 10	96	5.4	--	--	--	< 0.2	< 0.1
23-Aug-00	2.7 D	150 D	13 D	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	0.63 J	< 0.5 UJ
23-May-01	< 1	59	8.4	--	--	--	< 0.5	0.4 T
19-Nov-01	< 1	35	9	--	--	--	< 0.5	< 0.5
15-May-02	< 1	76	10	--	--	--	< 0.5	0.09 T
20-Nov-02	< 1	50	12	--	--	--	< 0.48	< 0.48
25-Feb-03	< 1	59	9.9	--	--	< 1	< 0.48	< 0.48
6-May-03	< 1	61	8.2	--	--	< 1	< 0.5	< 0.5
12-Aug-03	< 1	56	8.8	--	--	2	< 0.5	< 0.5
6-Nov-03	< 1	74 D	10	--	--	< 1	< 2.4	< 0.48
14-May-04	< 1	88 D	15	--	--	< 1	--	< 0.48 UB
3-Nov-04	< 1	55	8.3	--	--	< 1	--	< 0.48
10-May-05	< 5 D	81 D	10 D	--	--	< 5 D	--	< 0.5
1-Nov-05	< 1	118 D	13	--	--	0.4 T	--	< 0.5
16-May-06	< 1	81 D	9.8	--	--	0.31 T	--	0.26 T
6-Sep-06	< 1	130 D	18	--	--	0.75 T	--	--
6-Nov-06	< 1	180 D	20	--	--	0.7 T	--	< 0.5 UJ
10-Apr-07	< 1	110 D	16	--	--	1	--	< 0.5
30-Oct-07	< 1	52 D	14	--	--	0.71 T	--	< 0.5
30-Apr-08	< 1	85 D	14	--	--	0.92 T	--	< 0.5
14-Oct-08	< 1	83 D	13	--	--	0.91 T	--	< 0.5
6-Apr-09	< 1	54 D	11	110 D	16	1.6	--	< 0.5
2-Nov-09	< 1	58 D	12	110 D	20	1.9	--	< 0.5
26-Apr-10	< 1	48	12	150 D	20	1.9	--	< 0.5
26-Oct-10	< 1	55	17	180 D	29	2.9	--	< 0.5
14-Apr-11	< 1	29	12	180 D	20	2.3	--	< 0.5
10-Nov-11	< 1	15	6.6	84	9.8	0.74 T	--	< 0.5
21-Dec-11	--	--	--	--	--	--	--	< 0.5
1-May-12	< 1	21	9.4	130 D	16	1.4	--	--
13-Nov-12	< 1	20	8.7	140 D	18	1.3	--	--
23-Apr-13	< 1	7.1	4.9	66	12	0.84 T	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-3
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-04

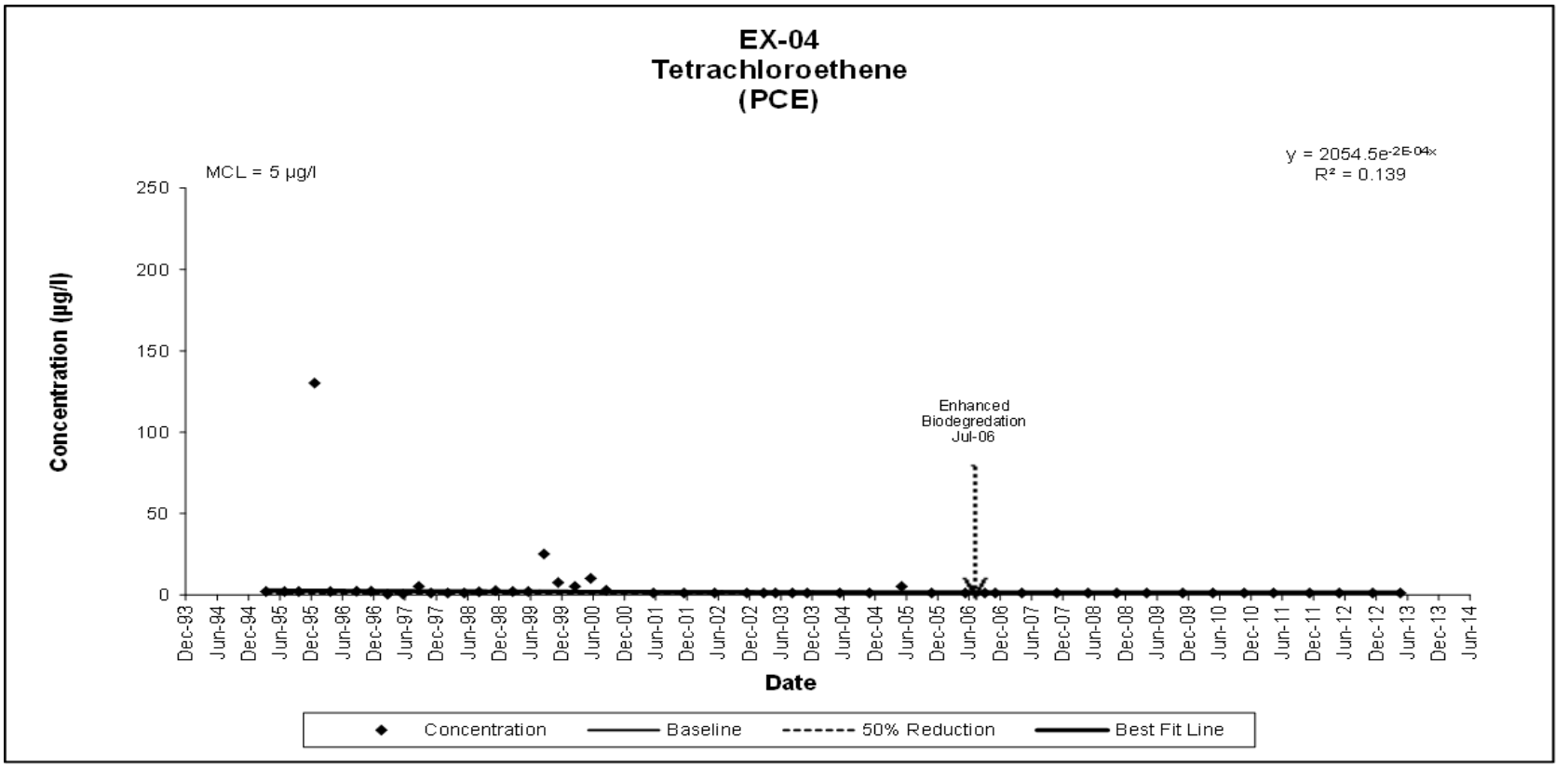
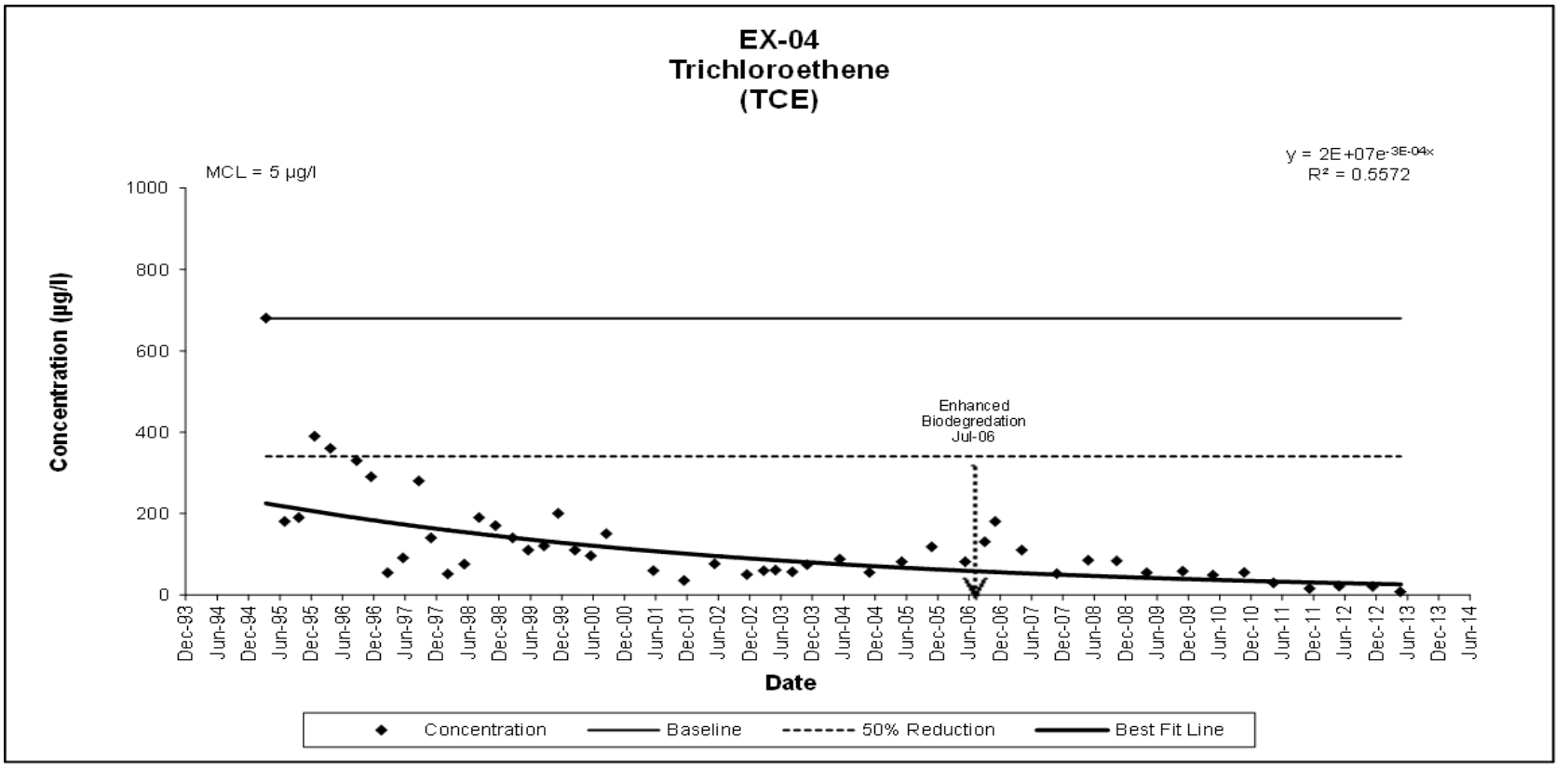


EXHIBIT B2-3
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-04



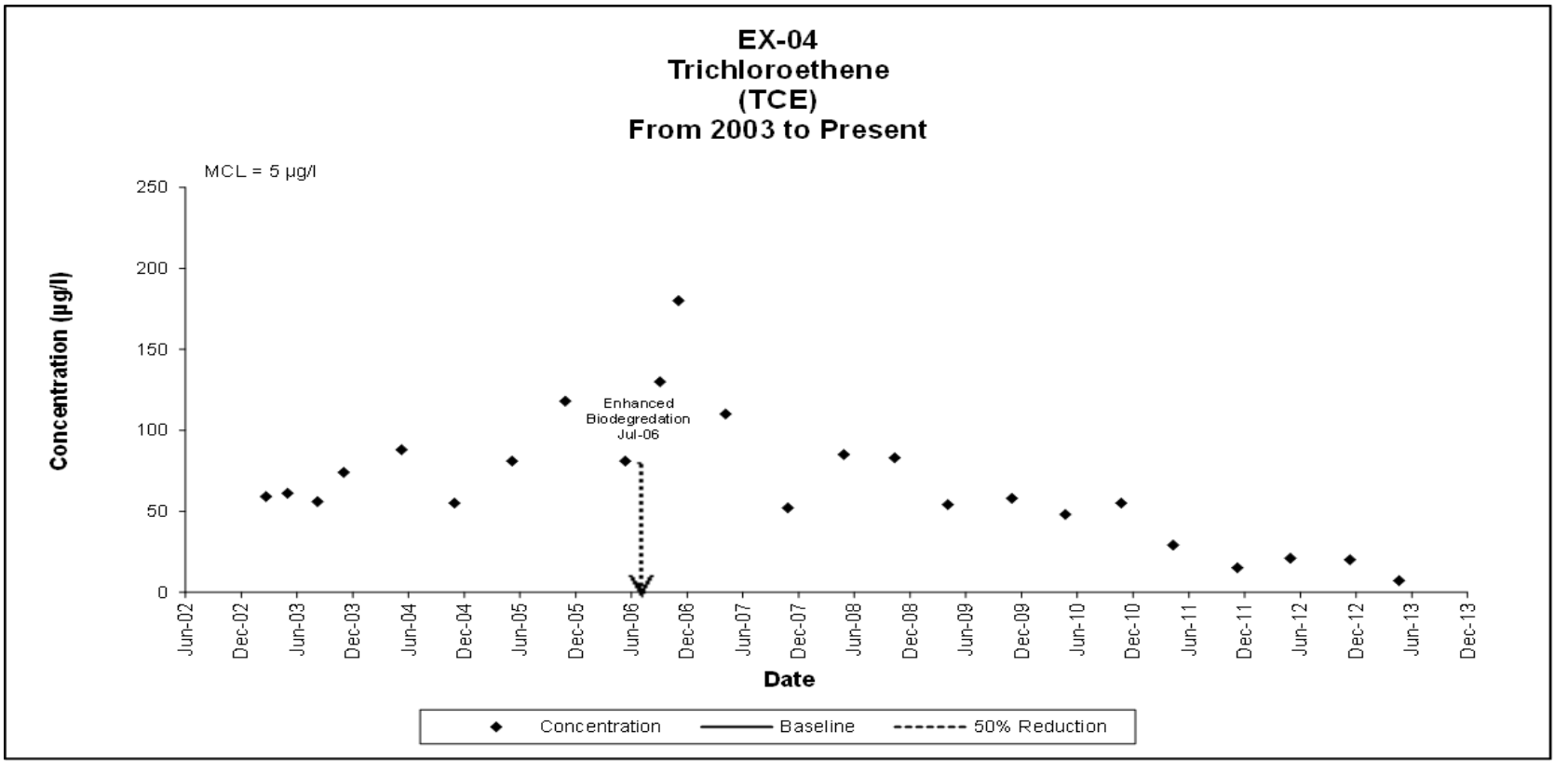
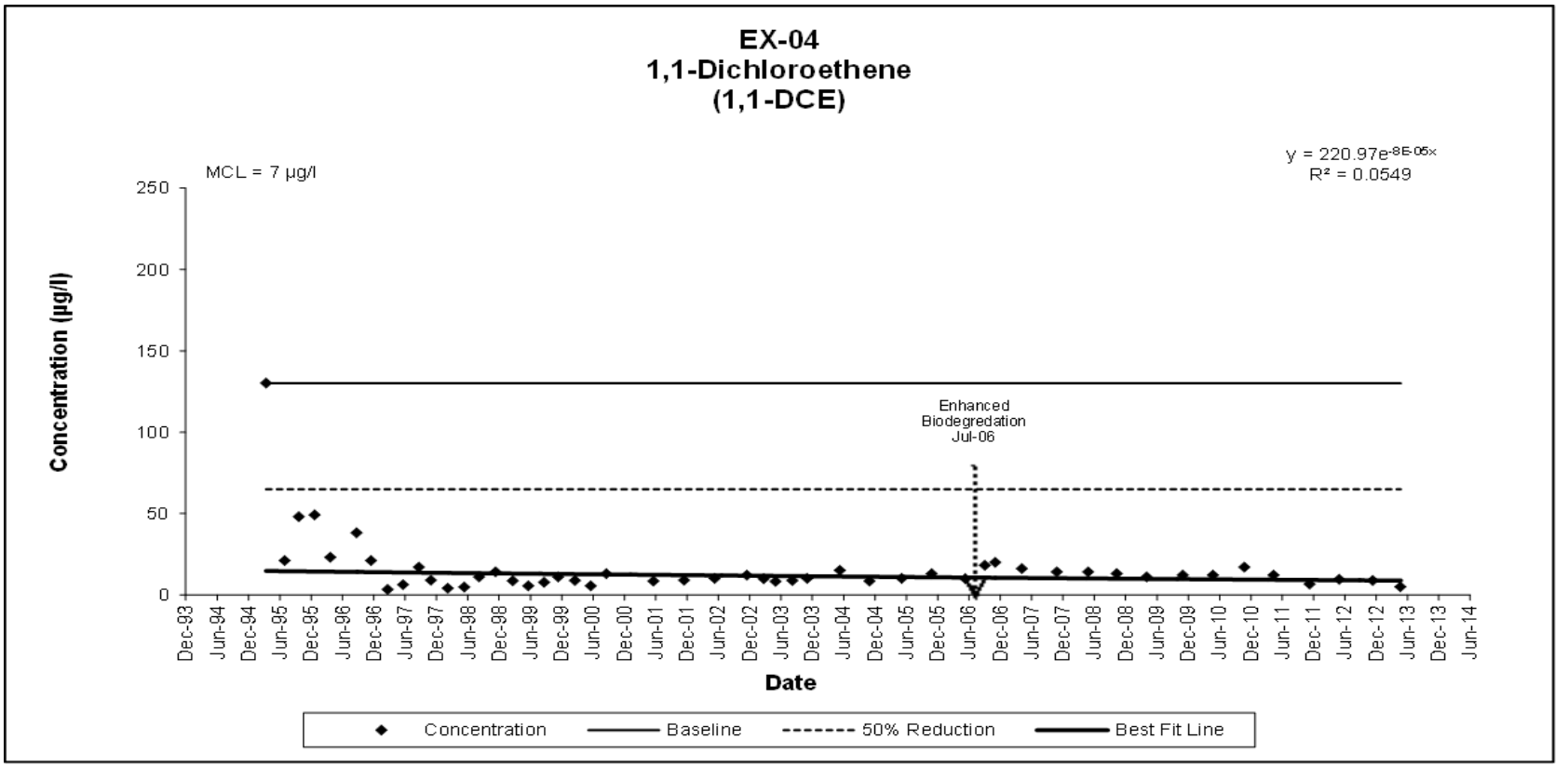


EXHIBIT B2-3
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-04



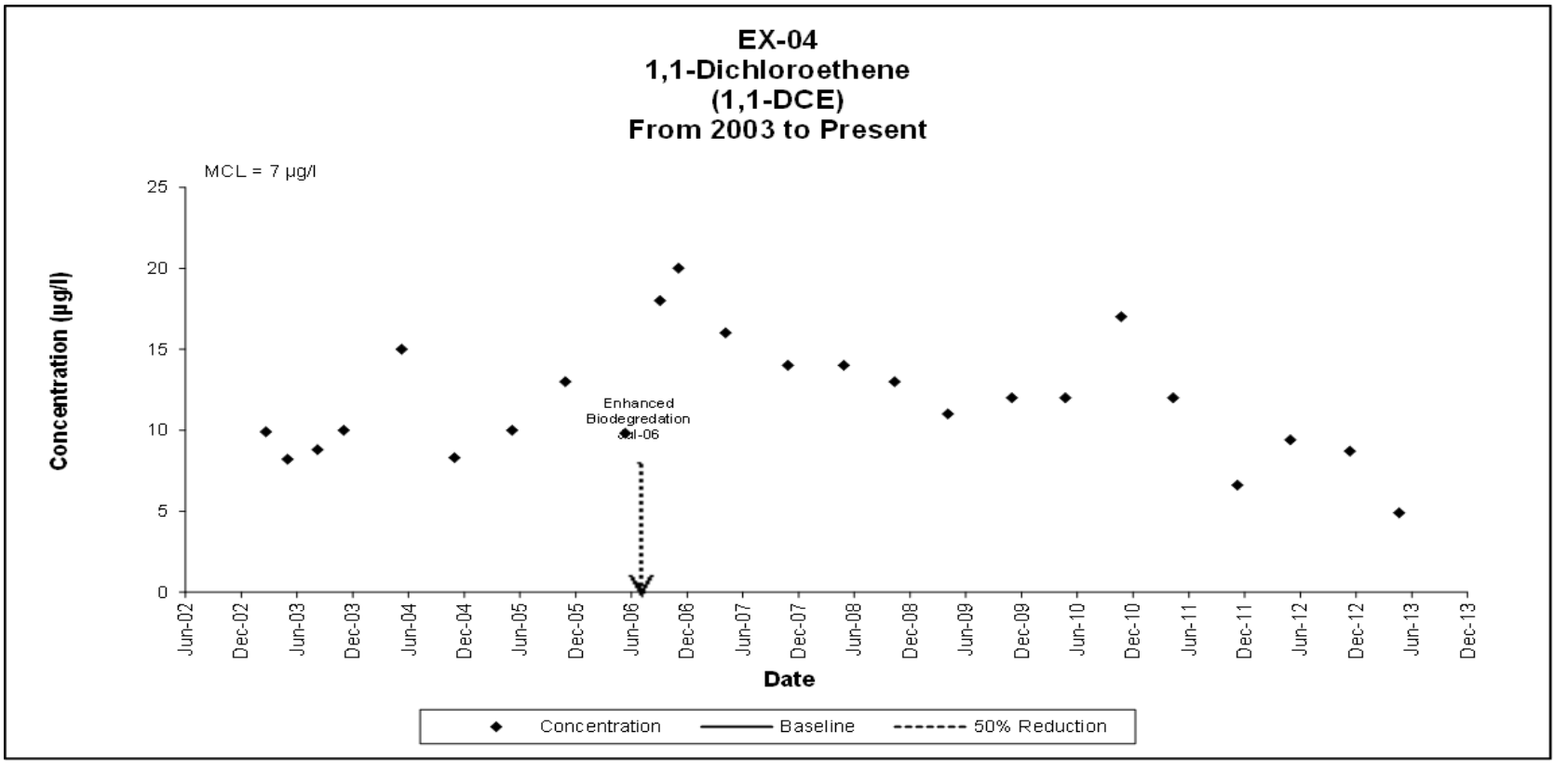
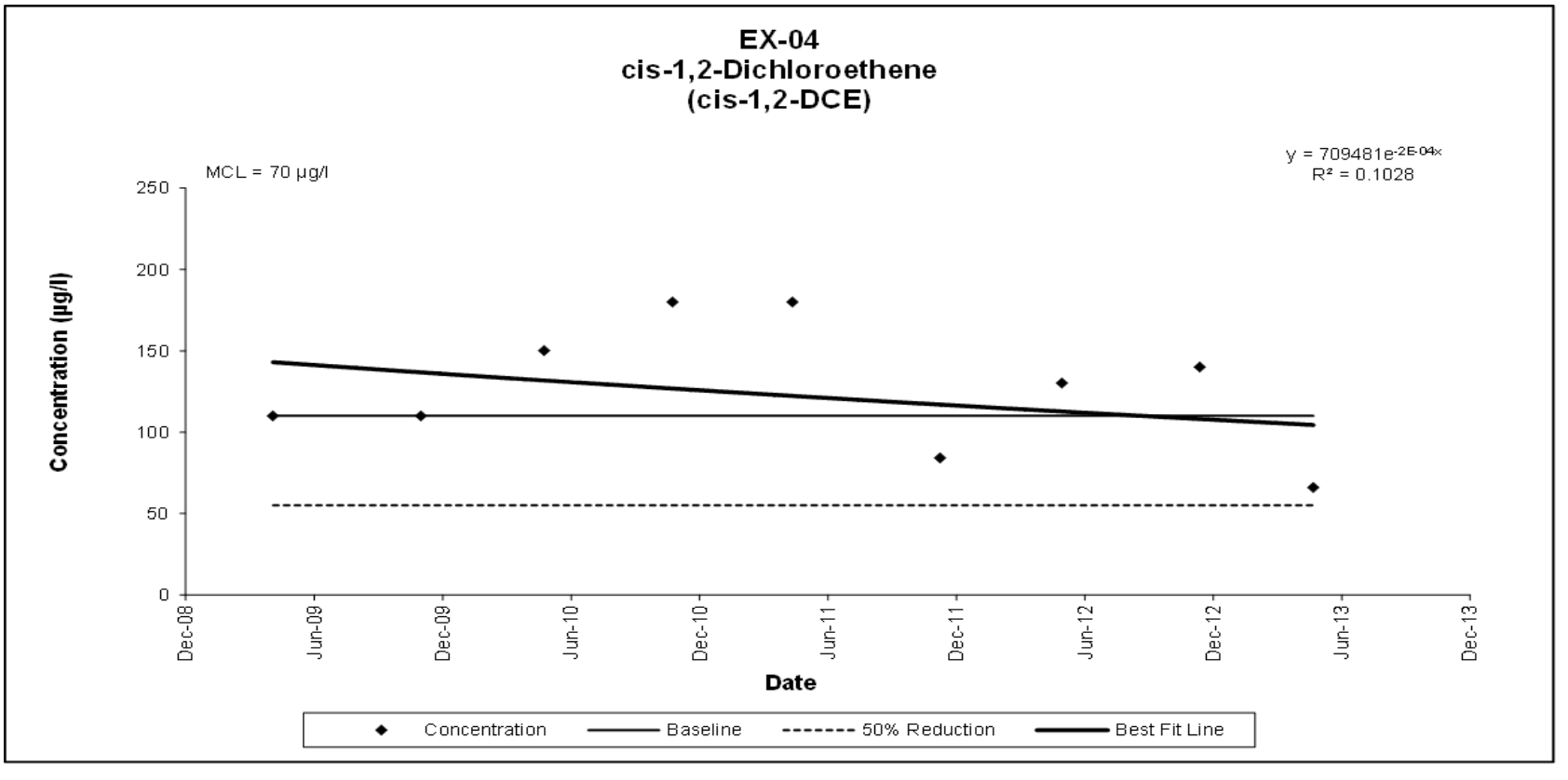


EXHIBIT B2-3
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-04



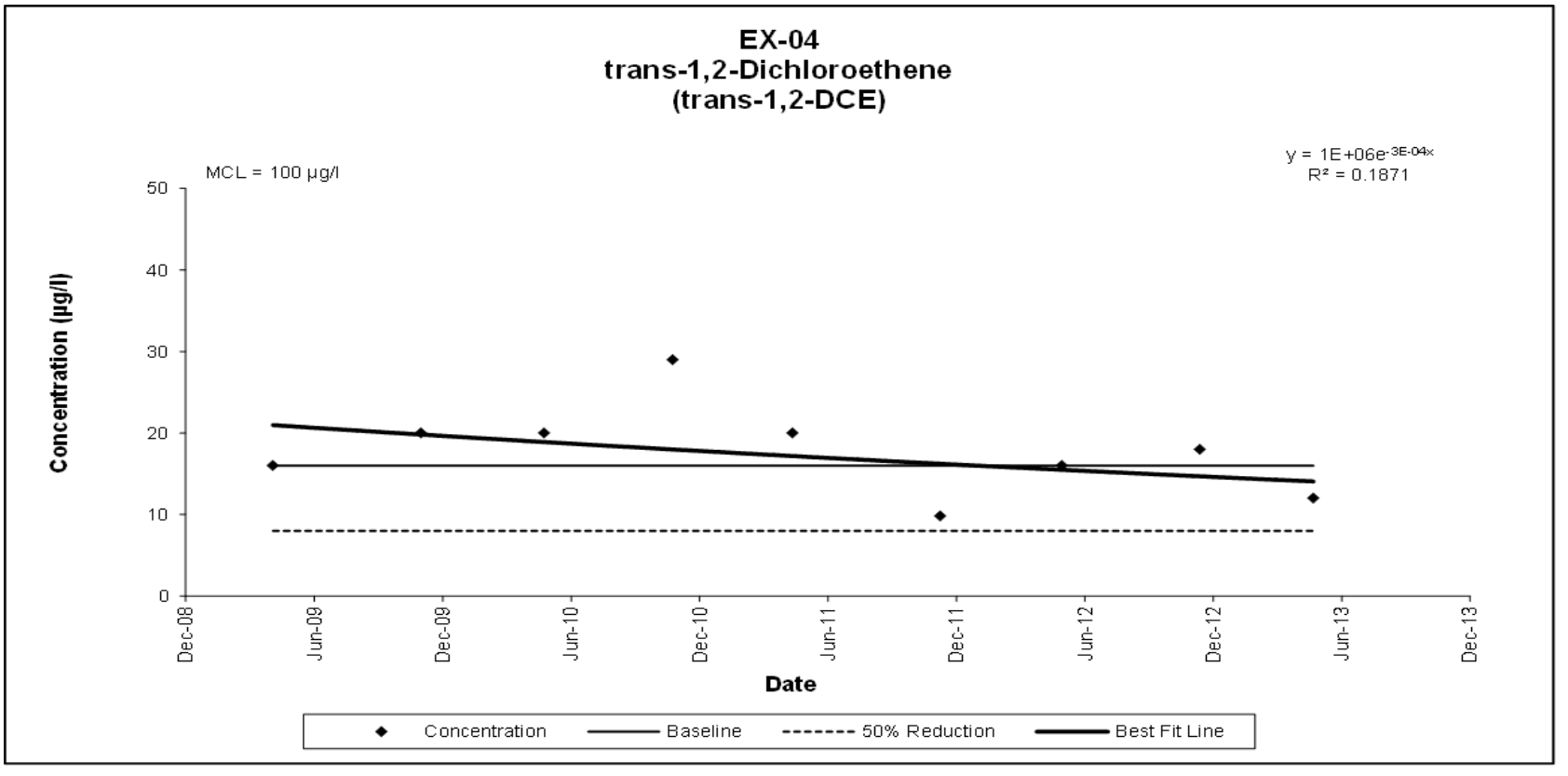


EXHIBIT B2-3
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-04

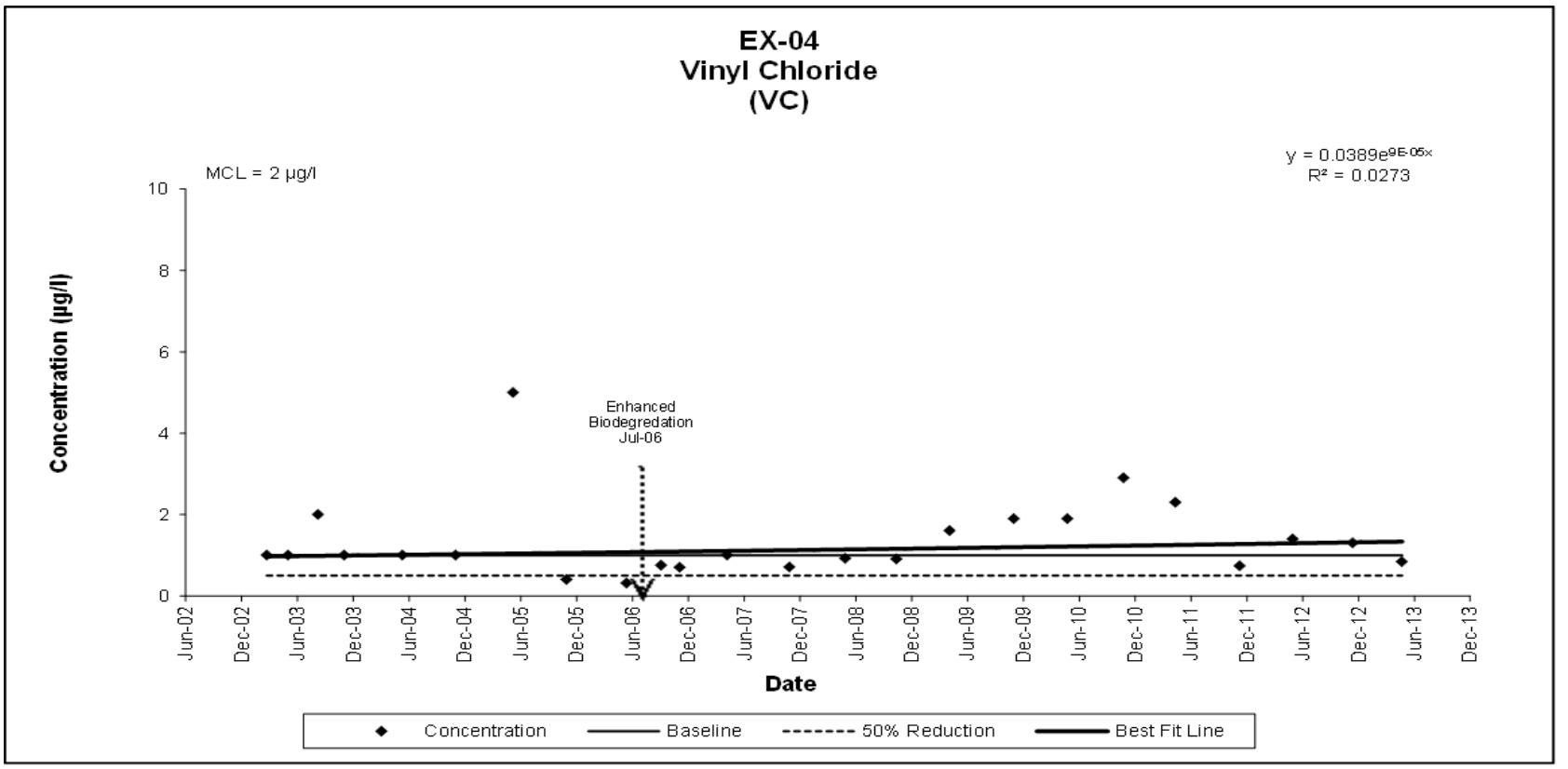


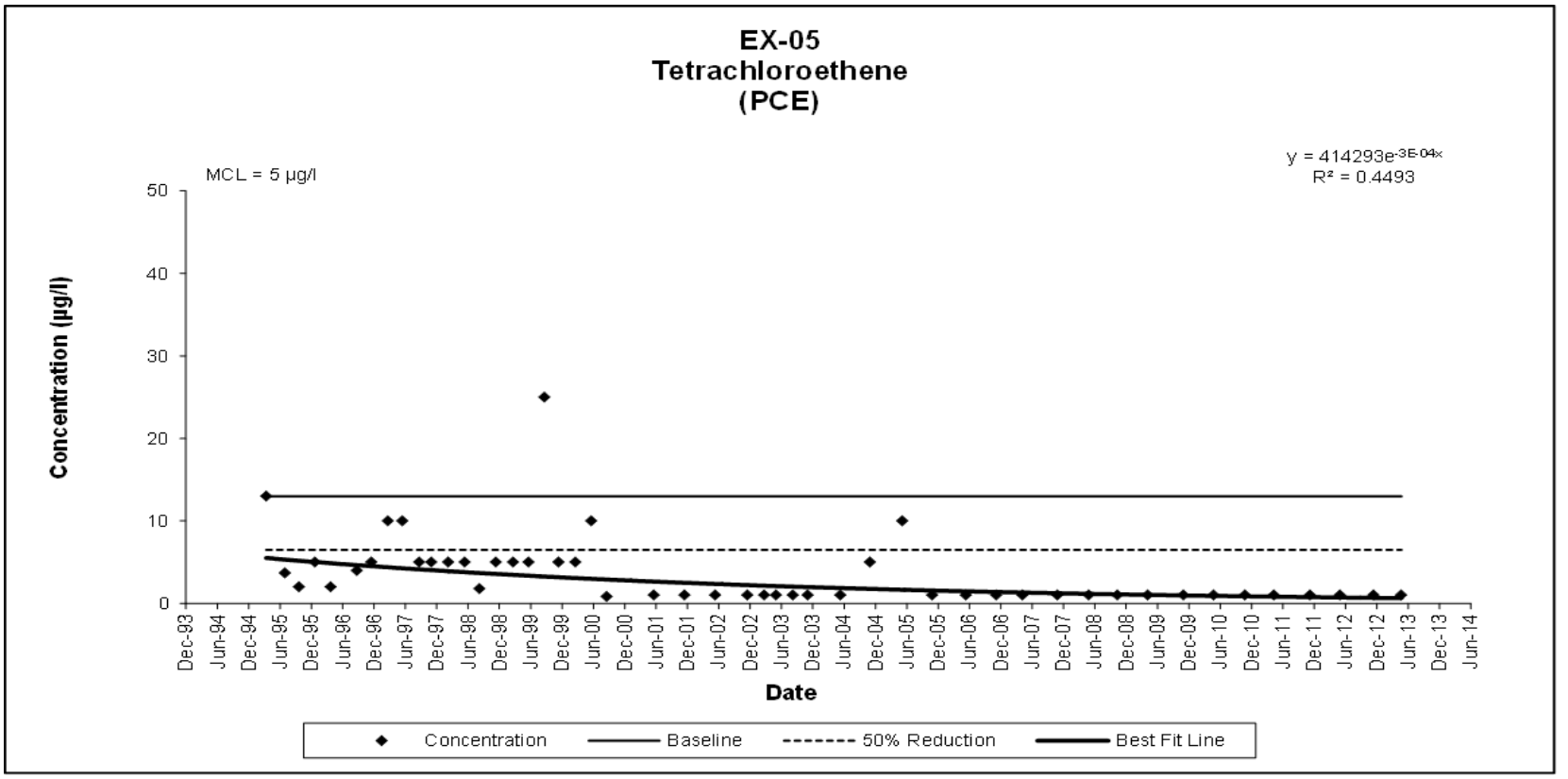
EXHIBIT B2-4
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-05

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	13	5500	450	--	--	--	< 20	< 2 J
6-Jul-95	3.7	1900	110	--	--	--	< 2	< 0.2
27-Sep-95	< 2	1900	320	--	--	--	< 2	< 0.2
27-Dec-95	< 5	1000	62	--	--	--	< 2	< 0.2
28-Mar-96	< 2	1100	55	--	--	--	< 2	< 0.2
28-Aug-96	< 4	180	9.5	--	--	--	< 10	< 0.2
21-Nov-96	< 5	200	10	--	--	1 T	< 0.25	< 1 UJ
26-Feb-97	< 10	520	23	--	--	--	< 0.25	< 1
21-May-97	< 10	850	43	--	--	--	< 0.25	1
26-Aug-97	< 5	250	13	--	--	--	< 0.25	1
6-Nov-97	< 5	260	11	--	--	--	< 0.25	< 1
12-Feb-98	< 5	430 B	27	--	--	--	< 0.25	< 1
19-May-98	< 5	280	16	--	--	--	< 0.25	< 1
12-Aug-98	1.8 J	190	11	--	--	--	< 0.25	< 1
17-Nov-98	< 5	360	20 J	--	--	--	< 0.25	< 0.5
24-Feb-99	< 5	330 JB	14 J	--	--	--	< 0.25	< 0.5
26-May-99	< 5 G	220 J	9.6	--	--	--	< 4 UJ	< 0.5
25-Aug-99	< 25 G	140	6.8 T	--	--	--	1.04	< 0.1
17-Nov-99	< 5	130	6.4	--	--	--	< 0.2	< 0.1
22-Feb-00	< 5	130	6.3	--	--	--	< 0.2	< 0.1
24-May-00	< 10	98	4	--	--	--	0.431	< 0.1
23-Aug-00	< 0.83 D	77 D	4.7 D	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	1.34 J	< 0.5 UJ
23-May-01	< 1	58	3	--	--	--	< 0.5	0.5
19-Nov-01	< 1	26	2	--	--	--	< 0.5	< 0.5
15-May-02	< 1	74 D	5	--	--	--	< 0.5	0.04 T
20-Nov-02	< 1	2	1	--	--	--	< 0.48	< 0.48
25-Feb-03	< 1	0.9 T	1	--	--	< 1	< 0.48	0.1 T
6-May-03	< 1	31	4.1	--	--	0.4 T	< 0.5	0.7
12-Aug-03	< 1	53	7.5	--	--	2.1	< 0.5	< 0.5
6-Nov-03	< 1	20	8.7	--	--	0.7 T	< 2.4	< 0.48
13-May-04	< 1	140 D	23	--	--	2.6	--	< 0.48
3-Nov-04	< 5 D	20 D	11 D	--	--	3 TD	--	< 0.48
10-May-05	< 10 D	34 D	10 D	--	--	< 10 D	--	< 0.5
1-Nov-05	< 1	2	13	--	--	0.9 T	--	< 0.5
16-May-06	< 1	6	12	--	--	0.68 T	--	< 0.5
7-Nov-06	< 1	0.6 T	19	--	--	1.1	--	< 0.5
9-Apr-07	< 1	0.76 T	20	--	--	2	--	< 0.5
30-Oct-07	< 1	0.5 T	17	--	--	9.3 J	--	< 0.5
29-Apr-08	< 1	0.37 T	10	--	--	44 D	--	< 0.5
14-Oct-08	< 1	0.45 T	13	--	--	40	--	< 0.5
7-Apr-09	< 1	0.44 T	12	180 D	210 D	47	--	< 0.5
2-Nov-09	< 1	0.43 T	8.5	150 D	170 D	27	--	< 0.5
26-Apr-10	< 1	0.44 T	5.8	140 D	130 D	20	--	< 0.5
26-Oct-10	< 1	0.5 T	9.9	170 D	170 D	16	--	< 0.5
13-Apr-11	< 1	0.37 T	9	140 D	150 D	17	--	< 0.5
9-Nov-11	< 1	0.36 T	8.6	140 D	150 D	12	--	< 0.5
1-May-12	< 1	0.47 T	8.3	150 D	140 D	13	--	--
13-Nov-12	< 1	0.53 T	9.1	150 D	150 D	11	--	--
23-Apr-13	< 1	0.51 T	9.3	150 D	160 D	11	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-4
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-05



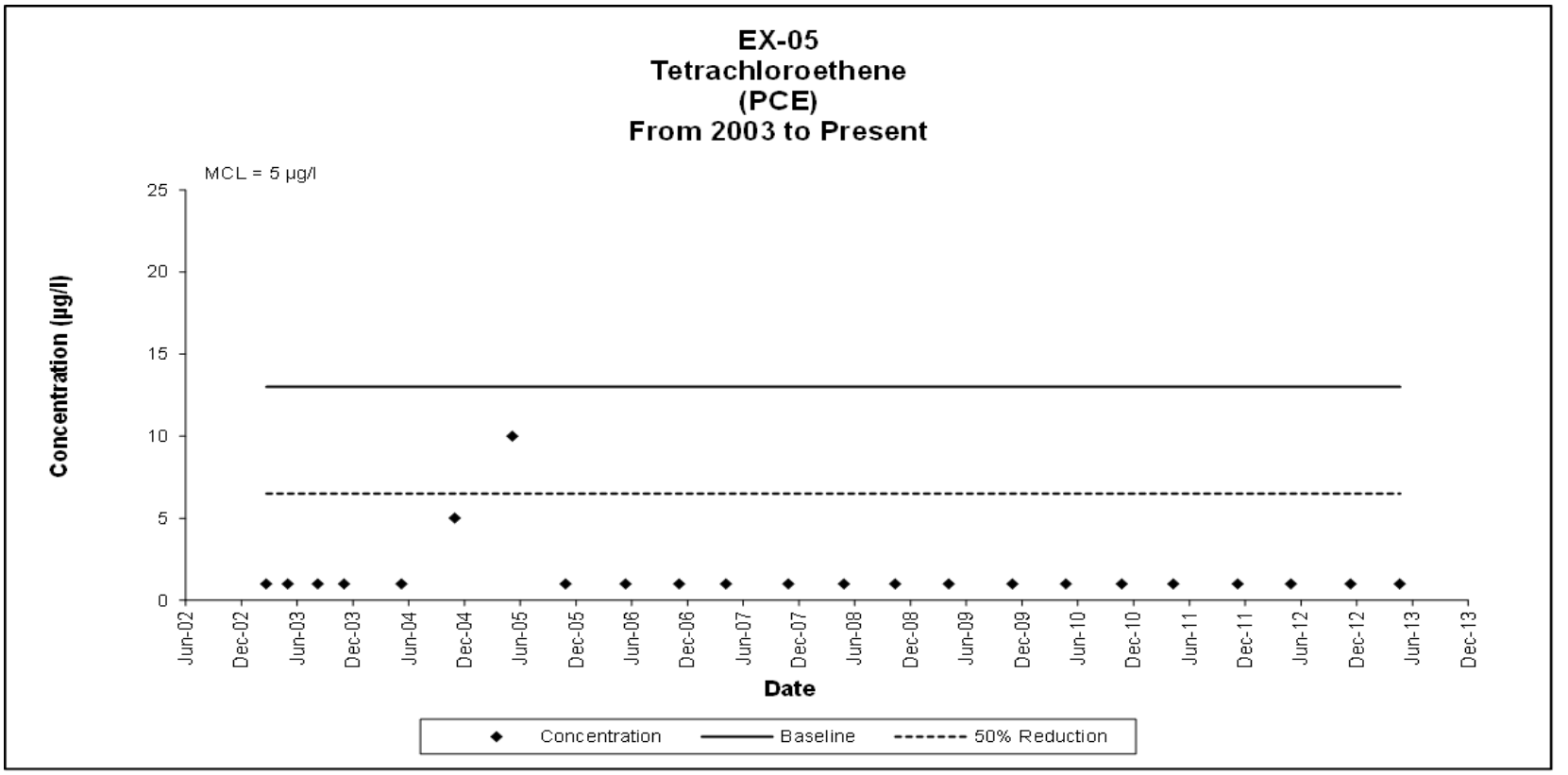
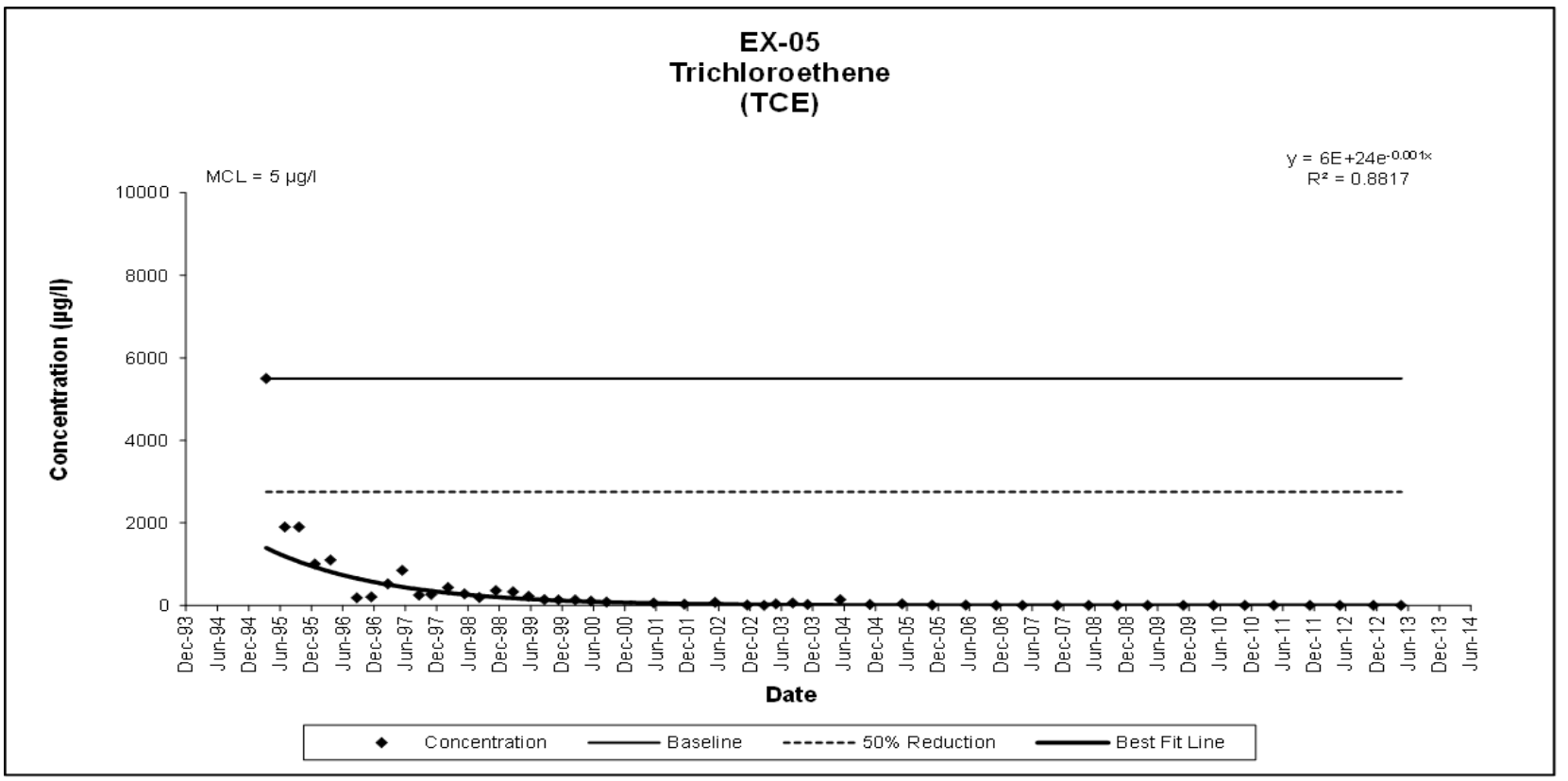


EXHIBIT B2-4
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-05



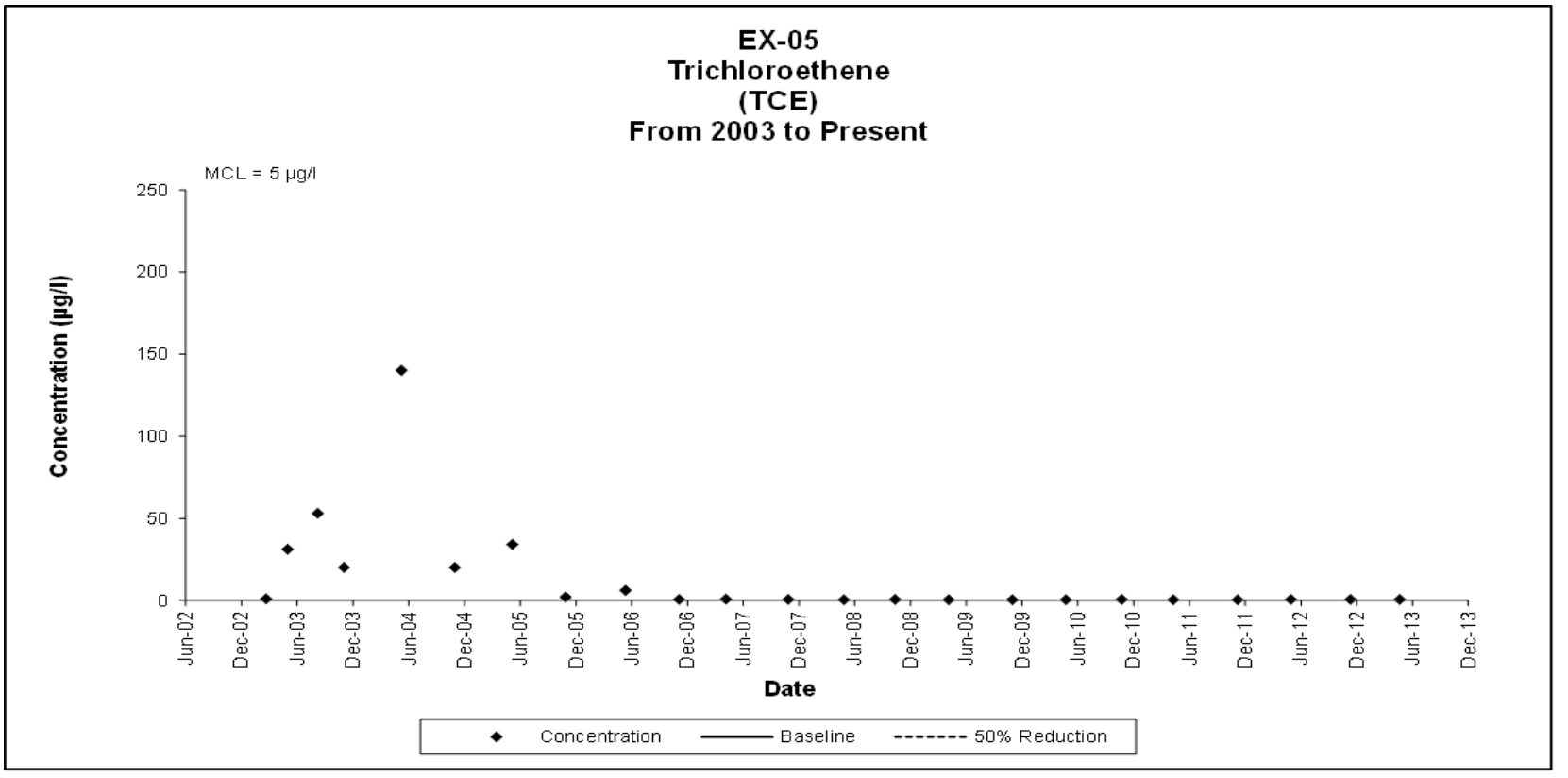
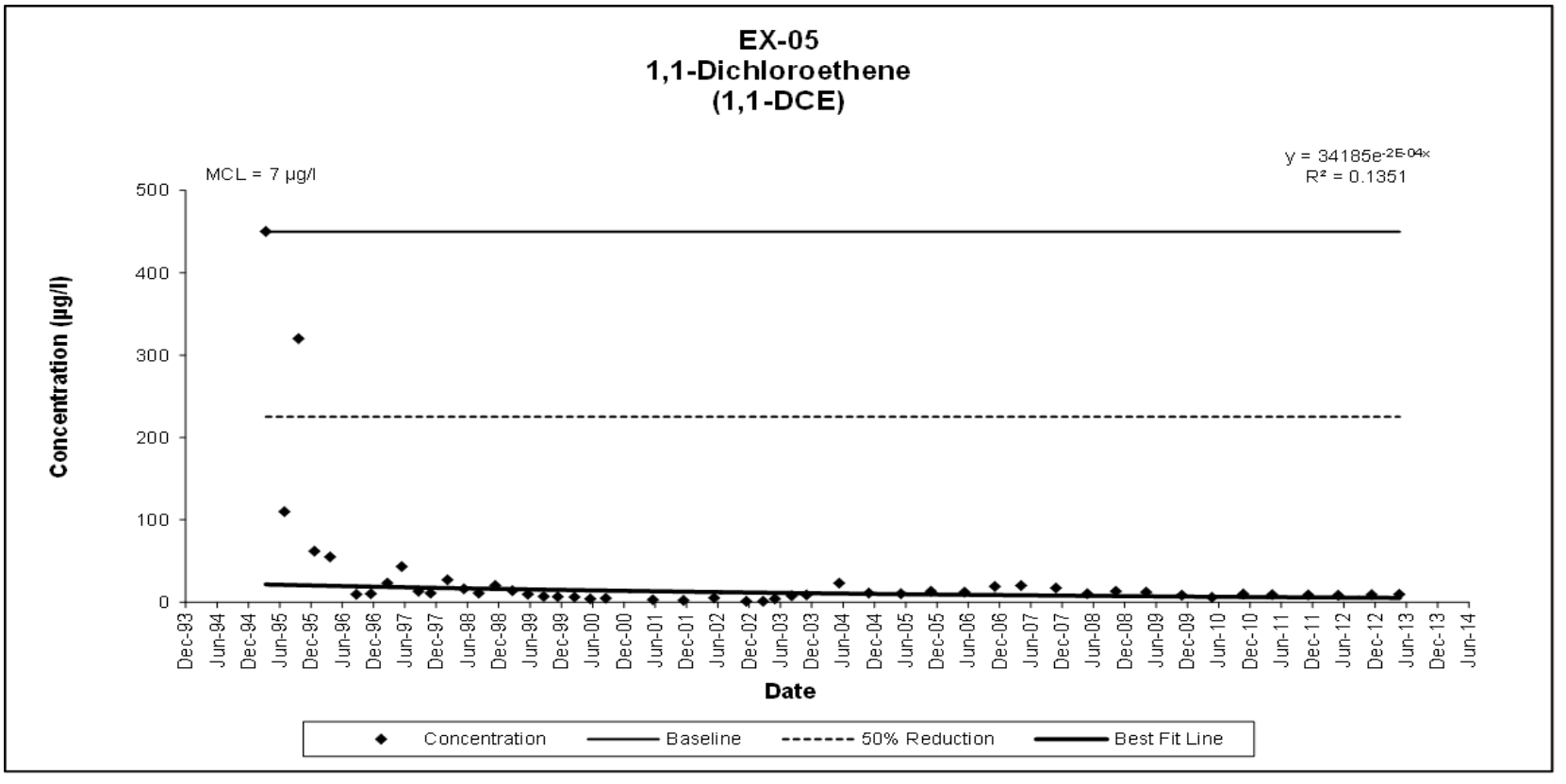


EXHIBIT B2-4
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-05



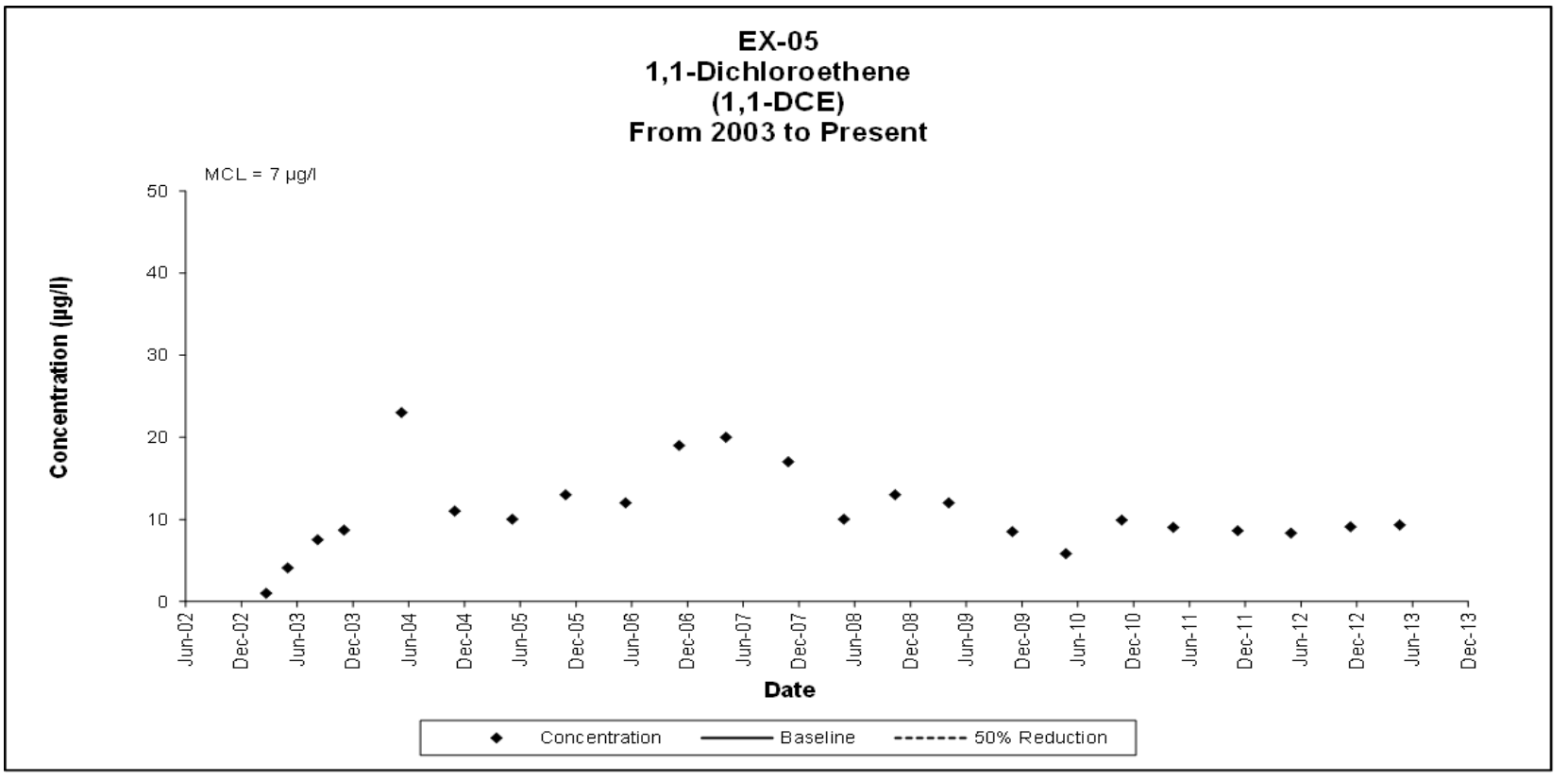
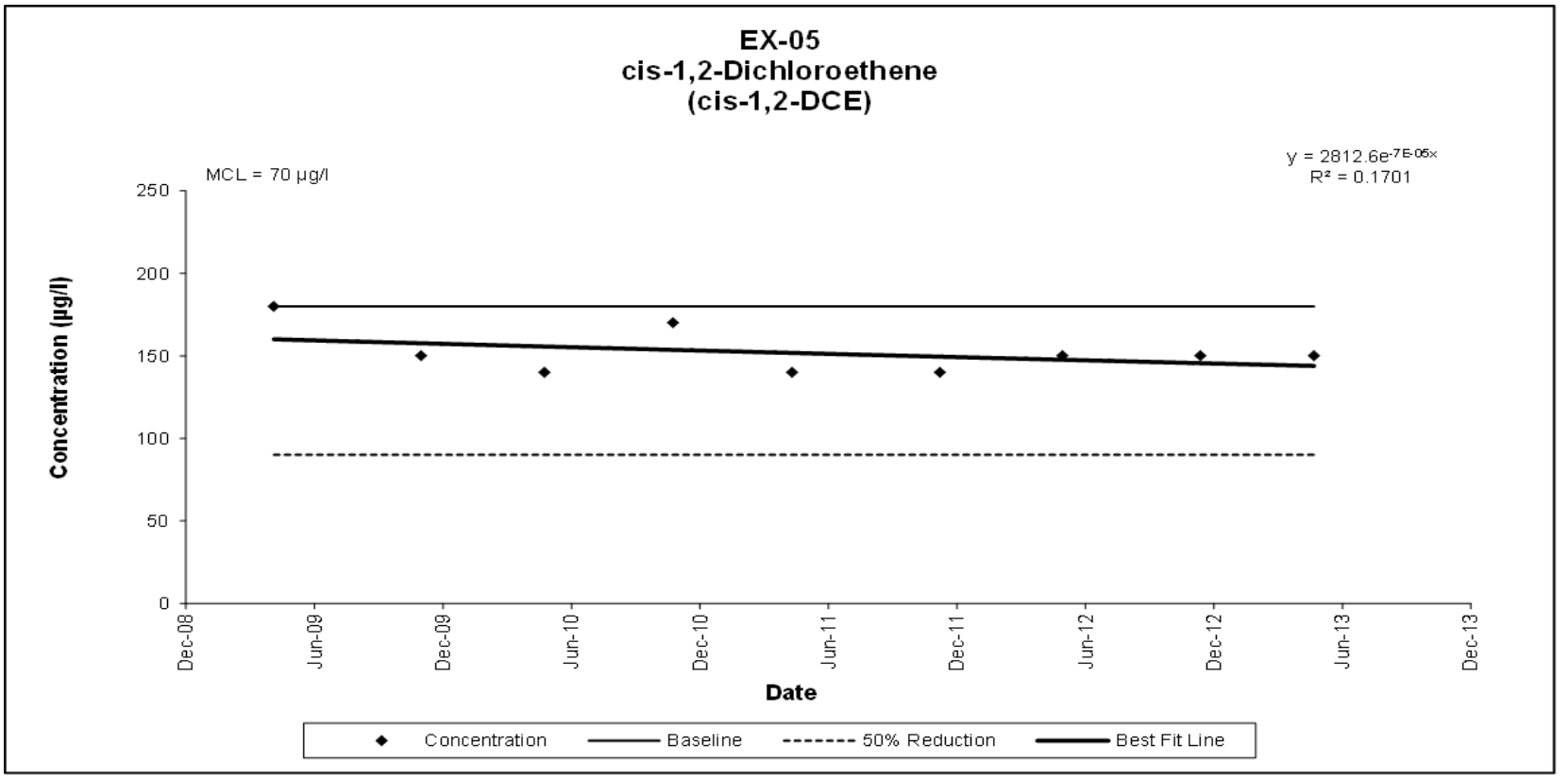


EXHIBIT B2-4
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-05



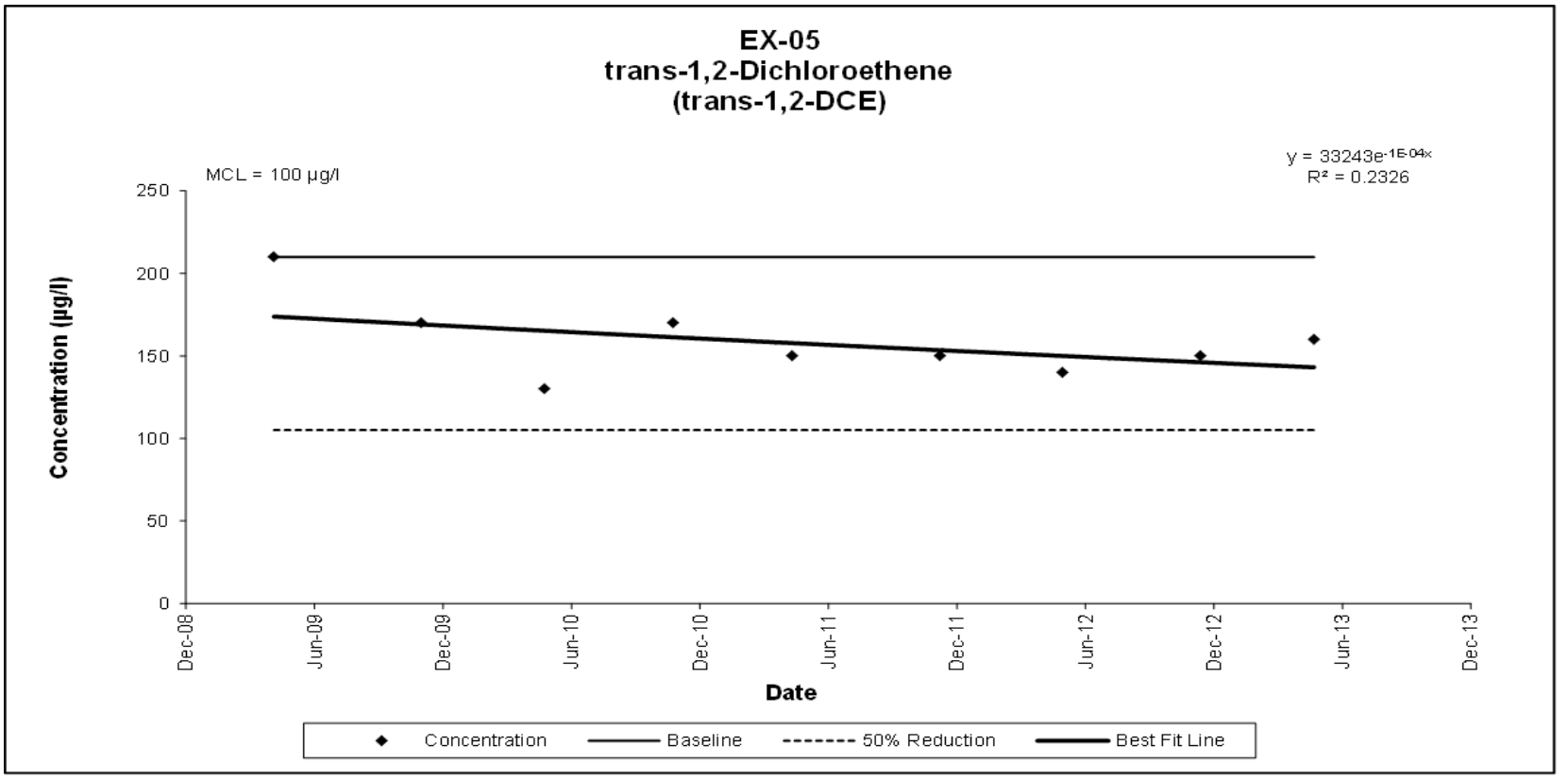


EXHIBIT B2-4
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-05

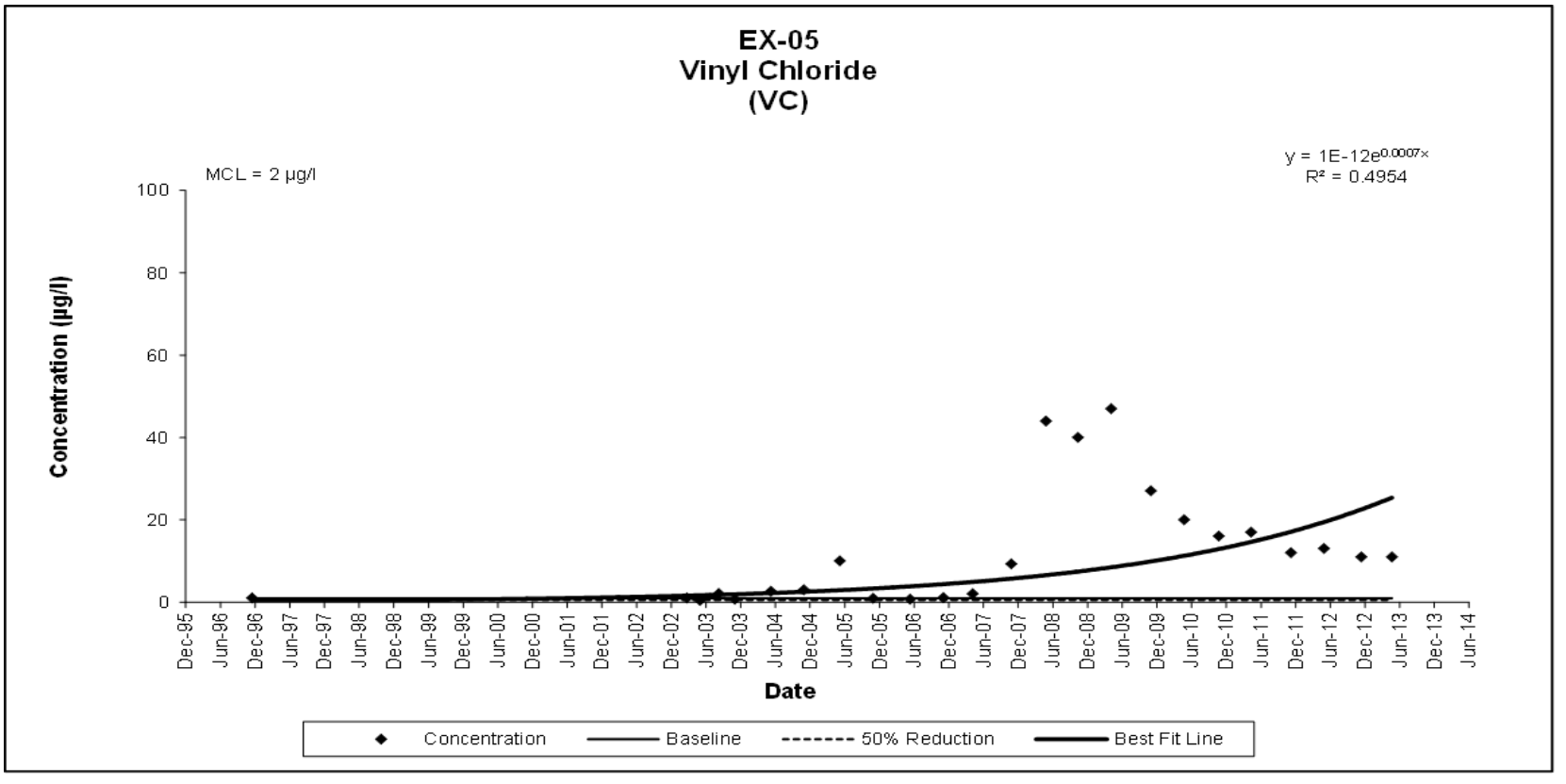


EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	23	210	86	--	--	--	150	0.671 J
6-Jul-95	53	160	21	--	--	--	< 20	< 40
27-Sep-95	47	150	71	--	--	--	< 2	< 20
27-Dec-95	33	140	28	--	--	--	< 2	< 0.2
28-Mar-96	43	170	21	--	--	--	240	< 20
28-Aug-96	41	360	24	--	--	--	< 10	38 J
20-Nov-96	51	420	23	--	--	53	< 2.5	19 J
26-Feb-97	67	490	19	--	--	--	< 2.5	46
21-May-97	81	850	21	--	--	--	< 2.5	37 J
26-Aug-97	74	460	16	--	--	--	1.7 J	40 B
6-Nov-97	72	490	16	--	--	--	< 2.5	--
12-Feb-98	68 B	460 B	19	--	--	--	3.6	--
19-May-98	130	680	15	--	--	--	4.5	--
12-Aug-98	100	650	21	--	--	--	< 5.5	--
17-Nov-98	17	58	1.4 J	--	--	--	< 0.3 G	5.1
24-Feb-99	65 JB	190 J	4.2 J	--	--	--	< 2.5 G	7
26-May-99	60	160	< 5 G	--	--	--	< 4 UJ	16
25-Aug-99	29	210	10 T	--	--	--	1.53	4.78
17-Nov-99	52	210	9.4 T	--	--	--	< 0.2 J	28.8 J
22-Feb-00	51	110	2.9 J	--	--	--	0.13 J	16.7
24-May-00	18	71	2.6 T	--	--	--	< 0.2	4.92 J
23-Aug-00	39 D	96	5.5 D	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	< 0.5	0.77
23-May-01	38 D	141 D	7 D	--	--	--	< 0.5	5.4 D
19-Nov-01	7.8	59	3.9	--	--	--	< 0.5	2.4
15-May-02	26	96 D	4.1	--	--	--	< 0.5	8.4 D
20-Nov-02	4.1	46	3.7	--	--	--	< 0.48	2
26-Feb-03	5.8	36	2.1	--	--	17	0.1 TJ	3.2 J
6-May-03	7.4	24	< 1	--	--	1	< 0.5	1.4
12-Aug-03	10	65 D	4.8	--	--	32	< 0.5	2.4
6-Nov-03	3.6	21	2	--	--	10	< 2.4	1.3
14-May-04	14	42	< 1	--	--	3.1	--	0.4 TB
3-Nov-04	7.4	19	< 1	--	--	1	--	0.6
10-May-05	5.1	11	< 1	--	--	0.5 T	--	< 0.5
1-Nov-05	5.5	30	2.4	--	--	18	--	0.9
16-May-06	11	22	0.47 T	--	--	2.1	--	1.2
6-Sep-06	< 1	5.4	2.2	--	--	16 J+	--	--
6-Nov-06	< 1	7.9	2.2	--	--	17	--	0.27 T
10-Apr-07	0.2036 T	7.1	0.71 T	--	--	6.9	--	0.31 T
30-Oct-07	< 1	2.1	0.43 T	--	--	4.2	--	0.13 T
30-Apr-08	< 1	5	0.82 T	--	--	8.9	--	0.16 T
13-Oct-08	< 1	5	1.6	--	--	29	--	< 0.5
7-Apr-09	< 1	3	0.79 T	16	2.3	10	--	0.13 T
3-Nov-09	< 1	1.2	0.33 T	6	1.4	3.6	--	< 0.5
26-Apr-10	< 1	2	< 1	3.6	0.62 T	1.4	--	< 0.5
26-Oct-10	< 1	1.5	0.34 T	8.3	4	4.1	--	< 0.5
14-Apr-11	0.54 T	2.4	0.25 T	4	0.51 T	1.4	--	< 0.5
10-Nov-11	< 1	1.1	0.45 T	10	5	5.3	--	< 0.5
1-May-12	< 1	0.93 T	0.42 T	8.3	3.7	6.5	--	< 0.5
14-Nov-12	0.28 T	1.6	0.24 T	4.7	1.8	2.3	--	< 0.5
23-Apr-13	1.1	3.1	< 1	3.9	0.73 T	1.4	--	< 0.5

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-- Not analyzed

EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07

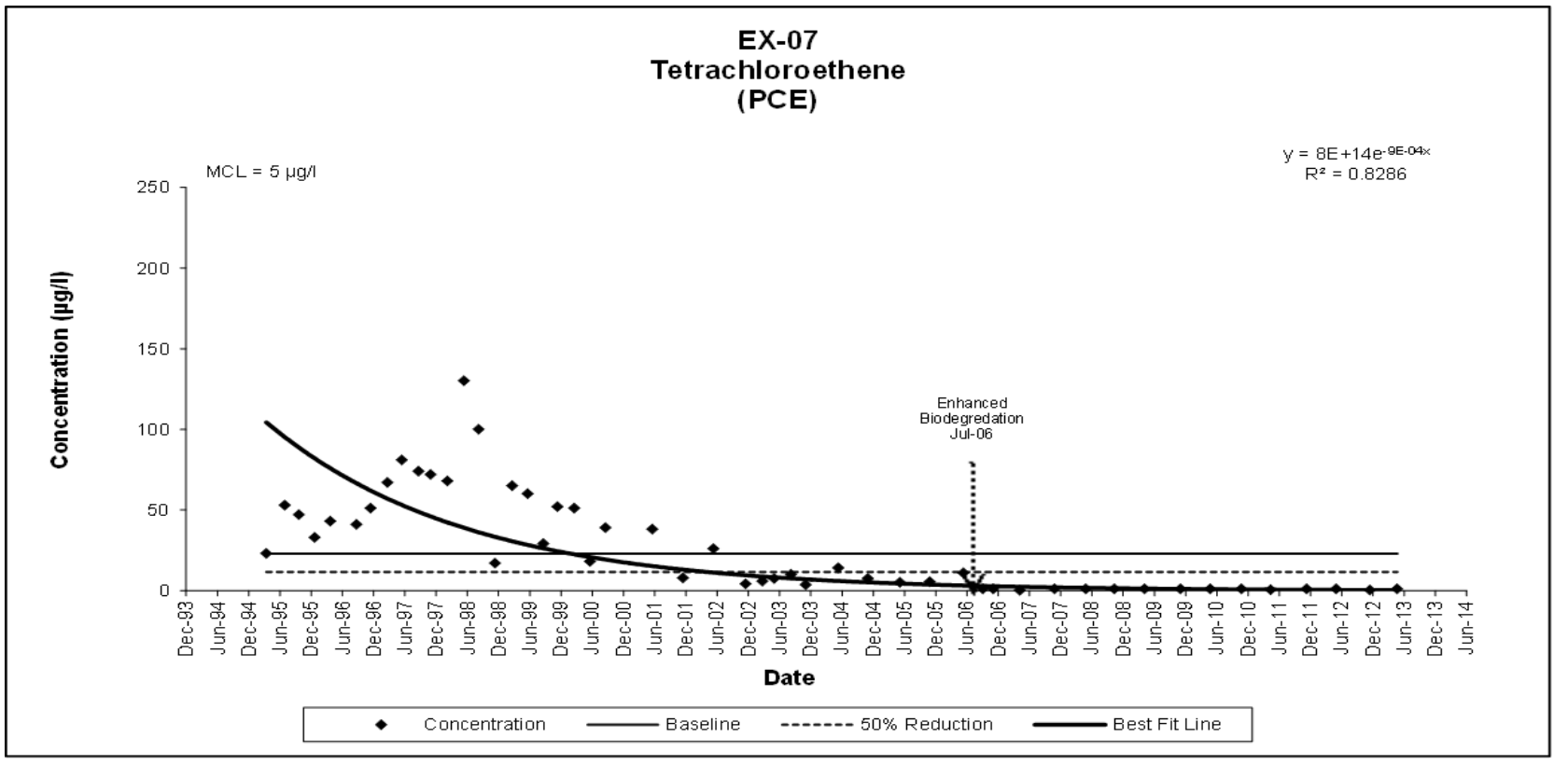


EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07

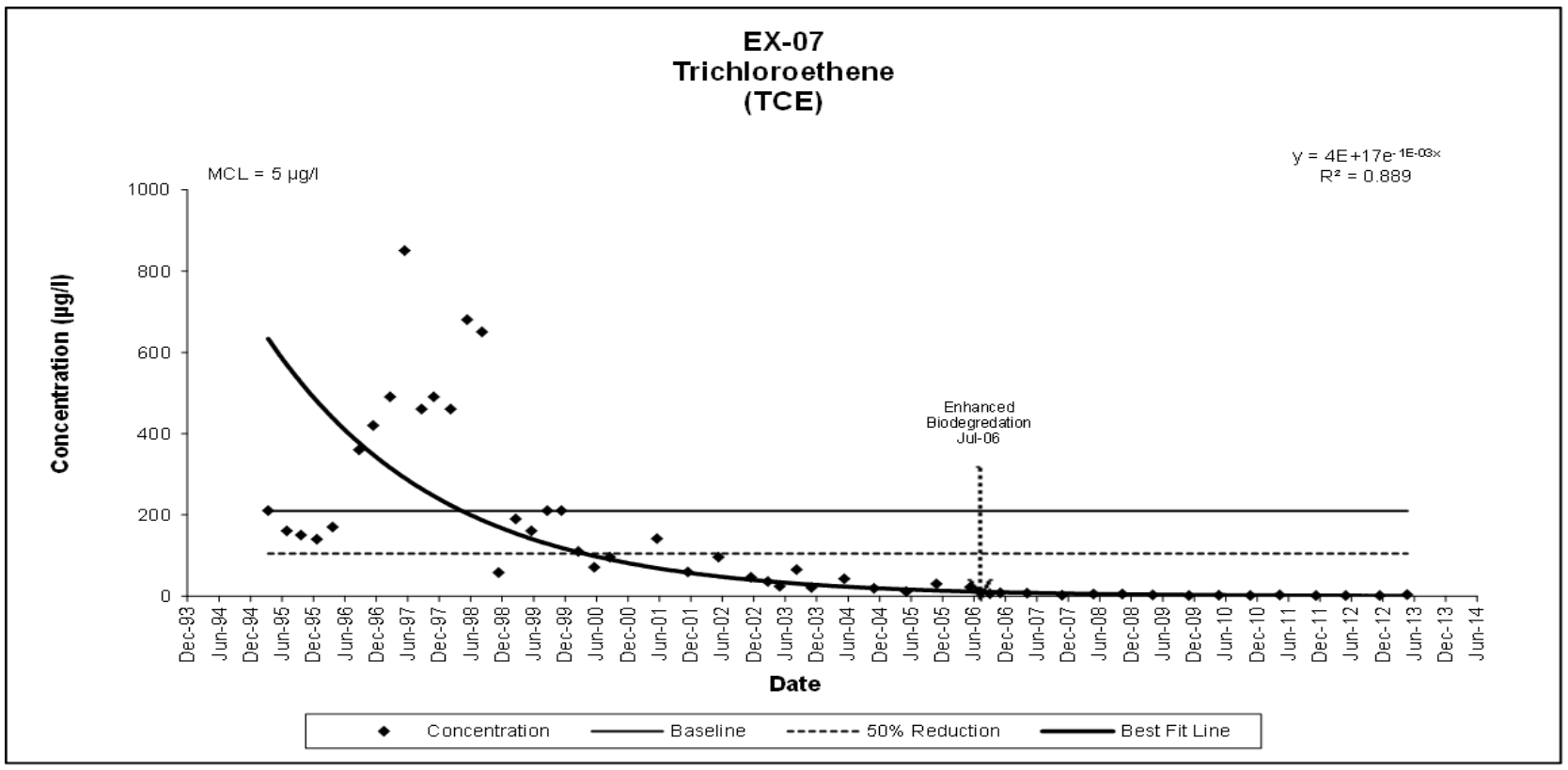


EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07

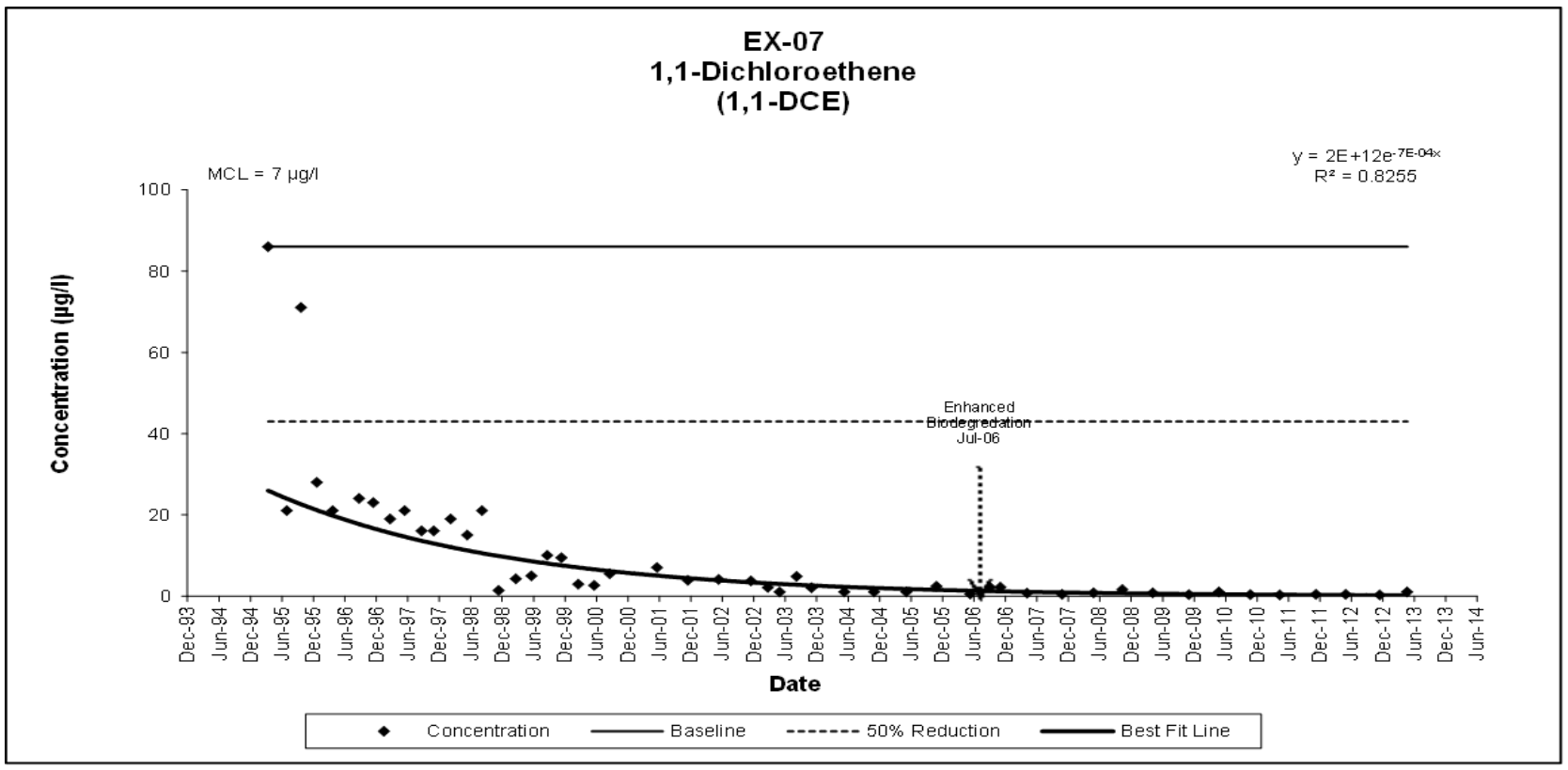
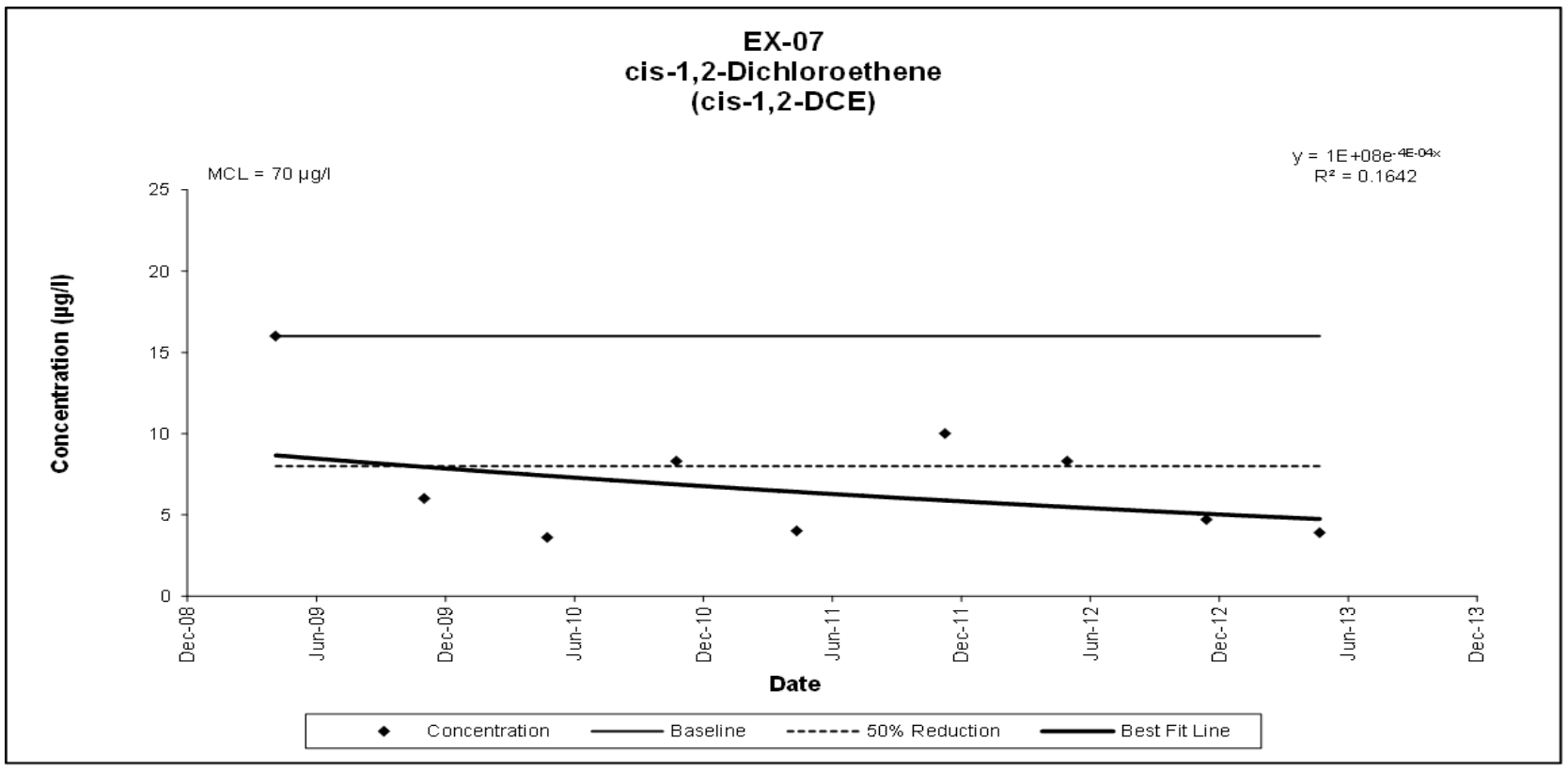


EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07



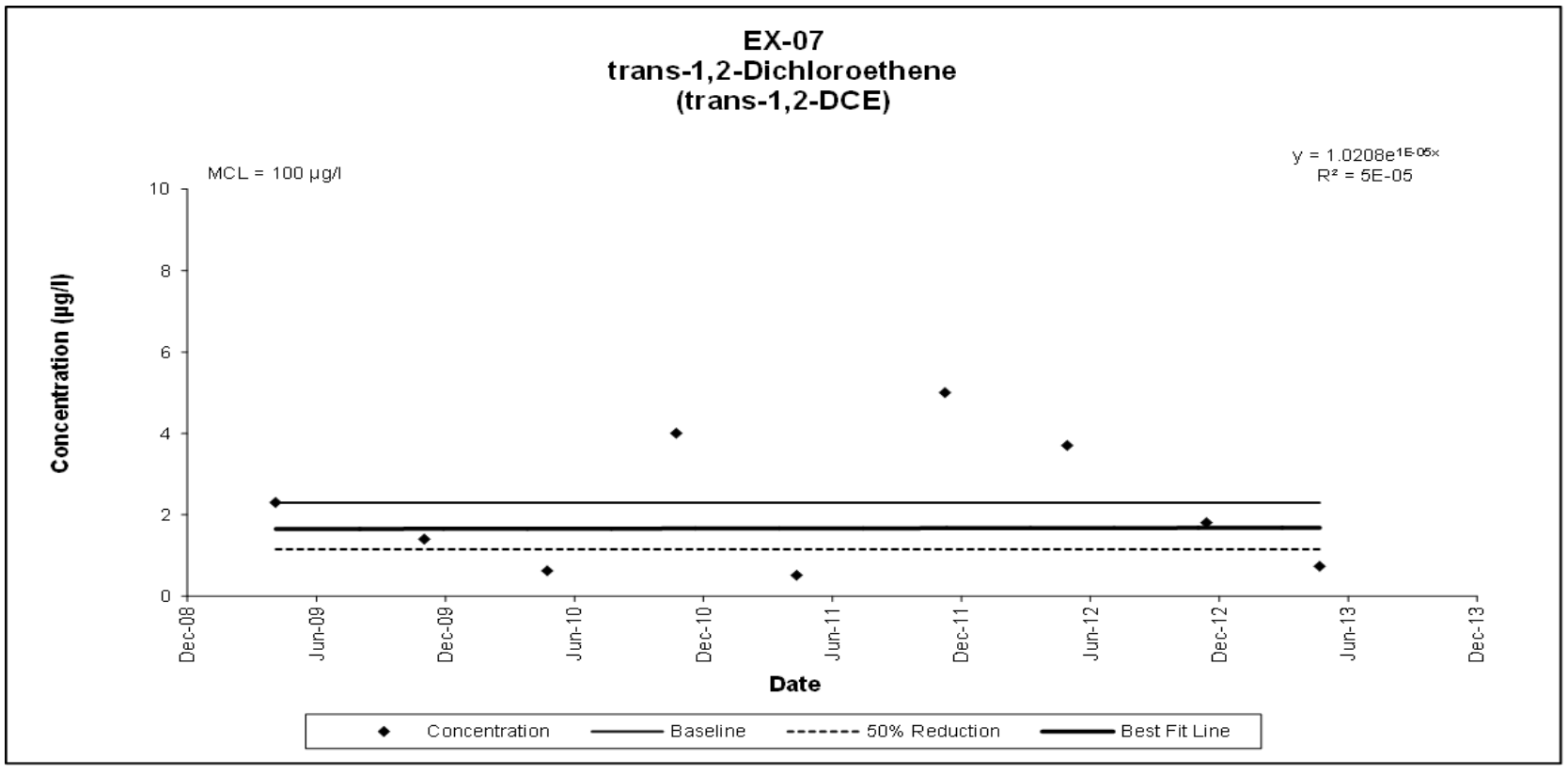


EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07

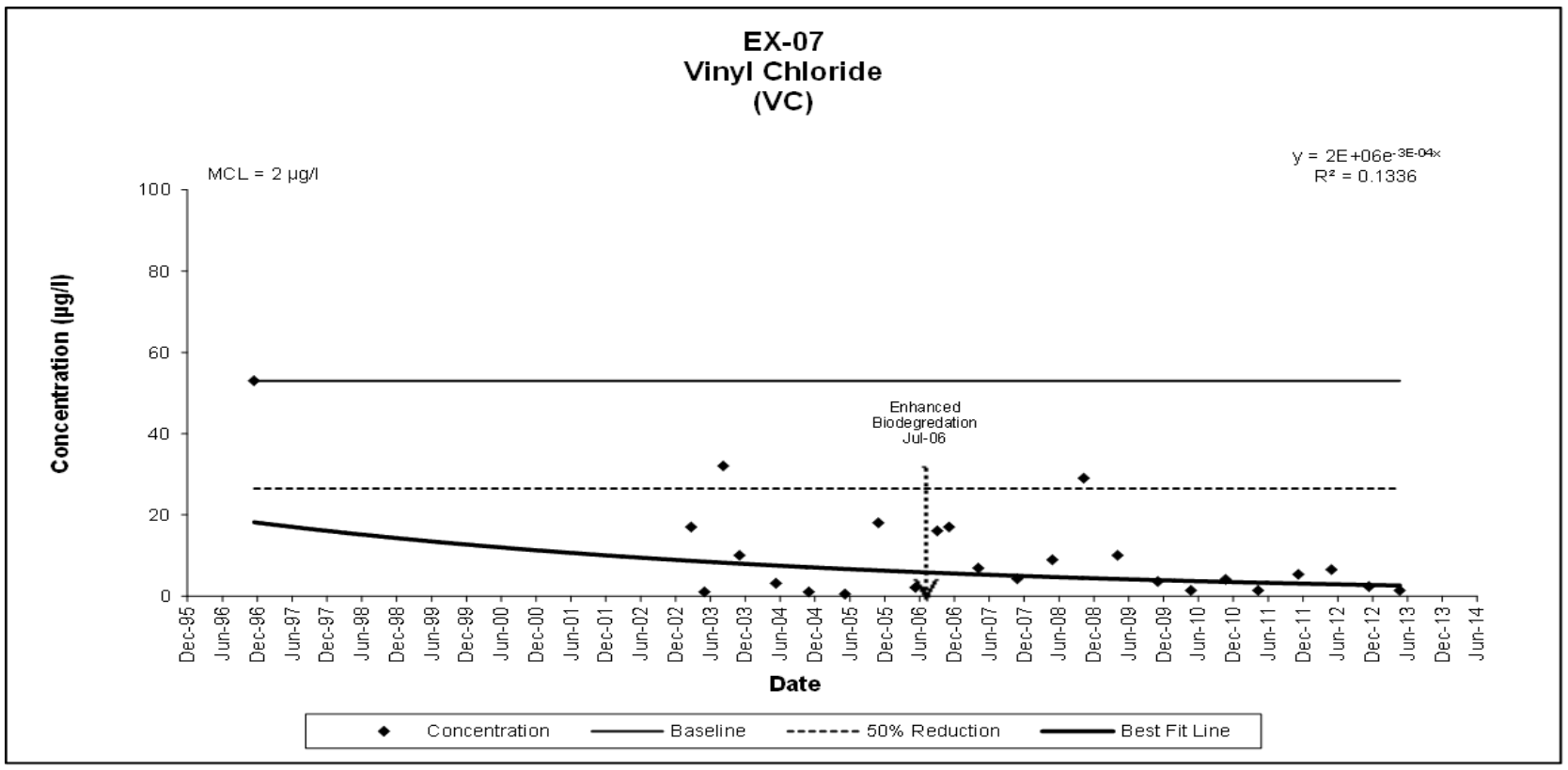


EXHIBIT B2-5
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-07

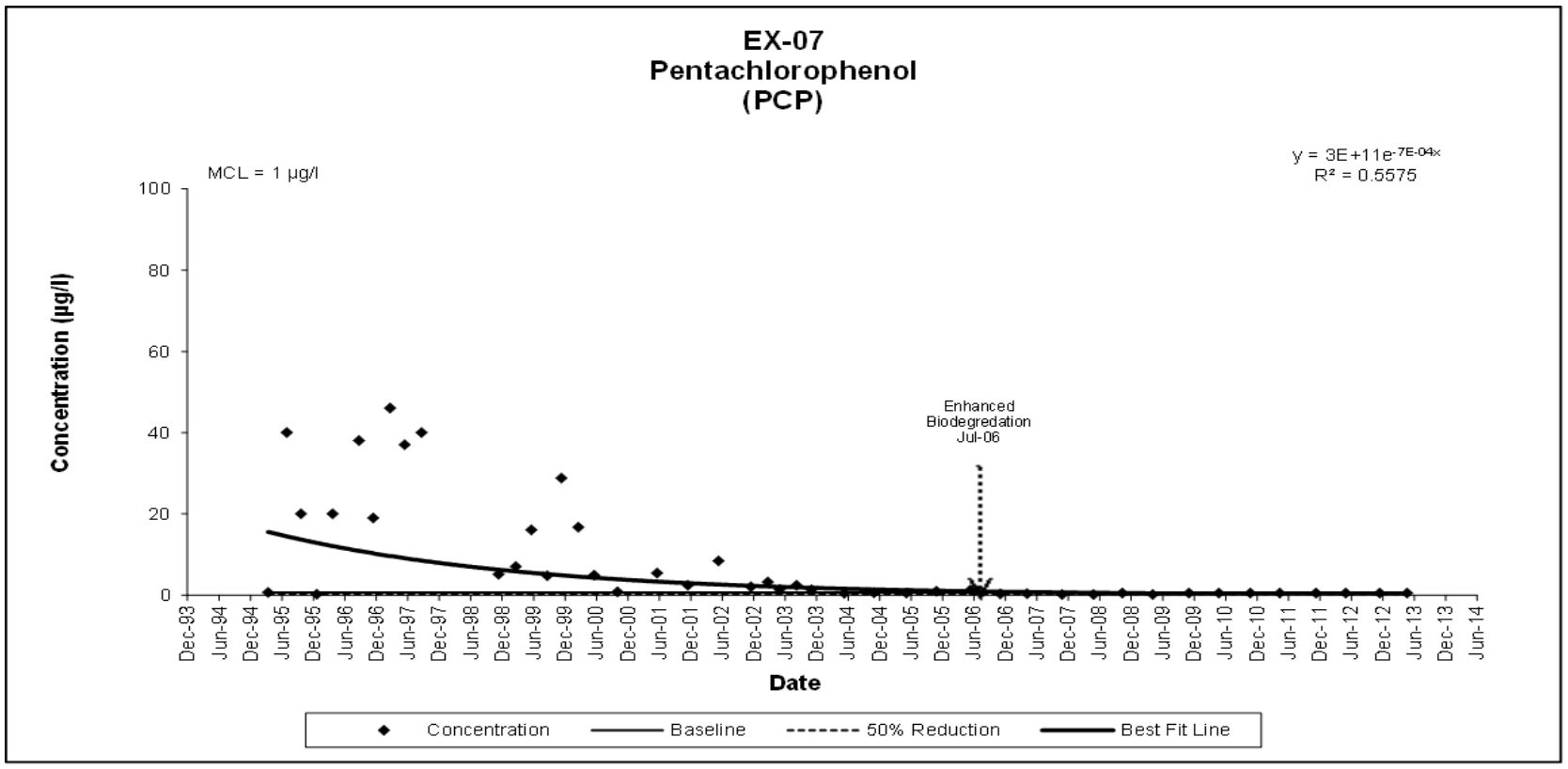


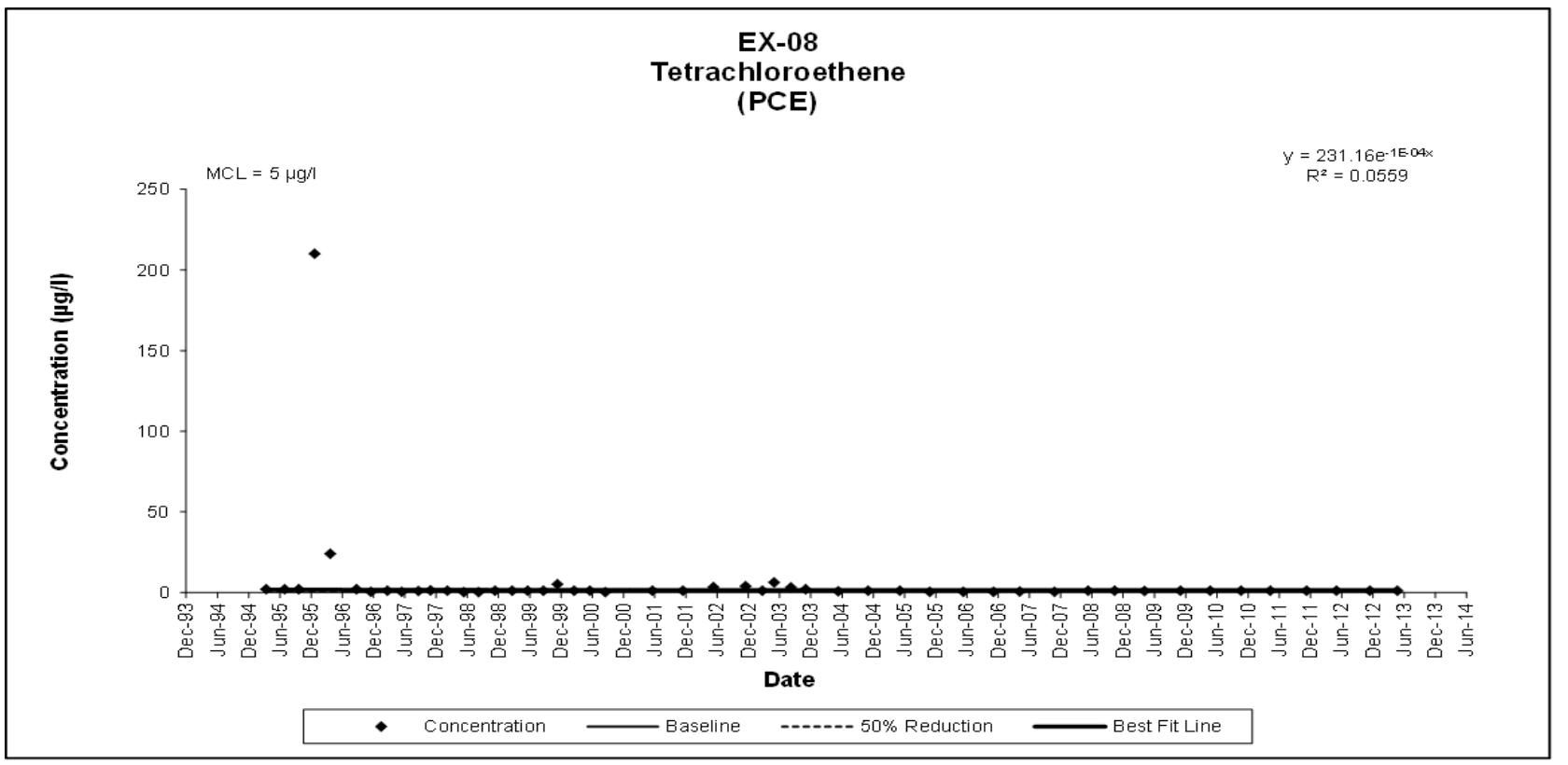
EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	< 2	< 2	< 2	--	--	--	< 10	18.5 J
6-Jul-95	< 2	< 2	< 2	--	--	--	< 20	< 40
27-Sep-95	< 2	< 2	< 2	--	--	--	< 2	30
27-Dec-95	210	420	22	--	--	--	980	29
28-Mar-96	24	23	< 2	--	--	--	< 2	22
28-Aug-96	< 2	< 2	< 2	--	--	--	< 10	20 J
21-Nov-96	0.33 T	3.9	0.88 T	--	--	0.55	< 0.25 UJ	14
26-Feb-97	< 1	0.94 T	0.15 T	--	--	--	< 0.25	8.3
21-May-97	0.32 T	1.2	0.42 T	--	--	--	< 0.25	10 J
26-Aug-97	0.82 T	2	0.45 T	--	--	--	< 0.25	11 B
6-Nov-97	1.3 B	1.4	0.34	--	--	--	< 0.25	11 J
12-Feb-98	< 1	0.39 JB	< 1	--	--	--	< 0.25	3
19-May-98	0.21 J	0.34 J	< 1	--	--	--	< 0.25	2.8
12-Aug-98	0.2 J	0.59 J	< 1	--	--	--	< 0.25	3.5
17-Nov-98	< 1	0.48 J	< 1	--	--	--	< 0.25	3.4
24-Feb-99	< 1 UJ	< 1 UJ	< 1	--	--	--	< 0.25	2.8
26-May-99	< 1	< 1	< 1	--	--	--	< 5 UJ	3
25-Aug-99	< 1	0.49 T	< 1	--	--	--	< 0.2	2.71
17-Nov-99	< 5	0.53 T	< 5	--	--	--	< 0.2	3.08
22-Feb-00	< 1	< 1	< 1	--	--	--	< 0.2	1.85
24-May-00	< 1	0.31 T	< 1	--	--	--	< 0.2	2.77 J
23-Aug-00	< 0.166	0.45	< 0.116	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	2.28 J	0.28 J
23-May-01	< 1	0.5 T	< 1	--	--	--	< 0.5	0.6
19-Nov-01	< 1	0.7 T	< 1	--	--	--	< 0.5	0.2 T
15-May-02	3.3	16	0.7 T	--	--	--	< 0.5	0.4 T
20-Nov-02	3.8	20	< 1	--	--	--	< 0.48	0.3 T
26-Feb-03	1	2.8	< 1	--	--	< 1	0.2 T	0.3 T
6-May-03	6.1	25	0.4 T	--	--	6.5	< 0.5	0.2 T
12-Aug-03	3	9.5	< 1	--	--	3.6	< 0.5	0.2 TJ
6-Nov-03	2	4.2	< 1	--	--	0.8 T	< 2.4	0.5 T
14-May-04	0.7 T	2	< 1	--	--	< 1	--	0.2 TUB
4-Nov-04	< 1	1	< 1	--	--	< 1	--	0.4 T
10-May-05	< 1	0.5 T	< 1	--	--	< 1	--	< 0.5
1-Nov-05	0.4 T	1	< 1	--	--	< 1	--	< 0.5
16-May-06	0.25 T	0.49 T	< 1	--	--	< 1	--	0.74
7-Nov-06	0.39 T	1.5	< 1	--	--	0.54 T	--	0.92
10-Apr-07	0.43 T	1.3	< 1	--	--	0.54 T	--	0.82
30-Oct-07	0.36 T	1.6	< 1	--	--	1.9	--	1.1
13-May-08	< 1	0.22 T	< 1	--	--	< 1	--	1.2
15-Oct-08	< 1	0.22 T	< 1	--	--	< 1	--	1.4
8-Apr-09	0.83 T	4.7	0.92 T	16	1.5	11	--	1
4-Nov-09	< 1	0.4 T	< 1	0.94 T	< 1	0.35 T	--	2.7 D
27-Apr-10	< 1	0.27 T	< 1	< 1	< 1	< 1	--	1.8
25-Oct-10	< 1	0.44 T	< 1	< 1	< 1	< 1	--	3.4 D
12-Apr-11	< 1	0.28 T	< 1	< 1	< 1	< 1	--	1.2
10-Nov-11	< 1	0.28 T	< 1	0.83 T	< 1	0.88 T	--	2.9 D
2-May-12	< 1	< 1	< 1	0.23 T	< 1	< 1	--	2
15-Nov-12	< 1	0.29 T	< 1	< 1	< 1	< 1	--	2.4 D
25-Apr-13	< 1	< 1	< 1	< 1	< 1	< 1	--	0.87

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08



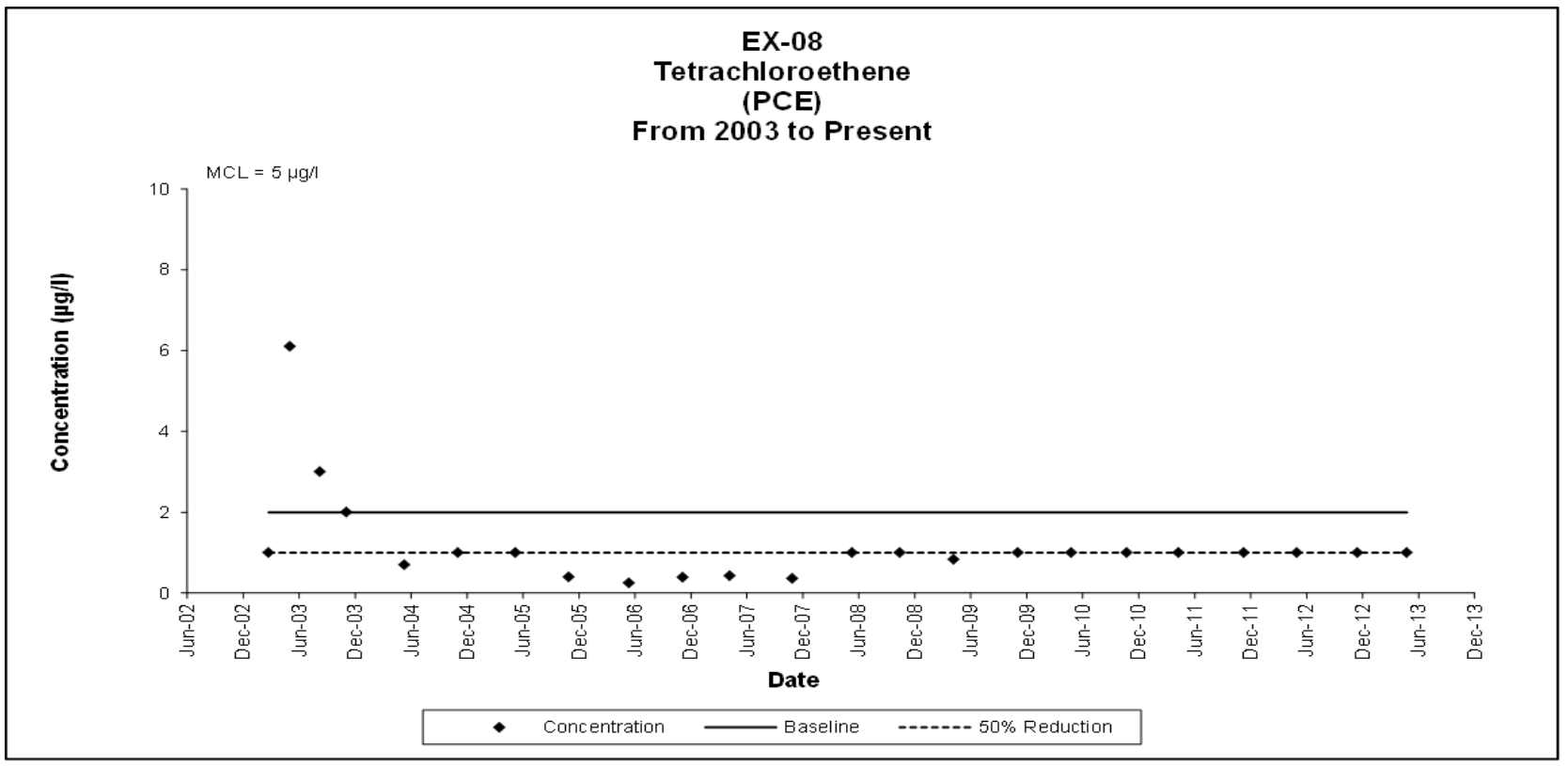
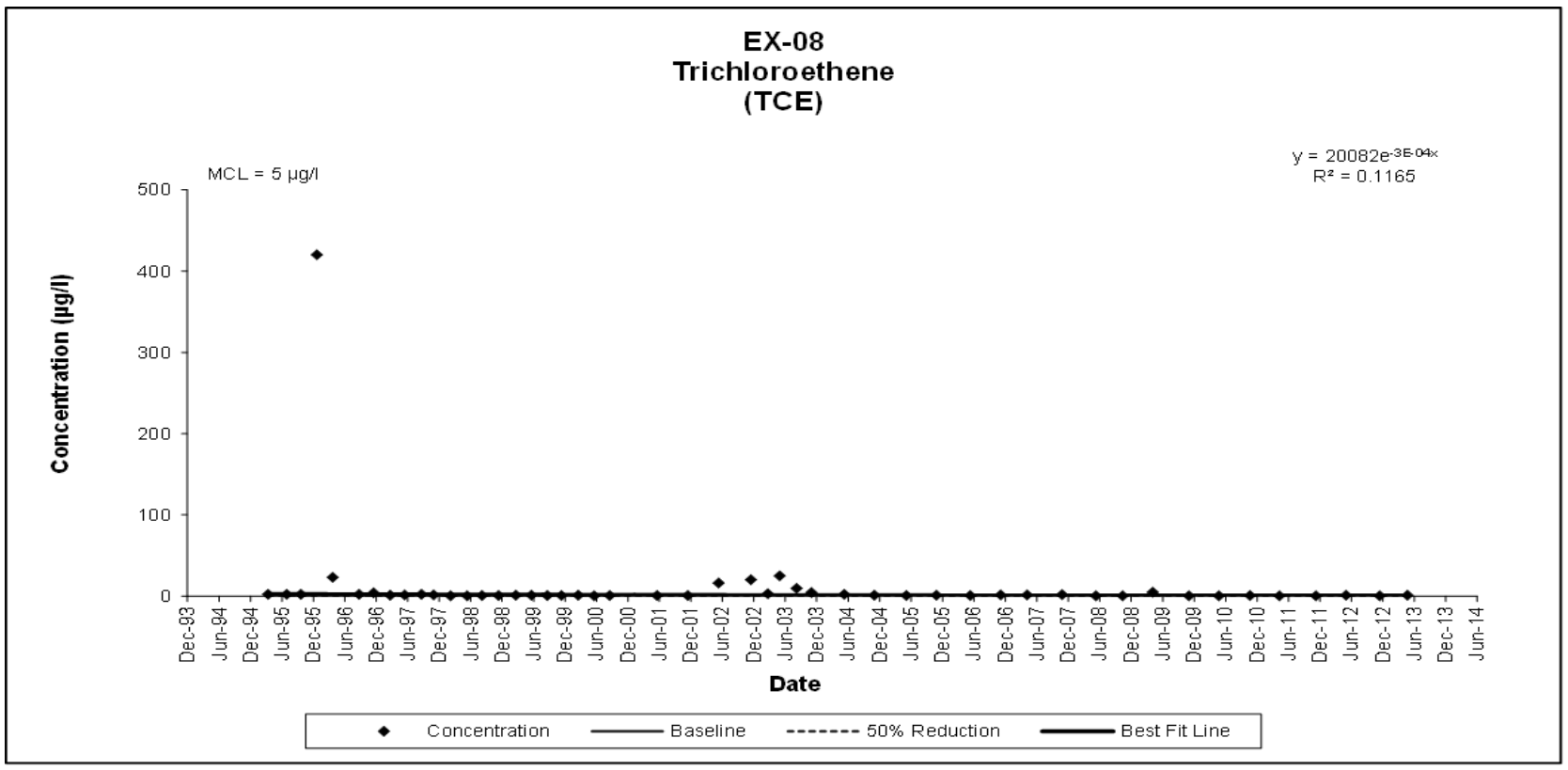


EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08



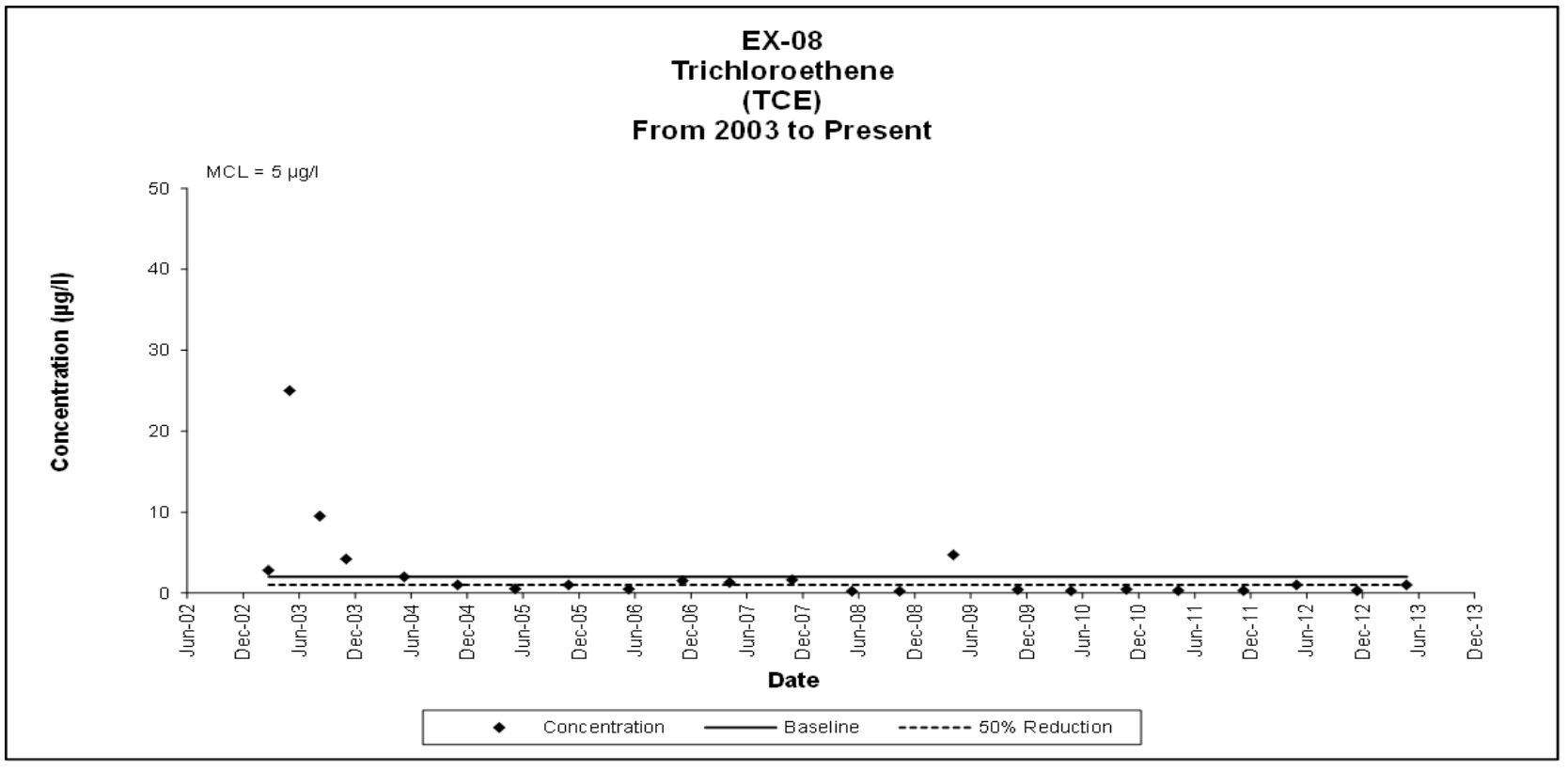
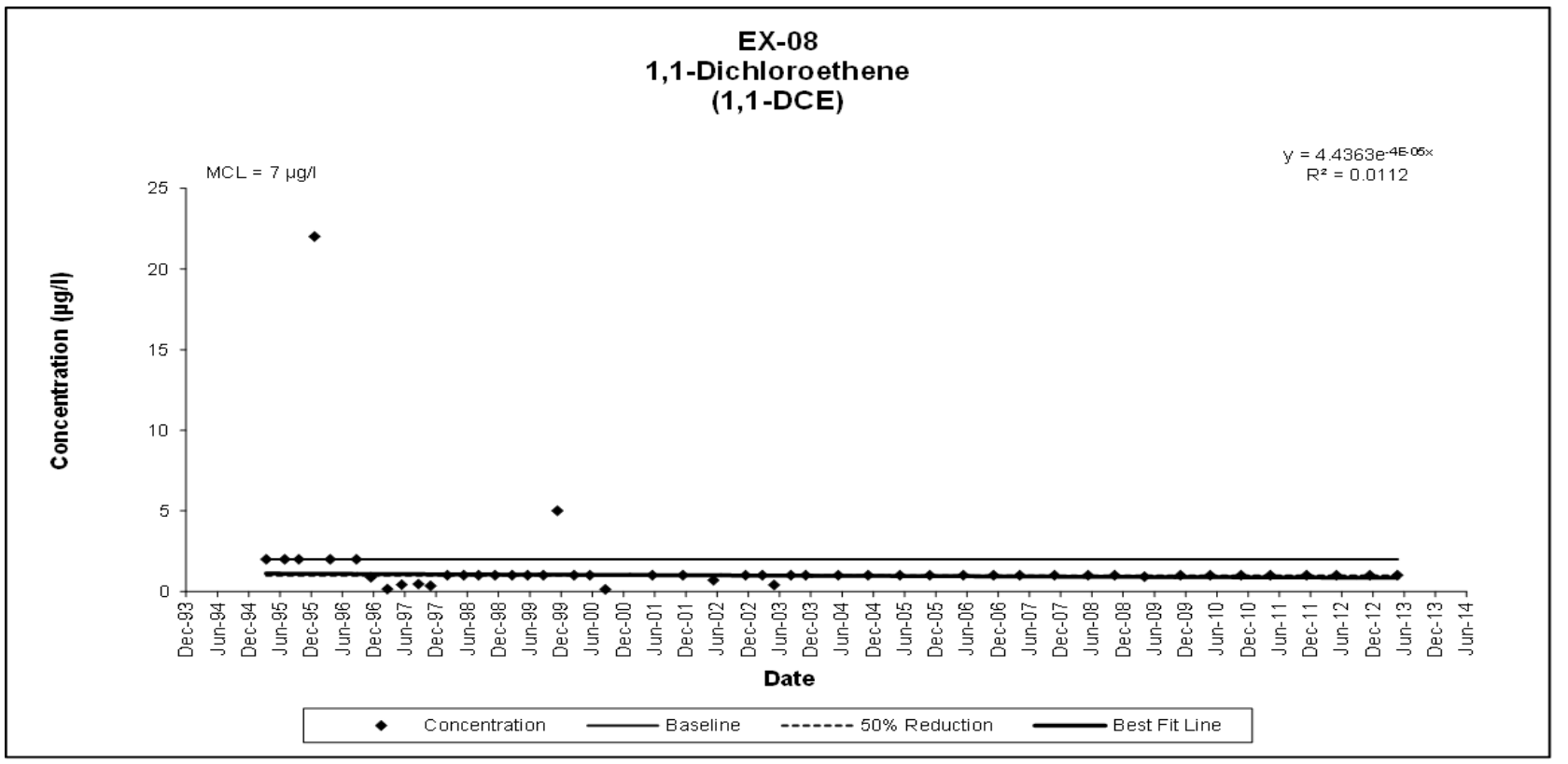


EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08



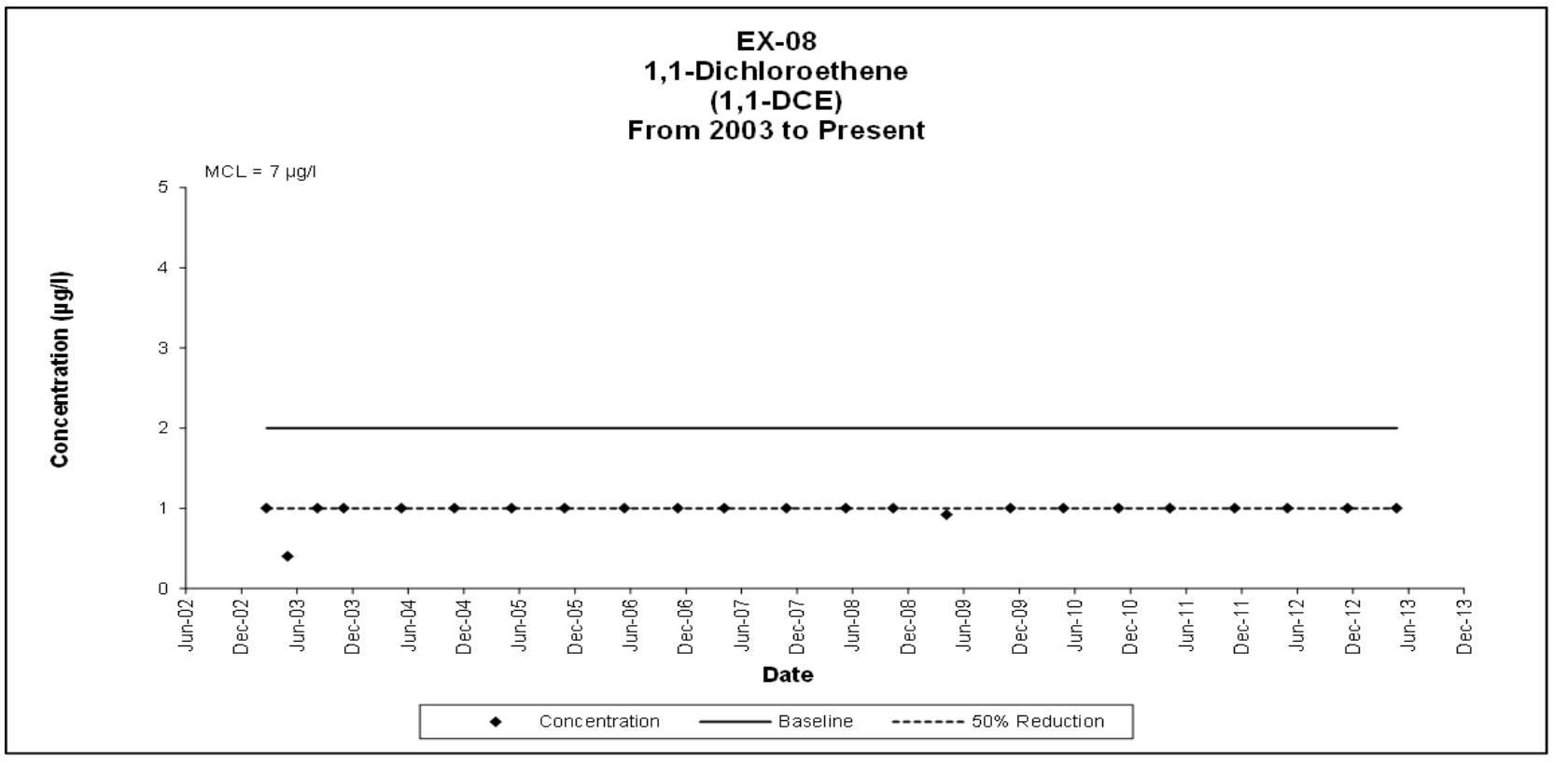
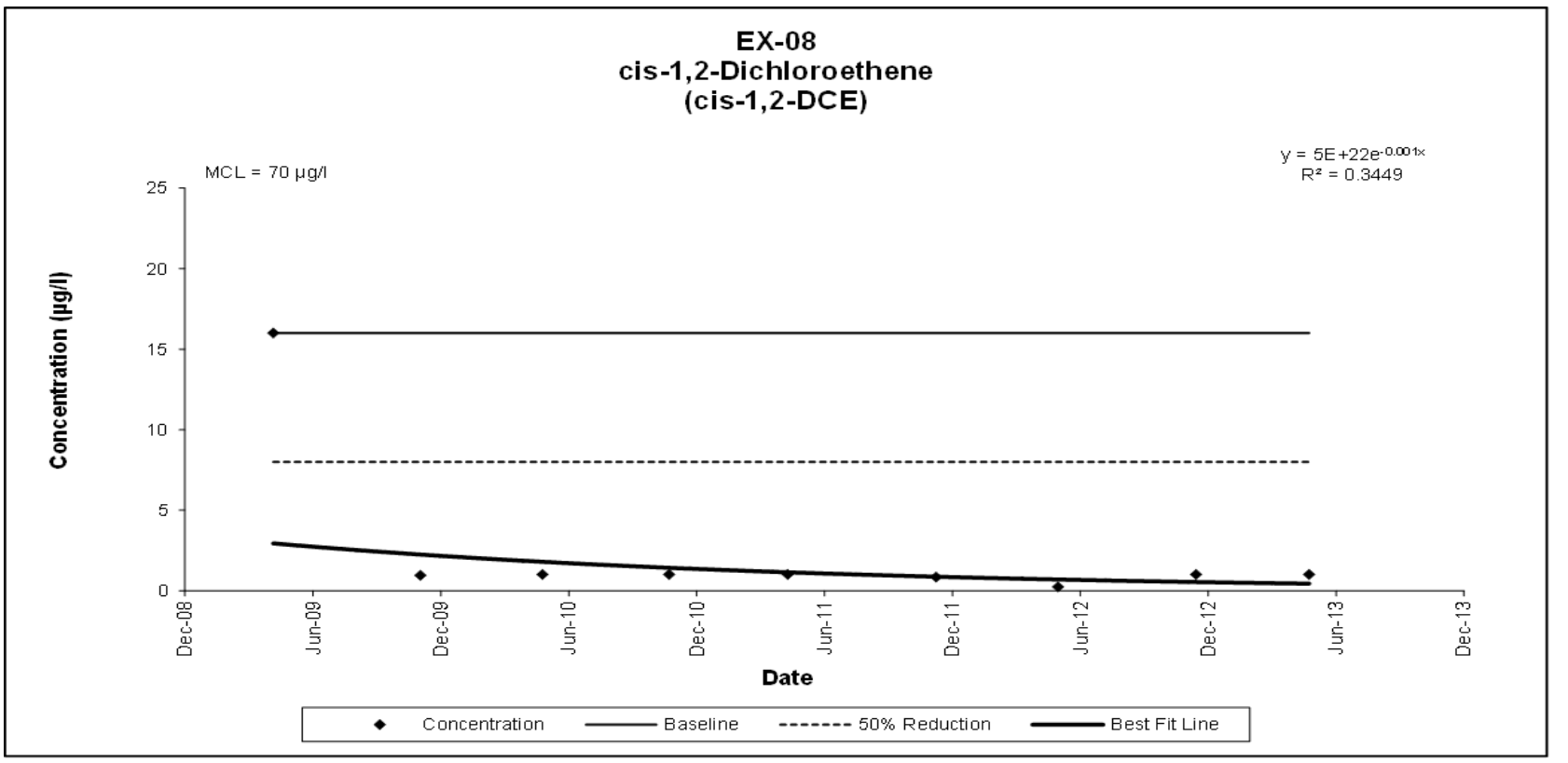


EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08



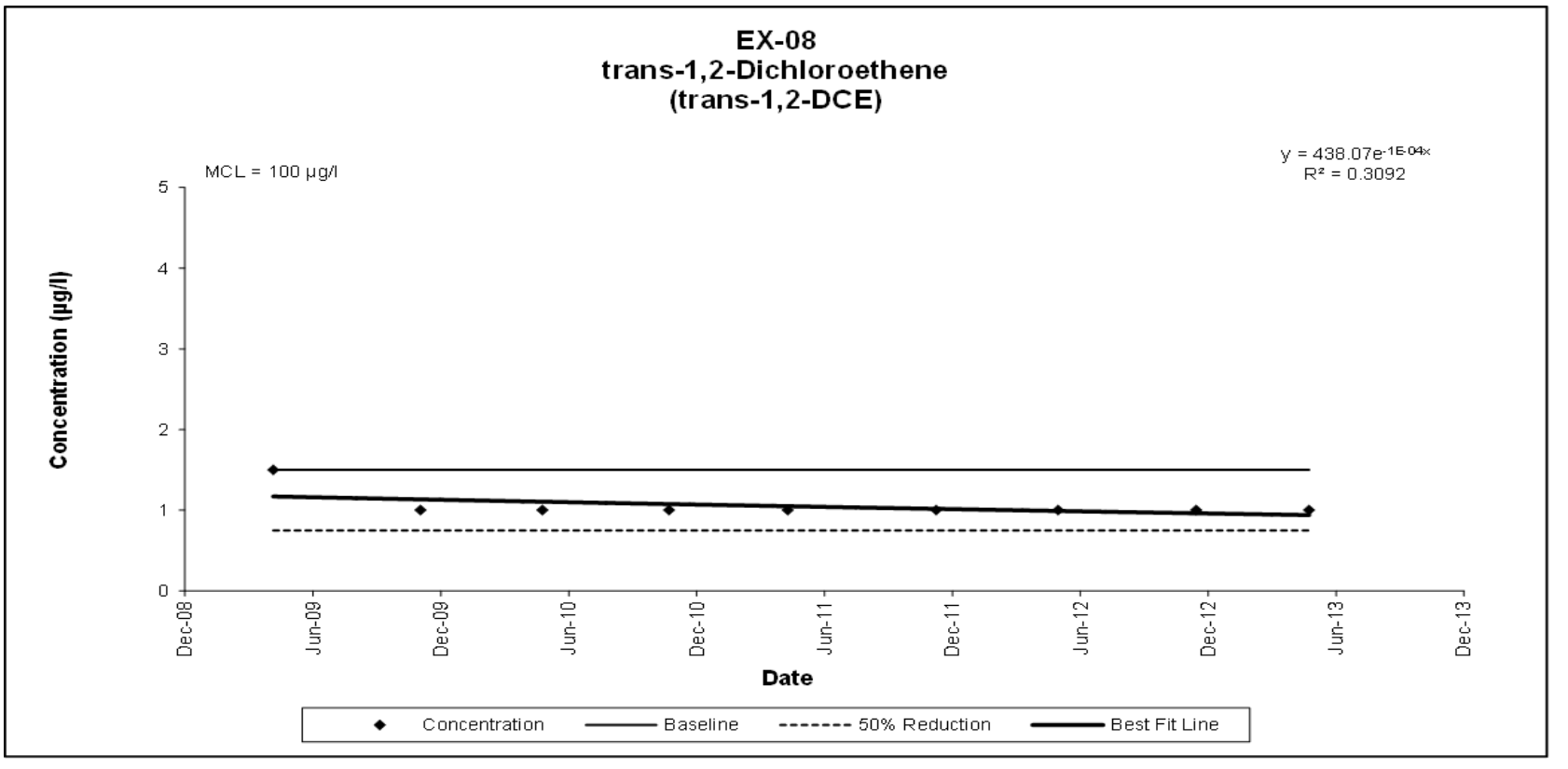
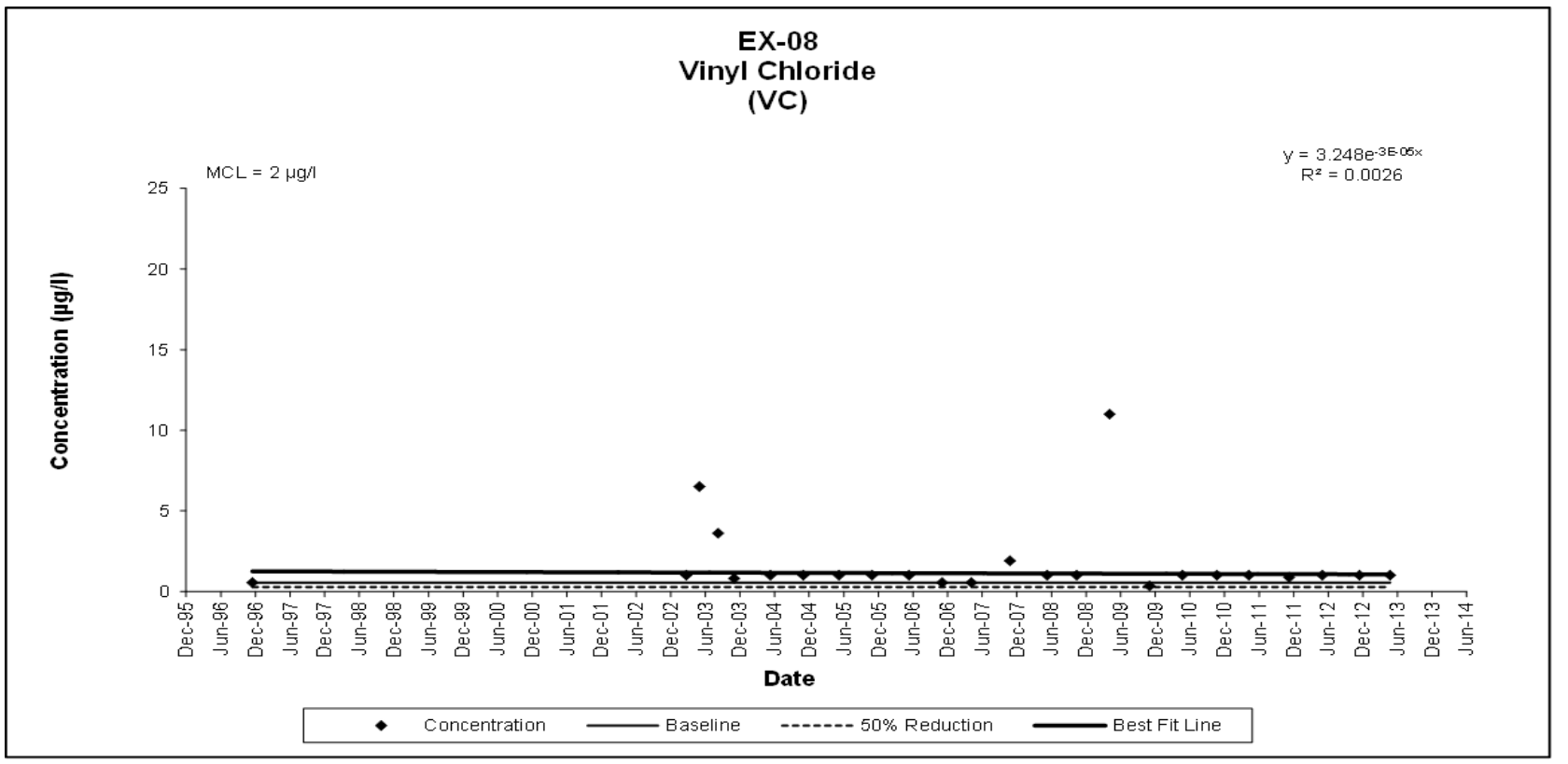


EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08



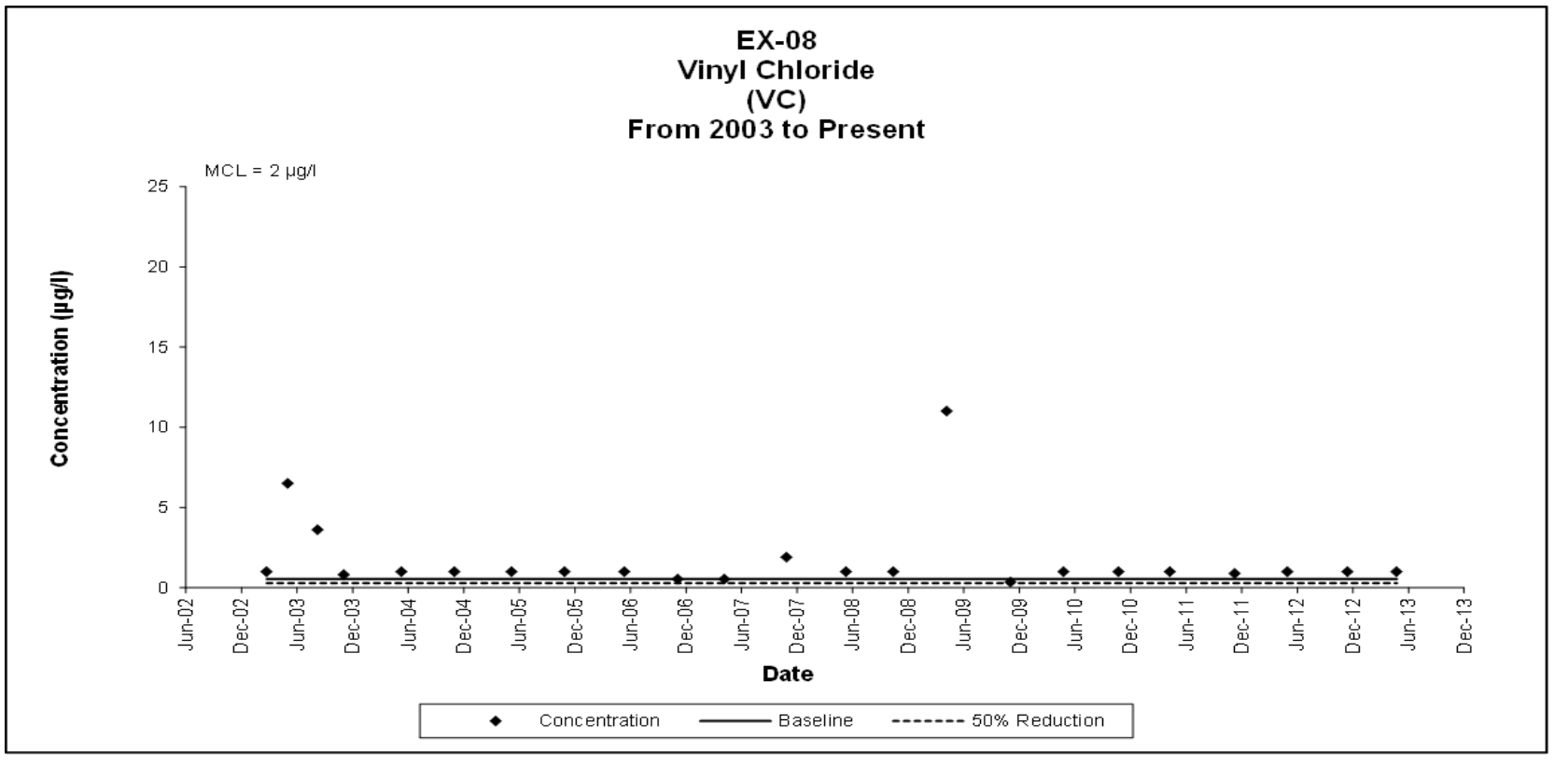


EXHIBIT B2-6
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-08

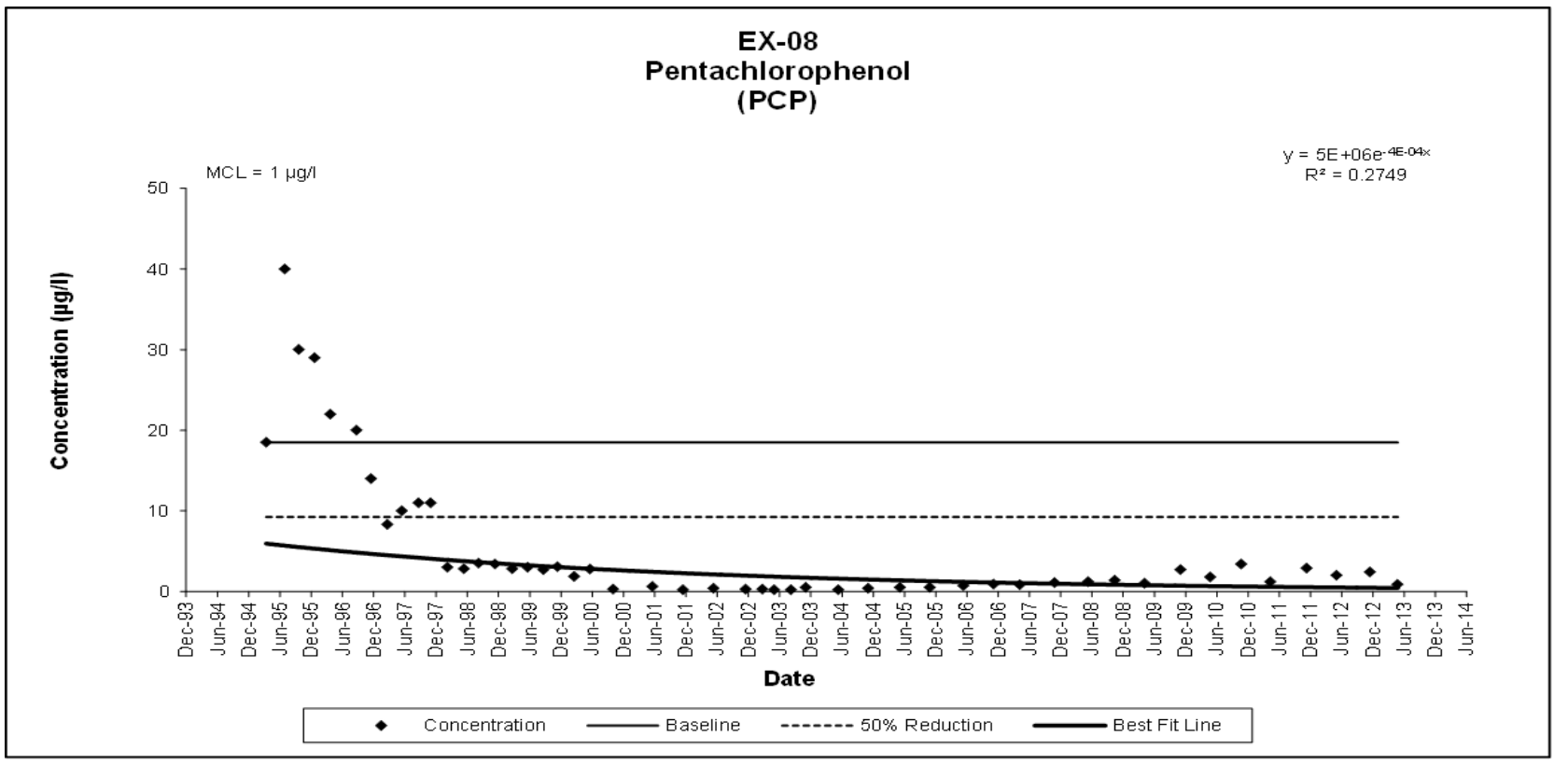


EXHIBIT B2-7
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-09

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	< 2	190	25	--	--	--	< 2	< 0.2 J
6-Jul-95	< 2	120	6.7	--	--	--	< 2 J	< 0.2 J
27-Sep-95	< 2	200	35	--	--	--	< 2	< 0.2
27-Dec-95	< 2	190	17	--	--	--	< 2	< 0.2
28-Mar-96	< 2	170	9.1	--	--	--	< 2	< 0.2
28-Aug-96	< 2	90	6.7	--	--	--	< 10	< 0.2
20-Nov-96	< 1	84	6.5	--	--	0.23	< 0.25	< 1
26-Feb-97	< 1	72	4.3	--	--	--	< 0.25	< 1
21-May-97	2	130	8	--	--	--	< 0.25	1
26-Aug-97	< 1	85	5.7	--	--	--	< 0.25	1
6-Nov-97	0.58 JB	60	4.1	--	--	--	< 0.25	< 1
12-Feb-98	< 1	19 B	1.9	--	--	--	< 0.25	< 1
19-May-98	< 1	38	3.5	--	--	--	< 0.25	< 1
12-Aug-98	< 1	73	5	--	--	--	< 0.25	< 1
17-Nov-98	< 1	29	2.8 J	--	--	--	< 0.25	< 0.5
24-Feb-99	< 1	30 J	2.3 J	--	--	--	< 0.25	< 0.5
26-May-99	< 1	12	1.1	--	--	--	< 4 UJ	< 0.5
25-Aug-99	< 1	35	2.7	--	--	--	< 0.2	< 0.1
17-Nov-99	< 5	21	1.9 T	--	--	--	< 0.2	< 0.1
22-Feb-00	< 1	9.2	1.4	--	--	--	< 0.2	< 0.1
24-May-00	< 1	17	1.7	--	--	--	< 0.2	< 0.1
23-Aug-00	25 D	310 D	19 D	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	0.43 J	< 0.5 UJ
23-May-01	< 1	5.9	0.8 T	--	--	--	< 0.5	< 0.5
19-Nov-01	< 1	4.6	1 T	--	--	--	< 0.5	< 0.5
15-May-02	< 1	2	< 1	--	--	--	< 0.5	< 0.5
20-Nov-02	< 1	2.9	1	--	--	--	< 0.48	< 0.48
26-Feb-03	< 1	2	0.8 T	--	--	< 1	< 0.48 UJ	< 0.48 UJ
6-May-03	< 1	1	1	--	--	< 1	< 0.5	< 0.5
12-Aug-03	< 1	0.8 T	1	--	--	< 1	< 0.5	< 0.5
5-Nov-03	< 1	1	2.4	--	--	< 1	< 2.4	< 0.48
13-May-04	< 1	0.5 T	< 1	--	--	< 1	--	0.1 T
4-Nov-04	< 1	0.7 T	0.7 T	--	--	< 1	--	< 0.48
10-May-05	< 1	0.5 T	< 1	--	--	< 1	--	< 0.5
1-Nov-05	< 1	0.4 T	0.6 T	--	--	< 1	--	< 0.5
16-May-06	< 1	0.42 T	0.32 T	--	--	< 1	--	< 0.5
7-Nov-06	< 1	0.7 T	1.3	--	--	< 1	--	< 0.5
10-Apr-07	< 1	0.27 T	1.7	--	--	0.22 T	--	< 0.5
30-Oct-07	< 1	0.6 T	1.8	--	--	1.2	--	< 0.5
30-Apr-08	< 1	< 1	0.61 T	--	--	< 1	--	< 0.5
13-Oct-08	< 1	0.36 T	1.8	--	--	< 1	--	< 0.5
7-Apr-09	< 1	0.29 T	2	24	6	< 1	--	< 0.5
3-Nov-09	< 1	0.33 T	1.6	19	5.8	< 1	--	< 0.5
27-Apr-10	< 1	0.28 T	2.8	35	10	< 1	--	< 0.5
27-Oct-10	< 1	0.25 T	1.7	26	8.2	< 1	--	< 0.5
14-Apr-11	< 1	0.21 T	1.2	17	5.6	< 1	--	< 0.5
10-Nov-11	< 1	0.24 T	1.2	15	5.3	< 1	--	< 0.5
21-Dec-11	--	--	--	--	--	--	--	< 0.5
1-May-12	< 1	0.21 T	2.1	25	7	0.22 T	--	--
13-Nov-12	< 1	0.29 T	2.5	35	9	0.22 T	--	--
23-Apr-13	< 1	0.23 T	2	25	7.5	< 1	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-7
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-09

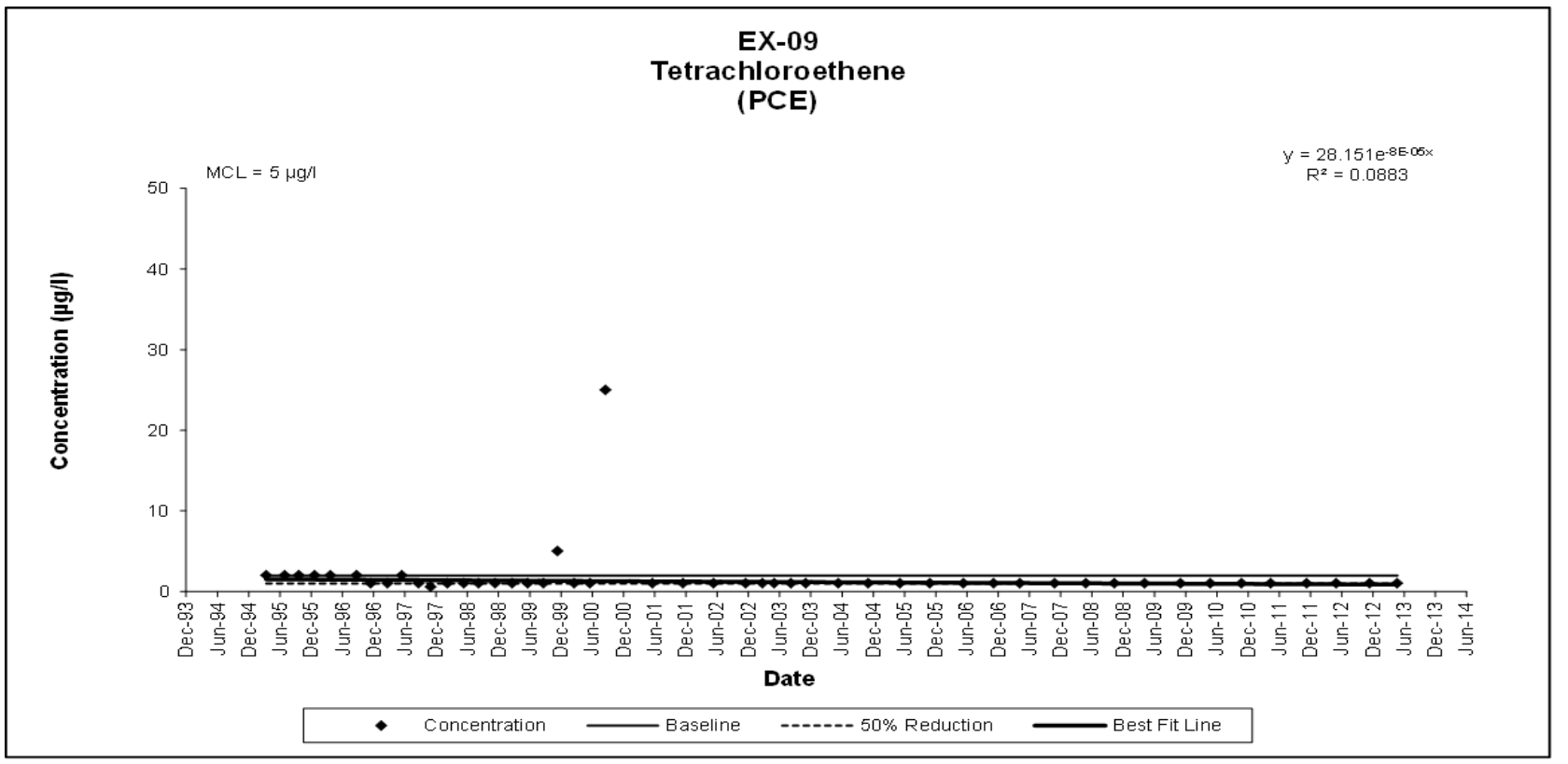
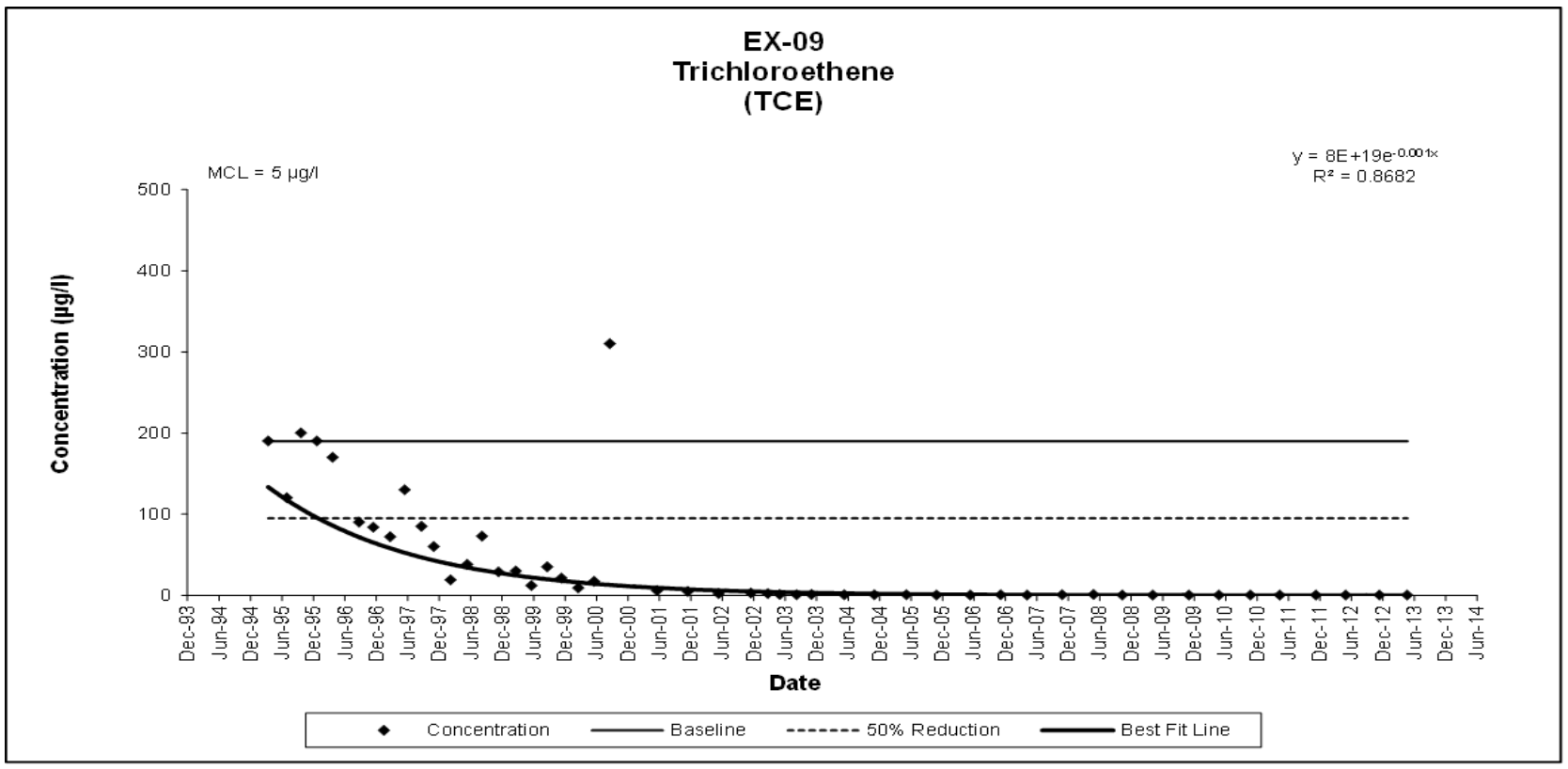


EXHIBIT B2-7
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-09



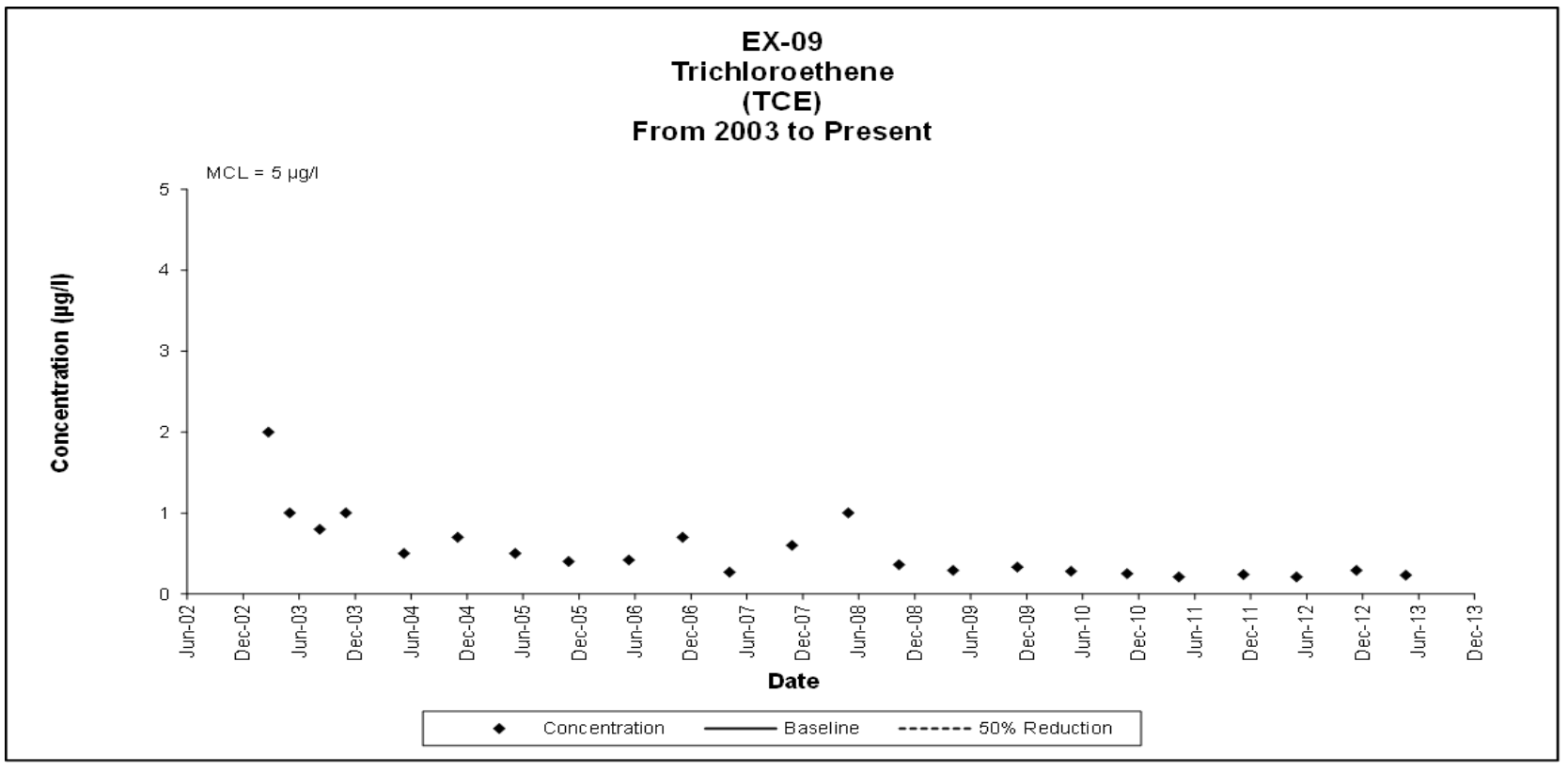
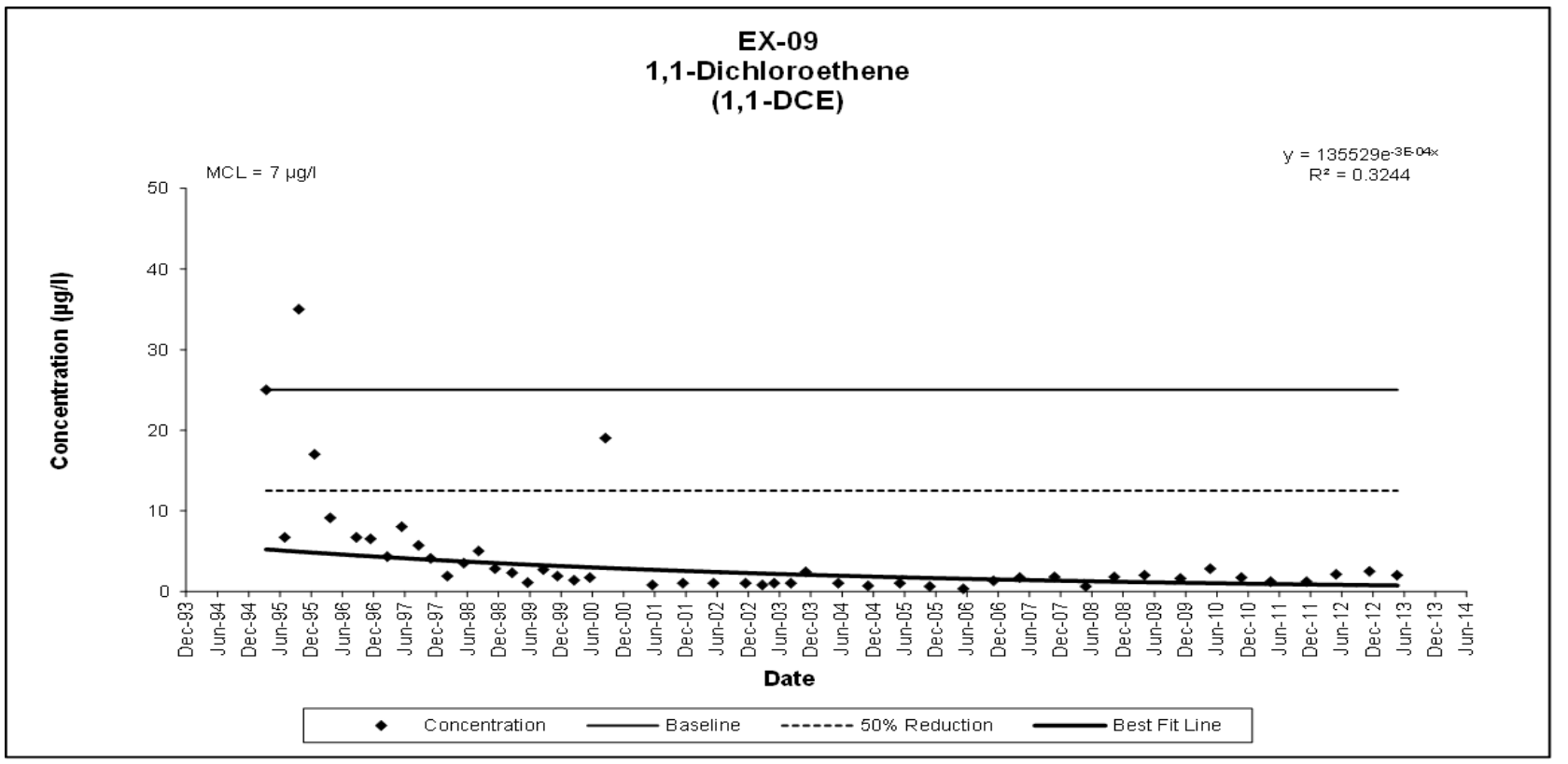


EXHIBIT B2-7
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-09



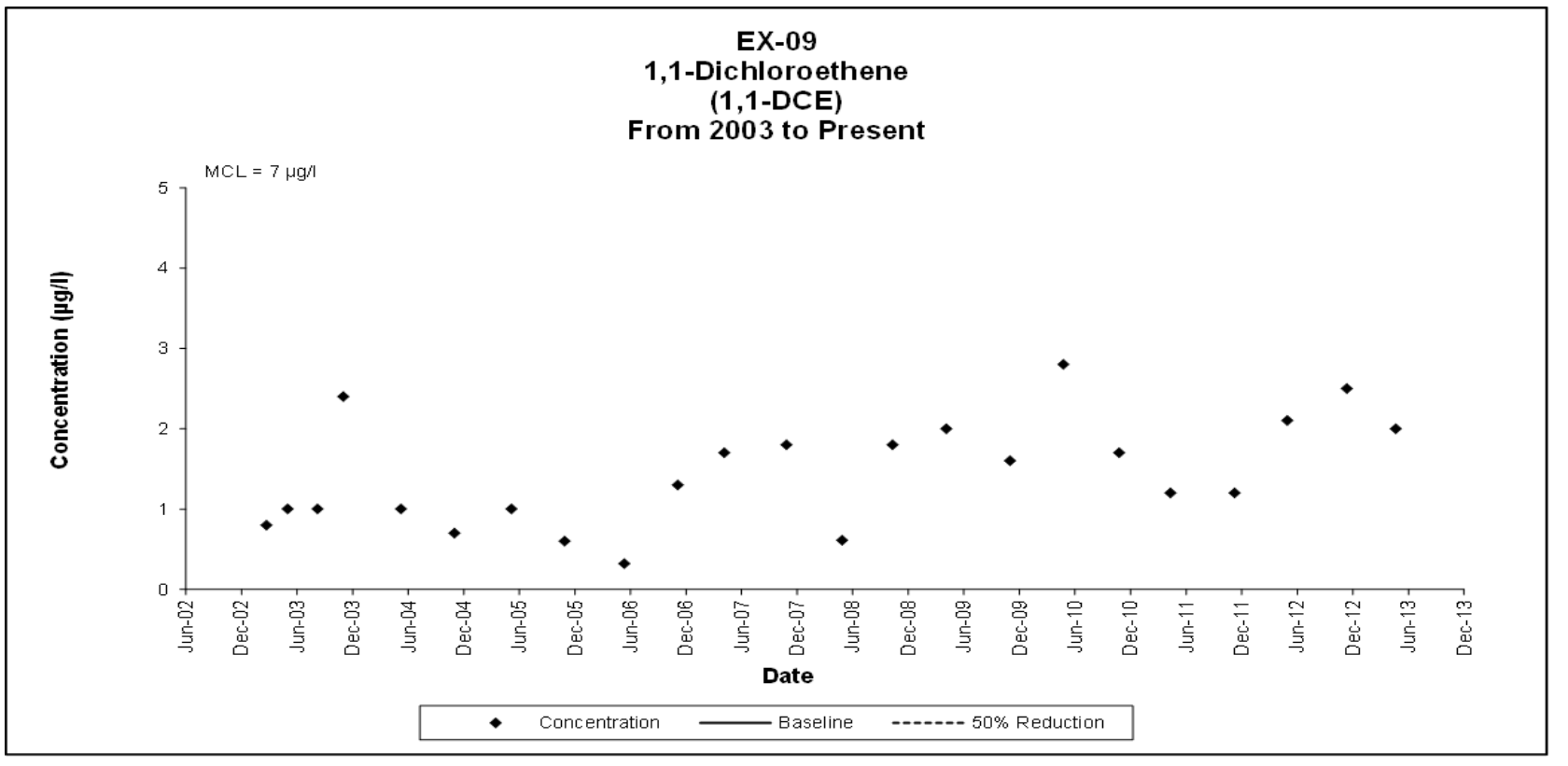
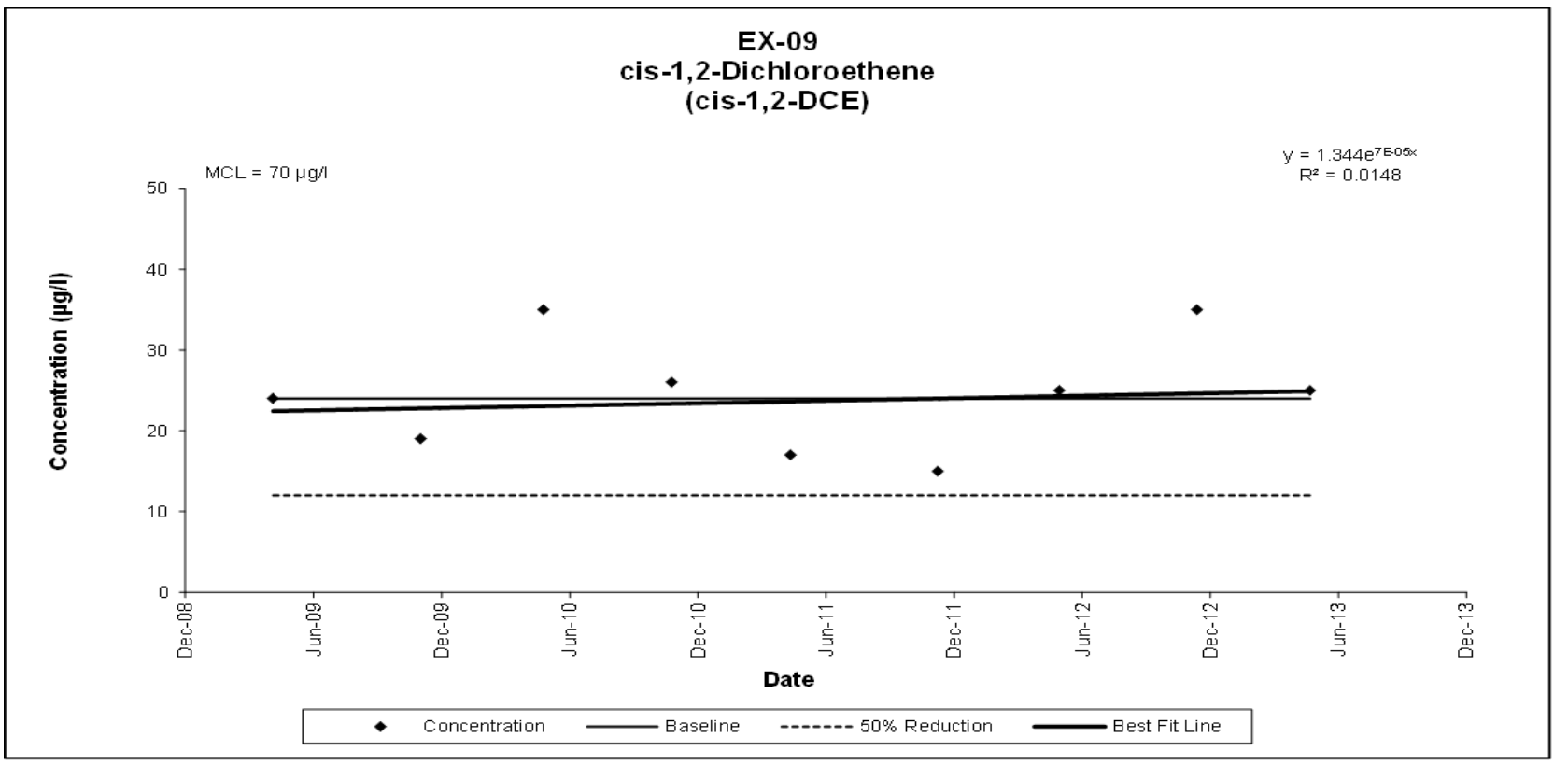


EXHIBIT B2-7
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-09



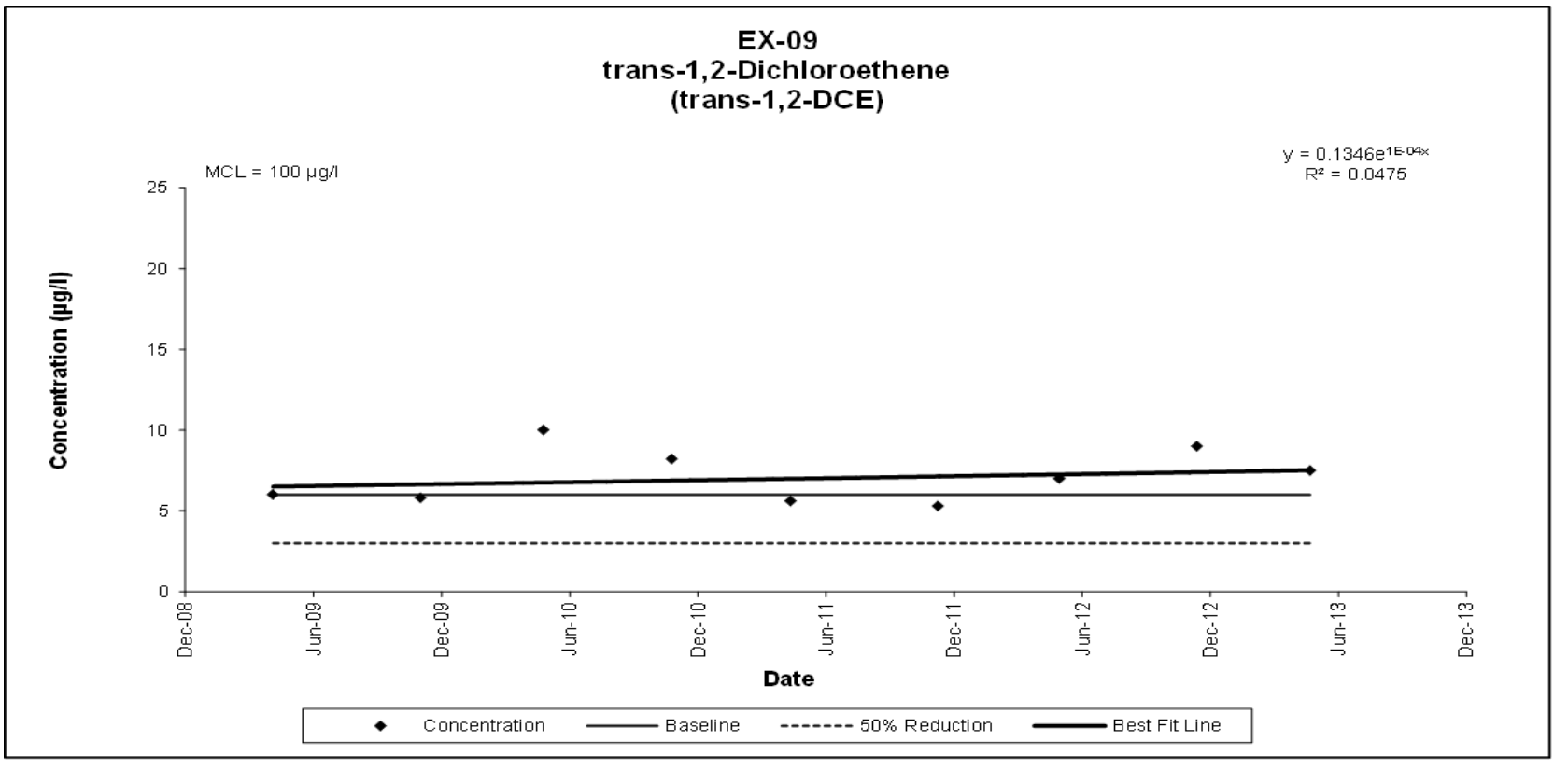
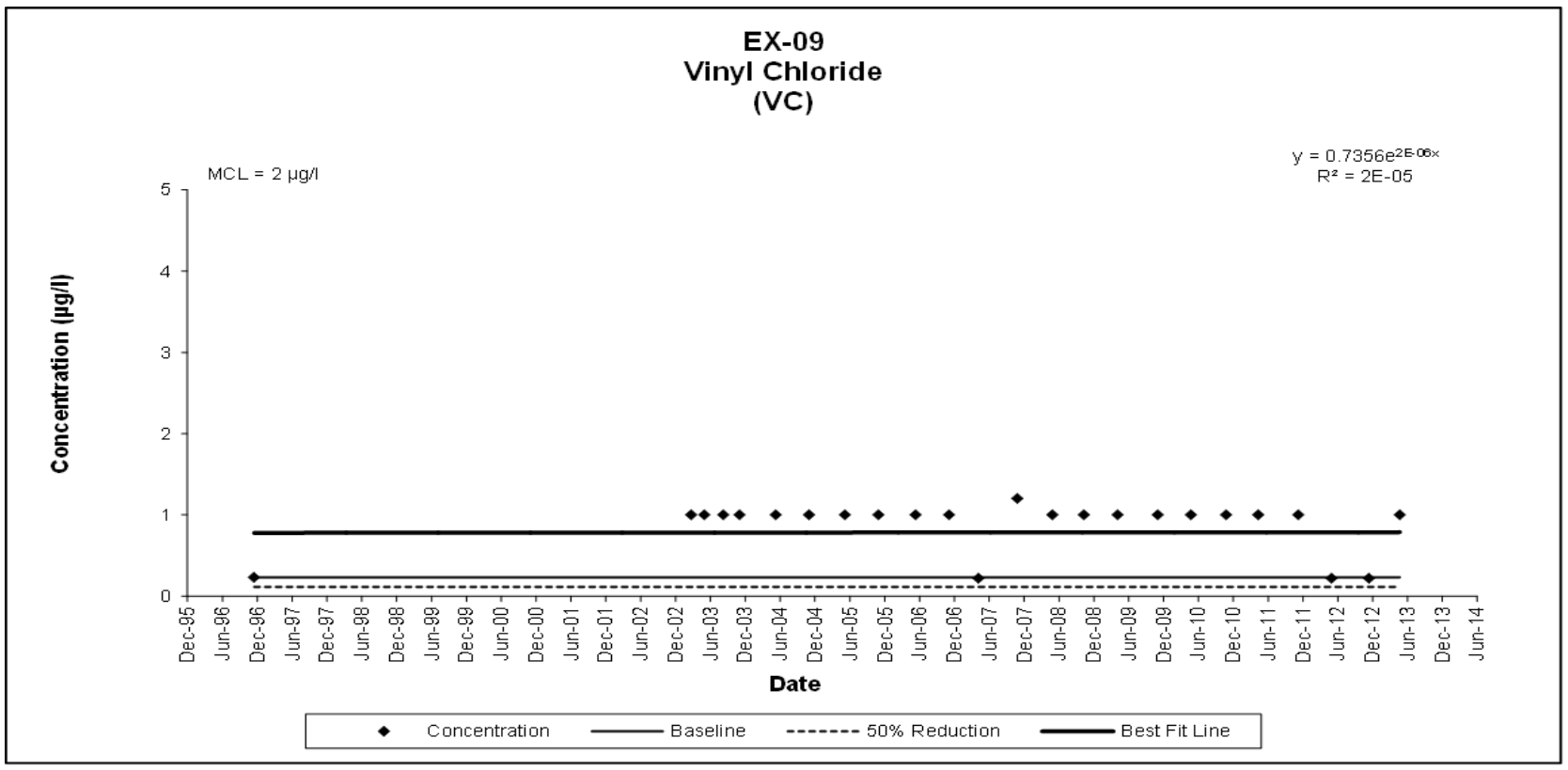


EXHIBIT B2-7
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-09



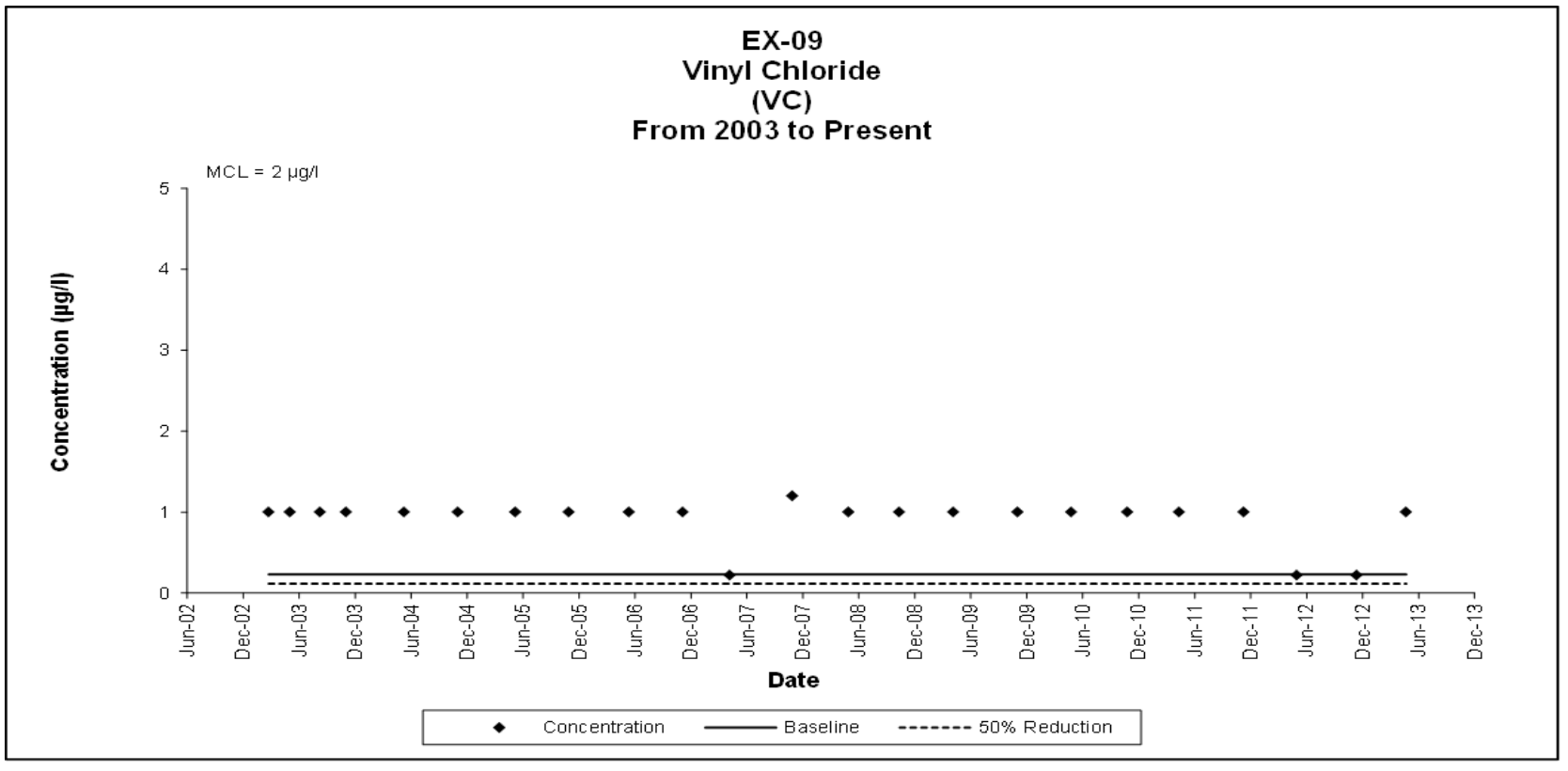


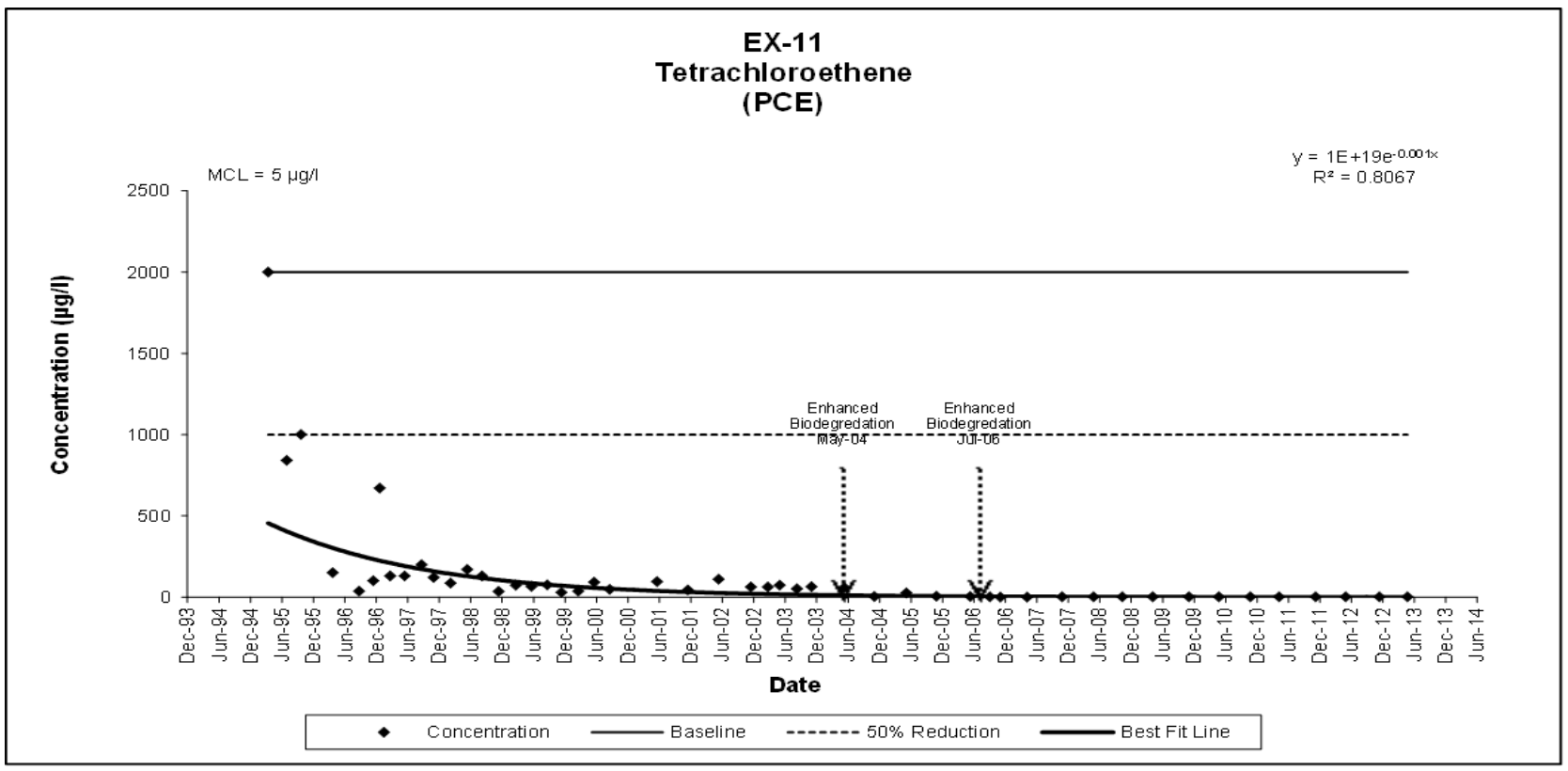
EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	2000	5900	380	--	--	--	3.89 J	< 2 J
6-Jul-95	840	3200	< 200	--	--	--	< 20 J	< 0.2 J
27-Sep-95	1000	1600	210	--	--	--	< 2	< 0.2
28-Mar-96	150	380	28	--	--	--	< 2	< 0.2
28-Aug-96	36	390	36	--	--	--	< 10	< 0.2
20-Nov-96	100	560	34	--	--	130	< 0.6 UJ	< 1
27-Dec-96	670	920	63	--	--	--	< 2	< 0.2
26-Feb-97	130	470	25	--	--	--	< 0.25	< 1
21-May-97	130	300	33	--	--	--	< 0.25	1
26-Aug-97	200	560	39	--	--	--	< 2.5	1
6-Nov-97	120	560	33	--	--	--	< 2.5	< 1
12-Feb-98	86 B	330 B	26	--	--	--	< 0.25	< 1
19-May-98	170	420	34	--	--	--	< 0.25	< 1
12-Aug-98	130	420	35	--	--	--	< 0.55	< 1
17-Nov-98	34	400	31 J	--	--	--	< 2.5 G	< 0.6 G
24-Feb-99	72 J	530 J	30 J	--	--	--	< 2.5 G	< 0.5
26-May-99	65	250 J	15	--	--	--	< 4 UJ	< 0.5
25-Aug-99	74	420	23	--	--	--	5.68	0.631
17-Nov-99	29 T	480	26 T	--	--	--	< 0.2	< 0.1
22-Feb-00	37	400	24	--	--	--	< 0.2	< 0.1
24-May-00	91	480 J	22	--	--	--	< 0.2	< 0.1
23-Aug-00	47 D	420 D	21 D	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	4.66	0.45
23-May-01	95 D	382 D	27 D	--	--	--	< 0.5	0.1 T
19-Nov-01	43 D	392 D	29 D	--	--	--	< 0.5	< 0.5
15-May-02	110 D	402 D	27 D	--	--	--	< 0.48	< 0.48
20-Nov-02	62 DJ	347 D	31 DJ	--	--	--	< 0.48	< 0.48 UJ
26-Feb-03	61	339	24	--	--	170	< 0.48 UJ	< 0.48 UJ
6-May-03	72 D	420 D	24	--	--	247 D	< 0.5	< 0.5 UJ
13-Aug-03	50	374 D	35	--	--	271 D	< 0.5	< 0.5 J
5-Nov-03	64 D	362 D	35 D	--	--	394 D	< 2.4	< 0.48 UJ
13-May-04	59 J	460 D	51 J	--	--	658 D	--	0.1 TJ
4-Nov-04	2.7	120 D	12	--	--	617 DJ	--	< 0.48 UJ
10-May-05	< 25 D	120 D	19 TD	--	--	500 D	--	< 0.5 UJ
31-Oct-05	< 5 D	82 D	15 D	--	--	580 D	--	< 0.5 UJ
16-May-06	3.2	210 DJ	20	--	--	380 DJ	--	< 0.5
6-Sep-06	0.56 T	23	0.99 T	--	--	310 D	--	--
6-Nov-06	0.36 TJ+	13 J+	1.2 J+	--	--	160 D	--	< 0.5
10-Apr-07	0.29 T	15	3.6	--	--	300 D	--	< 0.5
30-Oct-07	< 1	4.3	0.74 T	--	--	480 DJ	--	< 0.5
30-Apr-08	1.2	64 D	18	--	--	920 D	--	< 0.5
14-Oct-08	< 1	3.8	1.1	--	--	520 D	--	< 0.5
8-Apr-09	< 1	83 D	23	1200 D	120 D	560 D	--	< 0.5
3-Nov-09	< 1	2.5	3.4	300 D	78 D	840 D	--	< 0.5
26-Apr-10	< 1	35	20	1300 D	100	550 D	--	< 0.5
27-Oct-10	< 1	2.3	4.1	420 D	87	790 DJ-	--	< 0.5
11-Apr-11	1.7	26	15	740 D	81	230 D	--	< 0.5
9-Nov-11	< 1	2	1.2	97	54	240 D	--	< 0.5
1-May-12	< 1	14	6.1	360 D	73	590 D	--	< 0.5
13-Nov-12	< 1	3	1.3	140 D	65	470 D	--	< 0.5
24-Apr-13	< 1	69	15	670 D	84	460 D	--	< 0.5

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11



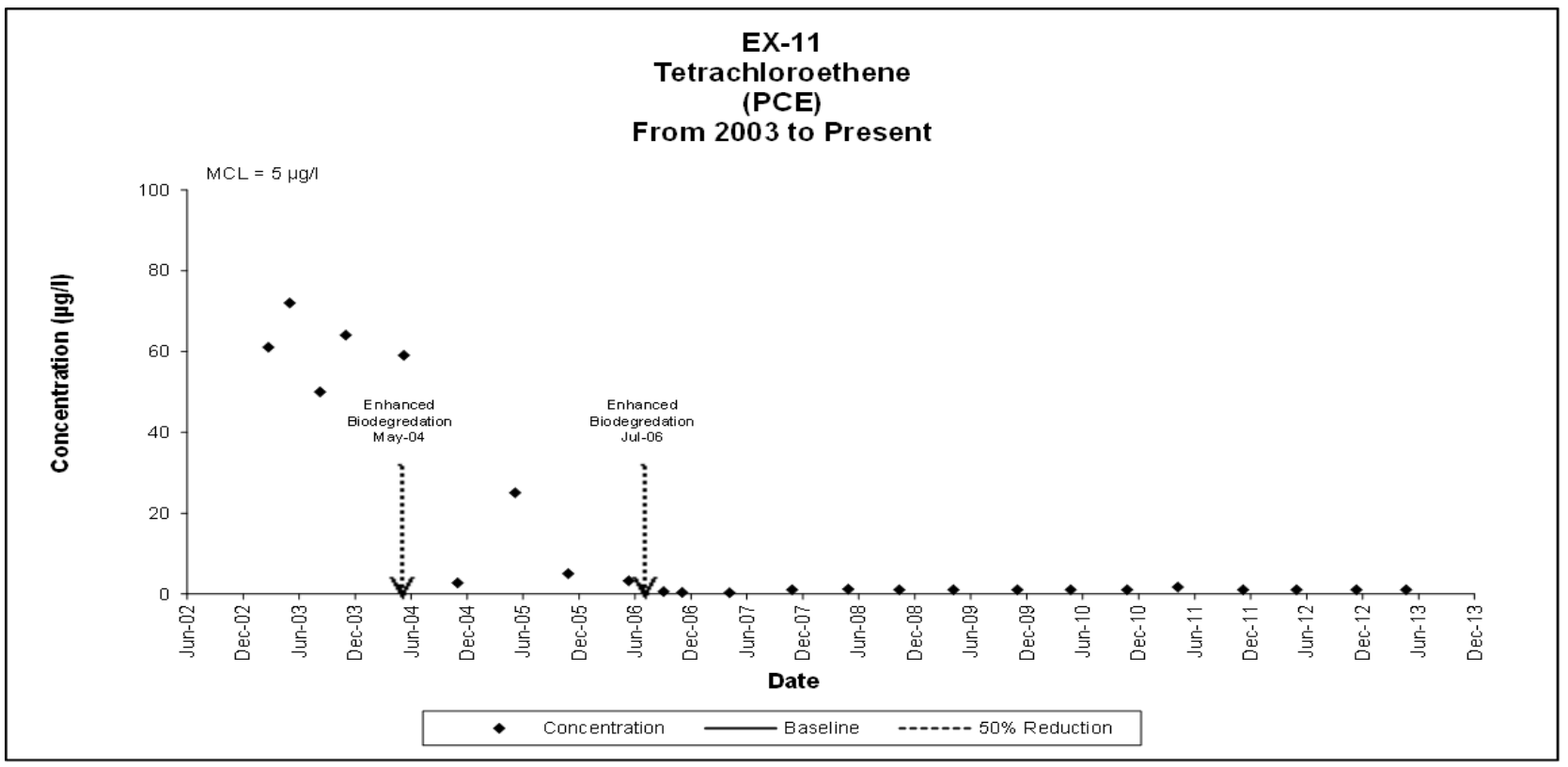
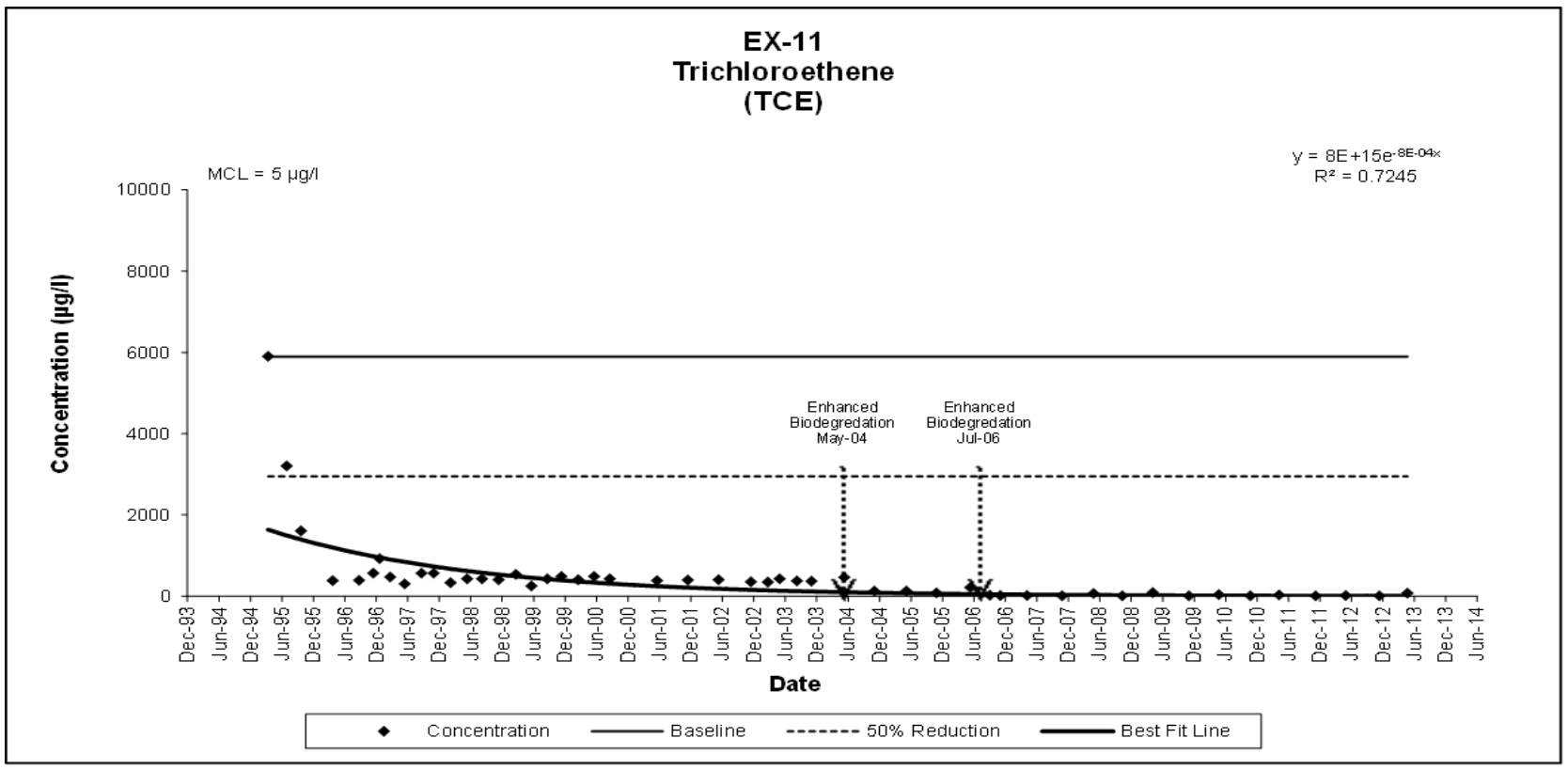


EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11



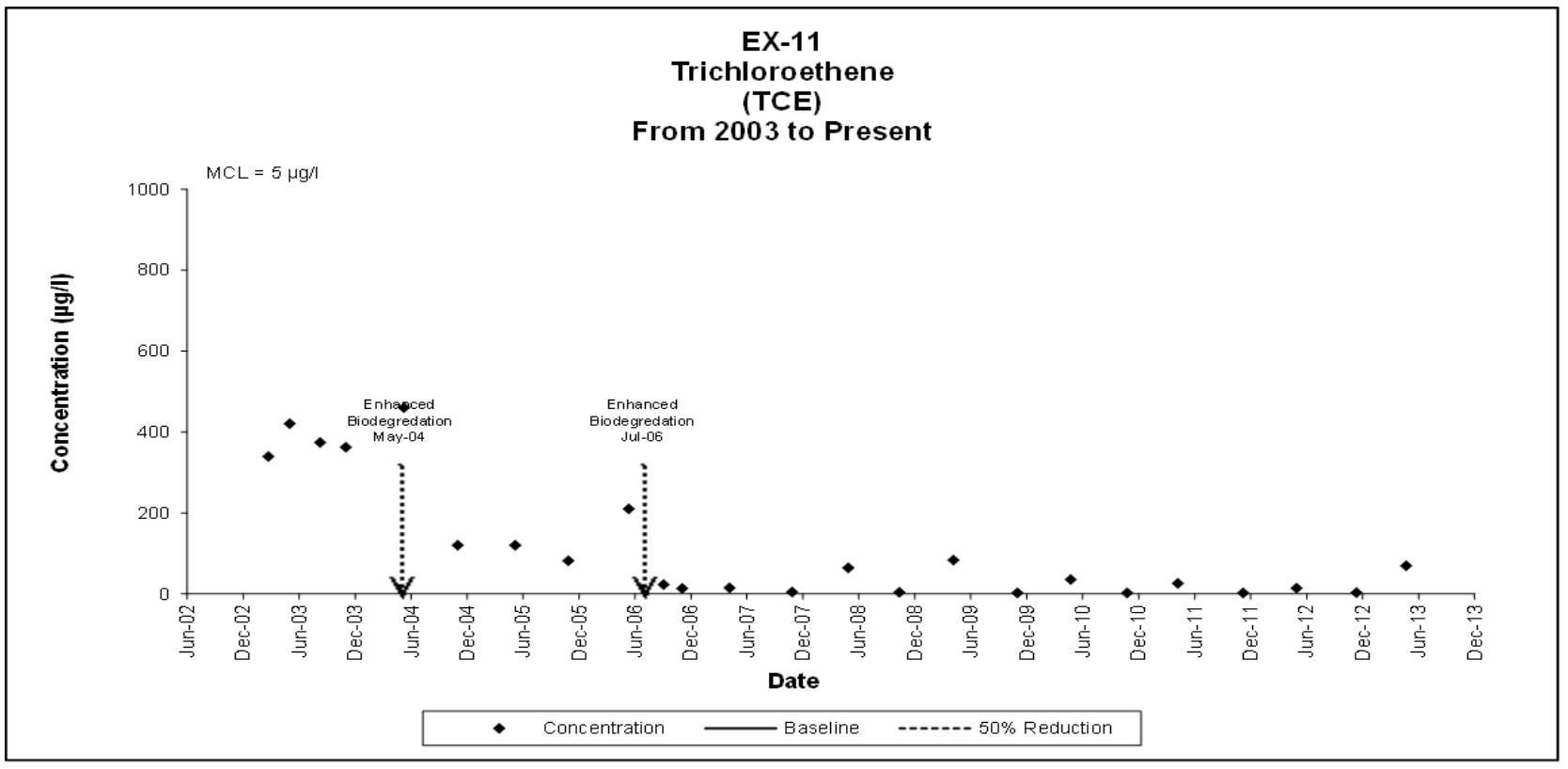


EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11

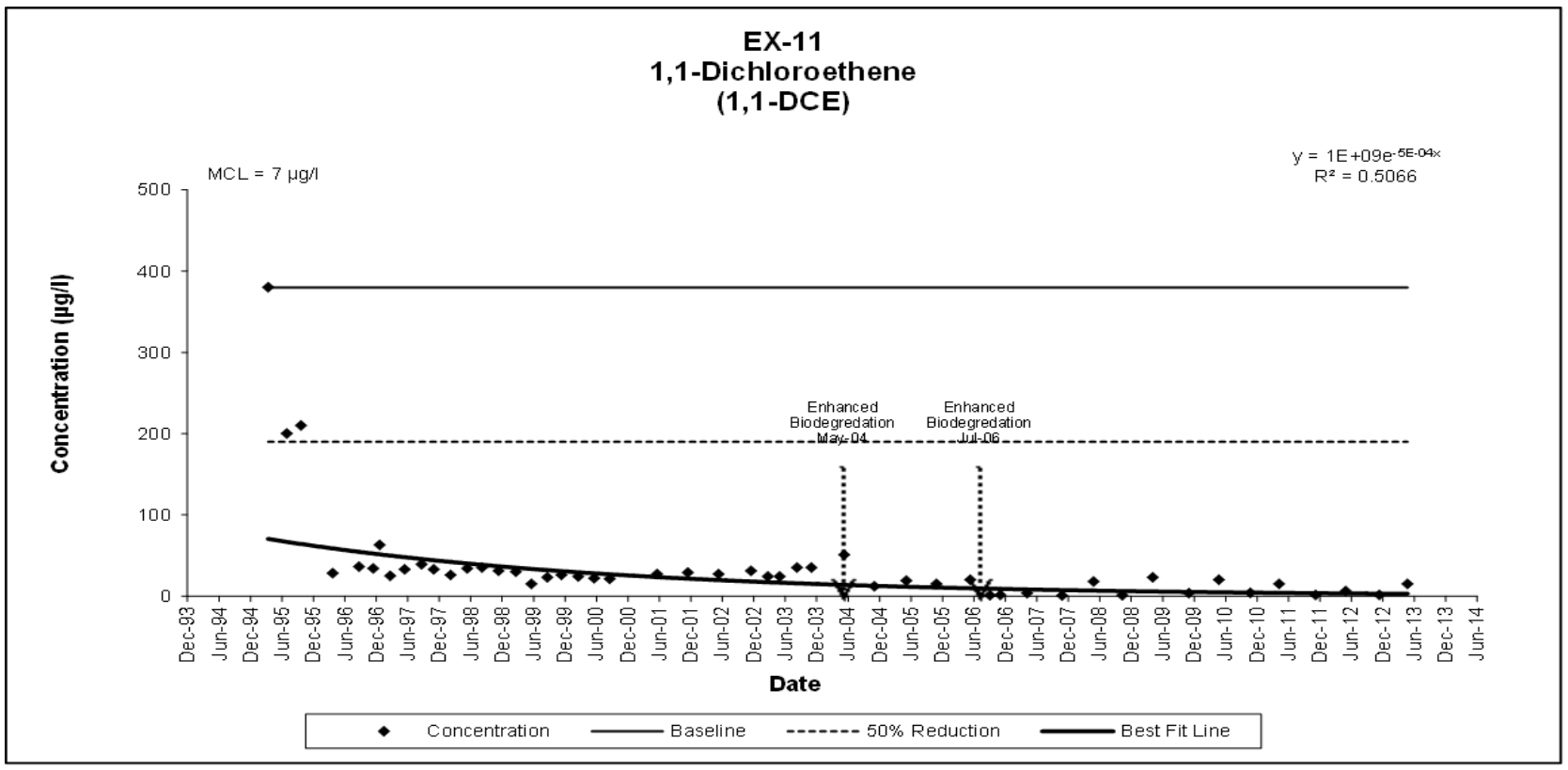


EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11

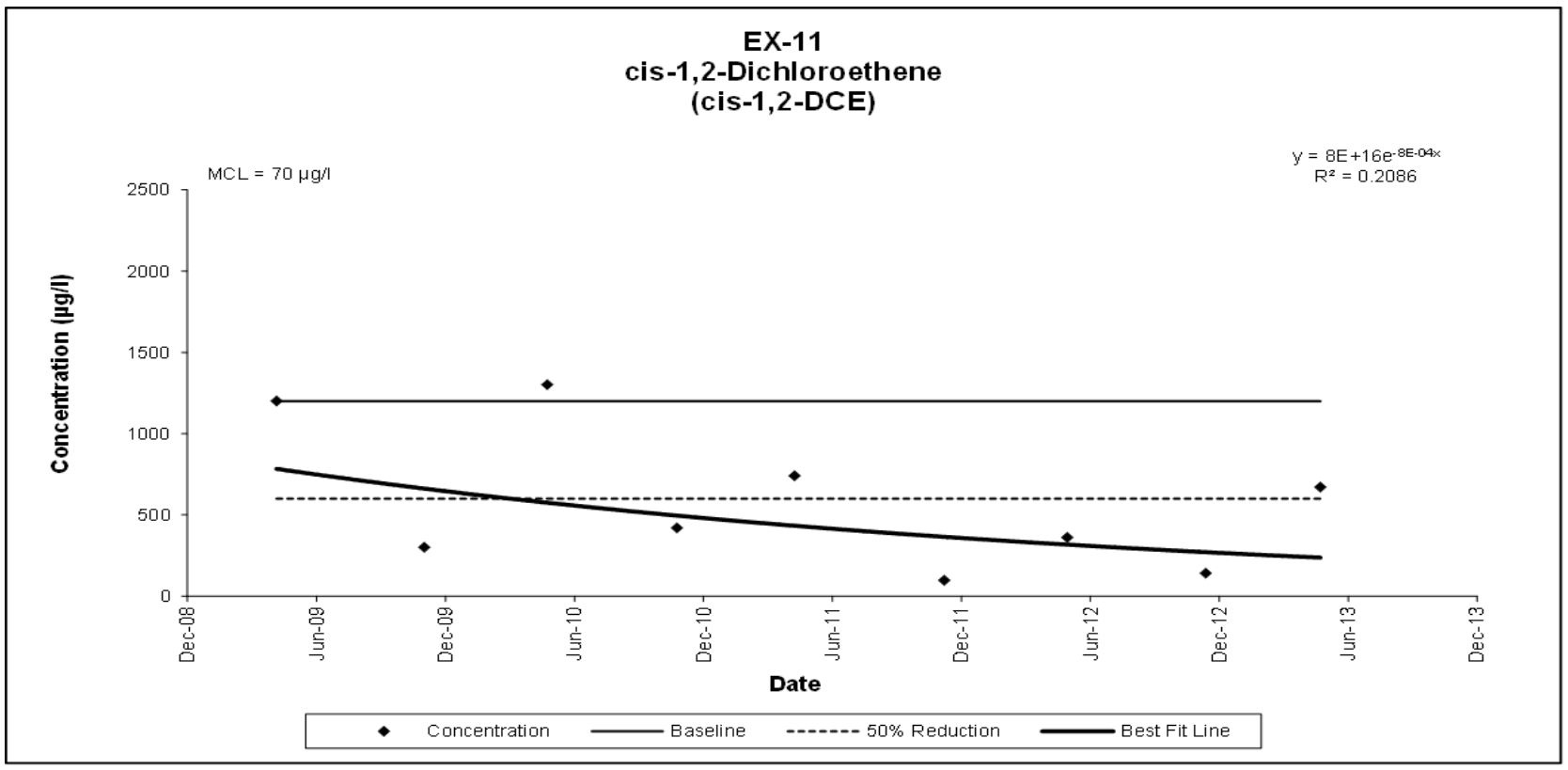


EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11

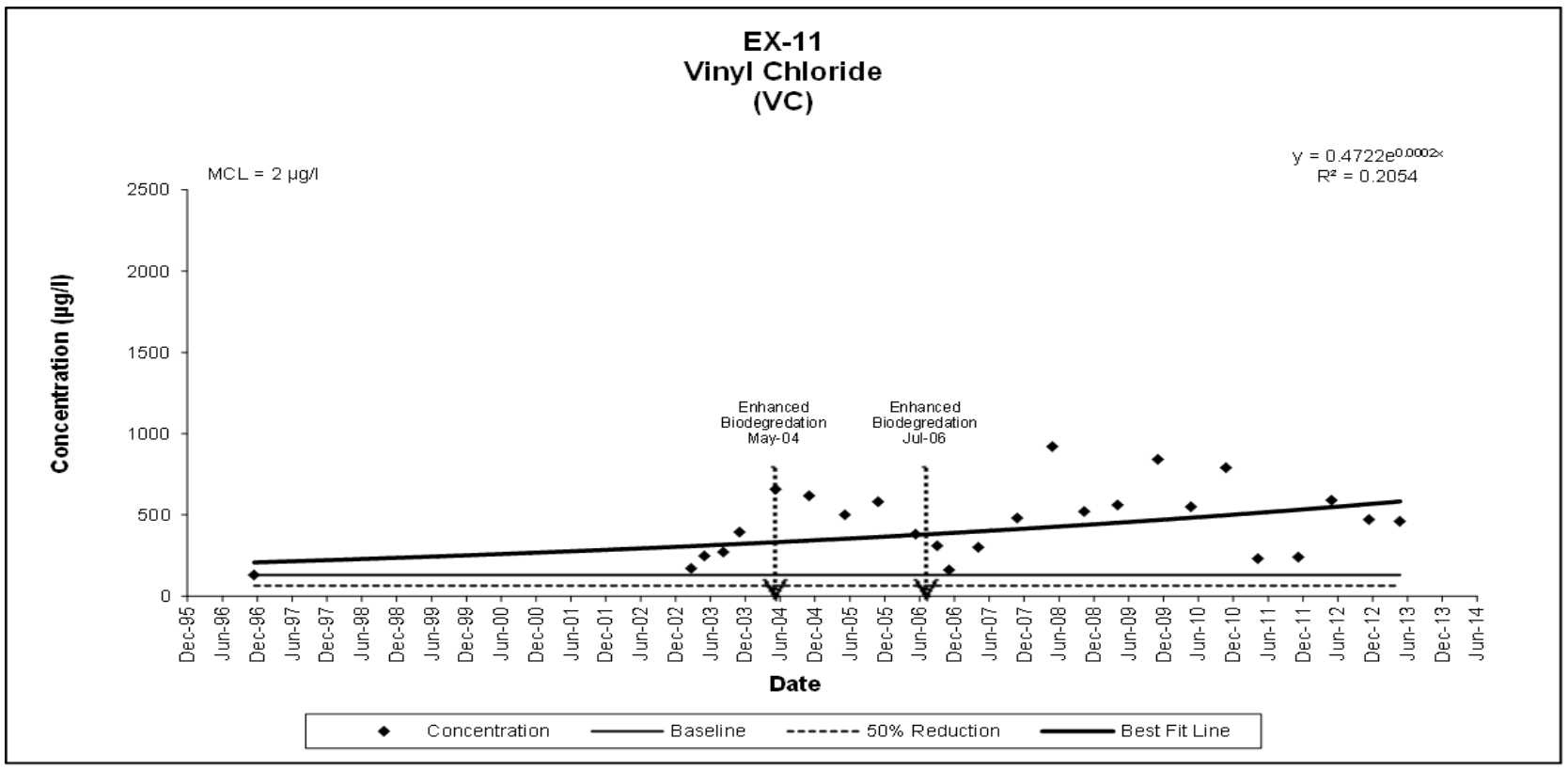
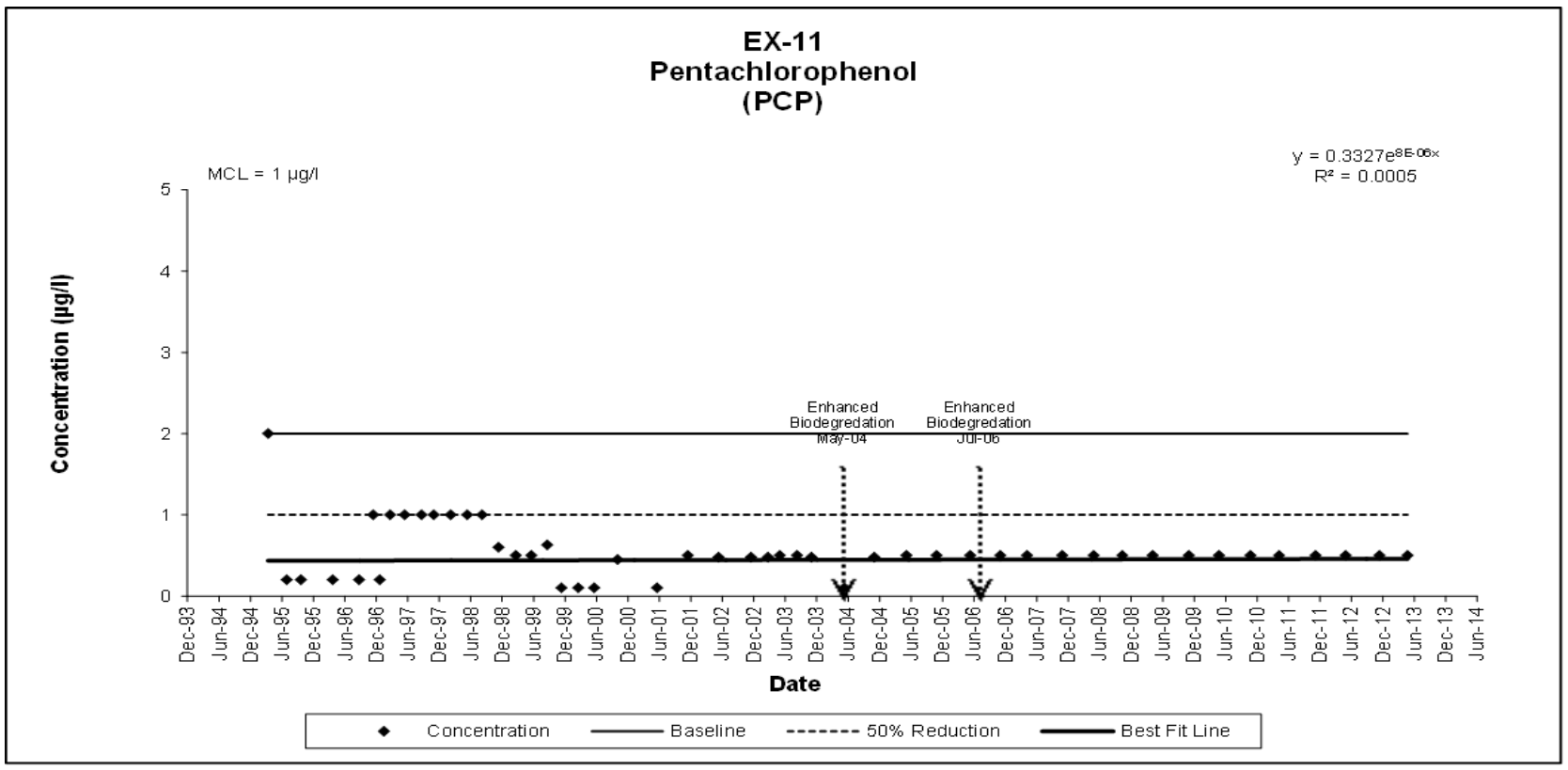


EXHIBIT B2-8
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL EX-11



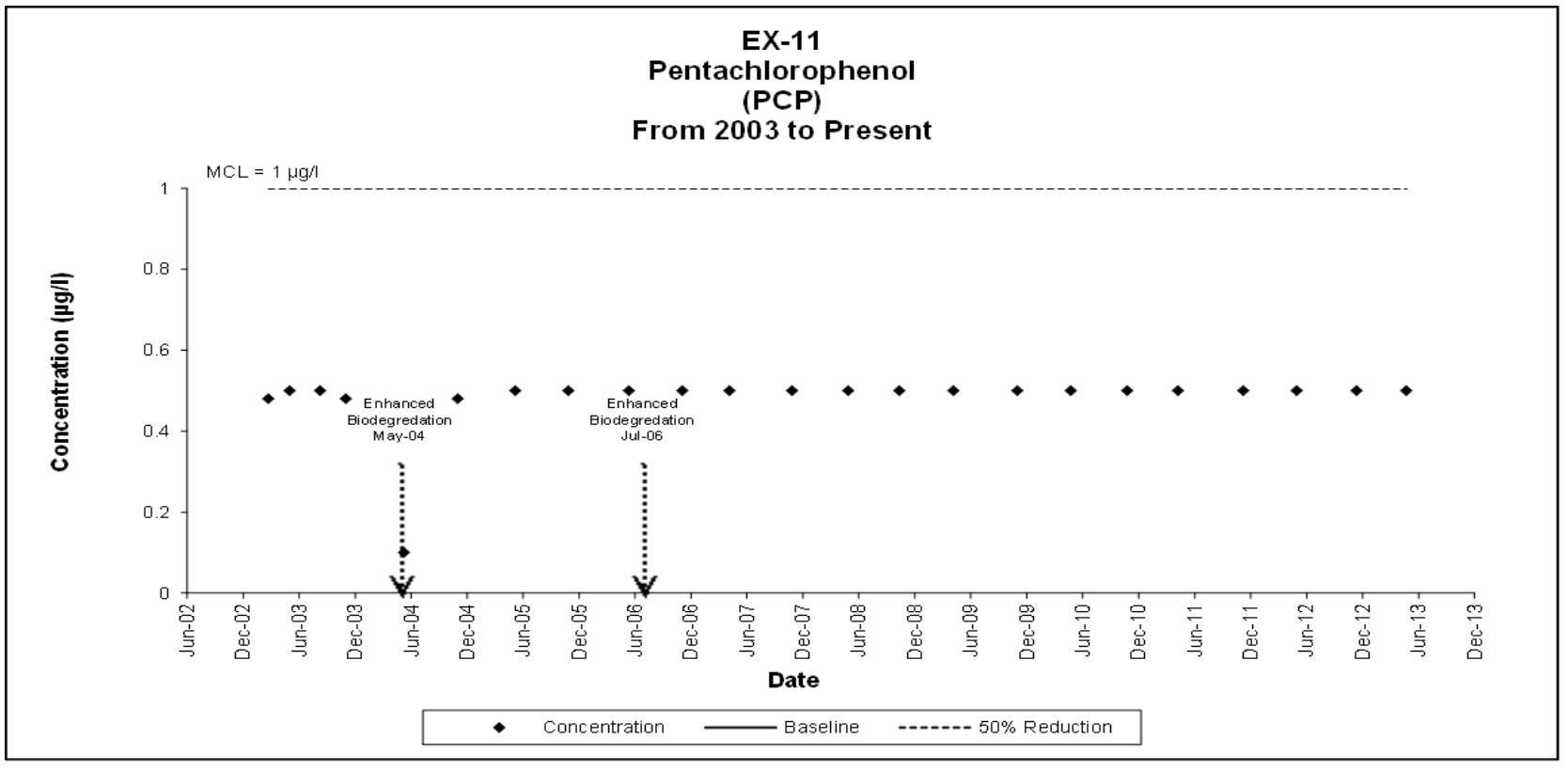


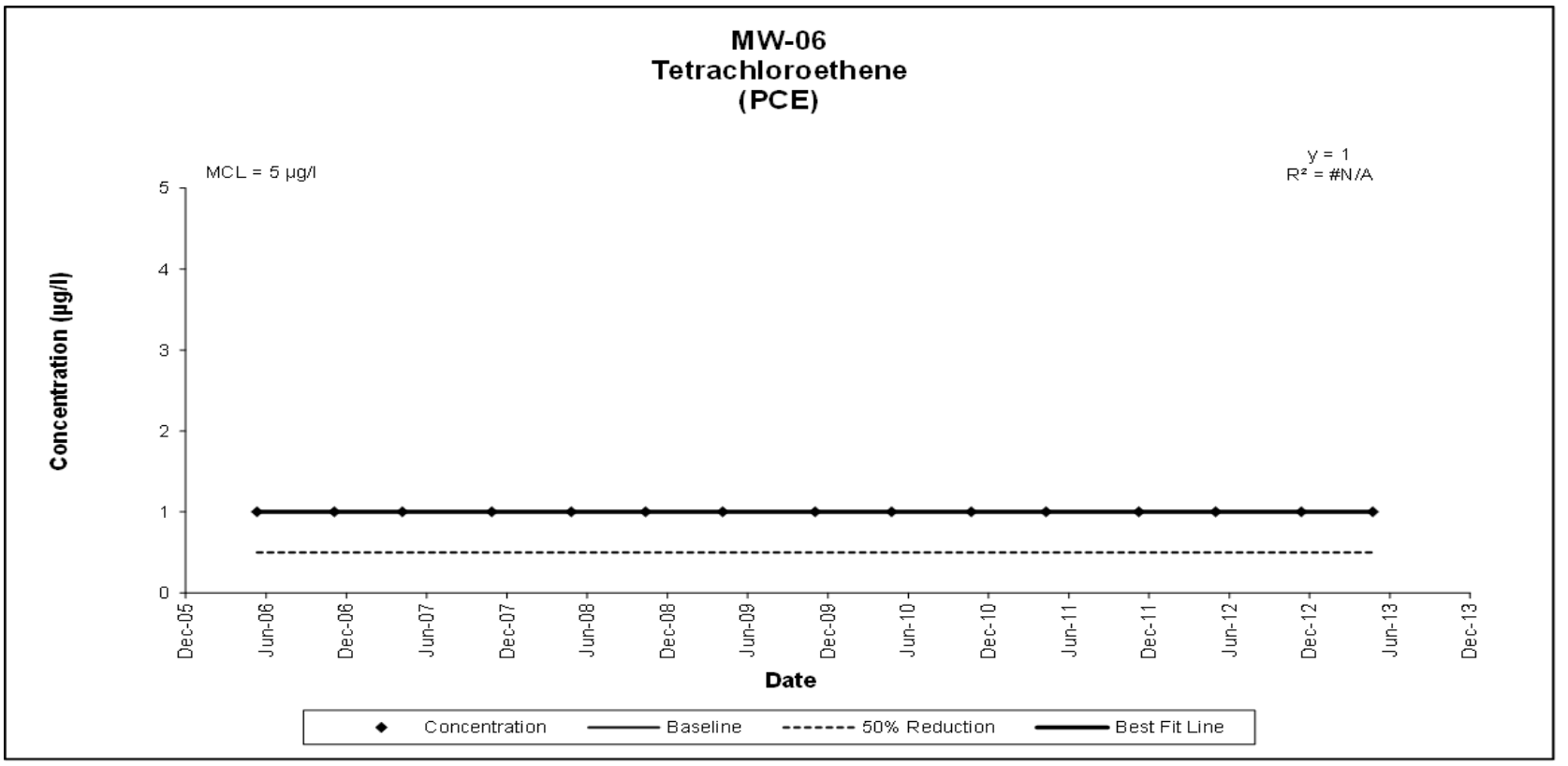
EXHIBIT B2-9
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-06

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
15-May-06	< 1	< 1	< 1	--	--	< 1	--	--
7-Nov-06	< 1	0.3 T	< 1	--	--	< 1	--	--
11-Apr-07	< 1	< 1	< 1	--	--	< 1	--	--
31-Oct-07	< 1	0.21 T	< 1	--	--	< 1	--	--
29-Apr-08	< 1	< 1	< 1	--	--	< 1	--	--
15-Oct-08	< 1	0.59 T	< 1	--	--	< 1	--	--
8-Apr-09	< 1	< 1	0.37 T	1.9	0.31 T	0.24 T	--	--
4-Nov-09	< 1	< 1	< 1	0.86 T	< 1	< 1	--	--
27-Apr-10	< 1	< 1	0.87 T	5.3	0.65 T	< 1	--	--
25-Oct-10	< 1	< 1	0.66 T	4.5	0.61 T	0.3 T	--	--
13-Apr-11	< 1	< 1	3.5	21	3.2	1.5	--	--
10-Nov-11	< 1	< 1	3	18	2.8	0.98 T	--	--
3-May-12	< 1	< 1	3.4	19	3.1	1.5	--	--
14-Nov-12	< 1	0.53 T	3.1	23	4.3	1.2	--	--
25-Apr-13	< 1	0.25 T	5.7	28	5.1	1.9	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-9
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-06



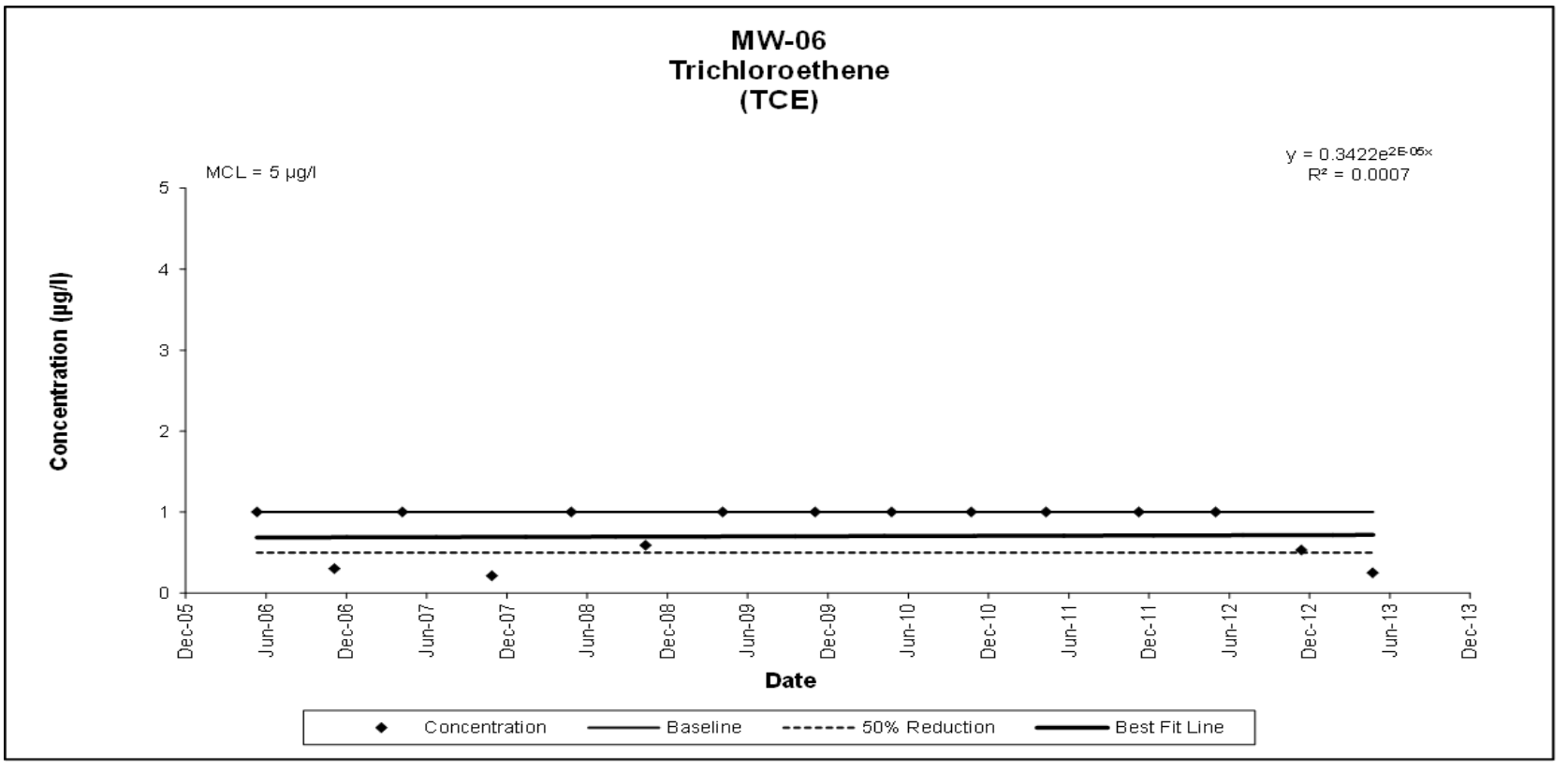
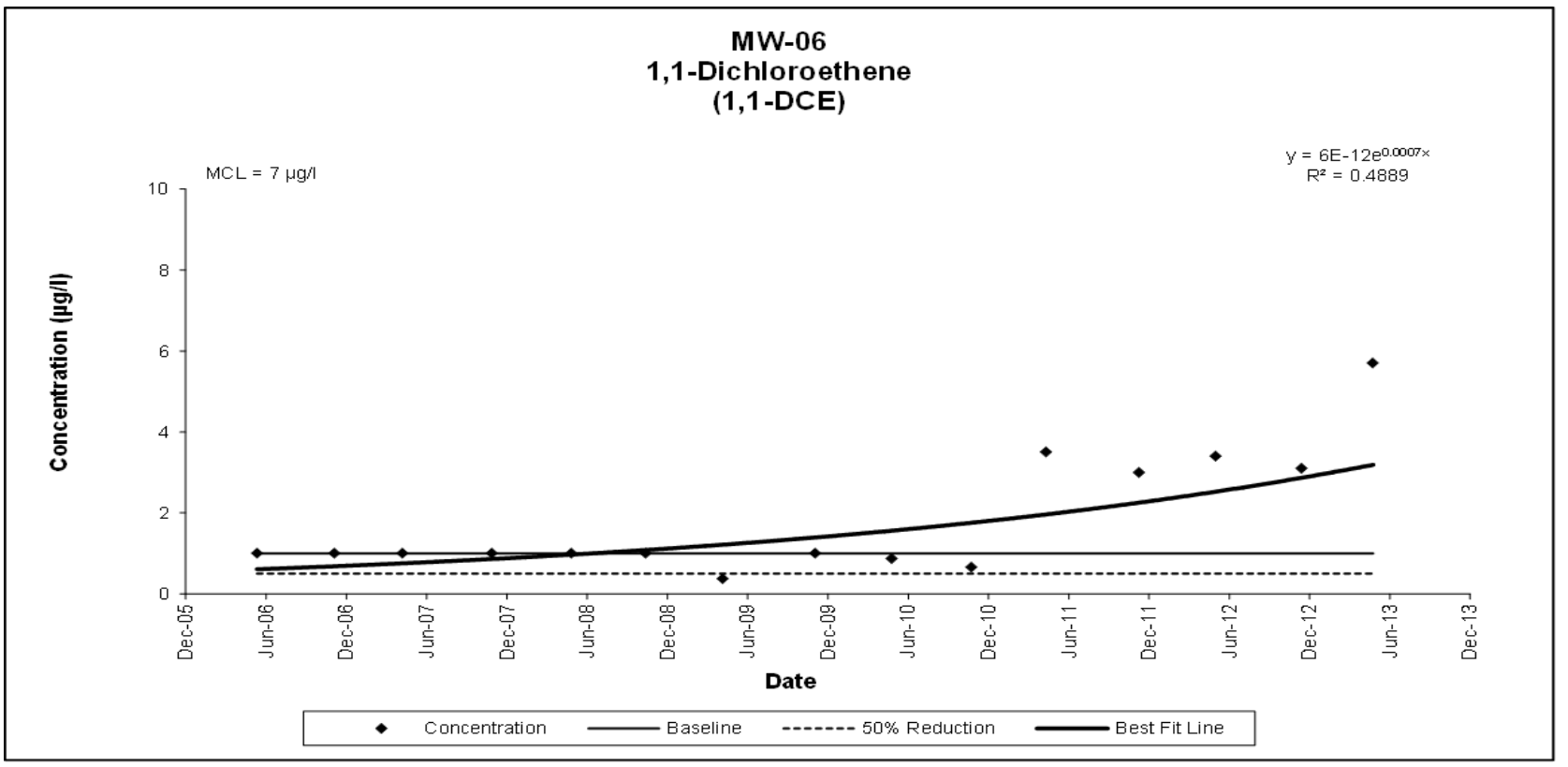


EXHIBIT B2-9
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-06



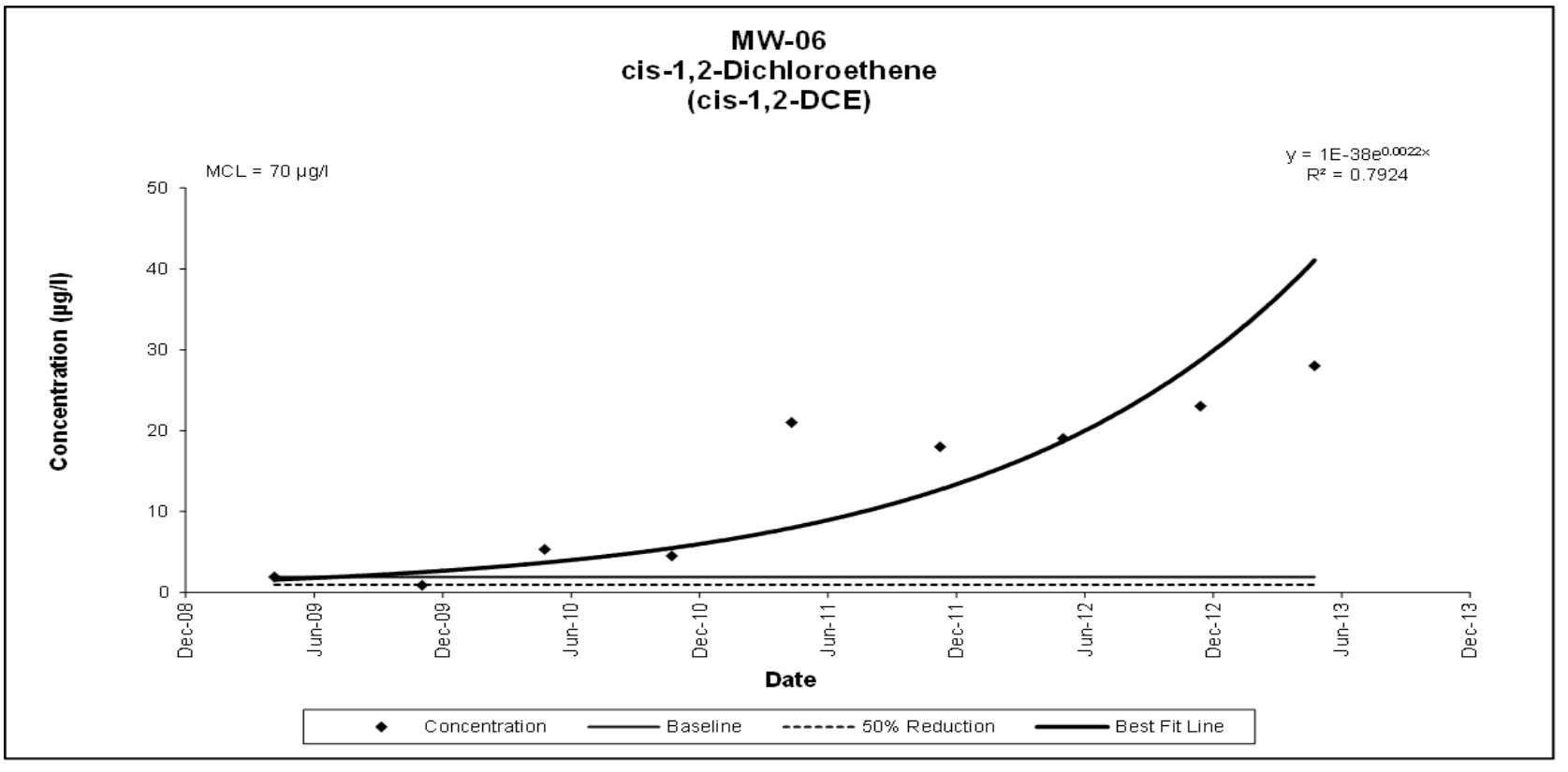
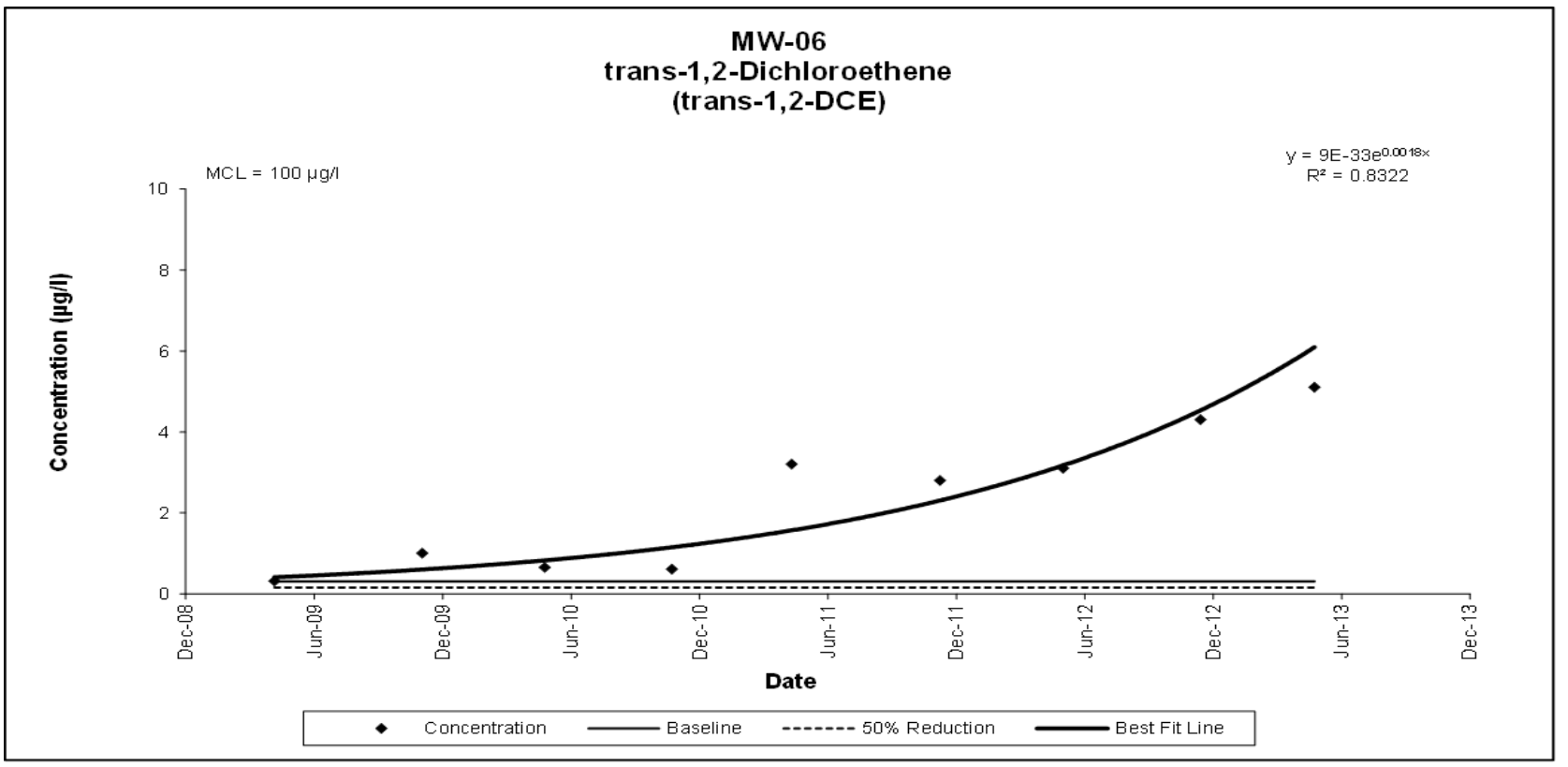


EXHIBIT B2-9
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-06



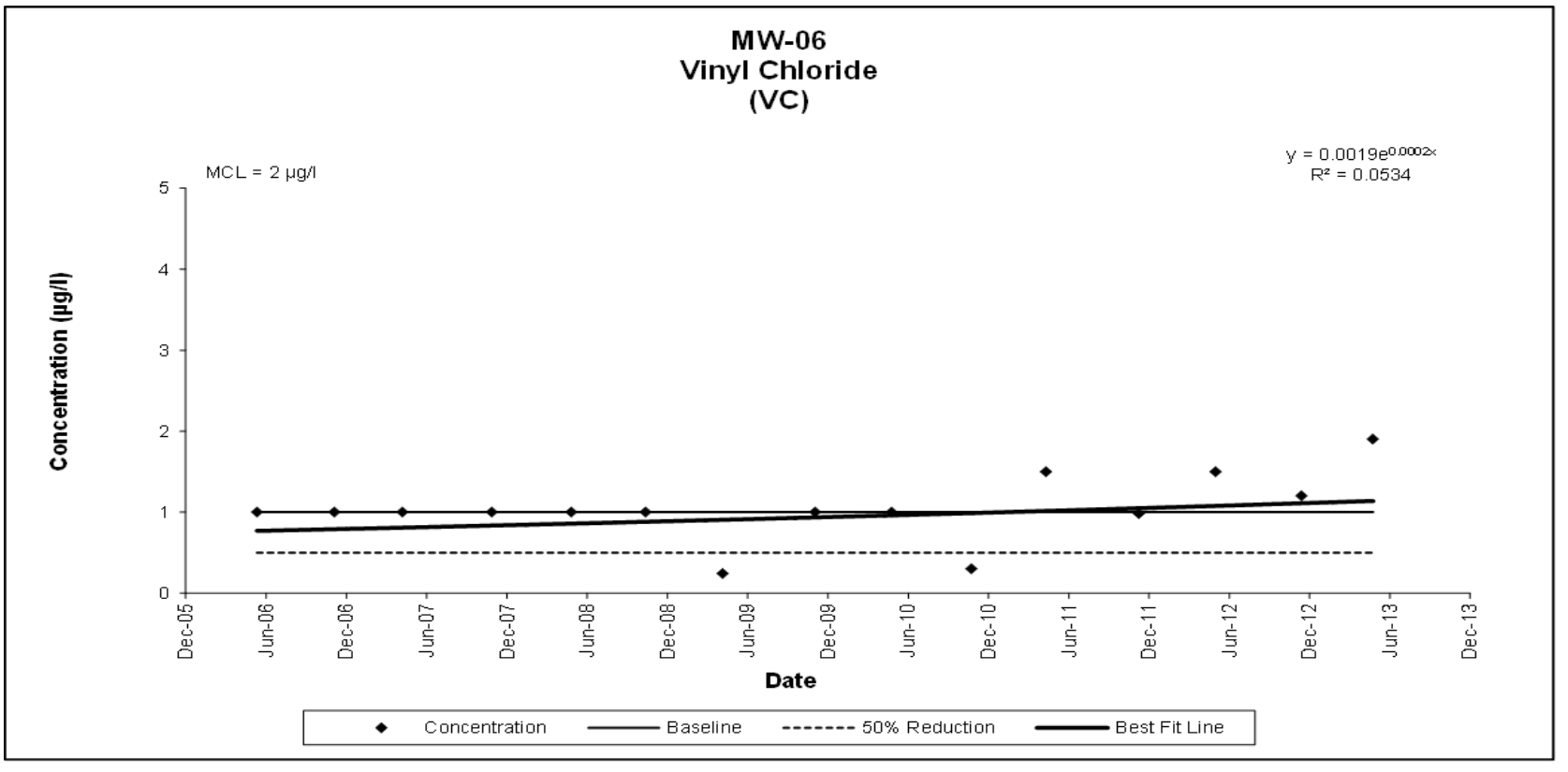


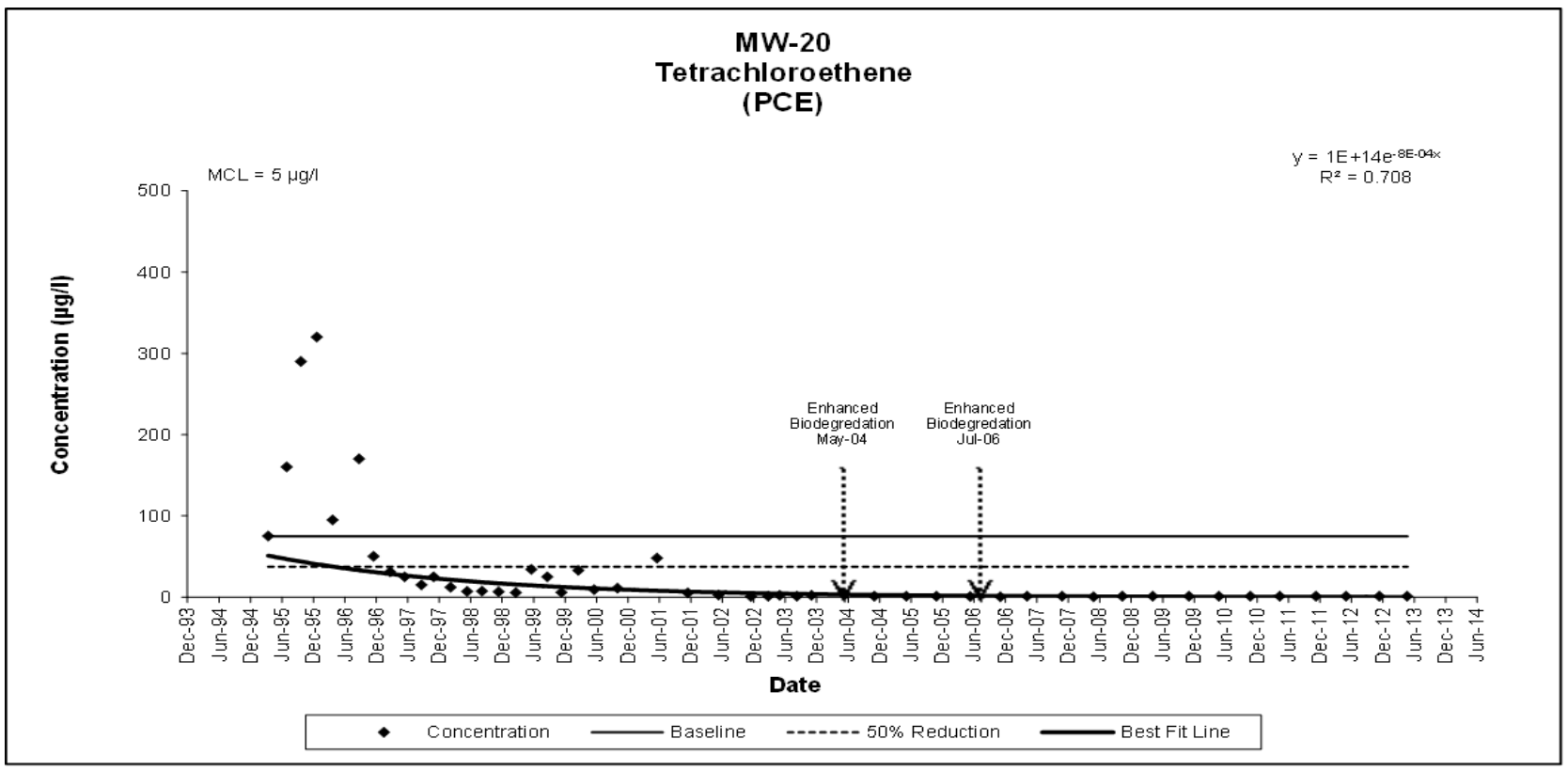
EXHIBIT B2-10
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-20

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
20-Mar-95	75 J	3600 J	350 J	--	--	--	< 2	< 0.2 J
6-Jul-95	160	3600	150	--	--	--	< 2	< 0.2
27-Sep-95	290	5500	580	--	--	--	< 2	< 0.2
27-Dec-95	320	3400	87	--	--	--	< 2	< 0.2
28-Mar-96	95	1700	45	--	--	--	< 2	< 0.2
28-Aug-96	170	2600	97	--	--	--	2.6 T	< 0.2
21-Nov-96	< 50	2700	100	--	--	50	< 1.5	< 1
26-Feb-97	31	1400	49	--	--	--	< 0.25	< 1
21-May-97	25	1000	40	--	--	--	< 0.25	< 1
26-Aug-97	15 T	1500	61	--	--	--	< 2.5	< 1
6-Nov-97	< 25	1400	50	--	--	--	< 0.25	< 1
12-Feb-98	< 12	630 B	35	--	--	--	< 0.25	< 1
19-May-98	7 J	830	35	--	--	--	< 0.25	< 1
12-Aug-98	7.1 J	810	36	--	--	--	< 0.25	< 1
17-Nov-98	6.4 J	510	25 J	--	--	--	< 0.25	< 0.5
24-Feb-99	5.3 JB	460 J	25 J	--	--	--	< 0.25	< 0.5
26-May-99	34	190	10	--	--	--	< 4 UJ	< 0.5
25-Aug-99	< 25 G	220	15 T	--	--	--	1.41	< 0.1
17-Nov-99	5.8 T	340	20 T	--	--	--	< 0.2 J	< 0.1 J
22-Feb-00	33	400	24	--	--	--	< 0.2	< 0.1
24-May-00	8.9 T	180	13	--	--	--	< 0.2	< 0.1
6-Oct-00	11 D	250 D	16 D	--	--	--	--	--
23-May-01	48 D	316 D	20 D	--	--	--	< 0.5	< 0.5
19-Nov-01	5 D	230 D	25 D	--	--	--	< 0.5	0.2 T
15-May-02	2.3	205 D	15	--	--	--	< 0.5	< 0.5
20-Nov-02	0.7 T	166 D	17	--	--	--	< 0.48	< 0.48
27-Feb-03	1	142	10	--	--	0.4 T	--	--
6-May-03	2	119 D	12	--	--	--	--	--
13-Aug-03	1	113 D	20	--	--	0.7 T	--	--
5-Nov-03	2	149 D	24	--	--	< 5 D	--	--
13-May-04	3.1	87 D	21	--	--	0.9 T	--	--
4-Nov-04	0.9 T	22	5.8	--	--	4.7	--	< 0.48
10-May-05	0.9 T	10	3.1	--	--	7.4	--	< 0.5
31-Oct-05	< 1	2.4	0.8 T	--	--	7.6	--	< 0.5
16-May-06	0.47 T	6.5	1	--	--	5.4	--	< 0.5
6-Nov-06	0.29 T	5.7	0.62 T	--	--	3.6	--	--
10-Apr-07	< 1	2.9	0.76 T	--	--	1.1	--	--
30-Oct-07	< 1	1.4	0.56 T	--	--	0.7 T	--	< 0.5
30-Apr-08	0.29 T	4.9	3.4	--	--	3.3	--	< 0.5
14-Oct-08	< 1	2.6	2	--	--	3.1	--	--
7-Apr-09	< 1	5.5	3.3	24	22	3	--	0.11 T
3-Nov-09	< 1	1.2	1.5	20	10	3.3	--	< 0.5
26-Apr-10	< 1	2.3	2.3	34	17	3.8	--	< 0.5
27-Oct-10	< 1	1	0.81 T	14	10	3.2	--	--
14-Apr-11	< 1	3.4	2	26	21	8.1	--	--
10-Nov-11	< 1	0.97 T	0.95 T	15	13	2.4	--	--
2-May-12	< 1	1.4	1.8	28	12	3	--	--
13-Nov-12	< 1	1.2	0.64 T	12	13	1.9	--	--
23-Apr-13	< 1	1.4	1.3	20	18	2.7	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-10
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-20



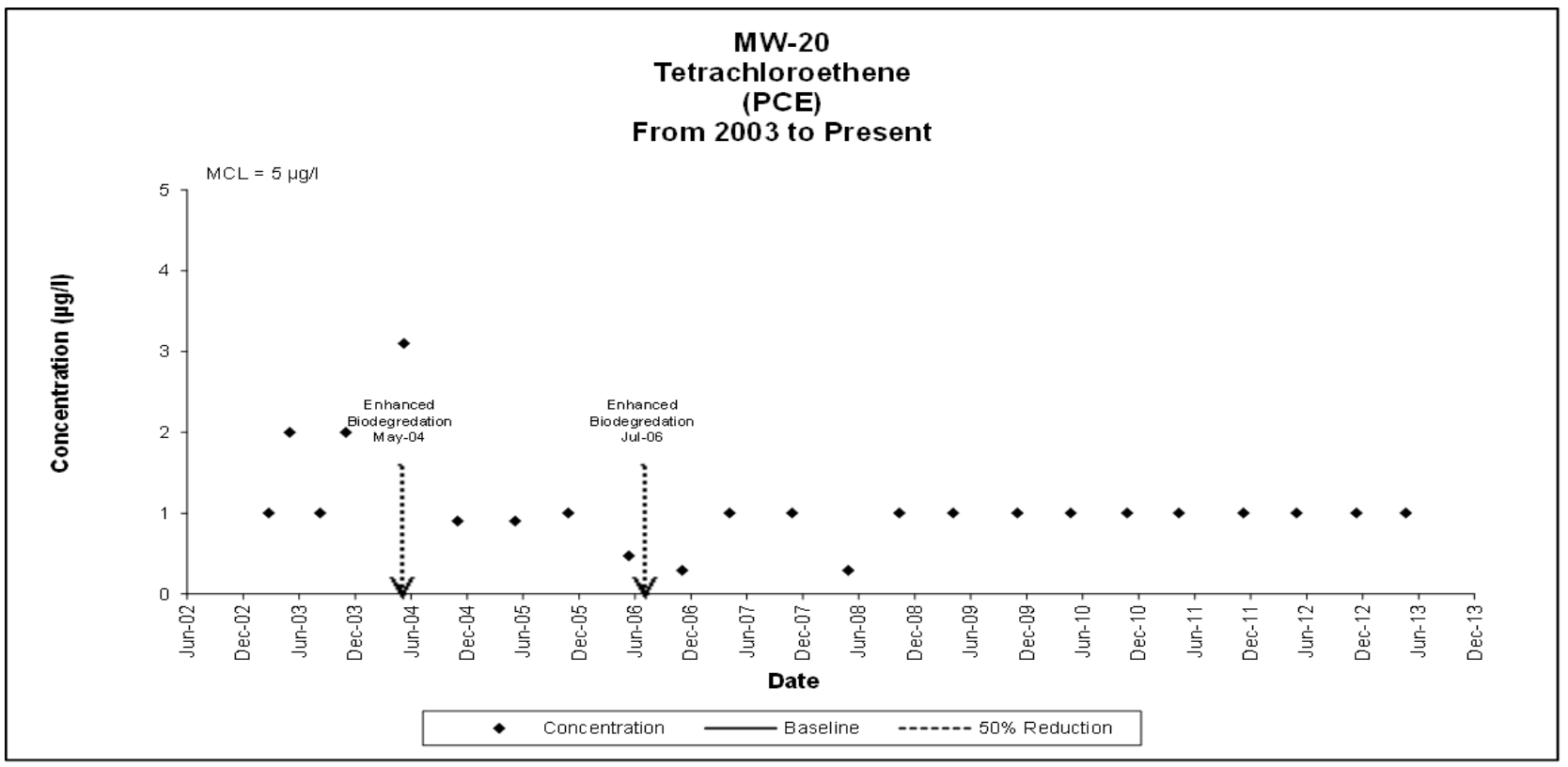
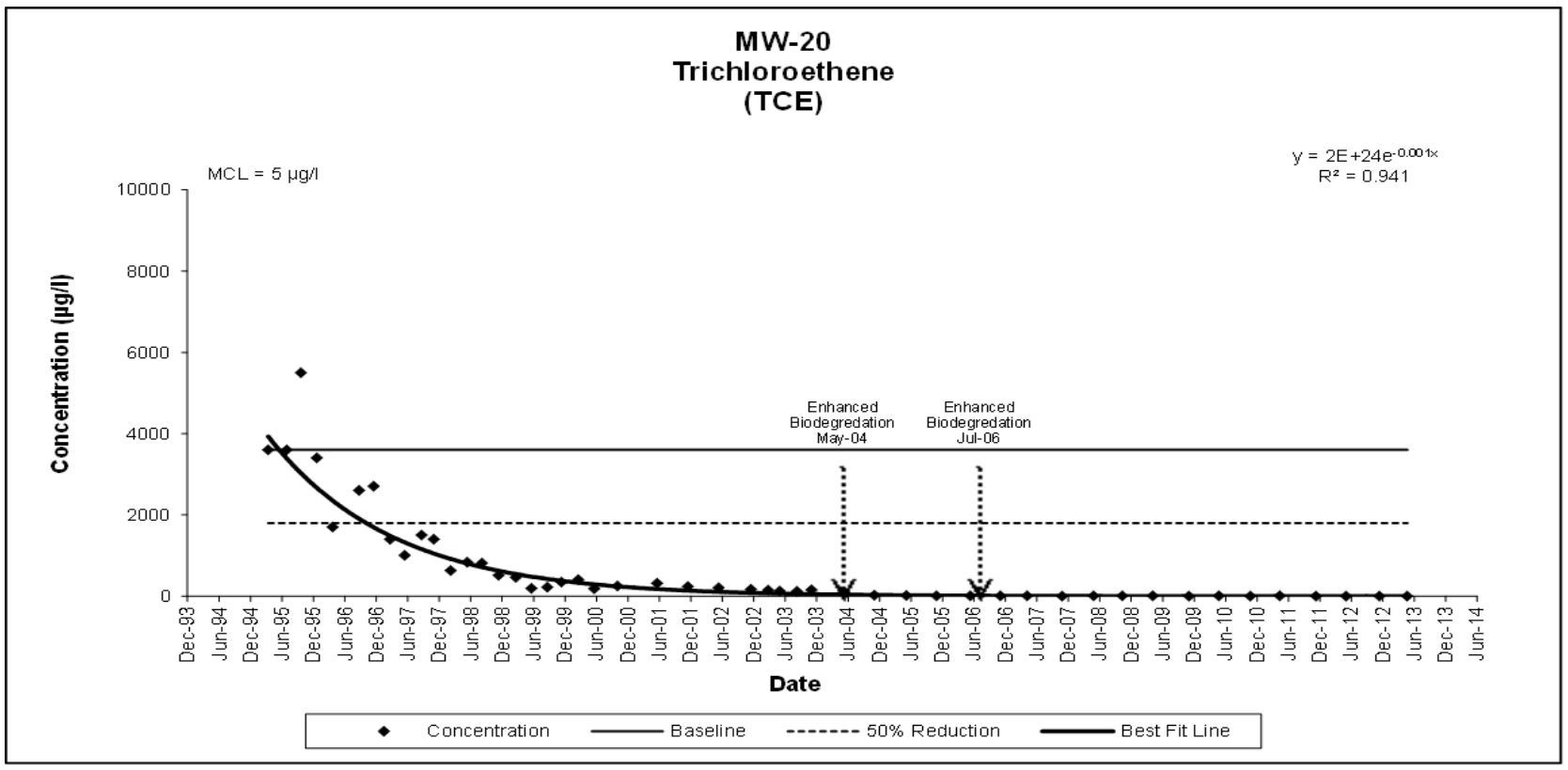


EXHIBIT B2-10
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-20



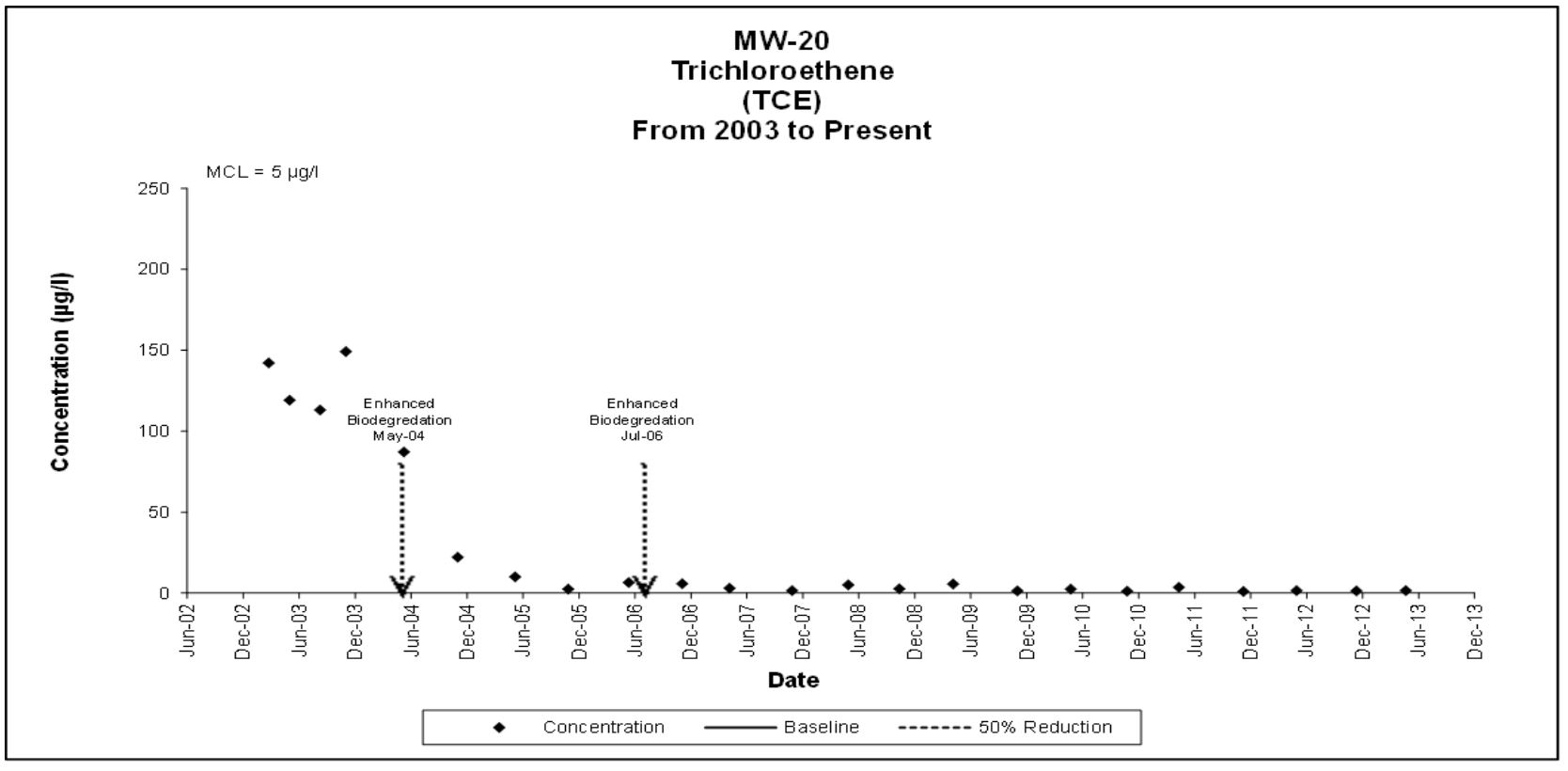
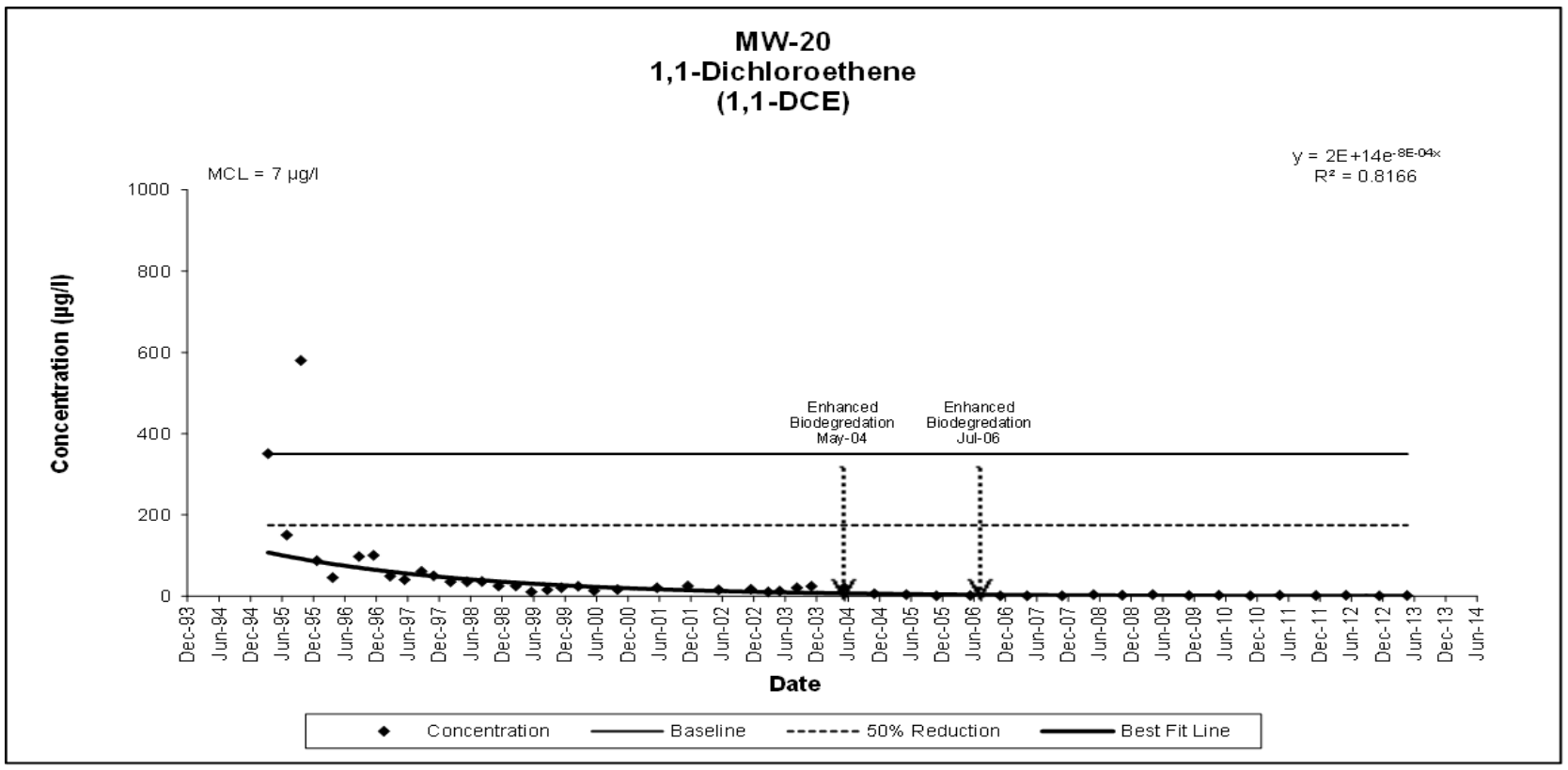


EXHIBIT B2-10
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-20



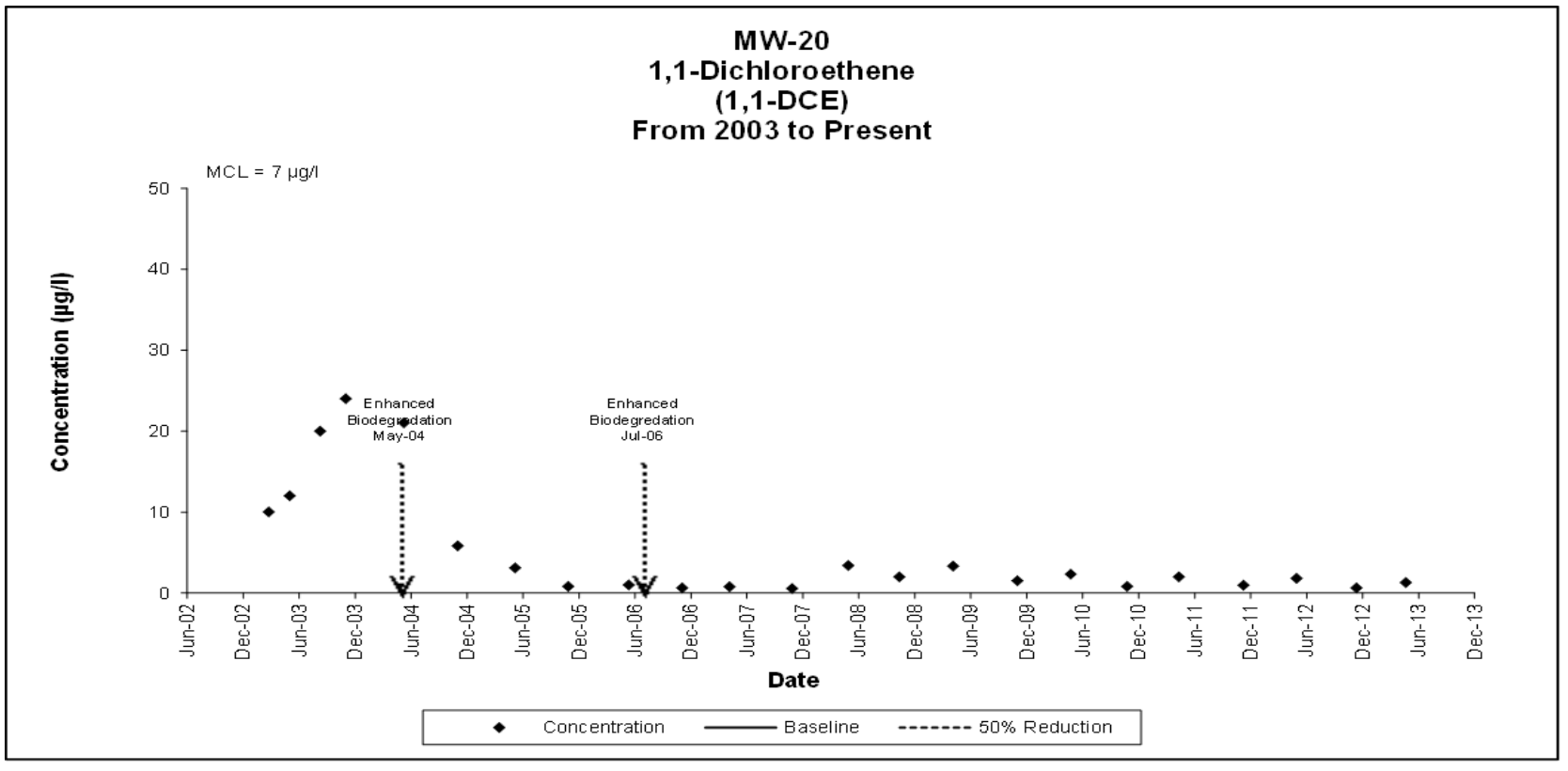
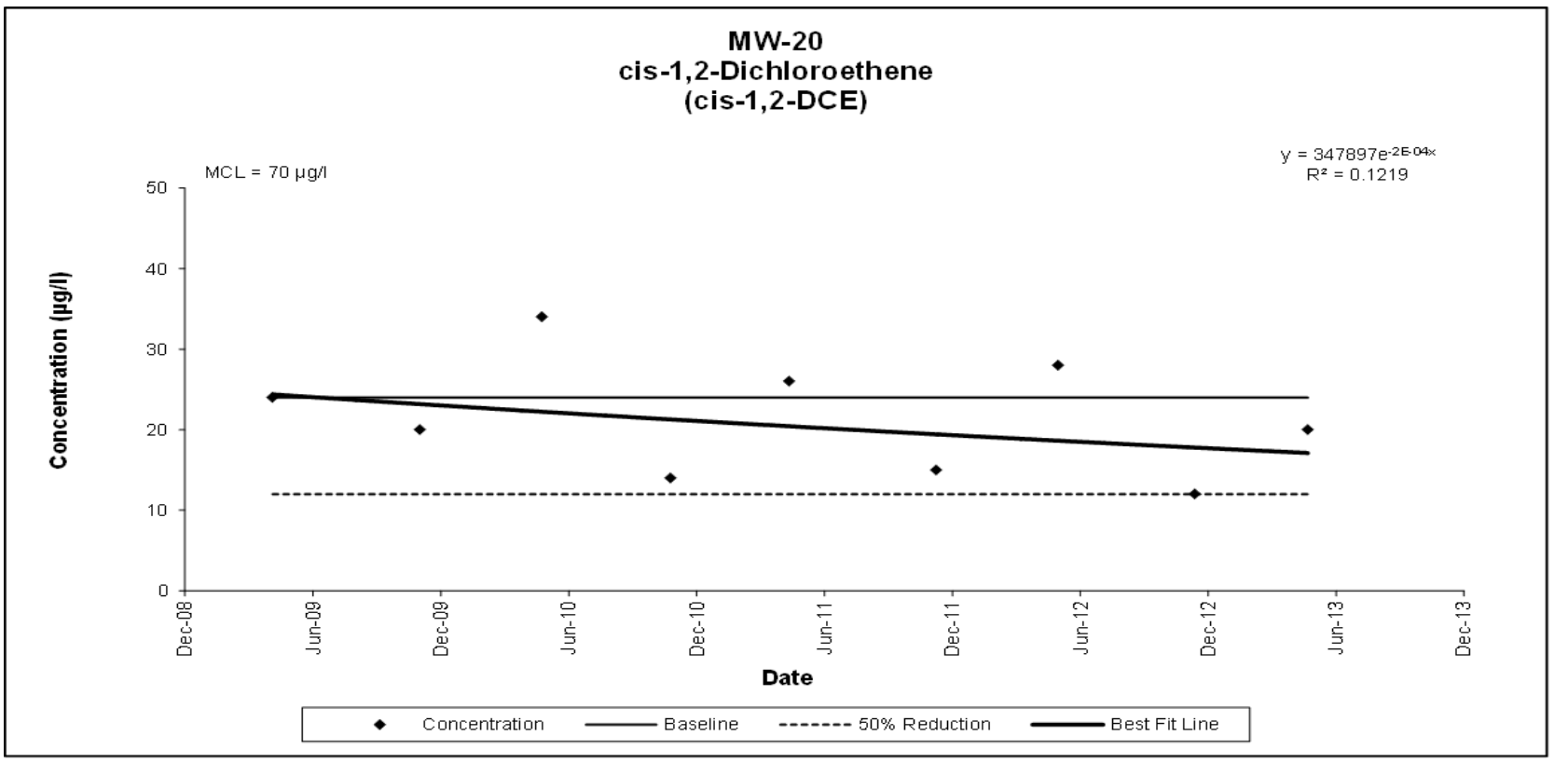


EXHIBIT B2-10
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-20



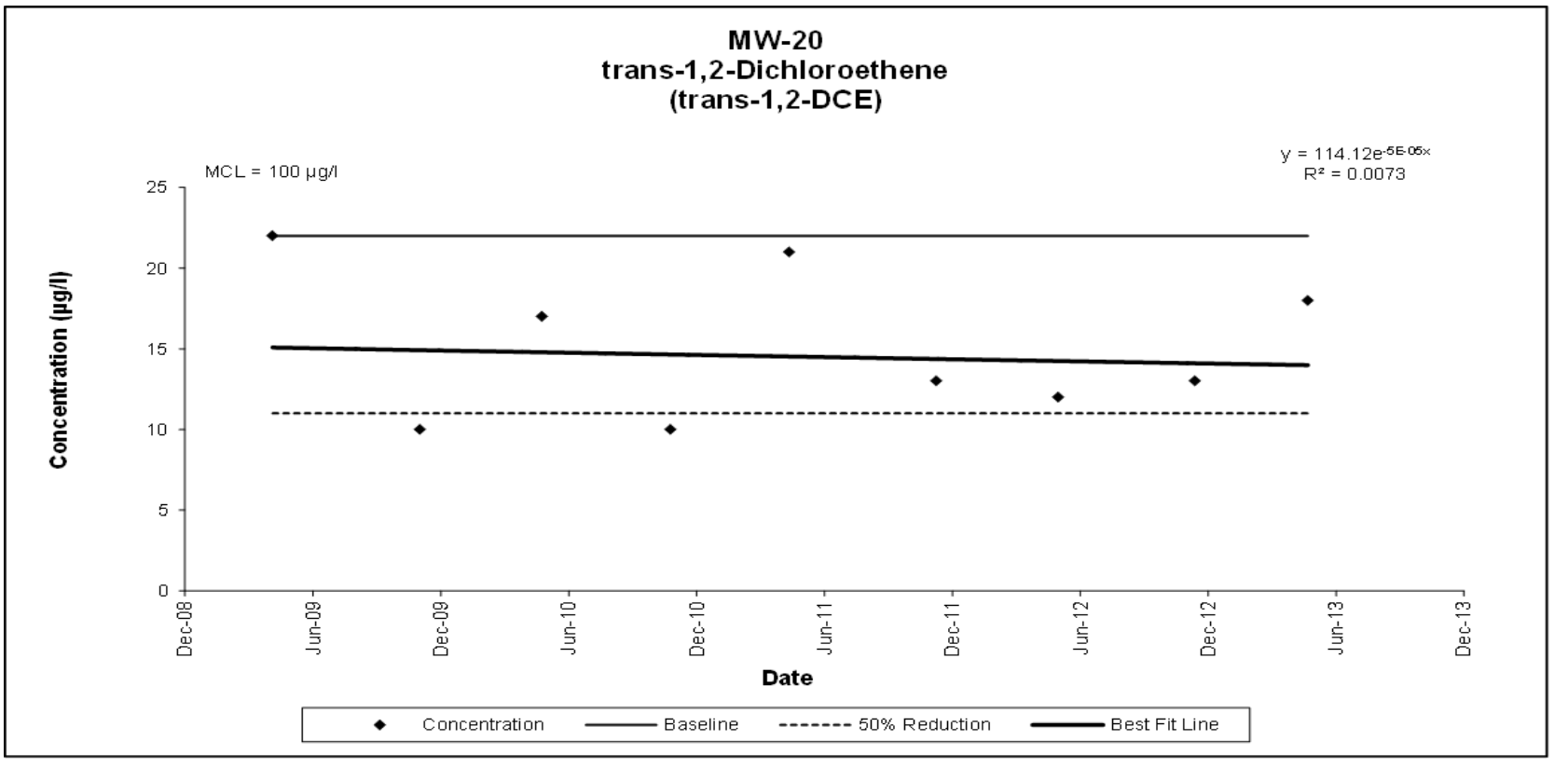
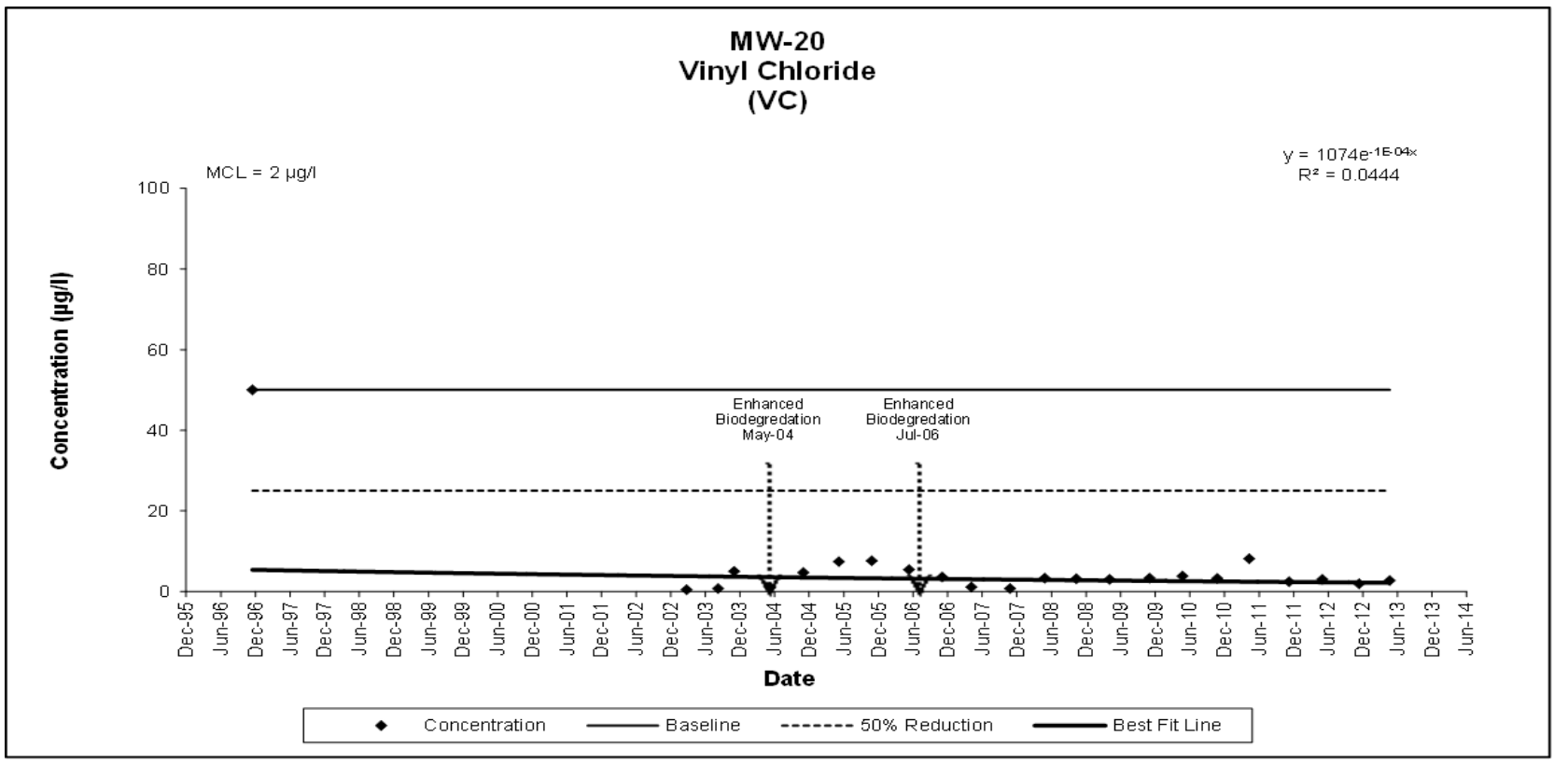


EXHIBIT B2-10
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-20



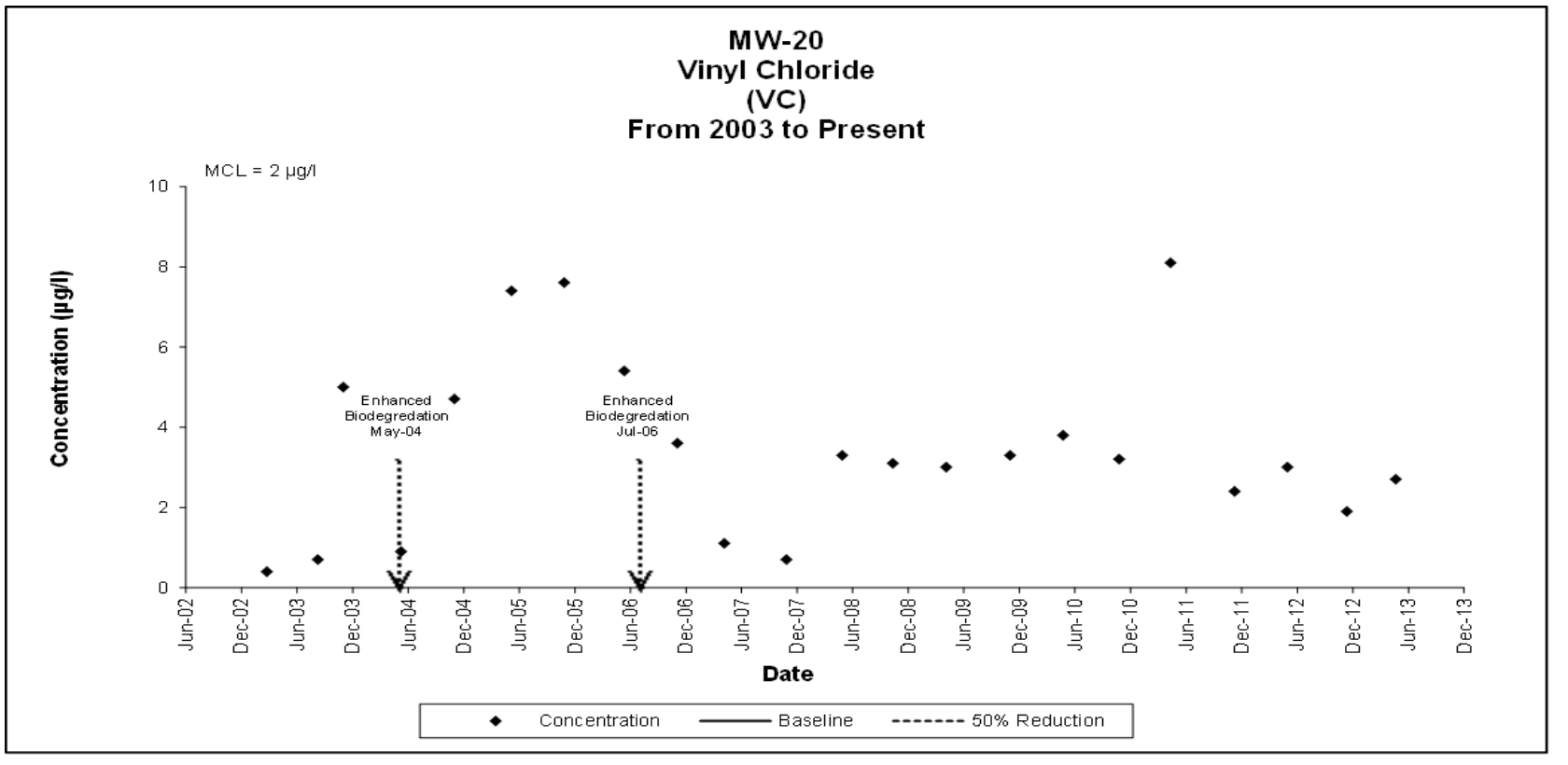


EXHIBIT B2-11
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-23

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
9-Mar-95	< 2	< 2	< 2	--	--	--	< 10 J	< 1 J
6-Jul-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
29-Sep-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
27-Dec-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
28-Mar-96	< 2	< 2	< 2	--	--	--	< 2	< 0.2
27-Aug-96	< 2	< 2	< 2	--	--	--	< 10	< 0.2
21-Nov-96	< 1	< 1	< 1	--	--	1.4 1.4	< 0.25 UJ	< 1
25-Feb-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
20-May-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
25-Aug-97	< 1	0.14 T	< 1	--	--	--	< 0.25	< 1
5-Nov-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
12-Feb-98	< 1	< 1	< 1	--	--	--	< 0.25 J	< 1
18-May-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
11-Aug-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
16-Nov-98	< 1	< 1	< 1	--	--	--	0.9	< 0.5
23-Feb-99	< 1	< 1	< 1	--	--	--	0.57 J	< 0.5
25-May-99	< 1	< 1	< 1	--	--	--	< 4 UJ	< 0.5
26-Aug-99	< 1	< 1	< 1	--	--	--	5	< 0.1
18-Nov-99	< 5	< 5	< 5	--	--	--	< 0.2 J	< 0.1 J
23-Feb-00	< 1	< 1	< 1	--	--	--	< 0.2	< 0.1
23-May-00	< 1	< 1	< 1	--	--	--	0.741	< 0.1
23-Aug-00	< 0.166	< 0.0672	< 0.116	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	0.07	< 0.5
24-May-01	< 1	< 1	< 1	--	--	--	< 0.5	< 0.5
14-May-02	< 1	< 1	< 1	--	--	--	< 0.5	< 0.5
27-Feb-03	< 1	< 2	< 1	--	--	< 1	--	--
5-May-03	< 1	< 1	< 1	--	--	< 1	--	--
13-Aug-03	< 1	< 1	< 1	--	--	< 1	--	--
6-Nov-03	< 1	< 1	< 1	--	--	< 1	--	--
13-May-04	< 1	< 1	< 1	--	--	< 1	--	--
4-Nov-04	< 1	< 1	< 1	--	--	< 1	--	--
9-May-05	< 1	< 1	< 1	--	--	< 1	--	--
2-Nov-05	< 1	< 1	< 1	--	--	< 1	--	--
15-May-06	< 1	< 1	< 1	--	--	< 1	--	--
7-Nov-06	< 1	< 1	< 1	--	--	< 1	--	--
11-Apr-07	< 1	< 1	< 1	--	--	< 1	--	--
31-Oct-07	< 1	< 1	< 1	--	--	< 1	--	--
29-Apr-08	< 1	< 1	< 1	--	--	< 1	--	--
15-Oct-08	< 1	< 1	< 1	--	--	< 1	--	--
8-Apr-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
4-Nov-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
27-Apr-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
26-Oct-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
13-Apr-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
10-Nov-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
2-May-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
15-Nov-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
25-Apr-13	< 1	< 1	< 1	< 1	< 1	< 1	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-12
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-24A

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
9-Mar-95	< 2	< 2	< 2	--	--	--	< 10 J	< 1 J
6-Jul-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
27-Sep-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
28-Dec-95	< 2	< 2	< 2	--	--	--	< 2	0.2
29-Mar-96	< 2	< 2	< 2	--	--	--	< 2	< 0.2
27-Aug-96	< 2	< 2	< 2	--	--	--	< 10	< 0.2
21-Nov-96	< 1	< 1	< 1	--	--	1 1	< 0.25	< 1 UJ
25-Feb-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
20-May-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
25-Aug-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
5-Nov-97	0.32 J	< 1	< 1	--	--	--	< 0.25	< 1
12-Feb-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
18-May-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
11-Aug-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
16-Nov-98	< 1	< 1	< 1	--	--	--	< 0.25	< 0.5
23-Feb-99	< 1	< 1	< 1	--	--	--	< 0.25	< 0.5
25-May-99	< 1	< 1	< 1	--	--	--	< 4 UJ	< 0.5
26-Aug-99	< 1	< 1	< 1	--	--	--	< 0.2	< 0.1
18-Nov-99	< 5	< 5	< 5	--	--	--	< 0.2 J	< 0.1 J
23-Feb-00	< 1	< 1	< 1	--	--	--	< 0.2	< 0.1
23-May-00	< 1	< 1	< 1	--	--	--	< 0.2	< 0.1
23-Aug-00	< 0.166	< 0.0672	< 0.116	--	--	--	--	--
7-Oct-00	--	--	--	--	--	--	< 0.5	< 0.5
24-May-01	< 1	0.3 T	< 1	--	--	--	< 0.5	< 0.5
14-May-02	< 1	< 1	< 1	--	--	--	< 0.5	< 0.5
27-Feb-03	< 1	< 2	< 1	--	--	< 1	--	--
5-May-03	< 1	< 1	< 1	--	--	< 1	--	--
13-Aug-03	< 1	< 1	< 1	--	--	< 1	--	--
6-Nov-03	< 1	< 1	< 1	--	--	< 1	--	--
13-May-04	< 1	< 1	< 1	--	--	< 1	--	--
4-Nov-04	< 1	< 1	< 1	--	--	< 1	--	--
9-May-05	< 1	< 1	< 1	--	--	< 1	--	--
2-Nov-05	< 1	< 1	< 1	--	--	< 1	--	--
15-May-06	< 1	< 1	< 1	--	--	< 1	--	--
7-Nov-06	< 1	< 1	< 1	--	--	< 1	--	--
11-Apr-07	< 1	< 1	< 1	--	--	< 1	--	--
31-Oct-07	< 1	< 1	< 1	--	--	< 1	--	--
29-Apr-08	< 1	< 1	< 1	--	--	< 1	--	--
15-Oct-08	< 1	< 1	< 1	--	--	< 1	--	--
8-Apr-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
4-Nov-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
28-Apr-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
25-Oct-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
13-Apr-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
11-Nov-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
2-May-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
14-Nov-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
24-Apr-13	< 1	< 1	< 1	< 1	< 1	< 1	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-13
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-25

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
9-Mar-95	< 2	< 2	< 2	--	--	--	< 10 J	< 1
6-Jul-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
29-Sep-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
28-Dec-95	< 2	< 2	< 2	--	--	--	< 2	< 0.2
29-Mar-96	< 2	< 2	< 2	--	--	--	< 2	< 2.2
27-Aug-96	< 2	< 2	< 2	--	--	--	< 10	< 0.2
21-Nov-96	< 1	< 1	< 1	--	--	1 1	< 0.25	< 1 UJ
26-Feb-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
20-May-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
26-Aug-97	< 1	< 1	< 1	--	--	--	< 0.25	< 1
6-Nov-97	0.48 JB	< 1	< 1	--	--	--	< 0.25	< 10
12-Feb-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
18-May-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
11-Aug-98	< 1	< 1	< 1	--	--	--	< 0.25	< 1
16-Nov-98	< 1	< 1	< 1	--	--	--	< 0.25	< 0.5
23-Feb-99	< 1	< 1	< 1	--	--	--	< 0.25	< 0.5
25-May-99	< 1	< 1	< 1	--	--	--	< 4 UJ	< 0.5
26-Aug-99	< 1	< 1	< 1	--	--	--	1.74	< 0.1
18-Nov-99	< 5	< 5	< 5	--	--	--	< 0.2	< 0.1
23-Feb-00	< 1	< 1	< 1	--	--	--	< 0.2	< 0.1
23-May-00	< 1	< 1	< 1	--	--	--	< 0.2	< 0.1
23-Aug-00	< 0.166	< 0.0672	< 0.116	--	--	--	5.85 J	< 0.5 UJ
24-May-01	< 1	< 1	< 1	--	--	--	< 0.5	< 0.5
14-May-02	< 1	< 1	< 1	--	--	--	< 0.5	0.03 T
27-Feb-03	< 1	< 2	< 1	--	--	< 1	--	--
5-May-03	< 1	< 1	< 1	--	--	< 1	--	--
13-Aug-03	< 1	< 1	< 1	--	--	< 1	--	--
6-Nov-03	< 1	< 1	< 1	--	--	< 1	--	--
14-May-04	< 1	< 1	< 1	--	--	< 1	--	--
4-Nov-04	< 1	< 1	< 1	--	--	< 1	--	--
9-May-05	< 1	< 1	< 1	--	--	< 1	--	--
2-Nov-05	< 1	< 1	< 1	--	--	< 1	--	--
15-May-06	< 1	< 1	< 1	--	--	< 1	--	--
7-Nov-06	< 1	< 1	< 1	--	--	< 1	--	--
11-Apr-07	< 1	< 1	< 1	--	--	< 1	--	--
31-Oct-07	< 1	< 1	< 1	--	--	< 1	--	--
29-Apr-08	< 1	< 1	< 1	--	--	< 1	--	--
15-Oct-08	< 1	< 1	< 1	--	--	< 1	--	--
8-Apr-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
4-Nov-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
28-Apr-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
25-Oct-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
12-Apr-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
11-Nov-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
2-May-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
15-Nov-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
25-Apr-13	< 1	< 1	< 1	< 1	< 1	< 1	--	< 0.5

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-14
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-30

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
10-Nov-11	< 1	0.59 T	5.8	64	1.6	14	--	< 0.5
21-Dec-11	< 1	0.7 T	9	75	1.9	25	--	< 0.5
8-Feb-12	< 1	0.66 T	7.3	71	1.5	15	--	< 0.5
30-Apr-12	< 1	0.65 T	7.6	75	1.7	20	--	< 0.5
28-Aug-12	< 1	0.77 T	4.3	31	0.96 T	5.9	--	< 0.5
13-Nov-12	< 1	1.1	4.8	30	1	5.5	--	< 0.5
25-Apr-13	< 1	0.63 T	5.6	30	0.93 T	6.5	--	< 0.5

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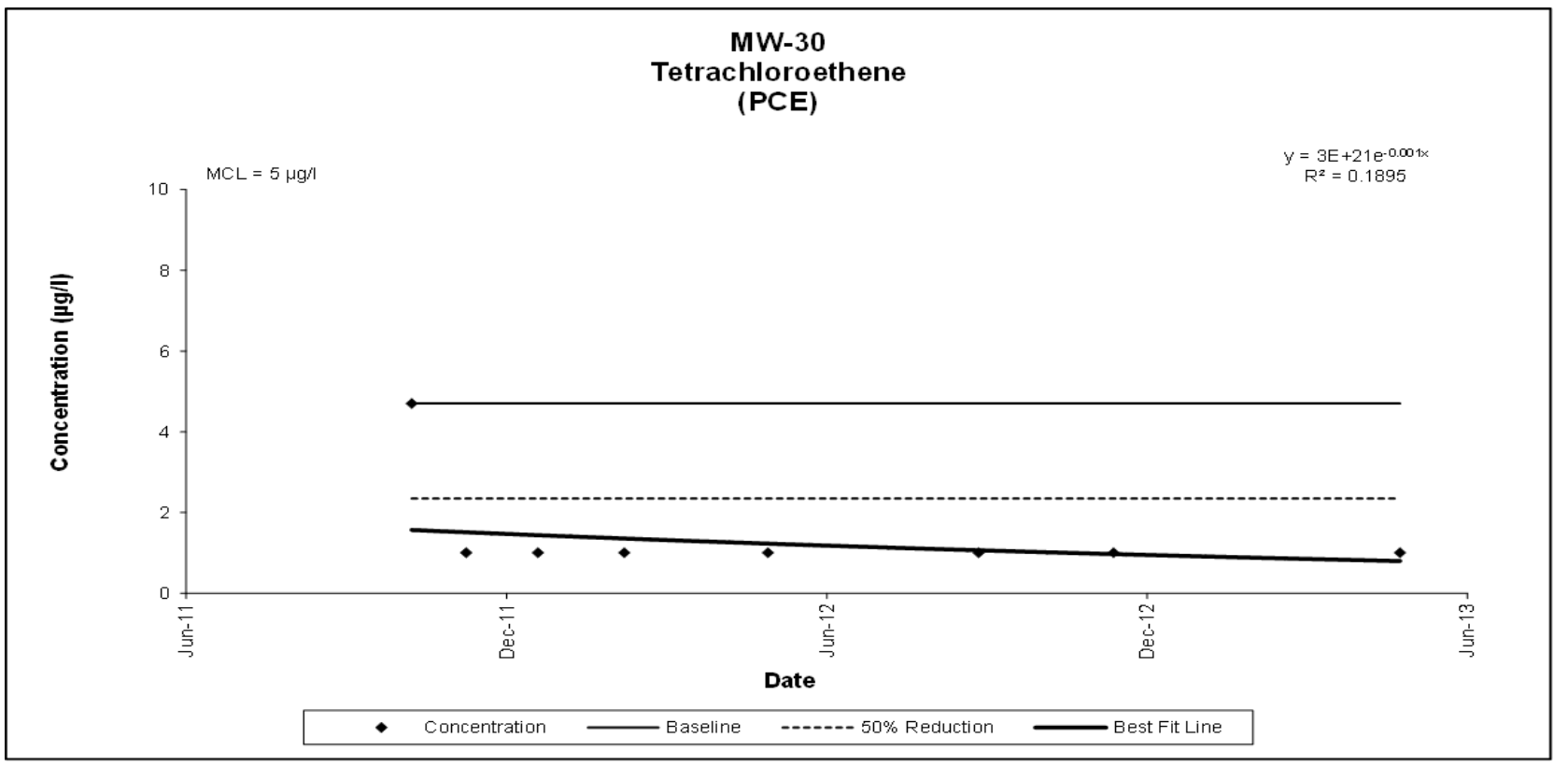
-- Not analyzed

EXHIBIT B2-14
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-30



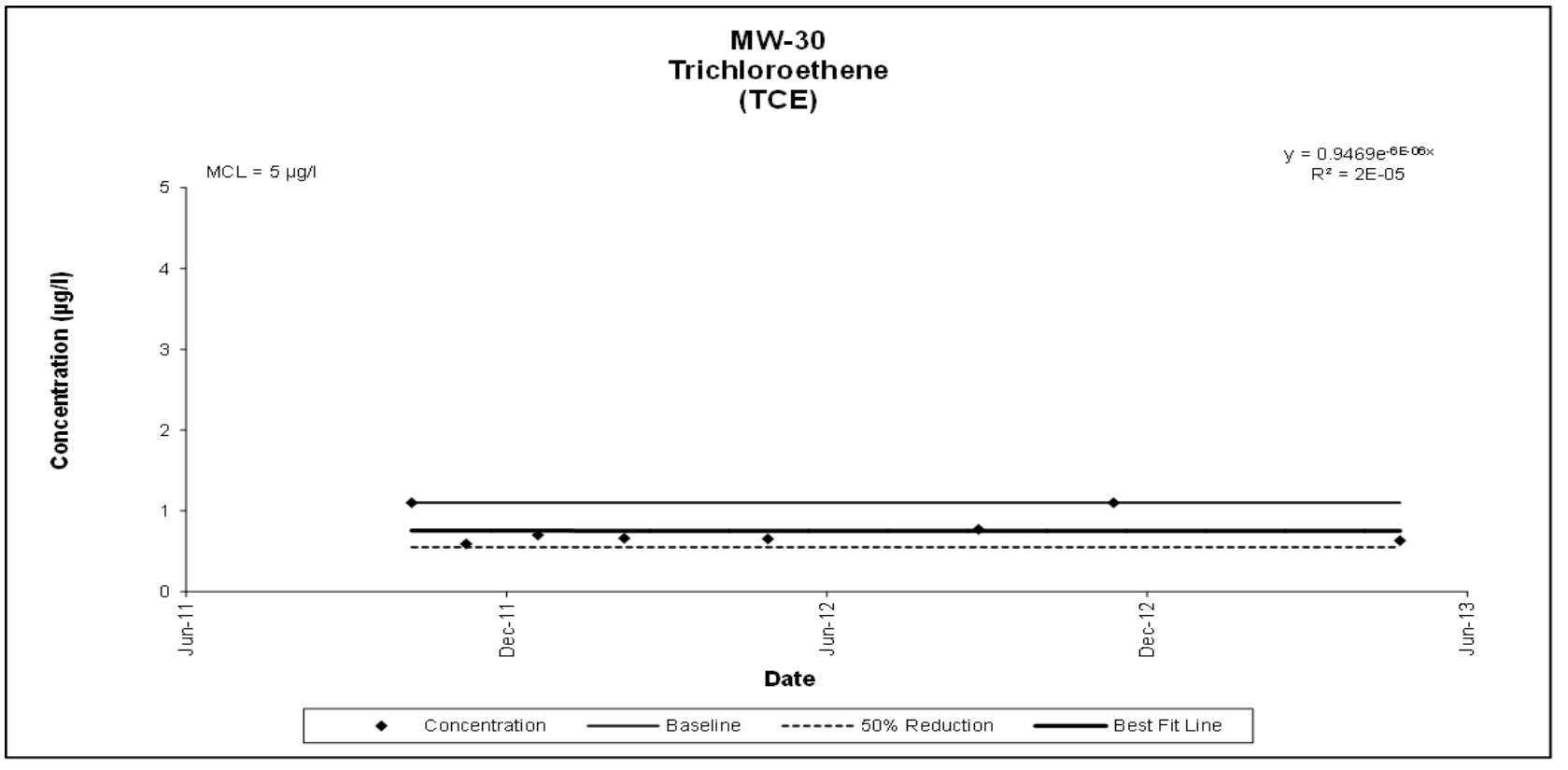
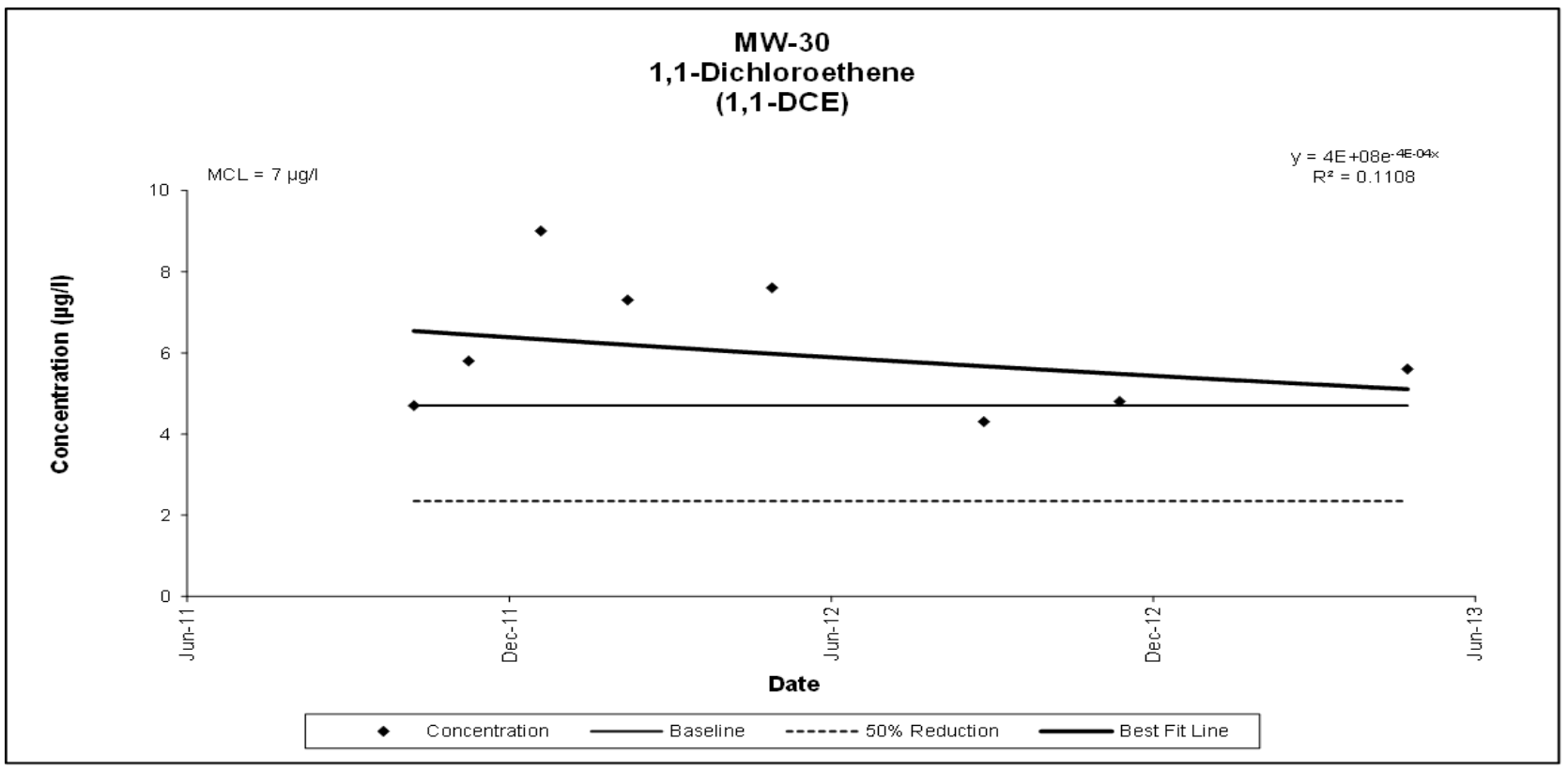


EXHIBIT B2-14
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-30



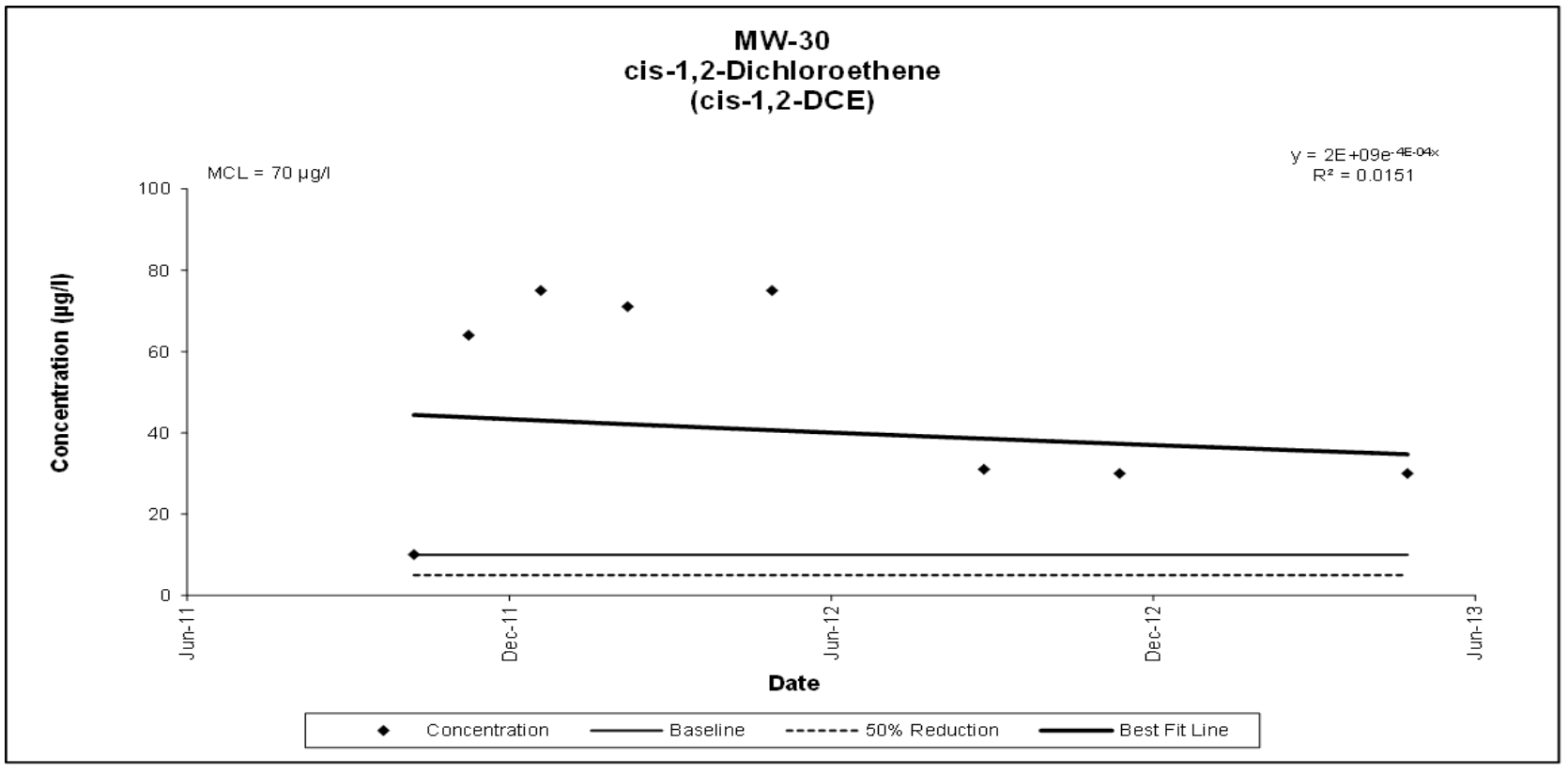
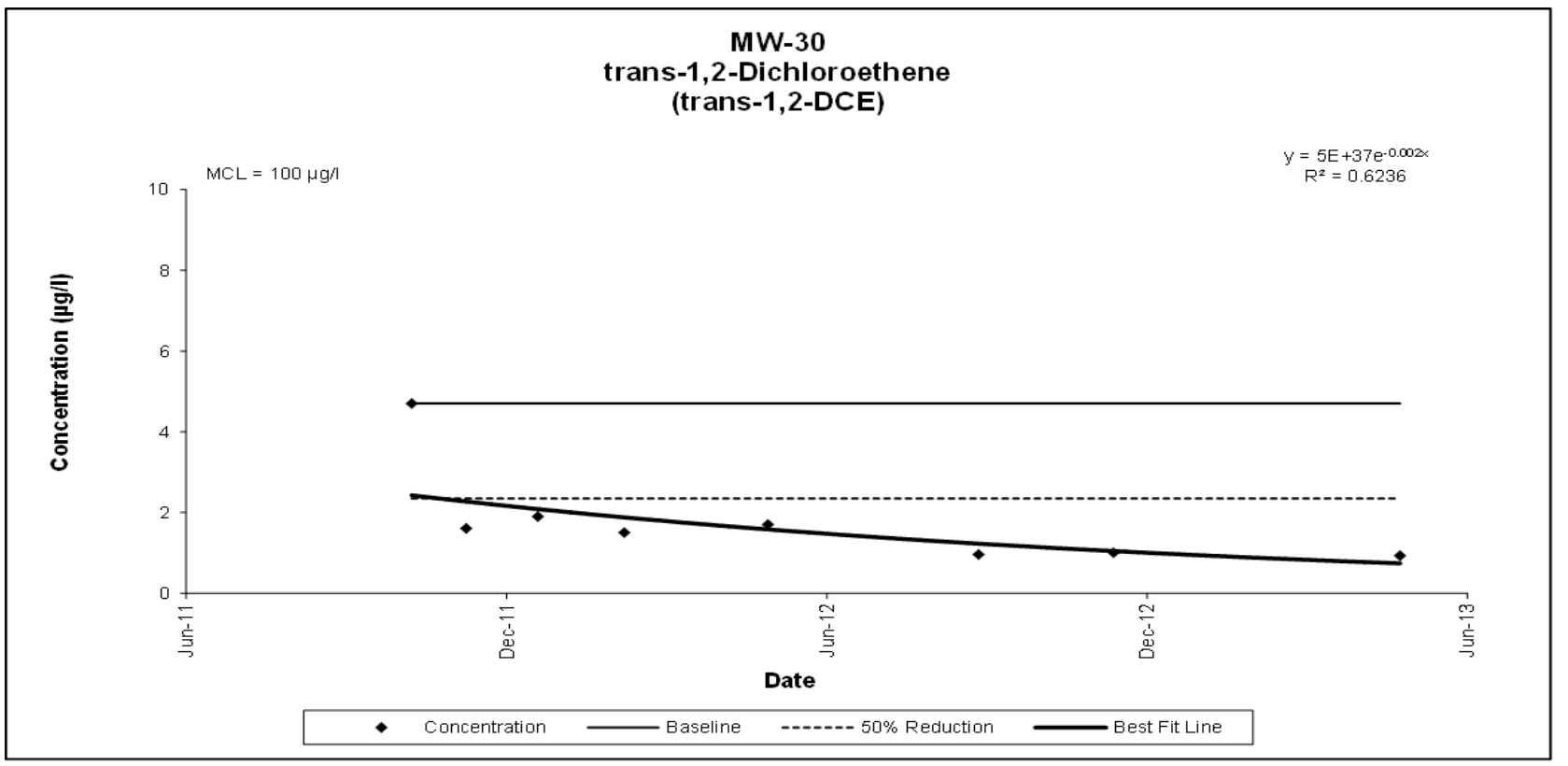


EXHIBIT B2-14
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-30



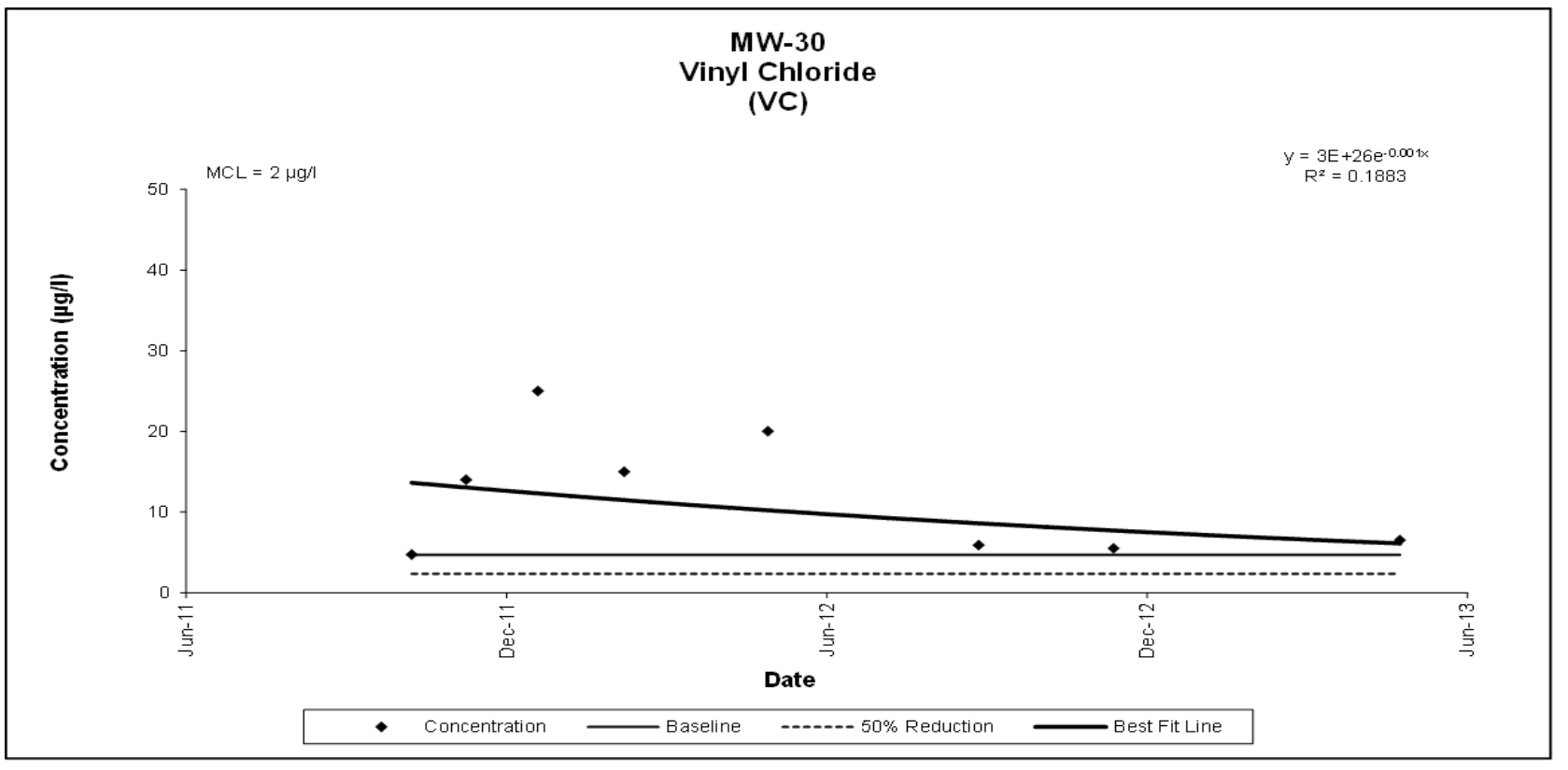


EXHIBIT B2-14
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL MW-30

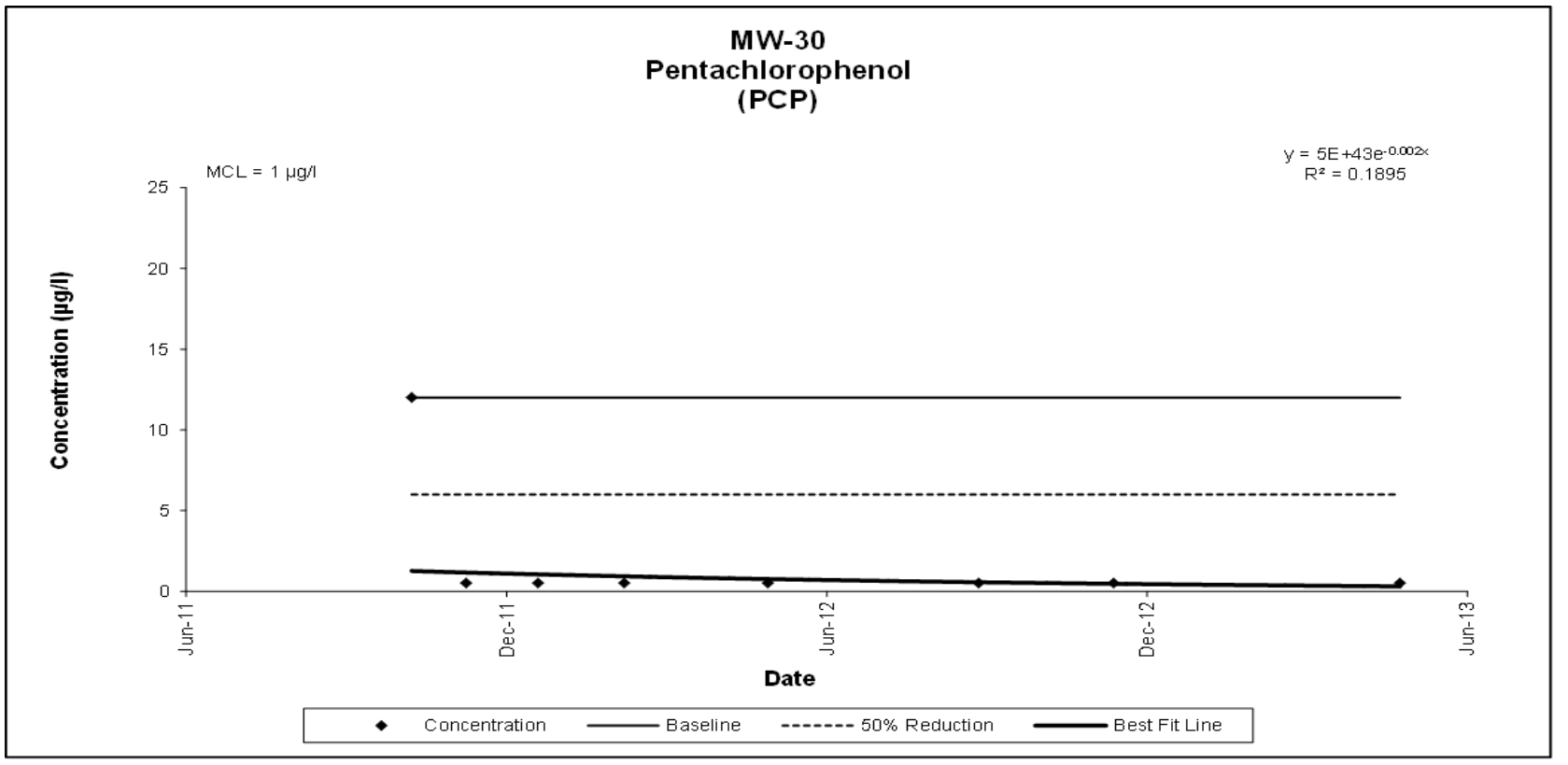


EXHIBIT B2-15
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL PZ-1

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
13-Aug-03	< 1	< 1	< 1	--	--	< 1	--	--
6-Nov-03	< 1	< 1	< 1	--	--	< 1	--	--
14-May-04	< 1	< 1	< 1	--	--	< 1	--	--
4-Nov-04	< 1	< 1	< 1	--	--	< 1	--	--
9-May-05	< 1	< 1	< 1	--	--	< 1	--	--
2-Nov-05	< 1	< 1	< 1	--	--	< 1	--	--
15-May-06	< 1	< 1	< 1	--	--	< 1	--	--
7-Nov-06	< 1	< 1	< 1	--	--	< 1	--	--
11-Apr-07	< 1	< 1	< 1	--	--	< 1	--	--
31-Oct-07	< 1	< 1	< 1	--	--	< 1	--	--
29-Apr-08	< 1	< 1	< 1	--	--	< 1	--	--
15-Oct-08	< 1	< 1	< 1	--	--	< 1	--	--
8-Apr-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
4-Nov-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
28-Apr-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
25-Oct-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
13-Apr-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
10-Nov-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
2-May-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
15-Nov-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
24-Apr-13	< 1	< 1	< 1	< 1	< 1	< 1	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

EXHIBIT B2-16
WASATCH CHEMICAL SITE
HISTORICAL DATA TRENDS
EXTRACTION WELL PZ-3

	LABORATORY PARAMETERS							
Sample Date	**PCE (µg/l)**	**TCE (µg/l)**	**1,1-DCE (µg/l)**	**cis-1,2-DCE (µg/l)**	**trans-1,2-DCE (µg/l)**	**VC (µg/l)**	**2,4-D (µg/l)**	**PCP (µg/l)**
14-May-04	< 1	< 1	< 1	--	--	< 1	--	--
4-Nov-04	< 1	< 1	< 1	--	--	< 1	--	--
9-May-05	< 1	< 1	< 1	--	--	< 1	--	--
2-Nov-05	< 1	< 1	< 1	--	--	< 1	--	--
15-May-06	< 1	< 1	< 1	--	--	< 1	--	--
7-Nov-06	< 1	< 1	< 1	--	--	< 1	--	--
11-Apr-07	< 1	< 1	< 1	--	--	< 1	--	--
31-Oct-07	< 1	< 1	< 1	--	--	< 1	--	--
29-Apr-08	< 1	< 1	< 1	--	--	< 1	--	--
15-Oct-08	< 1	< 1	< 1	--	--	< 1	--	--
8-Apr-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
4-Nov-09	< 1	< 1	< 1	< 1	< 1	< 1	--	--
28-Apr-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
25-Oct-10	< 1	< 1	< 1	< 1	< 1	< 1	--	--
12-Apr-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
11-Nov-11	< 1	< 1	< 1	< 1	< 1	< 1	--	--
3-May-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
14-Nov-12	< 1	< 1	< 1	< 1	< 1	< 1	--	--
24-Apr-13	< 1	< 1	< 1	< 1	< 1	< 1	--	--

Data qualifiers are defined in laboratory reports. For data collected since 2001, a list of data qualifier definitions is included at the front of this appendix.

-- Not analyzed

APPENDIX C

PLUME STABILITY STATISTICAL ANALYSIS

MWH®

BUILDING A BETTER WORLD

TECHNICAL MEMORANDUM

TO: Mr. Sam Garcia (USEPA Region 8) and Mr. Tony Howes (UDEQ) **DATE:** July 30, 2013

FROM: Paul Drake, Questar, and Susan Eyzaguirre (MWH) **REFERENCE:** 10502746

SUBJECT: Evaluation of Shallow Groundwater Plume Stability using Statistical Analyses

As presented in Questar's May 2013 Responses to the U.S. Environmental Protection Agency (USEPA) Office of Research and Development comments on the *Draft Natural Attenuation Evaluation* (MWH, 2011), this statistical evaluation of shallow groundwater plume stability was conducted to assess stability of the shallow groundwater plumes at the Wasatch Chemical Site (Site). Shallow groundwater concentrations persisting above MCLs are likely generated from subsurface residual contamination located just above the water table, as has recently (October 2011 and May 2013) been observed northeast of the Peterson Plumbing warehouse. Data suggest that shallow groundwater and residual contamination may be in equilibrium, limited by the rate of diffusion and hydrogeological constraints of the Site (i.e., inter-bedded, low-conductivity aquifer). If the shallow groundwater plumes prove to be stable, an equilibrium condition between groundwater and the residual contamination may exist and a petition for Alternative Performance Standards may be prepared and submitted to the regulatory agencies as outlined in Section VII of the Site Consent Decree (CD) (U.S. District Court, 1991).

1.0 BACKGROUND

1.1 Brief Site History

Industrial chemical operations began in 1957 at the Site and continued into the 1980s. A remedial investigation was conducted in the late 1980s and a feasibility study for soil and groundwater remedial alternatives was completed in August 1990 (Harding Lawson, 1990). RI data indicate shallow groundwater (less than 25 feet below ground surface [bgs]) and shallow soils (less than 5 feet bgs) were determined to have been impacted. A Record of Decision (ROD) (USEPA, 1991) and CD were completed and signed in 1991, and the Site continues to be federally regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Shallow groundwater contaminant concentrations at the Site, primarily chlorinated hydrocarbons and herbicides, have decreased by two and three orders of magnitude since 1995 when groundwater remediation began. An active pump-and-treat remedy was implemented for eight years until the change in groundwater concentrations over time was very small and significant mass removal was no longer occurring. In 2003 the extraction and treatment system was shut down and a period of monitored natural attenuation (MNA) was approved by the regulatory agencies. Biodegradation enhancement pilot tests were conducted in April 2004 and July 2006 in selected areas of the shallow groundwater plume; however, results were

limited and shallow groundwater contamination has remained persistent in some areas of the Site.

1.2 Shallow Groundwater Remediation Performance Standards

Remedial action performance standards for shallow groundwater at the Site require that contaminant levels of established "indicator chemicals" (USEPA, 1991) in groundwater within the area of attainment (inside Site boundaries, as defined in the CD be reduced to drinking water maximum contaminant levels (MCLs). Indicator chemicals established in the ROD include tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), dichlorophenoxyacetic acid (2,4-D), and pentachlorophenol (PCP), though monitoring of 2,4-D was discontinued in 2004 because its performance standard had been achieved across the Site. Acknowledging that groundwater remedial technologies at many sites are not successfully decreased to MCLs due to technical limitations, the Site CD states that the United States Environmental Protection Agency (USEPA) may be petitioned to waive or modify the performance standard requirements which cannot be achieved based upon a demonstration of technical impracticability from an engineering perspective.

The Site CD requires that in order to modify a performance standard, the justification of technical impracticability must "demonstrate with a 99% confidence limit that the concentrations of each contaminant for which a waiver or modification is sought remain at a statistically significant asymptotic value above MCLs". The justification must be based on a "four-point moving average or other statistical test" approved by the USEPA for "two years of quarterly monitoring" data. The "99% confidence limit" has been interpreted to mean a 99% confidence level. Additionally, two years of quarterly monitoring has been interpreted to mean eight data points, and based on the current sampling program, eight data points corresponds to four years of semi-annual monitoring.

1.3 Data Analyses

Trend analyses for indicator concentrations in shallow groundwater have been conducted since 2001 when mass removal rates leveled off considerably and the *Final Extraction and Treatment System Performance Standards, Milestones and Shutdown Procedures* document (Montgomery Watson, 2001) was submitted. As described in the *Technological Limits of Groundwater Remediation: A Statistical Evaluation Method* (American Petroleum Institute, 1991), linear regression methods have been used to identify trends in concentration time series data to ascertain whether "asymptotic" conditions exist. However, the validity of linear regression results is based on a number of underlying assumptions that are not always met for shallow groundwater data at the Site (see Section 3.0). Therefore, to provide a more thorough assessment of trends in shallow groundwater data and overall plume stability, Mann-Kendall and Thiel-Sen methods were used to evaluate indicator chemicals established in the ROD as well as vinyl chloride (VC) over the past four years (eight monitoring points). Throughout the remainder of this document, the currently monitored indicator chemicals and VC are referred to as constituents of concern (COCs).

Based on past linear regression results, declining trends in some wells across the Site have occurred since the groundwater extraction and treatment system was shut down in 2003.

These observations support the possibility of a remediation approach based on MNA; however, MNA as an alternative remedy is currently being reassessed, due to the discovery of residual contamination in shallow soils at the Site near the Peterson Plumbing warehouse. Therefore, a closer look at plume stability has been taken, and additional statistical tests, including Mann-Kendall and Theil-Sen, have been conducted to evaluate plume stability and/or plume containment. Specifically, for cases where COC concentrations have remained above the MCLs and no trend is indicated, the MCL is likely inappropriate or unattainable as a performance standard, and an Alternative Performance Standard may be proposed through a petition process outlined in the CD.

2.0 OBJECTIVES

This study includes evaluation of Site shallow groundwater COC data using the statistical methods described in this technical memorandum. These methods identify whether there are statistically significant trends in shallow groundwater concentrations through time, and if so how quickly concentrations are changing. Results from these analyses were evaluated to attain the following objectives:

- Evaluate plume stability and/or plume containment (i.e., wells where no statistically significant trends are identified)
- Demonstrate continued natural attenuation (i.e., decreasing trends in parent constituents, and increasing or decreasing trends of daughter products).
- Indicate where optimization of the sampling network and/or sampling frequency may be warranted (i.e., at wells with stable or decreasing concentrations below MCLs)
- Identify locations where an Alternative Performance Standard may be justified (i.e., wells with stable concentrations above MCLs).

3.0 STATISTICAL METHODS USED

The statistical methods used for this evaluation are described below. Figure C-1 depicts the decision logic criteria that were used through the application of these statistical methods to achieve the objectives stated in Section 2.0. Statistical calculations were performed following the USEPA Guidance *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities Unified Guidance* (USEPA, 2009). The software package Sanitas™ was used to conduct statistical testing. Sanitas™ is akin to ProUCL in that it is designed to comply with USEPA regulations and guidance and has similar functionality. Sanitas™ was configured to the USEPA Unified Guidance settings within the software. Descriptions of the statistical testing methods are provided in Attachment 1 (excerpts from the USEPA Unified Guidance).

It is important to note that the aim of statistical analysis is to draw inferences about the population based on the statistical sample. The population includes all possible concentrations or measurements at the location and the exact probability distribution, whereas the statistical sample is a finite subset of the population, commonly referred to as a data set.

3.1 Statistical Terms and Definitions

The primary statistical terms used in this memorandum are defined below.

- **Alpha (α)** - In hypothesis testing, α represents the percentage of cases for which a false conclusion is reached (e.g., based on the data set, the test concludes that there is a trend when in reality the population is not trending). When constructing confidence intervals, α represents the percentage of cases that the confidence interval will NOT contain the population parameter of interest (e.g., the population mean falls outside of the confidence interval that was constructed based on the data set).
- **Confidence level (1- α)** - In hypothesis testing, the confidence level represents the percentage of cases that a conclusion is reached (e.g., based on the data set, the test concludes that there is a trend when the population is truly trending). When constructing confidence intervals, the confidence level represents the percentage of cases where a confidence interval will actually contain the population parameter of interest (e.g., the true population mean falls inside of the confidence interval that was constructed based on the data set).
- **Confidence interval** - Provides an estimated range that intends to contain a given statistical characteristic of the population (e.g., mean) from which the data set is drawn. Assumes that the underlying population is stable (i.e., the mean, median, etc. are stationary over the period of the data set).
- **Confidence band** - Similar to a confidence interval, but it is constructed for trending data. Provides an estimated range, above and below the estimated trend line, that intends to contain a given statistical characteristic of the population (e.g., mean) from which the data set is drawn. Assumes that the underlying population is trending.
- **Non-detect** – An analytical parameter that is not detected by the laboratory instrument, but may actually be present at a value below the laboratory reporting limit. Non-detects are considered "left-censored" measurements because the result is assumed to fall within a certain low range (e.g., between zero and the laboratory reporting limit for groundwater analyses).
- **Non-parametric statistical method** - Statistical tests where the underlying probability distribution type is not assumed. These methods are typically based on either a ranking or an ordering of the data set values.
- **Outlier** - A value originating from a different statistical population than the rest of the sample, therefore violating the basic statistical assumption of identically-distributed measurements.
- **Parametric statistical methods** - Statistical tests that assume the underlying probability distribution type is known and can be characterized by a small set of mathematical parameters (e.g., mean, variance, etc.). Parametric tests use the assumed probability distribution to make inferences about the population.
- **Probability distribution** - Describes the relative frequencies of occurrence for each possible value (i.e., concentration). Probability distributions used in statistical testing make differing assumptions about how the underlying population is distributed. Examples of probability distributions include normal, lognormal, gamma, etc.

- **Skewness** - Measure of the degree of asymmetry of a probability distribution.

3.2 Data Input

Field and laboratory duplicates were removed prior to testing to avoid autocorrelation of the data. To comply with criteria outlined in the CD, data from the most recent eight sampling rounds were used in the analyses. Additionally, the USEPA Unified Guidance recommends at least four and preferably at least eight or more observations to perform the statistical analyses described below (USEPA, 2009). Thus far, only seven samples have been collected from monitoring location MW-30; therefore, results for this location will be reassessed after the next monitoring round (scheduled November 2013).

3.3 Statistical Analyses

The following statistical analyses were used to evaluate the Site data for the purposes outlined in Section 2.0. The decision logic criteria are also shown in Figure C-1.

3.3.1 Mann-Kendall and Theil-Sen Trend Analyses. Trend testing can answer two questions: 1) is there a statistically significant trend over the period of interest and 2) if there is a statistically significant trend, what is the rate of change? For data whose distribution does not fit a known probability distribution or for data sets with non-detect results, the USEPA Unified Guidance recommends using the non-parametric Mann-Kendall method to test for a trend. The Mann-Kendall method is preferred over linear regression because the validity of linear regression results is based on a number of underlying assumptions that may not always be met. These assumptions include: 1) the regression residuals are normally distributed, 2) the regression residuals are homoscedastic (i.e., the variance of the residuals do not depend on the x-value [i.e.,time]), 3) there is not significant skewness or outliers in the data, and 4) there are few if any non-detect data points (USEPA, 2009).

The Mann-Kendall procedure was used to evaluate data sets to test for a significant slope (i.e., trend) in the linear regression of the concentration values plotted against time (Gilbert, 1987). To comply with criteria outlined in the CD, an α of 0.01 (99% confidence level) was used to test for the presence of a trend. The Theil-Sen method, which is also a non-parametric alternative to linear regression, was used in conjunction with the Mann-Kendall method to determine a slope or rate of change of the trending data (Helsel, 2005). The Theil-Sen method estimates the change in median concentration over time, unlike linear regression which uses the change in mean concentration to calculate the slope. One benefit of evaluating median concentrations rather than mean concentrations is that the median is less influenced by outliers.

3.3.2 Confidence Intervals and Confidence Bands. The USEPA Unified Guidance recommends using confidence intervals and confidence bands to assess whether a given data set is statistically above or below current performance standards (MCLs) (USEPA, 2009). For data sets where trends are not present as determined by the Mann-Kendall trend analysis, the USEPA Unified Guidance recommends using confidence intervals for compliance assessment or corrective action monitoring. Specifically, the upper and lower

confidence interval limits should be compared to the performance standard (i.e., MCL) to determine whether groundwater concentrations are statistically above or below performance standards. Where trends are present as determined by the Mann-Kendall analysis, the USEPA Unified Guidance suggests that a confidence band about the Theil-Sen trend line be computed and compared to the performance standard (i.e., MCL). Either parametric or non-parametric methods should be applied depending on the data distribution.

To evaluate Site water-quality data with respect to MCLs, confidence intervals for non-trending data and confidence bands for trending data were computed. Results were used to determine whether the data exceed the MCL.

3.4 Decision Logic Criteria

The flow chart in Figure C-1 depicts how each of the analysis methods was applied. Based on this decision logic process, outcomes fell into three general recommendation categories:

Recommendation A: Continue Monitoring (for increasing trends and decreasing trends above MCLs)
Recommendation B: Evaluate Sampling Frequency, with the potential to decrease the frequency or terminate sampling in the future (for decreasing or non-trending data below MCLs)
Recommendation C: Evaluate Basis for a Potential Alternative Performance Standard, with the potential to decrease sampling in the future (for non-trending data above MCLs).

Steps taken to follow the decision logic criteria shown in Figure C-1 are described below.

1. Field and laboratory duplicates are removed from the data sets prior to input into Sanitas™ software.
2. The Mann-Kendall and Theil-Sen trend analyses are performed to assess potential data trends at an α of 0.01 (99% confidence level).
3. Where an increasing trend is identified:
    i. Data are compared to the MCL using a confidence band around the Theil-Sen trend line (α at 0.01).
        a. Data are above the MCL: Location/COC should continue to be monitored (Recommendation A).
        b. Data are below the MCL: Location/COC should continue to be monitored (Recommendation A). Further, the Theil-Sen slope may be used to estimate the time until concentrations reach the MCL.
4. Where a decreasing trend is identified:
    i. Data are compared to the MCL using a confidence band around the Theil-Sen trend line (α at 0.01).
        a. Data are above the MCL: Location/COC should continue to be monitored (Recommendation A). Further, the Theil-Sen slope may be used to estimate the time until concentrations reach the MCL.

b. Data are below the MCL: Evaluate sampling frequency (Recommendation B). Further, the Theil-Sen slope may be used to estimate the time until concentrations reach the MCL.

5. Where no trend is identified:
   i. Data are compared to the MCL using a confidence interval. Where parametric methods are appropriate, the confidence interval is constructed using an α of 0.05 (95% confidence level). Where non-parametric methods are appropriate, α_s are computed by the Sanitas™ algorithm and are less than 0.05.
      a. Data are above the MCL: Location/COC appears stable. Evaluate basis for a potential Alternative Performance Standard (Recommendation C).
      b. Data are below the MCL: Location/COC appears stable and has achieved its performance standard; therefore, evaluate needed sampling frequency (Recommendation B). Sampling may be decreased or eliminated.

The above steps were followed to evaluate the Site data and to make recommendations that are based on the statistical framework presented in the USEPA Unified Guidance (USEPA, 2009). Results are presented in the following section.

4.0 STATISTICAL EVALUATION RESULTS

4.1 Mann-Kendall Thiel-Sen Results

Results from the statistical analyses and the decision logic criteria process are summarized in Table C-1 for all locations/COCs where concentrations are statistically above the MCLs (lower confidence limit is greater than the MCL). A more complete tabulation of results, including locations/COCs where concentrations are not statistically greater than MCLs is included in Attachment 2, and graphical output for all analyses is included in Attachment 3. Recommendations (A, B and C) are indicated for each monitoring well and each COC on a Site map in Figure C-2. Recommendations are defined in Section 3.4 of this memorandum and shown for indicated locations/COCs in Table C-1 and on Figure C-2.

4.1.1 COCs > MCLs with Trends. Trends were detected at the 99% confidence level for only two of 50 locations/COCs: EX-04/TCE and EX-05/VC. These locations/COCs are highlighted in orange in tables called out on Figure C-2. The slope or rate of change of the trend for both of these data sets is decreasing (14.43 micrograms per liter per year [µg/l/yr] for EX-04/TCE, and 3.63 µg/l/yr for EX-05/VC). These slopes suggest natural attenuation is occurring at these locations.

4.1.2 COCs > MCLs without Trends. Ten of 50 locations/COCs fall in this category. Results from select COCs at seven of the eleven shallow wells evaluated show that a trend was not detected at the 99% confidence level, and based on the calculated confidence interval, data from the eight most recent samples fall above the MCL (see Table C-1). These locations include EX-02, EX-04, EX-05, EX-08, EX-11, MW-20, and MW-30. The absence of a

statistically significant trend at α equal to 0.01 and the occurrence of COCs above MCLs at these locations suggest that the contaminant plumes in these areas are stable, or as described in the CD, "the concentration of each contaminant … remains at statistically significant asymptotic values above MCLs."

4.1.3 COCs < MCLs without Trends. A total of 38 of 50 locations/COCs have concentrations statistically below the MCL and are not trending at the 99% confidence level. These are highlighted in yellow-green on Figure C-2 and are tabulated in Attachment 2. Results for *all* five COCs at four of the eleven shallow wells evaluated show that trends were not detected at the 99% confidence level, and based on the confidence intervals, data from the eight most recent samples of all five COCs at these four locations fall below the MCLs. These locations include ES-01, EX-07, EX-09, and MW-06. Furthermore, results from all but one COC at four additional shallow wells show that a trend was not detected at the 99% confidence level, and based on the confidence intervals, results from the eight most recent samples fall below the MCL. These locations include EX-08, EX-11, MW-20, and MW-30.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on results from the statistical analyses and the decision logic criteria process presented in Figure C-1, COC concentrations are either:

- *Attenuating* - Above the MCL and decreasing (two cases), or
- *Stable* - Below the MCL and not trending; performance standard met (38 cases), or
  - Above the MCL and not trending (10 cases).

These results are presented in Attachment 2 and shown in Figure C-2. The overall non-trending or decreasing concentrations at monitoring locations located on the Site support the concept that the plume is stable.

5.1 Monitoring Program

5.1.2 Continue Monitoring Where Trends Are Occurring. Statistically significant decreasing trends were indicated for only two locations/COCs: EX-04/TCE and EX-05/VC (locations/COCs highlighted in red on Figure C-2 and Table C-1). These conditions support the occurrence of natural attenuation, and it is recommended that these locations/COCs continue to be monitored because their concentrations over the eight most recent sampling events are statistically greater than their respective MCLs. Additionally, the Theil-Sen slope may be used in the future to predict when the MCL is expected to be reached. (No increasing trends were indicated.)

5.1.3 Decrease Sampling Frequencies where Performance Standards Have Been Met. At monitoring locations where results show that a COC concentration trend is not present and the confidence interval is below the MCL (see cases highlighted in yellow-green on Figure C-2, Recommendation B), it is recommended that sampling frequencies be evaluated. Non-trending results below the MCL were found for all COCs at ES-01, EX-07, EX-09, and MW-06, and for all but one COC at EX-08, EX-11, MW-20, and MW-30. The absence of a statistically

significant trend using a 99% confidence level and the lack of COC detections at these locations suggest that the plumes in these areas are stable.

5.2 Alternative Performance Standards

5.2.1 Evaluate the Basis for Potential Alternative Performance Standards where Data are above MCLs and Stable. Where results show that a COC concentration trend is not present and the lower confidence interval is above the MCL (see Table C-1 and Figure C-2), it is recommended that Alternative Performance Standards be pursued as outlined in the Site CD. This recommendation is suitable for select COCs at EX-02, EX-04, EX-05, EX-08, EX-11, MW-20, and MW-30.

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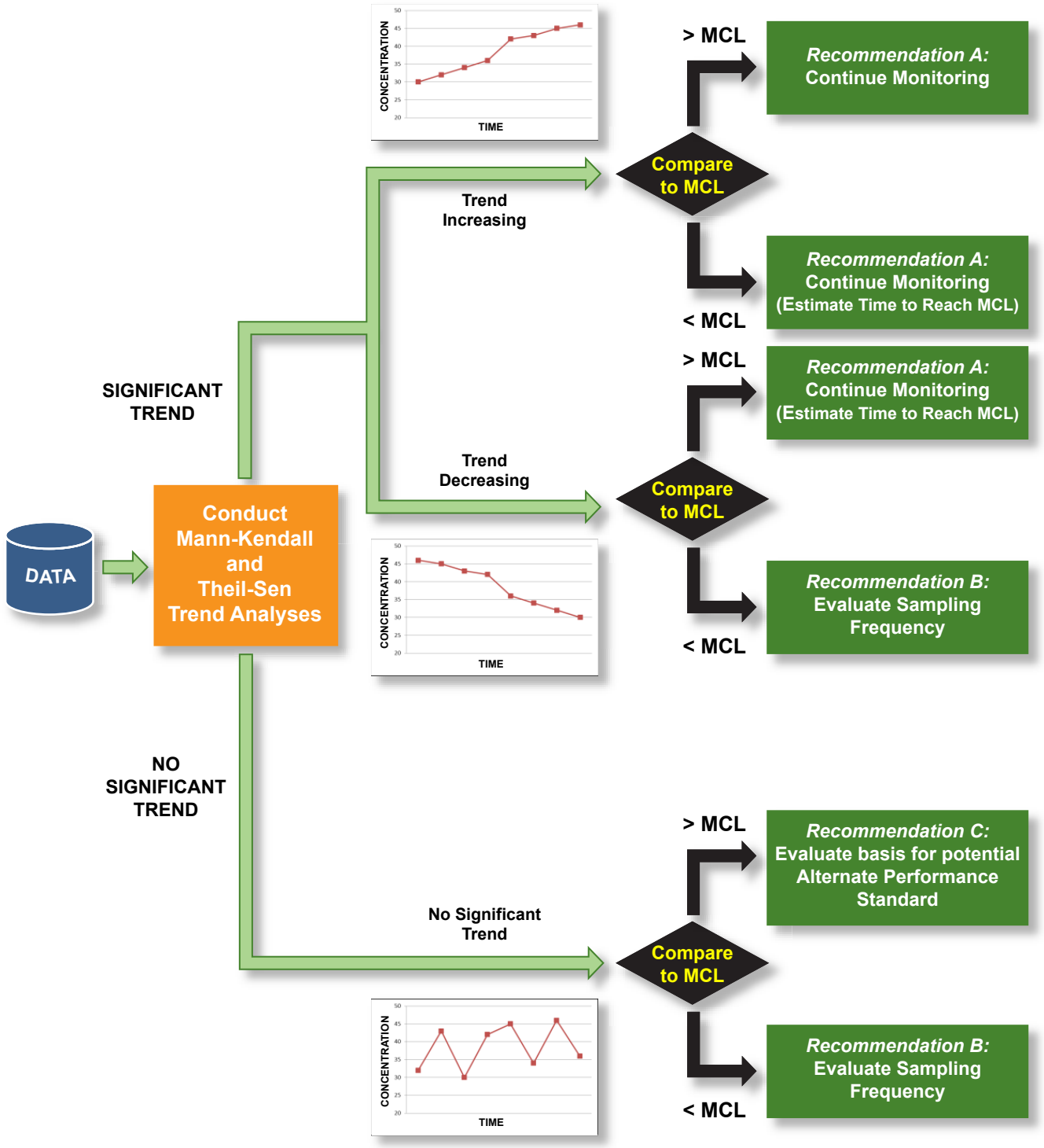
TABLE C-1
SHALLOW GROUNDWATER STATISTICAL ANALYSIS RESULTS
FOR MONITORING LOCATIONS WITH COCs ABOVE MCLs
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH
(Page 1 of 1)

Well	Constituent	Mean of Data Set (µg/l)	Data Distribution	Trend[a]	Slope[b] (µg/l/year)	UCL[c]	LCL[c]	Exceeds MCL[d]	Indication
EX-02	TCE	126.6	normal	No	NA	152.3	91.0	Yes	Stability
	1,1-DCE	9.0	normal	No	NA	9.8	8.3	Yes	Stability
	VC	117.8	normal	No	NA	160.1	75.6	Yes	Stability
	PCP	7.6	normal	No	NA	9.4	5.8	Yes	Stability
EX-04	TCE	31.6	normal	Yes	-14.4	44.7	18.6	Yes	Decreasing Trend
	1,1-DCE	10.3	normal	No	NA	12.9	7.8	Yes	Stability
EX-05	1,1-DCE	8.6	normal	No	NA	9.4	7.9	Yes	Stability
	VC	15.9	normal	Yes	-3.63	19.6	12.3	Yes	Decreasing Trend
EX-08	PCP	2.2	normal	No	NA	2.7	1.6	Yes	Stability
EX-11	VC	519.4	normal	No	NA	669.5	369.2	Yes	Stability
MW-20	VC	3.6	normal	No	NA	4.3	2.4	Yes	Stability
MW-30[e]	VC	13.1	normal	No	NA	18.7	7.5	Yes	Stability

Notes:
[a]Mann-Kendall method used to test for presence of a statistically significant slope (trend).
[b]Thiel-Sen method used to estimate the rate of change of the median concentration over time (slope).
[c]Confidence limits determined using a 95% confidence level ($\alpha = 0.05$), a standard level typically used for confidence limits.
[d]Exceeds MCL with statistical significance; determined by comparing the lower confidence limit to the MCL at the 95% confidence level.
[e]Seven data points were used for MW-30 (installed in October 2011).
[f]Alternative Performance Standards are defined in the Site Consent Decree (U.S. District Court, 1991)

APS	Alternative Performance Standard[f]		
COC	constituent of concern	LCL	lower confidence limit
MCL	maximum contaminant level	α	The percentage of cases for which a false conclusion
NA	not applicable		is reached (1-confidence level).
UCL	upper confidence limit	µg/l	micrograms per liter



MCL - Maximum contaminant level

MWH

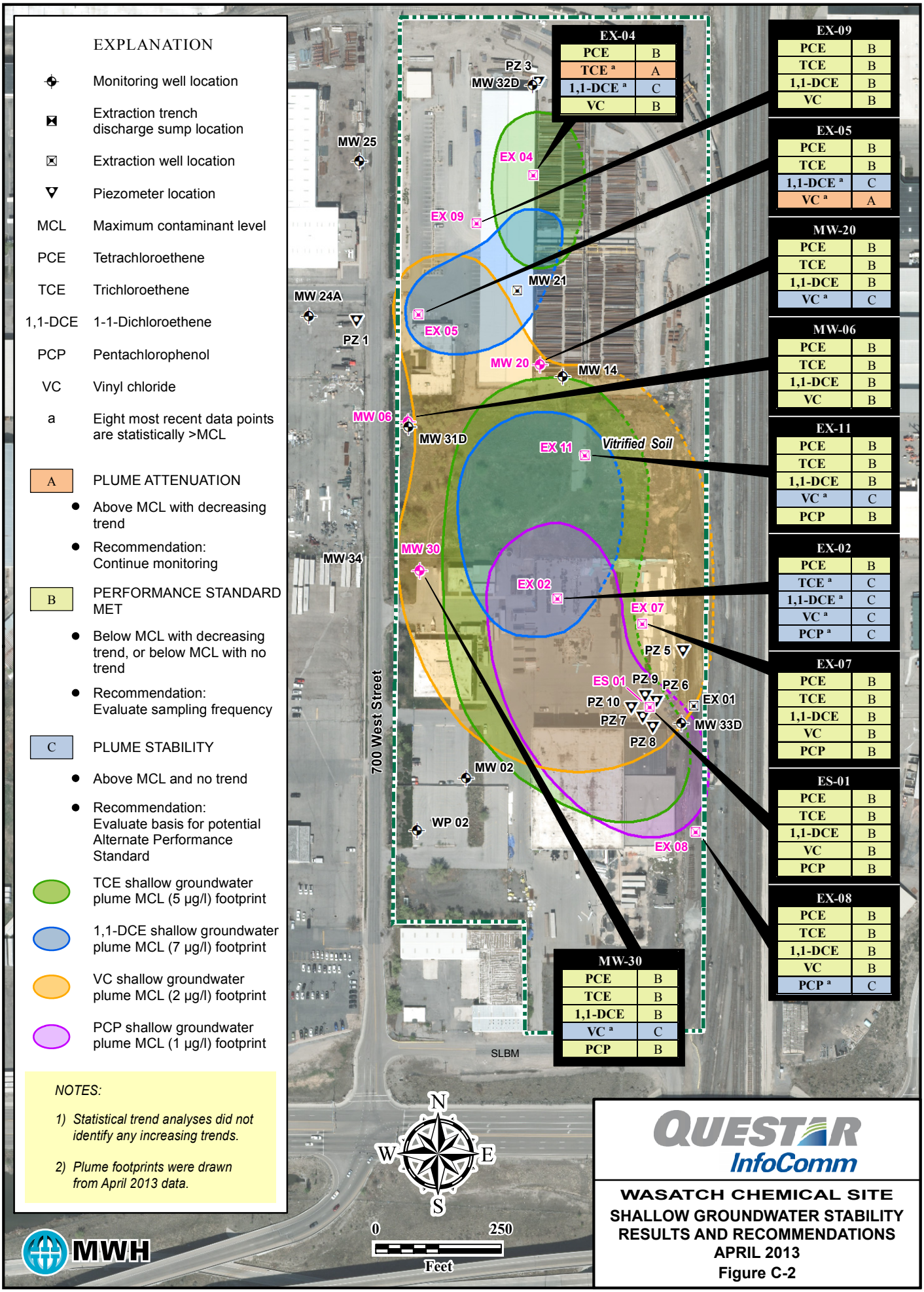
QUESTAR InfoComm

WASATCH CHEMICAL SITE

PLUME STABILITY EVALUATION FLOW CHART

Figure C-1

FILE: *Fig C-1_Plume Stability Eval Flow Chart_MOD.ai* 29 July 2013


EXPLANATION
Monitoring well location
Extraction trench discharge sump location
Extraction well location
Piezometer location
MCL Maximum contaminant level
PCE Tetrachloroethene
TCE Trichloroethene
1,1-DCE 1-1-Dichloroethene
PCP Pentachlorophenol
VC Vinyl chloride
a Eight most recent data points are statistically >MCL
A PLUME ATTENUATION
Above MCL with decreasing trend
Recommendation: Continue monitoring
B PERFORMANCE STANDARD MET
Below MCL with decreasing trend, or below MCL with no trend
Recommendation: Evaluate sampling frequency
C PLUME STABILITY
Above MCL and no trend
Recommendation: Evaluate basis for potential Alternate Performance Standard
TCE shallow groundwater plume MCL (5 µg/l) footprint
1,1-DCE shallow groundwater plume MCL (7 µg/l) footprint
VC shallow groundwater plume MCL (2 µg/l) footprint
PCP shallow groundwater plume MCL (1 µg/l) footprint
NOTES:
1) Statistical trend analyses did not identify any increasing trends.
2) Plume footprints were drawn from April 2013 data.
EX-04
PCE B
TCE a A
1,1-DCE a C
VC B
EX-09
PCE B
TCE B
1,1-DCE B
VC B
EX-05
PCE B
TCE B
1,1-DCE a C
VC a A
MW-20
PCE B
TCE B
1,1-DCE B
VC a C
MW-06
PCE B
TCE B
1,1-DCE B
VC B
EX-11
PCE B
TCE B
1,1-DCE B
VC a C
PCP B
EX-02
PCE B
TCE a C
1,1-DCE a C
VC a C
PCP a C
EX-07
PCE B
TCE B
1,1-DCE B
VC B
PCP B
ES-01
PCE B
TCE B
1,1-DCE B
VC B
PCP B
EX-08
PCE B
TCE B
1,1-DCE B
VC B
PCP a C
MW-30
PCE B
TCE B
1,1-DCE B
VC a C
PCP B
PZ 3
MW 32D
MW 25
EX 04
EX 09
MW 21
MW 24A
PZ 1
EX 05
MW 20
MW 14
MW 06
MW 31D
EX 11
Vitrified Soil
MW 30
MW 34
EX 02
EX 07
PZ 5
ES 01
PZ 9
PZ 6
PZ 10
EX 01
PZ 7
MW 33D
PZ 8
MW 02
WP 02
EX 08
700 West Street
SLBM
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250
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MWH
QUESTAR InfoComm
WASATCH CHEMICAL SITE
SHALLOW GROUNDWATER STABILITY RESULTS AND RECOMMENDATIONS
APRIL 2013
Figure C-2
DATE: 19 July 2013
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ATTACHMENT 1

EXCERPTS FROM EPA UNIFIED GUIDANCE FOR STATISTICAL ANALYSIS OF GROUNDWATER DATA

and noted as being below the target levels. One should also strongly consider comparing one or more verification resamples against the upper tolerance limit before identifying a clear violation.

►EXAMPLE 17-4

Use the following copper background data to establish a non-parametric upper tolerance limit and determine if either compliance well shows evidence of copper contamination.

	Copper Concentration (ppb)				
	Background Wells			Compliance Wells	
Month	Well 1	Well 2	Well 3	Well 4	Well 5
1	<5	9.2	<5		
2	<5	<5	5.4		
3	7.5	<5	6.7		
4	<5	6.1	<5		
5	<5	8.0	<5	6.2	<5
6	<5	5.9	<5	<5	<5
7	6.4	<5	<5	7.8	5.6
8	6.0	<5	<5	10.4	<5

SOLUTION

Step 1. The pooled background data in Wells 1, 2, and 3 have a maximum observed value of 9.2 ppb. Set the 95% confidence upper tolerance limit equal to this value. Because 24 background samples are available, **Table 17-4** in **Appendix D** indicates that the minimum coverage is equal to 88%. To increase either the coverage, more background samples would have to be collected.

Step 2. Compare each sample in compliance Wells 4 and 5 to the upper tolerance limit. Since none of the measurements at Well 5 is above 9.2 ppb, while one sample from Well 4 is above the limit, conclude that there may be significant evidence of copper contamination at Well 4 but not Well 5.

Step 3. Note that with only 88% coverage and 24 background samples, the risk of a false positive result is more than 10%. Well 4 should be resampled to determine whether the exceedance is replicated. ◄

17.3 TREND TESTS

The Unified Guidance recommends *trend testing* as an intrawell alternative to prediction limits or control charts when those methods are not suitable. Prediction limits and control charts (as well as *t*-tests and ANOVA) all involve a comparison of compliance and background populations under the key assumption that the underlying concentration distributions are *stationary over time*. That is, the populations are presumed to have stable (*i.e.*, roughly constant) means over the period of sampling prior to statistical evaluation.

Unfortunately, there is no guarantee that groundwater populations will remain stable during long-term monitoring. Because sampling at many sites is generally done on a quarterly, semi-annual, or annual basis, it will generally take one to two years or more to collect enough background data to run the statistical tests discussed in the Unified Guidance. Over this length of time, the statistical characteristics of groundwater may or may not change in significant ways.

If background groundwater conditions are in a state of flux, trend tests provide a significant advantage over both intrawell prediction limits and control charts. Both of the latter methods involve a designation of some portion of the historical sampling record as the intrawell background for a given compliance well. Ideally, this intrawell background should consist of measurements known to be uncontaminated and which represent a random sample from a stable underlying population, just as with *t*-tests and ANOVA. If the mean and/or standard deviation of the underlying population *changes* while intrawell background is being compiled, results of either prediction limit or control chart tests against more recently collected data can be severely biased or altogether inaccurate.

One drawback to the Shewhart-CUSUM control charts presented in **Chapter 20** is that they are somewhat sensitive to the parametric assumption of underlying normality. If the measurements are lognormal rather than normal, for instance, the nominal performance characteristics (*i.e.*, Type I error rate and statistical power) of control charts are significantly affected. By the same token, control charts are impacted if the intrawell background contains a large fraction of non-detects. Non-detect adjustments can sometimes be made to the baseline data via methods discussed in **Chapter 15**, but if a normalizing transformation or adjustment is not successful, no straightforward non-parametric control chart exists.

Consequently, neither prediction limits nor control charts are appropriate for every circumstance where an intrawell comparison may be warranted or necessary. Thus, ***the Unified Guidance recommends that users consider trend testing as an alternative to prediction limits or control charts when those methods are not suitable as intrawell techniques***. Tests for trend are specifically designed to identify those groundwater populations whose mean concentrations are not stationary over time, but rather are increasing (or decreasing) by measurable amounts. Ultimately, the goal of any reasonable detection or compliance/assessment monitoring program is to determine whether or not the concentration levels of key contaminants or indicator parameters have significantly increased during the period of monitoring and, if so, whether the increase is attributable to facility waste management practices.

The detection of trends is a complex subject. Whole textbooks are devoted to the more general topic of *time series analysis*, including the identification and modeling of time trends — step functions, linear and quadratic trends, exponential growth, *etc.* The Unified Guidance only attempts to identify the simplest kind of linear increases, not the specification or testing of more complex models. The methods described below are all designed to effectively test for (increasing) linear trends, though they will also identify simple increases over time when a trend is present but does not follow a strictly linear pattern.

The Unified Guidance recommends using trend tests in detection monitoring to measure the extent and nature of an apparent concentration increase, especially to determine whether or not the increase occurs consistently over time. Two questions are of particular interest: 1) is there a statistically significant, (positive) trend over the period of monitoring? and 2) what is the nature (*i.e.*, slope and intercept) of the trend? By identifying a positive trend, one can show that contaminant levels have gotten worse compared to early measurements from the well being tested. Furthermore, by measuring the nature

of the trend, including the average rate of increase per unit of time, one can estimate how rapidly concentration levels are increasing and the current mean- or median-level magnitude of contamination. Such information can provide an invaluable portrait of the changes occurring on-site and probably offers the most compelling evidence — under these conditions — for demonstrating that the basic null hypothesis of detection monitoring has been violated.

17.3.1 LINEAR REGRESSION

BACKGROUND AND PURPOSE

The most common way to measure a linear trend is to compute a *linear regression* of concentration data when plotted against the time or date of sample collection. By way of interpretation, each point along a linear regression trend line is an estimate of the true mean concentration *at that point in time*. Thus, a linear regression can be used to assess whether or not the population mean at a compliance well has significantly increased or decreased.

Linear regression is a standard technique in statistics textbooks and many data analysis software packages. It is more generally applicable to linear relationships between any pair of random variables and not simply to time trends. Good references for performing linear regression and for checking and verifying its assumptions include Draper and Smith (1998) and Cook and Weisberg (1999).

Unlike prediction limits or control charts which are constructed using only the background data, trend tests including linear regression are computed with all available earlier and more recent data at the compliance well of interest. One then might incorrectly assume that a comparison against intrawell background is not being conducted. But an intrawell comparison does occur with a trend test. Statistical identification of a structured pattern of increase from the first portion of the sampling record to more recent data indicates that concentration levels are no longer similar to intrawell background, but have risen more than expected by chance.

Statistical identification of a positive trend involves testing the estimated slope coefficient from the linear regression trend line. A specially constructed *t*-test is used to make this determination, as described below. If this test is significant, the slope is judged to be different from zero, indicating that a change in concentration levels has occurred over the period of sampling represented by the data set.

REQUIREMENTS AND ASSUMPTIONS

Linear regression as a parametric statistical technique makes a number of underlying assumptions. Among the most important of these are that the regression residuals (*i.e.*, the difference between each concentration measurement and its predicted value from the regression equation) are approximately normal in distribution, homoscedastic (*i.e.*, equal in variance at different times and for different mean concentration levels), and statistically independent. Significant skewness or the presence of outliers can bias or invalidate the results of a trend test based on linear regression. Furthermore, standard linear regression methods do not account for non-detects or missing data values at selected sampling events.

Because the key assumptions for linear regression depend not on the original measurements but rather on the regression residuals, a tentative trend line needs to first be constructed before its

assumptions can be checked. Once a linear regression on time is fitted to the data, the residuals around the trend line need to be computed and then tested for normality, apparent skewness, and equal variance over time. This last assumption is particularly important to testing whether the slope of an apparent trend is statistically different from zero (a zero slope indicating that well concentrations have not changed over time).

Inferences around a linear regression are generally appropriate when three conditions hold: 1) the residuals from the regression are approximately normal or at least reasonably symmetric in distribution; 2) a scatter plot of residuals versus concentrations indicates a scatter cloud of essentially uniform *vertical thickness or width* (i.e., the scatter cloud does not tend to increase in width with the level of concentration which would suggest a proportional effect between the underlying population mean and variance); and 3) a scatter plot of residuals versus time also exhibits a uniformly thick scatter cloud. If the thickness or width is substantially different at distinct time points, the assumption of equal variances over time may not be true.

If any of these conditions is substantially violated, it may indicate that the basic trend is either non-linear or the magnitude of the variance is not independent of the mean concentration level and/or the time of sampling. One possible remedy is to try a transformation of the concentration data and re-estimate the linear regression. This will change the interpretation of the estimated regression from a linear trend of the form $y = a + bt$, where y and t represent concentration and time respectively, to a non-linear pattern. As an example, if the concentration data are log-transformed, the regression equation will have the form $\log y = a + bt$. Back-transformed to the original concentration scale, the trend function will then have the form $y = \exp\left(a + bt\right)$.

In transforming the regression data this way, the estimated trend in the concentration domain (after back-transforming) no longer represents the original mean. Rather, the transformation induces a *bias* when converted back to the raw-scale data. If a log transformation is used, for instance, the back-transformed trend line will represent the raw-scale *geometric mean* and not the *arithmetic mean*. As with Student's t-tests on lognormal data (**Chapter 16**), demonstrating that the *geometric* mean is increasing also implies that the *arithmetic* mean has risen so long as the regression residuals are homoscedastic.

A minimum of 8 to 10 measurements is generally necessary to compute a linear regression, especially to estimate the variance around the trend line (known as the *mean squared error* or MSE). The regression residuals should be statistically independent, an assumption that can be approximately verified via one of the autocorrelation tests of **Chapter 14**.

One last assumption is that there should be few if any non-detects when computing a linear regression. As a matter of common sense, a significant increasing or decreasing trend should be based on reliably quantified measurements. If this is not the case, the user should check to see whether the "trend" may be an artifact induced by changes in detection and/or quantitation limits over time. The concentration levels of a series of non-detects may appear to be decreasing, for instance, simply because analytical methods have improved over the years leading to lower RLs. Such artifacts of plotting and data reporting should not be considered real trends.

When the assumptions of linear regression cannot be verified at least approximately, a non-parametric trend method should be considered instead. **Sections 17.3.2** and **17.3.3** discuss the *Mann-*

Kendall test for trend and the *Theil-Sen trend line*. These methods can be particularly valuable when constructing trends on data sets containing non-detects.

PROCEDURE

Step 1. Construct a time series plot of the compliance point measurements. If a discernible trend is evident, compute a linear regression of concentration against sampling date (time), letting x_i denote the ith concentration value and t_i denote the ith sampling date. Estimate the linear slope $\hat{b}$ with the formula:

$$\hat{b} = \sum_{i=1}^{n} (t_i - \bar{t}) \cdot x_i \Big/ (n-1) \cdot s_t^2 \qquad [17.21]$$

This estimate then leads to the regression equation, given by:

$$\hat{x}_t = \bar{x} + \hat{b} \cdot (t - \bar{t}) \qquad [17.22]$$

where $\bar{t}$ denotes the mean sampling date, s_t^2 is the variance of sampling dates, $\bar{x}$ is the mean concentration level, and $\hat{x}_t$ represents the estimated mean concentration at time t.

Note: though the variable t above represents time, it could just as easily signify another variable, perhaps a second constituent for which an association with x is estimated.

Step 2. Compute the regression residual at each sampling event i with equation [17.23]:

$$r_i = x_i - \hat{x}_i \qquad [17.23]$$

Check the set of residuals for lack of normality and significant skewness using the techniques in **Chapter 10**. Also, plot the residuals against the estimated regression values ($\hat{x}_i$) to check for non-uniform vertical thickness in the scatter cloud. Make a similar check by plotting the residuals against the sampling dates (t_i).

If the residuals are non-normal and substantially skewed and/or the scatter clouds appear to have a definite pattern (*e.g.*, funnel-shaped; "U"-shaped; or, residuals mostly positive on one end of graph and mostly negative on the other end, instead of randomly scattered around the horizontal line $r = 0$), repeat **Steps 1** and **2** after first attempting a normalizing transformation.

Step 3. Calculate the estimated variance around the regression line (also known as the *mean squared error* [MSE]) with equation [17.24]:

$$s_e^2 = \frac{1}{n-2} \sum_{i=1}^{n} r_i^2 \qquad [17.24]$$

Step 4. Compute the standard error of the linear regression slope coefficient using the s^2_e result from Step 3 in equation [17.25]:

$$se\left(\hat{b}\right) = \sqrt{s^2{}_e \Big/ \sum_{i=1}^{n} \left(t - \bar{t}\right)^2} \qquad [17.25]$$

Step 5. Test whether the trend is significantly different from zero by forming the *t*-statistic ratio in equation [17.26]:

$$t_b = \hat{b} \Big/ se\left(\hat{b}\right) \qquad [17.26]$$

This *t*-statistic (t_b) has n–2 degrees of freedom [*df*]. Given a level of significance (α), choose the critical point (t_{cp}) for the test as the (1– α) × 100th percentage point of the Student's *t*-distribution with (n–2) *df* or $t_{cp} = t_{1-\alpha,n-2}$. Compare t_b against the critical point. If $t_b > t_{cp}$, conclude that the slope of the trend is both positive and significantly different from zero at the α-level of significance. If $t_b < -t_{cp}$, conclude there is a significant decreasing trend. If neither exists, there is insufficient evidence of an increasing or decreasing trend.

►EXAMPLE 17-5

The following groundwater chloride measurements (n = 19) were collected over a five-year period at a solid waste landfill. Test for a significant trend at the α = 0.01 level using linear regression.

Sample Date	Chloride (ppm)	Elapsed Days	Residuals
2002-03-18	11.5	76	–0.25
2002-05-14	12.6	133	0.67
2002-08-22	13.8	233	1.56
2003-02-12	12.3	407	–0.48
2003-05-29	12.8	513	–0.30
2003-08-18	13.2	594	–0.15
2003-11-20	14.1	688	0.45
2004-02-19	13.3	779	–0.63
2004-04-26	13.1	846	–1.04
2004-07-29	13.2	940	–1.23
2004-11-09	15.3	1043	0.56
2005-02-24	15.0	1150	–0.08
2005-06-14	15.2	1260	–0.22
2005-08-23	15.8	1330	0.17
2005-10-17	16.1	1385	0.30
2006-02-08	15.1	1499	–1.06
2006-04-27	16.4	1577	0.00
2006-08-10	17.7	1682	0.98
2006-10-26	17.7	1759	0.74

SOLUTION

Step 1. Check for an apparent trend on a time series plot (**Figure 17-2**). Since the chloride values are increasing in reasonably linear fashion, compute the tentative regression line using equations [17.21] and [17.22]. To compute the slope estimate, first convert the sample dates to elapsed days using a starting date prior to the first event. In this case, choose an arbitrary starting date of 2002-01-01 as zero and compute the elapsed days as listed in the table above.

Using elapsed days as the time variable, compute the sample mean and variance to get:

$$\bar{t} = 941.79 \text{ days}$$
$$s_t^2 = 279374.3 \text{ days}^2$$

Then compute the tentative slope as:

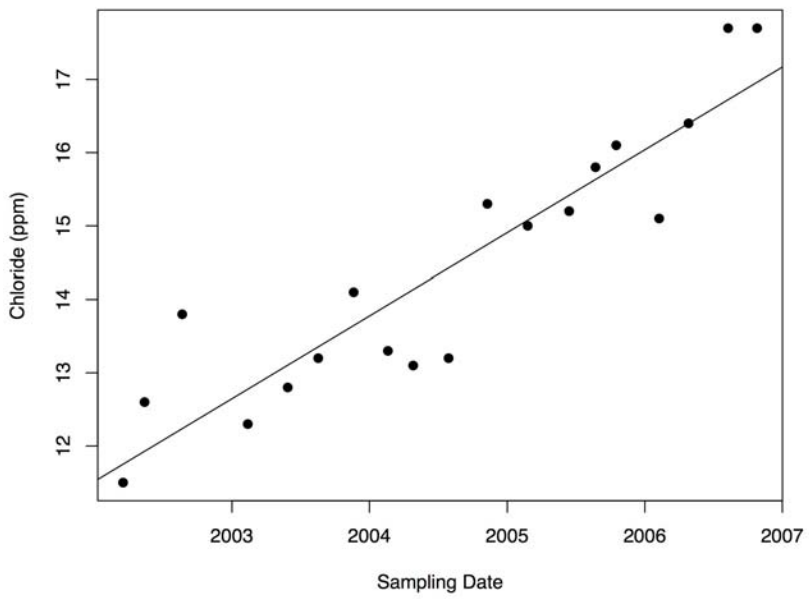
$$\hat{b} = \left[(76-941.79)\cdot 11.5 + \ldots + (1759-941.79)\cdot 17.7\right] / \left[(19-1)\cdot 279374.3\right] = .0031$$

and the regression line itself as:

$$\hat{x}_t = \bar{x} + \hat{b}\cdot(t-\bar{t}) = 14.432 + .0031\cdot(t-941.79)$$

where the mean chloride value is $\bar{x} = 14.432$ ppm. The regression line is overlaid on the scatter plot in **Figure 17-2**.

Figure 17-2. Time Series Plot of Chloride (ppm) Overlaid With Linear Regression



Step 2. Calculate the regression residual at each sampling event using equation [17.23]. This involves computing an estimated concentration along the regression line for each sampled time (t) and then subtracting from the observed concentration. For example, the residual at t = 407 is

$$x_t - \hat{x}_t = 12.3 - 12.78 = -0.48$$

All the residuals are listed in the table above. Then check the residuals for normality, homoscedasticity, and lack of association with the predicted values from the regression line.

Figure 17-3 is a probability plot of the residuals, indicating good agreement with normality. **Figure 17-4** is a scatter plot of the residuals versus sampling date and **Figure 17-5** is a scatter plot of the residuals versus predicted values from the trend line. Both of these last plots do not exhibit any particular trends or patterns with sampling date or the trend line predicted values; the residuals are fairly randomly scattered.

Step 3. Compute the MSE of the regression using the squared residuals in equation [17.24] to get

$$s_e^2 = \frac{1}{n-2} \cdot \sum_{i=1}^{n} r_i^2 = \frac{1}{17} \cdot \left[(-.25)^2 + (.67)^2 + \ldots + (.74)^2 \right] = 0.5628$$

Step 4. Calculate the standard error of the regression slope coefficient using equation [17.25]:

$$se\left(\hat{b}\right) = \sqrt{s^2{}_e \Big/ \sum_{i=1}^{n} (t - \bar{t})^2} = \sqrt{.5628 \Big/ \left[(76 - 941.79)^2 + \ldots + (1759 - 941.79)^2 \right]} = .00033$$

Step 5. Form the *t*-statistic ratio with formula [17.26] to get:

$$t_b = \hat{b} \big/ se\left(\hat{b}\right) = 0.0031 / 0.00033 = 9.39$$

Since $\alpha = 0.01$, compare this value to a critical point equal to the 99th percentile of a Student's *t*-distribution with $(n-2) = 17$ degrees of freedom, that is, $t_{cp} = t_{.99,17} = 2.567$. Since the *t*-statistic is substantially larger than the critical point, conclude the upward trend is significant at the 1% α-level. ◄

Figure 17-3. Probability Plot of Chloride Regression Residuals

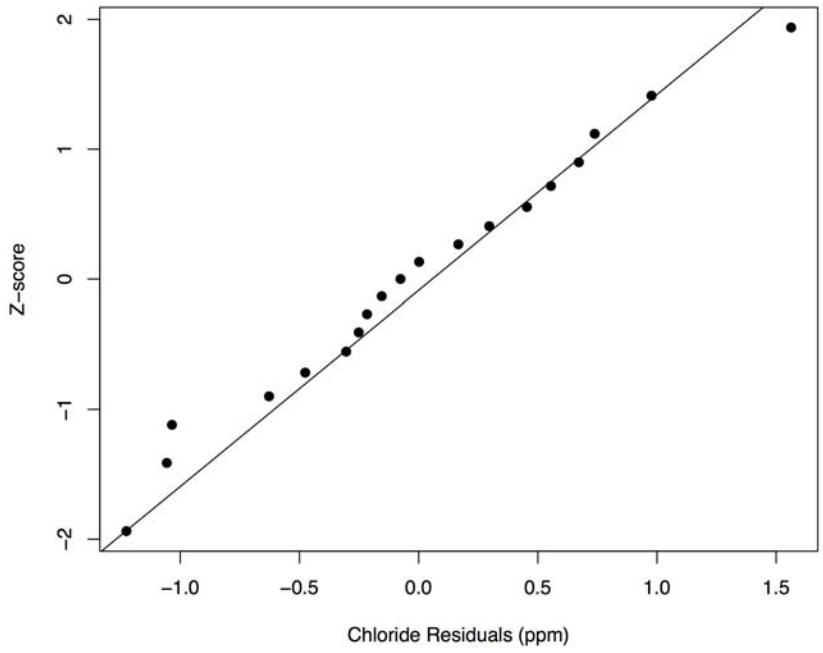


Figure 17-4. Scatter Plot of Chloride Residuals vs. Sampling Date

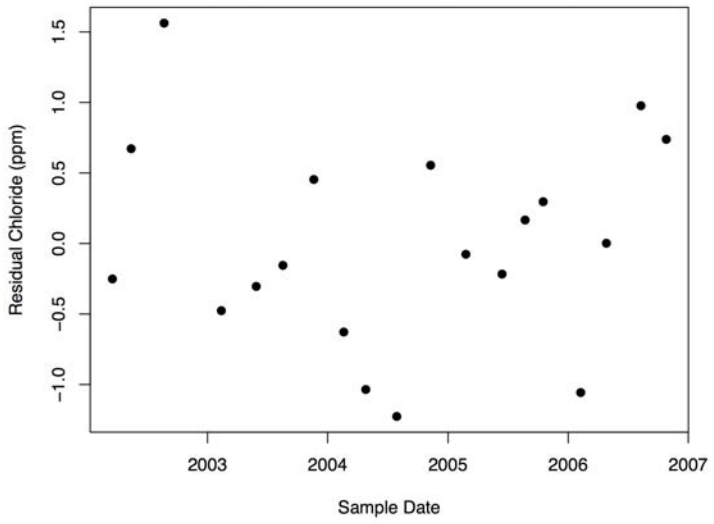
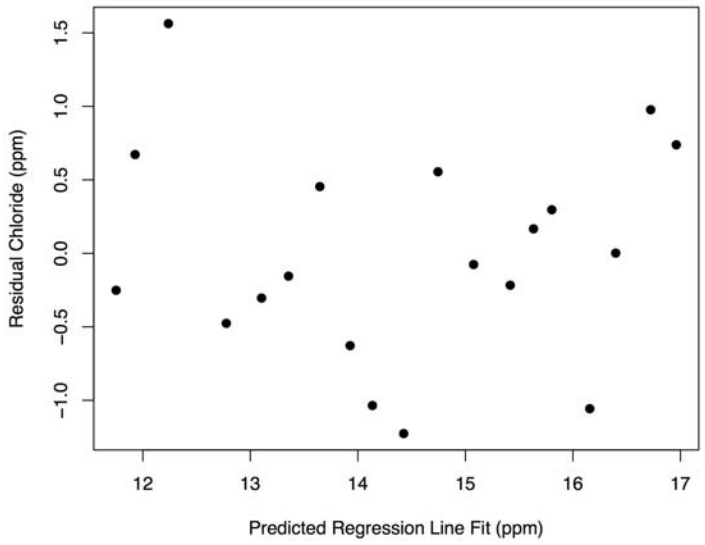


Figure 17-5. Scatter Plot of Chloride Residuals vs. Predicted Regression Fits



17.3.2 MANN-KENDALL TREND TEST

BACKGROUND AND PURPOSE

The Mann-Kendall test (Gilbert, 1987) is a non-parametric test for linear trend, based on the idea that a lack of trend should correspond to a time series plot fluctuating randomly about a constant mean level, with no visually apparent upward or downward pattern. If an *increasing* trend really exists, the sample taken first from any randomly selected pair of measurements should on average have a *lower* concentration than the measurement collected at a later point. The Mann-Kendall statistic is computed by examining all possible pairs of measurements in the data set and scoring each pair as follows. An earlier measurement less in magnitude than a later one is assigned a value of 1. If an earlier value is greater in magnitude than a later sample, the pair is tallied as –1; two identical measurement values are assigned 0.

After scoring each pair in this way and adding up the total to get the Mann-Kendall statistic (*S*), a positive value of *S* implies that a majority of the differences between earlier and later measurements are positive, suggestive of an upward trend over time. Likewise, a negative value for *S* implies that a majority of the differences between earlier and later values are negative, suggestive of a decreasing trend. A value near zero indicates a roughly equal number of positive and negative differences. This would be expected if the measurements were randomly fluctuating about a constant mean with no apparent trend.

To account for randomness and inherent variability in the sample, the Mann-Kendall test is based on the critical ranges of the statistic *S* likely to occur under stationary conditions. The larger the absolute

value of *S*, the stronger the evidence for a real increasing or decreasing trend. The critical points for identifying a trend get larger as the level of significance (α) drops. Only if the absolute value of the test statistic (*S*) is larger than the critical point is a statistically significant increasing or decreasing trend indicated.

REQUIREMENTS AND ASSUMPTIONS

As a non-parametric procedure, the Mann-Kendall test does not require the underlying data to follow a specific distribution. Ranks of the data are not explicitly used in forming the test statistic as with the Wilcoxon rank-sum. Only the relative magnitudes of the concentration values are needed to compute *S*, not the actual concentrations themselves. Non-detects can be treated by assigning them a common value lower than any of the detected measurements. Any pair of tied values or any pair of non-detects is simply given a score of 0 in the calculation of the Mann-Kendall statistic *S*.

This treatment of non-detects is an imperfect remedy since it is usually impossible to know whether censored values are actually tied in magnitude. Further complications are introduced when there are multiple RLs and/or an intermingling of detected values and RLs. Lab qualifiers may be used to aid the scoring of pairs that involve non-detects or estimated concentrations. Instead of treating all non-detects as tied, consider 'undetected or U' values as the lowest in magnitude, other non-detects as higher in magnitude than U's but lower than estimated concentrations ('J' or 'E' values). In this way, a richer scoring of the sample pairs may be possible.

When the sample size *n* becomes large, exact critical values for the statistic *S* are not readily available. However, as a sum of identically-distributed random quantities, the behavior of *S* for larger *n* tends to approximate the normal distribution by the Central Limit Theorem. Therefore a normal approximation to *S* can be used for $n > 10$[1]. In this case, a standardized *Z*-statistic is formed by first computing the expected mean value and standard deviation of *S*. From the discussion above, when no trend is present, positive differences in randomly selected pairs of measurements should balance negative differences, so the expected mean value of *S* under the null hypothesis of no trend is simply zero. The standard deviation of *S* can be computed using equation [17.27]:

$$SD\left[S\right] = \sqrt{\frac{1}{18}\left[n(n-1)(2n+5) - \sum_{j=1}^{g} t_j\left(t_j-1\right)\left(2t_j+5\right)\right]} \qquad [17.27]$$

where *n* is the sample size, *g* represents the number of groups of ties in the data set (if any), and t_j is the number of ties in the *j*th group of ties. If no ties or non-detects are present, equation [17.27] reduces to the simpler form:

$$SD\left[S\right] = \sqrt{\frac{1}{18}n(n-1)(2n+5)} \qquad [17.28]$$

[1] Guidance **Table 17-5** contains exact confidence levels up to $n = 10$. Exact confidence levels for $n \leq 20$ have been developed in (Hollander & Wolfe, 1999), Table A.30. These might be preferentially used if sample sizes are fairly small and the data contain non-detect values.

Once the standard deviation of *S* has been derived, the standardized *Z*-statistic for an increasing (or decreasing) trend is formed using the equation:

$$Z = \left(\left|S\right| - 1\right) \Big/ SD\left[S\right] \qquad [17.29]$$

Note that although the expected mean value of *S* is zero, applying the continuous normal to the discrete *S* distribution is an approximation. Therefore, a *continuity correction* is made to *Z* by first subtracting 1 from the absolute value of *S*. The final *Z*-statistic can then be compared to an α-level critical point taken from **Table 10-1** in **Appendix D** to complete the test.

PROCEDURE

Step 1. Order the data set by sampling event or time of collection, x_1, x_2, to x_n. Then consider all possible differences between distinct pairs of measurements, $(x_j - x_i)$ for $j > i$. For each pair, compute the *sign* of the difference, defined by:

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} 1 & \text{if } \left(x_j - x_i\right) > 0 \\ 0 & \text{if } \left(x_j - x_i\right) = 0 \\ -1 & \text{if } \left(x_j - x_i\right) < 0 \end{cases} \qquad [17.30]$$

Pairs of tied values including non-detects, will receive scores of zero using equation [17.30].

Step 2. Compute the Mann-Kendall statistic *S* using equation [17.31]:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \qquad [17.31]$$

In equation [17.31] the summation starts with a comparison of the very first sampling event against each of the subsequent measurements. Then the second event is compared with each of the samples taken after it (*i.e.*, the third, fourth, fifth, *etc.*). Following this pattern is probably the most convenient way to ensure that all distinct pairs are tallied in forming *S*. For a sample of size *n*, there will be $n \cdot (n\text{-}1)/2$ distinct pairs.

Step 3. If $n \leq 10$, and given the level of significance (α), determine the critical point s_{cp} from **Table 17-5 of Appendix D.** If $S > 0$ and $\left|S\right| > s_{cp}$, conclude there is statistically significant evidence of an increasing trend at the α significance level. If $S < 0$ and $\left|S\right| > s_{cp}$, conclude there is statistically significant evidence of a decreasing trend. If $\left|S\right| \leq s_{cp}$, conclude there is insufficient evidence to identify a significant trend.

Step 4. If $n > 10$, determine the number of groups of ties (*g*) and the number of tied values in each group of ties (t_j). Then use equation [17.27] to compute the standard deviation of *S* and equation [17.29] in turn to compute the standardized *Z*-statistic.

Step 5. Given the significance level (α), determine the critical point z_{cp} from the standard normal distribution in **Table 10-1** in **Appendix D**. Compare Z against this critical point. If $Z > z_{cp}$, conclude there is statistically significant evidence at the α-level of an increasing trend. If $Z < -z_{cp}$, conclude there is statistically significant evidence of a decreasing trend. If neither exists, conclude that the sample evidence is insufficient to identify a trend.

►EXAMPLE 17-6

Test for a significant upward trend using the Mann-Kendall procedure in the following set of sulfate measurements (ppm) collected over several years.

Sample No.	Sampling Date (yr.mon)	Sulfate Conc. (ppm)	Sample No.	Sampling Date (yr.mon)	Sulfate Conc. (ppm)
1	89.6	480	13	93.1	590
2	89.8	450	14	93.6	550
3	90.1	490	15	94.1	600
4	90.3	520	16	94.6	700
5	90.6	485	17	95.1	570
6	90.8	510	18	95.6	610
7	91.1	510	19	95.8	650
8	91.3	530	20	96.1	620
9	91.6	510	21	96.3	830
10	91.8	560	22	96.6	720
11	92.1	560	23	96.8	590
12	92.6	540			

SOLUTION

Step 1. Construct a time series plot of the sulfate observations to check for a possible trend as in **Figure 17-6**. A clearly rising concentration pattern is seen, although the variability in the measurements appears greater toward the end of the sampling record than at the beginning.

Step 2. Compute the difference between each distinct pair of measurements and determine the sign of the difference, using equation [17.30]. Then sum up the signs with equation [17.31]. Note that to make sure all the distinct pairs have been summed, begin with the first listed observation and compare it to each of values below it. Then take the second listed value and compare it to each of the remaining ones below it, *etc*. The Mann-Kendall statistic becomes:

$$S = \text{sgn}(450-480) + \text{sgn}(490-480) + \ldots + \text{sgn}(590-720) = 194$$

Step 3. Since the sample size $n = 23 > 10$, form the normal approximation to the Mann-Kendall statistic. Because there are some ties in the data, use equation [17.27] to compute the approximate standard deviation. Among the sulfate measurements, there are three groups of ties with 3, 2, and 2 tied values in each set respectively (at values 510, 560, and 590). The adjusted standard deviation is then:

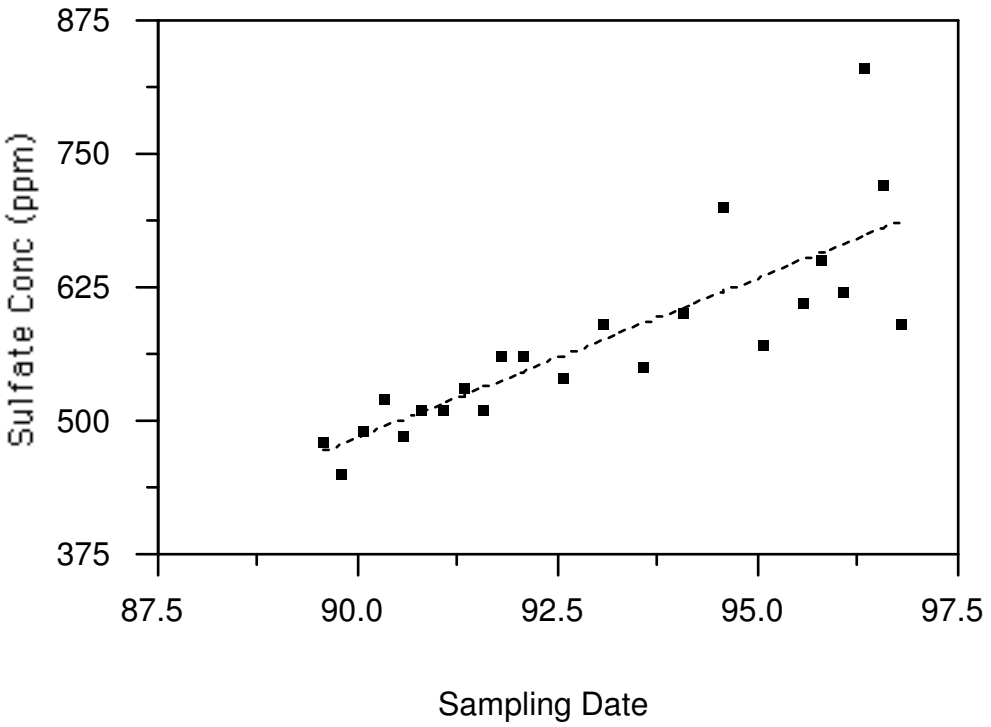
$$SD[S] = \sqrt{\frac{1}{18}\cdot\left[23\cdot(23-1)(2\cdot 23+5) - \left\{3\cdot(3-1)(2\cdot 3+5)+\ldots+2\cdot(2-1)(2\cdot 2+5)\right\}\right]} = 37.79$$

Finally, using equation [17.29], the normalized Mann-Kendall statistic is:

$$Z = \left(|194| - 1\right)/37.79 = 5.11$$

Step 4. The Z statistic can be compared to a critical point from the standard normal distribution in **Table 10-1** in **Appendix D**. As large as it is, the test statistic is bigger than the critical point for any usual significance level, suggesting that the trend appears to be real and not just a chance artifact of the sample. ◄

Figure 17-6. Time Series Plot of Sulfate Concentrations (ppm)



17.3.3 THEIL-SEN TREND LINE

BACKGROUND AND PURPOSE

The Mann-Kendall procedure is a non-parametric test for a significant slope in a linear regression of the concentration values plotted against time of sampling. But the Mann-Kendall statistic S does not indicate the *magnitude* of the slope or estimate the trend line itself even when a trend is present. This is slightly different from parametric linear regression, where a test for a significant slope follows naturally from the estimate of the trend line. Even a relatively modest slope can be statistically distinguished from zero with a large enough sample. It is best to first identify whether or not a trend exists, and then determine how steeply the concentration levels are increasing over time for a significant trend. The *Theil-Sen trend line* (Helsel, 2005) is a non-parametric alternative to linear regression which can be used in conjunction with the Mann-Kendall test.

The Theil-Sen method handles non-detects in almost exactly the same manner as the Mann-Kendall test. It assigns each non-detect a common value less than any other detected measurement (*e.g.*,

half the RL). Unlike the Mann-Kendall test, however, the actual concentration values are important in computing the slope estimate in the Theil-Sen procedure. The essential idea is that if a *simple slope estimate* is computed for every pair of distinct measurements in the sample (known as the set of *pairwise slopes*), the average of this series of slope values should approximate the true slope. The Theil-Sen method is non-parametric because instead of taking an *arithmetic average* of the pairwise slopes, the *median* slope value is determined. By taking the median pairwise slope instead of the mean, extreme pairwise slopes — perhaps due to one or more outliers or other errors — are ignored and have little if any impact on the final slope estimator.

The Theil-Sen trend line is also non-parametric because the median pairwise slope is combined with the median concentration value and the median sample date to construct the final trend line. As a consequence of this construction, the Theil-Sen line estimates the change in *median* concentration over time and not the *mean* as in linear regression.

REQUIREMENTS AND ASSUMPTIONS

The Theil-Sen procedure does not require normally-distributed trend residuals as in a linear regression. It is also not critical that the residuals be homoscedastic (*i.e.*, having equal variance over time and with increasing average concentration level). It *is* important to have at least 4 and preferably at least 8 or more observation on which to construct the trend. But trend residuals are assumed to be statistically independent. Approximate checks of this assumption can be made using the techniques of **Chapter 14**, once the estimated trend has been removed and the number of non-detect data is limited. Sampling events should also be spaced far enough apart relative to the site-specific groundwater velocity so that an assumption of *physical* independence of consecutive sample volumes is reasonable.

A more difficult problem is encountered when a large fraction of the data is non-detect. As long as less than half the measurements are non-detects occurring in the lower part of the observed concentration range, the median concentration value will be quantified and the median pairwise slope will generally be associated with a pair of detects. Larger proportions of non-detect data make computation of the Theil-Sen trend line more difficult and uncertain. The reason is that each time a non-detect is paired with a quantified measurement, the pairwise slope is known only within a range of values. One end of the range results from supposing the true non-detect concentration is equal to zero; the other when the non-detect concentration is equal to the RL.

PROCEDURE

Step 1. Order the data set by sampling event or time of collection, x_1, x_2, to x_n. Then consider all possible distinct pairs of measurements, (x_i, x_j) for $j > i$. For each pair, compute the simple pairwise slope estimate:

$$m_{ij} = \left(x_j - x_i\right) \Big/ \left(j - i\right) \qquad [17.32]$$

With a sample size of n, there should be a total of $N = n(n–1)/2$ such pairwise estimates m_{ij}. If a given observation is a non-detect, use half the RL as its estimated concentration.

Step 2. Order the N pairwise slope estimates (m_{ij}) from least to greatest and rename them as $m_{(1)}$, $m_{(2)}$, …, $m_{(N)}$. Then determine the Theil-Sen estimate of slope (Q) as the median value of this list.

Finding this value will depend on whether N is even or odd, but the following equation can be used:

$$Q = \begin{cases} m_{(\lceil N+1 \rceil/2)} & \text{if } N \text{ is odd} \\ \left(m_{(N/2)} + m_{(\lceil N+2 \rceil/2)} \right) \Big/ 2 & \text{if } N \text{ is even} \end{cases} \quad [17.33]$$

Step 3. Order the sample by concentration magnitude from least to greatest, $x_{(1)}$, $x_{(2)}$, to $x_{(n)}$. Determine the median concentration with the formula:

$$\tilde{x} = \begin{cases} x_{(n+1)/2} \ \textit{if n is odd} \\ \left(x_{n/2} + x_{(n+2)/2} \right) \Big/ 2 \quad \textit{if n is even} \end{cases} \quad [17.34]$$

Again replace each non-detect by half its RL during this calculation. Also find the median sampling date ($\tilde{t}$) using the ordered times t_1, t_2, to t_n by a similar computation.

Step 4. Compute the Theil-Sen trend line with the equation:

$$x = \tilde{x} + Q \cdot \left(t - \tilde{t} \right) = \left(\tilde{x} - Q \cdot \tilde{t} \right) + Q \cdot t \quad [17.35]$$

Using equation [17.35], an estimate can be made at any time (t) of the expected median concentration (x).

►EXAMPLE 17-7

Use the following sodium measurements to compute a Theil-Sen trend line. Note that the sample dates are recorded as the year of collection (2-digit format) plus a fractional part indicating when during the year the sample was collected. This allows an annual slope estimate, since 1 unit = 1 year.

Sample Date (yr)	Sodium Conc. (ppm)
89.6	56
90.1	53
90.8	51
91.1	55
92.1	52
93.1	60
94.1	62
95.6	59
96.1	61
96.3	63

SOLUTION

Step 1. Compute the pairwise slopes for each distinct pair of measurements using equation [17.32]. With n = 10 observations, there will be a total of 10(9)/2 = 45 such pairs. The first few are listed below:

$$m_{12} = (53-56)/(90.1-89.6) = -6$$
$$m_{13} = (51-56)/(90.8-89.6) = -4.17$$
$$m_{14} = (55-56)/(91.1-89.6) = -.667$$

Step 2. Since the total number of distinct pairs is odd, sort the list of pairwise slopes as in the table below and let Sen's estimated slope equal the middle or 23rd largest value in this list. This gives an estimate of Q = 1.33 ppm increase *per year*, an estimate in line with the time series plot of **Figure 17-7**.

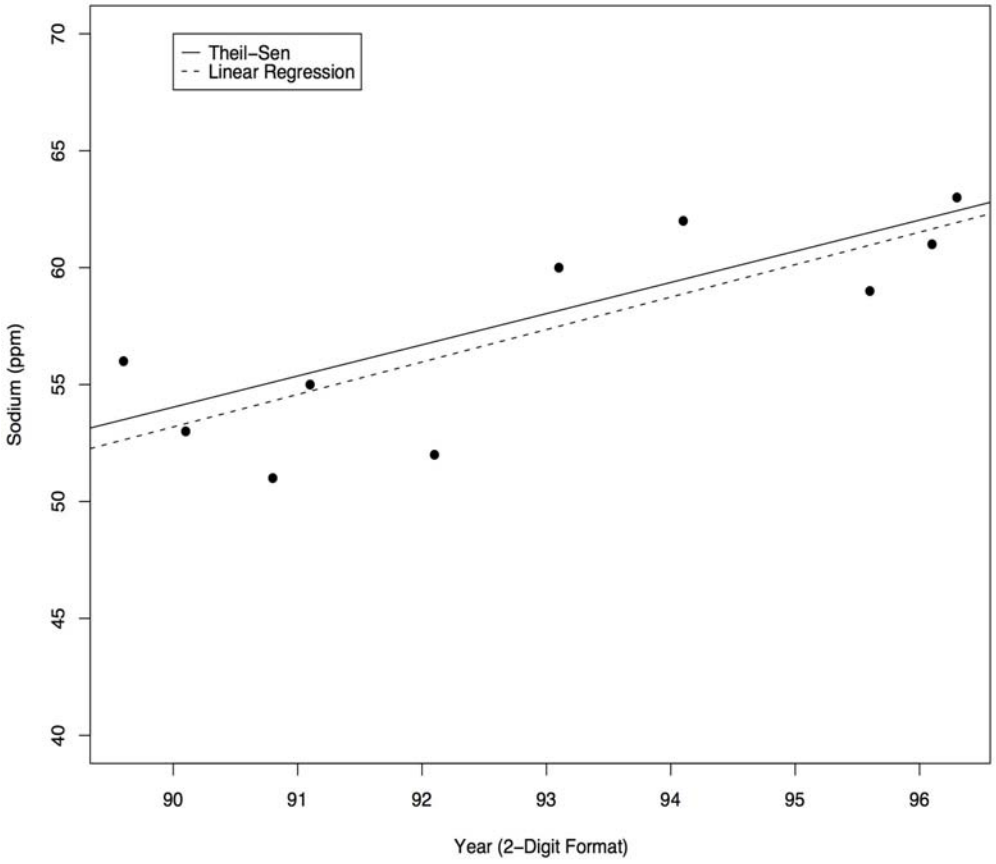
Step 3. Compute the median concentration value $\tilde{x} = 57.5$ and the median sample date $\tilde{t} = 92.6$ from the table above. Then calculate the Theil-Sen trend line using the slope estimate from Step 2:

$$x = 57.5 + 1.333(t - 92.6) = -65.97 + 1.333t$$

This trend line can be used to estimate the predicted median concentration (x) at any desired time in years (t). For example, at the beginning of 1998 (t = 98), the trend line would predict a median sodium concentration of approximately x = 64.7 ppm. ◄

Rank	Pairwise Slope	Rank	Pairwise Slope
1	-6	24	1.538
2	-4.167	25	1.613
3	-3	26	1.667
4	-2.857	27	1.887
5	-2	28	2
6	-1.6	29	2
7	-0.667	30	2
8	-0.5	31	2.182
9	-0.5	32	2.25
10	-0.4	33	2.25
11	0.333	34	2.333
12	0.455	35	2.333
13	0.5	36	2.5
14	0.769	37	2.619
15	0.769	38	3.333
16	0.889	39	3.913
17	0.938	40	4
18	1.045	41	5
19	1.091	42	5.714
20	1.143	43	8
21	1.2	44	10
22	1.333	45	13.333
23	1.333		

Figure 17-7. Time Series Plot of Sodium Concentrations (ppm)



CHAPTER 21. CONFIDENCE INTERVALS

Confidence intervals are the recommended general statistical strategy in compliance/assessment or corrective action monitoring. Groundwater monitoring data must typically be compared to a fixed numerical limit set as a GWPS. In compliance/assessment, the comparison is made to determine whether groundwater concentrations have increased above the compliance standard. In corrective action, the test determines whether concentrations have decreased below a clean-up criterion or compliance level. In compliance/assessment monitoring, the lower confidence limit [LCL] is of primary interest, while the upper confidence limit [UCL] is most important in corrective action. For single-sample background GWPS testing, the hypothesis structures are the same as for fixed-limit health-based standards. Where a GWPS is based on two- or multiple sample testing, a somewhat different hypothesis structure is used (**Section 7.5**) and detection monitoring test procedures in **Part III** are applicable.

General strategies for using confidence intervals in compliance/assessment or corrective action monitoring are presented in **Chapter 7**, including discussion of how regulatory standards should be matched to particular statistical parameters (*e.g.*, mean or upper percentile). More specific strategies and examples are detailed in **Chapter 22**. In this chapter, basic algorithms and equations for each type of confidence interval are described, along with an example of the calculations involved.

21.1 PARAMETRIC CONFIDENCE INTERVALS

Confidence intervals are designed to estimate statistical characteristics of some parameter of a sampled population. *Parametric* confidence intervals do this for known distributional models, *e.g.*, normal, lognormal, gamma, Weibull, *etc*. Given a statistical parameter of interest such as the population mean (μ), the lower and upper limits of a confidence interval define the most probable concentration range in which the true parameter ought to lie.

Like any estimate, the true parameter may not be located within the confidence interval. The frequency with which this error tends to occur (based on repeated confidence intervals on different samples of the same sample size and from the same population) is denoted α, while its complement ($1-\alpha$) is known as the *confidence level*. The confidence level represents the percentage of cases where a confidence interval constructed according to a fixed algorithm or equation will actually contain its

intended target, *e.g.*, the population mean. **Section 7.2** discusses the difference between one- and two-sided confidence intervals and how the α error is assigned.

A point worth clarifying is the distinction between α as the complement of the confidence level when constructing a confidence interval and the significance level (α) used in hypothesis testing. Confidence intervals are often used strictly for estimation of population quantities. In that case, no test is performed, so α does not represent a false positive rate. Rather, it is simply the fraction of similar intervals that do not contain their intended target.

The Unified Guidance focuses on confidence interval limits compared to a fixed standard as a formal test procedure. In this case, the complement (α) of the confidence level used to generate the confidence interval is equivalent to the significance level (α) of the test. This assumes that the true population parameter under the null hypothesis is no greater than the standard in compliance/assessment monitoring or not less than the standard in corrective action.[1]

The parametric confidence intervals presented in the Unified Guidance share some common statistical assumptions. The most basic is that measurements used to construct a confidence interval be independent and identically distributed [*i.i.d.*]. Meeting this assumption requires that there be no outliers (**Chapter 12**), a stationary mean and variance over the period during which observations are collected (**Chapters 3** and **14**), and no autocorrelation between successive sampling events (**Chapter 14**). In particular, sampling events should be spaced far enough apart so that approximate statistical independence can be assumed (at many sites, observations should not be sampled more often than quarterly). Sample data should also be examined for trends. The mean is not stationary under a significant trend, as assumed in applying the other methods of this section. An apparent trend may need to be handled by computing a confidence band around the trend line (**Section 21.3**).

Another common assumption is that the sample data are either normal in distribution or can be normalized via a transformation (**Chapter 10**). Normality can be difficult to check if the sample contains a significant number of left-censored measurements (i.e., non-detects). The basic options for censored samples are presented in **Chapter 15**. If the non-detect percentage is no more than 10-15%, it may be possible to assess normality by first substituting one-half of the reporting limit [RL] for each non-detect. For higher non-detect percentages up to 50%, the Unified Guidance recommends computing a censored probability plot using either the Kaplan-Meier or Robust Regression on Order Statistics [Robust ROS] techniques (both in **Chapter 15**).

If a censored probability plot suggests that the sample (or some transformation of the sample) is normal, either Kaplan-Meier or Robust ROS can be used to construct estimates of the mean ($\hat{\mu}$) and standard deviation ($\hat{\sigma}$) adjusted for the presence of non-detects. These estimates should be used *in place of* the sample mean ($\bar{x}$) and standard deviation (s) in the parametric equations below.

[1] Technically, α represents the *maximum* possible false positive rate associated with the composite null hypothesis H_0: $\mu \leq$ GWPS or H_0: $\mu \geq$ GWPS.

21.1.1 CONFIDENCE INTERVAL AROUND NORMAL MEAN

BACKGROUND AND PURPOSE

When compliance point data is to be compared to a fixed standard (*e.g.*, a maximum concentration limit [MCL]) and the standard in question is interpreted to represent an average or true mean concentration, a confidence interval around the mean is the method of statistical choice. A confidence interval around the mean is designed to estimate the true average of the underlying population, while at the same time accounting for variability in the sample data.

REQUIREMENTS AND ASSUMPTIONS

Confidence intervals around the mean of a normal distribution should only be constructed if the data are approximately normal or at least are reasonably symmetric (*i.e.*, the skewness coefficient is close to zero). An inaccurate confidence interval is likely to result if the sample data are highly non-normal, particularly for right-skewed distributions. If the observations are better fit by a lognormal distribution, special equations or methods need to be used to construct an accurate confidence interval on the arithmetic mean with a specified level of confidence (**Section 21.1.3**). *Therefore, checking for normality is an important first step*.

A confidence interval should not be constructed with less than 4 measurements per compliance well, and preferably 8 or more. The equation for a normal-based confidence interval around the mean involves estimating the population standard deviation via the sample standard deviation (s). This estimate can often be imprecise using a small sample size (*e.g.*, $n \leq 4$). The equation also involves a Student's t-quantile based on n–1 degrees of freedom [df], where n equals the sample size. The t-quantile is large for small n, leading to a much wider confidence interval than would occur with a larger sample size. For a 99% confidence level, the appropriate t-quantile would be $t = 31.82$ for $n = 2$, $t = 4.54$ for $n = 4$, and $t = 3.00$ for $n = 8$.

This last consideration is important since statistically significant evidence of a violation during compliance/assessment or success during corrective action is indicated only when the entire confidence interval is to one side of the standard (*i.e.*, it does not *straddle* the fixed standard; see **Chapter 7**). For a small sample size, the confidence interval may be so wide that a statistical difference is unlikely to be identified. This can happen *even if* the true mean groundwater concentration *is* different from the compliance or clean-up standard, due to the statistical uncertainty associated with the small number of observations. More specific recommendations on appropriate sample sizes are presented in **Chapter 22**, where the *statistical power* of the confidence interval tests is explored.

PROCEDURE

Step 1. Check the basic statistical assumptions of the sample as discussed above. Assuming a normal distributional model is acceptable, calculate the sample mean ($\bar{x}$) and standard deviation (s).

Step 2. Given a sample of size n and the desired level of confidence ($1-\alpha$), for each compliance well calculate either the lower confidence limit (for compliance/assessment monitoring) with the equation:

$$LCL_{1-\alpha} = \bar{x} - t_{1-\alpha,n-1}\frac{s}{\sqrt{n}} \quad [21.1]$$

or the upper confidence limit (for corrective action) with the equation:

$$UCL_{1-\alpha} = \bar{x} + t_{1-\alpha,n-1}\frac{s}{\sqrt{n}} \quad [21.2]$$

where $t_{1-\alpha,n-1}$ is obtained from a Student's *t*-table with (n–1) degrees of freedom (**Table 16-1** in **Appendix D**). To construct a two-sided interval with overall confidence level equal to (1–α), substitute α/2 for α in the above equations.

Step 3. Compare the limit calculated in **Step 2** to the fixed compliance or clean-up standard (*e.g.*, the MCL or alternate concentration limit [ACL]. For compliance/assessment monitoring, the LCL in equation [21.1] should be used to compute the test. For corrective action, the UCL in equation [21.2] should be used instead.

►EXAMPLE 21-1

The table below lists concentrations of the pesticide Aldicarb in three compliance wells. For illustrative purposes, the health-based standard in compliance monitoring for Aldicarb has been set to 7 ppb. Determine at the α = 5% significance level whether or not any of the wells should be flagged as being out of compliance.

	Aldicarb Concentration (ppb)		
Sampling Date	Well 1	Well 2	Well 3
January	19.9	23.7	5.6
February	29.6	21.9	3.3
March	18.7	26.9	2.3
April	24.2	26.1	6.9
Mean	23.10	24.65	4.52
SD	4.93	2.28	2.10
Skewness (γ_1)	0.506	–0.234	0.074
Shapiro-Wilk (W)	0.923	0.943	0.950

SOLUTION

Step 1. First test the data for non-normality and/or significant skewness. Based on four samples per well, the skewness coefficients and Shapiro-Wilk statistics have been computed and are listed above. None of the skewness coefficients are significantly different from zero. In addition, the α = .10 critical point for the Shapiro-Wilk test with n = 4 (as presented in **Chapter 10**) is 0.792, less than each of the Shapiro-Wilk statistics; consequently, there is no significant evidence of non-normality. Construct a normal-based confidence interval around the mean.

Step 2. Calculate the sample mean and standard deviation of the Aldicarb concentrations for each compliance well. These statistics are listed above.

Step 3. Since $\alpha = 0.05$, the confidence level must be set to $(1-\alpha) = 0.95$. Obtain the upper 95th percentile of the *t*-distribution with $(n-1) = 3$ degrees of freedom from **Table 16-1** in **Appendix D**, namely $t_{.95,3} = 2.353$. Then calculate the lower confidence limit [LCL] for each well's mean concentration, using equation [21.1]:

$$\text{Well 1: } LCL_{.95} = 23.10 - \left(2.353 \times 4.93\right) \Big/ \sqrt{4} = 17.30 \text{ ppb}$$

$$\text{Well 2: } LCL_{.95} = 24.65 - \left(2.353 \times 2.28\right) \Big/ \sqrt{4} = 21.97 \text{ ppb}$$

$$\text{Well 3: } LCL_{.95} = 4.52 - \left(2.353 \times 2.10\right) \Big/ \sqrt{4} = 2.05 \text{ ppb}$$

Step 4. Compare each LCL to the compliance standard of 7 ppb. The LCLs for Well 1 and Well 2 lie above 7 ppb, indicating that the mean concentration of Aldicarb in both of these wells significantly exceeds the compliance standard. However, the LCL for Well 3 is below 7 ppb. providing insufficient evidence at the $\alpha = 0.05$ level that the mean in Well 3 is out of compliance. ◄

21.1.2 CONFIDENCE INTERVAL AROUND LOGNORMAL GEOMETRIC MEAN

PURPOSE AND BACKGROUND

For many groundwater monitoring constituents, neither the assumption of normality nor approximate symmetry holds for the original concentration data. Often the underlying population is heavily right-skewed, characterized by a majority of lower level concentrations combined with a long right-hand tail of infrequent but extreme values. A model such as the lognormal distribution is commonly used to analyze such data.

The lognormal is traditionally designated by the notation $\Lambda(\mu, \sigma)$ (Aitchison and Brown, 1976), where μ and σ denote parameters controlling the *location* and *scale* of the population. Typically designated as $N(\mu, \sigma)$, a normal distribution also has parameters μ and σ which denote the true mean and standard deviation. These two parameters play different roles in lognormal distributions. The key distinction is between the *arithmetic* domain (or the original measurement scale of the data) and the *logarithmic* domain. The latter denotes the mathematical space following a logarithmic transformation. Transformed lognormal data are *normally-distributed* in the logarithmic domain. In this new domain, μ represents the true mean of the log-transformed measurements--- that is, the *log-mean*. Likewise, σ represents the true standard deviation of the log-transformed values or the *log-standard deviation*.

A common misperception is to assume that a standard equation for a normal-based confidence interval can be applied to log-transformed data, with the interval endpoints then back-transformed (*i.e.*, exponentiated) to the arithmetic domain to get a confidence interval around the lognormal *arithmetic* mean. Invariably, such an interval will underestimate the true mean. The Student t- confidence interval applies to a *geometric* mean of the lognormal population when back-transformed, rather than the higher-valued *arithmetic* mean. The reason is that the sample log-mean gives an estimate of the lognormal parameter μ. When this estimate is back-transformed to the arithmetic domain, one has an estimate of

$\exp(\mu)$ — the lognormal geometric mean — not an estimate of the lognormal arithmetic mean, which is expressed as $\exp(\mu + .5\sigma^2)$.

Although a confidence interval around the lognormal geometric mean is *not* an accurate estimate of the arithmetic mean, there are instances where such an interval may be helpful. While many GWPSs are interpreted to represent long-term arithmetic averages, some (as detailed in **Chapter 7**) can better represent medians or percentiles of the underlying distribution. Because the lognormal geometric mean is equivalent to the median, a geometric mean may in some cases be a better statistical parameter of comparison than the lognormal arithmetic mean. Furthermore, when the lognormal coefficient of variation is large, the arithmetic mean is substantially larger than the geometric mean, mostly due to infrequent but extreme individual measurements. The bulk of individual observations are located much closer to the geometric mean. It may be that a comparison of the GWPS to the geometric mean rather than to the arithmetic mean will provide a more reasonable test of long-term concentration levels.

Special equations or computational methods are used to construct an accurate confidence interval with a specified level of confidence (**Section 21.1.3**) when an estimate of the *arithmetic* mean is needed and the observations are approximately normal. There is another factor to consider when estimating an *upper* confidence limit on the lognormal arithmetic mean using Land's procedure (described in **Section 21.1.3**) or other possible procedures (see for instance Singh et al., 1997). When used with highly variable data, it can lead to severely-biased, high estimates of the confidence limit. This can make it very difficult to evaluate the success of corrective action measures.

In these cases, precise parametric estimation of the arithmetic mean may have to be foregone in favor of an alternate statistical procedure. One such alternative is a non-parametric confidence interval around the median (**Section 21.2**). Another alternative when the sample is approximately lognormal is an estimate around the geometric mean which is equivalent to the population median. A third more computationally intensive option is a *bootstrap confidence interval* around the lognormal arithmetic mean (see discussion in **Section 21.1.3**). Unlike the first two options, this last alternative allows a direct estimate of the arithmetic mean.

REQUIREMENTS AND ASSUMPTIONS

Confidence intervals around the geometric mean of a lognormal distribution should only be constructed if the log-transformed data are approximately normal or at least reasonably symmetric (*i.e.*, the skewness coefficient in the logarithmic domain is close to zero). The methods of **Chapter 10** can be used to test normality of the log-transformed values. If the log-transformed sample contains non-detects, normality *on the log-scale* should be assessed using a censored probability plot. Adjusted estimates of the mean and standard deviation on the log-scale can then be substituted for the log-mean ($\overline{y}$) and log-standard deviation (s_y) in the equations below. Like a normal arithmetic mean, a confidence interval around the lognormal geometric mean should not be constructed without a minimum of 4 measurements per compliance well, and preferably with 8 or more.

PROCEDURE

Step 1. Take the logarithm of each measurement, denoted as y_i, and check the n log-transformed values for normality. If the log-transformed measurements are approximately normal, calculate

the log-mean ($\overline{y}$) and log-standard deviation (s_y). If the normal model is rejected, consider instead a non-parametric confidence interval (**Section 21.2**).

Step 2. Given the desired level of confidence (1–α), calculate either the LCL (for compliance/assessment monitoring) with the equation:

$$LCL_{1-\alpha} = \exp\left(\overline{y} - t_{1-\alpha,n-1} \frac{s_y}{\sqrt{n}} \right) \quad [21.3]$$

or the UCL (for corrective action) with the equation:

$$UCL_{1-\alpha} = \exp\left(\overline{y} + t_{1-\alpha,n-1} \frac{s_y}{\sqrt{n}} \right) \quad [21.4]$$

where $t_{1-\alpha,n-1}$ is obtained from a Student's *t*-table with (n–1) degrees of freedom (**Table 16-1** in **Appendix D**). In order to construct a two-sided interval with the overall confidence level equal to (1–α), substitute α/2 for α in the above equations.

Step 3. Compare the limits calculated in **Step 2** to the fixed compliance or clean-up standard (*e.g.*, the MCL or ACL). For compliance/assessment, use the LCL in equation [21.3]. For corrective action, use the UCL in equation [21.4].

Note in either case that the regulatory authority will have to approve the use of the geometric mean as a reasonable basis of comparison against the compliance standard. In some cases, there may be few other statistical options. However, stakeholders should understand that the geometric and arithmetic means estimate two distinct statistical characteristics of the underlying lognormal population.

►EXAMPLE 21-2

Suppose the following 8 sample measurements of benzene (ppb) have been collected at a landfill that previously handled smelter waste and is now undergoing remediation efforts. Determine whether or not there is statistically significant evidence at the α = 0.05 significance level that the true geometric mean benzene concentration has fallen below the permitted MCL of 5 ppb.

Sample Month	Benzene (ppb)	Log Benzene log(ppb)
1	0.5	–0.693
2	0.5	–0.693
3	1.6	0.470
4	1.8	0.588
5	1.1	0.095
6	16.1	2.779
7	1.6	0.470
8	<0.5	–1.386

SOLUTION

Step 1. To estimate an upper confidence bound on the geometric mean benzene concentration with 95% confidence, first test the skewness and normality of the data set. Since the one non-detect concentration is unknown but presumably between 0 ppb and the RL of 0.5 ppb, a reasonable compromise is to impute this value at 0.25 ppb, half the RL. The skewness is computed as γ_1 = 2.21, a value too high to suggest the data are normal. In addition, a Shapiro-Wilk test statistic on the raw measurements works out to SW = 0.521, failing an assumption of normality at far below a significance level of α = 0.01.

On the other hand, transforming the data via natural logarithms gives a smaller skewness coefficient of γ_1 = 0.90 and a Shapiro-Wilk statistic of W = 0.896. Because these values are consistent with normality on the log-scale (the critical point for the Shapiro-Wilk test with n = 8 and α = 0.10 is 0.818), the data set should be treated as lognormal for estimation purposes. As a consequence, equation [21.4] can be used to construct a one-sided UCL on the geometric mean.

Step 2. Compute the sample log-mean and log-standard deviation. This gives $\bar{y}$ = 0.2037 log(ppb) and s_y = 1.2575 log(ppb).

Step 3. Apply the log-mean and log-standard deviation into equation [21.4] for a UCL with α = .05, n = 8, and 7 degrees of freedom. This gives an estimated limit of:

$$UCL_{.95} = \exp\left(\bar{y} + t_{.95,7} \frac{s_y}{\sqrt{8}} \right) = \exp\left(.2037 + 1.895 \times .4446\right) = 2.847 \text{ ppb}$$

Step 4. Compare the UCL to the MCL of 5 ppb. Since the limit is less than the fixed standard, there is statistically significant evidence that the benzene geometric mean, and consequently, the median benzene concentration, is less than 5 ppb. However, this calculation does *not* show that the benzene *arithmetic* mean is less than the MCL. Extreme individual benzene measurements could show up with enough regularity to cause the arithmetic mean to be higher than 5 ppb. ◄

21.1.3 CONFIDENCE INTERVAL AROUND LOGNORMAL ARITHMETIC MEAN

PURPOSE AND BACKGROUND

Estimation of a lognormal arithmetic mean is not completely straightforward. As discussed in **Section 21.1.2**, applying standard equations for normal-based confidence limits around the mean to log-transformed measurements and then exponentiating the limits, results in confidence intervals that are invariably underestimate the arithmetic mean.

Inferences on arithmetic means for certain kinds of skewed populations can be made either exactly or approximately through the use of special techniques. In particular, if a confidence interval on the arithmetic mean is desired, Land (1971; 1975) developed an exact technique along with extensive tables

for implementing it when the underlying population is lognormal. Land also developed a more complicated approximate technique (for a full description and examples see EPA, 1997) when the population can be transformed to normality via any other increasing, 1-1, and twice differentiable transformation (*e.g.*, square, square root, cube root, *etc*.).

Although the core of Land's procedure is a correction for the so-called 'transformation bias' that occurs when making back-transforming estimates from the logarithmic domain to the raw concentration domain, it can produce unacceptable results, particularly with UCLs. The Unified Guidance advises caution when applying Land's procedure, particularly when the lognormal population has a high coefficient of variation. In those cases, the user may want to consider alternate techniques, such as those discussed in Singh, *et al* (1997 and 1999). One option is to use EPA's free-of-charge **Pro-UCL** software Version 4.0 (www.epa.gov/esd/tsc/software.htm). It computes a variety of upper confidence limits, including a bootstrap confidence interval around the arithmetic mean. This technique can be applied to lognormal data to get a direct, non-parametric UCL that tends to be less biased and to give less extreme results than Land's procedure.

For cases or sample sizes not covered by **Tables 21-1** through **21-8** in **Appendix D** when using Land's procedure, Gibbons and Coleman (2001) describe a method of approximating the necessary *H*-factors. The same authors review other alternate parametric methods for computing UCLs.

REQUIREMENTS AND ASSUMPTIONS

Confidence intervals around the arithmetic mean of a lognormal distribution should be constructed only if the data pass a test of approximate normality *on the log-scale*. While many groundwater and water quality populations tend to follow the lognormal distribution, the data should first be tested for normality on the original concentration scale. If such a test fails, the sample can be log-transformed and re-tested. If the log-transformed sample contains non-detects, normality *on the log-scale* should be assessed using a censored probability plot (**Chapter 15**). If a lognormal model is tenable, adjusted estimates of the mean and standard deviation on the log-scale can be substituted for the log-mean ($\overline{y}$) and log-standard deviation (s_y) in the equations below.

As with normal-based confidence intervals, the confidence interval here should not be constructed with fewer than 4 measurements per compliance well, and preferably with 8 or more. The reasons are similar: the equation for a lognormal-based confidence interval around the arithmetic mean depends on the sample log-standard deviation (s_y), used as an estimate of the underlying log-scale population standard deviation. This estimate can be quite imprecise when fewer than 4 to 8 observations are used. A special factor (H) was developed by Land to account for variability in a skewed population. These factors are larger for smaller samples sizes, and need to be exponentiated to estimate the final confidence limits (see below). Consequently there is a significant penalty associated with estimating the arithmetic mean using a small sample size, occasionally seen in remarkably wide confidence limits. The effect is especially noticeable when computing an UCL for corrective action monitoring.

PROCEDURE

Step 1. Test the log-tranformed sample for normality. If the lognormal model provides a reasonable fit, denote the log-transformed measurements by y_i and move to Step 2.

Step 2. Compute the sample log-mean ($\overline{y}$) and log-standard deviation (s_y).

Step 3. Obtain the correct bias-correction factor(s) (H_α) from Land's (1975) tables (**Tables 21-1 through 21-8** in **Appendix D**), where the correct factor depends on the sample size (n), the sample log-standard deviation (s_y), and the desired confidence level ($1-\alpha$).

Step 4. Plug these factors into one of the equations given below for the LCL or UCL (depending on whether the comparison applies to compliance/assessment monitoring or to corrective action). Note that to construct a two-sided interval with an overall confidence level of ($1-\alpha$), the equations should be applied by substituting $\alpha/2$ for α.

$$LCL_{1-\alpha} = \exp\left(\overline{y} + .5s_y^2 + \frac{s_y H_\alpha}{\sqrt{n-1}} \right) \quad [21.5]$$

$$UCL_{1-\alpha} = \exp\left(\overline{y} + .5s_y^2 + \frac{s_y H_{1-\alpha}}{\sqrt{n-1}} \right) \quad [21.6]$$

Step 5. Compare the confidence limit computed in **Step 4** to the fixed compliance or clean-up standard. In compliance/assessment monitoring, use the LCL of equation [21.5]. In corrective action, use equation [21.6] for the UCL.

►EXAMPLE 21-3

Determine whether the benzene concentrations of **Example 21-2** indicate that the benzene arithmetic mean is below the permitted MCL of 5 ppb at the $\alpha = 0.05$ significance level.

SOLUTION

Step 1. From **Example 21-2**, the benzene data were found to fail a test of normality, but passed a test of lognormality (*i.e.*, they were approximately normal on the log-scale). As a consequence, Land's equation in [21.6] should be used to construct a one-sided UCL on the arithmetic mean.

Step 2. Compute the log-mean and log-standard deviation from the log-scale data. This gives $\overline{y}$ = 0.2037 log(ppb) and s_y = 1.2575 log(ppb).

Step 3. Using **Table 21-6** in **Appendix D**, pick the appropriate H-factor for estimating confidence limits around a lognormal arithmetic mean, noting that to achieve 95% confidence for a one-sided UCL, one must use ($1-\alpha$) = 0.95. With a sample size of n = 8 and a standard deviation on the log-scale of 1.2575 log(ppb), $H_{.95}$ = 4.069.

Step 4. Plug these values along with the log-mean of 0.2037 log(ppb) into equation [21.6] for the UCL. This leads to a 95% one-sided confidence limit equal to:

$$UCL_{.95} = \exp\left(.2037 + .5\left(1.5813\right) + \frac{\left(1.2575\right)\left(4.069\right)}{\sqrt{7}} \right) = 18.7 \text{ ppb}$$

Step 5. Compare the UCL against the MCL of 5 ppb. Since the UCL is greater than the MCL, evidence is not sufficient at the 5% significance level to conclude that the true benzene arithmetic mean concentration is now below the MCL. This conclusion holds despite the fact that all but one of the benzene measurements is less than than 5 ppb. In lognormal populations, it is not uncommon to see one or two seemingly extreme measurements coupled with a majority of much lower concentrations. Since these extreme measurements help determine the location of the arithmetic mean, it is not unreasonable to expect that the true mean might be larger than 5 ppb.

The contrast in this result to **Example 21-2** is noteworthy. In that case, the UCL on the geometric mean was only 2.85 ppb. The estimated lognormal coefficient of variation with these data (**Chapters 3** and **10**) is $CV = 1.965$, somewhat on the high side. It is no surprise that results for the arithmetic and geometric means on the same sample are rather different. Neither estimator is necessarily invalid, but a decision needs to be made as to whether the MCL for benzene in this setting should be better compared to an arithmetic mean or to a geometric mean/ median for lognormal distributions. ◄

21.1.4 CONFIDENCE INTERVAL AROUND UPPER PERCENTILE

BACKGROUND AND PURPOSE

Although most MCLs and ACLs appear to represent arithmetic or long-term averages (**Chapter 7**), they can also be interpreted as standards not to be exceeded with any regularity. Other fixed standards like nitrate/nitrite attempt to limit short-term risks and thus represent upper percentiles instead of means. In these cases, the appropriate confidence interval is one built around a specific upper percentile.

The particular upper percentile chosen will depend on what the fixed compliance standard represents or is intended to represent. If the standard is a concentration that represents the 90th percentile, the confidence interval should be built around the upper 90th percentile. If the standard is meant to be a *maximum*, 'not to be exceeded,' concentration, a slightly different strategy should be used. Since there is no maximum value associated with continuous distributions like normal and lognormal, it is not possible to construct a confidence interval around the population maximum. Instead, one must settle for a confidence interval around a sufficiently high percentile, one that will exceed nearly all of the population measurements. Possible choices are the upper 90th to 95th percentile. By estimating the location of these percentiles, one needs to determine whether a sufficiently small fraction (*e.g.*, at most 1 in 10 or 1 in 20) of the possible measurements will ever exceed the standard. For even greater protection against exceedances, the upper 99th percentile could be selected, implying that at most 1 in 100 measurements would ever exceed the standard. But as noted in **Chapter 7**, selection of very high percentiles using non-parametric tests can make it extremely difficult to demonstrate corrective action success.

Step 3. Compute the variance around the estimated trend line using equation [21.23]:

$$s_e^2 = \frac{1}{8} \cdot \left[(2.465)^2 + (-4.230)^2 + \ldots + (-2.761)^2 \right] = 15.60$$

Step 4. Since the comparison to the GWPS of 20 ppb is to be made at the $\alpha = 0.05$ significance level, the confidence limit is $(1-\alpha) = 95\%$ confidence. Since the remediation effort aims to demonstrate that the true mean TCE level has dropped below 20 ppb, a one-way UCL needs to be determined using equation [21.25]. A logical point along the trend to examine is the last sampling event at $t_0 = 30$. Using the estimated regression value at $t_0 = 30$, and the fact that $F_{.90,2,8} = 3.1131$, the UCL on the mean TCE concentration at this point becomes:

$$UCL_{95} = 6.861 + \sqrt{2 \times 15.60 \times 3.1131 \times \left[\frac{1}{10} + \frac{(30-15.3)^2}{9 \times 88.2333} \right]} = 12.87 \; ppb$$

Since this upper limit is less than the GWPS for TCE, conclude that the remediation goal has been achieved by $t_0 = 30$. In fact, other times can also be tested using the same equation. At the next to last sampling event ($t_0 = 26$), the UCL is:

$$UCL_{95} = 13.272 + \sqrt{2 \times 15.60 \times 3.1131 \times \left[\frac{1}{10} + \frac{(26-15.3)^2}{9 \times 88.2333} \right]} = 18.14 \; ppb$$

which also meets the remediation target at the $\alpha = 0.05$ level of significance.

Step 5. If the linear trend is ignored, a one-way UCL of the mean might have been used. The overall TCE sample mean $\bar{x} = 30.42$, the TCE standard deviation s = 15.508, and the upper 95th percentage point of the t-distribution with 9 degrees of freedom is $t_{.95,9}$ = 1.8331. Using equation [21.2] with the same data yields the following:

$$UCL_{.95} = 30.42 + (1.8331)(15.508) / \sqrt{10} = 39.41 \text{ ppb}$$

Had the linear trend been ignored when computing the UCL, the remediation target would not have been achieved. The downward trend induces the largest part of the variation observed over the two and a half years of sampling and needs to be taken into account. ◄

21.3.2 NON-PARAMETRIC CONFIDENCE BAND AROUND THEIL-SEN LINE

BACKGROUND AND PURPOSE

The Theil-Sen trend line is introduced in **Section 17.3.3** as a non-parametric alternative to linear regression. Whether due to the presence of non-detects or trend residuals that cannot be normalized, the

Theil-Sen method can usually construct a trend estimate without some of the assumptions needed by linear regression.

The Theil-Sen trend line is non-parametric because it combines the median pairwise slope (**Section 17.3.3**) with the median concentration value and the median sample date to construct the trend. Because of this construction, the Theil-Sen line estimates the change in *median* concentration over time and not the *mean* as in linear regression.

There are no simple formulas to construct a confidence band around the Theil-Sen line. However, a more computationally-intensive technique — bootstrapping — can be employed instead. The conceptual algorithm is fairly simple. First consider the set of n pairs of measurements used to construct the Theil-Sen trend. Each pair consists of a sample date (t_i) and the concentration value measured on that date (x_i) as a statistical sample. Next, repeatedly draw samples of size n *with replacement* from the original sample of pairs. These artificially constructed samples are known as *bootstrap samples*. At least 500 to 2,000 bootstrap samples are generated in order to improve the accuracy of the final confidence band. Note that a bootstrap sample is not precisely the same as the original because pairs are sampled with replacement. This means that a given pair might show up multiple times in any particular bootstrap sample.

For each bootstrap sample, use the Theil-Sen algorithm to construct an associated trend line (**Section 17.3.3**). Each of these trend lines is known as a *bootstrap replicate*. Finally, determine the distribution of the bootstrap replicates and select certain percentiles of this distribution to form lower and upper confidence limits. These limits can be constructed to represent a non-parametric simultaneous confidence band around the Theil-Sen trend line with $(1-\alpha)$ confidence.

REQUIREMENTS AND ASSUMPTIONS

The key requirements for constructing a confidence band around a Theil-Sen trend are the same as for the Theil-Sen procedure itself (**Section 17.3.3**). As a non-parametric procedure, the trend residuals do not have to be normal or have equal variance across the data range. But the residuals are assumed to be statistically independent. Approximate checks of this assumption can be made using the techniques of **Chapter 14**, after removing the estimated Theil-Sen trend and as long as there aren't too many non-detects. It is also important to have at least 8-10 observations from which to construct the bootstrap samples.

Non-detects can be accommodated by the Theil-Sen method as long as the detection frequency is at least 50%, and the censored values occur in the lower part of the observed concentration range. Then the median concentration value and the median pairwise slope used to compute the Theil-Sen trend will be based on clearly quantified values.

Since there are no simple mathematical equations which can construct the Theil-Sen confidence band, a computer software program is essential for performing the calculations. Perhaps the best current solution is to use the open-source, free-of-charge, statistical computing package **R** (www.r-project.org). A template program (or script) written in **R** to compute a Theil-Sen confidence band is listed in **Appendix C**. This script can be adapted to any site-specific data set and used as many times as necessary, once the **R** computing environment has been installed.

PROCEDURE

Step 1. Given the original sample of n measurements, form a sample of n pairs (t_i, x_i), where each pair consists of a sample date (t_i) and the concentration measurement from that date (x_i).

Step 2. Form B bootstrap samples by repeatedly sampling n pairs at random with replacement from the original sample of pairs in Step 1. Typically, set $B \geq 500$.

Step 3. For each bootstrap sample, construct a Theil-Sen trend line using the algorithm in **Section 17.3.3**. Denote each of these B trend lines as a bootstrap replicate.

Step 4. Determine a series of equally spaced time points (t_j) along the range of sampling dates represented in the original sample, $j = 1$ to m. At each time point, use the Theil-Sen trend line associated with each bootstrap replicate to compute an estimated concentration ($\hat{x}_j^B$). There will be B such estimates at each of the m equally-spaced time points when this step is complete.

Step 5. Given a confidence level (1–α) to construct a two-sided confidence band, determine the lower (α/2)th and the upper (1–α/2)th percentiles, denoted $\hat{x}_j^{[\alpha/2]}$ and $\hat{x}_j^{[1-\alpha/2]}$ from the distribution of estimated concentrations at each time point (t_j). The collection of these lower and upper percentiles along the range of sampling dates (t_j, $j = 1$ to m) forms the bootstrapped confidence band. To construct a lower confidence band, follow the same strategy. But determine the lower αth percentile $\hat{x}_j^{[\alpha]}$ from the distribution of estimated concentrations at each time point (t_j). For an upper confidence band, compute the upper (1–α)th percentile, $\hat{x}_j^{[1-\alpha]}$ at each time point (t_j).

Step 6. Depending on whether the regulated unit is in compliance/assessment or corrective action monitoring, compare the appropriate confidence band against the GWPS. Estimate at what point in time (if ever) the confidence band first sits completely to one side of the fixed comparison standard.

►EXAMPLE 21-8

In **Example 17-7**, a Theil-Sen trend line was estimated for the following sodium measurements. Note that the sample dates are recorded as the year of collection (2-digit format), plus a fractional part indicating when during the year the sample was collected. Construct a two-sided 95% confidence band around the trend line.

Sample Date (yr)	Sodium Conc. (ppm)
89.6	56
90.1	53
90.8	51
91.1	55
92.1	52
93.1	60
94.1	62
95.6	59
96.1	61
96.3	63

SOLUTION

Step 1. Designate the $n = 10$ (sample date, concentration) pairs as the original sample for purposes of bootstrapping. Set the number of bootstrap samples to $N_B = 500$.

Step 2. Sample at random and with replacement $N_B = 500$ times from the original sample to form the bootstrap samples. Compute a bootstrap replicate Theil-Sen trend line for each bootstrap sample. This gives 500 distinct linear trend lines.

Step 3. Divide the observed range of sampling dates from 89.6 to 96.3 into $m = 101$ equally-spaced time points, t_j (note: choice of m is arbitrary, depending on how often along the time range an estimate of the confidence band is needed). At each time point, compute the Theil-Sen concentration estimate using each bootstrap replicate trend. This leads to 500 estimates of the form:

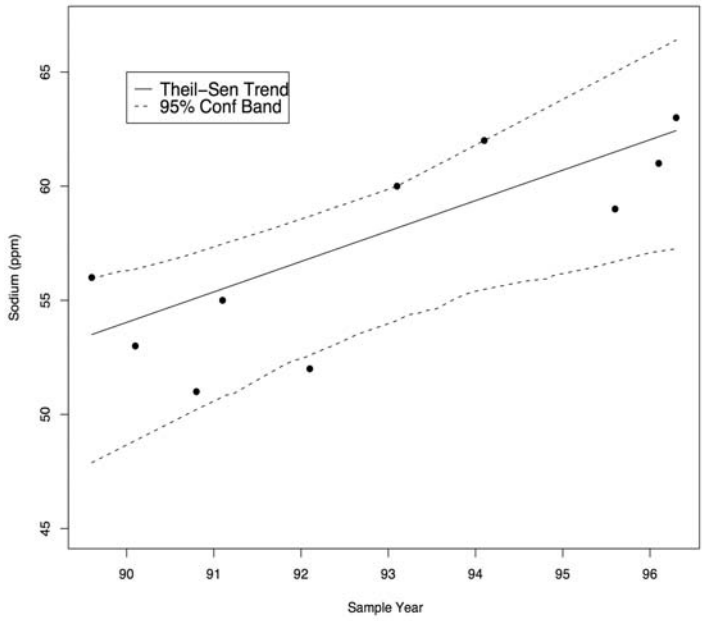
$$\hat{x}_j^B = \tilde{x}^B + Q^B \cdot \left(t_j - \tilde{t}^B\right)$$

where $\tilde{x}^B$ is the median concentration of the Bth bootstrap sample, Q^B is the Theil-Sen slope of the Bth bootstrap sample, and $\tilde{t}^B$ is the median sampling date of the Bth bootstrap sample.

Step 4. Given a two-way confidence level of 95%, compute the lower $\alpha/2 = 0.05/2 = 0.025$ and upper $(1-\alpha/2) = (1-0.05/2) = 0.975$ sample percentiles (**Chapter 3**) for the set of 500 concentration estimates associated with each time point (t_j). This entails sorting each set and finding the value closest to rank $(n+1) \times p$, where p = desired percentile. In a list of $n = 500$, find the sorted values closest to the ranks $501 \times 0.025 = 12.525$ for the lower percentile and $501 \times 0.975 = 488.475$ for the upper percentile. Collectively, the lower and upper percentiles plotted by the time points give an approximation to the 95% two-sided confidence band.

Step 5. Plot the lower and upper confidence bands as well as the original Theil-Sen trend line and the raw sodium measurements, as in **Figure 21-6**. The fact that the trend is increasing over time is confirmed by the rising confidence band. ◄

Figure 21-6. 95% Theil-Sen Confidence Band on Sodium Measurements



ATTACHMENT 2

STATISTICAL RESULTS

ATTACHMENT 2
SHALLOW GROUNDWATER STATISTICAL RESULTS SUMMARY - APRIL 2013
USING THE EIGHT MOST RECENT DATA POINTS FOR CONSTITUENTS OF CONCERN
WASATCH CHEMICAL SITE, SALT LAKE CITY, UTAH

Monitoring Location	COC	MCL (µg/l)	N	Mean (µg/l)	Standard Deviation (µg/l)	Data Distribution	% Non-detects	Trend at α 0.01[(a)]	Slope at α 0.01[(b)] (µg/l/year)	UCL (95% CL)	LCL (95% CL)	Exceeds MCL	MCL Exceedance Determination Method	Indication	Recommendation
ES-01	PCE	5	8	3.31	4.756	ln(x)	0	No	NA	4.482	0.4308	No	Confidence interval	Performance Standard met	B
	TCE	5	8	13.86	16.84	ln(x)	0	No	NA	20.96	2.339	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	1.763	2.315	unknown	50	No	NA	6.7	0.1	No	Confidence interval	Performance Standard met	B
	VC	2	8	15.47	20.98	ln(x)	0	No	NA	23.29	1.546	No	Confidence interval	Performance Standard met	B
	PCP	1	8	6.113	9.001	unknown	50	No	NA	26	0.05	No	Confidence interval	Performance Standard met	B
EX-02	PCE	5	8	0.4856	0.2799	ln(x)	0	No	NA	0.6431	0.2968	No	Confidence interval	Performance Standard met	B
	TCE	5	8	126.6	59.47	normal	0	No	NA	152.3	90.97	Yes	Confidence interval	Stability	C
	1,1-DCE	7	8	9.038	1.066	normal	0	No	NA	9.752	8.323	Yes	Confidence interval	Stability	C
	VC	2	8	117.8	63.09	normal	0	No	NA	160.1	75.55	Yes	Confidence interval	Stability	C
	PCP	1	8	7.6	2.638	normal	0	No	NA	9.367	5.833	Yes	Confidence interval	Stability	C
EX-04	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	31.64	19.43	normal	0	Yes	-14.43	44.65	18.62	Yes	Confidence band	Attenuation	A
	1,1-DCE	7	8	10.33	3.775	normal	0	No	NA	12.85	7.796	Yes	Confidence interval	Stability	C
	VC	2	8	1.66	0.7347	normal	0	No	NA	2.152	1.168	No	Confidence interval	Performance Standard met	B
EX-05	PCE	5	8	0.15	0.1414	unknown	100	No	NA	0.5	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	0.4506	0.06247	normal	0	No	NA	0.4925	0.4088	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	8.606	1.262	normal	0	No	NA	9.415	7.892	Yes	Confidence interval	Stability	C
	VC	2	8	15.94	5.454	normal	0	Yes	-3.625	19.59	12.28	Yes	Confidence band	Attenuation	A
EX-07	PCE	5	8	0.3025	0.3582	unknown	62.5	No	NA	1.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	1.729	0.7355	normal	0	No	NA	2.221	1.236	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	0.2788	0.132	normal	25	No	NA	0.3669	0.2052	No	Confidence interval	Performance Standard met	B
	VC	2	8	3.25	1.956	normal	0	No	NA	4.56	1.94	No	Confidence interval	Performance Standard met	B
	PCP	1	8	0.08125	0.02588	unknown	100	No	NA	0.1	0.05	No	Confidence interval	Performance Standard met	B
EX-08	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	0.27	0.122	normal	25	No	NA	0.351	0.208	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	VC	2	8	0.2288	0.2773	unknown	75	No	NA	0.88	0.1	No	Confidence interval	Performance Standard met	B
	PCP	1	8	2.159	0.8598	normal	0	No	NA	2.735	1.583	Yes	Confidence interval	Stability	C

ATTACHMENT 2
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Monitoring Location	COC	MCL (µg/l)	N	Mean (µg/l)	Standard Deviation (µg/l)	Data Distribution	% Non-detects	Trend at α 0.01[a]	Slope at α 0.01[b] (µg/l/year)	UCL (95% CL)	LCL (95% CL)	Exceeds MCL	MCL Exceedance Determination Method	Indication	Recommendation
EX-09	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	0.255	0.04209	normal	0	No	NA	0.2832	0.2268	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	1.888	0.5768	normal	0	No	NA	2.274	1.501	No	Confidence interval	Performance Standard met	B
	VC	2	8	0.13	0.05555	unknown	75	No	NA	0.22	0.1	No	Confidence interval	Performance Standard met	B
EX-11	PCE	5	8	0.6	0.9502	unknown	87.5	No	NA	2.5	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	18.98	23.08	ln(x)	0	No	NA	28.65	3.779	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	8.2	7.231	normal	0	No	NA	13.04	3.356	No	Confidence interval	Performance Standard met	B
	VC	2	8	519.4	224.2	normal	0	No	NA	669.5	369.2	Yes	Confidence interval	Stability	C
	PCP	1	8	0.08125	0.02588	unknown	100	No	NA	0.1	0.05	No	Confidence interval	Performance Standard met	B
MW-06	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	0.1725	0.1537	unknown	75	No	NA	0.53	0.1	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	2.541	1.869	normal	12.5	No	NA	3.793	1.289	No	Confidence interval	Performance Standard met	B
	VC	2	8	0.9475	0.7009	normal	25	No	NA	1.411	0.2967	No	Confidence interval	Performance Standard met	B
MW-20	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	8	1.609	0.8355	ln(x)	0	No	NA	1.96	1.097	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	8	1.413	0.5949	normal	0	No	NA	1.811	1.014	No	Confidence interval	Performance Standard met	B
	VC	2	8	3.55	1.928	normal	0	No	NA	4.308	2.43	Yes	Confidence interval	Stability	C
MW-23[c]	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	TCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	1,1-DCE	7	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	VC	2	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
MW-24A[d]	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	TCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	1,1-DCE	7	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	VC	2	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
MW-25[e]	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	TCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	1,1-DCE	7	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	VC	2	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B

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Monitoring Location	COC	MCL (µg/l)	N	Mean (µg/l)	Standard Deviation (µg/l)	Data Distribution	% Non-detects	Trend at α 0.01[a]	Slope at α 0.01[b] (µg/l/year)	UCL (95% CL)	LCL (95% CL)	Exceeds MCL	MCL Exceedance Determination Method	Indication	Recommendation
MW-30	PCE	5	7	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
	TCE	5	7	0.7286	0.1733	normal	0	No	NA	1.1	0.59	No	Confidence interval	Performance Standard met	B
	1,1-DCE	7	7	6.343	1.681	normal	0	No	NA	7.578	5.108	No	Confidence interval	Performance Standard met	B
	VC	2	7	13.13	7.603	normal	0	No	NA	18.71	7.545	Yes	Confidence interval	Stability	C
	PCP	1	7	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Performance Standard met	B
PZ-1[f]	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	TCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	1,1-DCE	7	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	VC	2	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
PZ-3[g]	PCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	TCE	5	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	1,1-DCE	7	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B
	VC	2	8	0.1	0	unknown	100	No	NA	0.1	0.1	No	Confidence interval	Stable at non-detect	B

(a) Mann-Kendall method used to test for a statistically significant slope trend.
(b) Thiel-Sen method used to estimate the rate of change of the median concentration over time (slope).
(c) MW-23 is an upgradient monitoring location; all data collected to date are non-detect except for one trace concentration of TCE for a sampled collected in August 1997.
(d) MW-24A is a downgradient shallow groundwater sentry well; all data collected to date are non-detect except for two trace concentrations detected in November 1997 and May 2001 for PCE and TCE, respectively.
(e) MW-25 is a downgradient shallow groundwater sentry well; all data collected to date are non-detect except for one trace concentration of PCE for a sample collected in November 1997.
(f) PZ-1 is a downgradient piezometer, added to the semiannual monitoring schedule in 2003; to date, all results for PZ-1 have been non-detect.
(g) PZ-3 is located on the Intsel Steel West property; it was added to the compliance monitoring network in 2004, after a sentry well (MW-26A, located north of the groundwater plumes) was inadvertently destroyed during Intsel construction activities; to date, all results for PZ-3 have been non-detect.

CL	confidence level
COC	constituent of concern; includes PCE, TCE, 1,1-DCE, VC, and PCP
LCL	lower confidence limit
MCL	maximum contaminant level
N	number of data points used
NA	not applicable
PCE	tetrachloroethene
PCP	pentachlorophenol
TCE	trichloroethene
UCL	upper confidence limit
VC	vinyl chloride
1,1-DCE	1,1-dichloroethene
α	The percentage of cases for which a false conclusion is reached (1-confidence level)
µg/l	micrograms per liter

A	Continue monitoring
B	Evaluate sampling frequency
C	Evaluate basis for potential Alternative Performance Standard

ATTACHMENT 3

GRAPHICAL OUTPUT

TREND ANALYSIS PLOTS

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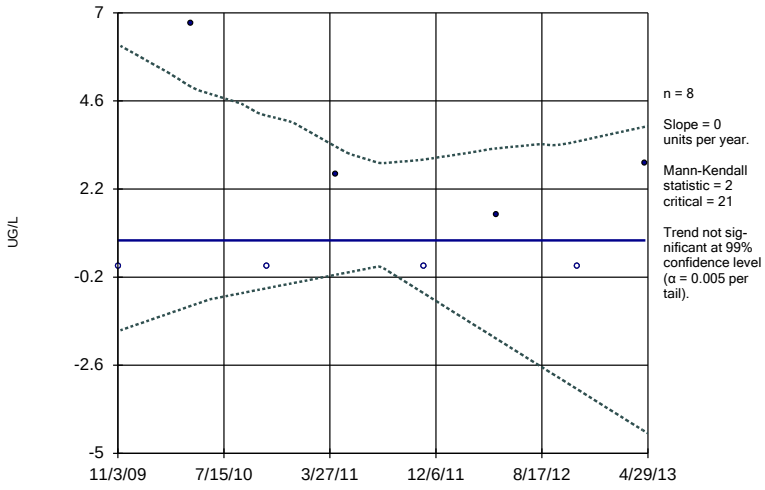
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

ES-01



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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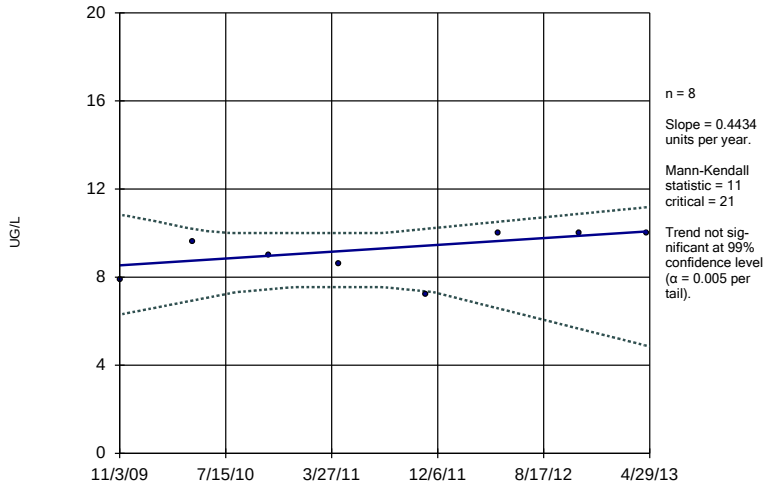
Sen's Slope and 99% Confidence Band

EX-02



Constituent: DCE11 Analysis Run 7/17/2013 3:17 PM
Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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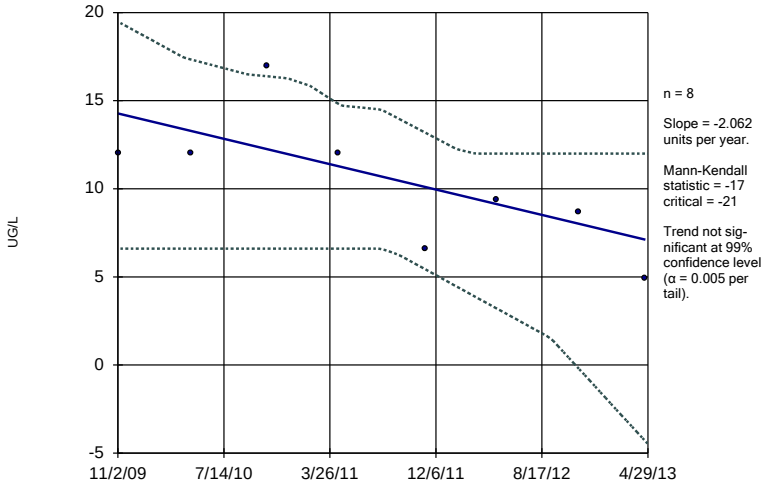
Sen's Slope and 99% Confidence Band

EX-04



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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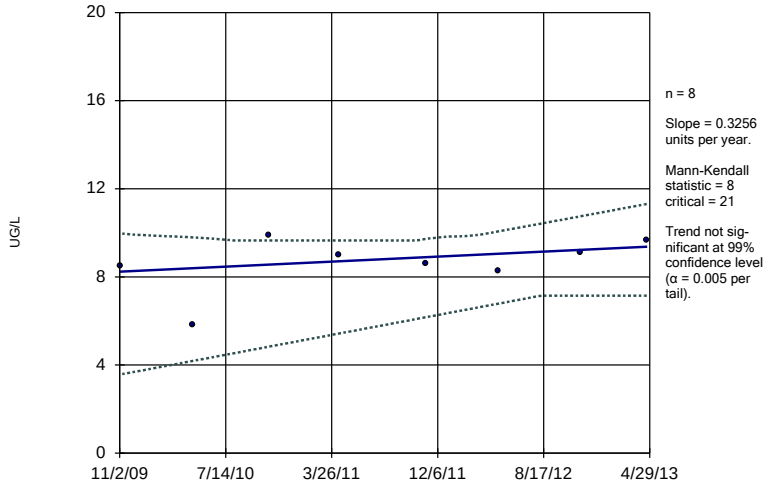
Sen's Slope and 99% Confidence Band

EX-05



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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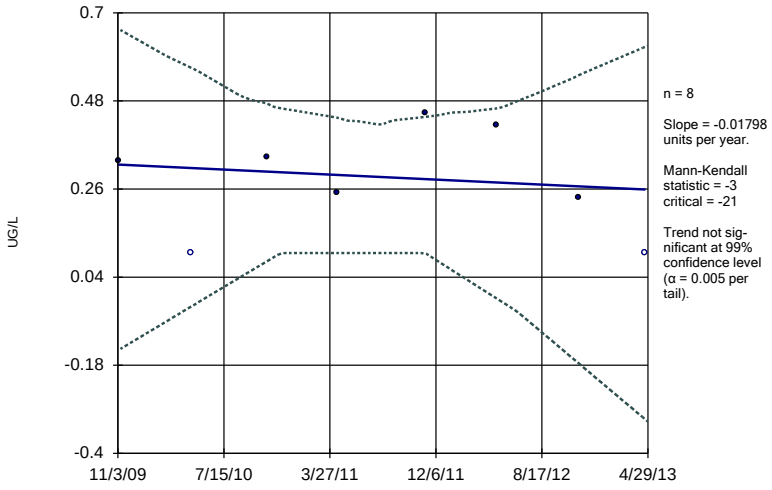
Sen's Slope and 99% Confidence Band

EX-07



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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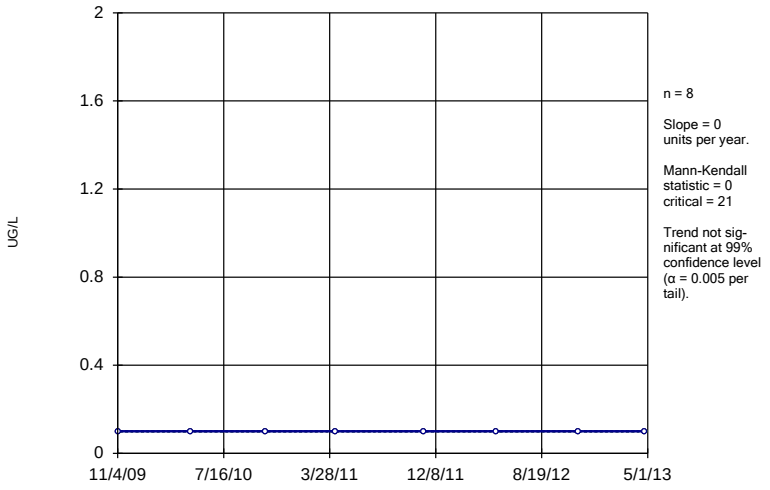
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

EX-08



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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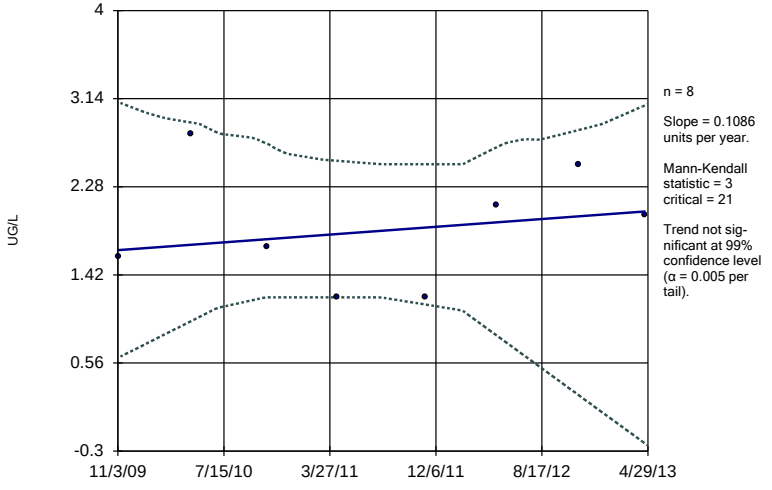
Sen's Slope and 99% Confidence Band

EX-09



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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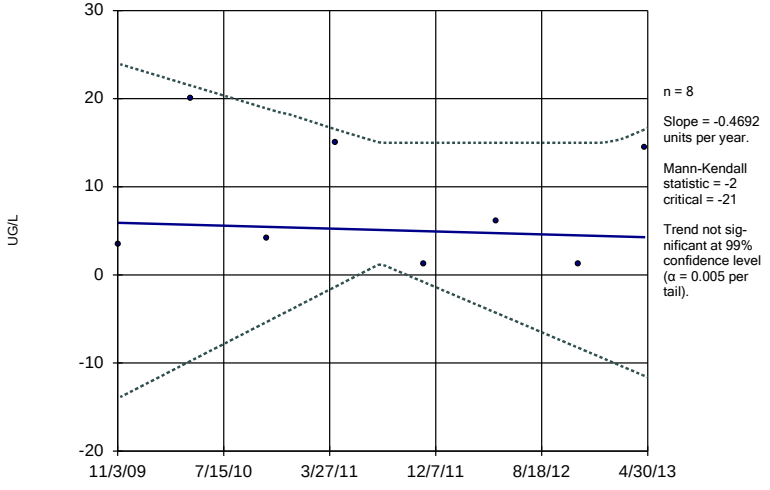
Sen's Slope and 99% Confidence Band

EX-11



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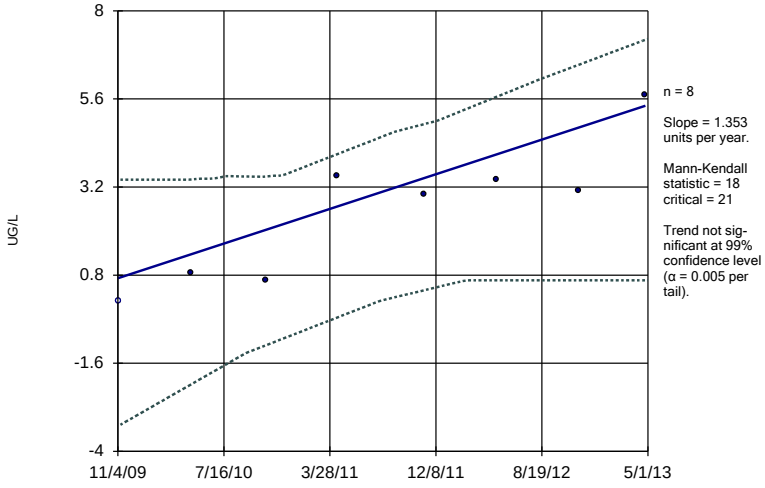
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

MW-06



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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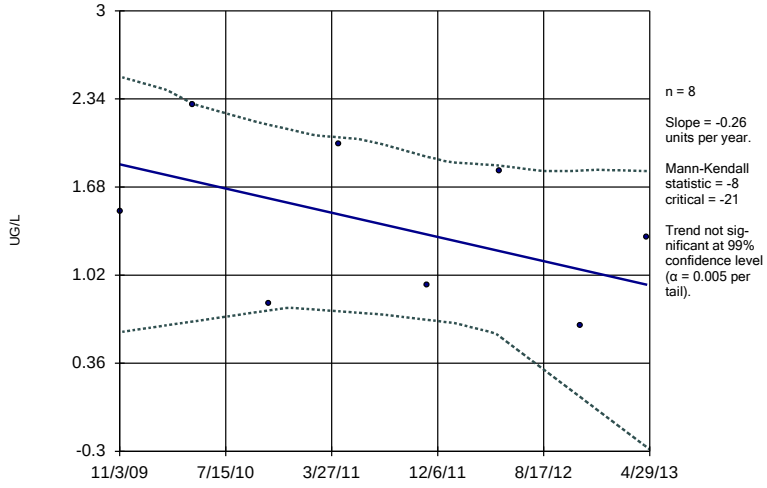
Sen's Slope and 99% Confidence Band

MW-20



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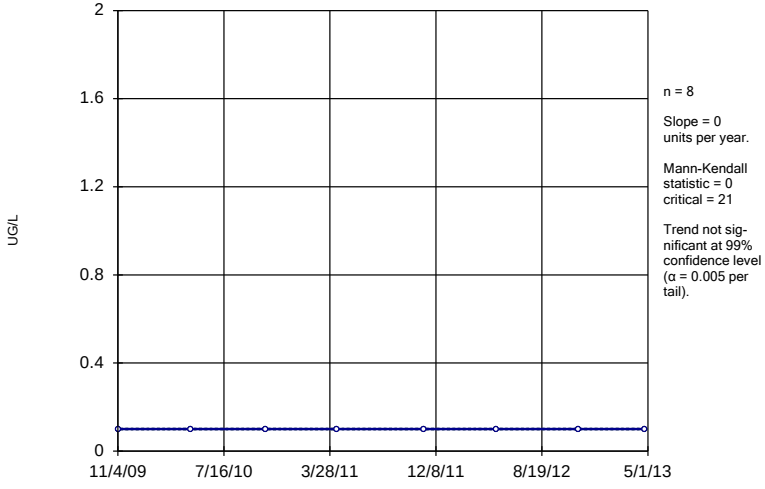
Sen's Slope and 99% Confidence Band

MW-23



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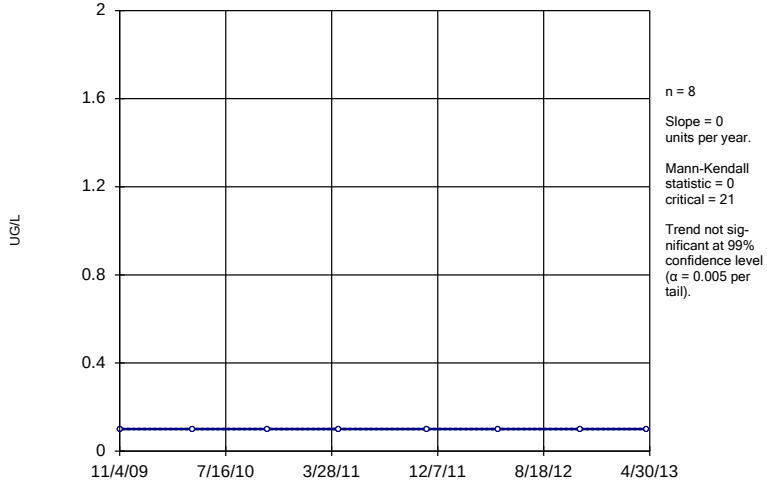
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

MW-24A



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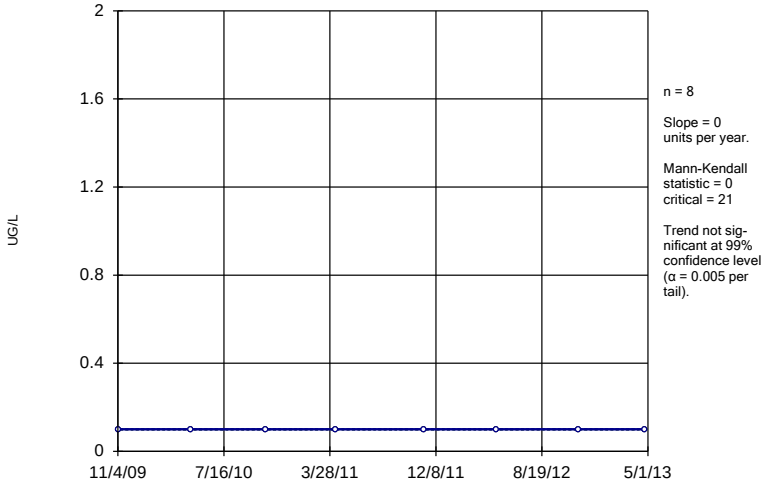
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

MW-25



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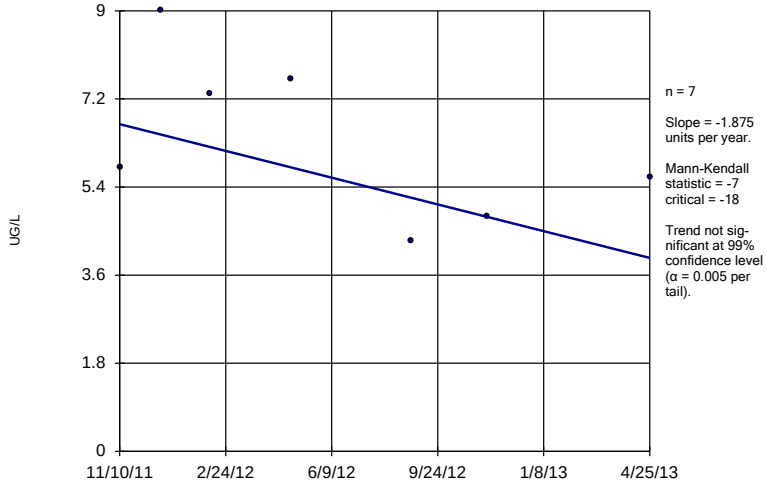
Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope Estimator

MW-30



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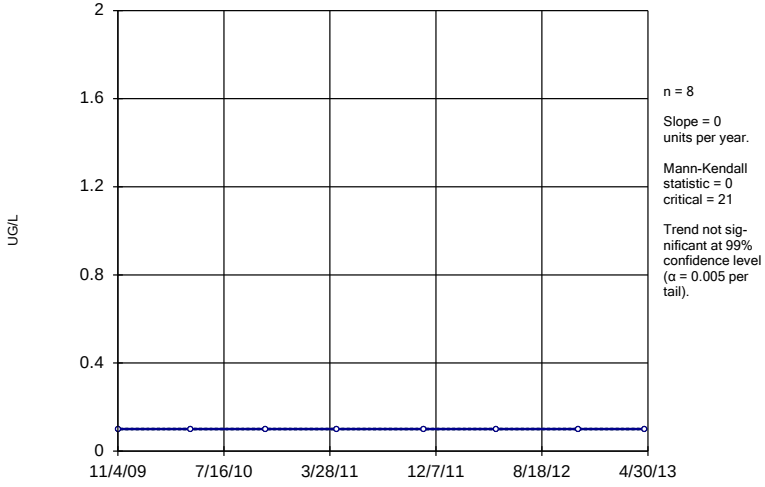
Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

Sanitas™ v.9.3.25 Software licensed to MWH. UG
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

PZ-1



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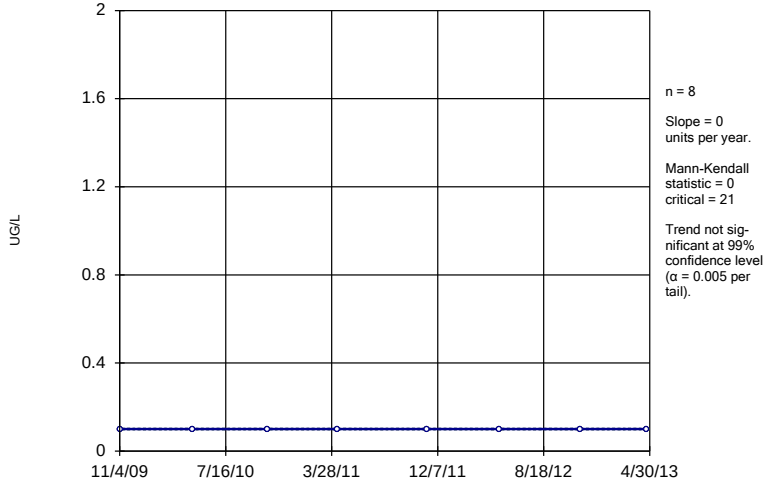
Sanitas™ v.9.3.25 Software licensed to MWH. UG
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

PZ-3



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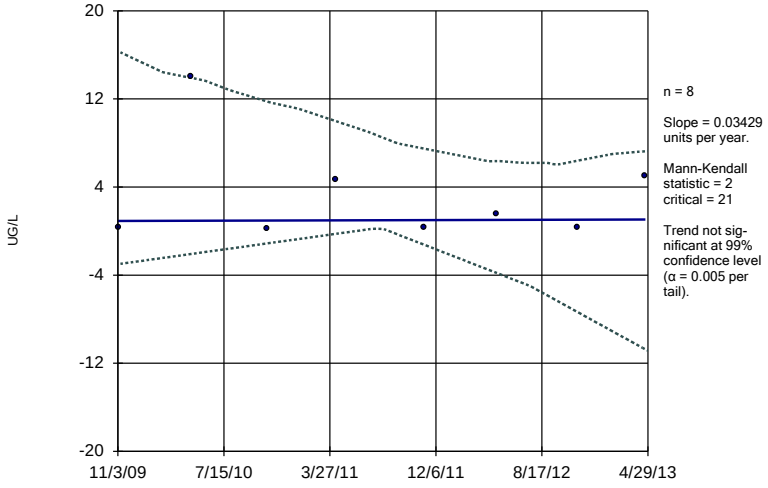
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

ES-01



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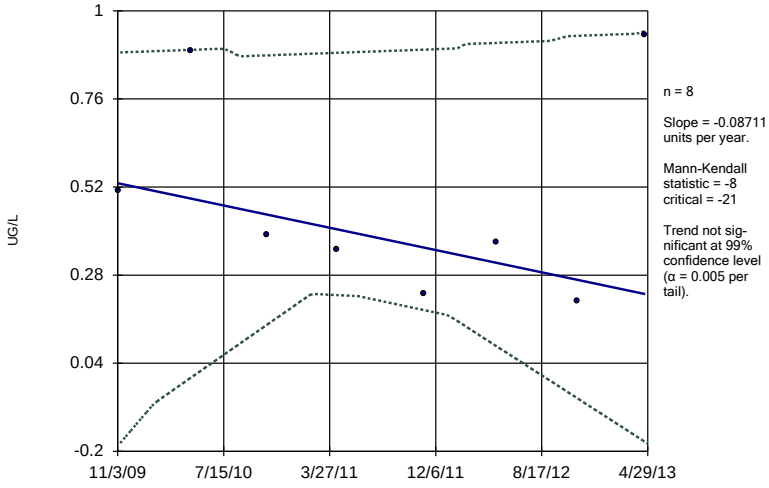
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

EX-02



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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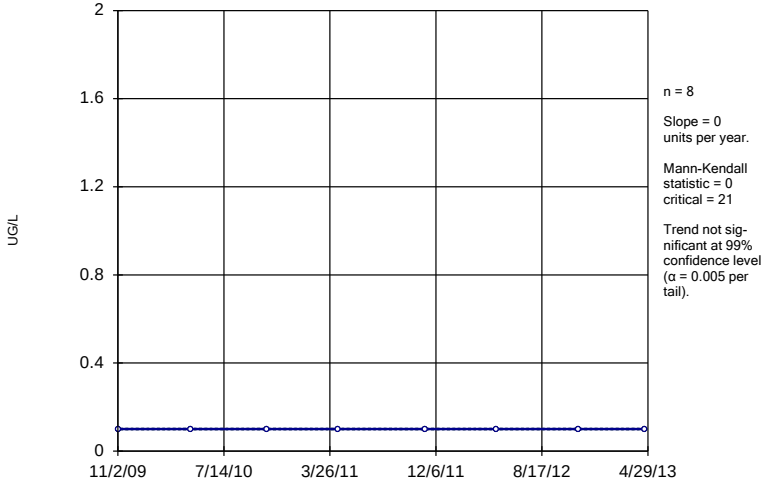
Sen's Slope and 99% Confidence Band

EX-04



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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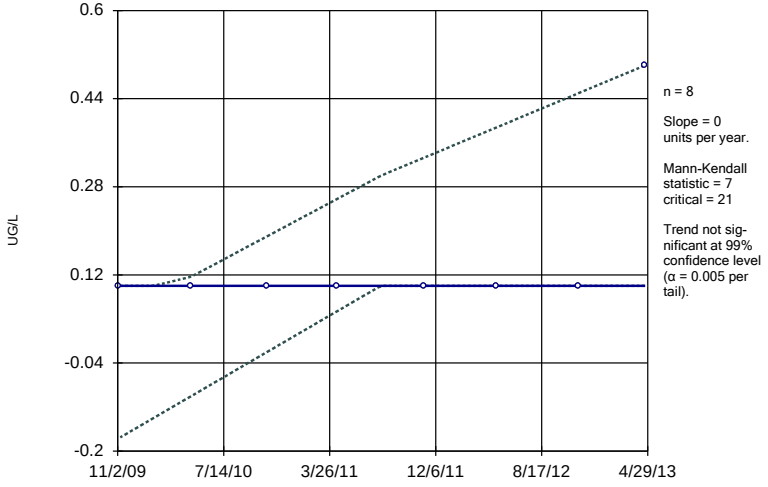
Sen's Slope and 99% Confidence Band

EX-05



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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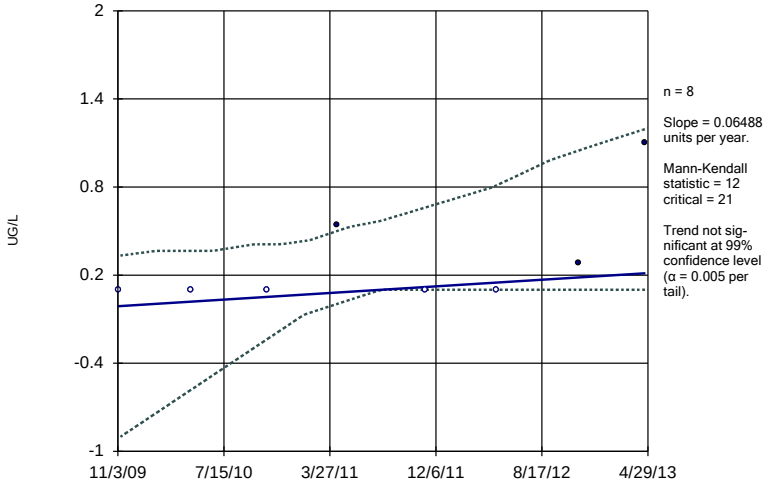
Sen's Slope and 99% Confidence Band

EX-07



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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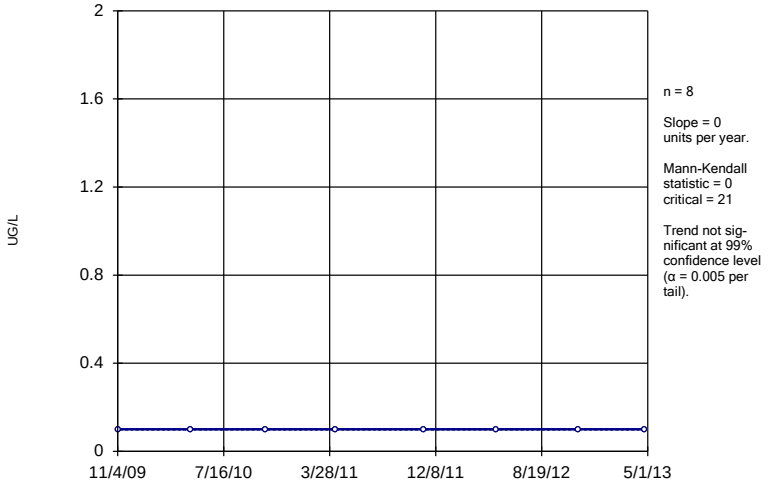
Sen's Slope and 99% Confidence Band

EX-08



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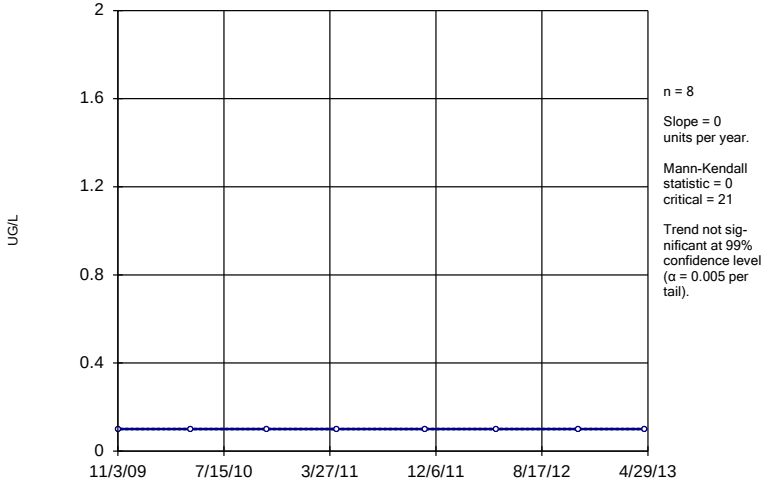
Sen's Slope and 99% Confidence Band

EX-09



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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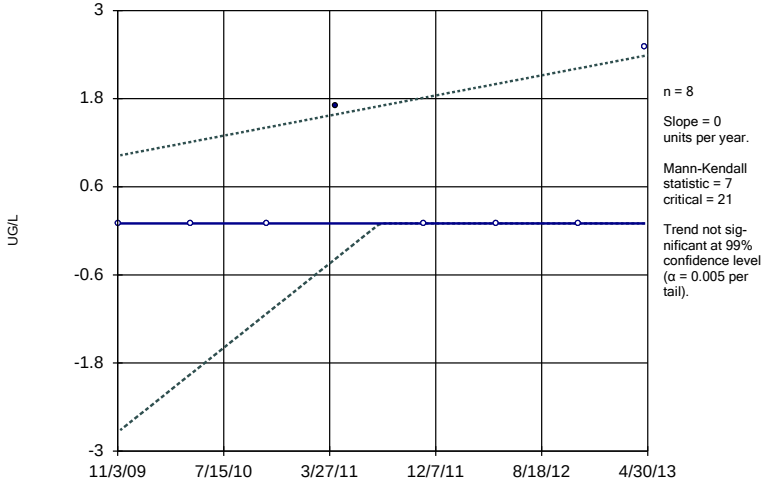
Sen's Slope and 99% Confidence Band

EX-11



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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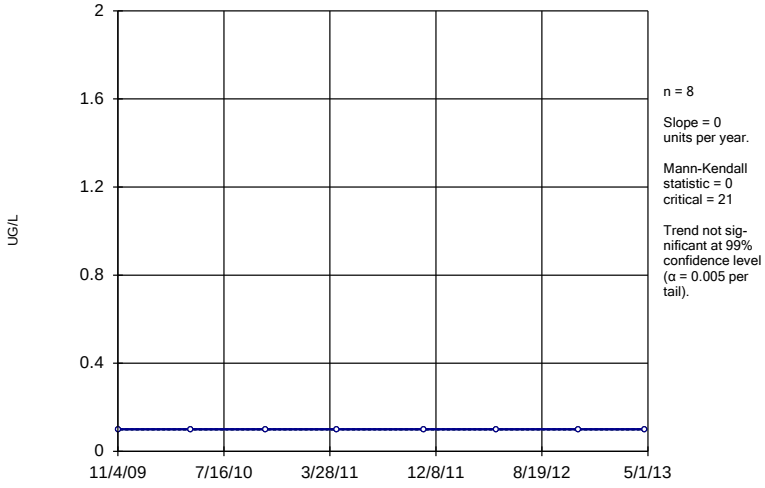
Sen's Slope and 99% Confidence Band

MW-06



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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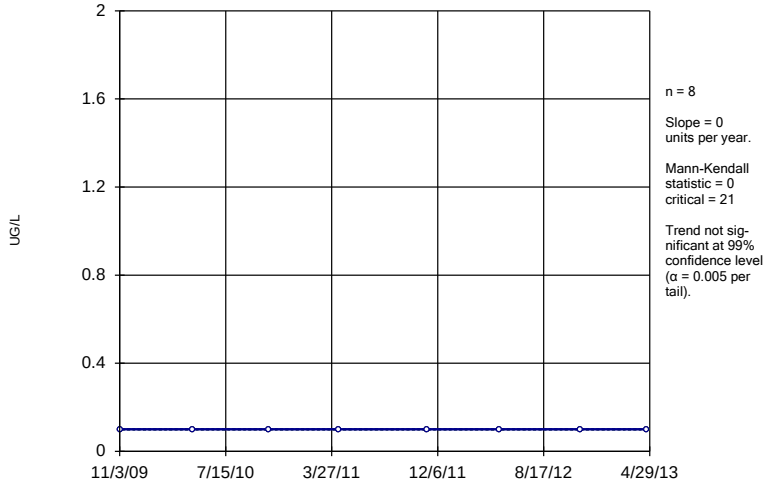
Sen's Slope and 99% Confidence Band

MW-20



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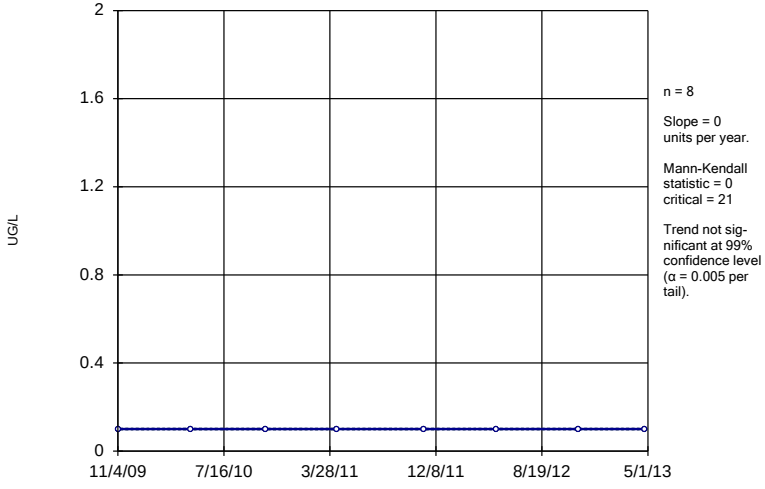
Sen's Slope and 99% Confidence Band

MW-23



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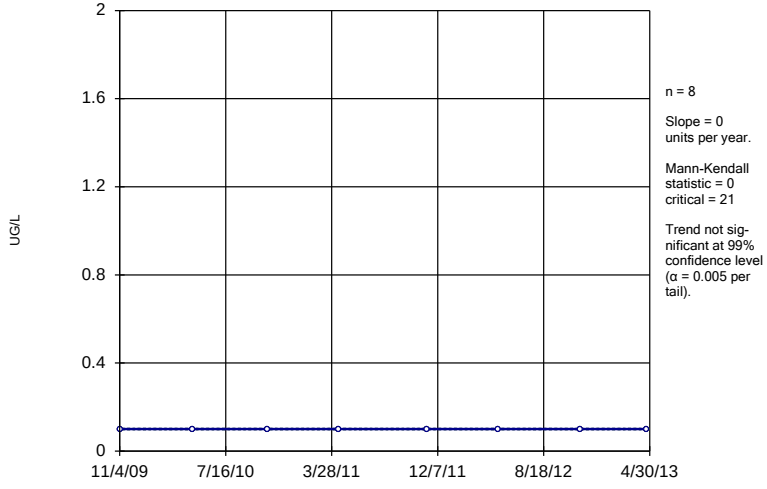
Sen's Slope and 99% Confidence Band

MW-24A



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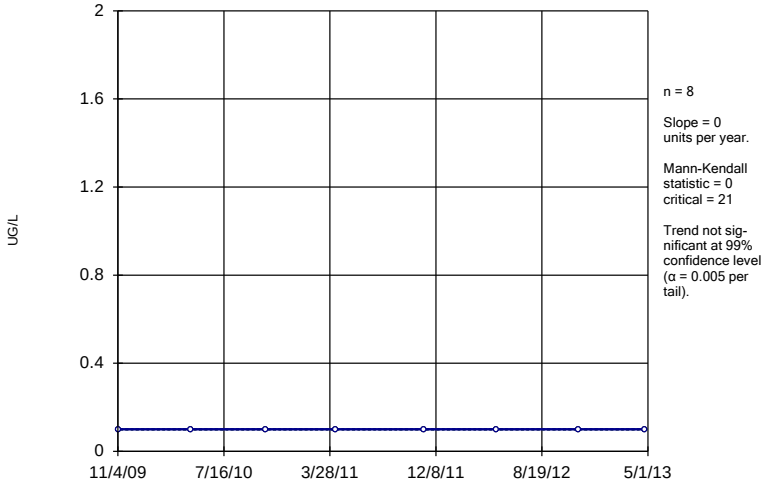
Sen's Slope and 99% Confidence Band

MW-25



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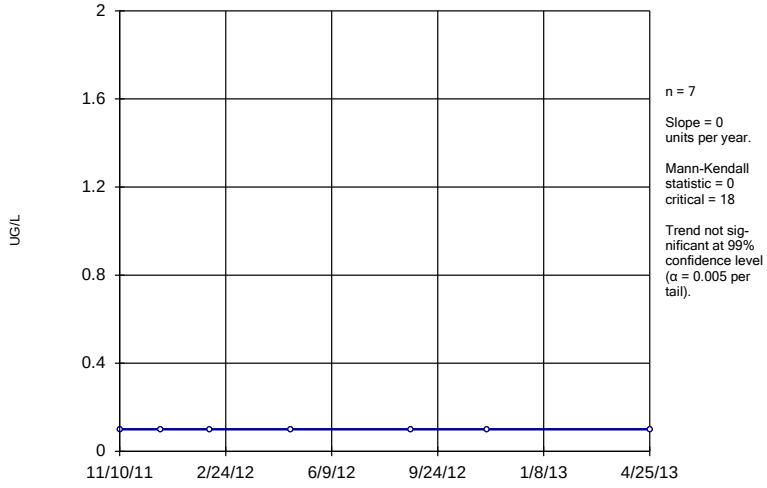
Sen's Slope Estimator

MW-30



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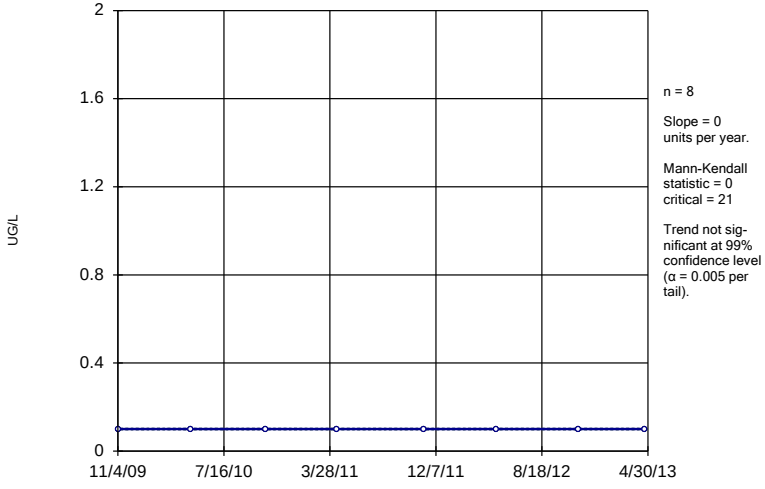
Sen's Slope and 99% Confidence Band

PZ-1



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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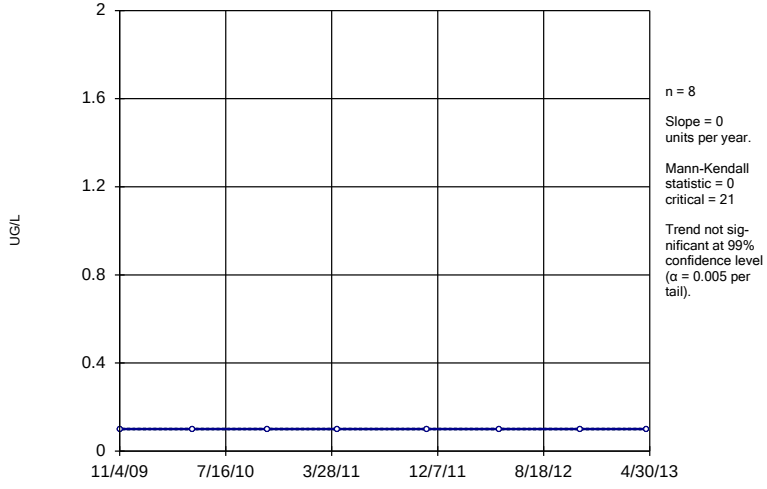
Sen's Slope and 99% Confidence Band

PZ-3



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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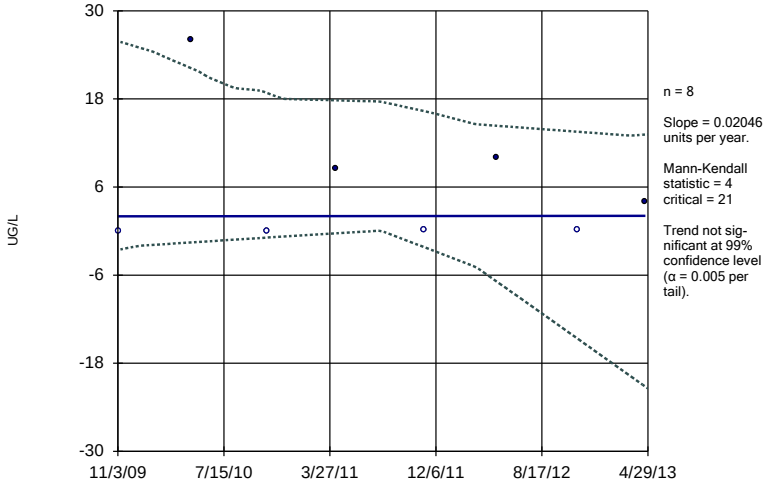
Sen's Slope and 99% Confidence Band

ES-01



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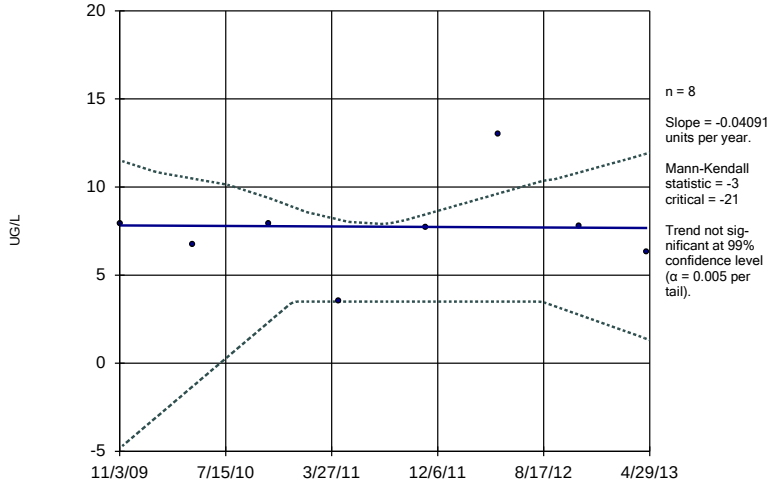
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

EX-02



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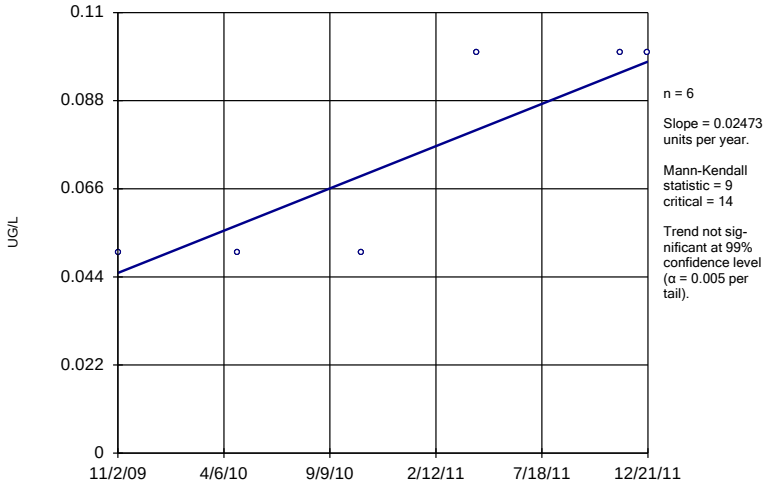
Sanitas™ v.9.3.25 Software licensed to MWH. UG
Hollow symbols indicate censored values.

Sen's Slope Estimator

EX-04



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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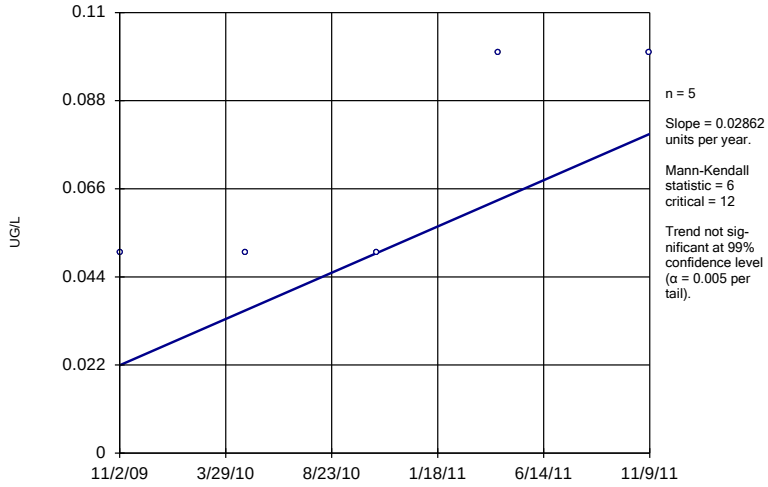
Sen's Slope Estimator

EX-05



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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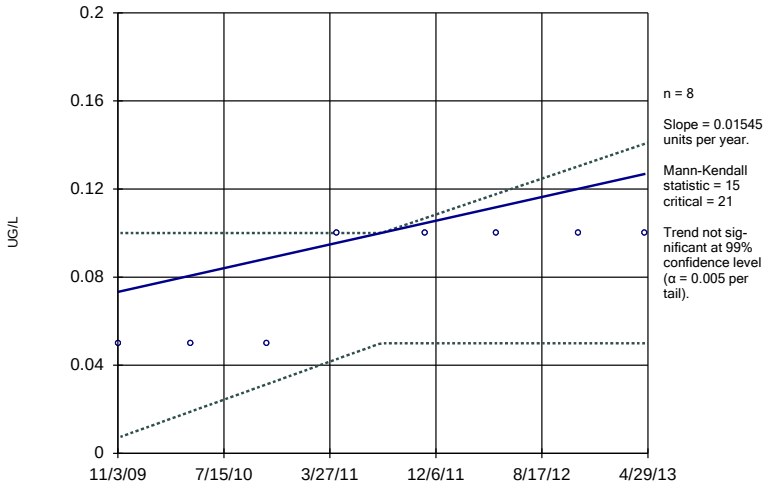
Sen's Slope and 99% Confidence Band

EX-07



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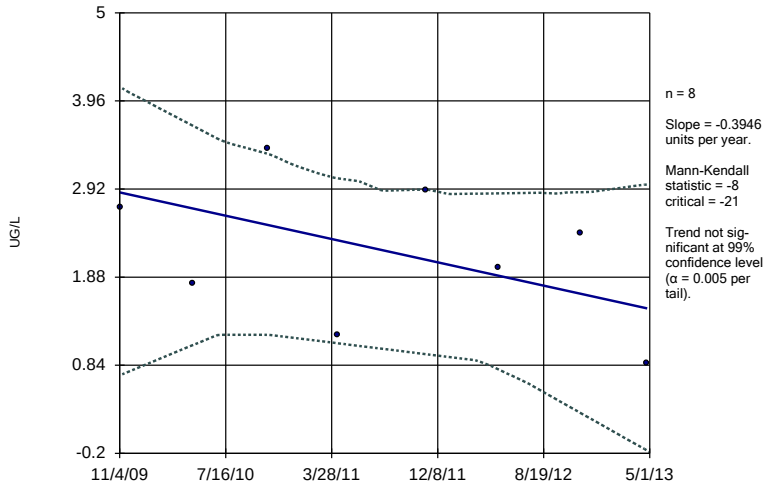
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

EX-08



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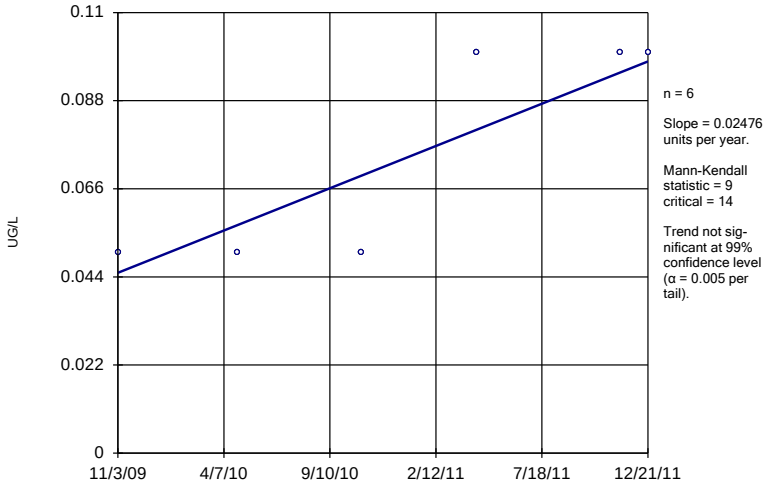
Sen's Slope Estimator

EX-09



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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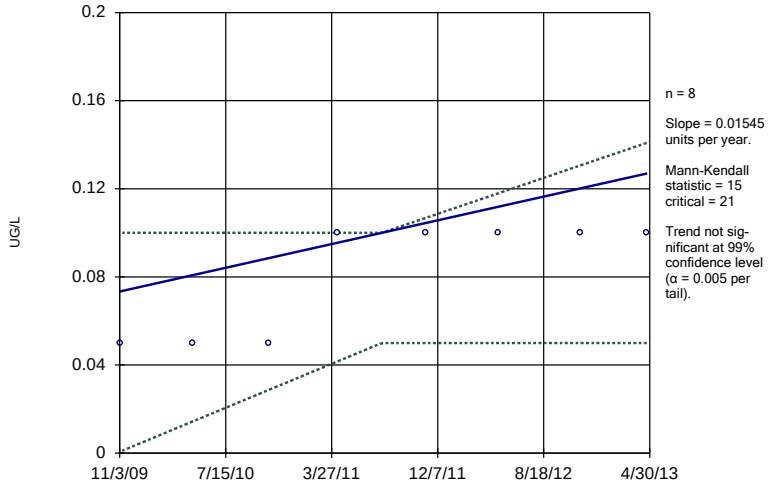
Sen's Slope and 99% Confidence Band

EX-11



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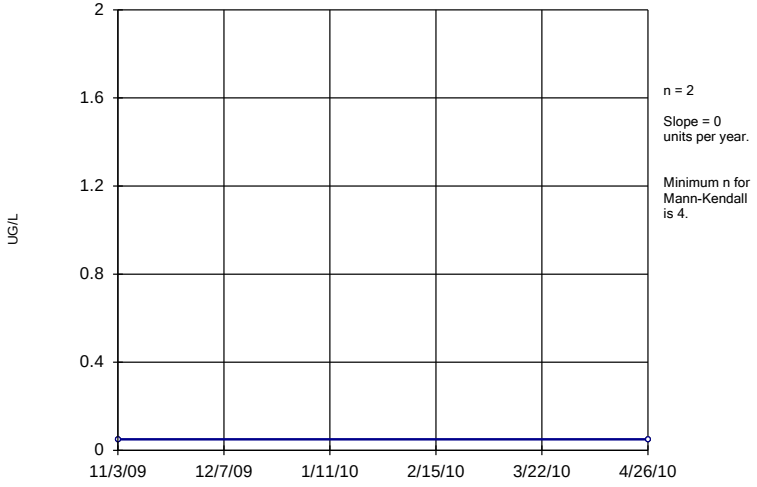
Sen's Slope Estimator

MW-20



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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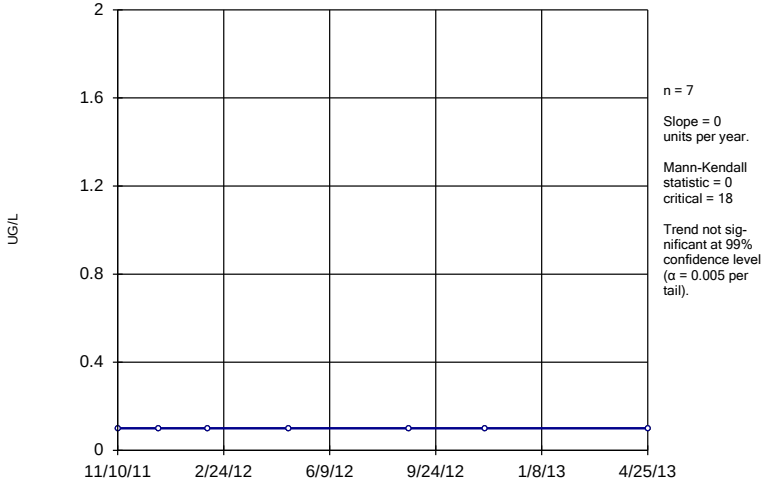
Sen's Slope Estimator

MW-30



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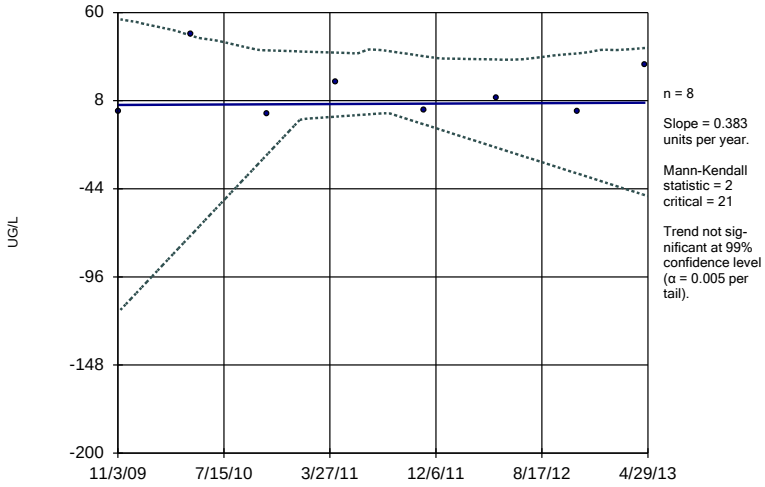
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

ES-01



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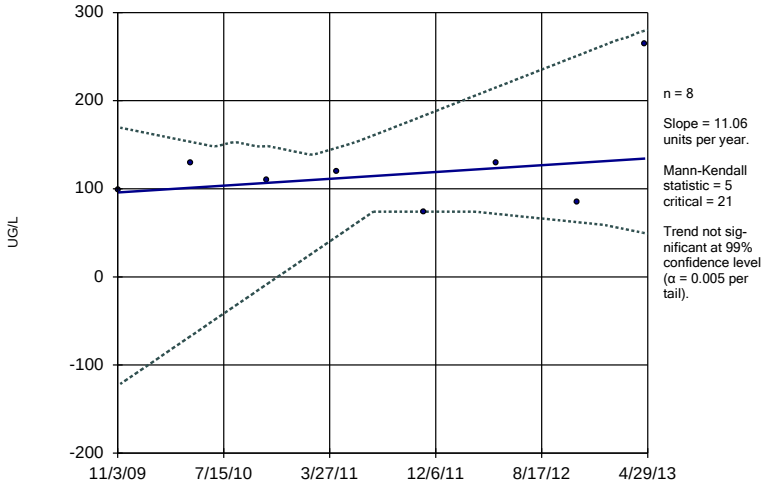
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

EX-02



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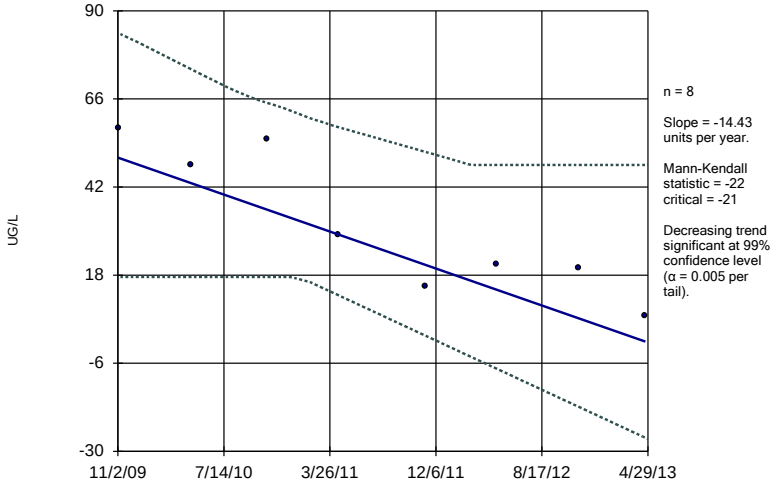
Sen's Slope and 99% Confidence Band

EX-04



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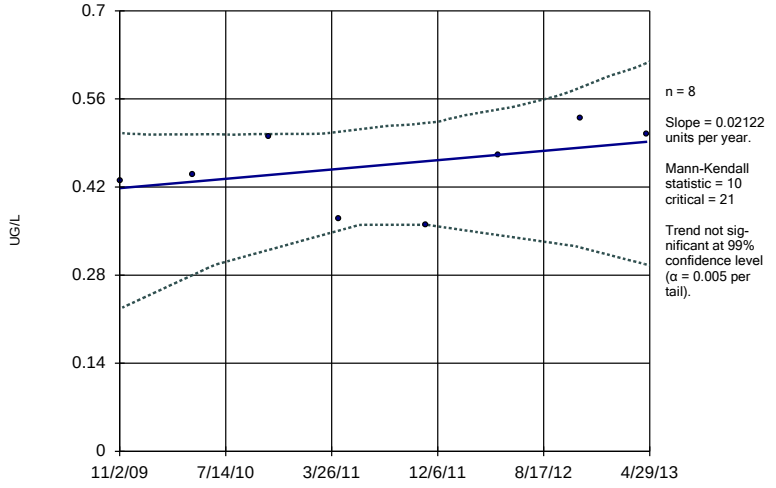
Sen's Slope and 99% Confidence Band

EX-05



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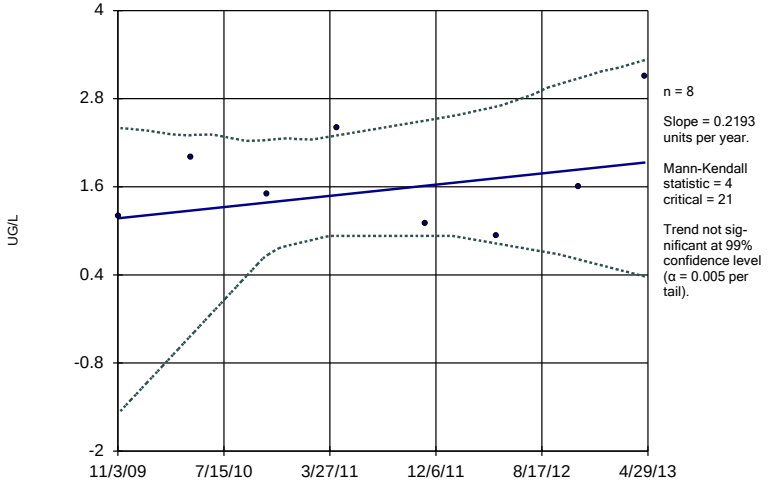
Sen's Slope and 99% Confidence Band

EX-07



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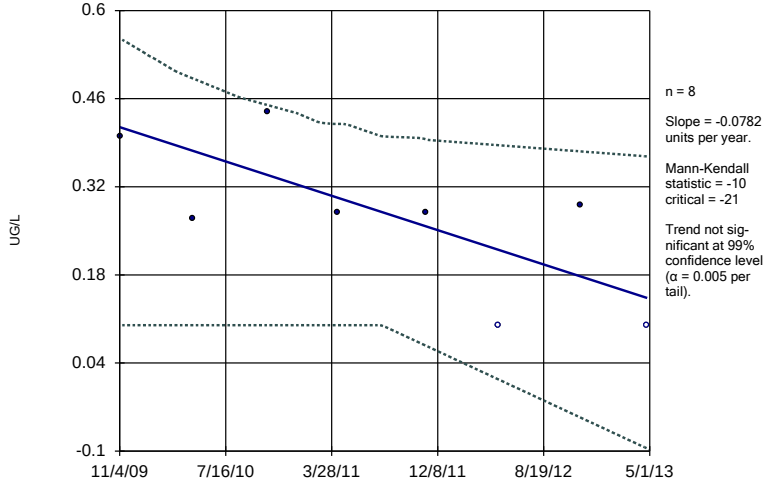
Sen's Slope and 99% Confidence Band

EX-08



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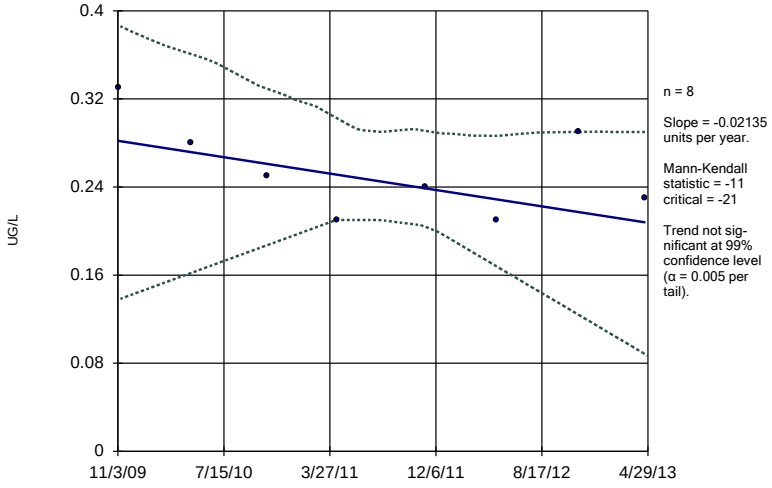
Sen's Slope and 99% Confidence Band

EX-09



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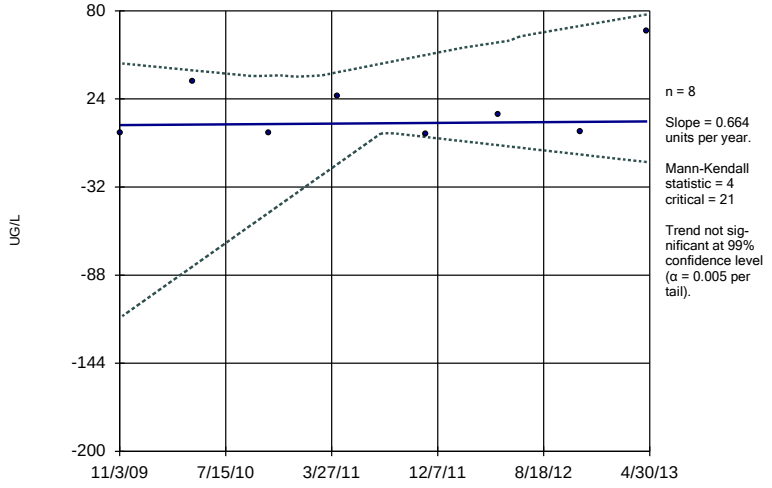
Sen's Slope and 99% Confidence Band

EX-11



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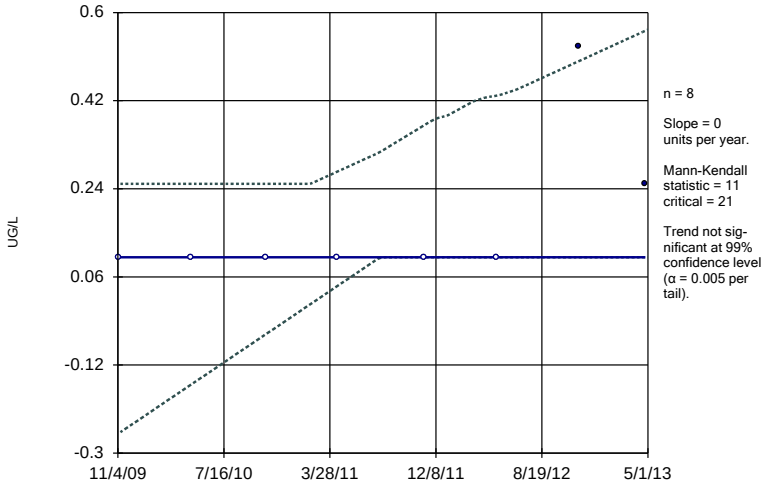
Sen's Slope and 99% Confidence Band

MW-06



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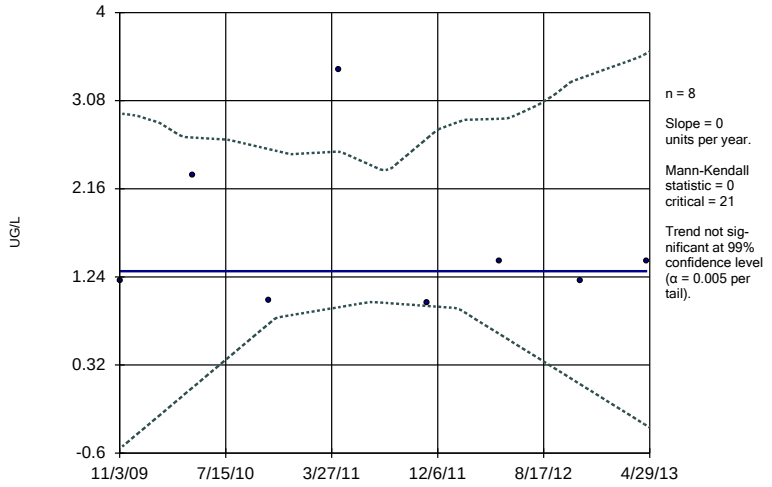
Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

Sen's Slope and 99% Confidence Band

MW-20



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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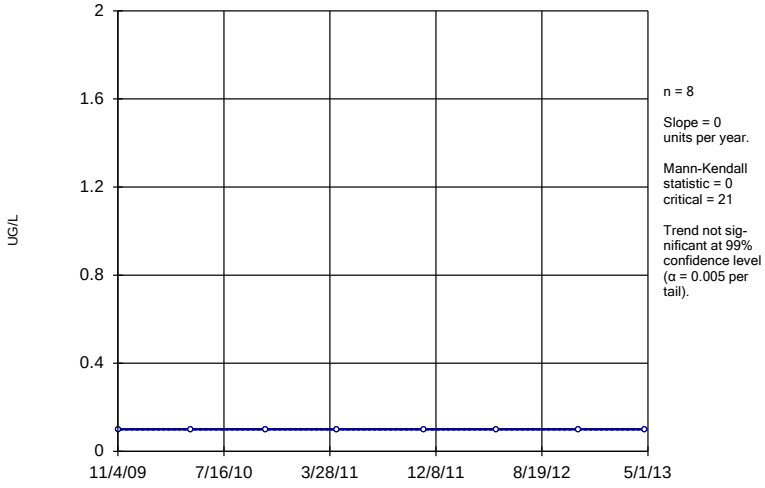
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

MW-23



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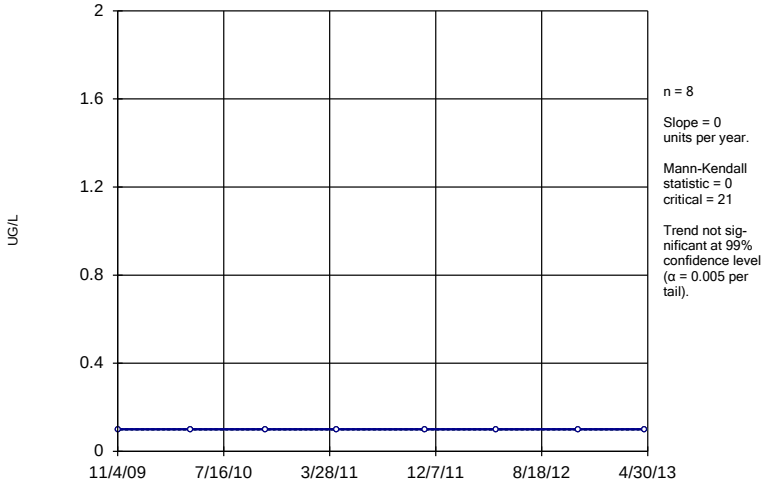
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

MW-24A



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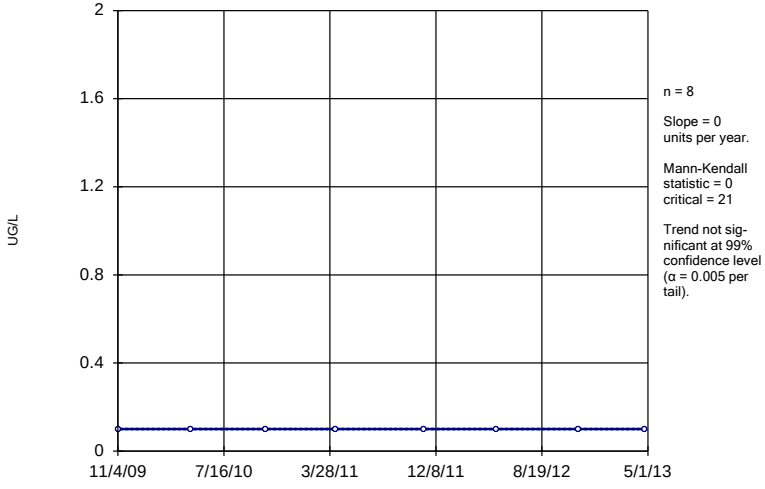
Sen's Slope and 99% Confidence Band

MW-25



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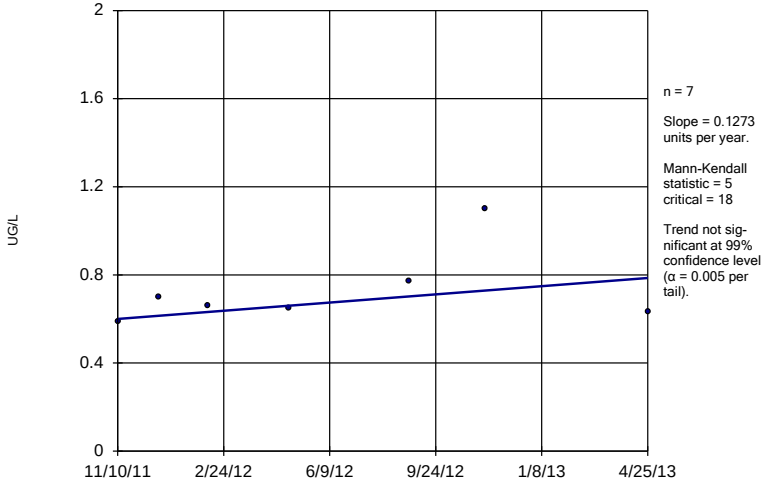
Sen's Slope Estimator

MW-30



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Sanitas™ v.9.3.25 Software licensed to MWH. UG
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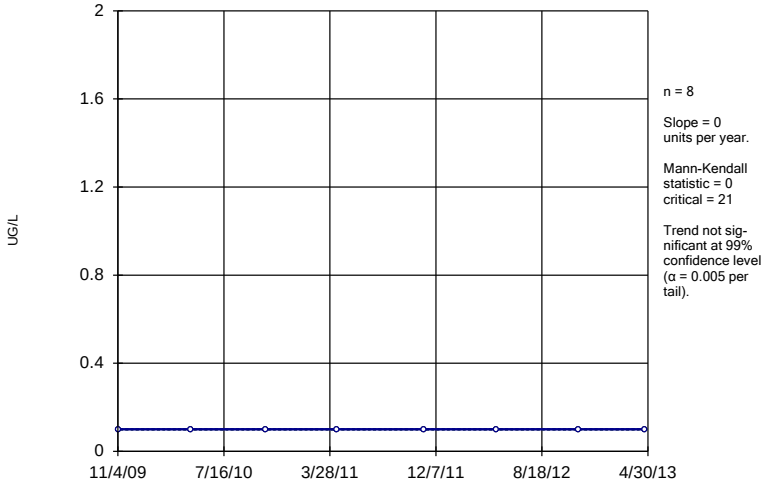
Sen's Slope and 99% Confidence Band

PZ-1



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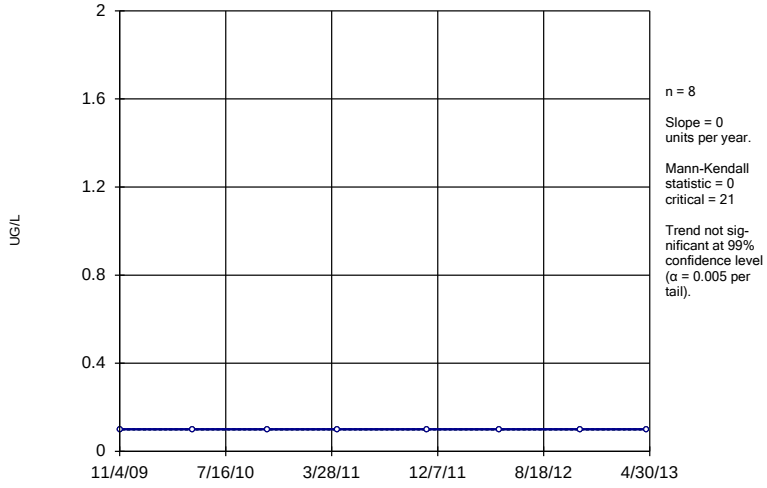
Sen's Slope and 99% Confidence Band

PZ-3



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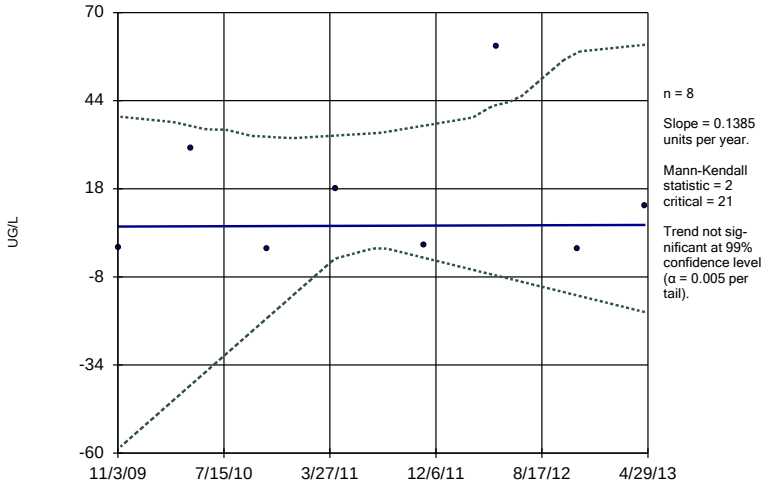
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

ES-01



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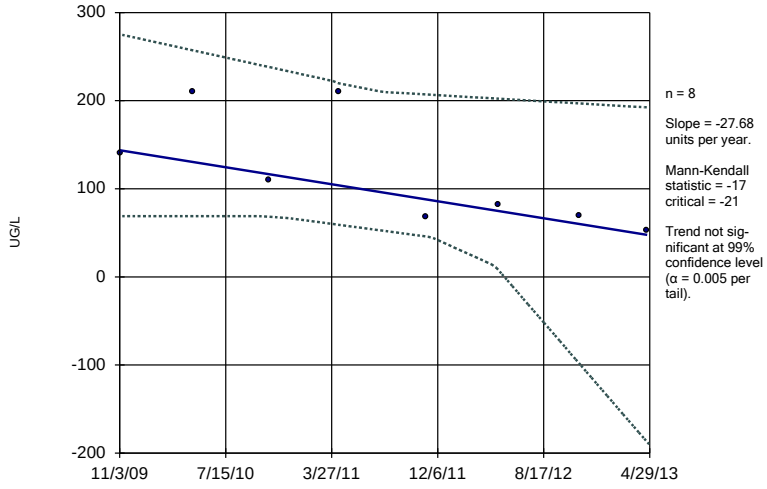
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

EX-02



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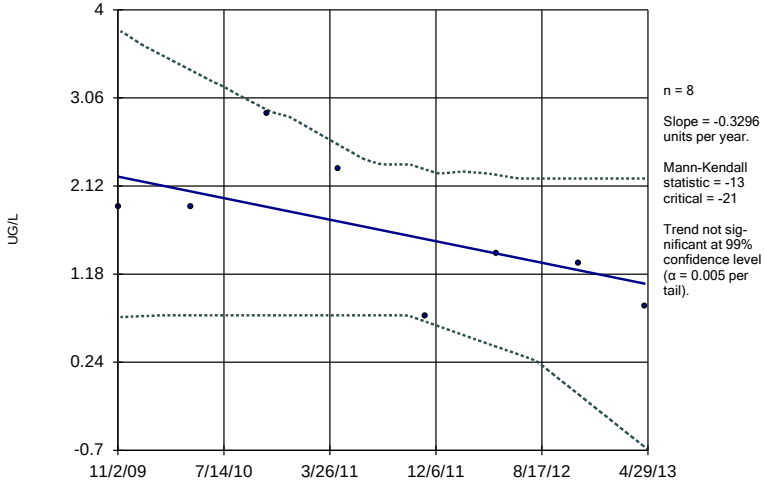
Sen's Slope and 99% Confidence Band

EX-04



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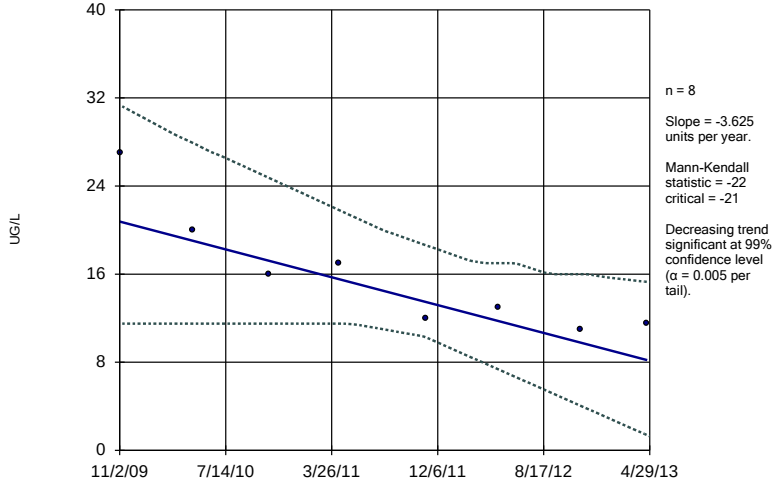
Sen's Slope and 99% Confidence Band

EX-05



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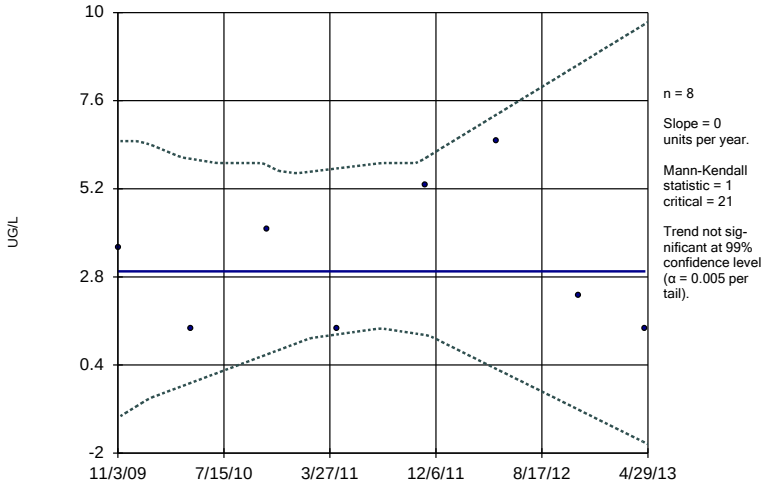
Sen's Slope and 99% Confidence Band

EX-07



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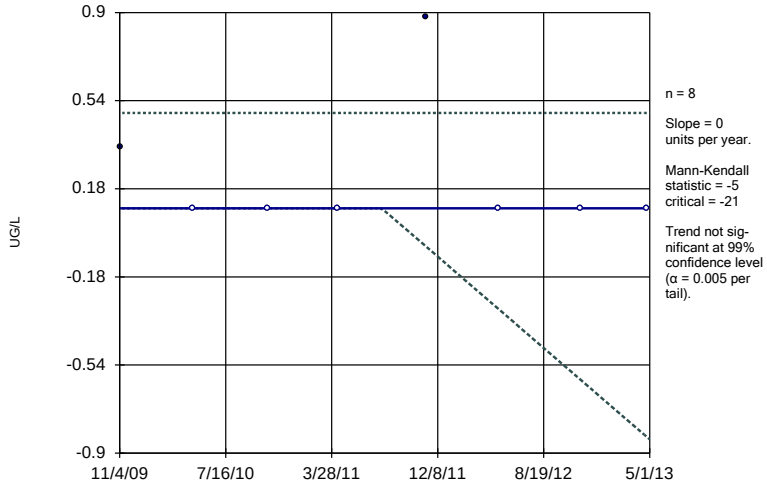
Sen's Slope and 99% Confidence Band

EX-08



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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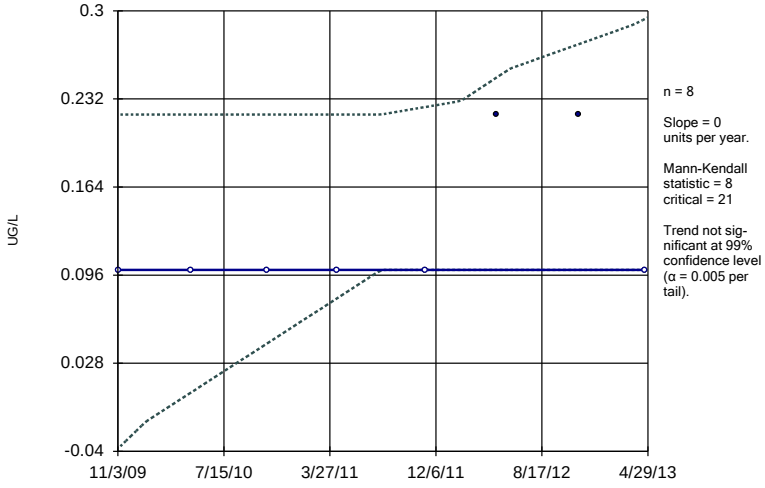
Hollow symbols indicate censored values.

Sen's Slope and 99% Confidence Band

EX-09



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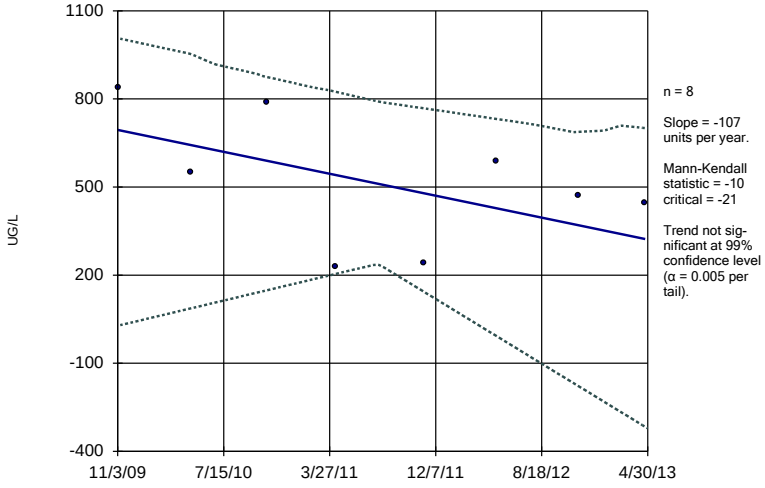
Sen's Slope and 99% Confidence Band

EX-11



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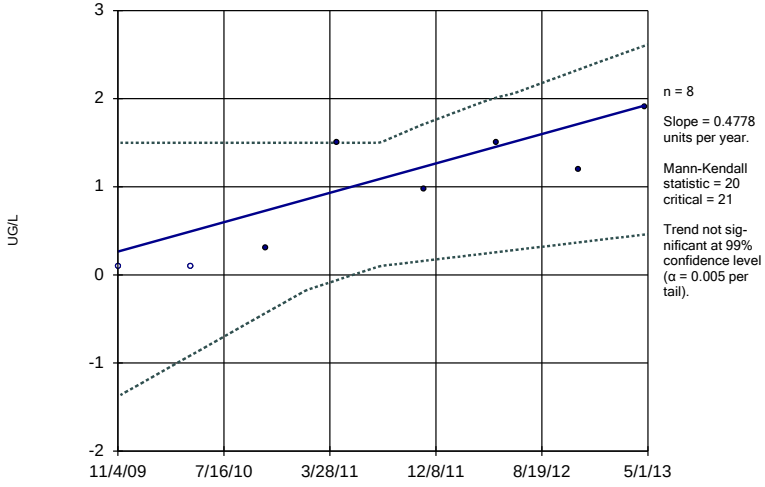
Sen's Slope and 99% Confidence Band

MW-06



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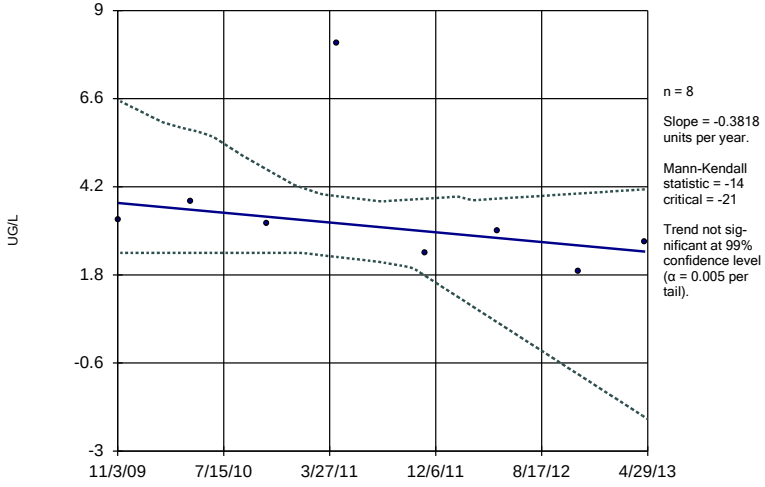
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope and 99% Confidence Band

MW-20



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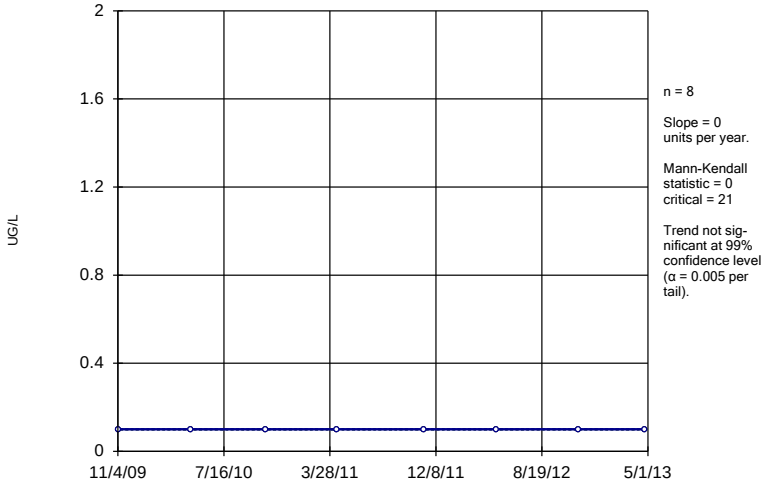
Sen's Slope and 99% Confidence Band

MW-23



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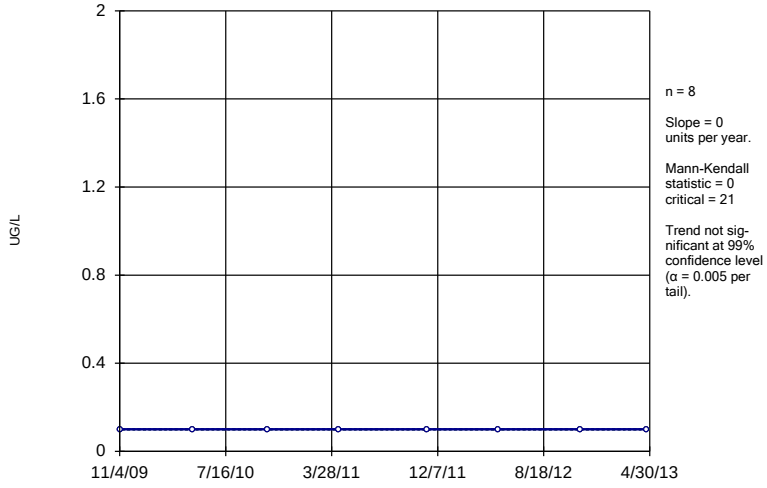
Sen's Slope and 99% Confidence Band

MW-24A



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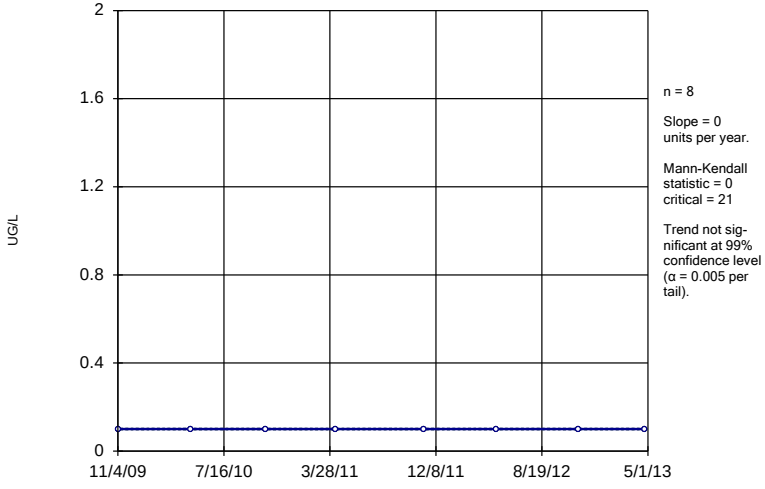
Sen's Slope and 99% Confidence Band

MW-25



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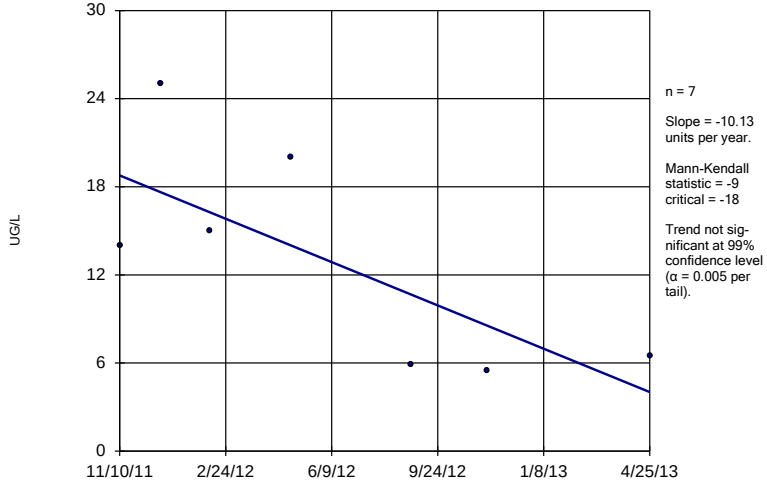
Sanitas™ v.9.3.25 Software licensed to MWH. UG

Sen's Slope Estimator

MW-30



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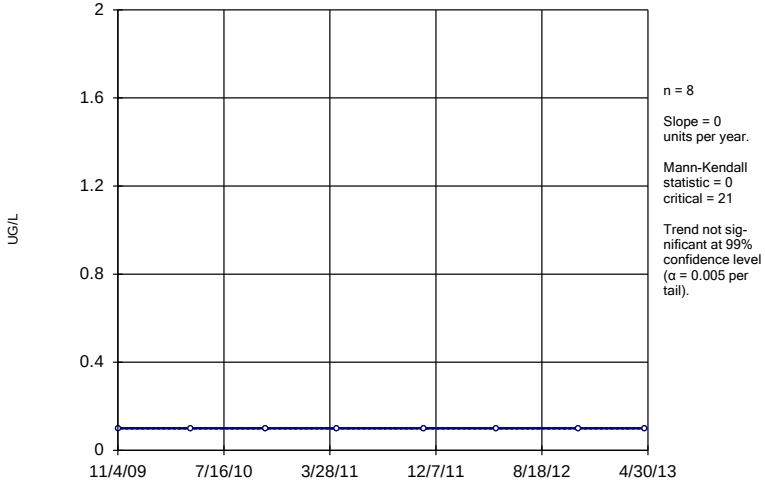
Sen's Slope and 99% Confidence Band

PZ-1



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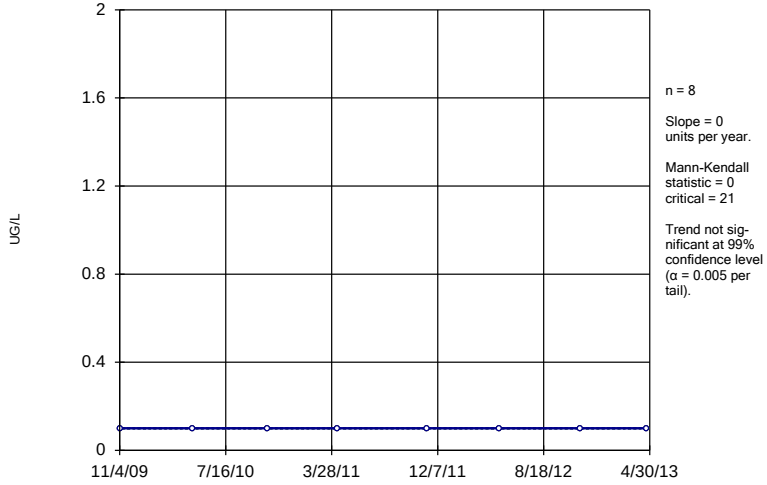
Sen's Slope and 99% Confidence Band

PZ-3



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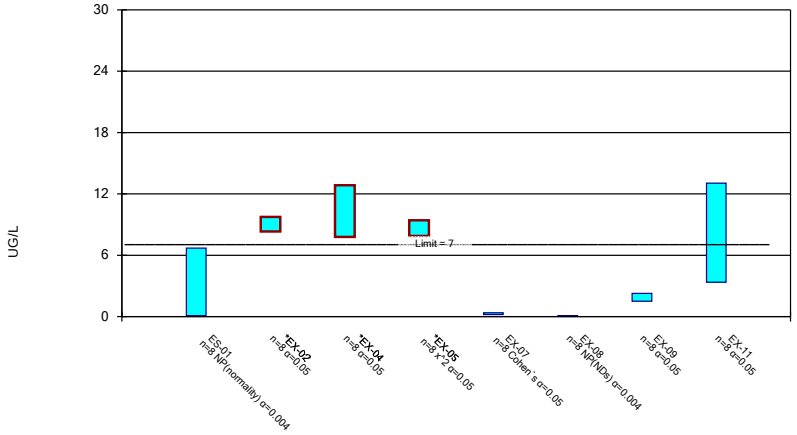
Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

CONFIDENCE INTERVAL PLOTS

Parametric and Non-Parametric (NP) Confidence Interval

Compliance limit is exceeded.* Normality Test: Shapiro Wilk, alpha based on n.



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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

Parametric Confidence Interval

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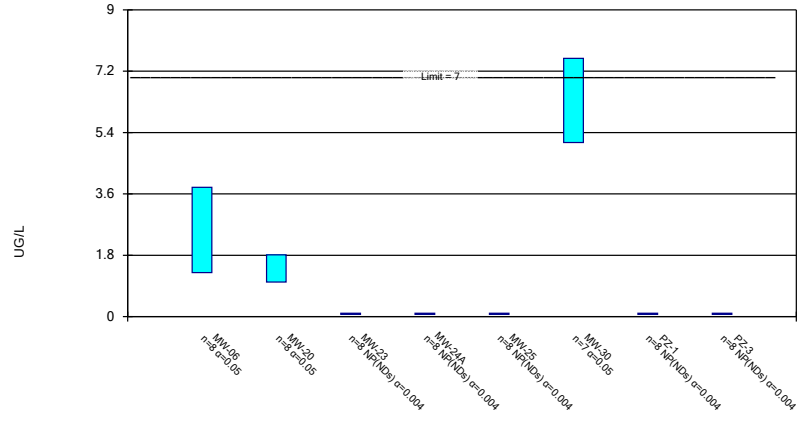

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Parametric and Non-Parametric (NP) Confidence Interval

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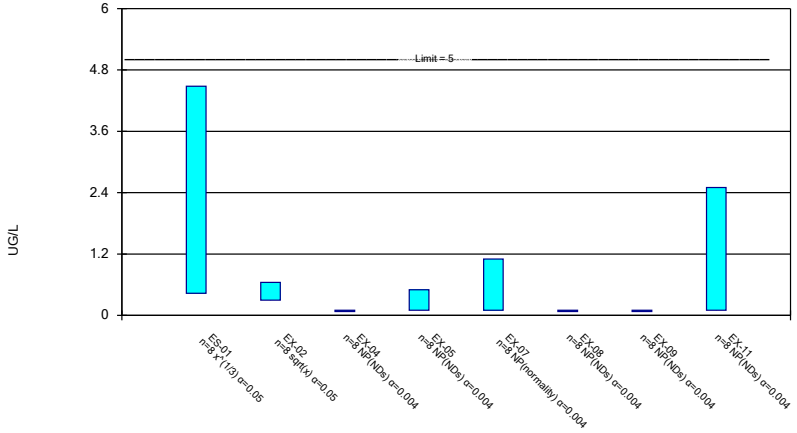

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Non-Parametric Confidence Interval

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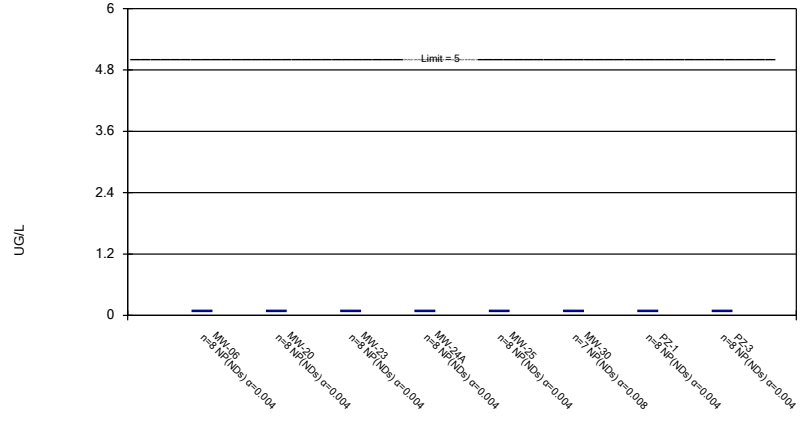

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Parametric and Non-Parametric (NP) Confidence Interval

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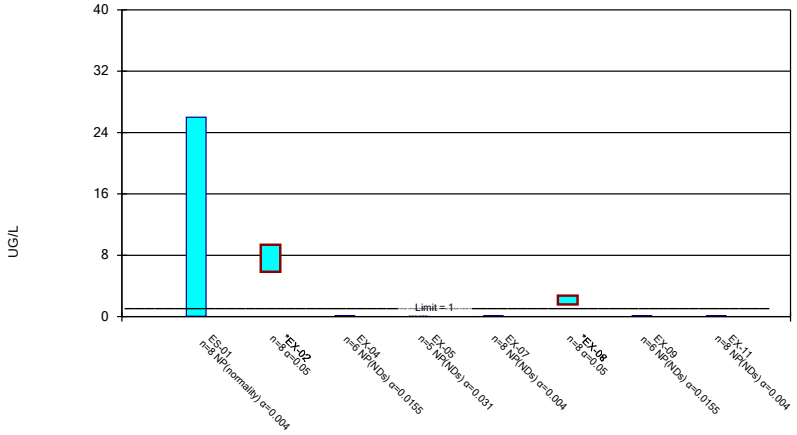

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Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

Non-Parametric Confidence Interval

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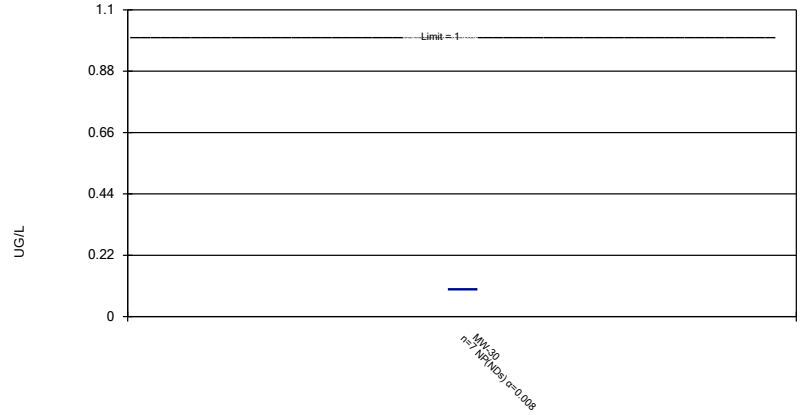

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Parametric Confidence Interval

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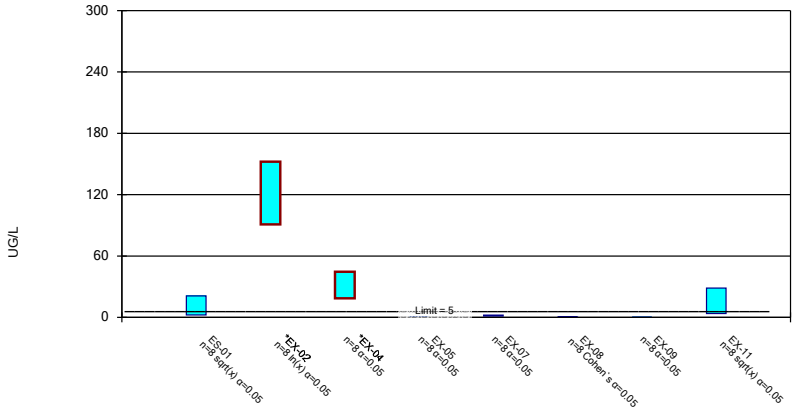

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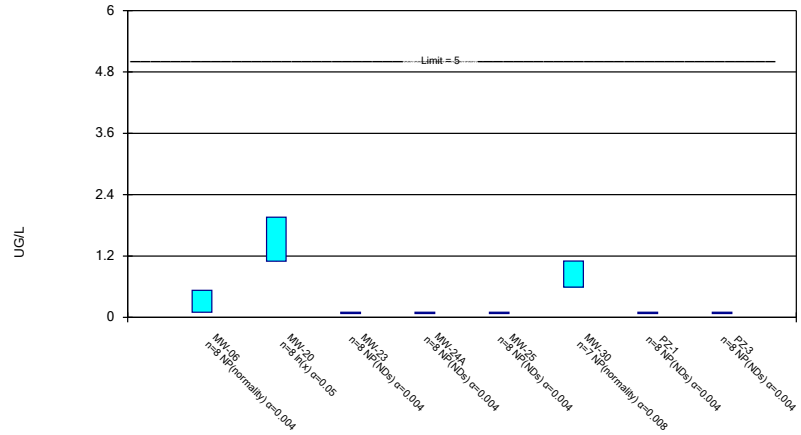
Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

Parametric and Non-Parametric (NP) Confidence Interval

Compliance Limit is not exceeded. Normality Test: Shapiro Wilk, alpha based on n.



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Parametric and Non-Parametric (NP) Confidence Interval

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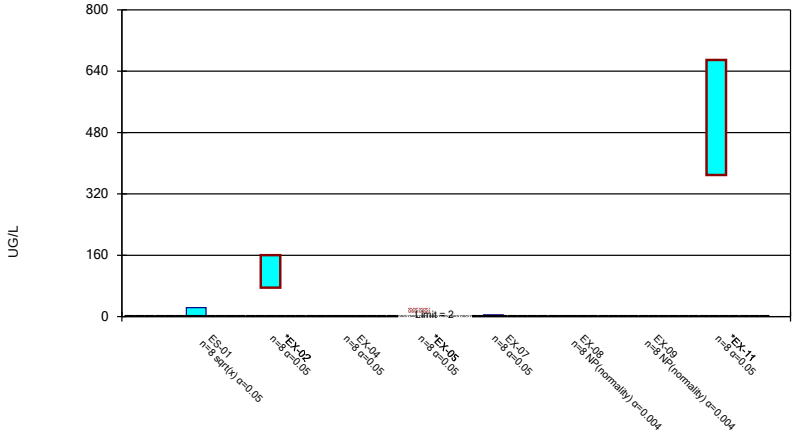

Constituent: VC Analysis Run 7/17/2013 3:48 PM

Facility: Wasatch Chem Client: Questar Data File: Wasatch Data for SANITAS_31May2013

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Parametric Confidence Interval

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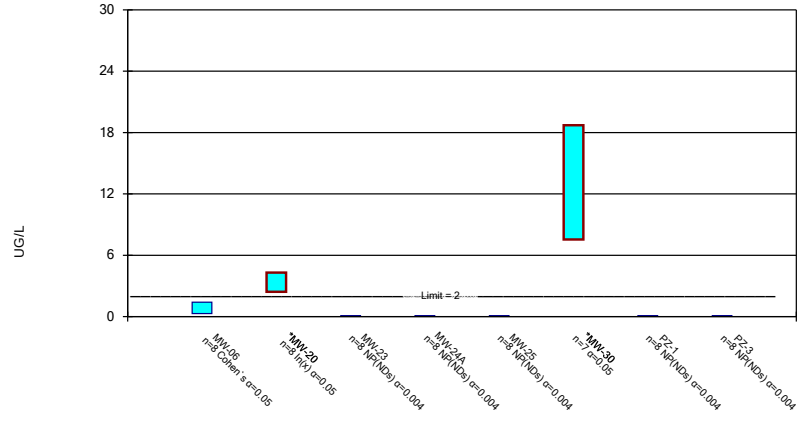

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