United States Environmental Protection Agency

EPA 542-R-14-009
Office of Solid Waste and Emergency Response
Office of Superfund Remediation and
Technology Innovation

Optimization Review
Lockwood Operable Unit 1 –
Beall Source Area

Billings, Montana

www.clu-in.org/optimization | www.epa.gov/superfund/cleanup/postconstruction/optimize.htm

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OPTIMIZATION REVIEW

LOCKWOOD OPERABLE UNIT 1 – BEALL SOURCE AREA

BILLINGS, MONTANA

Report of the Optimization Review

Site Visit Conducted at Lockwood Solvent Groundwater Plume Site

FINAL REPORT

September 19, 2014

EXECUTIVE SUMMARY

Optimization Background

The U.S. Environmental Protection Agency (EPA) defines optimization as the following:

> *"Efforts at any phase of the removal or remedial response to identify and implement specific actions that improve the effectiveness and cost-efficiency of that phase. Such actions may also improve the remedy's protectiveness and long-term implementation which may facilitate progress towards site completion. To identify these opportunities, regions may use a systematic site review by a team of independent technical experts, apply techniques or principles from Green Remediation or Triad, or apply other approaches to identify opportunities for greater efficiency and effectiveness. Contractors, states, tribes, the public, and PRPs* [potentially responsible parties] *are also encouraged to put forth opportunities for the Agency to consider."*(1)

An optimization review considers the goals of the remedy, available site data, the conceptual site model (CSM), remedy performance, protectiveness, cost-effectiveness and closure strategy. A strong interest in sustainability has also developed in the private sector and within Federal, State and Municipal governments. Consistent with this interest, optimization now routinely considers green remediation and environmental footprint reduction during optimization reviews.

An optimization review includes reviewing site documents, interviewing site stakeholders, potentially visiting the site for one day and compiling a report that includes recommendations in the following categories:

- Protectiveness
- Cost-effectiveness
- Technical improvement
- Site closure
- Environmental footprint reduction.

The recommendations are intended to help the site team identify opportunities for improvements in these areas. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent review and represent the opinions of the optimization review team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the State of Montana, the Region and other site stakeholders. Also note that while the recommendations may provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and quality assurance project plans (QAPP).

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1 U.S. Environmental Protection Agency (EPA). 2012. Memorandum: Transmittal of the National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion. From: James. E. Woolford, Director Office of Superfund Remediation and Technology Innovation. To: Superfund National Policy Managers (Regions 1 – 10). Office of Solid Waste and Emergency Response (OSWER) 9200.3-75. September 28.

Site-Specific Background

The Lockwood Solvent Groundwater Plume Site (LSGPS) consists of two operable units (OUs) and is located on the outskirts of Billings, Montana in EPA Region 8. OU1 consists of contaminated soils and a chlorinated solvent groundwater plume associated with the Beall Source Area (Area B), and OU2 consists of affected media associated with the Brenntag (Soco; Area A) Source Area. This optimization review addressed remedial components planned for affected soil and groundwater in OU1. The optimization review of remedial design (RD) considerations for OU2 is addressed under a separate optimization review report.

Beall Trailers of Montana, Inc. (Beall) manufactured and reconditioned tank trailers for the petroleum and asphalt industries from 1978 to 1990. Beall used steam and a solution of dissolved trichloroethene (TCE) to clean the tank trailers in an industrial steam-cleaning bay, with wastewater subsequently discharged to a septic system and drain field adjacent to the steam-cleaning bay. Various discharges of TCE-contaminated water from the steam-cleaning bay have been identified as the source of contamination to soil and groundwater in OU1.

In 1986, Lockwood Water and Sewer District (LWSD) personnel identified benzene and chlorinated solvents in Lockwood area water supply wells, leading to a number of investigations by the Montana Department of Environmental Quality (DEQ). In June 1998, DEQ performed an integrated site assessment in cooperation with the EPA, which identified Beall as a potential source of TCE and TCE degradation byproducts in the groundwater. The LSGPS was added to the National Priorities List (NPL) in 2000 (CERCLIS ID# MT0007623052).

In 2002, the DEQ conducted a Remedial Investigation (RI) that included surface and subsurface soil sampling, monitoring well construction and groundwater sampling, aquifer testing, surface water sampling, sediment sampling and indoor air sampling. Based on the RI results, the EPA and DEQ evaluated remedial alternatives as part of a Feasibility Study (FS) completed in July 2004. The LSGPS Record of Decision (ROD) was issued in 2005. The RD process is underway at OU1 with the goal of addressing contamination associated with the Beall Source Area.

The LSGPS was nominated for an optimization review by the EPA Office of Superfund Remediation and Technology Innovation (OSRTI) at the request of the Region 8 Remedial Project Manager (RPM) in September 2012. The review of design considerations for the selected remedy options for the LSGPS OU1 is intended to optimize the remedial response to address contamination in soil and groundwater, to achieve maximum protectiveness while improving remedy cost and energy efficiency and to minimize time required to attain cleanup levels.

Summary of Conceptual Site Model and Key Findings

Site surface soil and shallow subsurface soils are composed of interbedded sands and gravels, silty sands and silts in the area of OU1. Site investigation data from the RI indicate that the areas of highest contamination are in the immediate vicinity of the steam-cleaning bay, facility piping and an oil-water separator. TCE released from the steam-cleaning bay and associated components migrated under the influence of gravity through the unsaturated sandy silts to the saturated zone at approximately 42 to 45 feet (ft) below ground surface. It appears that contamination was able to migrate horizontally approximately 50 to 100 ft in the unsaturated zone. The extent of contamination in the saturated zone is not fully understood.

Data collected during the RI indicate groundwater contamination at OU1 occurs in two lobes. The western plume lobe (West Lobe) with high concentrations of dissolved TCE, is most likely the result of historical groundwater flow to the west caused by the hydraulic influences of a former LWSD water supply well (closed in 1986). The north-northwestern plume lobe (North Lobe) is consistent with the natural, regional groundwater flow direction. TCE is present in concentrations above the Maximum Contaminant Level (MCL) of 5 micrograms per liter (ug/L) in both plume lobes. TCE is also present in groundwater at concentrations below the MCL at locations between the two lobes, such as at monitoring well MW-213. While *cis*-1,2-dichloroethene is detected in the plumes, both the site team and optimization review team believe attenuation by biological degradation is not a strong process at the site.

Key findings of the optimization review team include:

- Site soils are more heterogeneous than indicated in cross-sections from the RI.
- The primary sources of uncertainty for the RD include the lack of understanding of the vertical distribution of contamination, the effect of geologic heterogeneity on selected remedy options, and the variability in groundwater flow direction.
- Increased understanding of source(s), plume morphology and plume behavior may significantly improve the effectiveness of remedy design and implementation.
- The presence of the unsaturated soil contamination in relatively tight silt with a low intrinsic permeability may create challenges for soil vapor extraction (SVE), one of the selected remedy options. Excavation or excavation combined with SVE may provide a cost-effective and more robust means of remediating the unsaturated soil.
- Area-wide, the groundwater flow direction appears to be toward the north/northwest with fairly flat gradients. There appears to be a component of westward groundwater flow maintaining the West Lobe of the plume. Currently, the plumes appear stable, but additional characterization of groundwater flow direction and gradients may provide more details on the long-term distribution of contaminants, particularly in the area between the plume lobes.
- Uncertainty about the distribution of contaminant mass in deeper silty or other low-permeability layers may reduce the efficacy of both the RD and performance monitoring of remedies for the source area. Matrix- or back-diffusion from silty layers may provide a long-term secondary source of contamination to groundwater. Continued low-level discharge of mass from downgradient secondary sources may introduce uncertainty into performance evaluation of the source remedies.
- The vertical distribution of contamination below the water table, which is currently unknown, will affect the design and performance of the *in situ* bioremediation (ISB) groundwater remedy, one of the selected remedy options.
- Groundwater flows through the sand and gravel aquifer relatively quickly. The results of effective source area remediation should become apparent at downgradient groundwater monitoring locations within a few years of implementation (for example, by decreasing statistical concentration trends). Depending on the concentration response in the downgradient plume, effective source remediation may preclude installation of an additional downgradient plume remedy. Lack of response in the downgradient plumes may indicate that an additional plume remedy is required.

Summary of Recommendations

The following is a summary of recommendations provided for the site:

Improving effectiveness –

Recommendations for improving remedy effectiveness include refinement of the CSM through additional characterization to support improved design and performance monitoring of the remedies. Recommended characterization activities include vertical characterization of soil and groundwater through deployment of multiple passive diffusion bags (PDB) in select monitoring wells, potentially supported by in-well borehole flow monitoring to confirm flow characteristics across the screen lengths; Membrane Interface Probe (MIP) survey; and deployment of Bio-Trap® samplers to assess the microbial community. Geologic, hydrogeologic and environmental chemistry data collected from characterization activities should be used to create detailed cross sections and, if possible, to support 3-dimensional visualization and analysis (3DVA) of the site.

SVE is recommended as a primary remedy option for contaminated soils in the source area (primarily for cost reasons). However, limited soil excavation of high concentration areas with subsequent SVE may be considered as a component of the SVE remedy to improve overall effectiveness. Along with limited excavation, ISB amendments are recommended for application to the base of the excavation to facilitate contact between the deeper contaminated media and the ISB treatments.

ISB remedy is recommended as a primary remedy option for the saturated source zone. Along with SVE, and limited excavation, ISB in the source area should reduce mass discharge of contamination downgradient.

Reducing cost –

The optimization review team compared costs associated with excavation and SVE as soil remedies. Overall, SVE appears to be a more cost effective approach than extensive excavation and disposal. A performance monitoring plan was developed by the optimization review team and is presented in this report for use in evaluating SVE effectiveness to prevent operating the SVE beyond the point where it is cost effective.

Source area performance monitoring should include groundwater monitoring in the downgradient plume. Results of plume monitoring will indicate if additional plume remedies are required. Delaying the design of any downgradient remedy until the effects of the source remedy are known will improve the design and may limit the scale of the plume remedy, resulting in cost savings.

Technical improvement –

Technical improvements to the remedy include the recommendations for additional site characterization (summarized above) and recommendations for a combination of SVE, ISB and excavation for the source area.

Site closure –

The addition of limited soil excavation in the source area should reduce the time to site closure by addressing soil that could be a continued source of mass to the dissolved plume. Additional site characterization should improve the efficacy of the remedy by targeting the final remedy design to the areas of highest contaminant mass, also reducing the time to attainment of cleanup levels.

Green remediation –

No recommendations are provided for green remediation at this time. Green remediation best management practices and footprint analysis can be revisited after characterization activities have been completed and the site team is developing a more targeted RD. In general, however, the additional characterization suggested should help target the remedy to the dimensions of source soils to be remediated and, therefore, reduce the footprint of the final remedy.

NOTICE AND DISCLAIMER

Work described herein was performed by Tetra Tech, Inc. (Tetra Tech) for the U.S. Environmental Protection Agency (EPA). GSI Environmental performed work under a subcontract to Tetra Tech. Work conducted by Tetra Tech, including preparation of this report, was performed under Work Assignment 2-58 of EPA contract EP-W-07-078 with Tetra Tech. The report was approved for release as an EPA document, following the Agency's administrative and expert review process.

This optimization review is an independent study funded by the EPA that focuses on protectiveness, cost-effectiveness, site closure, technical improvements and green remediation. Detailed consideration of EPA policy was not part of the scope of work for this review. This report does not impose legally binding requirements, confer legal rights, impose legal obligations, implement any statutory or regulatory provisions or change or substitute for any statutory or regulatory provisions. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Recommendations are based on an independent evaluation of existing site information, represent the technical views of the optimization review team and are intended to help the site team identify opportunities for improvements in the current site remediation strategy. These recommendations do not constitute requirements for future action; rather, they are provided for consideration by the State of Montana, EPA Region and other site stakeholders.

While certain recommendations may provide specific details to consider during implementation, these recommendations are not meant to supersede other, more comprehensive, planning documents such as work plans, sampling plans and quality assurance project plans (QAPP); nor are they intended to override applicable or relevant and appropriate requirements (ARARs). Further analysis of recommendations, including review of EPA policy may be needed prior to implementation.

PREFACE

This report was prepared as part of a national strategy to expand Superfund optimization from remedial investigation to site completion implemented by the United States Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI)[(2)]. The project contacts are as follows:

Organization	Key Contact	Contact Information
U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI)	Kirby Biggs	EPA OSRTI Technology Innovation and Field Services Division 2777 Crystal Drive Arlington, VA 22202 biggs.kirby@epa.gov phone: 703-823-3081
Tetra Tech (Contractor to EPA)	Jody Edwards, P.G.	Tetra Tech 45610 Woodland Road, Suite 400 Sterling, VA 20166 jody.edwards@tetratech.com phone: 802-288-9485
	Peter Rich, P.E.	Tetra Tech 51 Franklin Street Suite 400 Annapolis, MD 21401 peter.rich@tetratech.com phone: 410 990-4607
GSI Environmental, Inc. (Subcontractor to Tetra Tech)	Mindy Vanderford, Ph.D.	GSI Environmental, Inc. 2211 Norfolk Street, Suite 1000 Houston, TX 77098 mvanderford@gsi-net.com phone: 713-522-6300 x 186

2 U.S. Environmental Protection Agency (EPA). 2012. Memorandum: Transmittal of the National Strategy to Expand Superfund Optimization Practices from Site Assessment to Site Completion. From: James. E. Woolford, Director Office of Superfund Remediation and Technology Innovation. To: Superfund National Policy Managers (Regions 1 – 10). Office of Solid Waste and Emergency Response (OSWER) 9200.3-75. September 28.

LIST OF ACRONYMS AND ABBREVIATIONS

3DVA	3-Dimensional Visualization and Analysis
µg/kg	Micrograms per Kilogram
µg/L	Micrograms per Liter
ARAR	Applicable or Relevant and Appropriate Requirements
Beall	Beall Trailers of Montana, Inc.
Bgs	Below Ground Surface
cm^2	Square Centimeters
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cis-1,2-DCE	Cis-1,2-Dichloroethene
CSM	Conceptual Site Model
cVOC	Chlorinated Volatile Organic Compound
DEQ	Department of Environmental Quality
EPA	United States Environmental Protection Agency
FS	Feasibility Study
Ft	Feet
FYR	Five-Year Review
GAC	Granular Activated Carbon
GIS	Geographic Information Systems
IC	Institutional Controls
ISB	In Situ Bioremediation
K	Hydraulic Conductivity
K_R	Relative Hydraulic Conductivity
LSGPS	Lockwood Solvent Groundwater Plume Site
LTM	Long-Term Monitoring
LTRA	Long-Term Remedial Action
LWSD	Lockwood Waste and Sewer District
MAROS	Monitoring and Remediation Optimization System
MCL	Maximum Contaminant Level
mg/kg	Milligrams per Kilogram
MIP	Membrane Interface Probe
MW	Monitoring Well
N/A	Not Applicable
NI	Not Identified
NPL	National Priorities List
OSRTI	Office of Superfund Remediation and Technology Innovation
OSWER	Office of Solid Waste and Emergency Response
OU	Operable Unit
PCE	Tetrachloroethene
PDB	Passive Diffusion Bag
PRP	Potentially Responsible Party
PWT	Pacific Western Technologies, Ltd.

QAPP	Quality Assurance Project Plan
RAC	Remedial Action Contractor
RAO	Remedial Action Objective
RD	Remedial Design
RI	Remedial Investigation
ROD	Record of Decision
RPM	Remedial Project Manager
SVE	Soil Vapor Extraction
TCE	Trichloroethene
Trans-1,2-DCE	Trans-1,2-Dichloroethene
VI	Vapor Intrusion
VOC	Volatile Organic Compound

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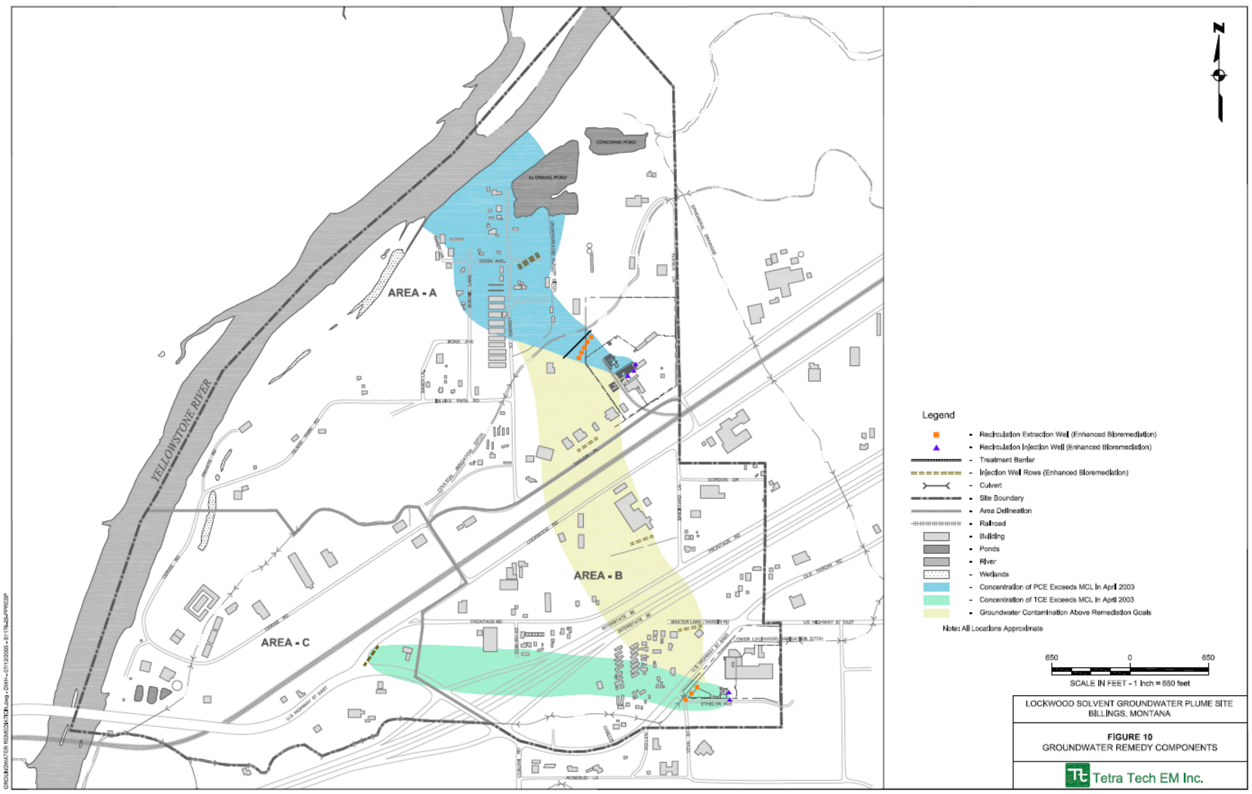
1.0 OBJECTIVES OF OPTIMIZATION REVIEW

1.1 Objectives of the Remedial Design Optimization

The Lockwood Solvent Groundwater Plume Site (LSGPS) occupies approximately 580 acres located on the outskirts of Billings, Montana in EPA Region 8. The site is managed as two operable units (OUs). OU1 consists of contaminated soils and the chlorinated solvent groundwater plume associated with the Beall Source Area (Area B), and OU2 consists of affected media associated with the Brenntag (Soco; Area A) Source Area (see Figure 1). Additional land is included in the greater LSGPS (Area C, see Figure 1), but this area contains no known primary sources of contamination and low-to non-detect levels of contaminants.

Figure 1: Site Map of Lockwood Solvent Groundwater Plume Site (EPA 2005)



This optimization review addressed remedial components planned for affected soil and groundwater in OU1. Remedial design (RD) for OU2 is addressed under a separate optimization review report.

The LSGPS was nominated for an optimization review by the United States Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI) at the request of the Region 8 Remedial Project Manager (RPM) in September 2012. The review of design considerations for the selected remedy options for the LSGPS OU1 is intended to optimize the remedial response to address contamination in soil and groundwater to achieve maximum protectiveness while improving remedy cost and energy efficiency and minimizing time required to attain cleanup levels.

An optimization review team (described below) was assembled and met with regulatory stakeholders and consultants in Billings, Montana and at the site in February 2013 to review site data, remedial action objectives (RAO) and cleanup levels, logistics and time frames to implement the remedy. This report presents findings, conclusions and recommendations for optimization. Objectives of the RD optimization review include:

- Review of conceptual site model (CSM)
- Review of RAOs
- Review of selected remedy options and associated remedial components and costs
- Evaluation of other potential alternative remedial components
- Provision of recommendations for the remedial strategy including:
    - Addressing and prioritizing data gaps in the CSM
    - Recommending improvements to selected remedy option components
    - Recommending consideration of other alternative remedial components
    - Prioritizing and sequencing of remedial components
    - Identifying decision points for contingent responses
    - Performance monitoring for recommended remedies
    - Remediation and data collection to support an exit strategy.

The recommendations are intended to help the site team identify opportunities for improvements in these areas. In many cases, further analysis of a recommendation, beyond that provided in this report, may be needed prior to implementation of the recommendation. Note that the recommendations are based on an independent evaluation and represent the opinions of the optimization review team. These recommendations do not constitute requirements for future action, but rather are provided for consideration by the State of Montana, the Region and other site stakeholders. Also note that while the recommendations may provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and quality assurance project plans (QAPP).

The national optimization strategy includes a system for tracking consideration and implementation of the optimization review recommendations and includes a provision for follow-up technical assistance from the optimization review team as mutually agreed upon by the site management team and EPA OSRTI.

1.2 Team Composition

The LSGPS optimization review team consisted of the following individuals:

Table 1: Optimization Review Team

Name	Affiliation	Phone	Email
Doug Sutton	Tetra Tech	732-409-0344	doug.sutton@tetratech.com
Mindy Vanderford	GSI Environmental, Inc.	713-522-6300	mvanderford@gsi-net.com

In addition to the optimization review team, the individuals listed below also attended the site visit or contributed to the site data review process:

Table 2: Site Visit and Review Participants

Name	Affiliation	Role	Email Address
Kirby Biggs	EPA OSRTI	Optimization Review Lead	biggs.kirby@epamail.epa.gov
Tillman McAdams	EPA Region 8	RPM for OU1	mcadams.tillman@epa.gov
Andrew Schmidt	Hydrogeologist, EPA Region 8	Technical Support	
John Podolinsky	Montana Department of Environmental Quality	State Lead for OU2	
Catherine LeCours	Pacific Western Technologies, Ltd.	RAC Contractor for OU1	
Roger Hoogerheide	EPA Region 8	RPM for OU2	
Jim Sullivan	Cardno Advanced Technologies, Inc.	PRP Contractor for OU2	

Notes: EPA OSRTI = U.S. Environmental Agency Office of Superfund Remediation Technology Innovation; RPM = Remedial Project Manager; OU = Operable Unit; RAC = Remedial Action Contractor; PRP = potentially responsible party.

Email contact information is provided for the site managers only. Communication with other participants can be coordinated through the site managers.

The site visit, which included the individuals above, was conducted on February 28, 2013.

1.3 Documents and Data Reviewed

The following documents were reviewed in support of the optimization review.

- *Final Billings Lockwood Pumping Test and Groundwater Monitoring Report* (MSE-HKM, Inc. – November 1998)
- *Final Report VOC Groundwater Plume Delineation & Potential Source Area Assessment, Lomond Lane Area* (Lockheed Martin – November 1999)
- *Final Report VOC Groundwater Plume Delineation & Potential Source Area Assessment With Soil Gas Synopsis* (Lockheed Martin – November 1999)
- *Comprehensive Indoor Air Sampling and Analytical Results Report* (Tetra Tech – October 2002)
- *Final Remedial Investigation Report Addendum 01* (Tetra Tech – December 2003)
- *Remedial Investigation Report* (Tetra Tech – June 2003)
- *Final Feasibility Study* (Tetra Tech – July 2004)
- *Record of Decision* (EPA – August 2005)
- *Remedial Design Supplementary Sampling Program & Quality Assurance Project Plan, Revision 2* (Pacific Western Technologies, Ltd. (PWT) – March 2012)
- PWT Notes and Calculations on Groundwater Plume Dewatering Plan (PWT – June 2012)

- EPA, 2012. Dewatering Monitoring Plan Lockwood Water and Sewer District Sewer Installation. Helena, MT, Region 8
- *Remedial Design, Beall Source Area Operable Unit 1, Aquifer Testing Program, Revision 2* (PWT – July 2012)
- *Data Trend Evaluation Technical Memorandum Remedial Design Supplemental Sampling Program*, (PWT – October 23, 2012)
- Site soil and groundwater monitoring data, lithologic data and Geographic Information System (GIS) files were received from the site contractor, PWT, in January 2013.

1.4 Quality Assurance

This optimization review used existing environmental data to interpret the CSM, evaluate potential remedy performance and make recommendations to improve the remedy. The quality of the existing data was evaluated by the optimization review team prior to using the data for these purposes. The evaluation for data quality included a brief review of how the data were collected and managed where applicable, the site QAPP was considered), the consistency of the data with other site data and the use of the data in the optimization review. Data of suspect quality were either not used as part of the optimization review or were used with the quality concerns noted. Where appropriate, this report provides recommendations to improve data quality.

2.0 CONCEPTUAL SITE MODEL

2.1 Site Background

Beall Trailers of Montana, Inc. (Beall) manufactured and reconditioned tank trailers for the petroleum and asphalt industries from 1978 to 1990. Beall used steam and a solution of dissolved trichloroethene (TCE) to clean the tank trailers in an industrial steam-cleaning bay, with wastewater subsequently discharged to a septic system and drain field adjacent to the steam-cleaning bay. Beall is no longer the property owner and the facility is inactive. However, the site is in the process of being reactivated under different ownership. The new owners have expressed the desire to continue use of the steam-cleaning bay, without TCE. Site remediation is currently being addressed under the Superfund program as a Fund-lead project.

In 1986, Lockwood Water and Sewer District (LWSD) personnel identified benzene and chlorinated solvents in Lockwood area water supply wells, leading to a number of investigations by the Montana Department of Environmental Quality (DEQ). In June 1998, DEQ performed an integrated site assessment in cooperation with the EPA. The assessment identified Beall as a potential source of TCE and TCE degradation byproducts in the groundwater. The investigation also identified the Brenntag West property (formerly the Dyce Chemical property and now the Soco West property, OU2) as a potential source of tetrachloroethene (PCE), TCE, cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride. In December 2000, the EPA placed LSGPS on the National Priorities List (NPL).

Land use within and around the LSGPS is categorized as light industrial, commercial and residential. The commercial and light industrial facilities include trucking, vehicle repair, truck tank manufacturing, chemical repackaging, petroleum pipelines, machine shops and auto salvage. The former Comet Oil Site, proposed for the NPL in 1988, is located on the east/northeast border of the LSGPS. The greater LSGPS area includes the OU1 and OU2 plume areas as well as 81 commercial and light industrial businesses, an estimated 75 residential single-family residences, two trailer parks and one apartment complex. LSGPS is bordered by the Yellowstone River on the west and northwest; thus some wetlands and ponds are also included in the greater LSGPS area.

In 2002, the DEQ conducted a Remedial Investigation (RI) that included surface and subsurface soil sampling, monitoring well construction and groundwater sampling, aquifer testing, surface water sampling, sediment sampling and indoor air sampling. Based on the RI results, the EPA and DEQ evaluated remedial alternatives as part of a Feasibility Study (FS) completed in July 2004. The November 2004 Proposed Plan detailed the human health risks, past activities and the preferred remedial alternative for the LSGPS. Public meetings were held and a comment period was provided for the Proposed Plan. EPA and DEQ selected a final remedy in the 2005 LSGPS Record of Decision (ROD). The RD process is underway at OU1 with the goal of addressing contamination associated with the Beall Source Area. In the time period between publication of the ROD and the present, site characterization activities have continued. Elements of the CSM presented in Section 2 are taken from the site decision documents (RI and ROD reports) and from discussions with the site team (RPMs and contractors). The optimization review team considered historic and more recent data, as well as site stakeholder input, to develop the recommendations for optimizing the RD included in Section 5.

2.2 Source

Between 1978 and 1990, TCE was used as part of the steam-cleaning process for truck trailers at the Beall facility. Based on the distribution of TCE in the subsurface, it appears that the majority of TCE was released from the steam-cleaning bay drain and the piping to an oil-water separator. Monitoring wells MW-200 and MW-201 are located closest to the release area. In 2002, maximum concentrations of TCE in groundwater at these wells were 1,867 and 1,850 micrograms per liter (µg/L), respectively. Soil samples collected in the unsaturated zone around the drain at the center of the steam-cleaning bay have had detections of concentrations up to 120 milligrams per kilogram (mg/kg) in the interval from 5 to 12.2 feet (ft) below ground surface (bgs) and up to 11 mg/kg in the interval from 33.0 to 41.5 ft bgs.

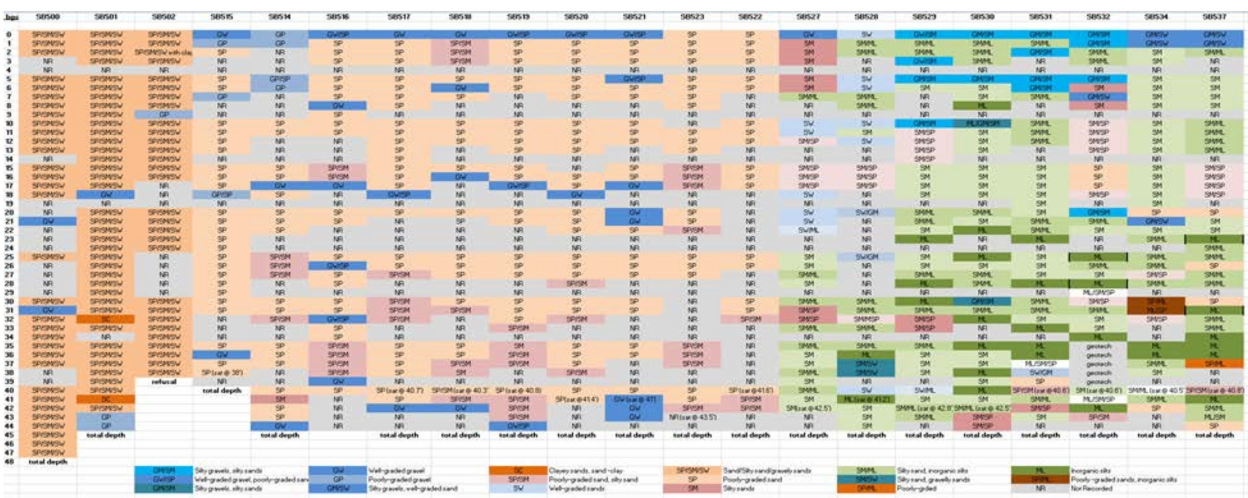
The hydrostratigraphy of the Beall Source Area consists of the following:

- approximately 40 ft of silt with interbedded sand lenses
- approximately 5 ft of fine sand (partially saturated)
- approximately 27 ft of sand and gravel (saturated)
- underlying sandstone and shale bedrock.

The water table is at approximately 42 ft bgs, with saturation at the bottom of the silt and sand unit and in the sand and gravel unit. The soil boring logs for MW-200 and MW-201 illustrate source area hydrostratigraphy (Attachment A). Table 4 lists the location, name and description of the affected media on site.

There is a significant lowering of topographic relief to the north and west of the former Beall property where the silt and sand overburden thickness decreases to approximately 20 ft. Generalized cross-sections that illustrate the regional hydrostratigraphy are provided in Figures 3-2 through 3-5 of the RI (Attachment A). Based on soil boring data from PWT, the formations are significantly more heterogeneous than depicted on these figures. Figure 2 (see Attachment C for larger version) illustrates the diversity of soil classification from bore holes in the source area (PWT, 2013) with the primary source area to the right of the figure (SB 537 is located near MW-200). The RI states that the alluvial aquifer pinches out to the south (upgradient) in the general area of the Lower Lockwood Irrigation Ditch as shown on Figure 3-1 of the RI (Attachment A).

Figure 2: OU1 Lithology. (Color coded depth vs. soil type for soil borings in the OU1 source area. Depth is between 0 and 47 ft bgs.)



Note: a larger version of this diagram is provided in Attachment A.

2.3 Soils and Unsaturated Subsurface

Site surface soil and shallow subsurface soils are composed of interbedded sands and gravels, silty sands and silts. TCE released from the primary source migrated under the influence of gravity through the unsaturated sandy silts to the saturated zone at approximately 42 to 45 ft bgs. It appears that contamination was able to spread horizontally approximately 50 to 100 ft in the unsaturated zone. Due to soil heterogeneity, the majority of the contamination that remains appears to be in the relatively less permeable silt layers, possibly resulting in a long-term secondary source of contamination.

Soil contamination has been evaluated by discrete soil samples collected from multiple depth intervals at over 60 locations on the former Beall property during the 2002 RI and a 2012 design-stage investigation. Soil contamination in the source area is generally confined to a 10,000 square ft area in the vicinity of the steam-cleaning bay. Soil contamination appears to extend primarily to the west, north and south of the steam-cleaning bay. Contamination does not appear to extend beyond the eastern property boundary of the facility. Horizontally, the highest concentrations in soil have been detected under the floor of the steam-cleaning bay. Vertically, based on the site data, soil contamination likely corresponds to the heterogeneity of soil types, with higher concentrations located in silts rather than in higher permeable sands.

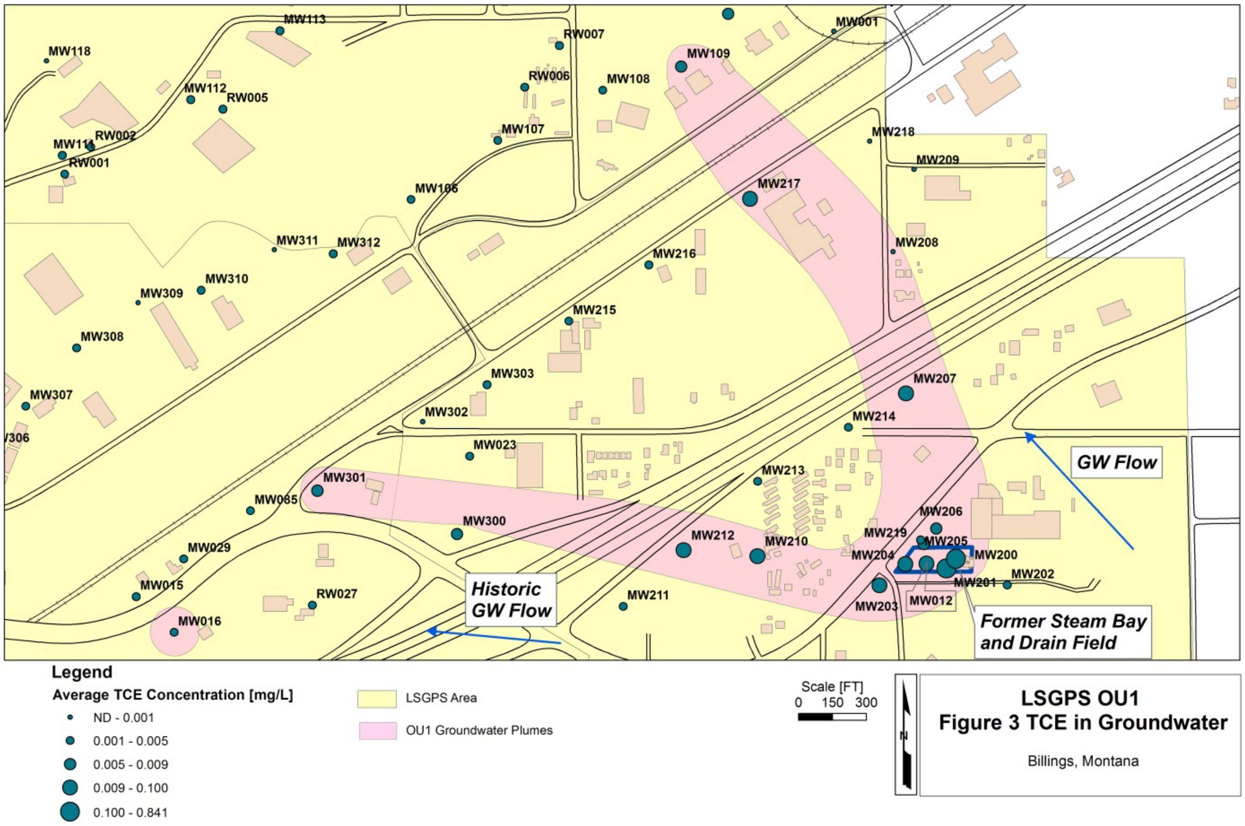
2.4 Groundwater

Data collected during the RI indicate groundwater contamination at OU1 occurs in two lobes as shown in Figure 3 (see Attachment C for larger version):

- A western lobe (West Lobe) with high concentrations that is most likely the result of historical groundwater flow to the west caused by the hydraulic influences of a former LWSD water supply well (closed in 1986);
- A north-northwestern lobe (North Lobe) that is consistent with the natural groundwater flow directions illustrated in Figures 3-7 and 3-8 of the RI (Attachment A).

Figures 3-7 and 3-8 of the RI (Attachment A) depict regional groundwater flow in the Lockwood area. Groundwater flow through much of the LSGPS is generally to the north-northwest, but has localized westward components. Groundwater flow along the southern boundary of the alluvial aquifer, in particular the area between monitoring wells MW-212 and MW-300, is more to the west. The site team believes that historical pumping at a municipal water supply well located along the rail line due west and slightly south of the OU1 source area has influenced significant contamination migration down the West Lobe of the plume (toward MW-203 and MW-210). Pumping at the municipal well ended in 1986, whereupon the groundwater flow appears to have returned to the natural gradient with a more north-northwest component generating the North Lobe of the OU1 plume. Examination by the optimization review team of the water levels on the former Beall property suggests current flow components to both the west and north-northwest. The leading edge of the North Lobe of the plume is near the OU2 source area, but recent data suggest the OU1 and OU2 plumes are not comingled at this time (EPA, 2012).

Figure 3: LSGPS OU1 TCE in Groundwater. (Groundwater wells are shown with the symbol size indicating the average TCE concentration 2003 – 2012.)



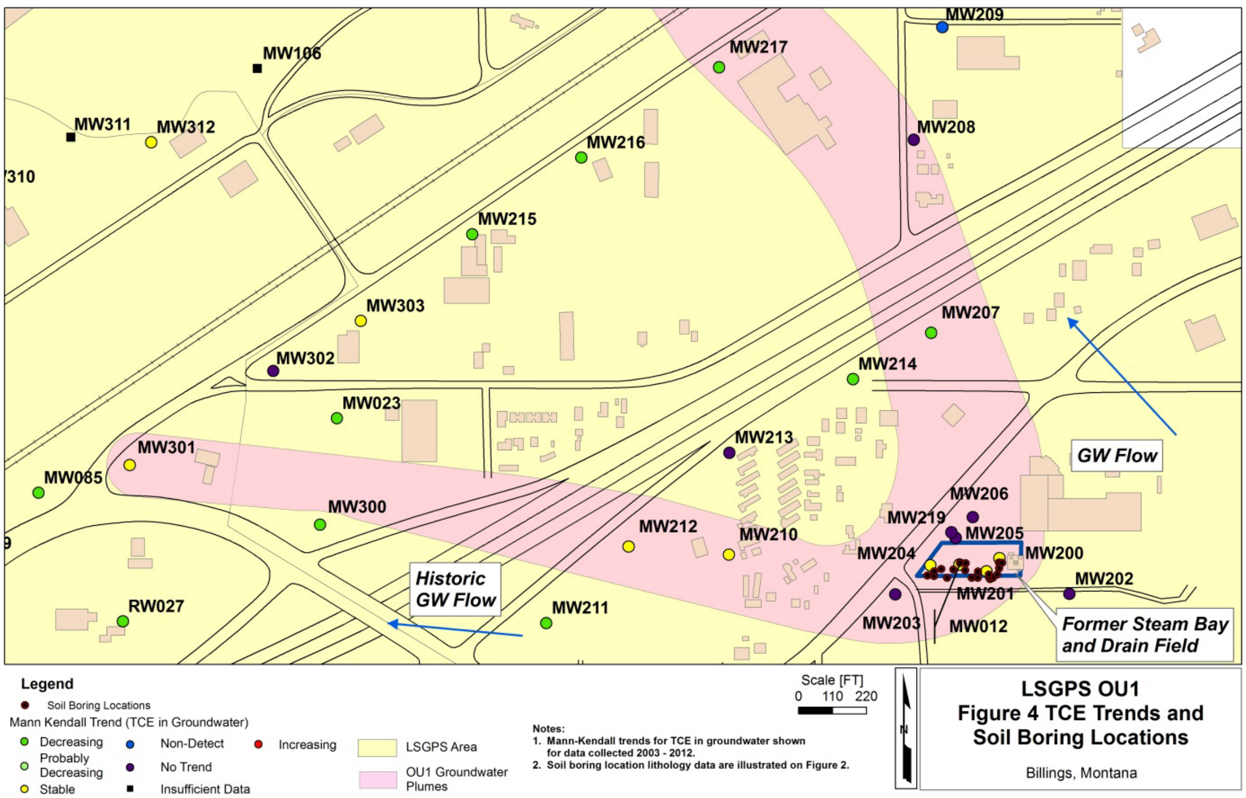
Groundwater monitoring has been conducted on an annual or semi-annual basis over the past 10 years, using approximately 28 monitoring wells in the immediate area of OU1, originally installed for site investigation and characterization. To date, wells have been sampled for characterization, delineation and short-term monitoring to track plume behavior and evaluate risk over time in support of the ROD and RD. The majority of the monitoring wells have long screen intervals (for example, 20 ft or greater) that extend throughout the alluvial aquifer. According to the site team, samples are collected using a low-flow sampling method from the center of the well screens.

Estimates of the hydraulic conductivity (K) reported from aquifer tests in the RI ranged from 10 ft per day to over 600 ft per day. Members of the site team (PWT) conducted an aquifer test in the Beall Source Area in 2013. Due to well construction issues, the extraction well yielded approximately 3 gallons per minute. After three days of pumping, a change in water level of approximately 0.1 ft was noted at an observation well approximately 15 ft from the test well. Based on these findings, the K is likely over 100 ft per day, but the data are insufficient to provide a more refined estimate. Furthermore, aquifer tests cannot account for the short-scale differences in K that could affect contaminant fate and transport. Based on the observed hydraulic head gradient of approximately 0.0015 ft per ft, a K of at least 100 ft per day and an assumed effective porosity of 0.2, the transport velocity is likely over 300 ft per year (Tetra Tech June 2003).

TCE is present in concentrations above the Maximum Contaminant Level (MCL) of 5 µg/L in both plume lobes. TCE is also present in concentrations below the MCL at locations between the two lobes, such as at monitoring well MW-213. At present, detected TCE concentrations remain highest in the source area (MW-200, MW-201 and MW-203). Concentrations along the West Lobe (MW-210 and MW-212), remain fairly elevated 30 years after termination of pumping at the LWSD water supply wells; this indicates to the site optimization review team that there may still be a westward flow component influencing the plume.

Based on non-parametric Mann-Kendall Trends for TCE (2003 – 2012) illustrated for individual well locations, TCE concentrations in the West Lobe, near the source, are still fairly elevated with stable concentration trends (See Figure 4). Concentration stability indicates that there may be a balance between releases from secondary sources via matrix- or back-diffusion and attenuation mechanisms such as dilution and degradation. Individual well concentration trends in the West Lobe are stable to decreasing (Mann-Kendall trend analysis 2003 – 2012, see Monitoring and Remediation Optimization System (MAROS) Reports in Attachment B and Figure 4) and estimates of total dissolved mass and center of mass are also stable (Attachment B), indicating the West Lobe plume is neither expanding nor shrinking under current conditions.

Figure 4: LSGPS OU1 TCE Concentration Trends



Notes: Mann-Kendall Trends: Green = Decreasing; Light Green = Probably Decreasing; Yellow = Stable; Blue = Non-detect; Purple = No Trend

Statistical concentration trends in the North Lobe are largely stable to decreasing, as are estimates of the total dissolved mass and center of mass for the plume (see MAROS reports Attachment B).

While cis-1,2-DCE is detected in the plumes, both the site team and optimization review team believe attenuation by biological degradation is not a strong process at the site. Based on a likely transport velocity of over 300 ft per year, the TCE detected in DP503, located west of the site near the on/off ramp of Interstate 90 (1000 – 1200 ft downgradient), represents approximately four years of groundwater contaminant flow downgradient from the Beall Source Area.

The vertical distribution of contaminant mass below the water table is not well understood. Based on analytical results from direct-push technology groundwater sampling, groundwater contamination concentrations appear to be higher in the upper alluvial groundwater than in deeper groundwater in the immediate source area. However, approximately 1,200 ft downgradient to the west, TCE concentrations at the water table (upper alluvial groundwater) appear to be similar to TCE concentrations at the bedrock surface (deeper groundwater). These results suggest that the primary source to groundwater contamination is from overlying unsaturated soils and that deeper contamination is the result of vertical migration of dissolved contamination to the saturated zone, followed by horizontal transfer with groundwater flow. However, additional data are needed to determine the presence or absence of secondary source material below the water table.

Plumes associated with OU1 do not discharge to surface water or sediments, and do not pose a significant ecological risk. No significant buildings are above the source soils or high contaminant concentration areas of the groundwater plume, so vapor intrusion (VI) is presumed not likely to be a complete exposure pathway. There are no current water supply wells remaining in the vicinity of contamination from OU1, therefore, there are no currently complete ingestion exposure pathways for groundwater.

The primary potentially complete exposure pathway is that of direct contact with affected soils, however, affected soil is fenced off and institutional controls (IC) were pending at the time of the review.

3.0 REMEDIAL ACTION OBJECTIVES AND SELECTED REMEDY OPTIONS

3.1 Remedial Action Objectives and Affected Media

RAOs for the Site were outlined in the 2005 ROD. The following RAOs are defined for groundwater, surface water and soil at the LSGPS:

- Prevent exposure of humans to groundwater and surface water contaminants in concentrations above regulatory standards.
- Reduce contaminant concentrations in the alluvial aquifer and surface water to below regulatory standards.
- Prevent or minimize further migration of the contaminant plume.
- Prevent or minimize further migration of contaminants from source materials (soil) to groundwater.

The ROD for OU1 identifies the principal threat waste as chlorinated solvent contamination found in the vadose zone soil and saturated soils at the former Beall property.

Table 3 outlines the groundwater cleanup standards for the site and the soil cleanup levels for the Beall source area. The soil cleanup levels were determined from recharge and leaching modeling conducted by the site team during the FS (*Final Feasibility Study* (Tetra Tech EMI – July 2004, Appendix D) to protect groundwater from contamination leaching from soil. Table 4 summarizes the affected or potentially affected media at the site.

Table 3: Contaminants of Concern and Cleanup Levels

Contaminant of Concern	Groundwater Cleanup Standard (µg/L)	Soil Cleanup Level (µg/kg)
Trichloroethene (TCE)	5	219
Tetrachloroethene (PCE)	5	241
Cis-1,2,-dichloroethene (cis-1,2-DCE)	70	1,636
Trans-1,2-Dichloroethene (Trans-1,2-DCE)	100	NI
Vinyl chloride	2	53

Notes: µg/kg = micrograms per kilogram; µg/L = micrograms per liter; NI= Not identified.

Table 4: Affected or Potentially Affected Media on Site

Media	Location	Composition	Potential Exposure/Migration Pathways
Surface Soil (vadose and saturated at depth)	Ground surface to 35 to 40 ft bgs	Silt with sand lenses, highly heterogeneous; can be saturated below 30 ft bgs	• Discharge to alluvial groundwater • Direct exposure by excavation
Sand	40 to 45 ft bgs	Saturated fine to silty sand	• Discharge to alluvial groundwater
Alluvial aquifer	45 to 70 ft bgs	Alluvial sand and gravel aquifer; some cobbles	• Drinking water wells historically located in this unit • Transport downgradient
Siltstone/sandstone bedrock	Below 70 ft bgs	Eagle Sandstone with some shale; groundwater in interconnected fractures	• Not currently affected • Potential for transport and discharge to deeper groundwater

Notes: ft bgs = feet below ground surface.

3.2 Selected Remedy Options

The remedy options selected for OU1 are described in the 2005 ROD and summarized in Table 5. For the Beall Source Area, the ROD specifies soil vapor extraction (SVE) as the remedy for unsaturated soils and an enhanced *in situ* bioremediation (ISB) system to treat the contaminated groundwater upgradient of US Highway 87 East (of Interstate 90) and for the leading edge of the plume. The enhanced ISB is anticipated to include injection of a chemical reductant to stimulate anaerobic biodegradation of chlorinated volatile organic compounds (cVOC).

The ROD recommends more detailed design studies for both the SVE and ISB components prior to implementation. To date, no remedies have been installed, but the primary source of TCE releases, the above-ground TCE tank in the steam-cleaning bay, has been removed and is no longer in use. A pilot test for SVE is in the design phase.

Based on additional investigation performed during the early design stage (PWT, 2012), the site team identified soils with an intrinsic permeability below 1×10^{-10} square centimeters (cm^2). As a result, the site team has been considering excavation of contaminated soils with on-site SVE treatment or off-site disposal as a potential alternative remedy. The feasibility of excavation may be contingent upon the potential re-use of the steam-cleaning bay by the new property owner.

Site-wide elements of the remedy include long-term groundwater monitoring, five-year reviews (FYR) and ICs, including restrictions on groundwater use.

Table 5: Remedy Options Selected in the ROD

Remedy	Target Medium	Description/Status
Soil Vapor Extraction (SVE)	Unsaturated vadose zone in source area	Collect and treat volatile contaminants in the vadose zone; design in progress, pilot test in design phase
In Situ Bioremediation (ISB) Treatment	Groundwater source and tail	Treat soil and groundwater with amendments that manipulate oxidation/reduction environment *in situ*; amendments to be chosen based on treatability studies, design in progress
Plugging private water supply wells and provide alternate supply	Alluvial aquifer	Plug municipal and private water wells in the LSGPS area-wide; supply of municipal water and sewer to residences is largely complete
Institutional Controls (ICs)	Commercial property, affected groundwater	Implement ICs that prevent exposure to impacted areas, restrict excavation or drilling into affected subsurface areas and groundwater use; status ongoing
Groundwater monitoring	Alluvial aquifer	Collection of contaminant concentration data to assess remedy performance and progress toward remedial goals and protectiveness; ongoing
Five-Year Reviews	All site media	Reports to document remedy performance and protectiveness will be prepared in future

4.0 FINDINGS

This section outlines the major findings of the optimization review team.

4.1 CSM Implications for Remedial Strategy

The CSM described in Section 2 has the following potential implications for a remedial strategy:

- The presence of the unsaturated soil contamination in relatively tight silt with a low intrinsic permeability may create challenges for SVE. Excavation may provide a cost-effective and more robust means of remediating the unsaturated soil if SVE pilot testing indicates that it cannot cost-effectively remove contaminant mass.
- There is a component of westward groundwater flow maintaining the West Lobe of the plume.
- Uncertainty about the distribution of contaminant mass in deeper silty or low-permeability layers may reduce remedial efficacy. Matrix- or back-diffusion from silty layers may provide a long-term secondary source of contamination to groundwater.
- The vertical distribution of contamination below the water table, which is currently unknown, will affect the design and performance of the ISB groundwater remedy.
- Based on historical groundwater monitoring data and trend analysis, the plumes emanating from the source appear to have stabilized and do not appear to be migrating significantly beyond the current plume footprint.
- Groundwater flows through the site relatively quickly. The results of effective source area remediation, particularly of secondary sources, will likely become apparent at downgradient groundwater monitoring locations within a few years of implementation.
- Increased understanding of source(s), plume morphology and plume behavior may significantly improve the effectiveness of remedy design and implementation.

4.2 Data Gaps

During the site meeting and document review several key data gaps and uncertainties in the LSGPS OU1 CSM were identified.

The primary sources of uncertainty for the RD include the lack of understanding of the vertical distribution of contamination, the effect of geologic heterogeneity on the selected remedy options, and the variability in groundwater flow direction. Each of these issues can be addressed through more detailed characterization of site geology and hydrogeology, particularly as related to vertical heterogeneity.

The lack of detailed information on the vertical extent and, to a lesser degree, the horizontal extent of soil contamination has several consequences for short- and long-term remedy design and performance monitoring. Understanding of the vertical distribution of contamination in unsaturated zone soils would provide an initial estimate of the total mass of contamination to be removed and would improve placement of remedial components in areas of maximum concentration. Accurate estimation of initial contaminant mass in soils would support remedy performance metrics assessing the extent of mass removal.

Contaminants trapped in low permeability unconsolidated deposits are difficult to remediate, and can act as long-term secondary sources of contamination to soil and groundwater. Remedies such as ISB and

SVE are most effective at removing contamination from higher permeability unconsolidated deposits. Residual pockets of high concentration contamination in low-permeability zones (such as the silts), particularly below the water table, can act as an ongoing source of dissolved groundwater contamination above cleanup levels. Determining the distribution of contamination in low versus high permeability deposits, in both unsaturated and saturated zones, is critical to establishing expectations for the long-term efficacy of the selected remedy options.

For dissolved phase contamination in groundwater, there is a general lack of understanding of the vertical distribution of contamination within the saturated thickness at downgradient locations. The 20 ft screen lengths introduce uncertainty into the assessment of vertical heterogeneity and the related distribution of mass. Locating high concentration areas within the saturated zone (for example, near the top or bottom of the aquifer) will help position remedial components for optimal efficacy.

Another source of uncertainty is the effect of variability in groundwater flow direction on the shape of the plumes. A westerly component of groundwater flow appears to remain even after termination of pumping at the municipal supply well to the west of the Beall Source Area. The groundwater gradient at the time of review appeared to have a stronger northerly component, but was fairly flat, so small differences in local gradient may impact the geometry of the plume. The long-term presence of a northward flow component of the West Lobe could cause residual contamination to migrate north (for example, from MW212 to MW213) into the area between the West and North Lobes increasing the contamination in that area. Detailed information supporting predictions about the flow direction may be obtained during characterization of vertical distribution of contamination and the distribution of lower vs. higher permeability unconsolidated deposits.

Table 6 summarizes data gaps identified by the optimization review team and associated recommendations to address these gaps.

Table 6: Identified Data Gaps and Recommendations

Medium	Data Gap(s)	Recommendation(s)
Unsaturated Soil (Vadose)	• Vertical and horizontal extent of highest contamination • Effect of heterogeneity in soil on SVE and ISB remedies	Prepare detailed delineation of down- and cross-gradient extent of contamination – (proposed sampling locations are detailed in Section 5.2) Conduct pilot testing for SVE and BioTraps® sampling for ISB (see sections 4.3, 5.1, 5.3 and 5.4.1)
Alluvial aquifer	• Vertical characterization of high mass zones • Possible presence of secondary sources below water table • Variable groundwater flow direction • Composition of microbial community (to optimize ISB remedy)	Implement: • Depth discreet groundwater sampling in existing monitoring wells with passive diffusion bag (PDB) technology (Section 5.2.1) • Vertical profiling of soil, including relative hydraulic conductivity (K_R) and groundwater contamination using Membrane Interface Probe (MIP) (Section 5.2.2) • Continued area-wide synoptic groundwater level monitoring at least annually • Sampling using Bio-Traps® or similar sampling approach for ISB (See Sections 5.2., 5.2, 5.3 and 5.4.1)
Siltstone/sandstone bedrock	Extent of contamination	Currently appears unaffected; continue sampling from bedrock intervals at existing well (MW-219).

4.3 Evaluation of Remedial Alternatives and Strategy

The optimization review team understands SVE is the primary remedial component selected for affected soils. The optimization review team believes it is beneficial to examine other remedial components to identify potential technical improvements or cost savings. The optimization review team identified excavation of contaminated soil as a potential remedial component that should be considered. Additionally, a comparison of remedial approaches may provide support for identifying contingent alternative remedies in case the selected remedy does not perform as expected. To this end, SVE (*in situ* and *ex situ* methods) and excavation are compared below on the basis of relative advantages and disadvantages for addressing site contamination.

Excavation

The primary technical and logistical advantages of excavation are 1) the certainty that targeted soil will be remediated, 2) the ability to effectively remediate contamination in low-permeability soils, and 3) the ability to complete remediation in a timely fashion once initiated. The technical and logistical disadvantages of this approach are 1) excavation to 40 ft bgs poses engineering challenges and requires extensive space on site and 2) the existing steam-cleaning bay would need to be dismantled and, potentially, reconstructed. In addition, development of a ROD amendment or other decision documents modifying the approach outlined in the ROD will be necessary to implement excavation.

The target area for excavation should be well-characterized to 40 ft bgs to define all of the unsaturated zone contamination that needs to be removed in order to avoid excavation of clean soil. The site team may want to add some soil samples at the 40 ft bgs interval to the investigation work described in Section 5.2. For this report, the optimization review team assumes that an area of 100 ft by 100 ft centered at the steam-cleaning bay would be excavated to a depth of 40 feet. Given the depth of the excavation, the work will need to be designed by a professional engineer. Shoring will likely be needed to the north due to the main building and to the south due to the road. An average slope of 1.5 to 1 (horizontal to vertical) or more would likely be needed to the east and west for safety and to allow access of equipment. In sum, there might be 8,000 square ft of shoring (two walls 100 ft wide and 40 ft deep) and 640,000 cubic ft of earth moved. In this scenario, the optimization review team assumes that up to 40,000 cubic ft (10% of the target volume) of soil might need to be disposed of at a local landfill. Based on these assumptions, the optimization review team estimates that the cost for an excavation remedy, including planning, design, field oversight and reporting might cost in the range of $1 million.

Once the SVE pilot test and high-density soil characterization are completed, a smaller, shallower area may be identified to optimize the excavation area. Excavation may be combined with another remedial approach such as *ex situ* SVE to further optimize the source remedy approach. A smaller and shallower excavation will provide cost savings due to reductions in shoring requirements and overall design and implementation efforts.

Reconstruction of the steam-cleaning bay (based on estimates for an 800 square ft car wash, Reed Construction Data, 2013) may require an additional $300,000, bringing total costs for extensive excavation to approximately $1.5M, 30% of which are associated with shoring. This approach includes the risk that costs would be significantly higher if more soil requires disposal or if affected soil must be disposed of at a hazardous waste landfill. This risk could not be mitigated once the excavation is begun. The estimated cost does not include a ROD modification or other decision documents that must be developed to support the change in remedial strategy.

SVE

The primary technical and logistical advantages of SVE are 1) the steam-cleaning bay does not need to be moved or demolished, and 2) the target treatment volume does not need to be as precisely defined. In addition, decision documents do not need to be modified. The technical and logistical disadvantages of this approach are that 1) there is less certainty with SVE than with excavation that soil cleanup levels will be achieved, 2) SVE will likely need to continue for two or more years, and 3) there are challenges in removing contaminant mass from low porosity materials.

The optimization review team assumes that soil vapors will primarily transport through poorly sorted sand lenses and layers within the more prevalent silt (silty gravel [GM], poorly graded gravel [GP], well-graded gravel, fine to coarse gravel [GW] and well-graded sand, fine to coarse sand [SW] lithology shown in Figure 2). Absent additional information from an SVE pilot test, the optimization review team assumes vapor extraction would occur from three separate depth intervals from wells with an approximate 10 ft radius of influence. Based on these assumptions, and on current site understanding, approximately 30 extraction locations would be used with extraction occurring from separate extraction wells at the following depth intervals: 0 to 15 ft bgs, 15 to 30 ft bgs, and 30 ft bgs to the water table.

Vapor extraction is expected to occur for up to two years with off-gas treatment using vapor phase granular activated carbon (GAC). Based on these assumptions and on current site understanding, the optimization review team estimates that the cost for design and construction would be approximately $600,000 and the cost for two years of operation and maintenance would be approximately $200,000 for a total estimated cost of remedy of approximately $800,000. Prior to implementation, an SVE pilot test at the three intervals noted above would need to be conducted to provide more information regarding flow rates and approximate radius of influence at each interval. The pilot test might cost an additional $30,000, assuming the wells installed for the test would be also used in the final remedy. Depending on performance of the SVE, additional years of operation may be necessary. The primary remedial risk is that contamination will remain in low-porosity strata.

The costs for excavation are somewhat higher; however, the uncertainty in the performance and duration of the SVE system is much greater. Construction time frames for both remedial approaches are similar; however, SVE operations will continue beyond the time required for excavation. Between the two primary options under consideration, the optimization review team favors the SVE approach, or a combination of SVE and targeted excavation, assuming the SVE pilot testing is successful. SVE is a lower cost option, and is more compatible with property redevelopment. More detailed recommendations for the remedy components are presented in Section 5.3 through 5.6.

5.0 RECOMMENDATIONS

Several recommendations are provided in this section related to remedy effectiveness, cost control, technical improvement and site closure strategy. Note that while the recommendations provide some details to consider during implementation, the recommendations are not meant to replace other, more comprehensive, planning documents such as work plans, sampling plans and QAPPs.

Recommendations provided below are focused on resolving uncertainty with regard to the CSM. General recommendations on remedial strategy and decision points have been developed based on data collected to date. However, specific recommendations for RD must be made after data gaps in the extent and magnitude of contamination have been addressed.

Cost estimates provided herein have levels of certainty comparable to those typically prepared for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) FS reports (-30% / +50%), and these cost estimates have been prepared in a manner generally consistent with EPA 540-R-00-002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, July, 2000. The costs presented do not include potential costs associated with community involvement activities that may be conducted prior to field activities or modification of decision documents. The estimated costs of these recommendations are summarized in Table 7.

5.1 Recommendations for Phased Remedial Strategy

A phased remedial approach is recommended for OU1. Optimization review team recommendations for the Site RD include source treatment by SVE, with possible excavation in high concentration areas where lithology limits the efficacy of SVE. Source treatment is anticipated to reduce volatile organic compound (VOC) discharge to the West and North Lobes, resulting in decreasing concentration trends and plume footprints.

The following is the recommended sequence for implementing the recommendations summarized in Table 6, and explained in detail in Sections 5.2 through 5.5:

- Address data gaps identified in Section 4.2 and Table 6 and discussed in Section 5.2 below.
- Re-evaluate remedial strategy and technology options, as needed, based on increased site understanding.
- Modify the relevant decision documents as necessary to accommodate recommended changes in remedial strategy.
- Design and implement the remedy to address areas of highest contaminant mass. Future remedy performance may be assessed by comparing the mass of contamination removed over time to initial estimates of total contaminant mass.
- Consider including soil excavation, if SVE pilot testing indicates that mass will not be removed from less permeable soils or if SVE does not meet cost or schedule goals. The time and efficacy benefits (complete source removal and easier ISB amendment injection) of excavation may outweigh the added cost of demolishing and rebuilding the steam-cleaning bay. The benefits of excavation could exceed the long-term downside of a slower or less effective SVE remedy, especially if excavation could reduce the scale of any downgradient plume remedy. Excavation could be used in combination with SVE to target shallower contamination from tighter formations once high density site characterization has been performed. A deep excavation project requires

more management, health & safety and community involvement efforts and presents greater short-term risks.

- Consider adding ISB amendment using injection wells at the northern and western property boundaries (this could be augmented or replaced with ISB amendment at the base of the excavation if excavation is implemented).
- Conduct performance monitoring for the source remedy for three to five years after implementation.
- Delay implementation of any remedy at the leading edge of the groundwater plumes until three to five years of source area remedy performance data have been collected and analyzed. Given the high rate of groundwater flow, the success of the source remedy should be apparent in downgradient wells relatively rapidly. Decreasing concentration trends and reduced plume footprints may indicate that a downgradient remedy is not required.

5.2 Recommendations for Resolving Vertical Extent of Contamination

Uncertainty regarding the vertical extent of contamination and heterogeneity within the source area, and the West and North Lobes of the plume is the primary data gap limiting design of an optimized remedy for OU1.

OU1 monitoring wells have long screened intervals (20 ft). The relatively high concentrations in two source area monitoring wells (MW-200 and MW-201) suggest that the other wells may display vertical heterogeneity in concentrations and may not be sampled from the correct interval to accurately characterize maximum contaminant concentrations and to delineate the plume. The optimization review team recommends reviewing well sampling techniques and optimizing sample collection to accurately characterize the saturated intervals with highest concentration.

Benefits of Implementing Section 5.2 Recommendations

- Accurately identify saturated intervals with the highest contaminant mass.
- Provide a better estimate of total dissolved mass to be treated.
- Optimize groundwater monitoring to track changes in the plume and remedy performance.
- Reduce uncertainty about location and extent of contaminant mass.

Accurate assessment of the location and magnitude of contaminant mass in the dissolved phase will guide development and implementation of the selected groundwater remedy option as well as assessment of the remedy's efficacy. The goal of the recommendations below is to outline the general saturated target treatment zones.

Recommendation 5.2.1: The optimization review team suggests sampling with multiple passive diffusion bags (PDBs) in existing long-screen-interval wells to provide greater vertical characterization at multiple intervals at key wells such as MW-200, MW-201, MW-203 to MW-207 and MW-210 to MW-214. PDBs may be deployed in wells used to define the plume such as MW-213. PDBs are often deployed in 2 ft intervals within each well. Selection of final low-flow sampling locations may be aided by in-well borehole flow monitoring to confirm flow characteristics across the screen lengths.

Sampling results will help better characterize the water quality within the West and North Lobe plumes. The sampling intervals for the long-term monitoring (LTM) program should be modified accordingly, based on the results. Monitoring intervals of high contaminant mass will provide more accurate assessment of source remedy performance and total mass destruction and recovery. The optimization review team recommends using existing and new data to prepare highly detailed cross-sections and maps of high concentration areas and heterogeneity within saturated units to target remediation in areas of highest contaminant mass.

The optimization review team estimates that the cost of sampling with PDBs at the specified wells will be approximately $20,000 for one event. This cost includes an addendum to the QAPP and field sampling plan for the PDBs, purchase of the PDBs, deployment of three PDBs per well, retrieval of the PDBs, laboratory analysis and preliminary data interpretation.

Recommendation 5.2.2: The site team should also consider using a Membrane Interface Probe (MIP) or depth-discrete groundwater sampling from the capillary fringe to bedrock in the source area to refine the target treatment zone. Hydraulic profiling, performed separately or in combination with the MIP or depth-discrete groundwater sampling, can also be conducted to better understand the vertical distribution of K. Areas of high K function *to transport* the majority of mass, while areas of low K *store and slowly release* contaminant mass. By identifying areas of transport vs. storage, remedies can be targeted to precise locations to treat or contain mass. As a result, the optimization review team suggests that up to 20 hydraulic profiling locations are appropriate.

The additional source area characterization work using hydraulic profiling and MIP or depth-discrete sampling for up to 20 locations should cost approximately $45,000, including an addendum to the QAPP, field sampling and preliminary data interpretation.

Recommendation 5.2.3: If the implemented remedy (excavation, SVE or both) does not achieve the applicable remediation goals or demonstrable decreases in concentration in the downgradient plume, the optimization review team recommends the site team consider using 3-dimensional visualization and analysis (3DVA) methods to support source area groundwater characterization, source(s) targeting, as applicable, RD and remedy performance monitoring.

The use of 3DVA would support an integrated analysis of source location(s); plume morphology; and plume behavior as related to site geology (bedrock and unconsolidated overburden visualized in terms of relative hydraulic conductivity [K_R]), groundwater contaminant chemistry, and temporal changes in water table elevations. Integrated analysis of these data will provide enhanced understanding of plume morphology and behavior and enable estimation of contaminant mass and volume. This information would provide a more refined basis to scope and design additional remedial strategies and components. 3DVA could also support remediation performance monitoring via application to subsequent groundwater monitoring data sets, including demonstration of reductions in plume area mass and volume. The cost of the initial 3DVA effort is anticipated to be in the range of $25,000 to $50,000, dependent upon data quantity and organization. The cost of each subsequent groundwater monitoring update would be on the order of $5,000.

5.3 Recommendations for Soil Remediation

Details on the relative technical merits of excavation vs. SVE remedies for soil are discussed in Section 4.0. Recommendations for soil remediation follow.

Recommendation 5.3: Between the two primary remedies being considered, the optimization review team favors the SVE remedial approach or a combination of SVE and excavation depending on the results of the SVE pilot test. Excavation may be considered a contingent response if SVE is not effective for highly contaminated, low-porosity soils

Benefits of Implementing Section 5.3 Recommendations

- SVE is recommended as a cost-effective, low-risk approach.
- Excavation or SVE with excavation is recommended as a contingent remedy if the pilot study and site characterization indicate that SVE will not be effective as a stand-alone remedy.

in the source area. Limited excavation of high concentration shallow soils followed by on-site SVE may be an effective way to target contaminant sources, without having to modify decision documents.

Overall, SVE costs are lower than excavation, and would not require modification of decision documents as a selected remedy option. SVE is more compatible with property re-use. Although, the optimization review team believes the SVE remedy will require more time to meet remedial goals, this is not a major concern, as no major exposure pathways are open.

SVE (or SVE/excavation) should be performed prior to ISB treatments in groundwater. Rapid remediation of residual soil sources could have a beneficial effect on remediation of groundwater by cutting off the source of contaminant transfer to groundwater. The velocity of groundwater in the saturated zone (300 ft per year) is fairly high, so remedial effects should be seen at downgradient locations within two years.

The cost of the excavation remedy (assuming an excavation measuring 100 ft by 100 ft by 40 ft), without rebuilding the steam-cleaning bay or modifying the ROD is in the range of $1 million, whereas the cost of design, implementation and operation of SVE with vapor phase GAC treatment for two years is approximately $800,000. An approach including SVE and small-scale excavation followed by SVE would have an approximate cost range of $800,000 to $1 million. If SVE pilot tests are not successful, the optimization review team recommends preparation of more detailed cost assessments including excavation, after consultation with the new owners of the property to determine if demolition of the steam-cleaning bay is a possibility.

5.4 Recommendations for Source Area Groundwater Characterization and Remediation

Before a source area groundwater remedy can be designed, additional information is needed to determine the distribution of mass both horizontally and vertically below the water table. Depending on the results of the characterization, remediation may be needed in the capillary fringe, upper portion of the unconsolidated saturated zone (including finer sands) and or middle to lower portion of the unconsolidated saturated zone (sand and gravel). The scope and cost will vary significantly with the volume to be treated. The optimization review team offers the following approaches to remediate these intervals. The approaches can be modified as needed once more information is available. It is recommended that ISB should follow the SVE remedy (Recommendation 5.2 above).

Benefits of Implementing Section 5.4 Recommendations

- Characterize microbial community to optimize choice of ISB strategy.
- Source area ISB may dramatically reduce mass flux to leading edge of plumes.
- If excavation is included as part of the soil remedy, ISB amendments can be added to the base of the excavation to stimulate degradation of remaining contamination, to improve remedy efficiency.

Recommendation 5.4.1: As an initial measure, the site team can install Bio-Traps® or a similar technology in MW-200 to evaluate the microbial community at the site and determine if bioaugmentation (addition of microbes) will be appropriate.

Recommendation 5.4.2: If the soil remedy includes excavation, ISB amendments may be added to the base of the excavation to stimulate biodegradation of contaminants. This approach would improve contaminant degradation in the capillary fringe of the aquifer. Emulsified vegetable oil might be applied as a 5% solution to the base of the excavation followed by an approximately equal volume of water. The cost of treatment would depend on the size of the excavation.

Recommendation 5.4.3: Application of emulsified vegetable oil, potentially with bioaugmentation would be appropriate through injection wells in the source area. Given the volumes of water needed to disperse the vegetable oil throughout the target area, extracted groundwater would be a reasonable source of water for blending and injection of the emulsified vegetable oil. Three, 6-inch extraction wells could be installed along the western and northwestern property boundaries to provide groundwater for the injection program. Injection could occur through six injection locations distributed from the vicinity of the steam-cleaning bay to the western property boundary.

Depending on the distribution of contaminant mass, two injection wells may be needed per location so that emulsified vegetable oil can be delivered effectively to the shallow, finer-grained material and deeper, coarser-grained material as needed. Injection should occur at the highest practical injection rate for timely delivery and a large radius of influence. Assuming contaminant mass is distributed such that remediation is needed throughout the unconsolidated aquifer, the optimization review team assumes that each injection location might receive approximately 30,000 pounds of emulsified vegetable oil delivered as a 3% solution (approximately 120,000 gallons of water) followed by an additional 160,000 gallons of chase water. The injections should be distributed evenly between the two injection intervals. Injection could occur simultaneously at three wells. After injections through the injection wells has been completed, injection of the same emulsified vegetable oil water combination used at each injection location should be conducted at the western and northwestern extraction wells using extracted water from the third extraction well.

The optimization review team anticipates that the design, implementation, and reporting of this injection event (including well installation) might cost up to $1.2 million. A repeat event for the same volume, which would likely be needed, would cost approximately $1 million because design, planning and well drilling would have already occurred. The cost for this remedial approach can be substantially reduced if remediation is not required from the water table to bedrock throughout the target treatment area.

Additional costs would be incurred for performance monitoring as described in the following section.

5.5 Recommendations for Remedial Performance Monitoring

Historically, over 28 groundwater wells have been installed in LSGPS Area A for characterization of contaminant distribution. Based on data from these locations, contamination is believed to occur in two lobes – one fairly high concentration lobe emanating from the source and extending to the west and a second, more dilute lobe extending north/northwest.

Remedial performance monitoring will be required for groundwater for all of the selected remedy options, including SVE, excavation or ISB.

Recommendation 5.5.1: A preliminary remedy performance monitoring matrix is included as Table 8. A total of 55 groundwater samples per year are recommended for the three to five years of active source remediation. After completion of the remedy performance monitoring period, the groundwater monitoring network can be reduced.

Benefits of Implementing Section 5.5 Recommendations

- Remedy performance can be evaluated more effectively.
- Quantitative metrics demonstrate remedy performance to stakeholders.
- Remedy performance monitoring can prevent operating remedies past their effective life span.

Recommended groundwater monitoring wells are listed for monitoring the remedy and plume spread for the source area, the West and North Lobe plumes and the edges of the plume. Sampling frequencies are recommended for each well group as well as potential data analysis techniques to support each monitoring objective.

After the multi-level PDB sampling recommended in Section 5.2 is complete, sampling should be conducted with low-flow sampling from the interval with the highest concentration indicated from the PDB sampling. Selection of final low-flow sampling locations may be aided by in-well borehole flow monitoring to confirm flow characteristics across the screen lengths. Samples should be analyzed for typical field stabilization parameters (including oxidation reduction potential, turbidity and pH), ferrous iron, nitrate, sulfate, and dissolved organic carbon, alkalinity and VOCs. During the ISB remedy, metals should be included in the sampling program to ensure that oxidation/reduction manipulation does not mobilize constituents such as arsenic and manganese. Inorganic sampling may be performed using low-flow techniques.

Additional data analyses to evaluate remedy performance may include mass flux estimates, and estimates and trends for total dissolved mass in the plume. All area wells should be monitored at least once during a FYR cycle. Data should be evaluated routinely to determine if a follow-up source area ISB injection event is required and if the dilute lobes of the plume are being restored in a timely manner. The sampling frequency can be revisited after three years of sampling.

Particular attention should be paid to future sampling results from MW-208, which showed non-detect results through 2010 with one detection of TCE in 2012. The detection in 2012 may be an artifact (no subsequent sample was available to confirm the detection) or it may indicate the North Lobe plume is migrating to the north/northeast. In addition, well MW-213 should be sampled periodically to detect any potential northward migration of the West Lobe resulting from the northerly component of groundwater flow.

Recommendation 5.5.2: Based on a spatial analysis of the monitoring network using the MAROS software, an additional groundwater monitoring well would be beneficial in the area of the North Lobe plume just west/southwest of MW-208 and north of MW-214. It is unclear if some of the wells not sampled in 2012 are still functional. If wells have been plugged or are not functional, additional wells may be required to demonstrate remedy performance or containment of the plume.

Recommendation 5.5.3: The sum of mass removed can be compared with estimates of total source area mass to assess progress toward remedial goals. In addition, remedy performance monitoring for the SVE system should include monitoring total contaminant mass removed by the SVE relative to energy and maintenance costs. The SVE system is preliminarily scoped to operate for two to three years. If the cost of operation exceeds the benefits derived from SVE operation, consider termination, contingency remedies or optimization of SVE operation. The cost of remedy performance monitoring and reporting for the SVE is anticipated to be $2,000.

5.6 Recommendations for Dissolved Downgradient Plume Remediation

Currently, cessation of groundwater extraction for municipal supplies and natural attenuation processes appear to have stabilized and controlled the further migration of OU 1 plumes. In addition, groundwater flows quickly at the site. The optimization review team finds it likely that quantifiable indications of performance of source area remediation may be realized at downgradient locations (at monitoring wells near Interstate 90) in less than three years.

Recommendation 5.6: Delay the decision on whether to implement any active remedy for the downgradient, leading edge of the groundwater plume until the effects of aggressive source treatment have been evaluated. Monitor the downgradient portion of the plume for three to five years after source area remedies have been implemented. Groundwater samples should be collected from groundwater intervals identified during the vertical characterization to have the highest contaminant concentrations. Aggressive source area treatment along with natural attenuation processes is anticipated to reduce the contaminant mass downgradient. Implementation of the source remedies may reduce the need or reduce the scale of active remediation in the downgradient plume.

Benefits of Implementing Section 5.6 Recommendations

- Source area treatment may eliminate the need for downgradient remedies.

The performance monitoring discussed in Section 5.5.3 will provide a good indication of source remedy performance between the source area and Interstate 90. The monitoring wells downgradient of Interstate 90 with historical TCE concentrations above MCLs can be monitored semi-annually for five years to determine the effect of source area remediation on these portions of the plume. Trend and simple statistical analyses of downgradient sampling can be used to determine if an additional downgradient remedy is appropriate. If time-series data indicate deceasing concentration trends at individual wells and a reduction in total dissolved mass in the downgradient plume after source area remedies have been installed, consider eliminating any active remediation for the downgradient plume from the RD. The optimization review team would not recommend the use of ISB to address concentrations below 10 µg/L. Application of ISB remedies are both ineffective and cost-prohibitive on a cost per mass basis for low concentrations.

5.7 Recommendations Related to Green Remediation

No recommendations are provided for green remediation at this time. Green remediation best management practices and footprint analysis can be revisited after characterization activities have been completed and the site team is developing a more targeted RD. In general, the additional characterization suggested should help target the volume to be remediated and, therefore, reduce the footprint of the final remedy.

The recommended remedy performance monitoring plan should help reduce the likelihood that the remedies will be run longer than is beneficial. Conversely, underperforming remedies can be modified or replaced earlier in the remediation process, thus saving costly time and material expenditures.

Table 7: Recommendations Summary

Recommendation	Effectiveness	Cost Reduction	Technical Improvement	Site Closure	Environmental Footprint Reduction	Estimated Capital Cost	Change in Annual Cost
5.2.1 Groundwater sampling using PDBs for vertical delineation of contaminants	◆		◆			$20,000	N/A
5.2.2 MIP survey or depth-discrete groundwater sampling from capillary fringe to bedrock in the source area	◆		◆			$45,000	N/A

Recommendation	Effectiveness	Cost Reduction	Technical Improvement	Site Closure	Environmental Footprint Reduction	Estimated Capital Cost	Change in Annual Cost
5.2.3 3DVA to support source area groundwater characterization, source(s) targeting, as applicable, remedy design and remedy performance monitoring	◆	◆	◆	◆		$25,000 - $50,000 (dependent on data quantity and organization.) $5,000 (per each subsequent sampling update.)	N/A
5.3 SVE for source soils with possible addition of excavation	◆		◆	◆		$800,000 - $1M	N/A
5.4.1 Bio-Trap® samplers to characterize microbial community	◆		◆			$3,000	N/A
5.4.2 ISB remedy at base of excavation	◆		◆	◆		(dependent on size of excavation)	
5.4.3 ISB remedy for saturated zone	◆		◆			$1,200,000	N/A
5.5.1 Remedy performance monitoring for groundwater			◆	◆		$50,000	N/A
5.5.2 Additional monitoring location in North Lobe of groundwater plume			◆	◆		$5,000	N/A
5.5.3 Performance monitoring of SVE system		◆			◆	$2,000	
5.6 Monitor downgradient groundwater for response prior to implementation of any downgradient plume remedy		◆				(no cost above performance monitoring program)	

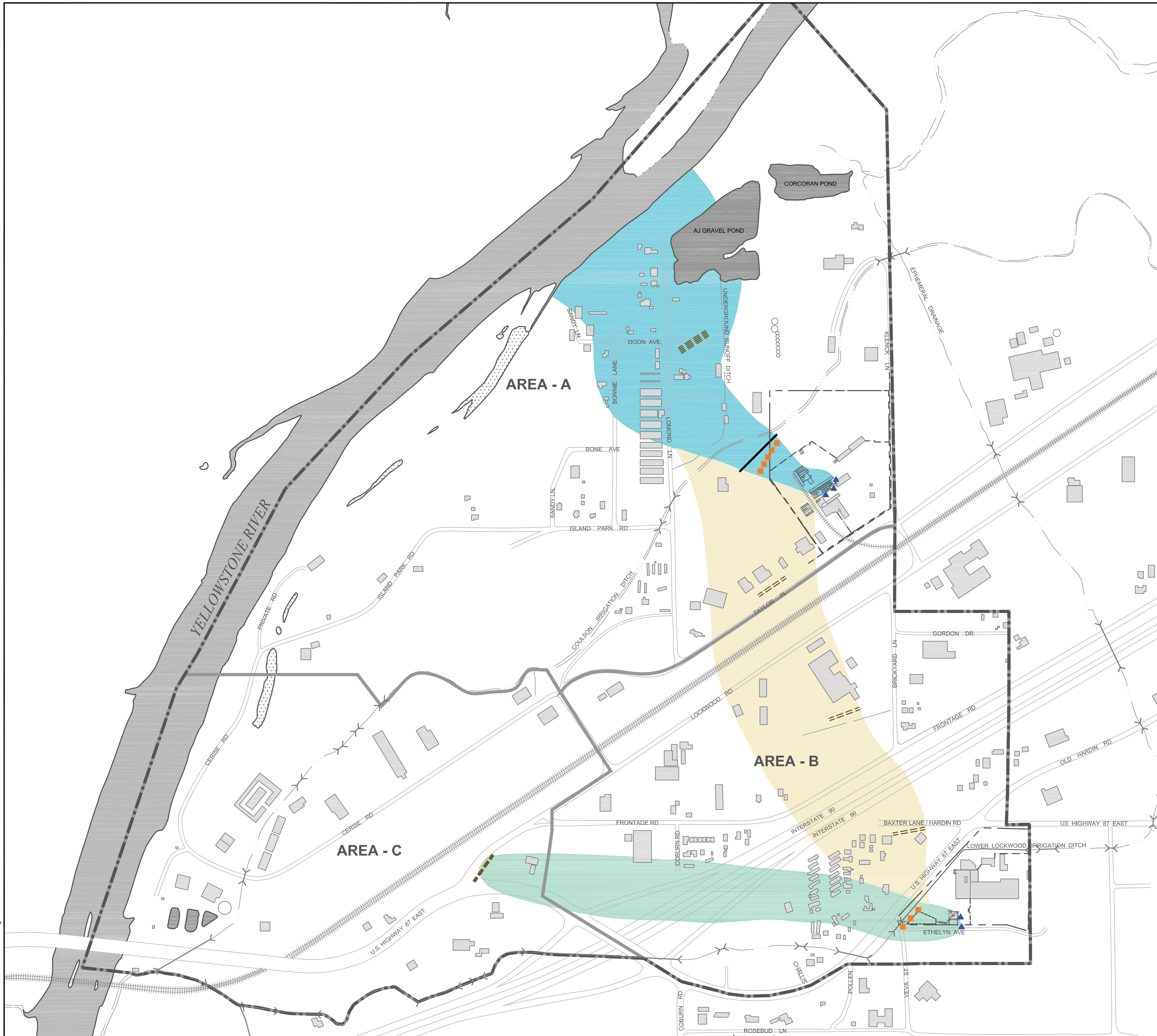
Notes: MIP = membrane interface probe; SVE = soil vapor extraction; ISB = *in situ* bioremediation; PDB = passive diffusion bag; 3DVA = 3-dimensional visualization and analysis; N/A = not applicable.

Table 8: Recommended Groundwater Performance Monitoring Program

Well Name	Unit	Objective	Parameters & Frequency	Analyses
MW-200 MW-201 MW-012 MW-204 MW-205 MW202	Source Area	Evaluate response to source treatment	VOCs quarterly for two years following source treatment (metals if ISB implemented) semi-annually after remedies	Concentration trend evaluation, mass discharge downgradient, mass removal vs. cost of remedy
MW-206 MW-207 MW-217 MW-214 Additional Well (N of MW-214, SW of MW-208)	North Lobe	Remedy Performance	VOCs semi-annually (metals and geochemical indicators during ISB treatment)	Concentration trend evaluation, mass discharge downgradient, mass removal vs. cost of remedy
MW108 MW109 MW208 MW215 MW216 MW218	North Lobe Edges	Delineate and evaluate plume migration	VOCs annually during active remediation, once every five years during LTRA	Compare to detection limits and cleanup standards—Monitor for plume expansion
MW203 MW210 MW212 MW300 MW301	West Lobe	Remedy Performance	VOCs semi-annually (metals and geochemical indicators during ISB treatment)	Concentration trend evaluation, mass discharge downgradient, mass removal vs. cost of remedy
MW023 MW211 MW213 MW215 MW302 MW303	West Lobe Edges	Delineate and evaluate plume migration	VOCs annually during active remediation, once every five years during LTRA	Compare to detection limits and cleanup standards—Monitor for plume expansion
MW-209 MW-219	Redundant	Do not monitor in near term		
SVE extraction wells (vapor)	Source area	Mass removal	Photoionization detector monthly and VOCs quarterly from key wells for comparison	Mass removal rate

Notes: MW = monitoring well; SVE = soil vapor extraction; VOCs = volatile organic compounds; LTRA = long term remedial action; ISB = *in situ* bioremediation.

ATTACHMENT A
OPTIMIZATION REVIEW FIGURES



GROUNDWATER REMEDIATION.dwg - DWH - 07/12/2005 - S1176-26-PPRESP

Legend

- Recirculation Extraction Well (Enhanced Bioremediation)
- Recirculation Injection Well (Enhanced Bioremediation)
- Treatment Barrier
- Injection Well Rows (Enhanced Bioremediation)
- Culvert
- Site Boundary
- Area Delineation
- Railroad
- Building
- Ponds
- River
- Wetlands
- Concentration of PCE Exceeds MCL in April 2003
- Concentration of TCE Exceeds MCL in April 2003
- Groundwater Contamination Above Remediation Goals

Note: All Locations Approximate

650 0 650

SCALE IN FEET - 1 inch = 650 feet

LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 10
GROUNDWATER REMEDY COMPONENTS

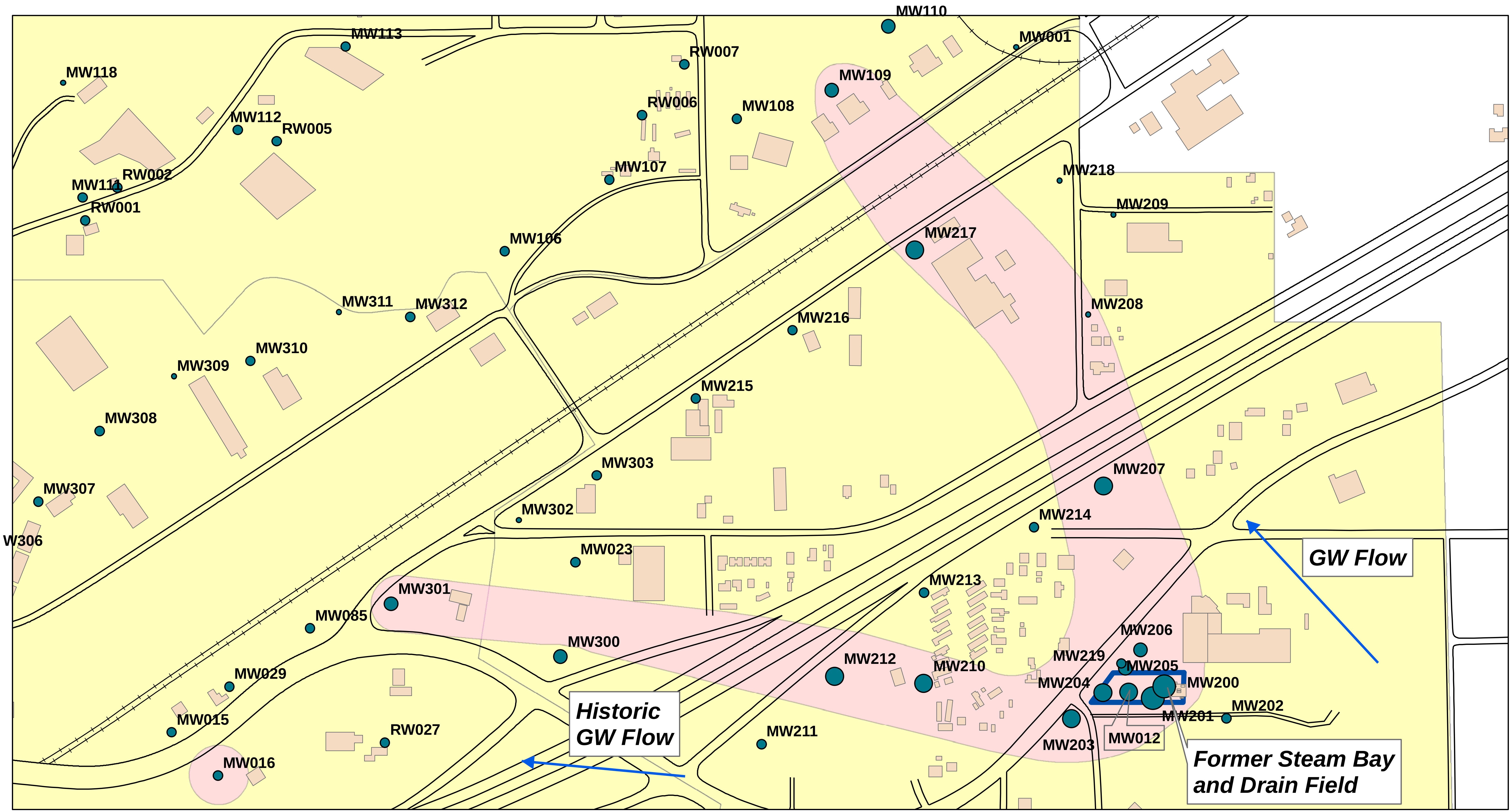
Tetra Tech EM Inc.

ft bgs	SB500	SB501	SB502	SB515	SB514	SB516	SB517	SB518	SB519	SB520	SB521	SB523	SB522	SB527	SB528	SB529	SB530	SB531	SB532	SB534	SB537
0	SP/SM/SW	SP/SM/SW	SP/SM/SW	GW	GP	GW/SP	GW	GW	GW/SP	GW/SP	GW/SP	SP	SP	GW	SW	GW/SM	GM/SM	GM/SM	GM/SM	GM/SW	GM/SW
1	SP/SM/SW	SP/SM/SW	SP/SM/SW	GP	GP	SP	SP	SP/SM	SP	SP	SP	SP	SP	SM	SM/ML	SM/ML	SM/ML	SM/ML	GM/SM	GM/SW	GM/SW
2	SP/SM/SW	SP/SM/SW	SP/SM/SW with clay	SP	NR	SP	SP	SP/SM	SP	SP	SP	SP	SP	SM	SM/ML	SM/ML	SM/ML	GM/SM	SM/ML	SM	SM/ML
3	NR	SP/SM/SW	SP/SM/SW	NR	NR	SP	SP	SP/SM	SP	SP	SP	SP	SP	SM	NR	GW/SM	SM/ML	NR	SM/ML	SM	NR
4	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
5	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	GP/SP	SP	SP	SP	SP	SP	GW/SP	SP	SP	SM	SW	GM/SM	GM/SM	GM/SM	GM/SM	SM	SM
6	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	GP	SP	SP	GW	SP	SP	SP	SP	SP	SM	SW	SM	SM	GM/SM	SM	SM	SM
7	SP/SM/SW	SP/SM/SW	SP/SM/SW	GP	NR	SP	SP	SP	NR	SP	SP	SP	NR	SM/ML	SM/ML	NR	SM	SM/ML	GM/SW	SM	SM
8	SP/SM/SW	SP/SM/SW	SP/SM/SW	NR	NR	GW	SP	NR	NR	NR	NR	SP	NR	NR	SM/ML	NR	ML	NR	SM	SM	SM
9	SP/SM/SW	SP/SM/SW	GP	NR	NR	SP	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
10	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP	SP	SP	SP	SP	SP	NR	SP	SW	SW	GM/SM	ML/GM/SM	SM/ML	SM/SP	SM	SM/ML
11	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SW	SM	SM/SP	SM	SM/ML	SM/SP	SM	SM/ML
12	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	NR	NR	SP	SP	SP	SP	SP	SP	SP	SM/SP	SW	SM/SP	SM	SM/ML	SM/SP	SM	SM/ML
13	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	NR	NR	SP	NR	SP	SP	NR	SP	NR	NR	NR	SM/SP	SM	NR	SM/SP	SM	SM/ML
14	NR	SP/SM/SW	SP/SM/SW	NR	NR	NR	SP	NR	NR	NR	NR	NR	NR	NR	NR	SM/SP	NR	NR	NR	NR	NR
15	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP/SM	SP	SP	SP	NR	SP	SP/SM	SP	SM/SP	SM/SP	SM	SM	SM	SP	SM	SM/SP
16	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP/SM	SP	GW	SP	SP	SP	SP/SM	SP	SM/SP	SM/SP	SM	SM	SM	SP	SM	SM/SP
17	SP/SM/SW	SP/SM/SW	NR	SP	GW	GW	SP	NR	GW/SP	SP	GW	SP/SM	SP	SM/SP	SM/SP	SM	SM	SM	SP	SM	SM/SP
18	SP/SM/SW	GW	NR	GP/SP	SP	NR	GW/SP	NR	NR	GW	NR	NR	NR	SW	NR	SM	SM	SM	SM/SP	SM	SM/SP
19	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	SM	NR	SM	NR
20	NR	SP/SM/SW	SP/SM/SW	SP	SP	SP	SP	SP	SP	SP	GW	SP	NR	SW	SW/GM	SM/ML	SM/ML	SM	GM/SM	SP	SP
21	GW	SP/SM/SW	SP/SM/SW	SP	SP	SP	NR	SP	SP	SP	GW	SP	NR	SW	NR	SM/ML	SM	SM/ML	SM/ML	GM/SW	SM
22	NR	SP/SM/SW	SP/SM/SW	SP	SP	NR	NR	NR	NR	SP	SP	SP/SM	NR	SW/ML	NR	SM	ML	SM/ML	SM	SM	SM
23	NR	SP/SM/SW	SP/SM/SW	SP	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ML	NR	ML	NR	SM/ML	ML
24	NR	SP/SM/SW	SP/SM/SW	SP	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	SM/ML
25	SP/SM/SW	SP/SM/SW	NR	SP	SP/SM	SP	SP	SP	SP	SP	SP	SP	SP	SM	SW/GM	SM	ML	SM	ML	SM/ML	SM/ML
26	NR	SP/SM/SW	NR	SP	SP/SM	GW/SP	SP	SP	SP	SP	SP	SP	SP	SM	NR	SM	SM	SM	SM/ML	SM/ML	SP
27	NR	SP/SM/SW	NR	SP	SP/SM	SP	SP/SM	SP	SP	SP	SP	SP	NR	SM/ML	NR	SM/ML	SM/ML	SM	SM	SM/SP	SM/ML
28	NR	SP/SM/SW	NR	SP	NR	SP	NR	NR	NR	SP/SM	NR	NR	NR	SM	NR	ML	SM/ML	ML	ML	SM/ML	SM/ML
29	NR	SP/SM/SW	NR	SP	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ML/SM/SP	NR	NR
30	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP	SP/SM	SP	SP	SP	SP	NR	SP	SM/ML	SM/ML	ML	GM/SM	SM/ML	SM/SP	SP/ML	SP
31	GW	SP/SM/SW	SP/SM/SW	SP	SP	SP	SP/SM	SP/SM	SP	SP	SP	NR	SP	SM/SP	SM/ML	SM/ML	SM/ML	SM/ML	SM/ML	ML/SP	ML
32	SP/SM/SW	SC	SP/SM/SW	NR	SP/SM	GW/SP	SP/SM	NR	SP	SP/SM	NR	NR	SP/SM	SM/SP	SM/MSP	SM/SP	ML	SM	SM	SM/SP	SM/ML
33	SP/SM/SW	SP/SM/SW	SP/SM/SW	NR	NR	SP	NR	NR	SP/SM	NR	NR	NR	NR	SM/ML	SM/ML	SM/SP	NR	ML	SM	NR	SM/ML
34	SP/SM/SW	NR	SP/SM/SW	NR	NR	SP	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ML	NR	ML
35	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP/SM	SP	SP	SM	SP	SP	SP/SM	NR	SM/ML	SM/ML	SM/ML	ML	ML	geotech	ML	ML
36	SP/SM/SW	SP/SM/SW	SP/SM/SW	GW	SP	SP/SM	SP	SP	SP/SM	SP	SP	SP/SM	NR	SM	ML	SM	SM	ML	geotech	ML	ML
37	SP/SM/SW	SP/SM/SW	SP/SM/SW	SP	SP	SP/SM	SP	SP/SM	SP/SM	SP	NR	SP/SM	NR	SM	SM/SW	SM	SM	ML/SM/SP	geotech	SM/ML	SP/ML
38	NR	SP/SM/SW	SP/SM/SW	SP (sat @ 38')	NR	SP/SM	SP	SM	NR	SP/SM	NR	NR	NR	SM/ML	SM/SW	SM	ML	SW/GM	geotech	SM	NR
39	NR	SP/SM/SW	refusal	NR	NR	GW	NR	NR	NR	NR	NR	NR	NR	SM	NR	NR	SM	SP	geotech	NR	NR
40	SP/SM/SW	SP/SM/SW		TD	SP	SP	SP (sat @ 40.7')	SP/SM (sat @ 40.3')	SP (sat @ 40.8)	SP	SP	SP	SP (sat @41.6')	SM/ML	SW	SW/ML	ML	SP/SM (sat @40.6')	SM (sat @40.6')	SM/ML (sat @ 40.5')	SP/SM (sat @ 40.8')
41	SP/SM/SW	SC			SM	NR	SP	SP/SM	SP/SM	SP(sat @41.4')	GW (sat @ 41')	SP	SP/SM	SM	ML (sat @ 41.2')	SM	SM	SM/ML	ML/SM/SP	SM/ML	ML
42	SP/SM/SW	SP/SM/SW			SP	NR	GW	GW	SP/SM	NR	GW	SP/SM	SP/SM	SM(sat @42.5')	SM	SM/ML (sat @ 42.8')	SM/ML (sat @ 42.5')	SM/SP	ML	SP	SM/ML
43	SP/SM/SW	GP			SP	NR	NR	NR	SP/SM	NR	GW	NR (sat @ 43.5')	NR	NR	SM	SM/ML	SM/SP	SM	SP/SM	NR	ML/SM
44	SP/SM/SW	GP			GW	NR	NR	NR	GW/SP	NR	NR	NR	NR	NR	SM	NR	SM/SP	NR	NR	NR	SP
45	SP/SM/SW	TD			TD		TD	TD	TD	TD	TD	TD	TD	TD	TD	TD	TD	TD	TD	TD	TD
46	SP/SM/SW																				
47	SP/SM/SW																				
47.5	TD																				

GM/SM	Silty gravels, silty sands	GW	Well-graded gravel	SC	Clayey sands, sand -clay	SP/SM/SW	Sand/Silty sand/gravely sands	SM/ML	Silty sand, inorganic silts	ML	Inorganic silts
GW/SP	Well-graded gravel, poorly-graded sands	GP	Poorly-graded gravel	SP/SM	Poorly-graded sand, silty sand	SP	Poorly-graded sand	SM/SW	Silty sand, gravelly sands	SP/ML	Poorly -graded sands, inorganic silts
GM/SM	Silty gravels, silty sands	GM/SW	Silty gravels, well-graded sand	SW	Well-graded sands	SM	Silty sands	ML/SM/SP	Silts, poorly graded sands	NR	Not Recorded

TD = Total Depth

Figure 2: OU1 Lithology. Color coded depth vs. soil type for soil borings in the OU1 source area. Depth is between 0 and 47 ft. (Adapted From PWT, 2013)



Legend

Average TCE Concentration [mg/L]

- ND - 0.001
- 0.001 - 0.005
- 0.005 - 0.009
- 0.009 - 0.100
- 0.100 - 0.841

LSGPS Area

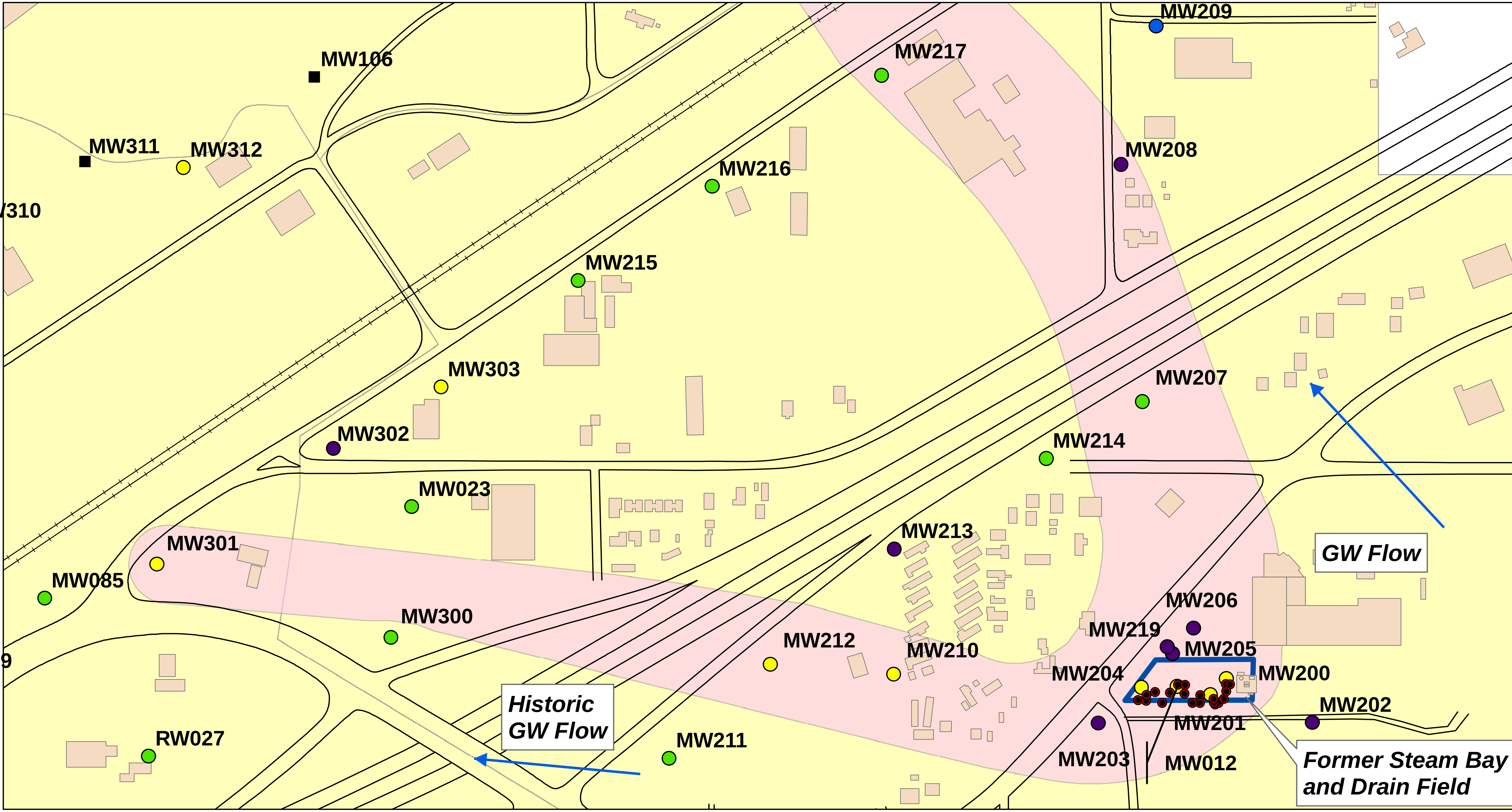
OU1 Groundwater Plumes

Scale [FT]
0 150 300

N

LSGPS OU1
Figure 3 TCE in Groundwater

Billings, Montana



Legend

Soil Boring Locations

Mann Kendall Trend (TCE in Groundwater)

- Decreasing
- Probably Decreasing
- Stable
- Non-Detect
- No Trend
- Insufficient Data
- Increasing
- LSGPS Area
- OU1 Groundwater Plumes

Scale [FT]
0 110 220

Notes:
1. Mann-Kendall trends for TCE in groundwater shown for data collected 2003 - 2012.
2. Soil boring location lithology data are illustrated on Figure 2.

N

LSGPS OU1
Figure 4 TCE Trends and Soil Boring Locations

Billings, Montana

ATTACHMENT B
SUPPLEMENTAL FIGURES FROM REMEDIAL INVESTIGATION REPORT

Attachment A
Figures Excerpted from Site Documents

Log of Borehole MW-200
Log of Borehole MW-201

Figures from RI Report

Figure 3-1
Figure 3-2
Figure 3-3
Figure 3-4
Figure 3-5
Figure 3-6
Figure 3-7
Figure 3-8

LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW200

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval
3152.5	0	Ground Surface		
	0–2	***Gravel***		
	2–4.5	***No Recovery***		
	4.5–6.5	***Sand*** Brown fine with silt to no staining and no odors	4.4	
	6.5–8.5	***Silt*** Brown with moderate fine sand and minor scattered fine-angular gravel, no staining and no odors	0.7	
	8.5–9.5	***No Recovery***		
	9.5–11.5	***Silt*** Brown silt with moderate clay grading to fine-graded sandy silt grading to fine-graded sand with some silt, no staining and no odors.	11.6	MW200SB001
	11.5–12	***No Recovery***	2.4	
	12–14	***Silt*** Brown with mnor fine sand and minor clay, no staining and no odors		
	14–14.5	***No Recovery***	2.9	
	14.5–16.5	***Sand*** Brown fine sand with some silt, no staining and no odors		
	16.5–17	***No Recovery***	1.1	
	17–19	***Sand*** Brown fine with variable silt, trace of scattered subrounded gravel, no staining and no odors		
	19–19.5	***No Recovery***	1.5	

Elevation scale: 3151.0, 3150.0, 3149.0, 3148.0, 3147.0, 3146.0, 3145.0, 3144.0, 3143.0, 3142.0, 3141.0, 3140.0, 3139.0, 3138.0, 3137.0, 3136.0, 3135.0, 3134.0, 3133.0

Depth scale: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20

Lithologic Symbol/ Recovery | Monitoring Well Completion

DRILLING DATE: 7/23-24/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 67.6
TOTAL WELL DEPTH (ft btoc): 67.6
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2
TOC ELEVATION (ft AMSL): 3152.46
GROUND ELEVATION (ft AMSL): 3152.47
DRILLING CO.: O'Keefe
WATER LEVEL (ft btoc): 42.4
GROUNDWATER ELEV (ft AMSL).: 3110.06

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LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW200

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Symbol/ Recovery	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval	Monitoring Well Completion
			Sand Interbedded layers of silty fine-graded sand to silt with clay, no staining and no odors			
			Sand Brown fine-graded silty sand with scattered silt and clay lenses, no staining and no odors, damp			
			No Samples	2.3		
			Silty Sand Brown fine silty with scattered silt and clay lenses, no staining or odors, damp	3.7		
			No Samples			
			Silt Brown with minor clay and fine sand, no staining or odors	8.9		
			No Samples			

Elevation scale: 3132.0, 3131.0, 3130.0, 3129.0, 3128.0, 3127.0, 3126.0, 3125.0, 3124.0, 3123.0, 3122.0, 3121.0, 3120.0, 3119.0, 3118.0, 3117.0, 3116.0, 3115.0, 3114.0, 3113.0

Depth scale: 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40

DRILLING DATE: 7/23-24/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 67.6
TOTAL WELL DEPTH (ft btoc): 67.6
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2
TOC ELEVATION (ft AMSL): 3152.46
GROUND ELEVATION (ft AMSL): 3152.47
DRILLING CO.: O'Keefe
WATER LEVEL (ft btoc): 42.4
GROUNDWATER ELEV (ft AMSL).: 3110.06

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LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW200

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Symbol/ Recovery	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval	Monitoring Well Completion
3112.0, 3111.0	41					
3110.0, 3109.0	42–44		***Sand*** Brown very moist fine with silt grading to wet fine-graded sand and silt, sand content increasing with depth, no odors, no staining	6.2	MW200SB002	
3108.0, 3107.0	44–46		***No Samples***			
3106.0 – 3093.0	46–60		***Sandy Gravel***			

Depth scale: 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60

Elevation scale: 3112.0, 3111.0, 3110.0, 3109.0, 3108.0, 3107.0, 3106.0, 3105.0, 3104.0, 3103.0, 3102.0, 3101.0, 3100.0, 3099.0, 3098.0, 3097.0, 3096.0, 3095.0, 3094.0, 3093.0

DRILLING DATE: 7/23-24/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 67.6
TOTAL WELL DEPTH (ft btoc): 67.6
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2
TOC ELEVATION (ft AMSL): 3152.46
GROUND ELEVATION (ft AMSL): 3152.47
DRILLING CO.: O'Keefe
WATER LEVEL (ft btoc): 42.4
GROUNDWATER ELEV (ft AMSL).: 3110.06

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YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW200

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Symbol/ Recovery	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval	Monitoring Well Completion
3092.0 – 3086.0	60.5 – 66					
3086.0 – 3084.5	66 – 67.6		***Bedrock***			
			End of Log			

Elevation scale: 3092.0, 3091.0, 3090.0, 3089.0, 3088.0, 3087.0, 3086.0, 3085.0, 3084.0, 3083.0, 3082.0, 3081.0, 3080.0, 3079.0, 3078.0, 3077.0, 3076.0, 3075.0, 3074.0, 3073.0

Depth scale: 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80

DRILLING DATE: 7/23-24/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 67.6
TOTAL WELL DEPTH (ft btoc): 67.6
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2
TOC ELEVATION (ft AMSL): 3152.46
GROUND ELEVATION (ft AMSL): 3152.47
DRILLING CO.: O'Keefe
WATER LEVEL (ft btoc): 42.4
GROUNDWATER ELEV (ft AMSL).: 3110.06

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YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW201

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval
3152.6	0	Ground Surface		
	0	***No Samples***		
3151.0	1	***Gravel*** Gravel		
3150.0	2	***Silt*** Brown silt with minor clay, grades at depth to silt with some fine-graded sand, no odors and no staining	145	
3149.0	3			
3148.0	4	***Silt*** Brown silt with fine-graded sand to thin gravel at about 5 feet	64	
3147.0	5	***Sand*** Sand and fine to medium graded gravel, subrounded with minor silt, no odors or staining		
3146.0	6			
3145.0	7	***Sand*** Sand and fine to medium gravel, subrounded, minor silt with no odors and no staining	245	MW201SB001
3144.0	8			
3143.0	9	***Silt*** With sand no odors or staining	19	
3142.0	10	***Sand*** Sand and gravel at the top 1 inch of split spoon		
3141.0	11			
3140.0	12	***Sand*** Fine sand with silt, no staining or odors	2.5	
3139.0	13	***Silt*** Silt and fine-graded sand, only small amount in split spoon recovered not enough for a sample.	0.7	
3138.0	14			
3137.0	15	***Silt*** Silt and fine sand with minor scattered pebbles grades to fine silty sand at depth, no staining or odors		
3136.0	16			
3135.0	17	***Silt*** Brown silt with some clay which changes to silt with minor sand which grades to fine sand at bottom of spilt spoon	2.5	
3134.0	18			
3133.0	19		8.1	
	20			

Lithologic Symbol/ Recovery | Monitoring Well Completion

DRILLING DATE: 6/25/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 69
TOTAL WELL DEPTH (ft btoc): 67.5
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2.0
TOC ELEVATION (ft AMSL): 3152.24
GROUND ELEVATION (ft AMSL): 3152.57
DRILLING CO.: Maxim
WATER LEVEL (ft btoc): 42.1 (10/28/02)
GROUNDWATER ELEV (ft AMSL).: 3110.14

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LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW201

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Symbol/ Recovery	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval	Monitoring Well Completion
3132.0 – 3131.0	21		***Sand*** Brown fine sand with silt which changes to silt with minor fine sand at bottom of split spoon, no staining or odors			
3130.0 – 3129.0	22 – 23		***Silt*** Brown silt with minor clay and variable fine sand, fine sand content increases with depth, not staining or odors	34.5		
3128.0 – 3127.0	24 – 26		***Silt*** Brown silt with minor clay and variable fine sand, no staining or odors	37.7		
3126.0 – 3124.0	27 – 28		***Silt*** Brown silt with minor clay interbedded with fine sand with some silt, layers 2-3 inches thick, soft and moist with no staining or odors	26.3		
3123.0 – 3122.0	29 – 31		***Silt*** Same as above with increasing fine sand towards bottom, not staining or odors	29.1		
3121.0 – 3119.0	32 – 33		***Silt*** Same as above, interbedded silt and fine sand layers, bottom 3 inches very moist and soft, no staining or odors	38.6		
3118.0	34		***Silt*** Brown very moist to wet 5 inches of silt with fine sand	24.6		
3117.0	35 – 36		***Clay*** Very tight clay with silt, damp		MW201SB002	
3116.0	37		***Silt*** Softer moist silt with fine-graded sand for bottom 3 inches, no staining or odors	6.8		
3115.0 – 3114.0	38		***Silt*** Brown silt changing to fine-graded sand with variable silt near top			
3113.0	39 – 40		***Sand*** One cm layer of coarser oxidized sand and trace of fine gravel at 37.5	14.7		

DRILLING DATE: 6/25/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 69
TOTAL WELL DEPTH (ft btoc): 67.5
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2.0
TOC ELEVATION (ft AMSL): 3152.24
GROUND ELEVATION (ft AMSL): 3152.57
DRILLING CO.: Maxim
WATER LEVEL (ft btoc): 42.1 (10/28/02)
GROUNDWATER ELEV (ft AMSL).: 3110.14

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LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

YELLOWSTONE COUNTY MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW201

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval
3112.0	41	***Silt*** Brown silt changing to fine-graded sand with variable silt near top		
3111.0	42	***Silt*** Brown silt		
3110.0	43	***Sand*** Fine-graded sand with silt	9.8	
3109.0	44	***Clay*** Clay with silt		
3108.0	45	***Sand*** Brown fine-graded sand with silt changing to very moist (almost wet), soft with silt and fine-graded sand	11.5	MW201SB003
3107.0	46			
3106.0	47	***Sand*** Brown fine-graded sand with variable silt becoming wet at 44 feet		
3105.0	48	***No Samples***		
3104.0	49			
3103.0	50	***Sand with Gravel*** Brown medium-graded sand with abundant fine to medium rounded to subrounded gravel, no staining or odors	1.9	
3102.0	51	***No Samples***		
3101.0	52			
3100.0	53			
3099.0	54	***Sandy Gravel*** Brown medium-graded sand with abundant fine to medium rounded to subrounded gravel, no staining or odors	0.5	
3098.0	55			
3097.0	56	***No Samples***		
3096.0	57			
3095.0	58			
3094.0	59			
3093.0	60	***Sandy Gravel***	0.1	

Lithologic Symbol/ Recovery | Monitoring Well Completion

DRILLING DATE: 6/25/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 69
TOTAL WELL DEPTH (ft btoc): 67.5
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2.0
TOC ELEVATION (ft AMSL): 3152.24
GROUND ELEVATION (ft AMSL): 3152.57
DRILLING CO.: Maxim
WATER LEVEL (ft btoc): 42.1 (10/28/02)
GROUNDWATER ELEV (ft AMSL).: 3110.14

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LOCKWOOD SOLVENT
GROUNDWATER PLUME SITE
YELLOWSTONE COUNTY
MONTANA

LOG OF BOREHOLE

Borehole/Well ID: MW201

Elevation (+/- AMSL)	Depth (ft bgs)	Lithologic Symbol/ Recovery	Lithologic Description	Headspace PID Reading	Soil Sample ID/ Sample Interval	Monitoring Well Completion
3092.0 – 3088.0	61–64		***No Samples***			
3088.0 – 3087.0	64–65		***Gravelly Sand*** Medium to coarse sand with some fine to medium graded gravel, more sand than gravel no staining and no odors	0.3	MW201SB004	
3087.0 – 3085.0	65–67		***No Samples***			
3085.0 – 3083.0	67–69		***Bedrock***			
	69		End of Log			

Elevation scale: 3092.0, 3091.0, 3090.0, 3089.0, 3088.0, 3087.0, 3086.0, 3085.0, 3084.0, 3083.0, 3082.0, 3081.0, 3080.0, 3079.0, 3078.0, 3077.0, 3076.0, 3075.0, 3074.0, 3073.0

Depth scale: 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80

DRILLING DATE: 6/25/02
DRILLING METHOD: HSA
BOREHOLE DEPTH (ft bgs): 69
TOTAL WELL DEPTH (ft btoc): 67.5
LOGGED BY: Randy Laskowski
CLIENT: MDEQ
PROJECT NO.: S1176-10RIRPRT

BOREHOLE DIAMETER (in.): 8.25
WELL CASING DIAMETER (in.): 2.0
TOC ELEVATION (ft AMSL): 3152.24
GROUND ELEVATION (ft AMSL): 3152.57
DRILLING CO.: Maxim
WATER LEVEL (ft btoc): 42.1 (10/28/02)
GROUNDWATER ELEV (ft AMSL).: 3110.14

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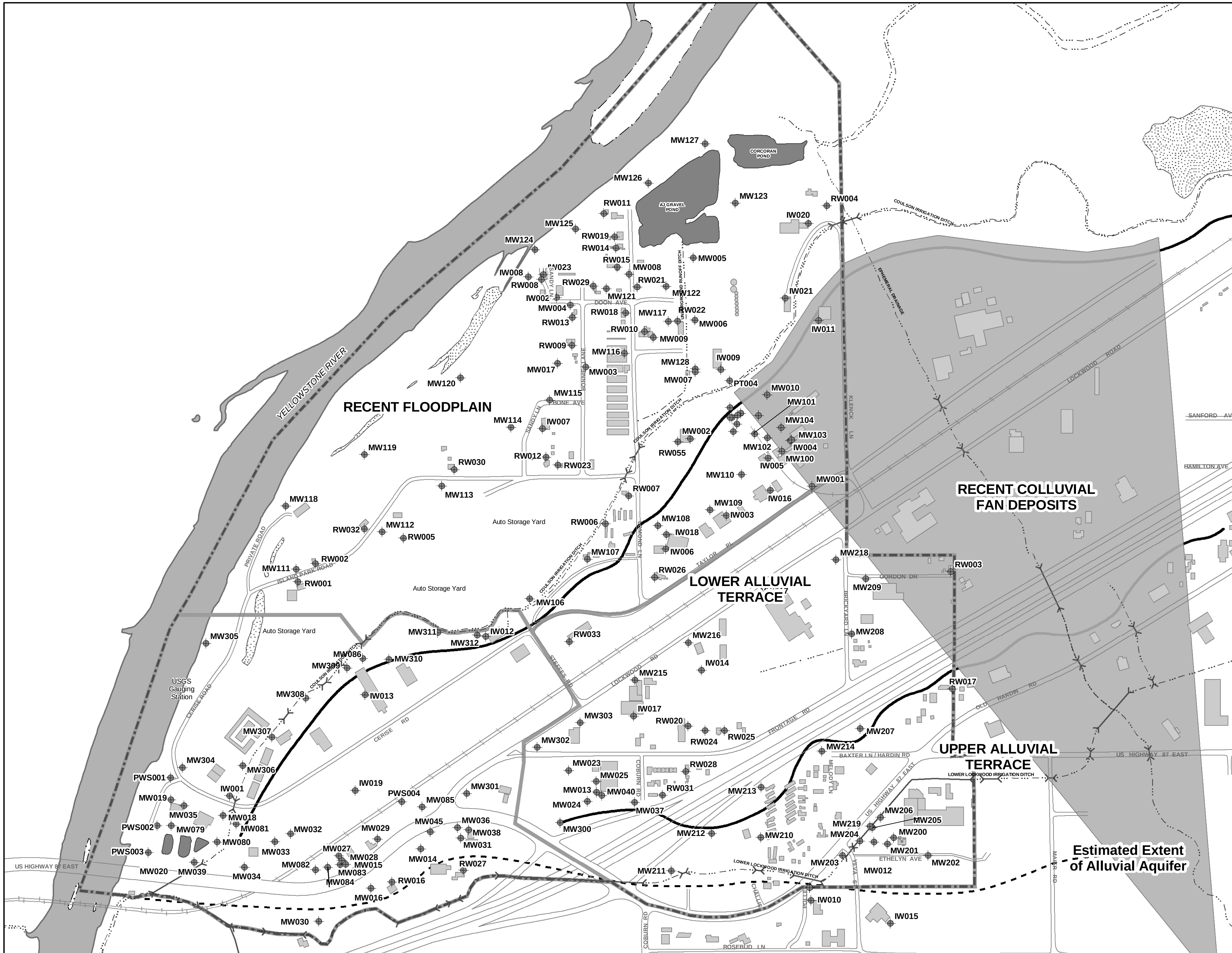


Legend

- Well Locations
- Roads
- Ditches
- Railroad
- Fence Line
- Culvert
- Area Delineations
- Site Boundary
- Alluvial Aquifer Extent
- Terrace Boundaries
- Buildings
- River Islands
- Ponds
- River
- Wetlands
- Recent Colluvial Fan Deposit

650 0 650 Feet

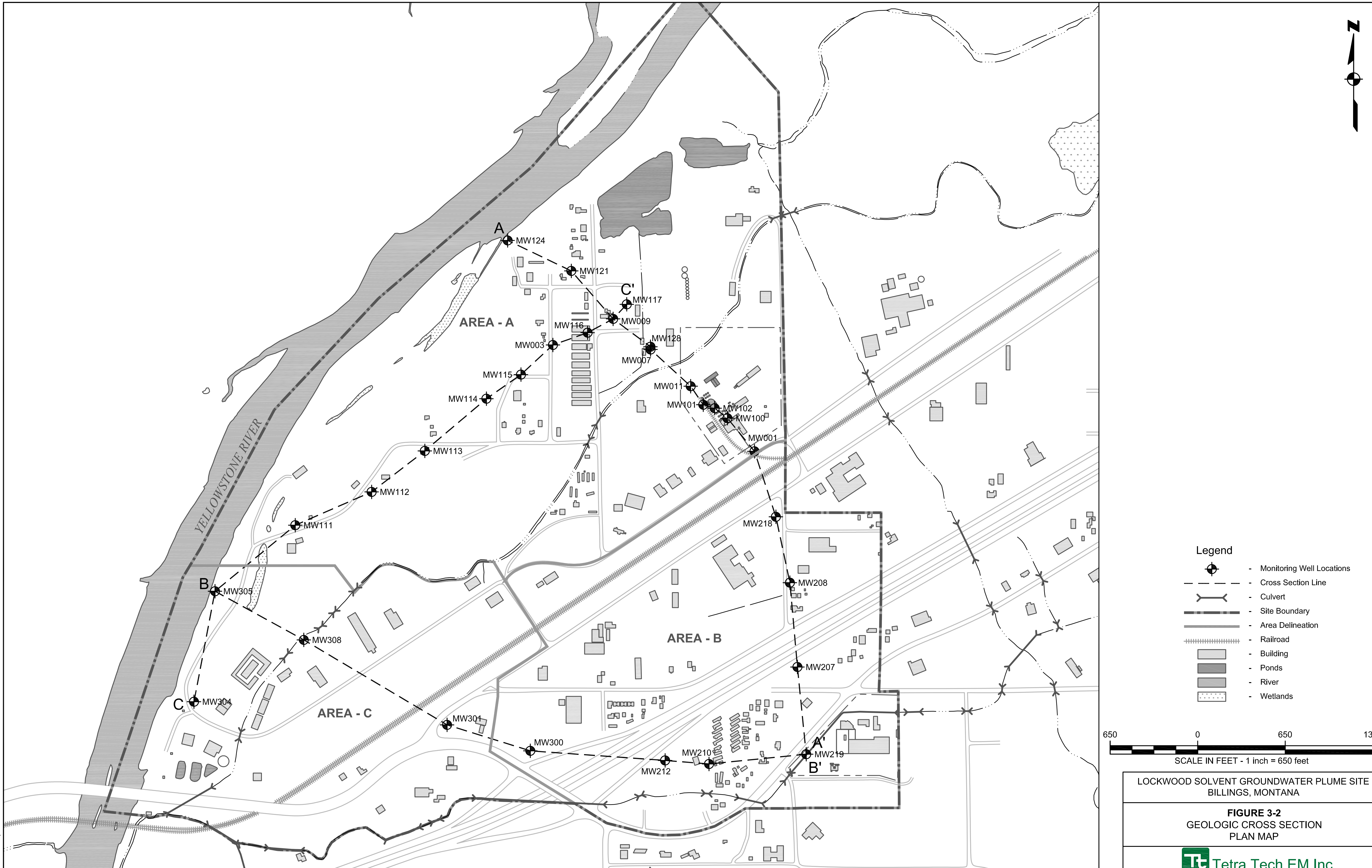
LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-1

GEOMORPHIC FEATURES

Tetra Tech EM Inc.

Fig3-1_GeomorphicFeats.mxd RSR 2/20/03 S1176-10RIRPRT

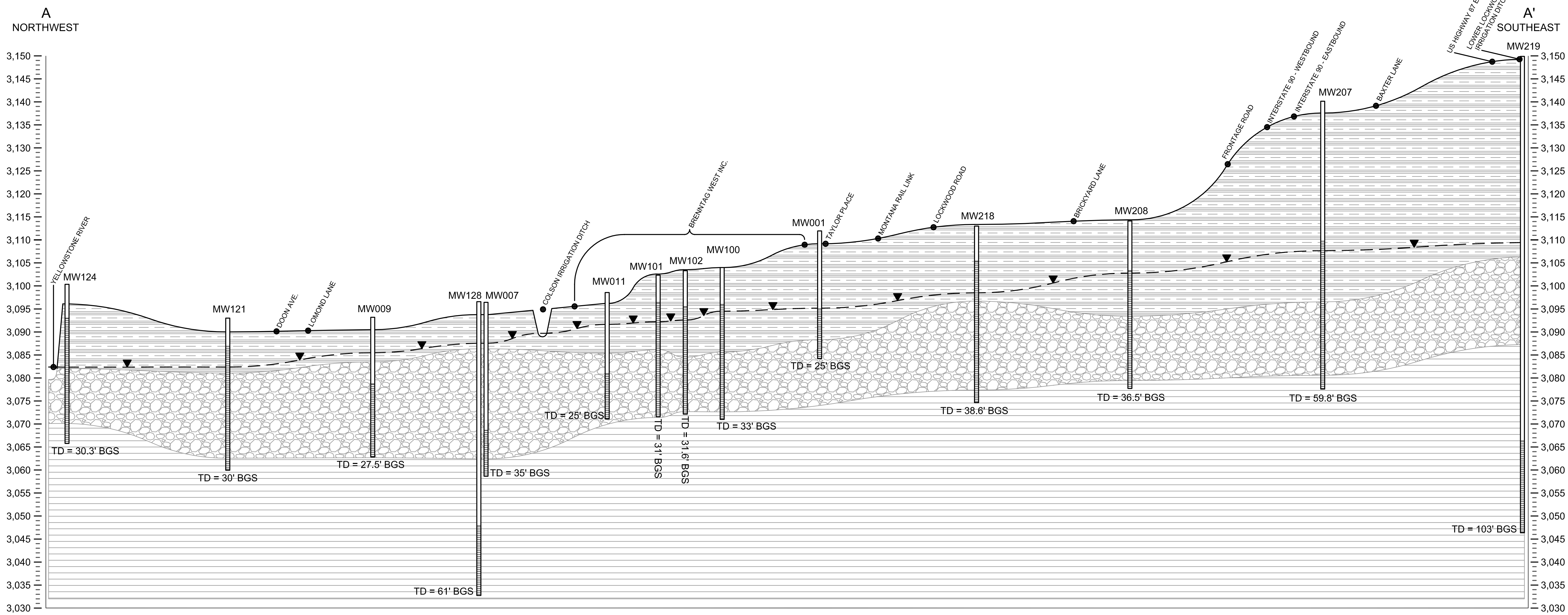


LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-2
GEOLOGIC CROSS SECTION
PLAN MAP

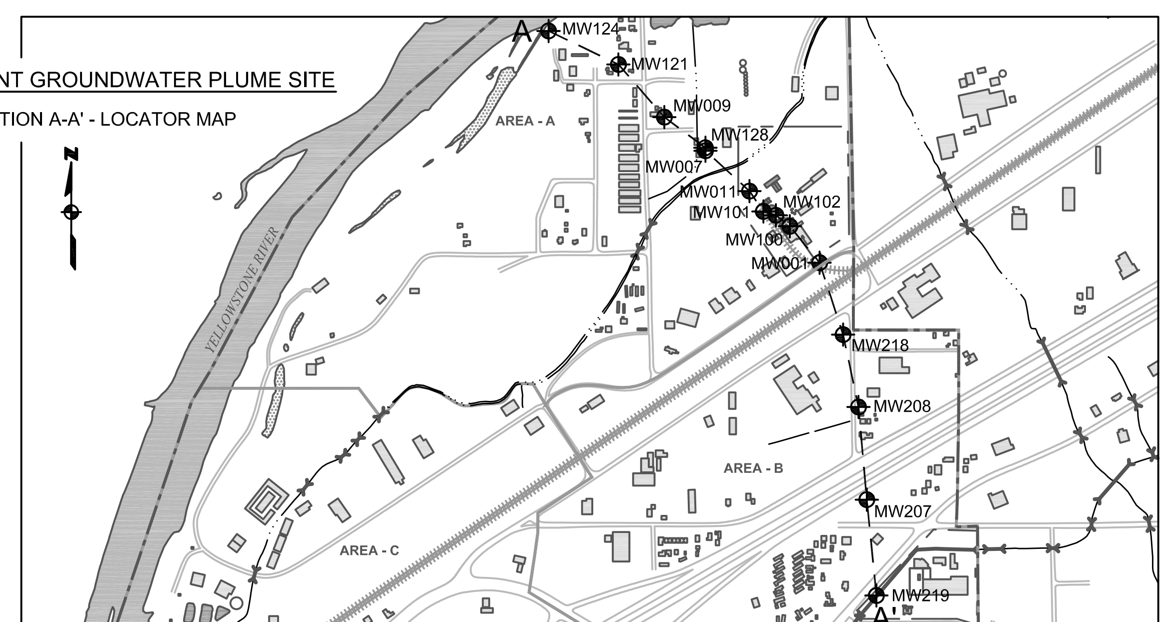
Tetra Tech EM Inc.

x-sect base map - DWH - 05/29/2003 - S1176-10-RIRPRT



LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

CROSS SECTION A-A' - LOCATOR MAP

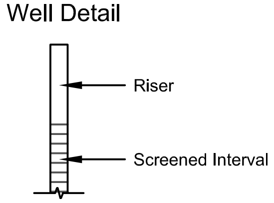


Legend

MW	-	Monitoring Well Locations
TD	-	Total Depth
BGS	-	Below Ground Surface
(symbol)	-	Groundwater Level
(symbol)	-	Silty Clay / Silt / Fine Sand
(symbol)	-	Gravels With Sand
(symbol)	-	Bedrock

Elevations Listed In Feet Above Mean Sea Level

Well Detail



325 0 325 650

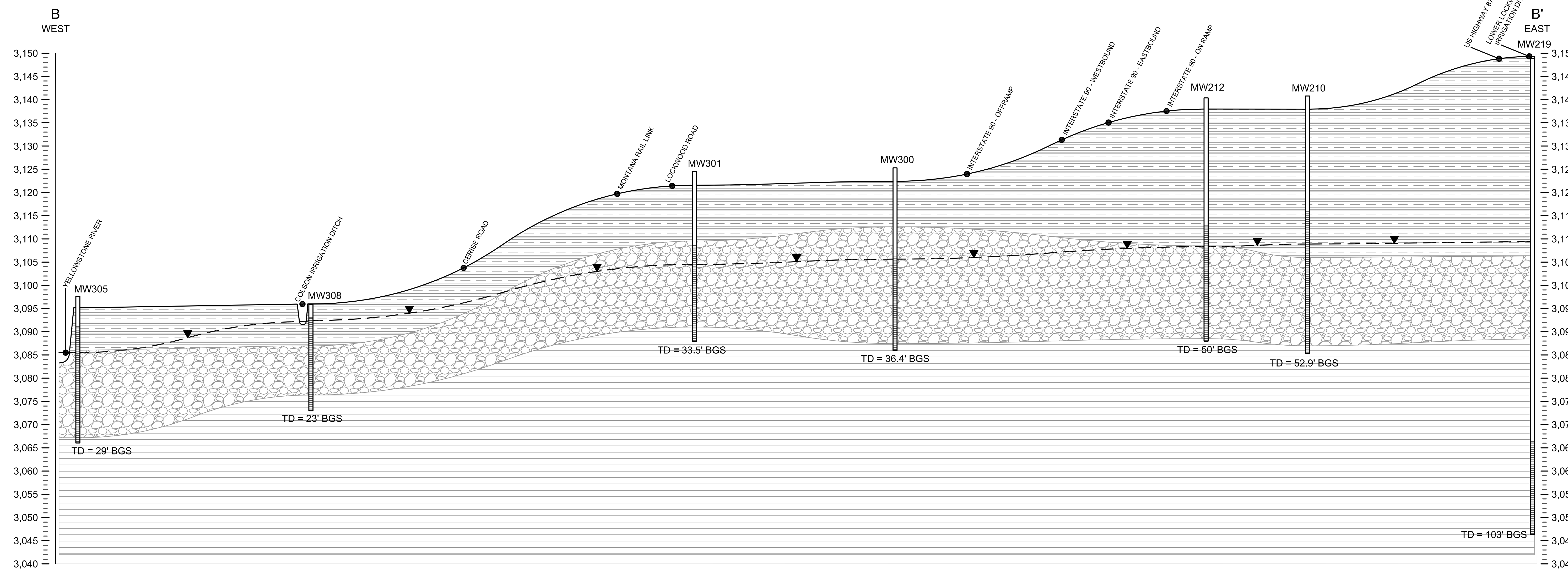
SCALE IN FEET - 1 inch = 325 feet
VERTICAL SCALE EXAGGERATED 15X

LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-3
GEOLOGIC CROSS SECTION
A-A'

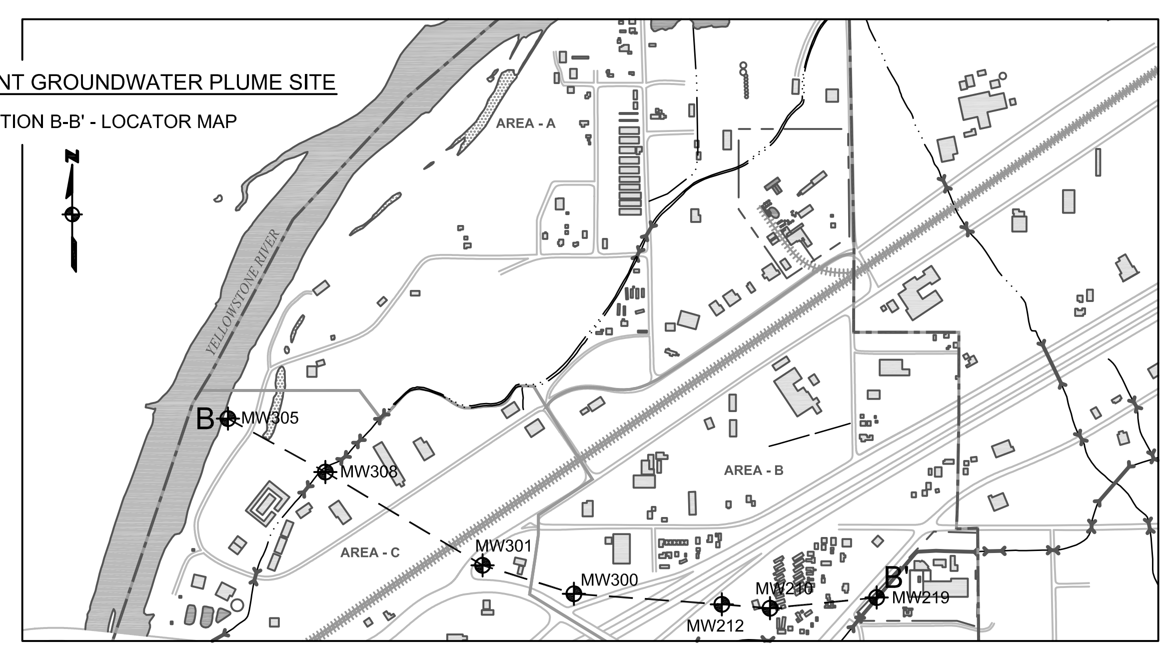
Tetra Tech EM Inc.

x-sect base map - DWH - 05/29/2003 - S1176-10-RIRPRT



LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

CROSS SECTION B-B' - LOCATOR MAP

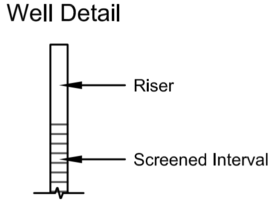


Legend

MW - Monitoring Well Locations
TD - Total Depth
BGS - Below Ground Surface
Groundwater Level
Silty Clay / Silt / Fine Sand
Gravels With Sand
Bedrock

Elevations Listed In Feet Above Mean Sea Level

Well Detail



325 0 325 650

SCALE IN FEET - 1 inch = 325 feet
VERTICAL SCALE EXAGGERATED 15X

LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-4
GEOLOGIC CROSS SECTION
B-B'

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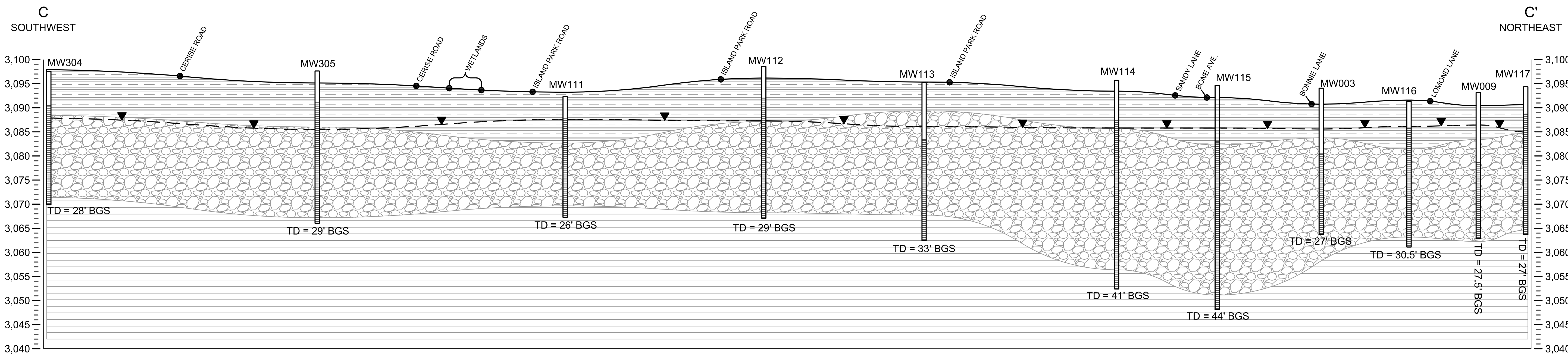
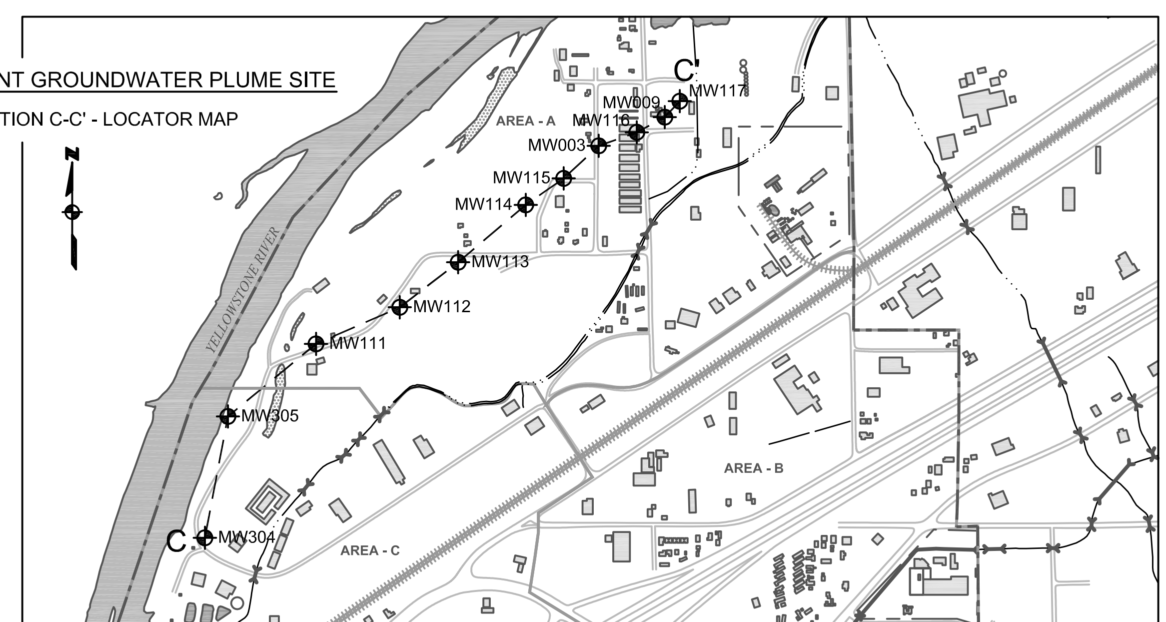
x-sect base map - DWH - 05/29/2003 - S1176-10-RIRPRT



LOCKWOOD SOLVENT GROUNDWATER PLUME SITE

CROSS SECTION C-C' - LOCATOR MAP

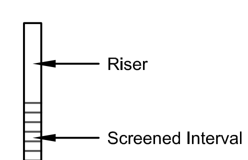


Legend

MW	-	Monitoring Well Locations
TD	-	Total Depth
BGS	-	Below Ground Surface
▼	-	Groundwater Level
	-	Silty Clay / Silt / Fine Sand
	-	Gravels With Sand
	-	Bedrock

Elevations Listed In Feet Above Mean Sea Level

Well Detail



325 0 325 650

SCALE IN FEET - 1 inch = 325 feet

VERTICAL SCALE EXAGGERATED 15X

LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-5
GEOLOGIC CROSS SECTION
C-C'

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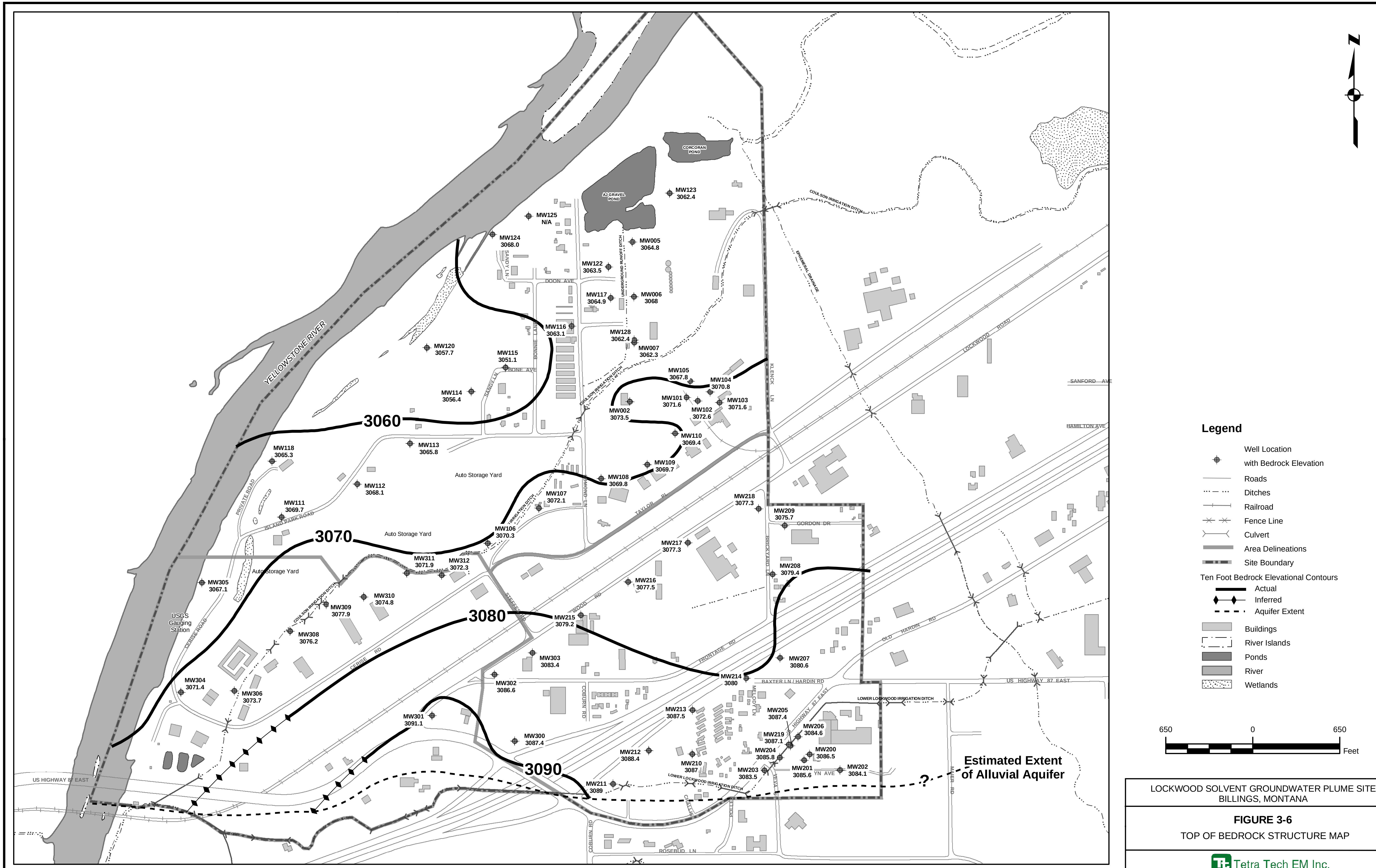
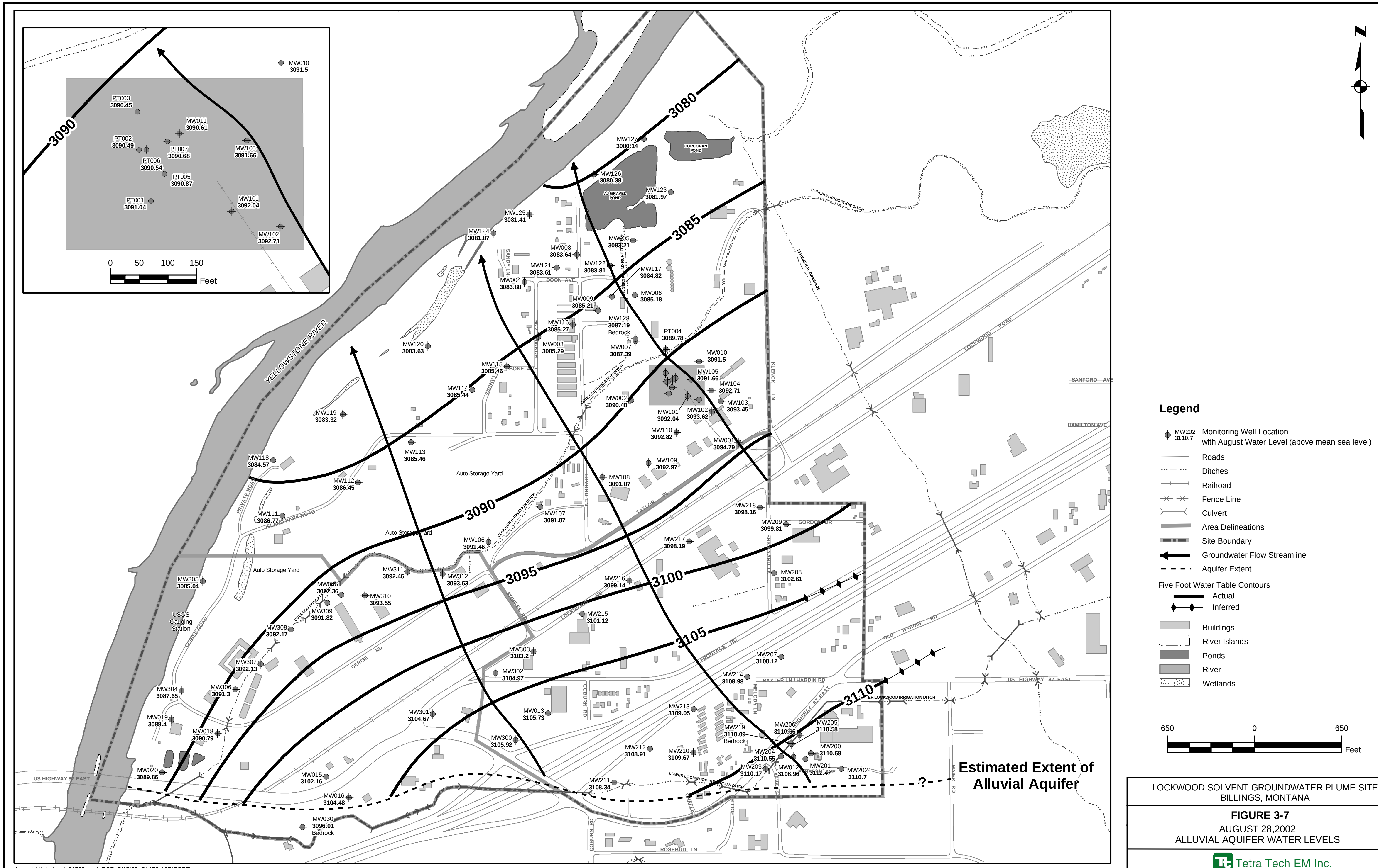
x-sect base map - DWH - 05/29/2003 - S1176-10-RIRPRT



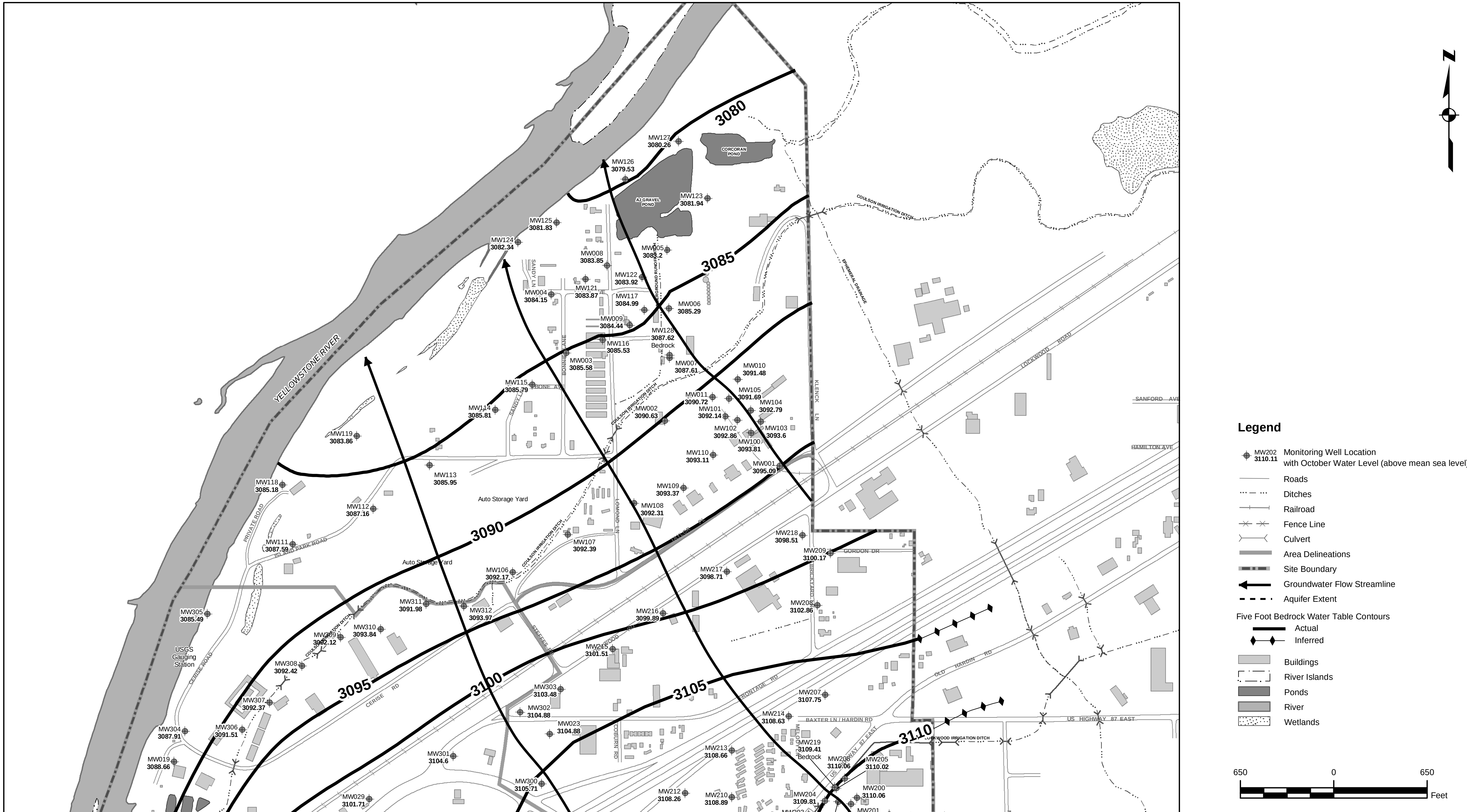
YELLOWSTONE RIVER
CORCORAN POND
AJ GRAVEL POND
Auto Storage Yard
USGS Gauging Station
3060
3070
3080
3090
MW123 3062.4
MW125 N/A
MW124 3068.0
MW005 3064.8
MW122 3063.5
MW117 3064.9
MW006 3068
MW116 3063.1
MW128 3062.4
MW007 3062.3
MW120 3057.7
MW115 3051.1
MW114 3056.4
MW105 3067.8
MW104 3070.8
MW101 3071.6
MW102 3072.6
MW103 3071.6
MW002 3073.5
MW110 3069.4
MW113 3065.8
MW118 3065.3
MW109 3069.7
MW108 3069.8
MW112 3068.1
MW107 3072.1
MW111 3069.7
MW218 3077.3
MW209 3075.7
MW106 3070.3
MW217 3077.3
MW311 3071.9
MW312 3072.3
MW208 3079.4
MW305 3067.1
MW216 3077.5
MW310 3074.8
MW309 3077.9
MW215 3079.2
MW308 3076.2
MW303 3083.4
MW207 3080.6
MW214 3080
MW304 3071.4
MW302 3086.6
MW306 3073.7
MW213 3087.5
MW205 3087.4
MW301 3091.1
MW206 3084.6
MW219 3087.1
MW300 3087.4
MW212 3088.4
MW204 3085.8
MW200 3086.5
MW210 3087
MW203 3083.5
MW201 3085.6
MW202 3084.1
MW211 3089
Estimated Extent of Alluvial Aquifer
?
US HIGHWAY 87 EAST
LOWER LOCKWOOD IRRIGATION DITCH
COULSON IRRIGATION DITCH
EPHEMERAL DRAINAGE
LOCKWOOD ROAD
SANFORD AVE
HAMILTON AVE
OLD HARDIN RD
FRONTAGE RD
BAXTER LN / HARDIN RD
GORDON DR
DOON AVE
BONE AVE
TAYLOR PL
ISLAND PARK ROAD
PRIVATE ROAD
CERISE ROAD
COBURN RD
ROSEBUD LN
KLENCK LN
BRICKYARD LN
MELODY LN
SANDY LN
BONNIE LN
Legend
Well Location with Bedrock Elevation
Roads
Ditches
Railroad
Fence Line
Culvert
Area Delineations
Site Boundary
Ten Foot Bedrock Elevational Contours
Actual
Inferred
Aquifer Extent
Buildings
River Islands
Ponds
River
Wetlands
650 0 650
Feet
N
LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA
FIGURE 3-6
TOP OF BEDROCK STRUCTURE MAP
Tetra Tech EM Inc.
Bedrock Elevations.mxd RSR 11/25/02 S1176-10RIRPRT



LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-7
AUGUST 28,2002
ALLUVIAL AQUIFER WATER LEVELS

Tetra Tech EM Inc.



LOCKWOOD SOLVENT GROUNDWATER PLUME SITE
BILLINGS, MONTANA

FIGURE 3-8
OCTOBER 28, 2002
ALLUVIAL AQUIFER WATER LEVELS

Tetra Tech EM Inc.

October_Waterlevel_051503.mxd RSR 5/15/03 S1176-10RIRPRT

ATTACHMENT C
MONITORING AND REMEDIATION OPTIMIZATION SYSTEM ANALYSIS REPORTS

Attachment B
MAROS Software Reports

West Lobe of Plume

Mann-Kendall Individual Well Trend Analysis
Individual Well Summary
MK TCE Trend Well MW-212
MK TCE Trend Well MW-213
First Moment – Total Dissolved Mass in West Lobe
Percent Mass by Well – West Lobe

MAROS Mann-Kendall Statistics Summary

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

Time Period: 4/25/2003 **to** 5/4/2012
Consolidation Period: No Time Consolidation
Consolidation Type: Median
Duplicate Consolidation: Average
ND Values: 1/2 Detection Limit
J Flag Values : Actual Value

Well	Source/ Tail	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples "ND" ?	Concentration Trend
cis-1,2-DICHLOROETHYLENE								
MW012	T	7	7	0.59	-11	93.2%	No	PD
MW023	T	7	5	0.44	-16	99.0%	No	D
MW200	S	7	7	0.68	-3	61.4%	No	S
MW201	S	7	7	0.59	-5	71.9%	No	S
MW202	S	5	2	0.69	1	50.0%	No	NT
MW203	S	7	7	0.68	-3	61.4%	No	S
MW204	S	7	7	0.93	-7	80.9%	No	S
MW210	T	8	8	1.27	-10	86.2%	No	NT
MW211	T	7	1	0.33	-2	55.7%	No	S
MW212	T	7	7	0.54	-17	99.5%	No	D
MW213	T	7	2	0.31	-7	80.9%	No	S
MW215	T	4	4	0.21	-4	83.3%	No	S
MW219	S	7	7	0.30	-3	61.4%	No	S
MW300	T	7	7	0.89	-17	99.5%	No	D
MW301	T	8	8	0.45	-10	86.2%	No	S
MW302	T	4	3	0.54	2	62.5%	No	NT
MW303	T	4	2	0.20	1	50.0%	No	NT
TRICHLOROETHYLENE (TCE)								
MW012	T	7	7	0.34	-1	50.0%	No	S
MW023	T	7	7	0.40	-20	100.0%	No	D
MW200	S	7	7	0.60	-7	80.9%	No	S
MW201	S	7	7	0.43	-1	50.0%	No	S
MW202	S	5	3	1.03	1	50.0%	No	NT
MW203	S	7	7	0.69	9	88.1%	No	NT
MW204	S	7	7	0.59	-5	71.9%	No	S
MW210	T	8	8	0.97	-8	80.1%	No	S

MAROS Mann-Kendall Statistics Summary

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

TRICHLOROETHYLENE (TCE)

Well	Source/ Tail	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples "ND" ?	Concentration Trend
MW211	T	7	4	1.11	-14	97.5%	No	D
MW212	T	7	7	0.33	-9	88.1%	No	S
MW213	T	7	6	0.58	9	88.1%	No	NT
MW215	T	4	4	0.26	-6	95.8%	No	D
MW219	S	7	2	1.88	-3	61.4%	No	NT
MW300	T	7	7	0.72	-21	100.0%	No	D
MW301	T	8	8	0.26	-1	50.0%	No	S
MW302	T	4	3	0.65	2	62.5%	No	NT
MW303	T	4	4	0.26	-2	62.5%	No	S

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

MAROS Individual Well Summary Report

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

COC	Priority COC for Well?	Detection Frequency	Recent Sample Above Goal?	MK Trend	COV	95% UCL	Outlier	Distribution Assumption	Attained Cleanup?	
									Normal	Lognormal
MW012										
DCE12C	NO	100 %	NO	PD	0.56	0.0823	NO	Normal	NO	NO
TCE	NO	100 %	YES	S	0.30	0.0251	NO	Normal	NO	NO
MW023										
DCE12C	YES	75 %	NO	D	0.77	0.0006	NO	Normal	YES	NO
TCE	YES	100 %	NO	D	0.35	0.0020	NO	Normal	YES	NO
MW200										
DCE12C	NO	89 %	YES	S	0.73	0.2147	YES	Normal	NO	NO
TCE	YES	89 %	YES	S	0.63	0.7387	NO	Normal	NO	NO
MW201										
DCE12C	NO	100 %	YES	S	0.56	0.8952	NO	Normal	NO	NO
TCE	YES	100 %	YES	S	0.37	1.1748	NO	Normal	NO	NO
MW202										
DCE12C	NO	40 %	NO	NT	1.84	0.0008	NO	Lognormal	YES	NO
TCE	NO	60 %	NO	NT	1.07	0.0046	NO	Normal	NO	NO
MW203										
DCE12C	NO	100 %	YES	S	0.59	0.1700	NO	Normal	NO	NO
TCE	YES	100 %	YES	NT	0.51	0.1328	NO	Normal	NO	NO
MW204										
DCE12C	NO	100 %	NO	S	1.09	0.0889	NO	Normal	NO	NO
TCE	NO	100 %	YES	S	0.57	0.0504	NO	Normal	NO	NO
MW210										
DCE12C	NO	100 %	NO	NT	1.27	0.0520	YES	Lognormal	YES	NO
TCE	YES	100 %	YES	S	0.94	0.0562	YES	No distribution	NO	NO
MW211										
DCE12C	NO	14 %	NO	S	0.00	0.0004	YES	No distribution	YES	YES
TCE	NO	57 %	NO	D	1.30	0.0020	YES	Lognormal	YES	NO
MW212										
DCE12C	NO	100 %	NO	D	0.55	0.0447	NO	Normal	YES	NO

MAROS Individual Well Summary Report

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

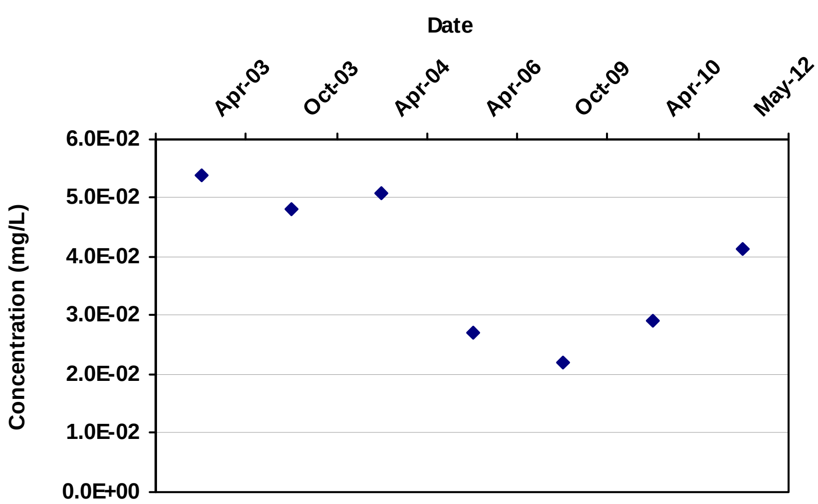
COC	Priority COC for Well?	Detection Frequency	Recent Sample Above Goal?	MK Trend	COV	95% UCL	Outlier	Distribution Assumption	Attained Cleanup?	
									Normal	Lognormal
TCE	NO	100 %	YES	S	0.33	0.0508	NO	Normal	NO	NO
MW213										
DCE12C	NO	29 %	NO	S	0.71	0.0003	YES	No distribution	YES	NO
TCE	NO	86 %	NO	NT	0.59	0.0026	NO	Normal	YES	NO
MW215										
DCE12C	NO	100 %	NO	S	0.21	0.0009	NO	Normal	NO	NO
TCE	YES	100 %	NO	D	0.24	0.0044	NO	Normal	NO	NO
MW219										
DCE12C	NO	100 %	NO	S	0.28	0.0017	NO	Normal	YES	NO
TCE	NO	38 %	NO	NT	1.91	0.0053	YES	No distribution	NO	NO
MW300										
DCE12C	NO	100 %	NO	D	0.81	0.0111	YES	Normal	YES	NO
TCE	YES	100 %	NO	D	0.52	0.0130	YES	Normal	NO	NO
MW301										
DCE12C	NO	100 %	NO	S	0.45	0.0084	NO	Normal	YES	YES
TCE	NO	100 %	YES	S	0.23	0.0073	NO	Normal	NO	NO
MW302										
DCE12C	NO	75 %	NO	NT	0.79	0.0014	NO	Normal	NO	NO
TCE	YES	75 %	NO	NT	0.81	0.0012	NO	Normal	NO	NO
MW303										
DCE12C	NO	50 %	NO	NT	0.93	0.0004	YES	Normal	NO	NO
TCE	YES	100 %	NO	S	0.17	0.0028	NO	Normal	NO	NO

MAROS Mann-Kendall Statistics Summary

Project: Lockwood | **User Name:** MV
Location: OU1 | **State:** Montana

Well: MW212
Well Type: T
COC: TRICHLOROETHYLENE (TCE)

Time Period: 4/25/2003 **to** 5/4/2012
Consolidation Period: No Time Consolidation
Duplicate Consolidation: Median
Consolidation Type: Average
ND Values: 1/2 Detection Limit
J Flag Values : Actual Value



Mann Kendall S Statistic:

-9

Confidence in Trend:

88.1%

Coefficient of Variation:

0.33

Mann Kendall Concentration Trend: (See Note)

S

Data Table:

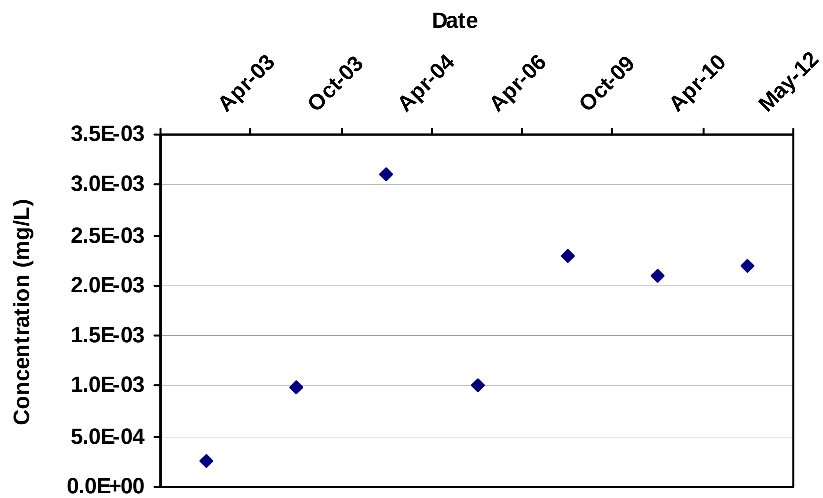
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW212	T	4/25/2003	TRICHLOROETHYLEN	5.4E-02		2	2
MW212	T	10/24/2003	TRICHLOROETHYLEN	4.8E-02		2	2
MW212	T	4/23/2004	TRICHLOROETHYLEN	5.1E-02		2	2
MW212	T	4/6/2006	TRICHLOROETHYLEN	2.7E-02		2	2
MW212	T	10/8/2009	TRICHLOROETHYLEN	2.2E-02		2	2
MW212	T	4/15/2010	TRICHLOROETHYLEN	2.9E-02		2	2
MW212	T	5/4/2012	TRICHLOROETHYLEN	4.2E-02		4	4

MAROS Mann-Kendall Statistics Summary

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

Well:	MW213	**Time Period:**	4/25/2003 **to** 5/4/2012
Well Type:	T	**Consolidation Period:**	No Time Consolidation
COC:	TRICHLOROETHYLENE (TCE)	**Duplicate Consolidation:**	Median
		Consolidation Type:	Average
		ND Values:	1/2 Detection Limit
		J Flag Values :	Actual Value



Mann Kendall S Statistic:

9

Confidence in Trend:

88.1%

Coefficient of Variation:

0.58

Mann Kendall Concentration Trend: (See Note)

NT

Data Table:

Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW213	T	4/25/2003	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW213	T	10/24/2003	TRICHLOROETHYLEN	9.9E-04		2	2
MW213	T	4/23/2004	TRICHLOROETHYLEN	3.1E-03		2	2
MW213	T	4/6/2006	TRICHLOROETHYLEN	1.0E-03		2	2
MW213	T	10/8/2009	TRICHLOROETHYLEN	2.3E-03		2	2
MW213	T	4/15/2010	TRICHLOROETHYLEN	2.1E-03		2	2
MW213	T	5/4/2012	TRICHLOROETHYLEN	2.2E-03		2	2

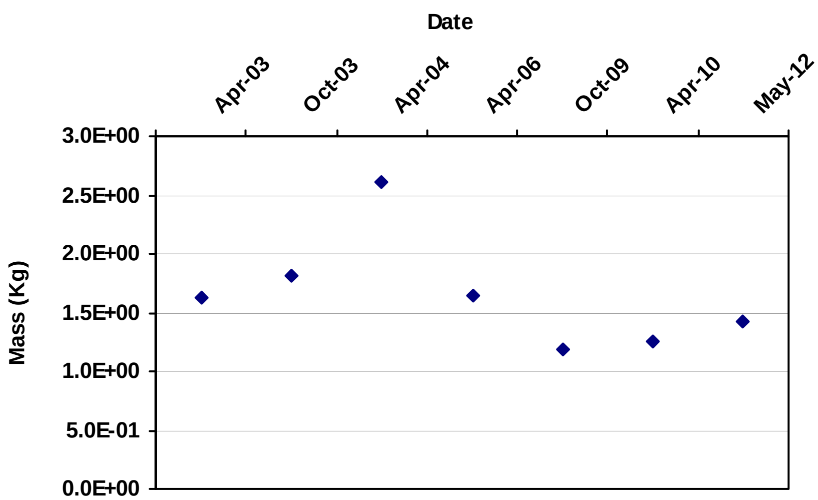
MAROS Zeroth Moment Analysis

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

Change in Dissolved Mass Over Time

COC: TRICHLOROETHYLENE (TCE)



Porosity: 0.25

Saturated Thickness:

Uniform: 20 ft

Mann-Kendall S Statistic:

-7

Confidence in Trend:

80.9%

Coefficient of Variation:

0.29

Zeroth Moment Trend:

S

Data Table:

Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
4/25/2003	TRICHLOROETHYLENE (TCE)	1.6E+00	17
10/24/2003	TRICHLOROETHYLENE (TCE)	1.8E+00	17
4/23/2004	TRICHLOROETHYLENE (TCE)	2.6E+00	17
4/6/2006	TRICHLOROETHYLENE (TCE)	1.6E+00	15
10/8/2009	TRICHLOROETHYLENE (TCE)	1.2E+00	14
4/15/2010	TRICHLOROETHYLENE (TCE)	1.3E+00	14
5/4/2012	TRICHLOROETHYLENE (TCE)	1.4E+00	13

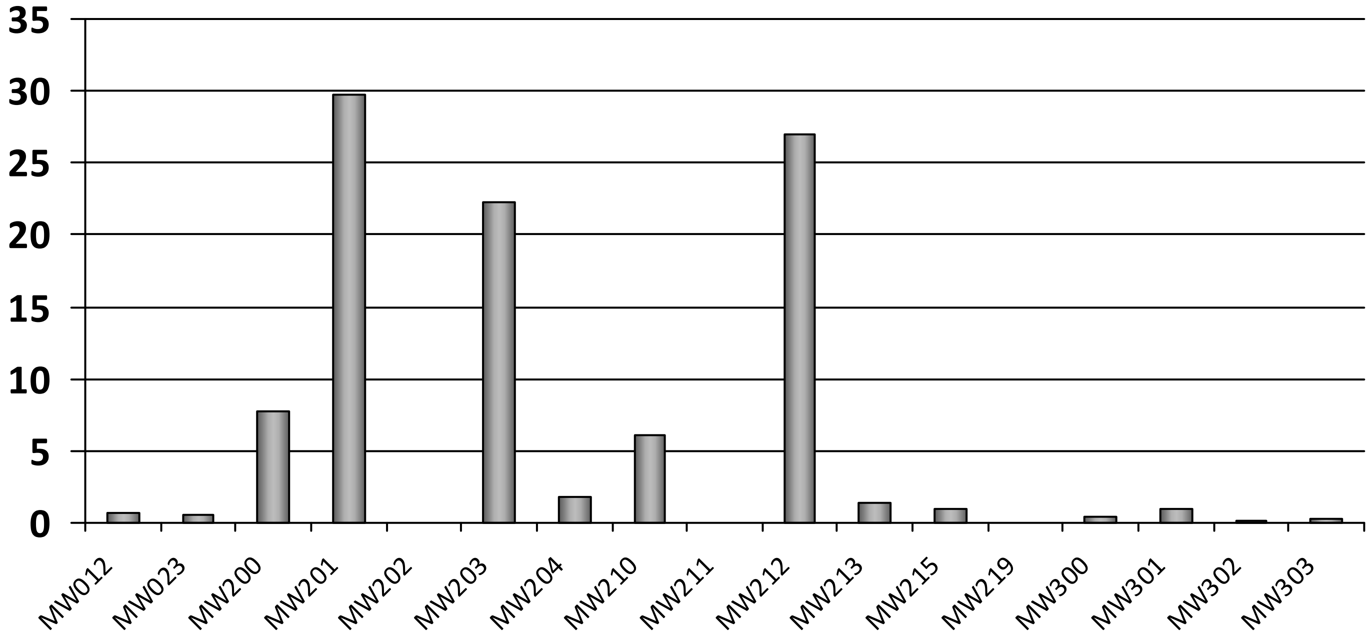
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); ND = Non-detect. Moments are not calculated for sample events with less than 6 wells.

MAROS Percent of Mass by Well

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

TRICHLOROETHYLENE (TCE) 5/4/2012



Well	Area (ft2)	Mass (mg)	Percent of Mass	Percent of Area
MW012	14,753.22	49.05	0.64	0.80
MW023	216,010.67	37.80	0.49	11.70
MW200	11,506.42	594.02	7.72	0.62
MW201	15,777.81	2,291.73	29.78	0.85
MW202	5,323.42	0.23	0.00	0.29
MW203	81,636.18	1,714.36	22.28	4.42
MW204	39,572.27	133.89	1.74	2.14
MW210	157,876.03	469.68	6.10	8.55
MW211	99,453.77	4.35	0.06	5.39
MW212	285,878.17	2,076.19	26.98	15.48
MW213	275,239.50	105.97	1.38	14.91
MW215	184,512.72	77.50	1.01	9.99
MW219	38,141.88	1.67	0.02	2.07
MW300	164,041.73	28.71	0.37	8.88

MAROS Percent of Mass by Well

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

Well	Area (ft2)	Mass (mg)	Percent of Mass	Percent of Area
MW301	55,389.88	74.64	0.97	3.00
MW302	70,769.42	12.38	0.16	3.83
MW303	130,503.24	22.84	0.30	7.07
	1,846,386.3	7,695.0	100	100

Attachment B
MAROS Software Reports

North Lobe of Plume

Mann-Kendall Individual Well Trend Analysis
Individual Well Summary
MK TCE Trend Well MW-207
MK TCE Trend Well MW-208
MK TCE Trend Well MW-217
First Moment – Total Dissolved Mass in West Lobe
Percent Mass by Well – West Lobe

MAROS Mann-Kendall Statistics Summary

Project: Lockwood | **User Name:** MV

Location: OU1 | **State:** Montana

Time Period: 4/25/2003 **to** 5/4/2012
Consolidation Period: No Time Consolidation
Consolidation Type: Median
Duplicate Consolidation: Average
ND Values: 1/2 Detection Limit
J Flag Values : Actual Value

Well	Source/ Tail	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples "ND" ?	Concentration Trend
cis-1,2-DICHLOROETHYLENE								
MW012	S	7	7	0.59	-11	93.2%	No	PD
MW108	T	6	5	0.36	-15	99.9%	No	D
MW109	T	6	6	0.22	-13	99.2%	No	D
MW200	S	7	7	0.68	-3	61.4%	No	S
MW201	S	7	7	0.59	-5	71.9%	No	S
MW202	S	5	2	0.69	1	50.0%	No	NT
MW204	S	7	7	0.93	-7	80.9%	No	S
MW205	S	7	7	1.05	-3	61.4%	No	NT
MW206	S	7	6	0.44	5	71.9%	No	NT
MW207	T	7	7	0.55	-17	99.5%	No	D
MW208	T	7	0	0.00	0	43.7%	Yes	ND
MW209	T	4	0	0.00	0	37.5%	Yes	ND
MW214	T	7	2	0.33	-5	71.9%	No	S
MW216	T	8	5	0.39	-25	100.0%	No	D
MW217	T	7	6	0.46	-19	99.9%	No	D
MW218	T	4	0	0.00	0	37.5%	Yes	ND
MW219	S	7	7	0.30	-3	61.4%	No	S
TRICHLOROETHYLENE (TCE)								
MW012	S	7	7	0.34	-1	50.0%	No	S
MW108	T	6	6	0.18	-12	98.2%	No	D
MW109	T	6	6	0.27	-11	97.2%	No	D
MW200	S	7	7	0.60	-7	80.9%	No	S
MW201	S	7	7	0.43	-1	50.0%	No	S
MW202	S	5	3	1.03	1	50.0%	No	NT
MW204	S	7	7	0.59	-5	71.9%	No	S
MW205	S	7	7	0.58	7	80.9%	No	NT

MAROS Mann-Kendall Statistics Summary

Project: Lockwood | **User Name:** MV

Location: OU1 | **State:** Montana

TRICHLOROETHYLENE (TCE)

Well	Source/ Tail	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples "ND" ?	Concentration Trend
MW206	S	7	7	0.54	3	61.4%	No	NT
MW207	T	7	7	0.51	-17	99.5%	No	D
MW208	T	7	1	1.77	6	76.4%	No	NT
MW209	T	4	0	0.00	0	37.5%	Yes	ND
MW214	T	7	7	0.60	-17	99.5%	No	D
MW216	T	8	8	0.26	-20	99.3%	No	D
MW217	T	7	7	0.29	-17	99.5%	No	D
MW218	T	4	0	0.00	0	37.5%	Yes	ND
MW219	S	7	2	1.88	-3	61.4%	No	NT

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A)-Due to insufficient Data (< 4 sampling events); Source/Tail (S/T)

The Number of Samples and Number of Detects shown above are post-consolidation values.

MAROS Individual Well Summary Report

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

COC	Priority COC for Well?	Detection Frequency	Recent Sample Above Goal?	MK Trend	COV	95% UCL	Outlier	Distribution Assumption	Attained Cleanup?	
									Normal	Lognormal
MW012										
DCE12C	NO	100 %	NO	PD	0.56	0.0823	NO	Normal	NO	NO
TCE	NO	100 %	YES	S	0.30	0.0251	NO	Normal	NO	NO
MW108										
DCE12C	NO	88 %	NO	D	0.38	0.0005	NO	No distribution	YES	NO
TCE	YES	100 %	NO	D	0.18	0.0028	NO	No distribution	YES	YES
MW109										
DCE12C	NO	100 %	NO	D	0.22	0.0010	NO	No distribution	YES	YES
TCE	YES	100 %	YES	D	0.26	0.0106	NO	No distribution	NO	NO
MW200										
DCE12C	NO	89 %	YES	S	0.73	0.2147	YES	Normal	NO	NO
TCE	YES	89 %	YES	S	0.63	0.7387	NO	Normal	NO	NO
MW201										
DCE12C	NO	100 %	YES	S	0.56	0.8952	NO	Normal	NO	NO
TCE	YES	100 %	YES	S	0.37	1.1748	NO	Normal	NO	NO
MW202										
DCE12C	NO	40 %	NO	NT	1.84	0.0008	NO	Lognormal	YES	NO
TCE	NO	60 %	NO	NT	1.07	0.0046	NO	Normal	NO	NO
MW204										
DCE12C	NO	100 %	NO	S	1.09	0.0889	NO	Normal	NO	NO
TCE	NO	100 %	YES	S	0.57	0.0504	NO	Normal	NO	NO
MW205										
DCE12C	NO	100 %	NO	NT	1.13	0.0091	NO	Lognormal	YES	NO
TCE	NO	100 %	NO	NT	0.54	0.0108	NO	Normal	NO	NO
MW206										
DCE12C	NO	78 %	NO	NT	0.60	0.0014	NO	Normal	YES	NO
TCE	NO	100 %	YES	NT	0.52	0.0094	NO	Normal	NO	NO
MW207										
DCE12C	NO	100 %	NO	D	0.55	0.0010	NO	Normal	YES	NO

MAROS Individual Well Summary Report

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

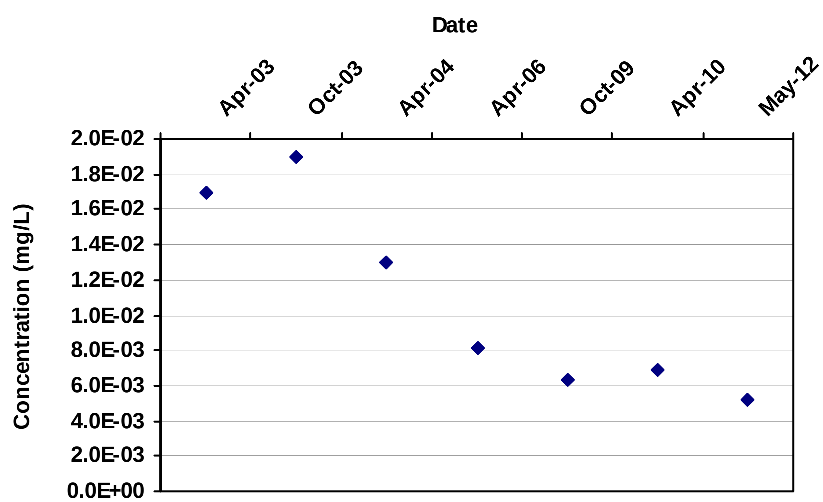
COC	Priority COC for Well?	Detection Frequency	Recent Sample Above Goal?	MK Trend	COV	95% UCL	Outlier	Distribution Assumption	Attained Cleanup?	
									Normal	Lognormal
TCE	NO	100 %	YES	D	0.48	0.0159	NO	Normal	NO	NO
MW208										
DCE12C	NO	0 %	NO	ND	0.00	0.0003	NO	No distribution	YES	YES
TCE	NO	22 %	NO	NT	1.91	0.0020	YES	No distribution	NO	NO
MW209										
DCE12C	NO	0 %	NO	ND	0.00	0.0003	NO	Normal	NO	NO
TCE	NO	0 %	NO	ND	0.00	0.0003	NO	Normal	NO	NO
MW214										
DCE12C	NO	29 %	NO	S	2.24	0.0004	NO	No distribution	YES	YES
TCE	NO	100 %	NO	D	0.57	0.0057	NO	Normal	NO	NO
MW216										
DCE12C	NO	56 %	NO	D	0.97	0.0004	NO	Normal	YES	YES
TCE	NO	100 %	NO	D	0.21	0.0038	NO	Normal	YES	YES
MW217										
DCE12C	NO	86 %	NO	D	0.57	0.0012	NO	Normal	YES	NO
TCE	NO	100 %	YES	D	0.28	0.0142	NO	Normal	NO	NO
MW218										
DCE12C	NO	0 %	NO	ND	0.00	0.0003	NO	Normal	NO	NO
TCE	NO	0 %	NO	ND	0.00	0.0003	NO	Normal	NO	NO
MW219										
DCE12C	NO	100 %	NO	S	0.28	0.0017	NO	Normal	YES	NO
TCE	NO	38 %	NO	NT	1.91	0.0053	YES	No distribution	NO	NO

MAROS Mann-Kendall Statistics Summary

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

Well:	MW207	**Time Period:**	4/25/2003 **to** 5/4/2012
Well Type:	T	**Consolidation Period:**	No Time Consolidation
COC:	TRICHLOROETHYLENE (TCE)	**Duplicate Consolidation:**	Median
		Consolidation Type:	Average
		ND Values:	1/2 Detection Limit
		J Flag Values :	Actual Value



Mann Kendall S Statistic:

-17

Confidence in Trend:

99.5%

Coefficient of Variation:

0.51

Mann Kendall Concentration Trend: (See Note)

D

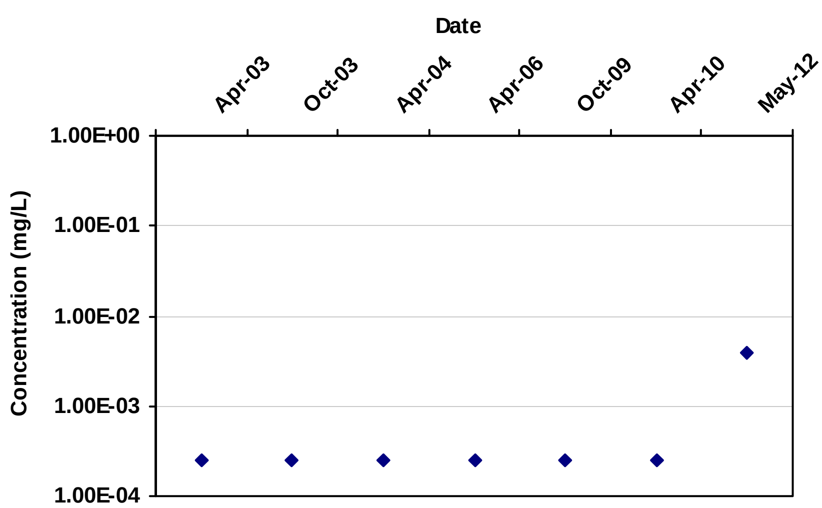
Data Table:

Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW207	T	4/25/2003	TRICHLOROETHYLEN	1.7E-02		2	2
MW207	T	10/24/2003	TRICHLOROETHYLEN	1.9E-02		2	2
MW207	T	4/23/2004	TRICHLOROETHYLEN	1.3E-02		2	2
MW207	T	4/6/2006	TRICHLOROETHYLEN	8.1E-03		2	2
MW207	T	10/8/2009	TRICHLOROETHYLEN	6.3E-03		2	2
MW207	T	4/15/2010	TRICHLOROETHYLEN	6.9E-03		2	2
MW207	T	5/4/2012	TRICHLOROETHYLEN	5.2E-03		2	2

MAROS Mann-Kendall Statistics Summary

Project: Lockwood | **User Name:** MV
Location: OU1 | **State:** Montana

Well:	MW208	**Time Period:**	4/25/2003 **to** 5/4/2012
Well Type:	T	**Consolidation Period:**	No Time Consolidation
COC:	TRICHLOROETHYLENE (TCE)	**Duplicate Consolidation:**	Median
		Consolidation Type:	Average
		ND Values:	1/2 Detection Limit
		J Flag Values :	Actual Value



Mann Kendall S Statistic:

6

Confidence in Trend:

76.4%

Coefficient of Variation:

1.77

Mann Kendall Concentration Trend: (See Note)

NT

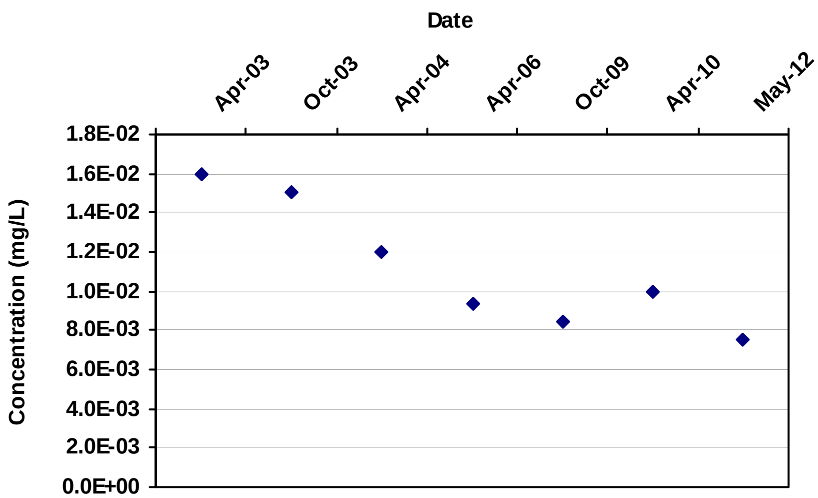
Data Table:

Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW208	T	4/25/2003	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW208	T	10/24/2003	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW208	T	4/23/2004	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW208	T	4/6/2006	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW208	T	10/8/2009	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW208	T	4/15/2010	TRICHLOROETHYLEN	2.5E-04	ND	2	0
MW208	T	5/4/2012	TRICHLOROETHYLEN	3.8E-03		6	4

MAROS Mann-Kendall Statistics Summary

Project: Lockwood | **User Name:** MV
Location: OU1 | **State:** Montana

Well:	MW217	**Time Period:**	4/25/2003 **to** 5/4/2012
Well Type:	T	**Consolidation Period:**	No Time Consolidation
COC:	TRICHLOROETHYLENE (TCE)	**Duplicate Consolidation:**	Median
		Consolidation Type:	Average
		ND Values:	1/2 Detection Limit
		J Flag Values :	Actual Value



Mann Kendall S Statistic:

-17

Confidence in Trend:

99.5%

Coefficient of Variation:

0.29

Mann Kendall Concentration Trend: (See Note)

D

Data Table:

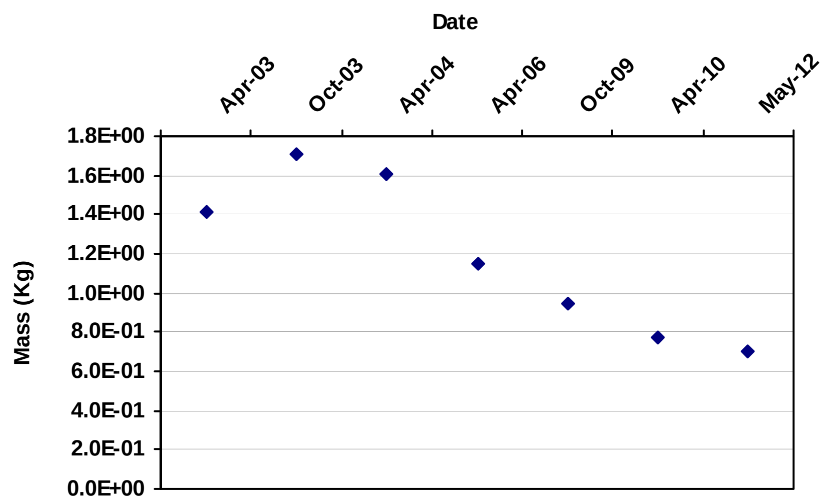
Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW217	T	4/25/2003	TRICHLOROETHYLEN	1.6E-02		2	2
MW217	T	10/24/2003	TRICHLOROETHYLEN	1.5E-02		2	2
MW217	T	4/23/2004	TRICHLOROETHYLEN	1.2E-02		2	2
MW217	T	4/6/2006	TRICHLOROETHYLEN	9.4E-03		2	2
MW217	T	10/8/2009	TRICHLOROETHYLEN	8.4E-03		2	2
MW217	T	4/15/2010	TRICHLOROETHYLEN	1.0E-02		2	2
MW217	T	5/4/2012	TRICHLOROETHYLEN	7.5E-03		2	2

MAROS Zeroth Moment Analysis

Project: Lockwood | **User Name:** MV
Location: OU1 | **State:** Montana

Change in Dissolved Mass Over Time

COC: TRICHLOROETHYLENE (TCE)



Porosity: 0.25

Saturated Thickness:
Uniform: 20 ft

Mann-Kendall S Statistic:
-17

Confidence in Trend:
99.5%

Coefficient of Variation:
0.34

Zeroth Moment Trend:
D

Data Table:

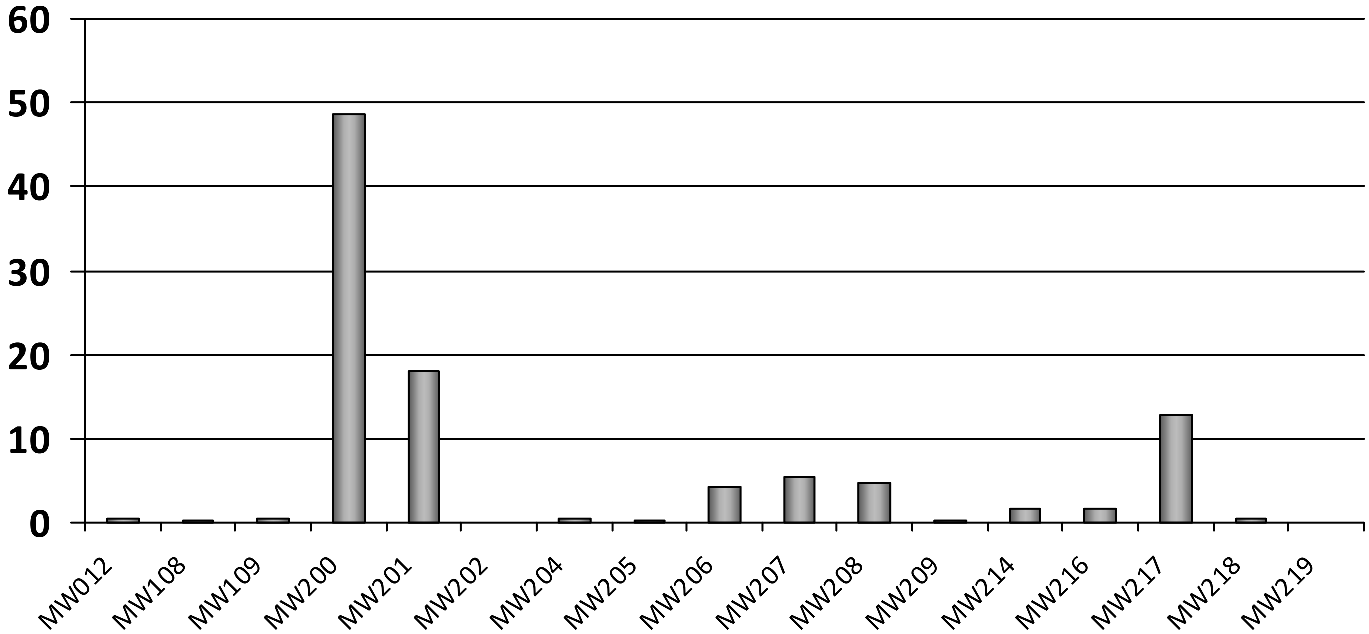
Effective Date	Constituent	Estimated Mass (Kg)	Number of Wells
4/25/2003	TRICHLOROETHYLENE (TCE)	1.4E+00	17
10/24/2003	TRICHLOROETHYLENE (TCE)	1.7E+00	17
4/23/2004	TRICHLOROETHYLENE (TCE)	1.6E+00	17
4/6/2006	TRICHLOROETHYLENE (TCE)	1.1E+00	15
10/8/2009	TRICHLOROETHYLENE (TCE)	9.5E-01	14
4/15/2010	TRICHLOROETHYLENE (TCE)	7.8E-01	14
5/4/2012	TRICHLOROETHYLENE (TCE)	7.0E-01	13

Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - Due to insufficient Data (< 4 sampling events); ND = Non-detect. Moments are not calculated for sample events with less than 6 wells.

MAROS Percent of Mass by Well

Project: Lockwood | **User Name:** MV
Location: OU1 | **State:** Montana

TRICHLOROETHYLENE (TCE) 5/4/2012



Well	Area (ft2)	Mass (mg)	Percent of Mass	Percent of Area
MW012	6,385.80	21.23	0.50	0.32
MW108	77,681.29	13.59	0.32	3.89
MW109	120,906.33	21.16	0.50	6.06
MW200	39,780.50	2,053.67	48.68	1.99
MW201	5,224.56	758.87	17.99	0.26
MW202	12,009.56	0.53	0.01	0.60
MW204	5,124.44	17.34	0.41	0.26
MW205	6,360.51	5.51	0.13	0.32
MW206	119,262.25	181.58	4.30	5.98
MW207	255,650.96	232.64	5.51	12.81
MW208	294,617.24	196.78	4.66	14.76
MW209	39,980.62	7.00	0.17	2.00
MW214	305,541.69	74.86	1.77	15.31
MW216	137,792.31	72.34	1.71	6.90

MAROS Percent of Mass by Well

Project: Lockwood **User Name:** MV

Location: OU1 **State:** Montana

Well	Area (ft2)	Mass (mg)	Percent of Mass	Percent of Area
MW217	412,048.05	540.81	12.82	20.65
MW218	107,471.19	18.81	0.45	5.38
MW219	49,956.96	2.19	0.05	2.50
	1,995,794.3	4,218.9	100	100