Innovations in Site Characterization

Case Study: The Role of a Conceptual Site Model for Expedited Site Characterization Using the Triad Approach at the Poudre River Site, Fort Collins, Colorado

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Foreword

This case study is one in a series designed to provide cost and performance information for innovative tools that support less costly and more representative site characterization. These case studies include reports on new technologies as well as novel applications of familiar tools or processes. They are prepared to offer operational experience and to further disseminate information about ways to improve the efficiency of data collection at hazardous waste sites.

Acknowledgments

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ACRONYMS AND ABBREVIATIONS

1,2,4-TMB	1,2,4-trimethylbenzene
1,3,5-TMB	1,3,5-trimethylbenzene
µg/kg	Microgram per kilogram
µg/L	Microgram per liter
AFCEE	Air Force Center for Environmental Excellence
AST	Aboveground storage tank
bgs	Below ground surface
BTEX	Benzene, toluene, ethylbenzene, xylene
BTSC	Brownfields Technology Support Center
CDPHE	Colorado Department of Public Health and the Environment
cfs	Cubic foot per second
COPC	Contaminant of potential concern
CSM	Conceptual site model
DMA	Demonstration of methods applicability
DRO	Diesel range organic
EPA	U.S. Environmental Protection Agency
FID	Flame ionization detector
FSP	Field sampling plan
GC/MS	Gas chromatography/mass spectrometry
gpm	Gallon per minute
GPR	Ground-penetrating radar
GRO	Gasoline range organic
HRR	High-resolution resistivity
HSA	Hollow-stem auger
MCL	Maximum contaminant level
mg/kg	Milligram per kilogram
MGP	Manufactured gas plant
mS/m	MilliSiemen per meter
MTBE	Methyl tert-butyl ether
NAPL	Non-aqueous phase liquid
OP-FTIR	Open-path Fourier transform infrared
PAH	Polynuclear aromatic hydrocarbon
Paragon	Paragon Consulting Group, Inc.
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene

PDB	Passive diffusion bag
PID	Photoionization detector
Poudre	Cache La Poudre
ppm	Part per million
PRP	Potentially responsible party
PVG	Poudre Valley Gas
QC	Quality control
RETEC	RETEC Group, Inc.
SA	Site Assessment
START	Superfund Technical Assessment and Response Team
Stewart	Stewart Environmental Consultants, Inc.
SVOC	Semivolatile organic compound
SW-846	Test Methods for the Evaluating Solid Waste
TBA	Targeted Brownfields Assessment
TCE	Trichloroethene
Tetra Tech	Tetra Tech EM Inc.
TPH	Total petroleum hydrocarbons
TQRS	Technology Quick Reference Sheets
UOS	URS Operating Services, Inc.
USGS	United States Geological Survey
UST	Underground storage tank
UV	Ultraviolet
VOC	Volatile organic compound
Western	Western Environmental Technologies, Inc.

CASE STUDY ABSTRACT

Cache La Poudre River
Fort Collins, Colorado

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Description:

This case study examines how systematic planning, an evolving conceptual site model (CSM), dynamic work strategies, and real time measurement technologies can be used to unravel complex contaminant distribution patterns and design a remedy at the Cache La Poudre (Poudre) River site. The investigation and design of the remedy involved a former burn landfill, hydrocarbon fuel contamination, and mobile manufactured gas plant (MGP) coal tar waste. The remedy was driven by recreational reuse and proximity to the Poudre River. The remedy involved pathway elimination and stream restoration in a location central to the City of Fort Collins, Colorado. Sites like this one are not uncommon throughout the United States as urban development reaches out to formerly rural areas near former MGPs. Thousands of similar sites are found across the United States, many of which have gone without mitigation because of similar issues in terms of the complexity and the contaminant distributions and political considerations making resolution of reuse issues perplexing. In this case study innovative technologies and strategies are discussed, which can help others with similar sites begin to address stakeholder concerns in a streamlined and economic fashion.

The site had been studied for several years; however, the specific goals of those studies resulted in a lack of a full understanding of contaminant distributions and pathways for migration. Furthermore, contamination did not adhere to typical patterns of migration. Site-specific conditions limited the extent of dissolved plume contamination in and around the non-aqueous phase liquid (NAPL) plume, making it difficult to identify and track contamination from the source area to the Poudre River. Through the cooperative efforts of the responsible parties, the regulators, and other stakeholders, a systematic plan involving the use of innovative approaches was used to progressively refine the CSM, select appropriate technologies, and sequence data collection efforts. The evolving CSM became the backdrop upon which site decisions were based, directing a realignment of investigative goals and providing a logical method for dissection of critical issues related to nature and extent of contamination and design of the remedy. By relying heavily on an evolving CSM, the project team finished the site characterization and attribution of responsibilities in less than a year. A remedy consisting of a barrier wall to stop the flow of coal tar to the river was installed along with a groundwater extraction system to remove hydraulic head, which has been driving the transport of coal tar a year after the characterization was completed. Rehabilitation of the Poudre River channel was also performed to restore the recreational potential and natural beauty of the area.

The investigatory and remediation efforts have so far included the following mix of innovative and traditional technologies:

- Electromagnetic induction and resistivity surveys
- Direct-push grab groundwater sampling and real-time analyses for volatile organic compounds (VOC)
- Passive soil gas survey to identify chlorinated solvents
- Passive diffusion bag sampling of groundwater exiting to surface water
- Auger drilling and trenching accompanied by fixed lab analyses
- Open-path Fourier transform infrared (FTIR) spectroscopy to identify VOC emissions from the landfill area in three dimensions
- Sheet pile wall with a water extraction and treatment system

	The technologies were employed in concert to develop and refine a CSM and improve the certainty of decision making. Because of the high profile nature of the site, being near the city center, results were shared with the press on a regular basis to keep the public informed of project findings. **Background** The Poudre River site was accepted by the U.S. Environmental Protection Agency (EPA) for a Targeted Brownfields Assessment (TBA) in May 2003. Contractor support to EPA Region 8 was provided under the Superfund Technical Assessment and Response Team 2 contract, initially by URS Operating Services, Inc. and subsequently by Tetra Tech EM Inc. (Tetra Tech). In October 2003, EPA issued a Technical Directive Document for Tetra Tech to conduct a site assessment after coal tar was identified in the Poudre River during the TBA. Historical records also indicated the presence of low levels of chlorinated solvent and hydrocarbon related constituents in groundwater beneath the site. The City of Fort Collins, in conjunction with stakeholders, identified the primary objectives for TBA data collection as establishing a connection between potential source areas and coal tar contamination found in the river, and to determine the potential for formal closure of the landfill. As part of this effort, data were also to be collected to support redevelopment efforts. The site also contains a former 12-acre landfill that operated from the late 1930s to the early 1960s. Upgradient of the former landfill on which the current recreation facility and several other buildings are located is a historical MGP that operated from approximately 1900 to 1930, manufacturing heating oil from coal and other petroleum products using a carbureted water gasification method. The major byproduct and subsequent contaminant from the MGP operation was coal tar. Portions of the former MGP property were purchased by a gasoline supply company and an energy utility company. Several releases of gasoline were recorded between the closing of the MGP and the present. Contaminated groundwater associated with the landfill and coal tar associated with historical MGP operations were identified below the landfill and in the nearby Poudre River. Contemporary features on the 19-acre property include the Northside Aztlan Community Center, a United Way facility, a park, playground, bike path, and parking areas. The City of Fort Collins currently operates a recreation center on the former landfill property and is interested in redevelopment of the site. Public interest and support is high for the construction of a new 50,000 square foot multi-generation recreation center on the property. Restoring the site and the nearby Poudre River will provide public access to river resources and protect recreational users and fisheries as well as wildlife habitat associated with the Poudre watershed.
Media and Contaminants:	*Groundwater:* • Site groundwater currently contains contaminants associated with coal tar, nearby gasoline and diesel spills, and possibly landfill materials or other unknown sources. Contaminants of potential concern primarily include polynuclear aromatic hydrocarbons (PAH), benzene, toluene, ethylbenzene, and xylene (BTEX) compounds, total petroleum hydrocarbons (TPH), methyl-t-butyl ether, trichloroethene, and tetrachloroethene. *Subsurface soil and river sediments* Subsurface soil and river sediments are impacted by NAPL materials containing PAHs, BTEX compounds, and TPH.

Results:	Attribution of the responsibility for the cleanup and the design of a remedy were accomplished in less than 6 months. Numerous innovative technologies (see below) provided a high density of information to help direct sampling and analysis efforts. Mitigation efforts were completed a year after characterization was completed by the primary responsible party to eliminate the continuing source of coal tar to the Poudre River and restore the river channel to native condition. Sufficient information was developed to support closure plans for the landfill and to support redevelopment at the site. The primary lesson learned from this site is that the use of innovative high density sampling methods in combination with traditional methods and an evolving CSM can help build understanding and trust (or social capital) amongst stakeholders thus accelerating the process needed to reach project objectives.
Technologies Demonstrated:	Innovative or real-time measurements applied at the site included the following methods: • Direct-push groundwater sampling methods • Electromagnetic geophysical methods • High-resolution resistivity geophysical methods • On-site gas chromatography/mass spectrometry analysis of VOCs in groundwater • Passive soil gas • Passive diffusion bag groundwater sampling methods • Open-path FTIR spectroscopy Various vendors were used to provide these services and are described in more detail in the Technology Quick Reference Sheets provided in this case study (Appendix 1). The EPA Region 8 mobile laboratory provided equipment needed to generate real-time results for volatile organics in groundwater using a Modified SW-846 method 8260.
Cost Savings:	Use of the Triad approach for site characterization resulted in an estimated cost savings of approximately 30 percent when compared with a more traditional approach that would involve multiple mobilizations and fixed-based analytical methods. In addition to saving costs, use of the Triad approach increased the size and quality of the data set used to make decisions about the site. Adequate characterization assured that a functional mitigation strategy was installed appropriately during the first attempt. It is difficult to evaluate the cost savings associated with installation of a poorly designed initial remedy, but the cost of the remedy in this case was approximately $13 million, so installation of a poorly designed system would have been very expensive in the long run.

EXECUTIVE SUMMARY

The following case study was prepared by Tetra Tech EM Inc. (Tetra Tech) in support of the U.S. Environmental Protection Agency's (EPA) Office of Superfund Remediation and Technology Innovation, Brownfields Technology Support Center (BTSC). The case study was developed as part of EPA's ongoing Triad initiative to promote streamlining cleanups at hazardous waste sites. The Triad approach uses a well defined systematic planning process, dynamic work strategies, and real-time measurement technologies to limit decision uncertainty and maximize the efficiency of activities conducted in support of cleanup at hazardous waste sites.

The Cache La Poudre (Poudre) River site is located in downtown Fort Collins, Colorado and the owner of the property is the City of Fort Collins. The area of concern is a commercial area comprising approximately 19 acres, which includes the Northside Aztlan Recreation Center, the United Way Building, a park, soccer fields, playground, bike path, river front, and a parking area. The site is adjacent to a historical manufactured gas plant (MGP) that operated just west of the property from approximately 1900 to 1930, which has since been demolished. The former MGP site is currently owned and operated by Schrader Oil as a petroleum distribution station. The site is the former location of a city owned and operated municipal burn landfill, which operated from approximately 1940 to the mid-1960s.

In May 2003, EPA issued a Targeted Brownfields Assessment (TBA) grant to evaluate the potential for official landfill closure to support the planned expansion of the recreation center, which was built on the former landfill. Coal tar and sheen, which had been observed in Poudre River sediment was also a concern relative to recreational use planned along the river front. Contractor support to EPA Region 8 was provided under the Superfund Technical Assessment and Response Team (START) 2 contract, initially by URS Operating Services, Inc. and subsequently by Tetra Tech. Region 8 Brownfields staff requested planning/scoping support from the BTSC to apply the Triad approach to the project.

A preliminary conceptual site model (CSM) was developed based on a review of existing data from previous investigations conducted at the site by Walsh Environmental. The preliminary CSM indicated that potential threats to human health and the environment could include, but were not limited to discharge of contaminated groundwater to the Poudre River and direct contact with contaminated surface water and sediments. Contaminants of potential concern included petroleum-related substances found in coal tar and suspected to be related to operation of the former MGP. Leaching of contaminants from the nearby landfill and fuel related storage facilities were also identified as a potential concern.

A review of the analytical results collected during previous investigations showed that a dissolved plume of benzene, toluene, ethylbenzene, and xylene (BTEX), polynuclear aromatic hydrocarbons (PAH), as well as diesel range organics existed in groundwater beneath the portion of the site immediately adjacent to the former MGP and petroleum storage facility. Methyl tert-butyl ether (MTBE) was identified in groundwater in a small area on the northwest side of the site. Consultants working for various interested parties theorized that coal tar found in the river was related to dumping in the landfill, migration of the coal tar from the MGP to the river, or upgradient source areas. Because of the lack of a dissolved phase plume that extended from the former MGP across the site to the river, it seemed unlikely that migration from the former MGP was occurring. The project teams rallied around the refinement of the CSM both near the river (RETEC Group, Inc. [RETEC] for Xcel Energy) and across the potential flow path from the former MGP, across the site, to the river. Separate investigations were performed by each party which culminated in the resolution of the flow path and design of the remedy in an efficient manner.

The initial TBA work plan called for a round of groundwater sampling and collection of water level measurements to obtain a baseline for the investigations to be conducted. The BTSC developed a "dynamic" sampling strategy based on the principles of the Triad approach to increase the density of sampling through the use of an array of innovative and field-based measurement technologies. The TBA work plan, developed by the Tetra Tech START 2 team as part of the TBA (in cooperation with the BTSC and EPA Region 8) called for the use of a geomagnetics survey and direct-push groundwater sampling coupled with on-site analysis of groundwater samples using gas chromatography/ mass spectrometry for volatile organic compounds (VOCs) to delineate further the dissolved phase plume.

Sampling activities were initiated in June 2003. The geophysical survey employed EM-34 terrain conductivity meters. This technique was used to define the top of the bedrock surface and identify metallic objects such as buried drums in the landfill. Direct-push methods were used to collect grab groundwater, soil, and any product encountered from across the site.

Results from the groundwater grab samples were analyzed on site in near real time using a modified EPA SW-846 Method 8260 to provide information on contaminants known to be present at the site such as tetrachloroethene (PCE), naphthalene, and BTEX. These results were used to further refine the CSM and provide an indication of areas where contamination and coal tar non-aqueous phase liquid (NAPL) might be present or migrating in the subsurface. Based on the initial geophysical survey results and direct-push groundwater sampling program, additional small gauge and full-sized monitoring wells were installed.

The results of the TBA were inconclusive regarding the pathway and source characteristics for coal tar; however, a plume of PCE was identified. Information obtained during the TBA was used to refine the CSM and develop strategies for the collection of data during a subsequent site assessment, which was needed once significant quantities of coal tar were observed in the river.

Concerns had been expressed by the City of Fort Collins about the potential for emissions of landfill gases and the potential for vertical migration of hazardous VOCs from coal tar associated contaminants, which could impair the city's plans to redevelop the landfill area. With support from the Monitoring and Measurement Technologies for the 21st Century initiative, EPA's office of research and development demonstrated the use of open-path Fourier transform infrared (OP-FTIR) spectroscopy at the site to evaluate fugitive emissions from the landfill area. The OP-FTIR method facilitates the collection of high density data and thus provides decision makers with a higher level of confidence that no emission sources were missed during the investigation. This survey showed that fugitive gas concentrations were sufficiently high as to warrant the appropriate design considerations during construction and confirmed the presence of hydrocarbon vapors above select portions of the landfill and free product plume. For more information concerning the use of OP-FTIR spectroscopy, see: http://clu-in.org/programs/21m2/openpath/op-ftir/ .

In October 2003, EPA issued a Technical Directive Document for Tetra Tech to conduct a full site assessment (SA), primarily to identify the source and pathways for coal tar observed in the Poudre River during the TBA. A river channel investigation was simultaneously initiated by a potentially responsible party (PRP) since definitive evidence as to the source of coal tar in the river appeared to be lacking. Because there was no well defined dissolved phase plume connecting the former MGP area with the observed seep of coal tar in the river, the PRP suspected that the source might be from areas other than the former MGP. During the river channel investigation, trenches were dug within the river channel and along the edges of the river bank where coal tar had been found. Traditional drilling methods were also used in an attempt to delineate the extent of contamination. Results of this investigation indicated that coal tar contamination was laterally pervasive along the interface between the shale bedrock and the overlying alluvium within the river channel and extended to some depth below the bedrock surface. Coal tar appeared only within the bedrock in upgradient areas outside of the river channel indicating that the coal tar might be moving within bedrock fractures. These findings reinforced the need for further investigative activities to identify source areas and define the pathway between the river and source areas.

A passive soil gas survey was then performed along with a high-resolution resistivity geophysical survey to further optimize where traditional drilling methods could be used to define the flow path for the observed contamination. Passive diffusion bag samplers were placed along the edge of the river bank where groundwater discharged to the river bed to provide information regarding the potential release of VOCs to the river (for more information see: http://sc.water.usgs.gov/publications/difsamplers.html). Results of the soil gas survey indicated the presence of PCE in the landfill. Passive diffusion bag sampler data also indicated that PCE in groundwater was discharging to the river at very low levels in areas adjacent to where the soil gas survey indicated the presence of PCE. However, concentrations exiting the site were relatively low, suggesting either a high dilution rate or that the PCE was primarily trapped in the vadose zone within the landfill.

Based on the results of the traditional drilling effort in the landfill, which was optimized using trenching results from the river channel investigation conducted by the primary responsible party, coal tar was found on and below the bedrock surface across the western half of the site. As it migrated across the site, coal tar penetrated into the fractured bedrock presumably following fractures until it reached an exit point to the river.

The primary responsible party, Xcel Energy, implemented a mitigation strategy that included the placement of a sheet pile wall to intercept coal tar migrating to the river and a French drain to remove the hydraulic head created by the sheet pile wall. Source remediation is also being considered to further limit the potential for coal tar migration to the river.

Cost savings for site characterization from the application of the Triad, as compared with the use of a more traditional, phased approach were estimated at approximately 30 percent. Limited investigations including Phase I and Phase II investigations and groundwater plume monitoring had been ongoing at the site for more than 3 years. However, development and refinement of the site CSM revealed that many of the previous investigations had failed to collect data that met the requirements to make project decisions regarding a remedy, partially because differing investigation objectives and conventional approaches to drilling, well installation, and sampling resulted in data gaps. Specifically, the TBA and refinement of the site CSM identified the need to map the bedrock surface beneath the site and evaluate the presence or absence of coal tar within the bedrock.

Within 6 months after systematic planning began for the TBA, EPA was able to negotiate with Xcel Energy, a former owner of the property where the former MGP was located, to conduct a voluntary

investigation of the extent of coal tar in the Poudre River. The TBA investigation and subsequent refinements of the CSM allowed EPA to secure additional funding for an SA, which identified source areas and fully delineated the nature and extent of the contamination on the site as well as facilitated the implementation of a remedial alternative that was installed by Xcel Energy.

1.0 INTRODUCTION

This case study was developed as part of U.S. Environmental Protection Agency's (EPA) ongoing initiative to promote the use of an integrated approach called the Triad. The Triad approach focuses on sound science using systematic planning, dynamic work strategies, and real-time measurement technologies to limit decision uncertainty at hazardous waste sites. Historically, sites have been cleaned up using a relatively static approach ("command and control") to the cleanup process. This type of an approach afforded both the purchaser and provider of services a certain level of comfort concerning what activities would be performed and how much they would cost. The command and control type of approach is not as efficient when attempting to manage a moving target, such as unforeseen contamination.

Regulators and site managers are increasingly recognizing the value of implementing a more dynamic approach to site cleanup that is flexible, and recognizes site-specific decisions and data needs that can increase project efficiency, reduce decision uncertainty, and expedite site reuse. The EPA's Triad initiative is just this type of dynamic approach. The Triad approach enables project managers to expedite site cleanup and reduce project costs. As such, the Triad is actually a more powerful tool for cost savings when used in support of the design, implementation, and optimization of cleanup processes where the preponderance of costs is generally incurred.

Overview of the Triad Approach

The past decade has seen significant advancements in data collection technologies and measurement systems. For many contaminants of concern, it is now possible to obtain information about their presence and level in "real-time", or quickly enough to potentially affect the progress of sampling work. Advancements in Global Positioning Systems allow rapid determination of spatial locations. Direct-push technologies provide a quicker and cheaper method for retrieving subsurface samples, and provide the possibility for pushing sensors into the ground for in situ measurements. In addition, over the last 30 years the professional environmental cleanup community has gained a much better understanding of likely contamination scenarios, and the environmental fate and transport processes that determine the future state of contaminated sites. This knowledge, combined with technology advancements, provides a new approach to address the uncertainty associated with hazardous waste site decision-making, and the design and implementation of cleanup strategies.

EPA has coined the term "Triad" to refer to this approach. EPA believes that implementation of the Triad can potentially lead to faster and more cost effective hazardous waste site remediation, while at the same

time improving the overall decision-making process and ultimately achieving the final goal of hazardous waste site programs: safe return of sites for productive use.

Systematic Project Planning

This component of the Triad approach is the farthest-reaching, as it covers the process of a remedial project from beginning to end. Systematic project planning refers to a systematic process of establishing a project team composed of all stakeholders, discussing and agreeing upon clear project objectives for site redevelopment, creating a conceptual site model (CSM) that documents the current understanding of the site, and managing the project in such a way that data collected during site characterization and remediation is used to update the CSM as the project proceeds. The goal of systematic project planning is to create an investigative and remedial approach for the site that reduces decision uncertainty to an acceptable level. This is accomplished by creating a dynamic work strategy that uses real-time measurement systems to fill in gaps in understanding of the CSM.

One critical aspect of systematic project planning is building understanding and trust, often referred to in Triad projects as social capital, amongst the various stakeholders. This sets the stage for understanding end user data needs and identifying exit strategies.

An important aspect of Triad projects is to plan a demonstration of methods applicability (DMA) for each real-time measurement system or decision support tool to be used at the site. The DMA can establish the suitability of a tool for characterizing the site, and can also show that the tool will work effectively in the environment of the site.

During later stages of a project, the CSM becomes more of a site model with real data making conditions sufficiently well understood such that a cleanup strategy can be evaluated. Fine-tuning the site conditions and monitoring of process efficiency become the focus of the data collection efforts performed in support of process optimization. Stakeholders can remain the same or even change as the focus in a project leans towards system design optimization, but communication of results, and learning from these results to optimize the project design, are areas where environmental professionals have experienced the greatest challenge to existing site assumptions.

System designs create changes in the natural environment, making previous assumptions concerning design inadequate. The heterogeneity in the environment for certain types of sites, such as those where dense non-aqueous phase liquid contaminants are involved, may indicate that previous characterization

efforts prepared in support of design are inadequate to accomplish project goals. For this reason, dynamic work strategies are needed to continually refine a project team's understanding of site conditions on a level adequate to support design and system optimization.

Dynamic Work Strategies

In a Triad project, dynamic work strategies are developed based on very specific project decisions. Project stakeholders weigh in during the development of initial dynamic work strategies, which are usually designed to support site characterization of potential risks to human health and the environment.

The initial dynamic work strategies developed for a site often take the form of a decision logic diagram based on the preliminary CSM. The decision logic or strategy is designed to test the assumptions of the CSM during characterization and ultimately during cleanup. Once characterization of risk has been estimated and the need for further action identified, the focus of dynamic work strategies for a project generally shifts towards remedy design objectives and risk management strategies.

Additional data types are rolled into the decision logic, and manageable decision units are introduced where necessary. As preliminary testing of a design is warranted, empirical data concerning process efficiencies and inadequacies may also be introduced into the decision logic, and new or better defined hypotheses may be tested. As implementation goes full scale, characterization efforts in support of disposal or treatment options may warrant additional revisions to dynamic work strategies and decision logic. To assure success, the project team may need to introduce data and information of many types that were not previously obvious to a project team. Data usually need to be collected on a much finer scale once areas of concern have been identified. Data density is usually driven by the economics of a design during the final stages of a project, or by the nature of the remedy being considered and or applied.

Real-Time Measurement Systems

The use of real-time measurement systems is very useful for site characterization to assure that representative results are used to evaluate initial risk at a site, and to develop the preliminary CSM used in support of risk characterization efforts. The less specific nature of some field-based tests and the emerging nature of some of the technologies make the direct application of field-based technologies to risk estimation challenging. Real-time measurement systems can sometimes be used in direct support of risk or lack of risk determination when a DMA is used to solidify the reliability of the results relative to project-specific risk related decisions.

One of the primary advantages of using real-time technologies for guiding and confirming cleanup objectives is that the lower cost allows for increased data density. This in turn increases decision certainty. The project team can decide whether to strike a balance between reduced cost and reducing uncertainty such that both are optimized in comparison to a traditional approach.

As more data are gathered concerning the utility of field-based methods to provide site-specific information and the need for risk estimation quality data diminishes, field-based technologies have an increased level of apparent benefit to a project. As unforeseen conditions arise during excavation or application of a remedy, real-time sensors can and should be used to identify and adapt to the changing project needs and site conditions. Because of the dynamic nature of natural systems and the changes induced during remedial efforts, field-based technologies during remedy testing and design optimization should be an essential element of any post-implementation monitoring and measurement scheme.

The Triad approach, a framework for efficiently managing decision uncertainty, can be applied to a site to reach project objectives faster and with fewer mobilizations. In addition, it is well suited to Brownfields projects where budget and schedule are crucial to successful project completion. Further information about the Triad approach is available on the World Wide Web at http://www.triadcentral.org, and in "*Using the Triad Approach to Streamline Brownfields Site Investigation and Cleanup*" (EPA 542-B-03-002; June 2003).

Background

The Brownfields Technical Support Center (BTSC) project members documented site activities in this case study, including the planning process and lessons learned by the Poudre River project teams. Such case studies are being developed by BTSC to assist others during the planning process at similar sites where Triad concepts are being considered for streamlining the site assessment (SA) and cleanup process. Thousands of other manufactured gas plant (MGP) sites are present across the United States and case studies like this one will add to the foundation of knowledge available on potential approaches that might be advantageous to consider.

The Cache La Poudre (Poudre) River site is located in downtown Fort Collins, Colorado and the current owner of the property is the City of Fort Collins. The site includes a historical MGP that operated just west and adjacent to the site from approximately 1900 to 1930, which has since been demolished, and a former municipal landfill that operated on the city's property from the late 1930s to the mid-1960s.

Poudre Valley Gas (PVG) Company produced manufactured gas in the first three decades of the twentieth century, until approximately 1930. The plant manufactured heating oil from coal using a carbureted water gasification method. Two gasholders (49.5 feet and 52 feet in diameter) were present at the site in the 1930s. One tar pit of unknown size was located north of the smaller, western gas holder. The aboveground portion of the western gasholder was removed before 1941. The second gasholder is thought to have been removed in 1966 (Walsh 2001a).

In May 2003, EPA issued a Targeted Brownfields Assessment (TBA) grant to evaluate the potential for official landfill closure. The goal of the evaluation was to facilitate the construction of a new community recreation center on the city's property and identify the source of coal tar and sheen observed in the Poudre River. Contractor support to EPA Region 8 was provided under the Superfund Technical Assessment and Response Team (START) 2 contract, initially by URS Operating Services, Inc. (UOS) and subsequently by Tetra Tech EM Inc. (Tetra Tech). Region 8 Brownfields staff requested planning/scoping support from the BTSC to apply the Triad approach to the project. Table 1 provides a summary of all parties involved.

2.0 PRELIMINARY CONCEPTUAL SITE MODEL

A CSM is an important planning tool used to compile and communicate essential site data needed to understand and then map out a strategy for site closure and cleanup. Key features of a site relative to the site-specific environmental decisions are the input to the model. As the model is refined based on those results needed during design and ultimately remediation of environmental conditions at a site, it becomes far less conceptual. The project team develops the preliminary CSM based on existing data before an investigation is planned and implemented. Existing data, such as geologic, hydrogeologic, contaminant types, source area characteristics, and other pertinent information are carefully reexamined to assure that the data proposed to be collected will be of sufficient quality and quantity to meet the project objectives. Project objectives are clearly stated and then translated into site-specific decisions and data collection activities designed to answer the questions raised by the existing data.

A CSM includes the identification of suspected contaminant sources and types of contaminants present, potential receptors and exposure points, potential migration pathways, and other project constraints. The CSM uses existing information on the types of contaminants, pathways, receptors, and future land uses to help define areas where further study is needed. The CSM is continually refined as information is gathered. Modifications to the project approach may be made as more is learned about the site and the data needs are refined. A dynamic work strategy is generally used along with real time data evaluation

and assessment techniques to continually update the CSM as more data becomes available. Continual revision of the CSM was a key element to the success of the Poudre River project.

2.1 SITE DESCRIPTION

The Poudre River site is located adjacent to the Fort Collins Northside Aztlan Center at 200 Willow Street in Fort Collins, Colorado. The area of concern is a commercial area comprising approximately 19 acres, which includes the Northside Aztlan Center, United Way Building, a park, soccer fields, playground, bike path, and parking areas. The site is bounded on the northeast by the Poudre River, on the northwest by a branch line of the Union Pacific Railroad, on the southwest by Willow Street and on the southeast by Linden Street and Pine Street (Figure 1).

The site also includes a historical landfill approximately 12 acres in size. Previous investigations document landfill debris to be between 9 and 14 feet in thickness with a 1- to 3-foot-thick silty clay cover (Walsh 2001b). Two buildings have been constructed on the former landfill. The Fort Collins Aztlan Center was built in 1973 and the United Way Building was built in 1985. Both buildings are equipped with methane monitoring systems. Each system has recorded incidences where methane alarms were triggered, but subsequent testing for methane indicated alarms were not due to actual methane intrusion. Figure 2 shows the other types of businesses and the expected outline of the historical landfill anticipated at the time of the TBA.

2.2 SUMMARY OF PREVIOUS INVESTIGATIONS

Previous investigations have summarized analytical results for samples historically collected at the site. Methane gas surveys were conducted at the landfill for the City of Fort Collins in 1977 by GeoTek, Inc. and in 1979 by Raymond Vail Associates. The 1977 survey reported methane concentrations ranging from 0.1 to 4.1 percent gas in 21 boring locations. The 1979 survey reported methane detections in four out of 27 boreholes. These detections ranged from five to 62 percent of the lower explosive level for methane, which is five to 15 percent methane gas by volume. The highest levels were found in the western portion of the landfill. Perimeter locations near residential, commercial, and industrial areas did not appear to be accumulating methane gas (Walsh 2001b).

The Colorado Department of Public Health and the Environment (CDPHE) reported that limited sampling of soil and groundwater occurred during construction of the United Way Building in 1985. Samples were analyzed for metals, semivolatile, and volatile organics (Walsh 2001b). In 1995, groundwater was also

sampled from monitoring wells MW-1, MW-2, and MW-3 (Figure 3). The sample from MW-1 contained approximately 3,600 micrograms per liter (µg/L) of naphthalene, 27 µg/L of benzene, 1,400 µg/L of xylene, and other hydrocarbons. MW-1 is located on the southern boundary of the former MGP site. In addition, chromium was also detected in groundwater in monitoring wells MW-1, MW-2, and MW-3 at concentrations ranging from 1,130 to 1,250 µg/L (Walsh 2001b).

In the late 1990s, an underground portion of the western gasholder used by the PVG Company was encountered during construction of the Burlington Northern Santa Fe railroad spur line (Stewart Environmental Consultants, Inc. [Stewart] 1996). The underground portion of the gasholder was 10.5 feet deep, was presumably filled with heating oil when in operation, and was potentially backfilled with waste oil or coal tar during plant closure. The contents of this gasholder were removed in 1996 by the City of Fort Collins under the CDPHE Voluntary Cleanup Program. The intact underground portion of the gasholder was filled with clean soil and left in place. Rail lines now pass over the former location of the gasholder (Walsh 2001b; Stewart 1996). During the 1996 gasholder tank removal, contaminated soil to the west, south, and east of the gasholder were removed to depths of 3 to 4 feet below ground surface (bgs). In addition, three test pits were excavated at locations immediately south and east of the gasholder (Figure 3). Soil containing coal tar, as well as green and blue-green stained soil layers, were observed in these test pits. Coal tar and other organic compounds were also visible in groundwater encountered in the test pits. Contaminated soil found at a depth greater than 4 feet bgs and associated groundwater were not remediated as part of the gasholder removal action (Walsh 2001b; Stewart 1996).

The city installed two monitoring wells (MW-9 and MW-12) on the city's property on the north side of Willow Street (Figure 3). MW-12 is located downgradient of the location of the former gasholder and MW-9 is located 200 feet from MW-12, but not directly downgradient of the former gasholder. Groundwater samples from MW-12 contained levels of benzene in excess of Colorado State drinking water standards. Groundwater samples from MW-9 contained naphthalene but no detectable benzene (Walsh 2001b).

In 1998, the Larimer County Health Department collected a water sample at a depth of 9 feet bgs from a sanitary sewer excavation located on the south side of Willow Street. The excavation was adjacent to the property owned by Schrader Oil Company, which includes part of the property where the PVG Company was previously located. Tentatively identified compounds detected in this sample included acenaphthylene, fluorene, phenanthrene, and substituted naphthalene (Walsh 2001b).

In 2001, Walsh drilled 11 boreholes (BTH-1 through BTH-11) which became monitoring wells to evaluate the extent of contamination at the site (Walsh 2001b). Soil and groundwater samples were collected from these boreholes and analyzed for the presence of volatile organic compounds (VOC), polynuclear aromatic hydrocarbons (PAH), total metals, and dissolved metals. PAHs were detected in groundwater samples from at least five of the wells, and VOCs were detected in soil samples from three locations (Walsh 2001b).

During the 2001 Phase I investigation, contamination was found downgradient of the PVG plant on the Fort Collins Aztlan Center property (Walsh 2001b). The nature and extent of soil and groundwater contamination located on the site are described in several other reports completed by Walsh in 2001 and 2002 under the Fort Collins Downtown River Corridor Brownfields Pilot Assessment Program (Walsh 2001a, 2001b, 2002a, 2002b). Coal tar related compounds, including benzene and naphthalene, were documented as being present at or above method reporting limits in soil and groundwater on the city's property. Detected contaminants were found primarily between the locations of the Fort Collins Aztlan Center, the United Way Building, and the previous location of the eastern most of the two former gasholders located south of Willow Street. A groundwater plume potentially containing coal tar and/or fuel related compounds was identified, extending north from Willow Street at least 500 feet onto the city's property (Walsh 2001a, 2001b, 2001c, 2001d, 2001e, 2002a, 2002b).

Schrader Oil, the company that owns a portion of the property that includes the previous location of the MGP (Figure 2), is conducting ongoing monitoring and remediation as part of a Colorado Department of Labor and Employment Oil Public Safety Corrective Action Plan. The Corrective Action Plan was implemented because of a 1994 leaking underground storage tank and a gasoline groundwater plume documented on the western and central portion of the Poudre River site and north of the Paragon Consulting Group, Inc. (Paragon) facilities (Paragon 2004).

In September 2002, UOS identified sheen on the Poudre River along the northern and eastern portion of the Poudre River site in a shallow section of the river bed during low flow conditions. Globules of coal tar potentially mixed with fuel related compounds were observed at one location as described in more detail later in this case study. A sample of water and sheen were collected on September 24, 2002. Several PAH compounds were detected at low levels in the samples (Walsh 2003). A sample of the product was also collected from the bottom of the Poudre River by UOS on February 5, 2003. The product was black/dark brown, viscous, and appeared to have a high surface tension while under water. When disturbed, the non-aqueous phase liquid (NAPL) dispersed into an oily sheen that rose to the water

surface. Analytical results document that the product is chemically consistent with products associated with the PVG plant (Walsh 2002b; UOS 2003).

2.3 SITE GEOLOGY

The site lies in the northeast Front Range of Colorado and a review of previous investigations identified the site as overlying Post-Piney Creek alluvium from the upper Holocene underlain by older Broadway alluvium from the Pleistocene (Figure 4). The reported thickness of the alluvium ranged from 5 to 15 feet. Pierre Shale bedrock was reportedly encountered at depths from 16 to 21.5 feet bgs.

2.4 SITE HYDROLOGY

The Poudre River flows along the eastern boundary of the site and flows in a southeastern direction adjacent to the site. Locally, the river has meandered significantly throughout the history of the site as evidenced by Sanborn maps collected as part of the Phase I conducted by Walsh (2001b). These Ox-bows or riverbank and channel deposits took on very different configurations over time prior to the placement of the landfill. It was hypothesized that the deposits could have represented points of discharge for materials leaving the PVG plant, which was an important consideration in development of the preliminary CSM. Figure 5 shows the approximate location of the river channels at a time shortly after the PVG plant was built (1906). A review of additional Sanborn maps from various times after the PVG was in place indicate that the river continued to migrate over time potentially creating other depressions or low areas where contaminants from the PVG plant could have been discharged. These perturbations in the river's path could also represent preferred pathways for the migration of contaminants from upgradient source areas, beneath the landfill, to the river.

Depth to groundwater at the site was reported to be from 10 to 15 feet bgs with the saturated zone underlain by a suspected semi-confining Pierre Shale bedrock layer. The reported groundwater flow direction was to the northeast/east across the site. It was believed that groundwater did not discharge directly to the river along the eastern edge of the site. Based on available data, it was hypothesized that the groundwater may have discharged to the river somewhere down river from the site as the known pieziometric surface began to coincide with the base elevation of the river bed. Direct discharge was suspected to be the greatest during periods of low flow, but this was considered speculative, and would need to be confirmed during subsequent field investigations. Any preferred pathways leaving the landfill or any portion of the site were also identified as potential points for groundwater discharge within the site boundaries. Based on discussions with the various interested parties and the City of Fort Collins, it did

not appear that groundwater was being used in the immediate area. According to City officials, water from the Poudre River is used by the City of Greeley

2.5 MEDIA OF POTENTIAL CONCERN

The media of potential concern at the site included subsurface soil, sediment, surface water, groundwater, and air (Figure 6). Previous investigations confirmed that upgradient sources resulted in the contamination of subsurface soil and groundwater beneath the site. Walsh (2001b) documented the potential threat from the volatilization of groundwater plume constituents to indoor air. Previous investigations had not identified surface water contamination above Maximum Contaminant Levels (MCL) in the Poudre River adjacent to the site. However, the potential for free product to be in direct contact with surface water mandated that impacts to surface water be further evaluated during future investigative activities.

Direct contact with surface soil was not considered a potential pathway of concern because no observations of contaminated surface soil had been reported. Direct contact with river sediment for recreational users was identified as a potential pathway of concern along the berm between the landfill surface and the river, but evaluation of this pathway was beyond the scope of previous investigations and was only a tertiary objective of the TBA and SA investigations.

2.6 CONTAMINANTS OF POTENTIAL CONCERN

The contaminants of potential concern (COPC) at the site were identified through historical information and documentation from previous investigations. Primary COPCs at the site include petroleum hydrocarbons (diesel range organics [DRO] and gasoline range organics [GRO]), BTEX, and PAHs associated with the coal tar.

Diesel and Gasoline Range Organics. Previous investigations had focused on specific compounds associated with coal tar such as naphthalene and benzene, so historical information concerning DROs and GROs was limited.

BTEX Compounds. Previous investigations at the site had also identified a benzene groundwater plume extending approximately 500 feet northeast from Willow Street between the Aztlan Center and the United Way building.

PAHs. PAH compounds such as naphthalene were identified in site groundwater during previous investigations. Additionally, the analysis of the product sample collected by UOS from the riverbed on February 5, 2003 revealed that the material contained high concentrations of many semivolatile organic compounds (SVOC), primarily PAHs. Naphthalene, one of the lightest and most soluble of these compounds, was chosen to delineate the dissolved plume as well as provide an indication of contaminant migration pathways or source areas during the TBA. Iso-concentration maps generated from groundwater data collected by previous investigations indicated a naphthalene plume extending from Willow Street east to near the middle of the site, but did not indicate that the naphthalene plume was reaching the Poudre River (Figure 7), as would be expected if the coal tar NAPL plume extended from the former PVG plant site to the seep area observed in the Poudre River.

Chlorinated Solvents. Previous investigations had not indicated the presence of chlorinated solvents at the site above MCLs.

Methyl tert-butyl ether. Detections of methyl tert-butyl ether (MTBE) were identified in site groundwater during previous investigations; however, the groundwater plume was estimated to only be present in the northwestern portion of the site adjacent to Willow Street.

2.7 EXPOSURE ROUTES AND RECEPTORS

A complete exposure pathway consists of four fundamental components: (1) a source and mechanism of chemical release, (2) an affected environmental medium and a probable chemical migration process, (3) an exposure point, and (4) an exposure route by which humans or ecological receptors could come into direct contact with a COPC. If any of these components is missing, then the exposure pathway is incomplete and no exposure can occur.

Potential exposure pathways for the site were selected based on current land use and the most probable future activities at the site, as well as an evaluation of potential transport or uptake pathways.
Prior to the field efforts conducted under the TBA, a pathway receptor diagram (Figure 6) was developed for the Poudre River site

The most likely receptors and exposure routes were determined to be human recreational users, along with terrestrial and aquatic organisms exposed to site contaminants via contact with river surface water or contaminated sediments. Exposures to recreational users of the park, soccer field, and bike path were considered minor because planned recreational use of the area would not likely require disturbance of

deeper (subsurface) soil associated with the landfill materials or NAPL. The groundwater to surface water exposure pathway is considered a potentially complete pathway based on existing information. It was determined that indoor air inhalation hazards may need further assessment as site reuse is planned and implemented.

2.8 PROPERTY REUSE SCENARIO

Reuse scenarios were established for the site. Currently, the City of Fort Collins intends to continue the use of the Aztlan recreational center and the park. The park includes bike paths, playing fields, a soccer field, and picnic areas. Under the Fort Collins Downtown River Corridor Implementation Program, redevelopment plans for the site include the construction of a new 50,000 square-foot multi-generational recreation center.

3.0 SYSTEMATIC PLANNING AND PREPARATION IN SUPPORT OF THE TARGETED BROWNFIELDS ASSESSMENT

Comprehensive, up-front planning is a key component of the Triad approach. Proper planning coupled with the use of dynamic work strategies and the correct monitoring and measurement tools will promote collection of data that will lead to defensible decisions. At the time of characterization, the cleanup goals for the site are used as the basis for developing a sampling strategy and selecting the appropriate analytical tools and methods for both sampling and analysis. By understanding the questions that need to be answered and the data and documentation necessary to make effective project decisions, project managers and team personnel can use systematic planning as a tool to develop a roadmap to success.

In May 2003, EPA issued a TBA grant to evaluate the potential for official landfill closure. As previously stated, the ultimate objective of the TBA was to facilitate the construction of a new community recreation center on the city's property and identify the source of coal tar and sheen identified in the Poudre River. Contractor support to EPA Region 8 was provided under the START 2 contract, initially by UOS and subsequently by Tetra Tech.

The BTSC provided support to EPA Region 8 and Tetra Tech, during project planning, including the development of a revised work plan and approach for the TBA, which incorporated the Triad approach (Tetra Tech 2003). The initial work plan developed by UOS was never completed or formally submitted for EPA review because it was decided early on to abandon the stated approach and move toward an investigation based on TBA and Triad principles. The elements of the initial plan did not receive full review by EPA and are described here as background information only.

3.1 INITIAL WORK PLAN

This section describes the activities originally identified under the TBA using a traditional Phase I and Phase II approach with fixed laboratory analyses. The original technical approach for this site was based on standard industry practices and American Society for Testing and Materials standards for conducting Phase I and Phase II SA investigations. Clarifications and modifications to the scope were discussed at scoping meetings between EPA, Tetra Tech, and legal and technical representatives for potentially responsible parties (PRP).

3.1.1 Site-Specific Objectives for Initial Work Plan

The original objective for the site TBA was to conduct an investigation to determine the source of the sheen and the product identified in the Poudre River. The Phase II work plan also called for investigation of the former landfill to evaluate the potential for formal closure of the landfill from the CDPHE. The data collected during this investigation was expected to complement a previous Phase I investigation conducted by Walsh at the site.

3.1.2 Development of the Original Sampling Approach

The original, pre-Triad sampling plan called for collection of authoritative judgmental samples to confirm the presence or absence of contamination at locations where previous reports had implied potential contaminant migration pathways for coal tar related compounds. Samples were to be collected using a Geoprobe® direct-push drill rig. The focus of the investigation was on the identification of preferential contaminant migration pathways such as paleochannels or topographic lows within the bedrock. The following primary activities were planned for the original Phase II SA investigation:

- Characterize site soil via direct-push sampling by collecting 20 surface soil samples and 27 subsurface soil samples (and associated quality control [QC] samples) and conducting off-site laboratory analyses for the identified COPCs
- Characterize site groundwater via the installation of seven standard monitoring wells and off-site laboratory analyses of 13 groundwater samples (and associated QC samples) for the identified COPCs
- Characterization of additional grab samples of coal tar and any other NAPL found during the investigation using standard methods and off-site analyses for the identified COPCs

3.1.3 The New Sampling Approach

In May 2003, EPA directed Tetra Tech to prepare a revised field sampling plan (FSP) for the TBA at the site based on principles of the Triad approach. The revised FSP was finalized in July 2003 and described field activities to be conducted to identify chemical characteristics of the coal tar material identified in the Poudre River adjacent to the site, evaluate the nature and extent of contamination at the site that could impact reuse or remedy design, and identify pathways for the coal tar material or other contaminants reaching river.

To streamline site characterization activities, project goals were reexamined and potential investigation design modifications identified. To the degree possible, the project team agreed that innovative technologies and approaches should be used to maximize the efficiency of more traditional methods of investigation. In particular, the use of geophysical methods and the EPA Region 8 Mobile Laboratory were identified as potential ways to maximize data collection efficiency. The BTSC examined the following project elements in an effort to redesign the program:

- The preliminary CSM to identify critical data gaps
- The proposed soil and water sampling and analytical programs to identify methods for cost effectively increasing sampling and analytical data density
- Other sources of information that could be obtained using innovative technologies to evaluate the potential for impacts from fugitive emissions and discharge of groundwater to surface water
- Alternative non-intrusive methods for identifying potential preferred pathways for contaminant migration

The new sampling approach developed as part of the reevaluation effort included the identification of a dynamic work strategy that incorporated the use of several field-based technologies to be used in refining the CSM. To provide evidence of preferential pathways for the subsurface migration of contaminants and to identify any buried metal objects such as drums that could act as potential sources, a geophysical survey was conducted using terrain conductivity meters. The geophysical survey was initiated prior to conducting any intrusive sampling the site. Potential pathways identified for evaluation included, discharge pipes, bedrock channels, former river channel features, buried objects, and dumping grounds. In addition to the geophysical survey, the project team, with support from one of the PRPs, undertook the sampling of all existing wells across the site and the collection of water level data to improve the team's understanding of hydrogeologic conditions and water quality. In addition to these activities, the project team planned to use direct-push groundwater sampling and analysis of the samples in near real time using the Region 8 Mobile Laboratory to increase the density of groundwater data and provide the results to the team in a shorter timeframe.

By using this approach instead of the traditional well installation approach, the density of sampling points was increased from seven wells and associated samples to more than 30 sampling locations with up to three sampling intervals per direct-push location. The cost savings was to be further enhanced by substituting small gauge temporary monitoring wells for groundwater sampling purposes where possible instead of larger, permanent monitoring wells; particularly where no contamination was found. Direct-push groundwater results and the other information obtained during the geophysical survey and existing monitoring well sampling event would then be used to optimize placement of permanent groundwater monitoring locations. Grab groundwater samples were analyzed for VOCs using a field-based gas chromatography/mass spectrometry (GC/MS) to guide the direct-push sampling program and identify samples for off-site analysis of PAHs and other potential COPCs not measured in the field. Appendix 1 contains Technology Quick Reference Sheets (TQRS) for each real-time technology used at the Poudre River site.

3.1.4 Analytical Options

Under the dynamic work strategy applied at the site, the use of real-time analytical results for decision-making allowed the investigation to focus on areas where elevated levels of contamination might be expected in a single mobilization.

For the purposes of this investigation, a modified SW-846 8260 method for the on-site analysis of VOCs was used to guide the direct-push sampling program. In addition to the on site GC/MS, a photoionization detector (PID) in series with a flame ionization detector (FID) was used to screen soil and groundwater samples to identify locations where preferential contaminant migration pathways or potential source areas might be located. Figure 8 provides the dynamic work strategy logic used to collect groundwater grab samples in the field. It should be noted that at several locations multiple samples from differing depths were taken, regardless of the results obtained from the initial sample collected at or slightly below the surface of the water table, to assure the team would not miss a deeper zone carrying contamination, which was not identified at the top of the water table.

The project team also concluded that a DMA was needed to ensure that the modified SW-846 Method 8260 analyses would provide identification of indicator compounds, in particular naphthalene, and provide method and matrix specific limits of detection. Indicator compounds such as BTEX and naphthalene in the dissolved phase would provide information on areas where the NAPL and coal tar related compounds could be expected. Evaluation of site-specific matrices and the corresponding

detection/reporting limits was conducted to ensure that the information provided by the mobile laboratory was of sufficient quality and that the detection/reporting limits were low enough to guide project decisions. The DMA consisted of an initial groundwater sampling event at the site using GC/MS analysis in the field to evaluate volatile target compounds expected at the site, achievable detection and reporting limits, development of an initial calibration curve and continuing calibration procedures, and finally evaluation of any site-specific matrix interferences. The DMA is discussed in further detail in Section 3.2.

3.1.5 Developing Decision Logic

Development of decision logic provides a clear process for how and when collection of samples for field and off-site analysis might be best used. A decision logic diagram (Figure 8) was developed prior to field work to provide field sampling personnel with a step-by-step process for screening direct-push soil and groundwater samples in the field. Using the decision logic diagram, the field team could identify locations where samples taken from the top of the water table indicated the necessity for collection of samples at the bedrock interface. Through this logic the field team was able to assess small-scale heterogeneity of dissolved contaminants at various depths and identify areas where the presence of coal tar NAPL at the bedrock interface was likely.

3.2 GRAB GROUNDWATER SAMPLING DEMONSTRATION OF METHODS APPLICABILITY

The DMA coincided with the collection of groundwater samples from 16 existing monitoring wells at the site. The samples were analyzed in the field using a modified SW-846 Method 8260 analysis. Based on stakeholder consensus, additional volume was sent to off-site laboratories for the analysis of VOCs, SVOCs, pesticides/polychlorinated biphenyls (PCB), dissolved metals, cyanide, GRO, DRO, and anions. Water level measurements at all monitoring well locations were also collected to help refine the CSM and develop a site-wide groundwater surface map.

The collection of VOC data enabled the field team to determine applicable detection and reporting limits for field-based GC/MS results, design an initial calibration and appropriate QC protocol, and evaluate the types and concentrations of contaminants expected in groundwater at the site. These data were then used in conjunction with the geophysical survey to refine the CSM, the direct-push groundwater and soil sampling scheme, and focus drilling in areas where coal tar NAPL was suspected.

3.3 TARGETED BROWNFIELDS ASSESSMENT FIELD EVENT

The TBA field activities included a geophysical survey followed by a direct-push groundwater grab and soil sampling investigation and finally, installation, development, and sampling of temporary and permanent monitoring wells. During site activities, portions of the site were closed to the public and access to the Poudre River was restricted.

3.3.1 Geophysical Survey

Prior to conducting any field sampling activities under the TBA, a geophysical survey was conducted at the site. The purpose of the survey was to provide evidence for preferential pathways for the subsurface migration of contaminants using geophysical techniques. Such pathways include (but are not limited to) discharge pipes, bedrock features, and subsurface features such as paleochannels.

Early on in the fieldwork planning process, the project team identified the potential configuration of the bedrock beneath the site based on a map provided in UOS's draft work plan that was created using boring logs. This map showed a steep dip in the bedrock beneath the site extending east toward the Poudre River. A review of the boring logs from the site suggested, however, that the information that served as the basis for this map was not very definitive because many borings did not extend to the shale bedrock; therefore, the boring logs do not show the shale bedrock. It was the BTSC's contention that the bedrock surface indicated on Figure 5 could be more representative of refusal than a geologic feature beneath the site. Refusal of direct-push or auger rigs has many causes including; the presence of trash, gravel zones, and metal objects. Therefore, the team decided to perform a geophysical survey to better refine the bedrock surface map and consequently the CSM.

The geophysical field team used two instruments for this investigation, the Geonics Limited EM31 and EM34 Terrain Conductivity meters. Both instruments measure electrical terrain conductivity by transmitting electromagnetic energy into the subsurface. This is termed an apparent electrical conductivity reading because the instruments measure a "bulk electrical conductivity," which is a measurement of the terrain's ability to carry electrical energy. This measurement may be influenced by lateral or vertical changes in the subsurface. The transmitted electromagnetic field induces eddy currents into the subsurface and the electromagnetic field carried by these currents are sensed by the receiver coil of the instrument and transmitted to the control box where they are amplified and tuned to read in the proper conductivity units, milliSiemens per meter (mS/m). It is a useful measurement, since finer particulate soil and high clay content soil can be distinguished from sands and gravelly soil, bedrock

features including paleochannels can be mapped, and buried metal such as pipes and drums can be located.

The EM31 was used to investigate the shallow subsurface, or unsaturated zone, since it has an affective exploration depth of approximately 12 feet with a fixed coil spacing of 3.7 meters. The EM 34 was used because the transmitter and receiver coil spacing can be varied in this instrument to obtain better targeted depth resolution, allowing the effective exploration depth to be increased and "tuned" to a targeted depth. A 10-meter coil spacing was used to investigate the saturated zone at the site. The instrument was set in the vertical dipole mode (coils placed horizontally on the ground) giving it a peak response from materials from approximately 3 to 7 meters bgs (10 to 20 feet). The average groundwater depth at the site is approximately 15 feet. A 20-meter coil spacing was used to investigate possible bedrock features, since in this configuration, the instrument has a peak response from materials from approximately 6 to 12 meters bgs (20 to 30 feet). Bedrock at the site is up to 21 feet bgs.

The TBA geophysical survey was performed from June 26 through June 29, 2003. On June 26, the project team laid out survey lines with wood stakes and flagging spaced 20 feet apart in an area measuring approximately 500 feet by 600 feet, parallel to the River (Figure 9). The survey started at the north corner of the property using the EM31 instrument. Measurements were recorded in a data logger along the survey lines approximately every 2 feet for good lateral resolution. The planned EM31 survey was completed that day. After evaluation of the data, the team decided to expand the survey in the northwest direction. The survey expansion was completed the following day, June 27, 2003.

The EM34 survey was performed on June 28 and June 29, 2003. The survey was performed using both the 10 meter and 20 meter receiver and transmitter coil spacing both set on the vertical dipole configuration to minimize near surface metal interference and maximize exploration depth. The survey was performed with the coils parallel to the direction of the survey. The 10 meter coil spacing survey was performed by taking readings every 10 feet along the survey lines, and the 20-foot coil spacing survey was performed by taking readings every 20 feet along the survey line.

For ground control, the field team used the fixed surveyed points of several permanent monitoring wells to fix the survey line points. Global Positioning Satellite readings were taken at well locations and tied to geophysical stake nodes in order to translate the geophysical grid into site coordinates such that the results could be plotted on existing investigative maps.

3.3.1.1 Geophysical Survey Results

Data were downloaded onto a computer and compiled into color contour maps using Geosoft Oasis Montaj® contouring and mapping software for presentation. The EM34 data were further processed by despiking readings from near surface metal to enable conductivity trends to be visualized more easily. Figure 10 provides an example of the geophysical survey results from the EM geophysical survey.

The EM31 and EM34 terrain conductivity surveys provided information to map the subsurface of the site. Variations in apparent ground conductivity were detected, suggesting that on-site fill materials are variable. These data supported the observed variance in groundwater movement. The range in apparent conductivity in the unsaturated zones indicated by the EM31 data is from less than 8 to over 20 mS/m. In general, the lower apparent conductivity materials are located at the northwest half of the site. The range of conductivities here would suggest loose fill, sand, and other porous materials (such as landfill debris). The higher conductivity areas of the southeast portion of the site nearer the buildings suggest engineering fill and fine-grained soil such as clay or clayey silts. In the vadose zone, groundwater movement would be more hindered in this area than in the looser fill of the northwest. This interpretation is also supported by the well logs, which show landfill debris mixed with gravelly sands at shallow depths in well log SB-05 in the low conductivity area, and thick clayey silts mixed with a lesser degree of landfill debris in the boring SB-01 in the high conductivity area south of the playground.

The EM34 data showed higher apparent conductivity ranging from approximately 14 to 30 mS/m in the northwest half of the site. This is likely due to the influence of higher conductivity from the saturated zone. Also, the higher apparent conductivity trends seen in the EM31 survey color contour map (Figure 10) become less prominent in the EM34 presentation. This was suggestive of the presence of looser, less conductive gravels and sands at greater depths. This finding is also supported by the boring log SB-01, which shows sandy gravels at depths greater than the exploration depth of the EM31. Also, the influence of bedrock topography becomes apparent with analysis of the EM-34 data. The EM34 maps indicated an apparent conductivity high trend at the east quadrant of the site near the river, which correlated very well with the bedrock topography contours. This feature suggests an expected increase in thickness of sandy gravel materials near the river bed.

An important finding from the EM geophysical survey was the relatively low volume of metal objects that were indicated within the former landfill. The most prominent feature was the water main that parallels the river near the bank at the east edge of the site. The service pipes at the northwest edge of the surveyed area were also detected in the geophysical survey data. No other pipes were interpreted to be present, but

there was a suggestion of pipe signatures that paralleled the service pipes approximately 100 feet to the south, as shown on Figure 10.

3.3.1.2 Geophysical Survey Conclusions

The geophysical data combined with boring log correlations suggested that groundwater movement in the unsaturated zone is influenced by the variability of materials ranging form tight clays to sands, gravels and landfill debris. The groundwater movement is probably largely influenced by bedrock topography in the saturated zone where materials are primarily sands and gravels that would not hinder groundwater movement. Any preferential pathway for contaminant migration is shallowly dipping and sloping to the east where the gradient of the bedrock surface is greatest. There also may be a channeling of groundwater along the linear feature as shown in the geophysical data across the northwest section of the site towards the northeast. However, this did not appear to be directly connected to the seep area.

There appeared to be no piping directly connected to the seep area. The geophysical survey defined service lines and the main water line very well, and *may* have identified a small pipe going across the site. However, if this is a pipe, it appears to not correlate with the seep area. The EM geophysical survey identified an apparent buried metal anomaly south of the seep area, which was largely masked by the presence of the water main (Figure 11). This area was reexamined during the subsequent SA using high resolution resistivity and invasive drilling techniques (see Section 7.0), and no large metal objects or source areas could be confirmed in the area.

3.3.2 Direct-Push Soil/Product Sampling

Following the TBA geophysical survey a direct-push sampling event was conducted. All boreholes were continuously cored and logged for lithologic description, and screened with a PID/FID. As planned in the decision logic diagram (Figure 8), where PID/FID readings exceeded 100 parts per million (ppm) or where visual inspection of soil cores indicated NAPL, a sample of the soil was collected and analyzed on site for VOCs using a modified SW-846 Method 8260 analysis. Another aliquot of the soil from the same interval was sent to an off-site laboratory for comparative analysis.

Eight soil samples (excluding the delineation soil samples, described below) were collected during this portion of the field activities. Two soil samples each were collected from monitoring well boreholes FC-MW-01, FC-MW-09, and FC-MW-15. One soil sample was collected from the monitoring well borehole FC-MW-12 and one from monitoring well borehole FC-MW-13. These soil samples were sent for off-

site analysis of SVOCs, VOCs, pesticides/PCBs, and DRO. These product data were later used to fingerprint the material in the source area adjacent to the former MGP for comparison with product found in the river as described in more detail in Section 3.3.7.

3.3.3 Coal Tar Product Delineation

Where coal tar product was encountered in soil boring FC-GW-15, near the Poudre River, additional borings were installed at 20-foot spacing around the location to assess the lateral and vertical extent of the coal tar NAPL and to evaluate relative potential NAPL impacts to the river.

Delineation boreholes were installed 20 feet north, south, east, and west of borehole FC-GW-15. PID readings were less than 30 ppm at each of the delineation borings. However, FID readings varied from less than 90 ppm to greater than 1000 ppm. It was suspected, but not confirmed, that the presence of methane was causing the high FID readings. The high FID readings were not sustained and lasted only a few seconds before dropping. No identifiable odors were detected in any of the delineation cores. Some black staining was observed at location FC-DS-02, which is 20 feet west of FC-GW-15. A soil sample was collected from 3 to 5 feet bgs at this location and sent for off-site laboratory analysis of SVOCs, VOCs, pesticides/PCBs, and DRO. Delineation sampling did not identify the presence of product at any of the four additional boreholes indicating a localized area of contamination at 17 to 18 feet bgs at FC-GW-15.

3.3.4 Direct-Push Groundwater Sampling

The TBA FSP (Tetra Tech 2003) estimated that a maximum of 90 groundwater grab samples from up to 45 different direct-push borehole locations would potentially be collected. A total of 48 groundwater grab samples were actually collected from 34 of the 42 locations where the direct-push tool was successfully advanced into the subsurface to groundwater. In the other eight locations, the direct-push rig met refusal prior to reaching groundwater. The high incidence of refusal at the site was initially attributed to landfill debris and a potential sandstone layer within the alluvium. Because refusal was not a significant issue during the limited subsurface investigations conducted previously at the site using hollow-stem auger (HSA) drill rigs, the high incidence of refusal encountered during the TBA was not anticipated. Figures 12 and 13 include the direct-push borehole locations where samples were proposed for collection.

Forty eight groundwater grab samples were analyzed for VOCs on site; additionally, sample aliquots from FC-GW-15 and FC-GW-33 were sent to off-site laboratories for analyses of suspected fuel-related

compounds in accordance with the established TBA decision logic (Figure 8) because a visual inspection of the sample indicated the presence of NAPL.

During the direct-push sampling program, visible NAPL resembling coal tar was only encountered at 17 to 18 feet bgs, at FC-GW-15 (Figure 12) located in the southeast portion of the site near the Poudre River. In an attempt to fingerprint the NAPL found in groundwater samples at this location, water was decanted from an extra 1-liter amber bottle at the laboratory and the remaining NAPL was solvent rinsed from the bottle. This resulted in approximately 4 grams of the NAPL product for extraction, which was submitted for analysis of SVOCs and pesticides/PCBs. The laboratory was able to analyze the extract for SVOCs at a relatively high dilution, however, due to the large number of non-target compounds the pesticide/PCB analysis could not be completed on the extract.

3.3.5 Monitoring Well Sampling Results

Five temporary and 10 permanent small-gauge monitoring wells were installed as part of the TBA field effort. Locations for the wells were identified based on field analytical results from the direct-push groundwater grab samples. After review of the grab sample field-based analytical results, the wells were installed at locations surrounding the landfill where the highest grab sample VOC concentrations were detected using the on-site GC/MS. Figures 12 and 13 include the locations of all temporary and permanent monitoring wells installed during the TBA investigation.

After installation, the monitoring wells were developed and sampled according to procedures described in the TBA FSP. Groundwater samples were analyzed at off-site laboratories for SVOCs, VOCs, pesticides/PCBs, dissolved metals, cyanide, DRO, and anions. Groundwater samples from newly installed groundwater monitoring wells were analyzed for the same constituents as existing upgradient monitoring well samples.

Results for all detected VOC and SVOC compounds are provided in Tables 2 and 3. Analytical results for pesticides, PCBs, cyanide, metals, and water quality parameters are not provided because these results yielded no reportable quantities, were not indicative of contamination, or were not above regulatory thresholds. The results of the TBA confirmed the existence of BTEX compounds in site groundwater. Benzene concentrations are highest in the southern portion of the Aztlan Center parking lot and east of Willow Street between the railroad spur to the north and Pine Street to the south.

For the TBA, existing monitoring wells and locations where NAPL product was visually identified were analyzed for DRO. The highest concentrations of DRO were detected in groundwater collected from wells in southern portions of the parking lot for the Northside Aztlan Center and just east of Willow Street adjacent to Giddings machine shop. These sampling locations are downgradient of the historical MGP location.

Although previously unreported, chlorinated solvents were detected in a significant number of groundwater samples across the site. The most prevalent chlorinated solvent detected was PCE, which was detected in the eastern portion of the site, along the Poudre River, and, predominantly, in the southeastern portion of the site near the United Way building (Figure 13).

Iso-concentration maps were created to provide a visual representation of some site contaminants in groundwater. These maps were created using the TBA field and off-site data, as well as historical observations. The contaminants: naphthalene, MTBE, and PCE were chosen based on the high frequency of detection. In order to further refine the site CSM and assist in the delineation of the groundwater plume, benzene was also mapped. Naphthalene was chosen as an indicator of PAH contaminants related to coal tar contamination (Figure 12).

3.3.5.1 Naphthalene in Groundwater

Figure 12 shows the concentrations of naphthalene in groundwater based on the results of the TBA. A review of Figure 12 shows concentrations of naphthalene in groundwater are highest in the area of the historical gas holders on the property of the former MGP west of Willow Street and downgradient of that location in the Aztlan Community Center parking lot. The plume generally follows the flow direction of groundwater at the site east and northeast towards the Poudre River.

Groundwater data from previous investigations conducted at the site indicated that the naphthalene plume extended east from Willow Street to the area of the playground located south of the Aztlan Community Center (Figure 7); however, the TBA investigation indicated that the naphthalene plume extended as far as the Poudre River (Figure 12). Naphthalene concentrations near the Poudre River however, were far lower than might be expected in groundwater at equilibrium with coal tar NAPL, and a significant data gap still existed between the Aztlan Community Center parking lot and the river. Therefore, the project team still faced considerable uncertainty concerning the location of any preferred pathway for coal tar NAPL migration to the river.

3.3.5.2 MTBE in Groundwater

MTBE was also detected in site groundwater during the TBA. Results from on-site analysis using a modified SW-846 Method 8260, off-site EPA Contract Laboratory Program VOC analyses, and Method 8260 analyses conducted at the EPA Region 8 laboratory all indicated the presence of MTBE in various groundwater samples. This highly soluble VOC target compound is not a component of coal tar contamination associated with the historical MGP. The highest concentrations of MTBE were observed along the western portion of the property adjacent to Willow Street. The highest detection of MTBE in groundwater (83.9 µg/L) from the TBA was located at FC-GW-34 (Figure 12). This direct-push location corresponds to past gasoline releases that have been documented on an upgradient adjacent property. Additional detections were found along the river near monitoring well FC-MW-04 providing evidence that the MTBE dissolved plume may extend to the river.

The presence of MTBE in site groundwater, particularly west of the Northside Aztlan Center parking lot, indicated that past gasoline spills in the area west/northwest of the property have migrated to the property. The presence of this contaminant suggested that more recent fuel-related spills may have commingled with coal tar from the historical MGP and subsequently may have enhanced the mobility of coal tar NAPL in the area.

3.3.5.3 Tetrachloroethene in Groundwater

Previous investigations at the site had not identified widespread PCE contamination on the property. A review of Figure 13 shows that detections of PCE are widespread in the area around the United Way Building with concentrations increasing south and east of this facility. The highest concentration of PCE in groundwater detected during the TBA was 42.1 µg/L at location BTH-10. The source of PCE was not identified during the TBA, although the subsequent SA investigation provided more information regarding potential source areas in this portion of the site (see Section 7.0).

3.3.6 Surface Water and Sediment Sampling

The initial sampling decision logic outlined in the FSP and Quality Assurance Project Plan for the TBA did not include the collection of river sediment or surface water samples. However, observations of a sheen and coal tar-like NAPL in the river in conjunction with relatively low stream flow allowed several samples of opportunity to be collected during the field sampling event. Three surface water samples (samples SW-1 through SW-3) and six sediment samples (samples FC-RS-01 through FC-RS-06) were collected from the river to evaluate potential impacts of the observed NAPL. Surface water and stream

sediment sample locations are included on Figures 12 and 13. Sample aliquots for both the surface water and sediment were collected for off-site analysis of VOCs, SVOCs, pesticides/PCBs, and GRO.

3.3.7 Product Fingerprinting

The origin of coal tar NAPL detected in the Poudre River adjacent to the Northside Aztlan Center in Fort Collins has been a major point of contention among interested parties including, Xcel Energy, Schrader Oil, and the City of Fort Collins. In an attempt to "fingerprint" the material found in the river, Tetra Tech, as tasked by EPA under the START 2 contract, evaluated the relative distributions of PAH compounds in four riverbed samples versus those found in three upgradient potential source area samples. The PAH analytical results for samples used in the fingerprinting evaluation are provided in Table 4. Sample results are compared to benzo-a-pyrene as a means to evaluate the relative ratios of constituents found in each sample. The results of the product fingerprinting are presented in Appendix 2. Table 5 shows the physical properties of a product sample. The physical properties of product can be critical to understanding the fate and transport tendencies of the material and can influence the remedial design at a site.

3.3.7.1 Product Samples Collected from the Poudre River

In September 2002, a sheen was noticed on the river near the south bank, in line with the axis of the identified plume of suspected coal tar related compounds. A sample of the NAPL (FC-PR-01) was subsequently collected from the bottom of the river by UOS on February 5, 2003. The product was dark brown to black, viscous, and appeared to have a high surface tension while under water. When disturbed, the NAPL dispersed into an oily sheen on the water surface. A second sample of the NAPL product, (FC-PS-01) was collected in September 2003 from the river bottom near the location of the FC-PR-01 seep area by Tetra Tech during the course of the TBA.

After the TBA was completed, additional NAPL samples were collected and added to the correlation analysis as well. NAPL sample PR-SB-8 was collected from a temporary well screened in bedrock within the river channel during the river channel investigation conducted by one of the PRPs (Xcel Energy) and their consultant RETEC (see Section 6.0; RETEC 2004; and Figure 14). This sample (PR-SB-8) was collected approximately 17 feet into bedrock from the bottom of a temporary well screened from 9 to 19 feet bgs. Bedrock at this location (PR-SB-8) began at 2 feet bgs. Finally, a soil sample (TR-01SP) containing visual NAPL contamination was collected from Trench-01 (see Figure 14) at the bedrock interface approximately 2 feet bgs during the same PRP river channel investigation.

3.3.7.2 Samples Collected from Potential Upgradient Sources

Upgradient samples were chosen based on historical visual observations identifying NAPL product. The first upgradient soil sample was collected from a test pit at the former MGP site (Figures 2 and 3). The product sample (TP-2, 11.5') was collected from 11.5 feet bgs at test pit 2 during the gasholder investigation conducted by Western Environmental Technologies, Inc. (Western) in 1996 (Western 1996).

Two additional product samples were collected from areas in the former landfill to evaluate the potential for sources of the material found in the river at these locations. Two locations were identified where limited product was encountered in the former landfill materials; however, additional delineation efforts did not yield product from nearby boreholes. Upgradient product sample [BTH-10 (5-15')] was collected by Walsh at location BTH-10 (Figure 3) during an investigation in 2001 (Walsh 2001b). Upgradient product sample (H1250) was collected by Tetra Tech between 17 and 18 feet bgs at direct-push borehole FC-GW-15 during the 2003 TBA (Tetra Tech 2004a).

3.3.7.3 Correlations of PAHs in River and Upgradient Samples

Tetra Tech used a statistical software package (STATISTICA™), to develop correlations between concentrations of PAHs in targeted samples collected in the Poudre River and from potential upgradient sources. In accordance with EPA guidance (EPA 2000), a proxy value of one half the quantitation limit was used for non-detected values. Results were normalized to benzo(a)pyrene to represent PAH ratios in each sample rather than absolute values. Correlations calculated for absolute values produced similar results. Correlation coefficients closer to 1 imply a strong relationship between the concentrations of PAH compounds in the samples. Values of correlation coefficients closer to zero imply little correlation between variables.

The high correlations (correlation coefficients of 0.94 to 0.98) between the concentrations of PAH compounds detected in the riverbed samples and in the former MGP sample (TP-2, 11.5') suggest that the PAHs found in these samples have a common origin and were generated by a common process (Appendix 2).

Samples collected from landfill materials (BTH-10 [5-15'] and H1250) had extremely poor correlations (0.01 to 0.10) when compared to the riverbed samples, indicating that these materials have a very different composition and do not have a common origin. Samples collected from the landfill materials

also had low correlation coefficients (-0.009 to 0.03) when compared to the MGP sample (TP-2, 11.5'), indicating that these materials have a very different composition and do not have a common origin.

3.3.7.4 Ratios of PAHs in River and Upgradient Samples

In addition to the correlations and scatterplots developed using the statistical software package (STATISTICA™), Tetra Tech developed bar/column plots for the evaluation of PAH ratios. Bar charts were completed using absolute concentrations of PAHs contained in riverbed and upgradient samples. In accordance with EPA guidance (EPA 2000) a proxy value of one half the quantitation limit was used for non-detected values. Bar charts are provided in Appendix 2 of this case study.

Four visual comparison bar charts were created comparing PAH ratios for riverbed samples and each of the three upgradient samples. A review of the PAH ratio comparison for river samples versus the MGP sample reveals very similar patterns. Both the river samples and the MGP sample have PAH concentrations where the highest concentrations are of naphthalene followed by phenanthrene, acenapthylene, and fluorene. Concentrations of the remaining 12 PAH compounds found in the river and MGP samples are comparatively low.

A review of the PAH ratio comparison between the river samples and landfill material sample BTH-10 (5-15') reveals very different patterns. Landfill material sample BTH-10 (5-15') has PAH concentrations where the highest is pyrene, followed by relatively high concentrations of benzo (b) fluoranthene, benzo (a) pyrene, acenapthylene, fluoranthene, and phenanthrene. Concentrations of the remaining 11 PAH compounds are also elevated relative to the highest concentration compound of pyrene. Sample BTH-10 (5-15') also has a low concentration of naphthalene relative to the remaining PAH compounds. This is in direct contrast to the MGP sample and all of the river samples where the predominant PAH compound in the sample is naphthalene.

Similarly, a review of the PAH ratio comparison between the river samples and landfill material sample H1250 reveals very different patterns. In landfill material sample H1250, the highest concentration PAH is pyrene, followed by relatively high concentrations of benzo (b) fluoranthene, benzo (a) pyrene, acenapthylene, fluoranthene, and phenanthrene. Concentrations of the remaining 11 PAH compounds are also elevated relative to the highest concentration compound of pyrene. Sample H1250 also has a very low concentration of naphthalene relative to the remaining PAH compounds. This is in direct contrast to the MGP sample and all of the river samples where the predominant PAH compound in the sample is naphthalene.

3.3.7.5 Summary Of PAH Correlation Findings

Both the scatter plot correlations and the bar/column plots for PAHs indicated that the material found in the PVG sample and those samples collected in the Poudre River were very similar in composition and may have a common origin or have been generated by a similar process. PAH ratios for other potential source materials, including localized free product and heavily contaminated soil samples collected within the historical landfill materials, correlated very poorly with the material collected at the former MGP and the river samples. Given the extremely strong correlations between the PVG sample and all four samples collected over a period of more than 1 year from the Poudre River, it is considered likely that these materials have a common origin. The PAHs found in other free product materials identified during the field activities of the TBA and SA appear very different in composition from both the MGP sample and all four river samples indicating that it is very unlikely that these materials are the source of the river contamination.

4.0 REVISED PRELIMINARY CONCEPTUAL SITE MODEL

At the conclusion of the TBA, the results were compiled and the CSM was once again refined to reflect the latest knowledge concerning the site (Figure 15). A hypothesis was proposed, which stated that interbedded caliche and/or cemented sandstone layers within the alluvium might be present across the site based on the high frequency of drilling refusal encountered during the TBA investigation. The identified presence of petroleum hydrocarbons and contaminants associated with more recent gasoline and diesel fuels during the TBA was also included. Finally, potential locations of coal tar NAPL sources and migration pathways were included; their identification was the major question remaining at the site and a primary objective of subsequent investigations.

The project team further hypothesized that either the coal tar NAPL was screened away from the shallow groundwater by some physical barrier downgradient of the former MGP site, or the pathway was not complete between the former MGP and the river. This hypothesis was based on the low concentrations of dissolved phased NAPL-associated contaminants identified in groundwater at downgradient areas of the site. If a complete pathway did not exist between the former MGP and the river, then the coal tar NAPL observed there could be the result of some type of dumping scenario in or near the river. These observations prompted one of the PRPs, Xcel Energy, to initiate a river channel investigation and a drilling program around the banks of the river in an attempt to identify localized sources that could be a source for the coal tar contamination identified in the river.

5.0 RIVER CHANNEL INVESTIGATION

An obvious source for the coal tar NAPL in the Poudre River and a complete pathway for coal tar migration from the former MGP to the river was not identified during the TBA. As a result, one of the PRPs, Xcel Energy, implemented a river channel area investigation in an attempt to identify the extent of the seep and the potential presence of localized source areas other than the former MGP itself. Xcel Energy's consultant, RETEC, conducted the investigation with oversight provided by Tetra Tech for EPA Region 8. The area of interest extended from near monitoring well BTH-15 and north along the riverbed to the railroad trestle (Figure 3).

5.1 Proposed Revisions To The Conceptual Site Model

The CSM proposed by Xcel Energy and their consultant RETEC, predicted that coal tar had been dumped in the Poudre River itself and/or it had been dumped in the former landfill adjacent to the seep area, and that no complete pathway for coal tar NAPL migration existed between the former MGP and the Poudre River. This CSM had extensive implications concerning the responsibility for cleanup and any potential remedy proposed for the site. If the source material was localized to the river channel, it should be possible to dig it out and simply backfill the portion of the impacted river channel. If the contamination observed in the river was the result of coal tar dumped within the landfill, then the City of Fort Collins could be identified as a PRP for the cleanup of the source material within the landfill and the implementation of any mitigation efforts.

If the source was found to be continuous and coupled with the former MGP, then the remediation of the river sediment would likely have to be accompanied by a mitigation effort to keep the coal tar NAPL from reentering the river channel. The EPA was skeptical of the suggestion that there was a localized source responsible for the observed contamination present in the river, but the discontinuous nature of the observed dissolved plume suggested that the potential for the presence of a localized source area clearly existed.

5.2 River Channel Investigation Activities

Based on the proposed revisions to the CSM as described above, Xcel Energy and RETEC decided to begin a parallel investigation in the immediate vicinity of the river channel. Although EPA provided suggestions for work plan enhancement, the PRP work plan was not developed by EPA and did not follow the principles of the Triad approach. EPA also continued preparation of work plans to support a

more extensive, site-wide SA investigation effort to identify the source and pathway for coal tar NAPL observed in the Poudre River.

5.2.1 River Channel Investigation Site Preparation

River diversion and dewatering of the river channel were selected by Xcel Energy as the preferred method for access to the river during the investigation. This would allow easy access for drilling, a relatively water-free investigation area within the river channel during trenching, removal of contaminated in-stream sediments, and for reconstruction of the channel and banks. Stream diversion and dewatering also served to reduce sediments generated during construction of the channel and enabled excavation in an environment relatively free of water.

Temporary earthen dams were constructed above and below the investigation area with a high-density polyethylene liner to divert flow from the area of excavation and reconstruction. A pump station with two, 12-inch pumps was set up to divert upstream flow 200 feet downstream of the excavation and reconstruction area (Figure 14). A temporary water treatment station, sediment stockpile, and dewatering pad were constructed to contain all investigation-derived wastes generated during river diversion and excavation.

5.2.2 River Channel Investigation Drilling Program

RETEC developed and implemented a bedrock investigation that included the use of HSA borings to evaluate the extent of coal tar within the riverbed; however, 20 additional borings were added during the investigation to investigate upland areas adjacent to the river and potential sources on the opposite (northeast) bank of the river (Figure 14). Soil borings were advanced using an HSA drill rig with 4.25-inch diameter auger flights equipped with a split-spoon sampling barrel. All borings where contamination was encountered were advanced to a depth of 10 feet past the last observed contamination, except for PRBB-16 and PRBB-21, which reached refusal before this depth could be achieved.

At borehole locations where pooled NAPL was encountered at the bedrock surface (PRSB-2, 3, 4, 8, 9, and PRBB-5), the 4.25-inch auger flights were pulled from the boring and larger diameter auger flights (10.25-inches in diameter) were advanced approximately 1 foot into bedrock using the same borehole. The augers were then retracted, and approximately 2 bags of granular bentonite were poured through the auger flights and hydrated, creating a plug to prevent the down-hole migration of contaminated fluids. The larger-diameter flights were left in place, acting as a temporary surface casing, and the 4.25-inch auger was advanced through them to the total depth of the boring. This procedure was followed wherever

coal tar NAPL was encountered at the alluvium/bedrock interface, except for location PRSB-1, where the borehole was advanced to depth with the 4.25-inch augers only.

Coal tar impacts were observed in the alluvium and within several distinct intervals of bedrock fractures and bedding planes in three borings in the river channel itself (PRSB-01, 02, and 09). In borings PRSB-08, 03, and 04, coal tar impacts were observed only within several distinct intervals of bedrock in individual fractures and bedding planes.

On the northeast riverbank, coal tar sheen and staining were observed in bedrock at 23 feet bgs within several bedding planes. A faint petroleum odor was also observed at 26.5 feet bgs in boring PRBB-16. Coal tar impacts were not observed in borings PRBB-14, 15, and 23 (Figure 14).

Nine borings were advanced along the southwest riverbank. Borings PRBB-10, 12, 6, 7, and 21 all showed coal tar impacts only within several distinct intervals of bedrock fractures and bedding planes. Borings PRBB-11 and PRBB-13, which are located along the riverbank at the south end of the site, showed no coal tar impacts of any kind. Coal tar impacts were not observed in borings PRBB-22, 17D, and PRBB-17S (alluvial) along the riverbank at the far north end of the site.

Three borings were advanced within the landfill area of the site. Borings PRBB-19 and PRBB-20 both exhibited coal tar impacts only within several distinct intervals of bedrock fractures and bedding planes. Borings PRBB-18 and PRBB-22, at the far north portion of the landfill, did not exhibit NAPL impacts of any kind.

Permanent wells were constructed at 13 locations on both banks of the river channel (Figure 14). All 13 wells were screened within the bedrock, except for PRBB-17S, which was screened from the bedrock alluvium interface into the alluvium and nested with monitoring well PRBB-17D to assess the vertical hydraulic gradient near the Poudre River. Bedrock monitoring wells were screened across NAPL impacted intervals or screened at the same depth as the nearest well locations where NAPL impacts were observed.

Five temporary monitoring wells were constructed within the river channel bottom (PRSB-2, 3, 4, 8, and 9). Temporary wells located within the river channel and one soil boring (PRSB-1) were abandoned and filled with granular bentonite before the river flow was restored.

5.2.3 River Channel Investigation Trenching Program

Observation trenches were excavated in the streambed in an attempt to identify source areas and potential pathways of coal tar NAPL to the river (Figure 14). An L-shaped observation trench (containing test pits TP-01 and TP-02) was excavated about 5 feet perpendicular to and approximately 175 feet parallel to the western side of the river channel in the observed seep area. A sump was constructed at the top of the L-shaped trench (TP-01) to collect water and coal tar NAPL, and pump them to a temporary water treatment system. In addition, 10 other trenches/test pits were excavated between the upstream and downstream diversion dams (Figure 14). Observations for each trench included:

- Coal tar NAPL impacts
- Bedrock/alluvium interface and elevation
- Bedrock elevation and alluvial thickness
- Coal tar NAPL impact elevations
- Coal tar NAPL flow characteristics
- Physical properties of the trench

Sampling protocols established in the work plan regarding the use of ultraviolet (UV) fluorescence technology to identify petroleum-related NAPL were waived by stakeholders during the excavation of TP-01 and TP-02 because visual observations were sufficient to meet the goals of the work plan due to the volume and obvious, visual nature of coal tar impacts.

Observations from trenching resulted in a better understanding of the characteristics of coal tar NAPL within the alluvial sediments and in the bedrock underlying the river channel. In general, coal tar was observed within the alluvial sediments from the seep area 200 feet upstream and from the western bank 40 to 50 feet across the channel to the eastern bank (Figure 14). Depth of trenching activities averaged from about 2 to 4 feet within the river channel. Coal tar observed in bedrock was far more widespread than in the alluvial sediments. Coal tar was observed in bedrock throughout the river channel and on the western river bank from PRSB-4 to PRSB-8 and west into the landfill. Coal tar was observed in both alluvial sediments and in bedrock fractures and bedding planes in test pits TP-01, 02, 10, 11, and 12. Coal tar was observed only in bedrock fractures and bedding planes in test pits TP-03, 04, 05, 06, and 07. Coal tar impacts were not observed in test pits TP-08 and TP-09 (Figure 14).

5.3 River Channel Investigation Conclusions

The summary conclusions from RETEC's report of the investigation (RETEC 2004) include the following: "Physical observations and chemical data indicate contaminant (NAPL) mass is concentrated beneath the river; Vertical and horizontal gradients fluctuate with seasonal changes in river stage and

likely control the presence of NAPL beneath the riverbed; The bedrock drilling investigation provided significant data to characterize the extent of NAPL at the site. However, the presence or absence of specific upgradient sources, potential transport mechanisms, and the rate of NAPL flow, if occurring at all, remains undefined; the question of whether the NAPL and groundwater system are in equilibrium, remains undefined."

Tetra Tech and EPA did not concur with many of the conclusions stated in the RETEC results report. During trenching along the bedrock surface, a continuous source of coal tar appeared to enter the trench. This indicated the potential for an ongoing source to the Poudre River. Secondly, the observation of product in fractures beneath the surface of the Pierre Shale bedrock suggested an explanation as to why there appeared to be little or no dissolved phase contamination associated with the coal tar NAPL plume in the overlying alluvial aquifer. The presence of coal tar in bedrock below the alluvium/bedrock interface was confirmed by borings placed by RETEC adjacent to the river on the upland (western) bank. Coal tar NAPL was discovered beneath the bedrock surface to a depth of nearly 10 feet below the alluvial contact. In EPA's opinion, this suggested that the previously unidentified bedrock fractures could be a pathway for coal tar migration to the river from upland sources, such as the former MGP. This pathway could provide an ongoing source to the river that had not been detected during previous investigations that focused on the overlying alluvium. However, because of the inconclusive nature of the findings reported by RETEC, EPA continued to pursue the development of an SA work plan to address data gaps and further refine the teams understanding of the potential flow path between the river and the MGP source area.

5.4 Evaluation Of Fugitive Emissions Using Ground-Based Optical Remote Sensing Technology

A study was conducted in September 2003 by ARCADIS and EPA personnel (with support from the Monitoring and Measurement Technologies for the 21st Century initiative; http://clu-in.org/programs/21m2/openpath/op-ftir/) to evaluate emissions of fugitive gases and VOCs at the site using an Open-Path Fourier Transform Infrared (OP-FTIR) spectrometer, Open-Path Tunable Diode Laser Absorption, and a Ultra-Violet Differential Optical Absorption Spectrometer. The objective of this application was to identify hot spots or emissions from the landfill to support selection of a site for the new indoor recreation facility being planned by the City of Fort Collins. The OP-FTIR instrument provided critical, supplemental data concerning fugitive emissions from the landfill surface. The study involved a technique developed through research funded by EPA's National Risk Management Research Laboratory, which used ground-based optical remote sensing technology, known as Optical Remote

Sensing-Radial Plume Mapping (Hashmonay and Yost 1999; Hashmonay and others. 1999; Wu and others 1999; Hashmonay and others. 2001; Hashmonay and others 2002). The effort identified emission hot spots (areas of relatively higher emissions), investigated source homogeneity, and calculated an emission flux rate for each compound detected at the site. Concentration maps in the horizontal and vertical planes were generated using the Horizontal Radial Plume Mapping, and Vertical Plume Mapping methods, respectively. For the complete report, see *Evaluation of Fugitive Emissions at a Brownfield Landfill in Fort Collins, Colorado using Ground-Based Optical Remote Sensing Technology* (EPA 2004a).

A gasoline hot spot was detected to the north of the playground adjacent to the recreation center. However, the study did not indicate the presence of any surface methane or other VOC hot spots that could be attributed to the landfill or other potential sources at the site. For more information on the use of OP-FTIR and this site go to http://clu-in.org/programs/21m2/openpath/op-ftir/

6.0 SITE ASSESSMENT ACTIVITIES

In October 2003, EPA issued a Technical Directive Document to Tetra Tech, under the START 2 contract, to perform an SA at the Poudre River site. Tetra Tech developed the SA for EPA Region 8 to address observed coal tar NAPL releases to the Poudre River. The SA was conducted in cooperation with Xcel Energy Inc., the primary PRP at the site, and with a secondary PRP, the Schrader Oil Company, under an *Administrative Order on Consent for Removal Action* approved by the EPA and Schrader Oil Company (Paragon 2004).

The project objectives and related activities described in the FSP were designed to:

1) Identify potential pathways and source area(s) for free product/NAPL identified in the Poudre River adjacent to the site.
2) Obtain data to refine the CSM, (i.e., bedrock surface, alluvial thickness, landfill thickness, bedrock lithology, etc).
3) Investigate whether PCE previously identified in the vicinity of the landfill was affecting the water quality of the Poudre River.
4) Facilitate the identification of the extent and the source area(s) for gasoline/MTBE contamination in groundwater at the site.
5) Generate data to support the design and implementation of a remedy at the site.

6.1 Site Assessment Field Sampling Activities

This section describes the sampling and field activities conducted under the SA to accomplish the objectives outlined in Section 1.0 of the FSP (Tetra Tech 2004b). SA field activities were conducted in the following sequence from February through August 2004:

1) In total, 333 passive soil gas samplers were deployed from February 25 through February 28.
2) In total, 47 passive diffusion bag (PDB) samplers were installed in the western bank of the river along the study area from March 8 through March 10.
3) In total, 329 passive soil gas samplers were retrieved and submitted for analysis from March 22 through March 25.
4) In total, 47 PDB samplers were retrieved and sampled from March 22 through March 23.
5) A resistivity geophysical survey was conducted from March 31 through April 8.
6) Drilling, soil, and grab groundwater sampling activities began on April 19 and concluded on July 7.
7) Groundwater levels were measured in all accessible monitoring wells and groundwater samples were collected from 27 monitoring wells from August 2 through August 4.

6.1.1 Soil Gas Survey

Initial field sampling activities included a soil gas survey, using the EMFLUX® passive soil-gas sampling system, in order to identify potential contaminant source areas, facilitate the delineation of groundwater contaminant plumes, provide information on discrete contaminant pathways, and provide data on the lateral distribution and types of contaminants present in the vadose zone. These data were also used to guide the subsequent drilling program. Prior to implementing the soil gas survey, a DMA study was conducted by Tetra Tech in areas previously identified as containing coal tar NAPL contamination in the subsurface. The DMA indicated that previously identified compounds associated with coal tar at the site could be detected using the technology, so a full-scale soil gas survey was implemented. In total, 333 passive soil-gas sampling devices were installed in a 50-foot grid across the entire site and placed every 25 feet along transects intersecting areas known and suspected to be contaminated (Figures 16 and 17). Soil gas samplers were also placed at 20-foot intervals along transects adjacent to the upgradient boundary of the site and along the river to locate contaminants entering the site from upgradient sources and to locate areas where contaminants may be leaving the site and discharging into the river. The soil gas samplers were left in place for approximately 25 days, after which they were recovered and sent to the manufacturer for laboratory analysis. Analysis procedures are described in more depth in the Technology Quick Reference Sheet (TQRS) in Appendix 1. Ambient air control samples, used as field blanks, were

also collected at various locations across the site. Soil gas samplers were installed and recovered following procedures discussed in Section 4.1 of the FSP (Tetra Tech 2004b).

The DMA indicated that several compounds associated with the presence of coal tar at the site could be detected in soil gas and that quantitative results could be estimated using the EMFLUX model. Compounds of interest included 1,3,5-trimethylbenzene (1,3,5-TMB), 1,2,4-trimethylbenzene (1,2,4-TMB), and napthalene. These compounds were used to help identify locations where the presence of coal tar NAPL in the subsurface was likely. Iso-concentration maps of target analyte distribution across the site were generated by Kriging the data (using ordinary Kriging techniques), and Kriging was also used to refine the CSM and optimize the field investigation drilling program. An iso-concentration map was generated for PCE (Figure 17) due to the number of locations where PCE was detected during the survey.

Several boring locations were chosen to investigate 'hotspots' where soil gas indicated an elevated concentration of the target chemicals 1,3,5-TMB, 1,2,4-TMB, and/or naphthalene. The visual presence of coal tar often correlated poorly with hotspots identified in soil gas during the survey. Several theories could explain this apparent lack of correlation:

- Boring logs for several borings advanced in locations of soil gas hotspots identified loose, dry, coarse material in the subsurface, which may have created a preferential pathway for soil gas in that area causing the soil gas hotspot.
- During past investigations, the field crews have encountered and sampled isolated petroleum based products in the landfill that appear to be unrelated to coal tar contamination from the former MGP (Tetra Tech 2004a; Appendix 2), which may be another explanation for some of the observed hotspots.
- The elevated concentrations of target chemicals detected beneath the parking lots relative to other areas of known contamination across the site may result from the asphalt acting as a vapor barrier, which would not only trap contaminant vapors and concentrate them but also cause them to degrade more slowing by creating a reducing atmosphere.
- Chemicals might also leak from vehicles, enter cracks in the pavement, and accumulate directly beneath the parking lots.

6.1.2 Passive Diffusion Bag Sample Results

To identify contaminant discharge locations to the river, 47 PDB samplers were installed approximately 2 feet below the depth of saturation in the riverbank along the Aztlan landfill border (Figure 17). The PDB samples were collected and analyzed for VOCs after an equilibration period of 14 days.

PDB samplers were also installed in three monitoring wells (FC-MW-03, FC-MW-04, and FC-MW-05) located near the river and screened above bedrock within the alluvial zone (Figure 12). PDB samplers were installed in these monitoring wells to assess the correlation between water sampled by the PDB samplers in the river bank and groundwater in the alluvial aquifer to ensure that the PDB samples were representative of groundwater discharging into the Poudre River and that they were properly placed below the groundwater/surface water mixing zone. Figure 17 provides detected concentrations of PCE in PDB samples placed in the riverbank.

VOC compounds detected in the PDB sampling included limited low level detections of contaminants potentially related to primarily landfill materials, such as chlorinated solvents (PCE, trichloroethene [TCE], 1, 2 dichloroethene, and vinyl chloride). Chlorobenzenes are commonly used as solvents, in coolants, as a component of lubricants, as an ingredient in wood preservatives, and in the manufacture of pesticides and herbicides (EPA 2004b). The extensive detections of chlorinated solvents in soil gas were not considered related to the site coal tar contamination. Although chlorinated solvent contamination is present in the landfill, it does not appear to be migrating in substantial quantities from the landfill to the river, probably because of the high organic content of the landfill and the lack of infiltration as a result of the presence of the landfill cap.

The types of contaminants detected and the range of concentrations correlate very well between the monitoring well PDB samples and nearby riverbank PDB samples. Additionally, the distribution of chlorinated solvents detected in PDB samples from the riverbank correlated well with chlorinated solvents detected in the soil gas survey (Figure 17). Results for the PDB bags did not indicate widespread dissolved phase contamination discharges to the river that are related to coal tar. This may be attributed to poor recoveries of the PDB samplers for less volatile coal tar related compounds (such as naphthalene, 1,2,4-TMB, and 1,3,5-TMB) or provide further evidence that dissolved phase contaminants were not discharging to the river in significant concentrations or quantities. The PDB samplers did, however, assist in further identifying the widespread presence of PCE and its degradation products such as TCE, 1,2-dichloroethene, and vinyl chloride in site groundwater. The samplers further revealed that most of these contaminants are migrating to the river in low concentrations. Of the nine different compounds detected, PCE is the only VOC target compound that appears to be discharging to the river at concentrations at or above the applicable maximum contaminant levels (MCL) (see Figure 17). The MCL for PCE is 5 µg/L.

6.1.3 Geophysical Survey

Tetra Tech procured the services of a geophysical subcontractor, hydroGEOPHYSICS, Inc., to employ high-resolution resistivity (HRR) and ground-penetrating radar (GPR) geophysical survey methods to better define the bedrock surface and to identify the presence or absence of preferential pathways such as bedrock fractures, subsurface channels in alluvium, or underground pipelines. The survey was conducted prior to the drilling mobilization to allow time for data evaluation, CSM refinement, and subsequent sampling strategy refinement.

The extent of the geophysical survey and transect lines are presented in Figure 18. Figure 19 provides a graphical example of the HRR survey results with several boring locations plotted to demonstrate agreement between bedrock elevations encountered in the field and interpretations from the HRR survey. The HRR survey provided good characterization of subsurface conditions across the site, which correlated well with subsurface conditions encountered during the drilling program. Soil conditions across the site were not conducive to GPR signal penetration resulting in poor subsurface characterization using GPR. A DMA might have shown this prior to conducting a full survey. As a result of the poor characterization by GPR, the performance-based contract did not allow the GPR cost to be incurred.

Resistivity results were useful for determining the presence of low conductivity materials such as gravels, highs and lows in the bedrock surface, and the depth of the landfill. These data, along with soil gas survey results, were used to direct the intrusive soil sampling program discussed in the following section of this report.

6.1.4 Soil Sampling

To clearly define the preferred pathway for the NAPL from the former MGP to the river, a traditional HSA drilling program was undertaken. Traditional drilling methods were used because of the depths at which the coal tar was expected to be observed in bedrock based on the river channel program results and problems with refusal using direct-push technologies encountered during the TBA investigation. The program was designed to rely heavily on the observation and description of core samples in the field using a detailed consistent core description routine and UV light box and microscopic analyses to identify the presence or absence of NAPL in the dark-colored Pierre Shale bedrock.

6.1.4.1 Soil Core Logging and Soil Sampling Procedures

Soil borings were advanced using an HSA drill rig and 4.25-inch diameter auger flights equipped with a split-spoon sampling barrel. All boreholes were continuously cored to the total depth of the boring (up to

25 feet into bedrock). The entire core was logged and lithologic descriptions prepared in accordance with industry accepted practices and screened with a PID/FID for VOCs. Contaminant-related features such as odor, staining, and/or unusual solid constituents such as manmade debris, were noted on the logs. The FSP called for the visual observation of NAPL to be documented following the standardized descriptions listed below:

- No Visible Evidence – No visible evidence of oil on soil sample
- Sheen – Any visible sheen in the water on soil particles as described by the sheen testing method presented later in this section
- Staining – Visible brown or black staining in soil; can be visible as mottling or in bands; typically associated with fine-grained soil
- Coating – Visible brown or black oil coating soil particles; typically associated with coarse-grained soil such as coarse sand, gravels, and cobbles
- Oil Wetted – Visible brown or black oil wetting the soil sample; oil appears as a liquid and is not held by soil grains (Soil oozing petroleum typically contains 2 to 3 percent petroleum.)

A UV light box was used to aid in the visual observation of petroleum-related NAPL and the description of core samples. Using a standardized sample description method can assist in the evaluation of boring logs to assure that the mapped extent of contamination is consistent and that NAPL characteristics are described in a detailed manner that will provide sufficient information to support design of a remedy.

In addition to PID/FID and visual inspection, the presence of NAPL in soil cores was periodically evaluated using a qualitative water sheen test. This water sheen test was conducted for portions of the core where visual inspection did not indicate the presence of NAPL.

The water sheen test was performed by placing soil in a small plastic bag filled with distilled water, shaking the bag and observing the water's surface for signs of sheen. Sheen was classified according to the FSP as follows:

- No Sheen (NS) – No visible sheen on water surface
- Slight Sheen (SS) – Light colorless film; spotty to globular; spread is irregular, not rapid; areas of no sheen on water surface remain; film dissipates rapidly
- Moderate Sheen (MS) – Light to heavy film; may have some color or iridescence; globular to stringy; spread is irregular to flowing; few remaining areas of no sheen on water surface.
- Heavy Sheen (HS) – Heavy colorful film with iridescence; stringy in appearance; spread is rapid; sheen flows off the sample; most of water surface may be covered with sheen

To characterize the vertical extent of contamination where pooled coal tar NAPL was encountered at the bedrock surface, the 4.25-inch auger flights were pulled from the boring and larger diameter auger flights (e.g., 8.25-inches in diameter) were advanced to approximately 1 foot into bedrock using the same borehole. Approximately 2 feet of granular bentonite was then poured through the auger flight and hydrated to create a plug, preventing possible down-hole migration of contaminated fluids. The larger diameter flights were then left in place, acting as a temporary surface casing, and the 4.25-inch auger was advanced through them to the total depth of the boring.

The FSP called for up to 20 soil samples to be collected from soil cores where PID/FID readings were greatest and/or where other field screening techniques indicated the presence of contamination.

6.1.4.2 Soil Sampling Results

Based on the revised CSM, the project team was able to limit the number of soil borings. In total, 11 soil samples were collected from nine soil borings during the SA to chemically characterize the soil profile. One coal tar product sample was collected from TTMW-07. The product sample was submitted for analysis of physical properties only. Physical property results for the product sample were used in conjunction with 12 additional soil and bedrock geotechnical samples collected from five borings to support future remedial and/or removal actions.

All 11 soil samples were submitted to a fixed laboratory for analysis of VOCs by EPA SW-846 Method 8260, SVOCs by EPA SW-846 Method 8270, TPH-purgeable compounds by Iowa Method OA1 (SW-846 Method 8015 modified), and TPH-extractable compounds by Iowa Method OA2 (SW-846 Method 8015 modified) where sufficient sample volume was available.

Results for all compounds detected in soil samples are provided in Table 6. Coal tar-related compounds detected in the soil samples correlate well with observations of coal tar NAPL contamination and with the approximate boundaries of coal tar impacts provided in Figure 20. Soil samples collected between the upland area of the site in the vicinity of the Aztlan Community Center parking lot and the sand playground area (Figure 2) contained elevated GRO compounds and DRO compounds. Chromatograms for TPH samples at these locations indicate fresh, non-weathered fuel patterns for gasoline and diesel. These relatively fresh fuel signatures in conjunction with multiple detections of MTBE in groundwater (a gasoline additive used since the 1980s) reinforced the theory that more recent gasoline and diesel spills may be mixing with historical coal tar contaminants from the former MGP in the upland areas of the site, which was consistent with the revised preliminary CSM (Figure 13).

Coal tar NAPL contamination in the vadose zone was observed in one soil sample. Soil sample SA-SB-20 was collected from 9 to 10 feet bgs at location MGPMW-2D on the Schrader Oil Property (the site of the former MGP; see Figures 2 and 20). This sample was collected from the alluvium directly above the bedrock contact at 10 feet bgs after black, tar-like staining and strong fuel/mothball-like odors were observed. It should be noted that the sample media was stuck in a very hot core barrel for approximately 15 minutes because the core barrel could not be immediately opened; therefore, many of the light-end, volatile chemical constituents were probably lost before the sample could be containerized. The sample contained highly elevated concentrations of GRO (970 milligrams per kilogram [mg/kg]), TPH (9,900 mg/kg), 1,2,4-TMB (980 micrograms per kilogram [µg/kg]), xylenes (total), 9,900 µg/kg, dibenzofuran (6,600 µg/kg), and 14 target PAH compounds. The observation of coal tar NAPL contamination at this location in both alluvium and bedrock fractures was a significant addition to the development of the CSM considering that the sample was collected upgradient and approximately 8 vertical feet above coal tar NAPL observed at the bedrock/alluvium contact in the Aztlan Community Center parking lot at soil boring TTSB-02 (Figure 20). This observation provided the project team with an indication that the source for coal tar observed on the Aztlan Community Center property was located on or very near to the former MGP.

A potential source for PCE contamination was also revealed by the soil sample results. Sample SA-SB-04 (from soil boring TTSB-09) was collected in the vadose zone from an organic, silty layer encountered directly below the landfill material. PCE was detected at a concentration of 140 µg/kg in this sample and was the only compound detected in the VOC fraction. This sample did not contain detected concentrations of coal tar related compounds. The PCE concentration is elevated relative to PCE concentrations observed in other soil samples from the site and PCE groundwater concentrations at this location (see data for SA-GW-01). This observation was interpreted by the team as a possible indication that a source area for the observed PCE contamination was located within the landfill itself.

One coal tar product sample (TTMW-07 Product) was also collected during the SA drilling activities. The sample was collected shortly after installation of monitoring well TTMW-07 by pumping product from the bottom of the well using a peristaltic pump. The sample was collected and submitted for physical analyses to assist in design of proposed remedial systems.

In total, 12 soil/bedrock samples were collected from five soil borings located near the Poudre River and submitted for geotechnical analysis to satisfy engineering requirements for proposed remedial

alternatives. Results of geotechnical analyses for samples collected during the SA are provided in Table 7, and in Section 4.3 of the SA FSP (Tetra Tech 2004b) in more detail.

6.1.5 Grab Groundwater Sampling

The dynamic work strategy resulted in the collection of a total of 11 grab groundwater samples collected where soil borings were advanced without the installation of a monitoring well and visual inspection, and results for sheen tests did not indicate the presence of NAPL. Results for grab groundwater samples collected during the SA are provided in Table 8 and sample locations are provided on Figure 20. Grab groundwater sample procedures are discussed in Section 4.4 of the SA FSP (Tetra Tech 2004b).

The shallow grab groundwater sample results confirmed that a significant dissolved phase plume of petroleum-related contaminants did not extend far beyond the known boundaries of coal tar NAPL at the site. The grab groundwater results confirmed the presence of MTBE downgradient of more recent gasoline releases, and also confirmed the presence of PCE in groundwater near the center of the former landfill, an area that was not sampled during the TBA.

6.1.6 Monitoring Well Sampling

Groundwater samples were collected from 11 monitoring wells installed during the SA and 16 existing monitoring wells following procedures described in Section 4.6 of the SA FSP (Tetra Tech 2004b). The samples were collected using micropurge groundwater sampling techniques and analyzed at an off-site laboratory for VOCs, SVOCs, GRO, DRO, cations, and anions. See Figure 3 and Figure 20 for monitoring well locations.

Compounds related to coal tar or NAPL at the site were detected at the greatest concentrations in monitoring wells screened across coal tar contamination with the highest concentrations observed in monitoring wells located near the former MGP. High concentrations of coal tar related chemicals and other types of contamination were generally absent across most of the site. The low solubility of many of the chemical constituents detected at the site and the relatively high estimated flow rates along the base of the alluvial sediments is a likely explanation for the low contaminant concentration reported in groundwater across the site.

Relatively high levels of BTEX constituents were detected in samples from monitoring wells located near the MGP and downgradient from more recent fuel releases. This observation, along with the presence of MTBE in monitoring wells downgradient from the Schrader Oil recorded fuel releases, provide evidence

that gasoline and diesel spills along Willow Street are mixing with the MGP coal tar or NAPL, as indicated in the revised preliminary CSM (Figure 14).

PCE was detected in groundwater samples from monitoring wells screened in the alluvial aquifer and the bedrock, with the majority and highest detections coming from locations near the center of the site. This observation provided a further indication that the source of PCE observed in groundwater was not upgradient of the site as previously proposed, but perhaps from within the landfill as indicated by passive soil gas results (Figure 17).

Low-level detections of 1,2 dichlorobenzene were considered more likely related to landfill materials than coal tar contamination. Chlorobenzenes, including 1,2 dichlorobenzene, are commonly used as solvents, in coolants, as a component of lubricants, or as an ingredient in wood preservatives, pesticides, and herbicides (EPA 2004b).

Elevated GRO and BTEX compounds were observed in groundwater sample SA-MW-13 collected from monitoring well PRBB-10 (Figure 10). This location is within the area of coal tar impacts within bedrock (Figure 21). Relatively high concentrations of BTEX compounds were not observed in other groundwater samples collected from areas of known or expected coal tar impacts near the Poudre River. It was hypothesized that the relatively elevated concentrations of gasoline range hydrocarbons and total BTEX could be indicative of local gasoline dumping, a spill scenario, or that another source for gasoline contamination to groundwater was located hydrologically upgradient to the northwest of the site. However, it is important to note that other recent investigations at the site had not detected these compounds in groundwater samples taken from areas upgradient of this location (Tetra Tech 2004a; Tetra Tech 2004c; RETEC 2004). The project team used BTEX ratios to provide an indication as to the age of the potential release. An examination of the (benzene+toluene)/(ethylbenzene+xylenes) ratio (0.58) and the benzene/toluene ratio (0.57) indicated that the gasoline contaminants in this sample were probably less than 10 years old since ratios greater than 0.5 indicate relatively younger releases. (Air Force Center for Environmental Excellence [AFCEE] 1999; Kaplan and Galperin 1996; Weiner 2000).

The (B+T)/(E+X) ratios observed in the upland area of the site range from 0.12 to 7.79 with and average value of 3.0 (see Table 9). Literature values for (B+T)/(E+X) ratios in groundwater in contact with fresh gasoline range from 1.0 to 5.0 (AFCEE 1999; Kaplan and Galperin 1996). When (B+T)/(E+X) ratios greater than 5.0 are observed it may be an indication that the sample was not collected near the source of the fresh gasoline NAPL since benzene and toluene tend to be more mobile than ethylbenzene and xylenes (AFCEE 1999; Kaplan and Galperin 1996; Weiner 2000). (B+T)/(E+X) ratios of less than 0.5

are generally observed at sites where releases are greater than 10 years old, for example at locations MGPMW-3S and FC-MW-15 (Figures 3 and 4). The high (B+T)/(E+X) ratios observed in wells from the Schrader property may be an indication that a more recent gasoline release has occurred in the vicinity of these monitoring wells than the documented 1994 and 1995 releases from the Schrader Oil Bulk Plant (COSTIS event IDs 2287 and 2223) and the 1996 Scout 66 gas station (COSTIS event ID 4273) release.

7.0 CONCLUSIONS

After the SA fieldwork was completed and all data were examined, the project team reached several conclusions with respect to the stated objectives of the investigation.

1) The source of coal tar/NAPL contamination observed in the Poudre River appeared to be located on or very near the former MGP site. This conclusion was based on the following observations:
    a. Coal tar NAPL contamination was observed consistently between the Poudre River and the former PVG Company site.
    b. Coal tar NAPL contamination was not observed in the landfill material. Based on coverage of soil borings across the site from the SA and previous investigations and soil gas data, it was determined that it is unlikely that coal tar was deposited within the landfill.
    c. Coal tar NAPL contamination was observed only in alluvial material and in the top, weathered bedrock interval from the Aztlan Community center parking lot (soil boring FC-MW-12) to the sand playground area (soil boring TTSB-15). The greatest coal tar NAPL thickness in alluvium was observed beneath the Aztlan Community center parking lot in soil boring TTSB-02, which is near the former MGP site.
    d. Coal tar NAPL contamination was observed only in bedrock fractures extending from the sand playground area to near the banks of the Poudre River, in several borings advanced within portions of the bedrock high in the southwest portion of the study area, and on the Schrader Oil property.
    e. Coal tar NAPL contamination was observed in alluvium (soil sample SA-SB-20) and in bedrock fractures in soil boring MGPMW-2D located on the Schrader Oil property and site of the former MGP. Coal tar NAPL contamination was not observed continuously between the alluvium and the contaminated bedrock interval at boring MGPMW-2D, indicating that contamination in the bedrock fractures at this location originated upgradient or side-gradient and is not the result of vertical contaminant migration.
    f. Coal tar NAPL contamination that was observed on the former MGP property (MGPMW-2D) is upgradient and approximately 8 vertical feet above coal tar NAPL contamination observed in the Aztlan center parking lot at soil boring TTSB-02.

2) The lateral and vertical distribution of coal tar/NAPL contamination in alluvium and in bedrock may be structurally constrained by the bedrock surface configuration and structural integrity across the site. This conclusion was based on the following observations:
    a. The bedrock surface from Willow Street adjacent to the former PVG plant to approximately the sand playground area forms a slight valley trending northeast/southwest (Figure 21). This valley may laterally control the spread of coal tar

in alluvium in that area and may have directed and continue to direct coal tar in alluvium to the northwest.

b. Competent, less fractured, sandstone and silty sandstone appears to control the vertical migration of coal tar across the site where it occurs in the southwest and along the northwest portions of the site (Figure22). Boring logs indicate that where the more competent bedrock member is encountered in the upland areas of the site, and elsewhere, no coal tar contamination is encountered in bedrock. Northwest of the sand playground the less competent siltstone and silty sandstone bedrock member occurs and coal tar in alluvium is not encountered but coal tar is found within bedrock fractures. It appears that coal tar flows from upgradient source areas along the top of bedrock to the area of the sand playground and abruptly moves down into bedrock fractures through vertical and/or near vertical joints. From here, it appears that coal tar travels horizontally along fracture plains until hydraulic forces bring it back to the bedrock surface in the vicinity of the Poudre River.

c. The competent, less fractured sandstone and silty sandstone bedrock member that appears to form a slight ridge extending northeast from the Aztlan Center parking lot (Figure 22) may laterally control the migration of coal tar to the northwest within the bedrock fractures. Relatively competent silty sandstone and siltstone also occur in the southeast portions of the site that are generally more competent and less fractured, which may also serve to laterally control coal tar migration within bedrock fractures to the southeast.

3) Coal tar may be commingled with other petroleum products in upland areas of the site. This conclusion was based on the following observations:

a. GRO compounds, DRO compounds (identified as diesel fuel), and MTBE (in groundwater only) have been detected at elevated concentrations in soil and groundwater samples adjacent to Willow Street and the Aztlan Community Center parking lot. Chromatograms for TPH samples at these locations indicate relatively fresh, non-weathered fuel patterns for gasoline and diesel (chromatograms for samples from the Schrader property were not reviewed). These relatively fresh fuel signatures in conjunction with multiple detections of MTBE (a gasoline additive used since the 1980s) indicate that more recent gasoline and diesel spills may be mixing with historic coal tar NAPL. The relatively newer, light-end petroleum products can act as solvents for the less mobile coal tar compounds, exacerbating the problem of coal tar migration at the site.

b. In addition to samples from the upland area in the Aztlan Community Center parking lot, significantly elevated GRO compounds and BTEX compounds have also been detected in groundwater and soil samples from the Schrader property. Coal tar and other related byproducts generated by the former MGP would be approximately 70 years old and would typically contain relatively low BTEX constituents even when fresh and unweathered. It is unlikely that in such an aerobic environment that these relatively volatile, mobile, and bioavailable (especially in aerobic conditions) chemical constituents (e.g., benzene) would remain in high concentrations after such a long period of time. This provides further evidence that a more recent petroleum product release is commingled with coal tar NAPL at the site.

4) An examination of (benzene + toluene)/(ethylbenzene + xylene), or (B+T)/(E+X) ratios in shallow groundwater from the upland area of the site, and the Schrader Property wells sampled during this SA, indicate that these contaminants originated from groundwater in contact with relatively fresh gasoline.

5) Multiple sources of chlorinated solvents may exist at the site. This conclusion was based on the following observations:

a. Chlorinated solvents, primarily PCE and its degradation or 'daughter' products TCE, 1,2-dichloroethene, and vinyl chloride have been detected throughout site groundwater and in one soil sample. In addition to numerous historical detections of these compounds in site groundwater, seven out of 11 groundwater grab samples and 15 out of 21 monitoring well samples contained detected concentrations of PCE.

b. Most of the chlorinated solvent contamination observed in groundwater across the site is likely originating in the former landfill. The most prevalent chlorinated solvent detected in samples from all media at the site is PCE. PCE detected in groundwater across the site correlates well with PCE detected in soil gas (Figures 16 and 17). Although the soil gas survey has identified PCE in upgradient boundary areas of the site (to the west/northwest) analyses of groundwater samples from these areas have not identified PCE contamination (Tetra Tech 2004a; RETEC 2004) indicating that the source of PCE in soil gas from that area is the vadose or unsaturated zone.

c. An additional, off-site source of PCE contamination may be located to the southwest of the southern portion of the site. The soil gas survey, results for recent groundwater samples (Tetra Tech 2004a) and the PDB samples from the riverbank all indicate a significant source of PCE southeast of the United Way building. PCE concentrations in groundwater samples from recent investigations (Tetra Tech 2004a) and soil gas samples from the SA, both located along the southwestern site border, are relatively elevated when compared to downgradient samples. The soil gas survey and results for recent groundwater samples (Figure 13; Tetra Tech 2004a) have not identified significant PCE concentrations downgradient of the former Giddings machine shop relative to PCE concentrations located further downgradient at the site. This suggests that the property located adjacent and upgradient to the site may be an additional source for PCE contamination in groundwater. Further investigations focused on this question would be necessary to accurately identify PCE source areas.

6) Chlorinated solvents are reaching the Poudre River in concentrations above MCLs adjacent to the site. This conclusion was based on the following observation:

a. VOC data for the PDB samples indicate that elevated concentrations of chlorinated solvents are reaching the Poudre River. Twenty two out of the 47 PDB samples collected contained detected concentrations of PCE. Of these 22 detections, eight values exceeded the MCL of 5 µg/L. Detected concentrations of PCE in PDB samples ranged from 1 to 18 µg/L. The highest concentrations of PCE reaching the Poudre River appear to be in the southeast portion of the site.

7.1 Final Conceptual Site Model

The final CSM (Figure 22) provides a graphical representation of newly acquired knowledge concerning the site including the fact that many previously installed monitoring wells and drilling programs were adequate to assess dissolved contaminants but were not useful in locating and identifying coal tar NAPL migration pathways in the subsurface. A review of this figure allows future project personnel to design sampling and analysis plans that provide for the collection of data necessary to make project decisions.

The CSM can be useful in locating potential source areas as well. The final CSM was also used in designing the remedial alternative implemented at the site.

The chosen mitigation strategy consisted of the placement of a sheet pile wall to exclude coal tar from the river and a French drain to remove the hydraulic head created by the sheet pile wall. Source remediation is also being considered to further limit the potential for coal tar migration to the river.

7.2 Site Geology

Knowledge of the site geology changed significantly during the SA investigation as a result of using HSA drilling techniques that facilitated better lithologic recovery and characterization of bedrock beneath the site. Additional literature research was also done and incorporated after preliminary findings from the PRP investigation indicated that bedrock fractures and bedding planes were a likely pathway for coal tar NAPL reaching the river. The following text provides a review of the site geology based on updated knowledge.

Native soil appears sparse within the study area with surface soil across the site consisting primarily of silty sand and sandy silt underlain by landfill material. A continuous layer of alluvial material, identified as Broadway alluvium, from 5 to 15 feet thick is encountered beneath the landfill and elsewhere across the study area. Size analysis of the coarse-grained alluvium indicated that the average grain-size distribution is 50 percent well-graded sand, 25 percent coarse gravel, and 25 percent cobbles to 12 inches. A micaceous, humic layer of finer material containing plant remains, which is believed to be Post-Piney Creek alluvium, was encountered intermittently across the site overlying the coarser alluvium at thicknesses from 0.5 to 5.5 feet. During previous investigations, the site had also been identified as overlying Post-Piney Creek Alluvium from the upper Holocene underlain by older alluvial gravel consisting of Broadway Alluvium from the Pinedale Glaciation, Pleistocene (Tetra Tech 2004a; Shelton and Rogers 1987). Upper Cretaceous Pierre Shale is the bedrock member underlying the site at a depth of between 9 and 21.5 feet bgs (Figure 21).

The Pierre Shale is from 5,000 to 8,000 feet thick and locally consists of olive-gray to dark gray sandy shale, shale, and siltstone, with a distinct local member of fine-grained sandstone and silty sandstone (Shelton and Rogers 1987). The shale member is found in central and northeastern portions of the site. It is typically highly weathered at the alluvium/shale contact with fractured bedding planes and joints that decrease with depth.

The sandstone member is typically massive with claystone and siltstone stringers and minor bedding plane fractures and joints that decrease rapidly with depth. In areas of the site where this member was encountered in the vadose zone it appeared highly weathered, friable and fractured at a much higher frequency. The more competent, massive sandstone was encountered in the western, southern, and southeastern portions of the site and appears to form a prominent high extending south from near the center of the United Way building parking lot to the northeast between soil boring TTSB-03 and monitoring wells PRBB-17S and PRBB-17D. A bedrock contour map was generated from soil borings and geophysical HRR data (Figure 21).

7.3 Site Hydrology

A better understanding of site hydrology resulted from observations made during the SA investigation, additional literature research on regional hydrology, and slug test analysis done for the alluvium and bedrock at the site. The following text presents a review of site hydrology based on updated knowledge incorporated from the SA investigation.

7.3.1 Surface Water

United States Geological Survey (USGS) surface water gauging Station 06752260, located approximately 1,000 feet downstream from the site near the Linden Street bridge, indicates that the 29-year mean stream flows range from 24.8 cubic feet per second (cfs) in December to 872 cfs in June (USGS 2004). Locally, flow rates for the Poudre River are controlled by releases from upstream reservoirs, precipitation, and overland flow events.

A persistent seepage face along the southwest bank of the river adjacent to the site indicates that the Poudre River is a gaining stream from the alluvial aquifer in that reach during normal and low flow conditions. The seepage face was not observed on the southwest bank of the river when stream flows were above 600 cfs on July 1, 2004 (USGS 2004), indicating that the flow gradient may reverse and the river and adjacent banks may be influenced by bank storage effects during flows near or greater than 600 cfs. Furthermore, the lack of an apparent seepage face on the northeast bank of the river adjacent to the site during normal and low flow conditions may indicate that the Poudre River is a losing stream from that bank and that the river within that reach is a flow-through stream, which is not locally acting as a groundwater divide for the alluvial aquifer (Dingman 1994).

7.3.2 Hydrogeology

Groundwater generally flows in an east-northeast direction across the site. Locally there were no identified drinking water wells or surface water intakes on or adjacent to the site. Hydrogeologic units at the site consist of a surficial alluvial aquifer and the Pierre Shale bedrock. Shelton and Rogers (1987) report generalized yields for alluvial materials in the study area ranging from 25 to 1,000 gallons per minute (gpm) and for bedrock ranging from 0 to 25 gpm.

Head differences between the two hydrogeologic units suggest that the Pierre Shale locally is a semi-confining aquifer. Past investigations conducted in the study area indicate that the Pierre Shale is a confining aquifer (Shelton and Rogers 1987). Slug test results for the alluvial aquifer and Pierre Shale found at the site are discussed in Section 2.5.3 of the SA report (Tetra Tech 2004d).

Depth to groundwater in the alluvial aquifer ranges from 8 to 15 feet bgs with a saturated thickness ranging from less than 4 feet (FC-MW-12) to greater than 6 feet (BTH-15). The alluvial aquifer is laterally confined in the southwestern portion of the site by a prominent bedrock high (Figure 21).

8.0 LESSONS LEARNED

Using the Triad approach, the amount of information available to support site decision making was greater than what would have been available using only traditional methods. With the information gained during the TBA and SA investigations, the City of Fort Collins and the PRPs moved forward with a reuse plan and design/construction of mitigation strategies (see Figure 23). The original judgmental TBA sampling plan was revised through the cooperative development of a Triad type systematic plan, which called for the use of a dynamic work strategy for the groundwater and soil investigations, and the use of innovative field-based technologies. Through the development and the continual refinement of the CSM, the project team was able to clearly communicate the data gaps and discuss with stakeholders the data needs and potential approaches. The CSM became a centralized means for discussing results and future steps for the sampling and analysis program.

An element investigated under the SA, which had not been examined as part of previous investigations, was the groundwater to surface water pathway that included an evaluation using a novel application of PDB samplers placed in the riverbank adjacent to the landfill. These data provided an indication of dissolved contaminant concentrations reaching the river via groundwater discharge zones. The presence of PCE in the vadose zone of the landfill and the discharge of the PCE to the river was clearly defined by

the PDB samplers; however, the PDB samplers did not appear to adequately detect the presence of less volatile compounds, such as naphthalene.

Refinement of the site CSM indicated that dissolved plume contaminants related to coal tar NAPL do not always approximate the location of the corresponding coal tar NAPL and contamination can extend beyond locations where coal tar is observed (Figure12). It is also important to note that significantly elevated dissolved phase contamination was only detected when groundwater was sampled in zones where coal tar NAPL was present. This may indicate that elevated dissolved phase contaminants are only observed very near or within the coal tar NAPL plume at MGP coal tar sites. This observation may be the rule rather than the exception for MGP coal tar sites due to the strong tendency for coal tar constituents to cling tightly to each other; it also stresses the need for a high density of information and the need for a very refined CSM when looking for targets that could be narrowly distributed with only a very restricted dissolved phase plume to act as a signature around high levels of contamination.

Direct-push grab groundwater sampling methods met with limited success due to high-rates of refusal experienced in the field. This was also impacted by the fact that coal tar NAPL contamination was deeper than expected in many areas, including well within the bedrock. Had the site been more conducive to direct-push grab groundwater sampling methods, this approach could have yielded the type of information needed to delineate the coal tar NAPL plume more efficiently and cost-effectively; however, in many cases traditional methods may need to be used in combination with innovative sampling methods to improve data density. Tools such as the Waterloo profiler, for example, could have been used at the site instead of direct-push retractable screen methods, allowing better characterization of groundwater during the TBA. For information on other direct-push technologies available see the EPA's Field Analytical Technologies Encyclopedia website at: http://fate.clu-in.org/.

Geophysical methods provided a relatively inexpensive approach for addressing the project team's presumptions about the distribution of geologic features, such as preferred pathways at the site and allowed the development of a more accurate CSM.

Soil gas methods and PDB samplers were demonstrated to be important alternative characterization methods for evaluating volatile organic contamination in landfills without needing to directly penetrate the landfills. The passive soil gas method employed at this site did not however, appear to adequately detect the presence of the target SVOCs, such as naphthalene.

Laboratory methods and field-based methods must be well constrained and both types of data reviewed carefully before decision support is deemed adequate or sufficiently representative for making site decisions. The DMA studies used at the site showed the strengths and weaknesses of the technologies used well before full-scale programs were implemented in the field. One exception was the application of GPR, which was not tested in the field prior to conducting the survey. This resulted in data that were not of use to the project team; however, the cost of the survey was not passed on to the EPA due to the performance based contracting used for the geophysical vendor. If the vendor had been able to do a DMA for this technology, they may have avoided the unnecessary time and expense of running a GPR survey that resulted in inadequate data and loss of payment.

For the TBA and SA investigations, the project team and the stakeholders worked as a cooperative and efficient group to support the implementation of data collection efforts. This was primarily facilitated by making the maximum use of existing data to construct a CSM early in the project. Other consultants had conducted field sampling at the site for many years based on objectives which were not the same as those used during the investigations described in this case study. By clearly redefining the project objectives and tying them to data collection activities based on the evolving CSM, the project team and stakeholders where able to compress the investigative process (Figure 23) and complete implementation of mitigation efforts in as few mobilizations as possible.

9.0 COST COMPARISON

The TBA and SA at the site were conducted using principles consistent with the Triad approach and produced considerable savings when compared with more traditional characterization and remedial design approaches. The River Channel Investigation conducted by the PRP provided some valuable site information but is not considered part of the site characterization activities completed under the Triad approach. Due to the fact that costs were never fully developed for a site characterization or remedial design based solely on a “traditional” approach it is difficult to assess cost savings for the site using a traditional phased approach versus the Triad approach. However, the use of systematic planning, a dynamic work plan, and field-based measurement technologies with limited off-site comparative analysis, allowed for a cost-effective site characterization with savings estimated at 30 percent over traditional methods. Table 10 provides a cost breakdown for site activities conducted under the Triad versus costs assumed for a more traditional approach.

The Poudre River site was fully characterized in two mobilizations while still providing a significantly increased quantity of data to satisfy project goals and move the site to the remedial phase. Much of the

information collected was also used for developing and optimizing a remedial design, providing further cost and time savings. Estimation of project costs for the work plan originally identified for the site was difficult because the plan was changed to incorporate a more dynamic, field-based strategy before cost scenarios had been fully calculated. Where possible, existing costs developed for the initial approach have been used to assist in this cost comparison.

The cost comparison provided in Table 10 assumes that a traditional approach would have required at least four mobilizations to fully evaluate the nature and extent of contamination at the property. The costs associated with these mobilizations would have also been accompanied by costs for developing four different work plans and accompanying sets of fixed laboratory analytical suites. In general, planning and field preparation costs (including the DMA) under the Triad approach are higher, however additional mobilizations and data collection activities are minimized. In this case, the higher data density and completeness of the resulting data set eliminated the need for a third mobilization to address additional data gaps. The use of a dynamic approach to field activities provided total site coverage using spatial grids and allowed the field team to respond to areas with samples containing elevated levels of contaminants. Under a more traditional plan, areas of contamination may have been missed, and any that were encountered may not have been identified until after all the analytical data had been received and reported to project decision makers.

The dynamic work strategy and the use of field-based measurement technologies, a geophysical survey, and a mobile laboratory for the analysis of VOCs allowed rapid identification of areas of contamination and real-time decision making to evaluate and help delineate the nature and extent of the contamination. The real-time data provided flexibility to the field program that targeted areas of interest and provided analytical cost savings. The use of field-based measurement technologies also resulted in collection of the data necessary to choose collaborative and comparative samples that provided the best coverage of spatial variability and ranges of contaminant concentrations. Due to resource constraints, a limited number of samples were collected for comparative and collaborative analyses at a fixed laboratory, so it was important to use field-based results to assist in choosing those samples for off-site analysis that provided the best information given the budget for the site.

Use of the Triad approach at the Poudre River site allowed the property to move quickly from investigation and characterization to construction of a remediation system in less than 2 years. With little agreement among stakeholders as to the best approach for site funding, remediation, and closure, previous sampling events and attempts at characterization did not provide the information necessary to identify contaminant source areas and pathways, and implement a remedy. The cost savings are estimated at

$163,350 or 30 percent (Table 10) using the Triad approach despite additional meetings, consultations, and planning activities that were held between EPA Region 8, the BTSC, and the project team.

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TABLES

TABLE 1

INTERESTED PARTIES

POUDRE RIVER SITE

Interested Party	Role	Consultant
EPA Region 8	Lead agency/Regulator	Tetra Tech EM Inc.
City of Fort Collins	Owner of Northside Aztlan Center and Park area	Walsh Environmental Scientists and Engineers, LLC.
Xcel Energy	Former owner of the MGP property/PRP	The RETEC Group, Inc.
Schrader Oil Company	Current owner of the MGP property/PRP	Paragon Consulting Group, Inc.

Notes:

EPA U.S. Environmental Protection Agency
MGP Manufactured gas plant
PRP Potentially responsible party

TABLE 2

VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Type	Sample Date	Matrix	Depth (feet below ground surface) Top	Depth (feet below ground surface) Bottom	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
BTH-01	MW	7/21/03	WATER	12.6	12.6	Benzene	490	
						M,P-Xylene	17.3	J
						o-Xylene	30.1	
						1,2,4-Trimethylbenzene	18.3	J
						1,3,5-Trimethylbenzene	4.4	J
						Naphthalene	370	
						Bromofluorobenzene	73	
						Difluorobenzene	56	
BTH-02	MW	7/22/03	WATER	14.6	14.6	o-Xylene	160	
						Benzene	29.6	
						cis-1,2-Dichloroethene	7.06	
						Ethylbenzene	41.5	
						m,p-Xylene	174	
						Naphthalene	6500	
						Trichloroethene	14.4	
						1,2,4-Trimethylbenzene	160	
						1,3,5-Trimethylbenzene	44	
						Isopropylbenzene	15.3	
						n-Propylbenzene	8.53	
						p-Isopropyltoluene	5.45	
						Bromofluorobenzene	98	
						Difluorobenzene	50	
						Methyl tert-butyl ether	25	
						Benzene	46	
						Bromofluorobenzene	73	
						Difluorobenzene	52	
BTH-04	MW	7/18/03	WATER	13	13	Bromofluorobenzene	76	
						Difluorobenzene	44	
BTH-05(D)	QC	7/18/03	WATER	16.5	16.5	Naphthalene	170	
						o-Xylene	58.0	
						Toluene	6.7	J
						1,2,4-Trimethylbenzene	49.9	
						1,3,5-Trimethylbenzene	7.76	J
						Isopropylbenzene	14.5	J
						n-Propylbenzene	7.95	J
						p-Isopropyltoluene	2.28	J
						Methyl tert-butyl ether	5.46	J
						Benzene	374	
						Ethylbenzene	70	
						m,p-Xylene	6.08	J
						Bromofluorobenzene	93	
						Difluorobenzene	56	
BTH-06	MW	7/18/03	WATER	15	15	Bromofluorobenzene	77	
						Difluorobenzene	46	
BTH-08	MW	7/17/03	WATER	16.8	16.8	Bromofluorobenzene	76	
						Difluorobenzene	43	
BTH-09	MW	7/18/03	WATER	18	18	Tetrachloroethene	16.4	
						Trichloroethene	1.71	
						Bromofluorobenzene	77	
						Difluorobenzene	44	
BTH-10	MW	7/17/03	WATER	14.6	14.6	Tetrachloroethene	42.1	
						Bromofluorobenzene	76	
						Difluorobenzene	44	

TABLE 2

VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Type	Sample Date	Matrix	Depth (feet below ground surface) Top	Depth (feet below ground surface) Bottom	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
BTH-11	MW	7/16/03	WATER	17.1	17.1	Tetrachloroethene	6.31	
						Trichloroethene	10.5	
						Bromofluorobenzene	76	
						Difluorobenzene	44	
BTH-13	MW	7/18/03	WATER	14.6	14.6	M,P-Xylene	5.9	J
						Naphthalene	151	
						o-Xylene	10.3	J
						Tetrachloroethene	5	J
						Toluene	1.56	J
						1,2,4-Trimethylbenzene	13.8	J
						1,3,5-Trimethylbenzene	3.38	J
						Methyl tert-butyl ether	6.14	J
						Isopropylbenzene	2.78	J
						Benzene	4.49	
						Ethylbenzene	1.91	
						Bromofluorobenzene	79	
						Difluorobenzene	45	
FC-GW-02	GP	7/22/03	WATER	14	14	Tetrachloroethene	1.77	J
						Toluene	1.59	J
FC-GW-02	GP	7/22/03	WATER	15	15	Tetrachloroethene	2.47	J
						Trichloroethene	1.88	J
FC-GW-02	GP	7/22/03	WATER	16	16	Tetrachloroethene	2.31	J
FC-GW-02	GP	7/22/03	WATER	17	17	Tetrachloroethene	1.78	J
FC-GW-03	GP	7/22/03	WATER	14	14	Tetrachloroethene	2.34	J
						Trichloroethene	1.61	J
FC-GW-03	GP	7/22/03	WATER	17	17	Tetrachloroethene	3.74	J
						Trichloroethene	2.92	J
FC-GW-04	GP	7/22/03	WATER	17	17	Tetrachloroethene	5.94	J
						Trichloroethene	3.83	J
FC-GW-04	GP	7/22/03	WATER	18	18	Tetrachloroethene	8.39	J
						Trichloroethene	2.88	J
FC-GW-05	GP	7/23/03	WATER	16	16	Tetrachloroethene	9.36	J
						Trichloroethene	3.27	J
FC-GW-05	GP	7/23/03	WATER	17	17	Tetrachloroethene	7.18	J
						Trichloroethene	2.22	J
FC-GW-05	GP	7/23/03	WATER	18	18	Tetrachloroethene	9.27	J
						Trichloroethene	2.81	J
FC-GW-07	GP	7/23/03	WATER	13	13	Naphthalene	70.7	
						Tetrachloroethene	4.63	J
						Chloroform	1.67	J
						cis-1,2-Dichloroethene	3.01	J
						Trichloroethene	8	J
FC-GW-08	GP	7/23/03	WATER	13	13	Methyl tert-butyl ether	2.67	J
						Tetrachloroethene	3.89	J
						Trichloroethene	7.19	J
FC-GW-09	GP	7/23/03	WATER	10	10	Naphthalene	28.0	
						Tetrachloroethene	5.32	J
FC-GW-11	GP	7/23/03	WATER	12	12	Tetrachloroethene	15.6	J
FC-GW-12	GP	7/23/03	WATER	12	12	Tetrachloroethene	22.5	
FC-GW-13	GP	7/23/03	WATER	11	11	cis-1,2-Dichloroethene	2.96	J
						2-Hexanone	4.4	J
						Tetrachloroethene	29.9	

TABLE 2

VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Type	Sample Date	Matrix	Depth (feet below ground surface) Top	Depth (feet below ground surface) Bottom	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
FC-GW-14	GP	7/23/03	WATER	11	11	Methyl tert-butyl ether	1.97	J
						cis-1,2-Dichloroethene	5.15	J
						Tetrachloroethene	11.9	J
						Trichloroethene	3.76	J
FC-GW-15	GP	7/24/03	WATER	11	11	cis-1,2-Dichloroethene	4.05	J
						Tetrachloroethene	16.4	J
FC-GW-15	GP	7/24/03	WATER	17	17	Butylbenzene	1.79	J
						cis-1,2-Dichloroethene	4.27	J
						Naphthalene	51	
						Tetrachloroethene	17.7	J
						tert-Butylbenzene	1.85	J
						Trichloroethene	11.6	J
						1,2,4-Trimethylbenzene	14.3	J
						1,3,5-Trimethylbenzene	6.17	J
						Bromofluorobenzene	74	
						Difluorobenzene	48	
FC-GW-16	GP	7/25/03	WATER	11	11	cis-1,2-Dichloroethene	2.83	J
						Tetrachloroethene	32.2	
FC-GW-16	GP	7/25/03	WATER	15	15	cis-1,2-Dichloroethene	1.77	J
						Tetrachloroethene	34.9	
FC-GW-17	GP	7/25/03	WATER	12	12	cis-1,2-Dichloroethene	3.79	J
						Tetrachloroethene	21.1	
						Trichloroethene	2.19	J
FC-GW-18	GP	7/25/03	WATER	12	12	Tetrachloroethene	23.4	
FC-GW-19	GP	7/25/03	WATER	12	12	cis-1,2-Dichloroethene	8.55	J
						Tetrachloroethene	13.6	J
FC-GW-19	GP	7/25/03	WATER	15	15	Chloroform	2.08	J
						Tetrachloroethene	38.4	
FC-GW-20	GP	7/25/03	WATER	12	12	Tetrachloroethene	30.8	
FC-GW-21	GP	7/25/03	WATER	15	15	Methyl tert-butyl ether	1.95	J
						Benzene	6	J
						Tetrachloroethene	3.48	J
						1,2,4-Trimethylbenzene	2.98	J
FC-GW-22	GP	7/26/03	WATER	15	15	cis-1,2-Dichloroethene	2.18	J
						Tetrachloroethene	14.5	J
FC-GW-33	GP	7/27/03	WATER	13	13	Methyl tert-butyl ether	20.5	JD
						Benzene	85.6	JD
						Ethylbenzene	104	JD
						m,p-Xylene	152	JD
						Naphthalene	2990	
						o-Xylene	149	JD
						Toluene	28.5	JD
						1,2,4-Trimethylbenzene	94.8	JD
						1,3,5-Trimethylbenzene	25.3	JD
FC-GW-33	GP	7/27/03	WATER	18	18	Benzene	360	
						m,p-Xylene	54.6	JD
						Naphthalene	6880	
						o-Xylene	118	JD
						Toluene	18	JD
						1,2,4-Trimethylbenzene	207	
						1,3,5-Trimethylbenzene	45.1	JD
						Isopropylbenzene	21.4	JD
						p-Isopropyltoluene	18.1	JD
FC-GW-34	GP	7/27/03	WATER	13	13	Naphthalene	14.0	J

TABLE 2

VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Type	Sample Date	Matrix	Depth (feet below ground surface) Top	Depth (feet below ground surface) Bottom	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
FC-GW-34	GP	7/27/03	WATER	16	16	Methyl tert-butyl ether	83.9	
						Benzene	4.66	J
						Naphthalene	10.7	J
FC-GW-35	GP	7/26/03	WATER	17.5	17.5	Naphthalene	10.2	J
FC-GW-36	GP	7/26/03	WATER	13	13	Trichloroethene	5.25	J
FC-MW-03	MW	10/3/03	WATER	17.3	17.3	Acetone	6.1	
						Chloromethane	0.24	J
						1,3-Dichlorobenzene	0.15	J
						1,4-Dichlorobenzene	0.16	J
						Methylene Chloride	0.48	J
						Tetrachloroethene	1.4	
						Trichloroethene	1	
						1,3,5-Trimethylbenzene		J
FC-MW-04	MW	10/3/03	WATER	16.5	16.5	Methyl tert-butyl ether	0.67	
						Chloroform	0.22	J
						cis-1,2-Dichloroethene	2.7	
						Methylene Chloride	0.62	B
						Tetrachloroethene	7	
						Trichloroethene	7.9	
						trans-1,2-Dichloroethene	0.35	J
						1,3,5-Trimethylbenzene		J
FC-MW-05	MW	10/3/03	WATER	15.5	15.5	Methyl tert-butyl ether	3	
						Acetone	7.9	
						Chloroform	0.36	J
						cis-1,2-Dichloroethene	0.43	J
						Methylene Chloride	0.63	B
						Tetrachloroethene	7.3	
						Trichloroethene	2.6	
						1,3,5-Trimethylbenzene		J
						Methyl Acetate	3.6	
FC-MW-07	MW	10/6/03	WATER	13.6	13.6	Chloroform	0.86	
						cis-1,2-Dichloroethene	0.97	
						Trichloroethene	0.98	
						Tetrachloroethene	25	D
						1,3,5-Trimethylbenzene		J
FC-MW-08	MW	10/7/03	WATER	14	14	Chloromethane	0.5	JB
						cis-1,2-Dichloroethene	4.7	
						Methylene Chloride	0.53	
						Tetrachloroethene	12	
						Trichloroethene	1.8	
						Vinyl Chloride	0.23	J
FC-MW-09	MW	10/6/03	WATER	17.5	17.5	Acetone	5.5	
						Chloroform	0.49	J
						cis-1,2-Dichloroethene	0.28	J
						Ethylbenzene	0.5	
						Tetrachloroethene	7.7	
						Trichloroethene	0.48	J
						1,3,5-Trimethylbenzene		J
FC-MW-10	MW	10/7/03	WATER	17.5	17.5	Carbon Disulfide	0.35	J
						Chloroform	0.3	J
						Chloromethane	0.58	B
						Methylene Chloride	0.34	J
						Tetrachloroethene	0.69	

TABLE 2

VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Type	Sample Date	Matrix	Depth (feet below ground surface) Top	Depth (feet below ground surface) Bottom	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
FC-MW-11	MW	10/7/03	WATER	14.4	14.4	Methyl tert-butyl ether	0.48	J
						Methylcyclohexane	0.23	J
						Acetone	11	
						Benzene	530	D
						Toluene	11	
						Cyclohexane	0.21	J
						Isopropylbenzene	6	
FC-MW-12	MW	10/6/03	WATER	17.2	17.2	Methylcyclohexane	0.28	J
						Methyl tert-butyl ether	30	D
						Acetone	12	
						Benzene	54	D
						Ethylbenzene	8.2	
						Toluene	1.6	
						Cyclohexane	0.26	J
						Isopropylbenzene	6.9	
FC-MW-15	MW	10/7/03	WATER	16	16	Methyl tert-butyl ether	0.74	
						Methylcyclohexane	0.52	
						Acetone	8.6	
						Benzene	110	D
						Carbon Disulfide	0.93	
						Chloromethane	0.54	B
						Styrene	9.4	
						Toluene	24	
						Cyclohexane	0.28	J
						Isopropylbenzene	8.6	
FC-TW-01	TW	10/1/03	WATER	13.5	13.5	Ethylbenzene	0.5	
						Methylene Chloride	0.5	JB
						1,3,5-Trimethylbenzene		J
FC-TW-02	TW	10/1/03	WATER	21	21	Ethylbenzene	0.5	
						Methylene Chloride	0.5	JB
						Tetrachloroethene	0.58	
						Trichloroethene	0.49	J
						1,3,5-Trimethylbenzene		J
FC-TW-06	TW	9/30/03	WATER	17	17	Isopropanol		
						Chloroform	0.37	J
						Chloromethane	0.5	JB
						cis-1,2-Dichloroethene	2.4	
						Ethylbenzene	0.5	
						Methylene Chloride	1	B
						Tetrachloroethene	31	D
						Trichloroethene	1.9	
						1,2,4-Trimethylbenzene		
FC-TW-13	TW	9/30/03	WATER	18	18	Isopropanol		
						Ethylbenzene	0.5	
						Methylene Chloride	0.81	B
						1,2,4-Trimethylbenzene		
FC-TW-14	TW	9/30/03	WATER	17.5	17.5	Isopropanol		
						Ethylbenzene	0.5	
						Methylene Chloride	0.74	B
						1,2,4-Trimethylbenzene		

TABLE 2

VOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Type	Sample Date	Matrix	Depth (feet below ground surface) Top	Depth (feet below ground surface) Bottom	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
FC-WW-01	IDW	10/8/03	WATER			Xylenes (total)	4.1	
						Acetone	42	
						Benzene	5.2	
						Chloromethane	2.5	JB
						Ethylbenzene	1.3	J
						Methylene Chloride	3.5	
MW-09	MW	7/22/03	WATER	13.3	13.3	Bromofluorobenzene	75	
						Difluorobenzene	49	
SW-1	SL	9/23/03	WATER	0	0	Isopropanol		
						Acetone	5.6	
						Ethylbenzene	0.5	
						Methylene Chloride	0.13	J
						1,2,4-Trimethylbenzene		
SW-2	SL	9/23/03	WATER	0	0	Isopropanol		
						Acetone	3.7	J
						Ethylbenzene	0.5	
						1,2,4-Trimethylbenzene		
SW-3	SL	9/23/03	WATER	0	0	Isopropanol		
						Acetone	6.4	
						Ethylbenzene	0.5	
						1,2,4-Trimethylbenzene		
MW-11	MW	7/21/03	WATER	16.2	16.2	Methyl tert-butyl ether	6.78	J
						Toluene	118	
						1,2,4-Trimethylbenzene	50.3	
						1,3,5-Trimethylbenzene	10.1	J
						Isopropylbenzene	4.08	J
						n-Propylbenzene	2.14	J
						o-Xylene	78.3	
						Benzene	760	
						Ethylbenzene	78.5	
						m,p-Xylene	102	
						Naphthalene	1800	
						Bromofluorobenzene	78	
						Difluorobenzene	60	
MW-02	MW	9/30/03	WATER	11	11	Isopropanol		JD
						Xylenes (total)	150	D
						Benzene	240	D
						Methylene Chloride	20	JDB
						1,2,4-Trimethylbenzene	130	JND

Notes:

B	The compound was also detected in blank sample.
D	The result was reported from a sample dilution.
GP	Geoprobe
IDW	Investigation-derived waste
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
µg/L	Microgram per liter
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a "tentative identification."
QC	Quality control
SL	Surface location
TBA	Targeted Brownfields Assessment
TW	Temporary well

TABLE 3

SEMIVOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Source	Sample Date	Sample Matrix	Sample Depth (feet below TOC)	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
BTH-01	MW	7/21/03	WATER	12.6	Fluorene	3	J
BTH-01	MW	7/21/03	WATER	12.6	2-Methylnaphthalene	6	J
BTH-01	MW	7/21/03	WATER	12.6	Phenanthrene	4	J
BTH-01	MW	7/21/03	WATER	12.6	Phenol	13	
BTH-01	MW	7/21/03	WATER	12.6	1,1'-Biphenyl	2	J
BTH-01	MW	7/21/03	WATER	12.6	Acenaphthylene	10	JD
BTH-01	MW	7/21/03	WATER	12.6	2-Methylnaphthalene	7	JD
BTH-01	MW	7/21/03	WATER	12.6	Naphthalene	230	D
BTH-01	MW	7/21/03	WATER	12.6	Phenanthrene	4	JD
BTH-01	MW	7/21/03	WATER	12.6	Phenol	13	JD
BTH-01	MW	7/21/03	WATER	12.6	Acenaphthene	2	J
BTH-01	MW	7/21/03	WATER	12.6	Acenaphthylene	10	J
BTH-01	MW	7/21/03	WATER	12.6	Carbazole	2	J
BTH-01	MW	7/21/03	WATER	12.6	Dibenzofuran	1	J
BTH-02	MW	7/21/03	WATER	14.7	Acenaphthene	3	J
BTH-02	MW	7/21/03	WATER	14.7	Acenaphthylene	8	J
BTH-02	MW	7/21/03	WATER	14.7	Fluorene	4	J
BTH-02	MW	7/21/03	WATER	14.7	Phenanthrene	3	J
BTH-02	MW	7/21/03	WATER	14.7	Acetophenone	2	J
BTH-02	MW	7/21/03	WATER	14.7	1,1'-Biphenyl	3	J
BTH-02	MW	7/22/03	WATER	14.6	Acenaphthene	80	
BTH-02	MW	7/22/03	WATER	14.6	Anthracene	7.6	
BTH-02	MW	7/22/03	WATER	14.6	Dibenzofuran	10	
BTH-02	MW	7/22/03	WATER	14.6	Fluoranthene	3.8	J
BTH-02	MW	7/22/03	WATER	14.6	Fluorene	42	
BTH-02	MW	7/22/03	WATER	14.6	Phenanthrene	37	
BTH-02	MW	7/22/03	WATER	14.6	Pyrene	3.8	J
BTH-02	MW	7/22/03	WATER	14.6	1,1'-Biphenyl	39	
BTH-02	MW	7/22/03	WATER	14.6	Acenaphthene	130	JD
BTH-02	MW	7/22/03	WATER	14.6	Acenaphthylene	120	JD
BTH-02	MW	7/22/03	WATER	14.6	2-Methylnaphthalene	410	JD
BTH-02	MW	7/22/03	WATER	14.6	Naphthalene	3500	D
BTH-05	MW	7/18/03	WATER	16.5	Acenaphthene	46	
BTH-05	MW	7/18/03	WATER	16.5	Acenaphthylene	38	
BTH-05	MW	7/18/03	WATER	16.5	Anthracene	2	J
BTH-05	MW	7/18/03	WATER	16.5	Carbazole	4	J
BTH-05	MW	7/18/03	WATER	16.5	Dibenzofuran	4	J
BTH-05	MW	7/18/03	WATER	16.5	Fluorene	13	
BTH-05	MW	7/18/03	WATER	16.5	Naphthalene	53	
BTH-05	MW	7/18/03	WATER	16.5	Phenanthrene	11	
BTH-05	MW	7/18/03	WATER	16.5	Phenol	12	
BTH-05	MW	7/18/03	WATER	16.5	1,1'-Biphenyl	19	
BTH-08	MW	7/17/03	WATER	16.8	Acenaphthylene	2	J
BTH-13	MW	7/18/03	WATER	14.6	Fluorene	5.3	
BTH-13	MW	7/18/03	WATER	14.6	2-Methylnaphthalene	21	
BTH-13	MW	7/18/03	WATER	14.6	Naphthalene	22	
BTH-13	MW	7/18/03	WATER	14.6	Phenanthrene	3.6	J
BTH-13	MW	7/18/03	WATER	14.6	1,1'-Biphenyl	5	
BTH-13	MW	7/18/03	WATER	14.6	Acenaphthene	4.3	J
BTH-13	MW	7/18/03	WATER	14.6	Acenaphthylene	26	
FC-GW-15	GP	7/24/03	WATER	17	Acenaphthylene	1600	
FC-GW-15	GP	7/24/03	WATER	17	Anthracene	320	J
FC-GW-15	GP	7/24/03	WATER	17	Benzo(b)fluoranthene	340	J
FC-GW-15	GP	7/24/03	WATER	17	Benzo(k)fluoranthene	300	J
FC-GW-15	GP	7/24/03	WATER	17	Fluorene	110	J
FC-GW-15	GP	7/24/03	WATER	17	2-Methylnaphthalene	210	J
FC-GW-15	GP	7/24/03	WATER	17	Phenanthrene	360	J
FC-GW-15	GP	7/24/03	WATER	17	Pyrene	290	J
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Acenaphthylene	14	
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Anthracene	4.1	J
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Benzo(a)anthracene	1.8	J
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Dibenzofuran	3.5	J

TABLE 3

SEMIVOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Source	Sample Date	Sample Matrix	Sample Depth (feet below TOC)	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Fluoranthene	2.7	J
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Fluorene	22	
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	2-Methylnaphthalene	74	
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Phenanthrene	8.3	
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	1,1'-Biphenyl	16	
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Acenaphthylene	21	JD
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Fluorene	35	D
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	2-Methylnaphthalene	72	D
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Naphthalene	160	D
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	Phenanthrene	12	JD
FC-GW-33 (18-19.5)	GP	7/27/03	WATER	18	1,1'-Biphenyl	25	D
FC-MW-03	MW	10/3/03	WATER	17.3	4-Nitroaniline	20	
FC-MW-04	MW	10/3/03	WATER	16.5	4-Nitroaniline	20	
FC-MW-05	MW	10/3/03	WATER	15.5	4-Nitroaniline	20	
FC-MW-07	MW	10/6/03	WATER	13.6	4-Nitroaniline	20	
FC-MW-09	MW	10/6/03	WATER	17.5	Naphthalene	1.1	J
					4-Nitroaniline	20	
FC-MW-11	MW	10/7/03	WATER	14.4	Acenaphthene	25	
FC-MW-11	MW	10/7/03	WATER	14.4	Anthracene	15	
FC-MW-11	MW	10/7/03	WATER	14.4	Benzo(a)anthracene	2.1	J
FC-MW-11	MW	10/7/03	WATER	14.4	Benzo(a)pyrene	1.2	J
FC-MW-11	MW	10/7/03	WATER	14.4	Chrysene	2.2	J
FC-MW-11	MW	10/7/03	WATER	14.4	Dibenzofuran	13	
FC-MW-11	MW	10/7/03	WATER	14.4	2,4-Dimethylphenol	17	
FC-MW-11	MW	10/7/03	WATER	14.4	Fluoranthene	8.1	
FC-MW-11	MW	10/7/03	WATER	14.4	Fluorene	50	
FC-MW-11	MW	10/7/03	WATER	14.4	Phenanthrene	72	
FC-MW-11	MW	10/7/03	WATER	14.4	Phenol	8.2	
FC-MW-11	MW	10/7/03	WATER	14.4	Pyrene	10	
FC-MW-11	MW	10/7/03	WATER	14.4	Acetophenone	3.8	J
FC-MW-11	MW	10/7/03	WATER	14.4	1,1'-Biphenyl	37	
FC-MW-11	MW	10/7/03	WATER	14.4	Acenaphthylene	130	JD
FC-MW-11	MW	10/7/03	WATER	14.4	2-Methylnaphthalene	490	D
FC-MW-11	MW	10/7/03	WATER	14.4	Naphthalene	1800	D
FC-MW-11	MW	10/7/03	WATER	14.4	Phenanthrene	66	JD
FC-MW-11	MW	10/7/03	WATER	14.4	1-Methylnaphthalene	680	JN
FC-MW-12	MW	10/6/03	WATER	17.2	Acenaphthene	44	
FC-MW-12	MW	10/6/03	WATER	17.2	Anthracene	6.9	
FC-MW-12	MW	10/6/03	WATER	17.2	Dibenzofuran	7	
FC-MW-12	MW	10/6/03	WATER	17.2	Fluoranthene	4.8	J
FC-MW-12	MW	10/6/03	WATER	17.2	Fluorene	20	
FC-MW-12	MW	10/6/03	WATER	17.2	4-Methylphenol	3	J
FC-MW-12	MW	10/6/03	WATER	17.2	Phenanthrene	42	
FC-MW-12	MW	10/6/03	WATER	17.2	Phenol	2.7	J
FC-MW-12	MW	10/6/03	WATER	17.2	Pyrene	5.3	
FC-MW-12	MW	10/6/03	WATER	17.2	1,1'-Biphenyl	29	
FC-MW-12	MW	10/6/03	WATER	17.2	1-Methylnaphthalene	4.4	JN
FC-MW-12	MW	10/6/03	WATER	17.2	Acenaphthene	60	JD
FC-MW-12	MW	10/6/03	WATER	17.2	Acenaphthylene	120	JD
FC-MW-12	MW	10/6/03	WATER	17.2	2-Methylnaphthalene	210	JD
FC-MW-12	MW	10/6/03	WATER	17.2	Naphthalene	1800	D
FC-MW-12	MW	10/6/03	WATER	17.2	Phenanthrene	56	JD
FC-MW-15	MW	10/7/03	WATER	16	Acenaphthene	72	
FC-MW-15	MW	10/7/03	WATER	16	Anthracene	10	
FC-MW-15	MW	10/7/03	WATER	16	Dibenzofuran	10	
FC-MW-15	MW	10/7/03	WATER	16	2,4-Dimethylphenol	2.8	J
FC-MW-15	MW	10/7/03	WATER	16	Fluoranthene	6.6	
FC-MW-15	MW	10/7/03	WATER	16	Fluorene	32	
FC-MW-15	MW	10/7/03	WATER	16	2-Methylphenol	1.6	J
FC-MW-15	MW	10/7/03	WATER	16	4-Methylphenol	4.6	J
FC-MW-15	MW	10/7/03	WATER	16	Phenanthrene	60	
FC-MW-15	MW	10/7/03	WATER	16	Phenol	4.2	J

TABLE 3

SEMIVOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Source	Sample Date	Sample Matrix	Sample Depth (feet below TOC)	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
FC-MW-15	MW	10/7/03	WATER	16	Pyrene	7.5	
FC-MW-15	MW	10/7/03	WATER	16	1,1'-Biphenyl	41	
FC-MW-15	MW	10/7/03	WATER	16	1-Methylnaphthalene	4.4	JN
FC-MW-15	MW	10/7/03	WATER	16	Acenaphthene	74	JD
FC-MW-15	MW	10/7/03	WATER	16	Acenaphthylene	130	JD
FC-MW-15	MW	10/7/03	WATER	16	2-Methylnaphthalene	310	D
FC-MW-15	MW	10/7/03	WATER	16	Naphthalene	2500	D
FC-MW-15	MW	10/7/03	WATER	16	Phenanthrene	60	JD
FC-TW-01	TW	10/1/03	WATER	13.5	4-Nitroaniline	20	
FC-TW-02	TW	10/1/03	WATER	21	4-Nitroaniline	20	
FC-TW-02	TW	10/1/03	WATER	21	4-Nitroaniline	100	
FC-TW-06	TW	9/30/03	WATER	17	4-Nitroaniline	20	
FC-TW-13	TW	9/30/03	WATER	18	4-Nitroaniline	20	
FC-TW-14	TW	9/30/03	WATER	17.5	4-Nitroaniline	20	
FC-WW-01	IDW	10/8/03	WATER		Acenaphthene	14	
FC-WW-01	IDW	10/8/03	WATER		Acenaphthylene	10	
FC-WW-01	IDW	10/8/03	WATER		Anthracene	1.6	J
FC-WW-01	IDW	10/8/03	WATER		Chrysene	1.2	J
FC-WW-01	IDW	10/8/03	WATER		Dibenzofuran	1.9	J
FC-WW-01	IDW	10/8/03	WATER		2,4-Dimethylphenol	11	
FC-WW-01	IDW	10/8/03	WATER		4,6-Dinitro-2-methylphenol	1.8	J
FC-WW-01	IDW	10/8/03	WATER		Fluoranthene	2.8	J
FC-WW-01	IDW	10/8/03	WATER		Fluorene	10	
FC-WW-01	IDW	10/8/03	WATER		2-Methylnaphthalene	51	
FC-WW-01	IDW	10/8/03	WATER		4-Methylphenol	1.3	J
FC-WW-01	IDW	10/8/03	WATER		Pentachlorophenol	1.6	J
FC-WW-01	IDW	10/8/03	WATER		Phenanthrene	22	
FC-WW-01	IDW	10/8/03	WATER		Phenol	2.4	J
FC-WW-01	IDW	10/8/03	WATER		Pyrene	4.3	J
FC-WW-01	IDW	10/8/03	WATER		Acetophenone	1.6	J
FC-WW-01	IDW	10/8/03	WATER		1,1'-Biphenyl	4.8	J
FC-WW-01	IDW	10/8/03	WATER		Acenaphthene	15	D
FC-WW-01	IDW	10/8/03	WATER		Acenaphthylene	11	D
FC-WW-01	IDW	10/8/03	WATER		Dibenzofuran	2	JD
FC-WW-01	IDW	10/8/03	WATER		2,4-Dimethylphenol	11	D
FC-WW-01	IDW	10/8/03	WATER		Fluoranthene	3	JD
FC-WW-01	IDW	10/8/03	WATER		Fluorene	11	D
FC-WW-01	IDW	10/8/03	WATER		2-Methylnaphthalene	55	D
FC-WW-01	IDW	10/8/03	WATER		Naphthalene	130	D
FC-WW-01	IDW	10/8/03	WATER		Phenanthrene	24	D
FC-WW-01	IDW	10/8/03	WATER		Phenol	2.9	JD
FC-WW-01	IDW	10/8/03	WATER		Pyrene	4.6	JD
FC-WW-01	IDW	10/8/03	WATER		1,1'-Biphenyl	5.1	JD
SW-1	SL	9/23/03	WATER	0	4-Nitroaniline	20	
SW-2	SL	9/23/03	WATER	0	4-Nitroaniline	20	
SW-3	SL	9/23/03	WATER	0	4-Nitroaniline	20	
MW-02	MW	9/30/03	WATER	11	Acenaphthene	5.3	
MW-02	MW	9/30/03	WATER	11	Anthracene	7.2	
MW-02	MW	9/30/03	WATER	11	Dibenzofuran	5.6	
MW-02	MW	9/30/03	WATER	11	Fluoranthene	2	J
MW-02	MW	9/30/03	WATER	11	Fluorene	23	
MW-02	MW	9/30/03	WATER	11	2-Methylphenol	3.3	J
MW-02	MW	9/30/03	WATER	11	4-Methylphenol	15	
MW-02	MW	9/30/03	WATER	11	Phenanthrene	15	
MW-02	MW	9/30/03	WATER	11	Pyrene	3.5	J
MW-02	MW	9/30/03	WATER	11	1,1'-Biphenyl	6.8	
MW-02	MW	9/30/03	WATER	11	Acenaphthylene	88	JD
MW-02	MW	9/30/03	WATER	11	2-Methylnaphthalene	250	D
MW-02	MW	9/30/03	WATER	11	Naphthalene	1300	D
MW-02	MW	9/30/03	WATER	11	4-Nitroaniline	1000	
MW-11	MW	7/21/03	WATER	16.2	ACENAPHTHENE	35	
MW-11	MW	7/21/03	WATER	16.2	Acenaphthylene	67	

TABLE 3

SEMIVOLATILE ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING TBA

POUDRE RIVER SITE

Sample Name	Sample Source	Sample Date	Sample Matrix	Sample Depth (feet below TOC)	Analyte	Sample Concentration (µg/L)	Laboratory Qualifier
MW-11	MW	7/21/03	WATER	16.2	Anthracene	8	J
MW-11	MW	7/21/03	WATER	16.2	Carbazole	5	J
MW-11	MW	7/21/03	WATER	16.2	Dibenzofuran	7	J
MW-11	MW	7/21/03	WATER	16.2	2,4-Dimethylphenol	39	
MW-11	MW	7/21/03	WATER	16.2	Fluoranthene	3	J
MW-11	MW	7/21/03	WATER	16.2	Fluorene	36	
MW-11	MW	7/21/03	WATER	16.2	4-Methylphenol	14	
MW-11	MW	7/21/03	WATER	16.2	Phenanthrene	39	
MW-11	MW	7/21/03	WATER	16.2	Phenol	2	J
MW-11	MW	7/21/03	WATER	16.2	Pyrene	4	J
MW-11	MW	7/21/03	WATER	16.2	Acetophenone	3	J
MW-11	MW	7/21/03	WATER	16.2	1,1'-Biphenyl	22	
MW-11	MW	7/21/03	WATER	16.2	Acenaphthene	35	JD
MW-11	MW	7/21/03	WATER	16.2	Acenaphthylene	76	JD
MW-11	MW	7/21/03	WATER	16.2	2,4-Dimethylphenol	26	JD
MW-11	MW	7/21/03	WATER	16.2	Fluorene	39	JD
MW-11	MW	7/21/03	WATER	16.2	2-Methylnaphthalene	92	JD
MW-11	MW	7/21/03	WATER	16.2	Naphthalene	1000	D
MW-11	MW	7/21/03	WATER	16.2	Phenanthrene	39	JD
MW-11	MW	7/21/03	WATER	16.2	1,1'-Biphenyl	23	JD

Note:

D	The result was reported from a sample dilution.
GP	Geoprobe
IDW	Investigation-derived waste
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
µg/L	Microgram per liter
MW	Monitoring well
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a "tentative identification."
SL	Surface location
TBA	Targeted Brownfields Assessment
TOC	Top of casing
TW	Temporary well

TABLE 4

PAH CONCENTRATIONS IN µg/kg, CACHE LA POUDRE RIVER SAMPLES AND POTENTIAL UPGRADIENT SOURCE SAMPLES

POUDRE RIVER SITE

PAH Compound	Sample FC-PR-01 µg/kg	Sample FC-PR-01 Normalized to Benzo(a)pyrene	Sample TP-2, 11.5' µg/kg	Sample TP-2, 11.5' Normalized to Benzo(a)pyrene	Sample FC-PS-01 µg/kg	Sample FC-PS-01 Normalized to Benzo(a)pyrene	Sample H1250 µg/kg	Sample H1250 Normalized to Benzo(a)pyrene	Sample BTH-10 (5-15') µg/kg	Sample BTH-10 (5-15') Normalized to Benzo(a)pyrene	Sample PRSB-8DL µg/kg	Sample PRSB-8DL Normalized to Benzo(a)pyrene	Sample TR01SP µg/kg	Sample TR01SP DL Normalized to Benzo(a)pyrene
NAPHTHALENE	270,000	19.29	1,055,000	3,196.97	13,000,000	15.85	125	0.03	500	0.38	220,000,000	25.88	1,100,000	24.67
ACENAPHTHYLENE	110,000	7.86	350,000	1,060.61	4,300,000	5.24	6500	1.76	1,100	0.85	31,000,000	3.65	290,000	6.40
ACENAPHTHENE	32,000	2.29	**330**	1.00	1,900,000	2.32	10000	2.70	360	0.28	60,000,000	7.06	180,000	3.93
FLUORENE	72,000	5.14	184,950	560.45	3,600,000	4.39	12000	3.24	660	0.51	52,000,000	6.12	280,000	6.13
PHENANTHRENE	150,000	10.71	335,500	1,016.67	8,500,000	10.37	22000	5.95	880	0.68	89,000,000	10.47	490,000	10.67
ANTHRACENE	49,000	3.50	120,000	363.64	2,400,000	2.93	7400	2.00	420	0.32	28,000,000	3.29	150,000	3.27
FLUORANTHENE	55,000	3.93	124,000	375.76	2,300,000	2.80	8600	2.32	970	0.75	32,000,000	3.76	180,000	4.00
PYRENE	49,000	3.50	139,000	421.21	3,100,000	3.78	9900	2.68	2,400	1.85	31,000,000	3.65	170,000	3.73
BENZO(A)ANTHRACENE	19,000	1.36	46,300	140.30	1,100,000	1.34	4800	1.30	740	0.57	12,000,000	1.41	66,000	1.47
CHRYSENE	20,000	1.43	**330**	1.00	1,300,000	1.59	4200	1.14	770	0.59	13,000,000	1.53	69,000	1.53
BENZO(B)FLUORANTHENE	6,700	0.48	**330**	1.00	440,000	0.54	4800	1.30	1,400	1.08	**8,500,000**	1.00	27,000	0.59
BENZO(K)FLUORANTHENE	12,000	0.86	**330**	1.00	530,000	0.65	4200	1.14	**200**	0.15	6,800,000	0.80	40,000	0.87
BENZO(A)PYRENE	14,000	1.00	**330**	1.00	820,000	1.00	3700	1.00	1,300	1.00	8,500,000	1.00	47,000	1.00
INDENO(1,2,3-CD)-PYRENE	7,500	0.54	**330**	1.00	1,500,000	1.83	1200	0.32	450	0.35	**8,500,000**	1.00	**60,000**	1.37
DIBENZO(A,H)-ANTHRACENE	1,500	0.11	**330**	1.00	1,500,000	1.83	150	0.04	**200**	0.15	**8,500,000**	1.00	**60,000**	1.37
BENZO(G,H,I)PERYLENE	6,500	0.46	**330**	1.00	1,500,000	1.83	1300	0.35	480	0.37	**8,500,000**	1.00	**60,000**	1.37

Notes:

Values in bold print represent one half the quantitation limit for non-detected compounds.

µg/kg Microgram per kilogram
PAH Polynuclear aromatic hydrocarbon

TABLE 5

TTMW-07 COAL TAR PRODUCT SAMPLE PHYSICAL ANALYSIS RESULTS FROM SA

POUDRE RIVER SITE

Physical Method	Analytical Method	Result	Units
Specific Gravity	ASTM D1475-85	1.02	N/A
Viscosity @ 10 degrees Celsius	ASTM D445	30.65	cSt
Viscosity @ 20 degrees Celsius	ASTM D445	20.32	cSt
Water Content	ASTM E 203	11.79	% water
Surface Tension	ASTM D1331	31	dynes/cm

Notes:

ASTM	American Society for Testing and Materials
cSt	centistokes
dynes/cm	dynes per centimeter
N/A	Not Applicable
SA	Site Assessment

TABLE 6

ORGANIC COMPOUNDS DETECTED IN SOIL DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Upper Sample Depth (ft)	Lower Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/kg)	Laboratory Qualifier	Laboratory Reporting Limit	Dilution Factor
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	VOA	1,2,4-Trimethylbenzene	9800		3000	602
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	VOA	m&p-Xylene	4400		3000	602
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	VOA	Naphthalene	450000		24000	602
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	VOA	o-Xylene	5500		3000	602
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	VOA	Xylene (Total)	9900		3000	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	2-Methylnaphthalene	150000		20000	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Acenaphthene	6700		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Acenaphthylene	35000		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Anthracene	17000		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Benzo(a)anthracene	8700		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Benzo(a)pyrene	6200		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Benzo(k)fluoranthene	5100		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Chrysene	8900		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Dibenzofuran	6600		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Fluoranthene	16000		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Fluorene	35000		3900	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Naphthalene	170000		20000	12
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Phenanthrene	64000		20000	5.92
MGPMW-2D	SA-SB-20	6/29/2004	SOIL	TTEMI	NA	9	10	SVOA	Pyrene	21000		3900	5.92
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	VOA	1,2,4-Trimethylbenzene	360		290	57.3
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	VOA	Naphthalene	25000		2300	229
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	2-Methylnaphthalene	3800		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Acenaphthene	2600		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Acenaphthylene	22000		3800	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Anthracene	8200		3800	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Benzo(a)anthracene	3800		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Benzo(a)pyrene	2900		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Benzo(b)fluoranthene	2700		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Benzo(g,h,i)perylene	560		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Benzo(k)fluoranthene	1500		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Chrysene	3800		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Dibenzofuran	2100		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Fluoranthene	7500		3800	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Fluorene	15000		3800	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Indeno(1,2,3-cd)pyrene	620		380	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Naphthalene	34000		3800	1.14
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Phenanthrene	36000		3800	5.72
TTSB-01	SA-SB-01	4/19/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Pyrene	9700		3800	11.4
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	1,2,4-Trimethylbenzene	3800		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	1,3,5-Trimethylbenzene	1300		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	m&p-Xylene	480		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	Naphthalene	86000		5600	562
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	n-Butylbenzene	870		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	n-Propylbenzene	1100		280	56.2

TABLE 6

ORGANIC COMPOUNDS DETECTED IN SOIL DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Upper Sample Depth (ft)	Lower Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/kg)	Laboratory Qualifier	Laboratory Reporting Limit	Dilution Factor
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	o-Xylene	740		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	p-Isopropyltoluene	490		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	VOA	Xylene (Total)	1200		280	56.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	2-Methylnaphthalene	7800		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Acenaphthene	28000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Acenaphthylene	51000		19000	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Anthracene	25000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Benzo(a)anthracene	17000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Benzo(a)pyrene	14000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Benzo(b)fluoranthene	13000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Benzo(g,h,i)perylene	2800	J	3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Benzo(k)fluoranthene	7700		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Chrysene	17000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Dibenzofuran	5400		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Fluoranthene	33000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Fluorene	33000		3700	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Naphthalene	130000		19000	11.2
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Phenanthrene	110000		19000	5.46
TTSB-02	SA-SB-02	4/20/2004	SOIL	TTEMI	NA	15	15.5	SVOA	Pyrene	50000		19000	5.46
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	VOA	Naphthalene	5600		560	56
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Acenaphthene	640		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Acenaphthylene	3300		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Anthracene	1900		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Benzo(a)anthracene	1500		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Benzo(a)pyrene	1300		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Benzo(b)fluoranthene	1200		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Benzo(k)fluoranthene	400		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Chrysene	1500		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Fluoranthene	3100		1800	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Fluorene	1100		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Naphthalene	1100		370	1.12
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Phenanthrene	7800		1800	5.59
TTSB-05	SA-SB-03	4/22/2004	SOIL	TTEMI	NA	18.5	19	SVOA	Pyrene	3700		1800	5.59
TTSB-09	SA-SB-04	4/27/2004	SOIL	TTEMI	NA	4	9	VOA	Tetrachloroethene	140		6.0	1.19
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	VOA	1,2,4-Trimethylbenzene	28		5.6	1.12
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	VOA	Acetone	42		22.	1.12
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	VOA	Naphthalene	49		11.	1.12
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	VOA	n-Butylbenzene	13		5.6	1.12
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	VOA	o-Xylene	5.8		5.6	1.12
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	VOA	Xylene (Total)	5.8		5.6	1.12
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	SVOA	Acenaphthylene	390		360	1.1
TTSB-15	SA-SB-07	5/5/2004	SOIL	TTEMI	NA	17	17.5	SVOA	Phenanthrene	550		360	1.1
TTSB-15	SA-SB-08	5/5/2004	SOIL	TTEMI	NA	18	18.5	VOA	Methylene chloride	8.1		5.4	1.07
TTSB-15	SA-SB-08	5/5/2004	SOIL	TTEMI	NA	18	18.5	SVOA	Phenanthrene	710		360	1.09

TABLE 6

ORGANIC COMPOUNDS DETECTED IN SOIL DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Upper Sample Depth (ft)	Lower Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/kg)	Laboratory Qualifier	Laboratory Reporting Limit	Dilution Factor
TTSB-16	SA-SB-09	5/6/2004	SOIL	TTEMI	NA	19	19.5	VOA	Methylene chloride	10		6.1	1.22
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	VOA	1,2,3-Trichlorobenzene	450		340	67.6
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	VOA	Naphthalene	400000		27000	2700
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	VOA	Xylene (Total)	400		340	67.6
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	2-Methylnaphthalene	68000		8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Acenaphthene	4400		450	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Acenaphthylene	27000		8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Anthracene	12000		8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Benzo(a)anthracene	6700	J	8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Benzo(a)pyrene	4200		450	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Benzo(b)fluoranthene	2800		450	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Benzo(g,h,i)perylene	710		450	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Benzo(k)fluoranthene	3600		450	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Chrysene	7000	J	8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Dibenzofuran	2100		450	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Fluoranthene	12000		8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Fluorene	20000		8900	1.35
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Indeno(1,2,3-cd)pyrene	810		450	27
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Naphthalene	83000		8900	27
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Phenanthrene	50000		8900	27
TTSB-21	SA-SB-10	5/11/2004	SOIL	TTEMI	NA	0	21.5	SVOA	Pyrene	18000		8900	27

Notes:

ft	Feet
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
µg/kg	Microgram per kilogram
NA	Not applicable
SA	Site Assessment
SVOA	Semivolatile organic analysis
TTEMI	Tetra Tech EM Inc.
VOA	Volatile organic analysis

TABLE 7

SOIL AND BEDROCK GEOTECHNICAL ANALYSIS RESULTS FROM SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Company	Upper Sample Depth (ft)	Lower Sample Depth (ft)	Media	Analysis	Moisture (%)	Dry Density	Unconfined Compressive Strength (psf)	Soil Type
TTSB-22	SA-SB-11	5/12/2004	TTEMI	9	10.5	Landfill	ASTM D2937, CU w/ pore pressure	NA	NA	NA	
TTSB-22	SA-SB-12	5/12/2004	TTEMI	11.5	13	Alluvium	ASTM D2937, direct shear	NA	NA	NA	
TTSB-22	SA-SB-13	5/12/2004	TTEMI	21.5	22	Bedrock	Unconfined Compressive Strength	14.3	117	23400	Sandstone, Medium moist, olive-gray
TTSB-25	SA-SB-14	5/17/2004	TTEMI	9	10.5	Bedrock	Unconfined Compressive Strength	20.1	108	8000	Sandstone, Medium moist, olive
TTSB-26	SA-SB-15	5/18/2004	TTEMI	10	10.5	Bedrock	Unconfined Compressive Strength	16.5	114	16500	Sandstone, medium moist, olive
TTSB-27	SA-SB-15B	5/19/2004	TTEMI	4.5	5	Landfill	ASTM D2937, direct shear	NA	NA	NA	
TTSB-27	SA-SB-16	5/19/2004	TTEMI	17	17.5	Bedrock	Unconfined Compressive Strength	20.6	104	NP	Sandstone/claystone, moist, dark yellow, olive brown
TTSB-27	SA-SB-16B	5/19/2004	TTEMI	17.5	18	Bedrock	Unconfined Compressive Strength	21.2	104	2900	Weathered sandstone, medium moist, olive
TTSB-27	SA-SB-16C	5/19/2004	TTEMI	16.5	17	Bedrock	Unconfined Compressive Strength	18.4	110	8100	Sandstone, medium moist, olive brown
TTSB-28	SA-SB-17	5/19/2004	TTEMI	9	10.5	Landfill	ASTM D2937, direct shear	NA	NA	NA	
TTSB-28	SA-SB-18	5/19/2004	TTEMI	14	15.5	Alluvium	ASTM D2937, direct shear	NA	NA	NA	
TTSB-28	SA-SB-19	5/19/2004	TTEMI	19	20.5	Alluvium	ASTM D2937, direct shear	NA	NA	NA	

Notes:

ASTM	American Society for Testing and Materials
CU	Consolidated-undrained
ft	Feet
NA	Not applicable
NP	Not possible
psf	Pounds per square foot
TTEMI	Tetra Tech EM Inc.

TABLE 8

ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/L)	Laboratory Qualifier	Laboratory Reporting Limit
BTH-07	SA-MW-18	8/4/2004	WATER	TTEMI	NA	19	VOA	Methyl-tert-butyl ether	1.3		1.0
BTH-07	SA-MW-18	8/4/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	1.3		1.0
BTH-08	SA-MW-11	8/3/2004	WATER	TTEMI	NA	NA	VOA	Methyl-tert-butyl ether	2.6		1.0
BTH-08	SA-MW-11	8/3/2004	WATER	TTEMI	NA	NA	VOA	Tetrachloroethene	5.3		1.0
BTH-08	SA-MW-11	8/3/2004	WATER	TTEMI	NA	NA	VOA	Trichloroethene	4.4		1.0
BTH-09	SA-MW-04	8/3/2004	WATER	TTEMI	NA	19	VOA	1,2-Dichlorobenzene	1		1.0
BTH-09	SA-MW-04	8/3/2004	WATER	TTEMI	NA	19	VOA	Chloroform	1.7		1.0
BTH-09	SA-MW-04	8/3/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	17		1.0
BTH-14	SA-MW-10	8/3/2004	WATER	TTEMI	NA	18	VOA	Tetrachloroethene	8.6		1.0
BTH-14	SA-MW-10	8/3/2004	WATER	TTEMI	NA	18	VOA	Trichloroethene	1.3		1.0
BTH-15	SA-MW-06	8/3/2004	WATER	TTEMI	NA	17	VOA	1,2-Dichlorobenzene	1.1		1.0
BTH-15	SA-MW-06	8/3/2004	WATER	TTEMI	NA	17	VOA	Tetrachloroethene	1.9		1.0
BTH-15	SA-MW-06	8/3/2004	WATER	TTEMI	NA	17	VOA	Trichloroethene	1.1		1.0
FCMW03	FCMW03	7/7/2004	WATER	TTEMI	NA	19.83	VOA	Tetrachloroethene	1.3		1.0
FCMW04	FCMW04	7/7/2004	WATER	TTEMI	NA	18.69	VOA	1,2-Dichloroethene (Total)	3.4		1.0
FCMW04	FCMW04	7/7/2004	WATER	TTEMI	NA	18.69	VOA	cis-1,2-Dichloroethene	2.9		1.0
FCMW04	FCMW04	7/7/2004	WATER	TTEMI	NA	18.69	VOA	Tetrachloroethene	6.5		1.0
FCMW04	FCMW04	7/7/2004	WATER	TTEMI	NA	18.69	VOA	Trichloroethene	7.8		1.0
FC-MW-04	SA-MW-21	8/4/2004	WATER	TTEMI	NA	17.5	VOA	1,2-Dichloroethene (Total)	3.1		1.0
FC-MW-04	SA-MW-21	8/4/2004	WATER	TTEMI	NA	17.5	VOA	cis-1,2-Dichloroethene	3.1		1.0
FC-MW-04	SA-MW-21	8/4/2004	WATER	TTEMI	NA	17.5	VOA	Tetrachloroethene	6		1.0
FC-MW-04	SA-MW-21	8/4/2004	WATER	TTEMI	NA	17.5	VOA	Trichloroethene	10		1.0
FCMW05	FCMW05	7/7/2004	WATER	TTEMI	NA	18.18	VOA	Tetrachloroethene	3.5		1.0
FCMW05	FCMW05	7/7/2004	WATER	TTEMI	NA	18.18	VOA	Trichloroethene	1.8		1.0
FC-MW-05	SA-MW-19	8/4/2004	WATER	TTEMI	SA-MW-1999	17.5	VOA	Tetrachloroethene	6.9		1.0
FC-MW-05	SA-MW-19	8/4/2004	WATER	TTEMI	SA-MW-1999	17.5	VOA	Trichloroethene	1.9		1.0
FC-MW-05	SA-MW-1999	8/4/2004	WATER	TTEMI	SA-MW-19	17.5	VOA	1,2,3-Trichlorobenzene	1.4		1.0
FC-MW-05	SA-MW-1999	8/4/2004	WATER	TTEMI	SA-MW-19	17.5	VOA	1,2,4-Trichlorobenzene	1.1		1.0
FC-MW-05	SA-MW-1999	8/4/2004	WATER	TTEMI	SA-MW-19	17.5	VOA	Hexachloro-1,3-butadiene	1.6		1.0
FC-MW-05	SA-MW-1999	8/4/2004	WATER	TTEMI	SA-MW-19	17.5	VOA	Tetrachloroethene	7.2		1.0
FC-MW-05	SA-MW-1999	8/4/2004	WATER	TTEMI	SA-MW-19	17.5	VOA	Trichloroethene	2.2		1.0
FC-MW-09	SA-MW-17	8/4/2004	WATER	TTEMI	NA	18.5	VOA	Chloroform	1		1.0
FC-MW-09	SA-MW-17	8/4/2004	WATER	TTEMI	NA	18.5	VOA	Tetrachloroethene	18		1.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	1,2,4-Trimethylbenzene	28		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	1,2-Dichloroethane	2.1		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	1,3,5-Trimethylbenzene	3.1		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	Benzene	81		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	Ethylbenzene	6.4		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	Isopropylbenzene (Cumene)	4.4		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	m&p-Xylene	6		4.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	Methyl-tert-butyl ether	110		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	Naphthalene	57		20.
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	n-Butylbenzene	2.1		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	o-Xylene	14		2.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	VOA	Xylene (Total)	20		6.0
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	SVOA	Acenaphthene	27		10.
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	SVOA	Acenaphthylene	210		100

TABLE 8

ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/L)	Laboratory Qualifier	Laboratory Reporting Limit
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	SVOA	Fluorene	14		10.
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	SVOA	Naphthalene	39		10.
FC-MW-12	SA-MW-07	8/3/2004	WATER	TTEMI	NA	18.5	SVOA	Phenanthrene	40		10.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	1,2,4-Trimethylbenzene	16		5.0
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	1,3,5-Trimethylbenzene	5		5.0
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	Benzene	7.2		5.0
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	Ethylbenzene	9.2		5.0
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	m&p-Xylene	13		10.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	Naphthalene	430		50.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	o-Xylene	7.4		5.0
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	VOA	Xylene (Total)	21		15.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	SVOA	2-Methylnaphthalene	73		10.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	SVOA	Acenaphthene	26		10.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	SVOA	Acenaphthylene	13		10.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	SVOA	Fluorene	16		10.
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	SVOA	Naphthalene	240		100
FC-MW-15	SA-MW-09	8/3/2004	WATER	TTEMI	NA	17	SVOA	Phenanthrene	12		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	1,2,4-Trimethylbenzene	74		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	1,3,5-Trimethylbenzene	22		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Acetone	100		100
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Benzene	74		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Chloroform	19		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Ethylbenzene	130		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	m&p-Xylene	140		20.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Methylene chloride	19		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Naphthalene	2900		500
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	o-Xylene	81		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Styrene	14		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Toluene	130		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	VOA	Xylene (Total)	220		30.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	SVOA	2-Methylnaphthalene	530	J	1000
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	SVOA	Acenaphthene	42		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	SVOA	Acenaphthylene	89		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	SVOA	Fluorene	50		10.
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	SVOA	Naphthalene	2600		1000
PRBB-10	SA-MW-13	8/3/2004	WATER	TTEMI	NA	34	SVOA	Phenanthrene	32		10.
PRBB-11	SA-MW-05	8/3/2004	WATER	TTEMI	NA	35	VOA	1,2-Dichloroethene (Total)	1.5		1.0
PRBB-11	SA-MW-05	8/3/2004	WATER	TTEMI	NA	35	VOA	cis-1,2-Dichloroethene	1.5		1.0
PRBB-11	SA-MW-05	8/3/2004	WATER	TTEMI	NA	35	VOA	Methyl-tert-butyl ether	4.1		1.0
PRBB-11	SA-MW-05	8/3/2004	WATER	TTEMI	NA	35	VOA	Tetrachloroethene	1.1		1.0
PRBB-17D	SA-MW-02	8/2/2004	WATER	TTEMI	NA	38	VOA	Acetone	100		10.
PRBB-7	SA-MW-01	8/2/2004	WATER	TTEMI	NA	39	VOA	Chloroform	1.7		1.0
PRBB-7	SA-MW-01	8/2/2004	WATER	TTEMI	NA	39	VOA	Naphthalene	13		10.
PRBB-7	SA-MW-01	8/2/2004	WATER	TTEMI	NA	39	VOA	Tetrachloroethene	30		1.0
TTMW-02	SA-MW-12	8/4/2004	WATER	TTEMI	NA	27.5	VOA	Acetone	77		10.
TTMW-04	SA-MW-15	8/4/2004	WATER	TTEMI	SA-MW-1599	28	VOA	Chloroform	1.5		1.0
TTMW-04	SA-MW-15	8/4/2004	WATER	TTEMI	SA-MW-1599	28	VOA	Tetrachloroethene	7.8		1.0

TABLE 8

ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/L)	Laboratory Qualifier	Laboratory Reporting Limit
TTMW-04	SA-MW-1599	8/4/2004	WATER	TTEMI	SA-MW-15	28	VOA	Chloroform	1.6		1.0
TTMW-04	SA-MW-1599	8/4/2004	WATER	TTEMI	SA-MW-15	28	VOA	Tetrachloroethene	8.2		1.0
TTMW-05	SA-MW-14	8/4/2004	WATER	TTEMI	NA	32.5	VOA	Tetrachloroethene	1.8		1.0
TTMW-08	SA-MW-08	8/3/2004	WATER	TTEMI	NA	33	VOA	Chloroform	1.7		1.0
TTMW-08	SA-MW-08	8/3/2004	WATER	TTEMI	NA	33	VOA	Tetrachloroethene	30		1.0
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	1,2,4-Trimethylbenzene	38		20.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	1,3,5-Trimethylbenzene	10	J	20.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	Ethylbenzene	8.4	J	20.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	m&p-Xylene	6.6	J	40.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	Naphthalene	1300		200
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	o-Xylene	13	J	20.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	sec-Butylbenzene	32		20.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	Tetrachloroethene	33		20.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	VOA	Xylene (Total)	20	J	60.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	2-Methylnaphthalene	510		200
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Acenaphthene	36		10.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Acenaphthylene	170	J	200
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Anthracene	14		10.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Dibenzofuran	13		10.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Fluorene	69		10.
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Naphthalene	1100		200
TTMW-10	SA-MW-16	8/4/2004	WATER	TTEMI	NA	29	SVOA	Phenanthrene	54		10.
TTMW-11	SA-MW-20	8/5/2004	WATER	TTEMI	NA	33	VOA	Acetone	13		10.
TTMW-11	SA-MW-20	8/5/2004	WATER	TTEMI	NA	33	VOA	Tetrachloroethene	3.2		1.0
TTSB-09	SA-GW-01	4/27/2004	WATER	TTEMI	NA	18	VOA	Chloromethane	1.4		1.0
TTSB-09	SA-GW-01	4/27/2004	WATER	TTEMI	NA	18	VOA	Naphthalene	6		5.0
TTSB-09	SA-GW-01	4/27/2004	WATER	TTEMI	NA	18	VOA	Tetrachloroethene	2.7		1.0
TTSB-11	SA-GW-03	5/4/2004	WATER	TTEMI	NA	19	VOA	Naphthalene	19		5.0
TTSB-11	SA-GW-03	5/4/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	5.9		1.0
TTSB-11	SA-GW-03	5/4/2004	WATER	TTEMI	NA	19	VOA	Trichloroethene	1.5		1.0
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	VOA	Naphthalene	72		5.0
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	SVOA	2-Methylnaphthalene	44		10.
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	SVOA	Acenaphthene	12		10.
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	SVOA	Acenaphthylene	29		10.
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	SVOA	Fluorene	37		10.
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	SVOA	Naphthalene	38		10.
TTSB-14	SA-GW-02	5/4/2004	WATER	TTEMI	NA	19	SVOA	Phenanthrene	48		10.
TTSB-16	SA-GW-04	5/6/2004	WATER	TTEMI	NA	9	VOA	Acetone	12		10.
TTSB-16	SA-GW-04	5/6/2004	WATER	TTEMI	NA	9	VOA	Chloroform	6.7		1.0
TTSB-16	SA-GW-04	5/6/2004	WATER	TTEMI	NA	9	VOA	Tetrachloroethene	1		1.0
TTSB-16	SA-GW-04	5/6/2004	WATER	TTEMI	NA	9	VOA	Trichloroethene	1.5		1.0
TTSB-16	SA-GW-05	5/6/2004	WATER	TTEMI	NA	22	VOA	1,2-Dichloroethene (Total)	1.1		1.0
TTSB-16	SA-GW-05	5/6/2004	WATER	TTEMI	NA	22	VOA	Acetone	19		10.
TTSB-16	SA-GW-05	5/6/2004	WATER	TTEMI	NA	22	VOA	cis-1,2-Dichloroethene	1.1		1.0
TTSB-16	SA-GW-05	5/6/2004	WATER	TTEMI	NA	22	VOA	Methyl-tert-butyl ether	1.5		1.0
TTSB-16	SA-GW-05	5/6/2004	WATER	TTEMI	NA	22	VOA	Tetrachloroethene	2.9		1.0
TTSB-16	SA-GW-05	5/6/2004	WATER	TTEMI	NA	22	VOA	Trichloroethene	2.8		1.0

TABLE 8

ORGANIC COMPOUNDS DETECTED IN GROUNDWATER DURING SA

POUDRE RIVER SITE

Point Name	Sample ID	Sample Date	Sample Media	Sample Company	Duplicate ID	Sample Depth (ft)	Analytical Group	Chemical Name	Laboratory Concentration (µg/L)	Laboratory Qualifier	Laboratory Reporting Limit
TTSB-17	SA-GW-06	5/7/2004	WATER	TTEMI	NA	17.5	VOA	Chloromethane	2		1.0
TTSB-17	SA-GW-06	5/7/2004	WATER	TTEMI	NA	17.5	VOA	Methyl-tert-butyl ether	4.8		1.0
TTSB-17	SA-GW-06	5/7/2004	WATER	TTEMI	NA	17.5	VOA	Tetrachloroethene	3.5		1.0
TTSB-18	SA-GW-07	5/10/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	4.9		1.0
TTSB-18	SA-GW-07	5/10/2004	WATER	TTEMI	NA	19	VOA	Trichloroethene	4		1.0
TTSB-19	SA-GW-08	5/10/2004	WATER	TTEMI	NA	19	VOA	Acetone	28		10.
TTSB-19	SA-GW-08	5/10/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	21		1.0
TTSB-20	SA-GW-09	5/11/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	4.7		1.0
TTSB-20	SA-GW-09	5/11/2004	WATER	TTEMI	NA	19	VOA	Trichloroethene	3		1.0
TTSB-20	SA-GW-10	5/11/2004	WATER	TTEMI	NA	19	VOA	Tetrachloroethene	4.3		1.0
TTSB-20	SA-GW-10	5/11/2004	WATER	TTEMI	NA	19	VOA	Trichloroethene	2.8		1.0

Notes:

ft	Feet
J	Estimated value
µg/L	Microgram per liter
NA	Not applicable
SVOA	Semivolatile organic analysis
TTEMI	Tetra Tech EM Inc
VOA	Volatile organic analysis

TABLE 9

RATIO OF (B+T)/(E+X) BY SAMPLE LOCATION

POUDRE RIVER SITE

Sample Location	(B+T)/(E+X) ratio
MGPMW-1S	3.76
MW-2	7.79
MGPMW-3S	0.12
FC-MW-12	3.07
FC-MW-15	0.24
Average:	3.00

Notes:

B Benzene
E Ethylbenzene
T Toluene
X Xylene

TABLE 10

COST COMPARISON BETWEEN A TRADITIONAL APPROACH AND THE TRIAD APPROACH

POUDRE RIVER SITE

Task Description	Labor Hours	Labor Costs at $75/Hour	Subcontractor Costs	ODCs[b]	Actual Cost Using the Triad vs. Estimated Traditional Costs
Background review, project planning, preparation of the work plan, and site visit for the first mobilization of the TBA.	**400**	**$30,000**	**N/A**	**$500**	**$30,500**
	300	$22,500	N/A	$500	$23,000
Background review, project planning, preparation of the work plan, and site visit for the second mobilization[a] of the TBA. The second mobilization is assumed necessary to collected data for data gaps identified during the first mobilization of the TBA.	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	300	$22,500	N/A	$500	$23,000
First mobilization for the TBA. Field investigation including pre-field work and post-field paperwork	**650**	**$48,750**	**$45,00 Driller $12,000 Geophysics $800 IDW**	**$10,000**	**$116,550**
	450	$33,750	$30,000 Driller $800 IDW	$8,000	$72,550
Second mobilization for the TBA. Field investigation including pre-field work and post-field paperwork,[a]	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	300	$22,500	$20,000 Driller $800 IDW	$6,000	$49,300
Sample analysis, interaction with labs, and data validation for the first TBA mobilization.	**80**	**$6,000**	**Soil Gas Survey $65,000** **Mobile Laboratory (provided by EPA Region 8)** **$17,500 Fixed lab VOC, SVOC, TPH, Pest/PCB, and metal analyses** **CLP lab analyses (provided by EPA Region 8)**	**N/A** **N/A** **N/A** **N/A**	**$71,000** **$0** **$17,500** **$0**
	160	$12,000	$86,000 Fixed lab VOC, SVOC, TPH, Pest/PCB, and metal analyses	N/A	$98,000

TABLE 10

COST COMPARISON BETWEEN A TRADITIONAL APPROACH AND THE TRIAD APPROACH

POUDRE RIVER SITE

Task Description	Labor Hours	Labor Costs at $75/Hour	Subcontractor Costs	ODCs[b]	Actual Cost Using the Triad vs. Estimated Traditional Costs
Sample analysis, interaction with labs, and data validation for the second mobilization[a] to address data gaps identified during the initial phase of the TBA	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	80	$6,000	$26,000 Fixed lab VOC, SVOC, TPH, Pest/PCB, and metal analyses	N/A	$32,000
Data evaluation, TBA report preparation, and file closeout for the first mobilization	**300**	**$22,500**	**N/A**	**$1,000**	**$23,500**
	200	$15,000	N/A	$1,000	$16,000
Data evaluation, TBA report preparation, and file closeout for the second mobilization[a]	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	200	$15,000	N/A	$1,000	$16,000
Background review, project planning, preparation of the work plan, and site visit for the first mobilization of the SA.	**300**	**22,500**	**N/A**	**$500**	**$23,000**
	250	$18,750	N/A	$500	$19,250
Background review, project planning, preparation of work plan, and site visit, for the second mobilization[a] of the SA. The second mobilization is assumed necessary to collect data for data gaps identified during the initial phase of the SA.	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	250	$18,750	N/A	$500	$19,250
First mobilization for the SA Field Investigation including pre-field work and post-field paperwork	**650**	**$48,750**	**$85,00 Driller $24,000 Geophysics $1,600 IDW**	**$16,000**	**$116,550**
	450	$33,750	$85,000 Driller $1,600 IDW	$16,000	$72,550
Second mobilization for the SA. Field Investigation including pre-field work and post-field paperwork[a]	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	300	$22,500	$40,000 Driller $800 IDW	$6,000	$69,300
Sample analysis, interaction with labs, and data validation for the first mobilization of the SA.	**250**	**$18,750**	**$28,500 Fixed lab VOC, SVOC analyses**	**N/A**	**$71,000**
	250	$18,750	$28,500 Fixed lab VOC, SVOC analyses	N/A	$71,000

TABLE 10

COST COMPARISON BETWEEN A TRADITIONAL APPROACH AND THE TRIAD APPROACH

POUDRE RIVER SITE

Task Description	Labor Hours	Labor Costs at $75/Hour	Subcontractor Costs	ODCs[b]	Actual Cost Using the Triad vs. Estimated Traditional Costs
Sample analysis, interaction with labs, and data validation for the second mobilization of the SA. The second mobilization is assumed necessary to collect data for data gaps identified during the initial phase of the SA.	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	250	$18,750	$28,500 Fixed lab VOC, SVOC analyses	N/A	$71,000
Data evaluation, SA report preparation, and file closeout for the first mobilization	**200**	**$15,000**	**N/A**	**$1,000**	**$16,000**
	200	$15,000	N/A	$1,000	$16,000
Data evaluation, SA report preparation, and file closeout for the second mobilization	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
	200	$15,000	N/A	$1,000	$16,000
Consultations about use of Triad approach	**200**	**$15,000**	**N/A**	**$1,500**	**$16,500**
	N/A	N/A	N/A	N/A	N/A
Totals	**3,030**	**$227,250**	**$279,400**	**$30,500**	**$537,150**
	4,140	310,500	348,000	42,000	700,500
Percent savings using the Triad approach	36%	36%	25%	27%	30%

Notes: **TRIAD** Costs associated with the Triad approach

TRADITIONAL Estimated costs from a traditional approach

a A second mobilization and sampling event was assumed as a requirement under a traditional approach.

b ODCs: Includes copies, phone, sample shipment, computer time, field equipment rentals and supplies including test kits and fluorescence detector for TPH and PAH field analyses, travel, per diem, vehicle rental, gasoline etc.

IDW Investigation-derived wastes

N/A Not applicable

ODC Other direct cost

PAH Polynuclear aromatic hydrocarbon

SA Site Assessment

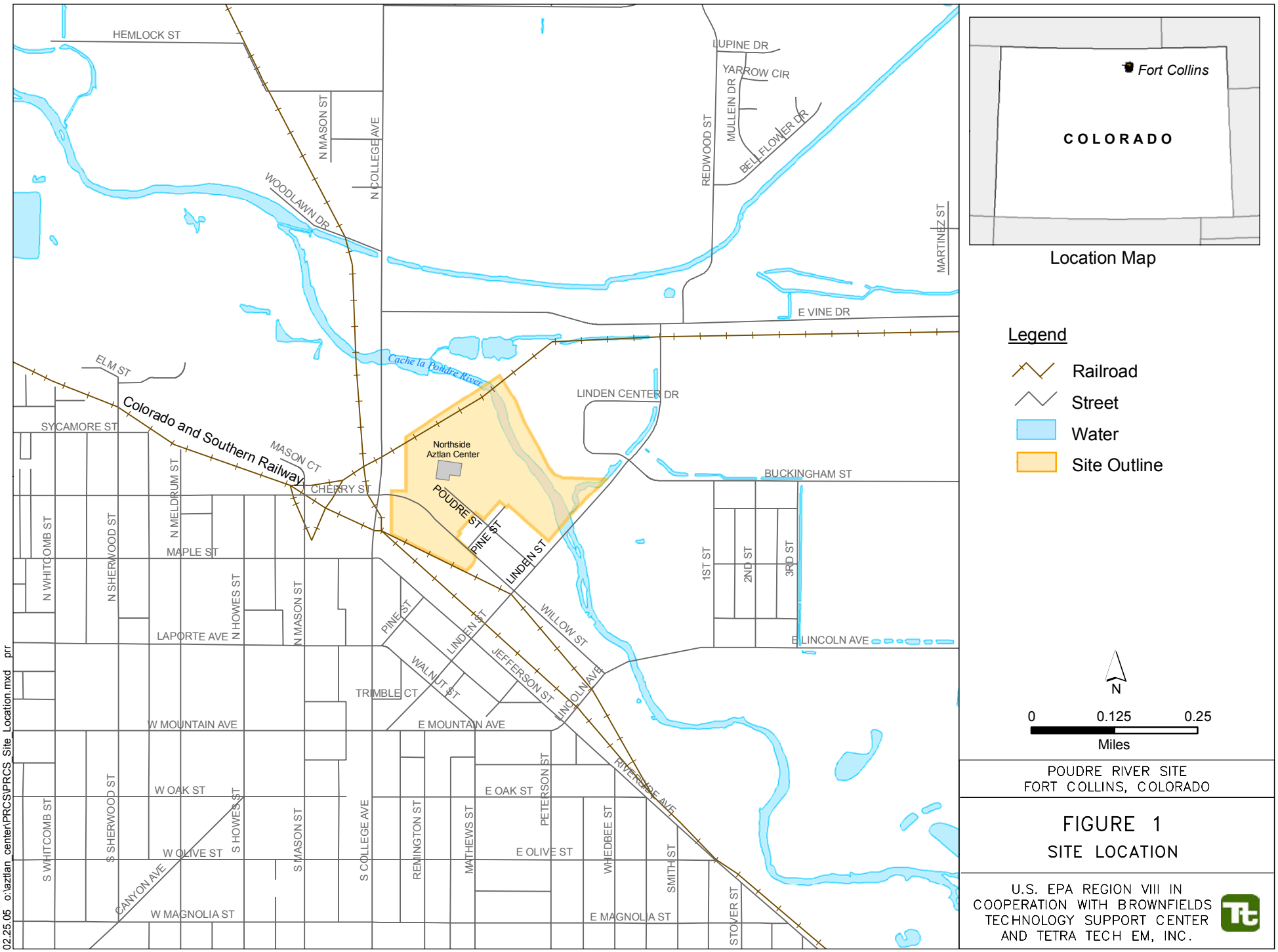
SVOC Semivolatile organic compound

TBA Targeted Brownfields Assessment

TPH Total petroleum hydrocarbon

VOC Volatile organic compound

FIGURES



Location Map

Legend

- Railroad
- Street
- Water
- Site Outline

N

0 0.125 0.25

Miles

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 1
SITE LOCATION

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

List of Area Structures

1 - Historical Power Plant Site
2 - CSU Engines and Energy Conversion Lab
3 - Rapid Lube
4 - The Family Center
5 - Scout 66 Gas Station
6 - A Classic Touch
7 - Schrader Oil Company Maintenance Facility
8 - Schrader Oil Company Bulk Plant
9 - Historical Gas Plant
10 - Giddings Machine Shop
11 - Interstate Batteries
12 - Clear Cut Glass
13 - Education and Life Training Center
14 - El Burrito
15 - Ranchway
16 - Northern Colorado Feeders Supply
17 - Ranchway
18 - Schrader Building
19 - United Way Building
20 - Public Service Company
21 - Playground
A - Northside Aztlan Center
G - Gas Holders
R - Residential

Cache La Poudre River

College Avenue

Pine Street

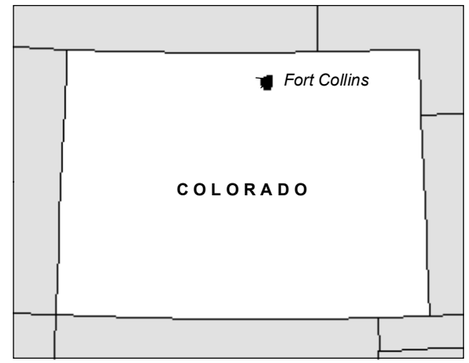
Linden Street

Willow Street

Flow Direction

A

A'



Location Map

Legend

- Cross-Section Transect
- Paved Area
- Recreation Path
- Railroad
- Proposed Barrier Wall
- Proposed Barrier Wall Easement
- Proposed IWTP
- Building
- Approximate Extent of Observed Fill and Trash Debris
- Approximate Extent of Old Landfill
- Site Outline
- Former Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property

N

0 200 400
Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 2

SITE LAYOUT

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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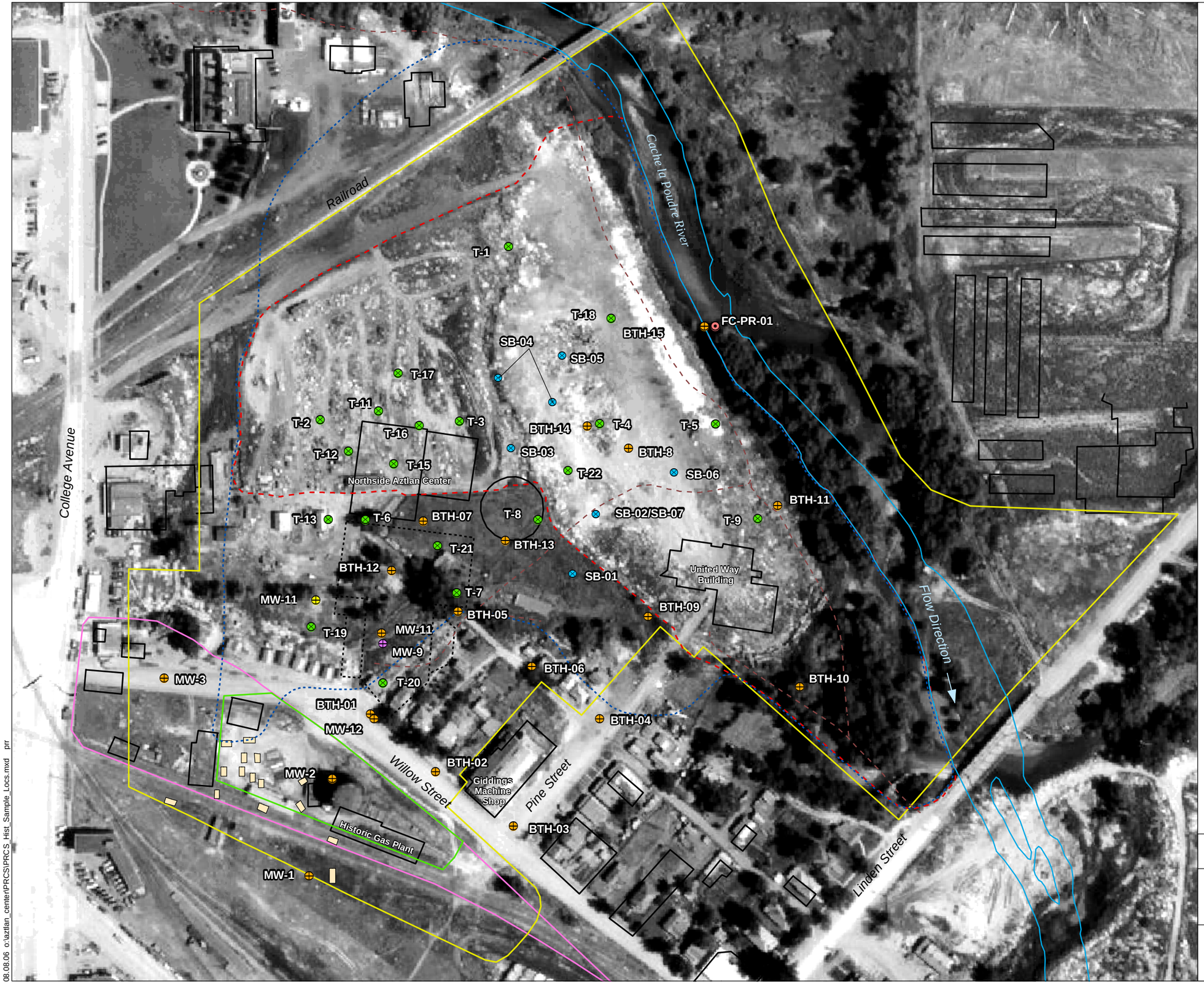

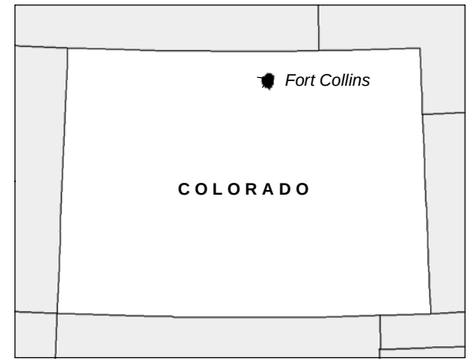

Location Map

Legend

- T-1: Terracon Bore Hole Location
- Product Sample Location
- Paragon Monitoring Well Location
- Schrader Monitoring Well Location
- Soil Boring Location
- BTH-14: Walsh Well Location
- Recreation Path
- Current River Channel
- Test Pit
- Building
- Proposed Aztlan Recreation Center
- Approximate Extent of Former Landfill
- Approximate Extent of Observed Fill and Trash Debris
- Site Outline
- Previous Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property

Note: Aerial Photo from USGS, July 14, 1951.

N

0 75 150 300

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 3

HISTORICAL SAMPLE LOCATIONS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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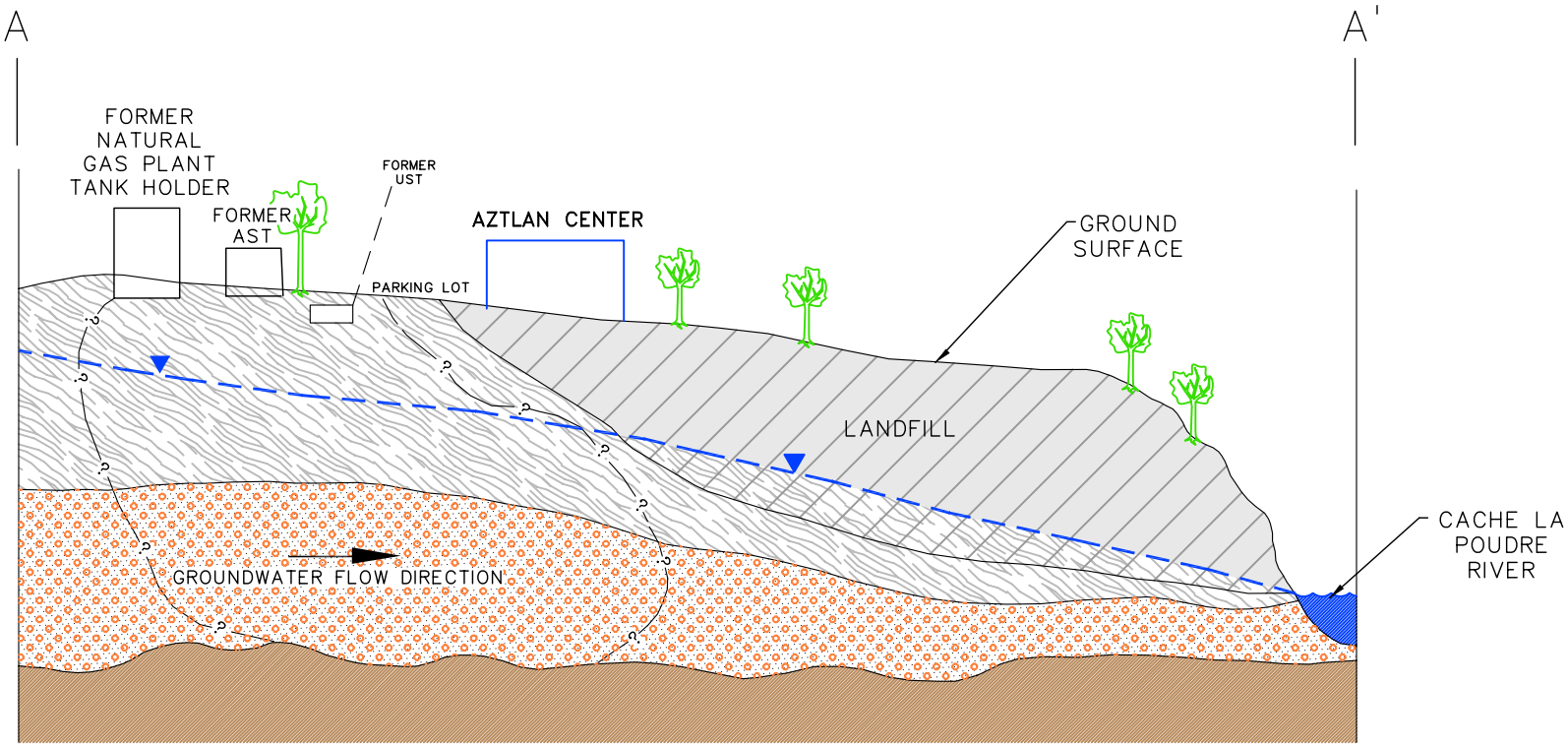

NOT TO SCALE

LEGEND

- WATER TABLE (APPROXIMATE)
- —?—?— BENZENE AND NAPTHALENE PLUME BOUNDARY
- AST ABOVEGROUND STORAGE TAMK
- UST UNDERGROUND STORAGE TANK
- POST-PINEY CREEK ALLUVIUM (UPPER HOLOCENE)
- BROADWAY ALLUVIUM (PLEISTOCENE)
- PIERRE SHALE
- LANDFILL
- CACHE LA POUDRE RIVER

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 4
PRELIMINARY CONCEPTUAL SITE MODEL DIAGRAM

U.S. EPA REGION VIII
IN COOPERATION WITH
BROWNFIELDS TECHNOLOGY SUPPORT CENTER

College Avenue

Northside Aztlan Center

Cache la Poudre River

Flow Direction

United Way Building

Giddings Machine Shop

Historic Gas Plant

Willow Street

Pine Street

Linden Street

4950

4948

4946

4944

4942

Fort Collins

COLORADO

Location Map

Legend

- Recreation Path
- Current River Channel
- Bedrock Contour (1 foot contour)
- Building
- Proposed Aztlan Recreation Center
- Historical River Channel (1906)
- Approximate Extent of Observed Fill and Trash Debris
- Landfill Outline
- Approximate Boundary of NAPL Impacts Observed in Unconsolidated Alluvium and Bedrock (dashed where inferred)
- Site Outline
- Previous Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property

Note: Bedrock surface elevations interpolated from borehole logs from previous investigation (UOS Phase I).

N

0 75 150 300

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 5

PRELIMINARY BEDROCK SURFACE CONTOUR MAP WITH FORMER RIVER CHANNEL

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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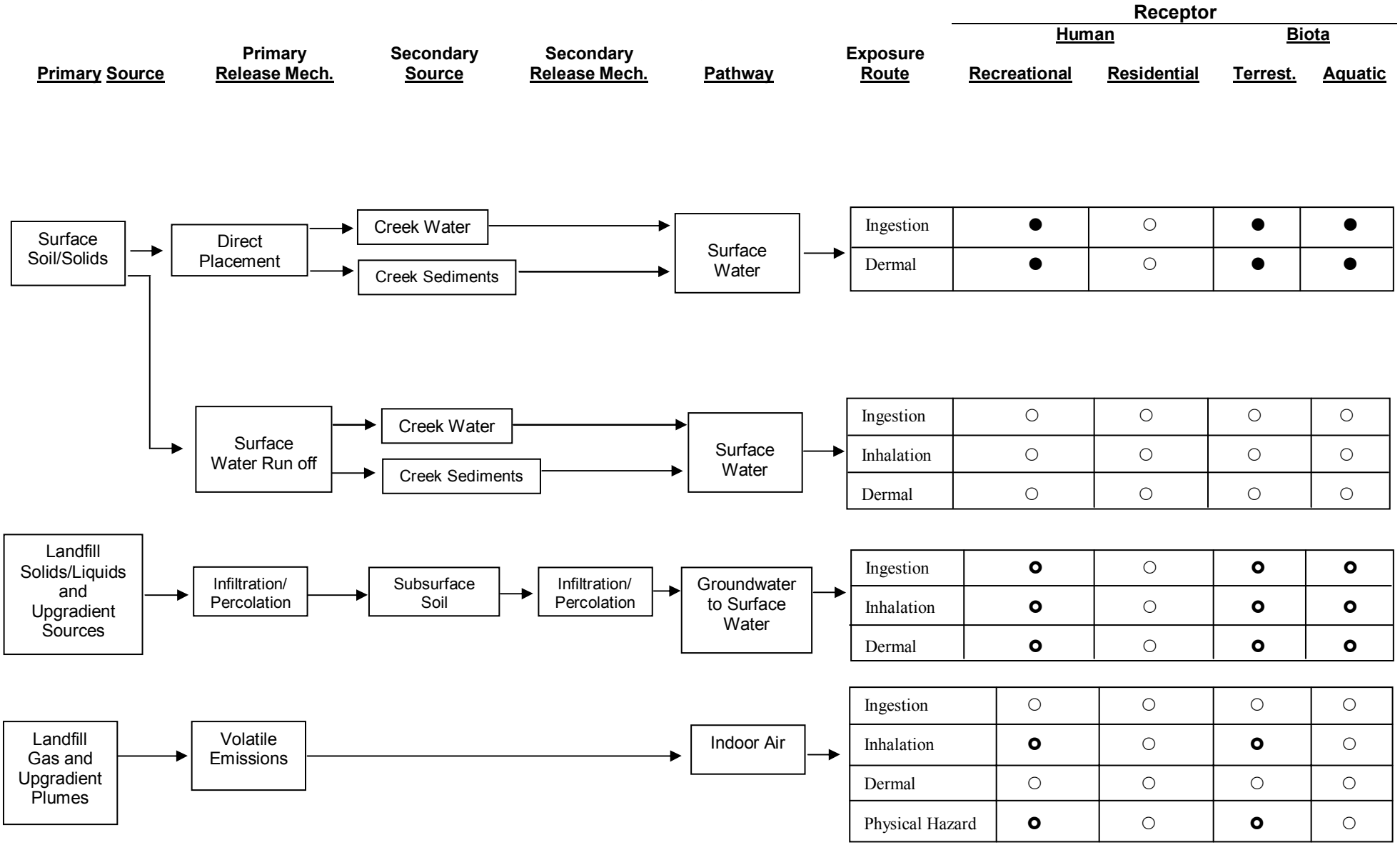
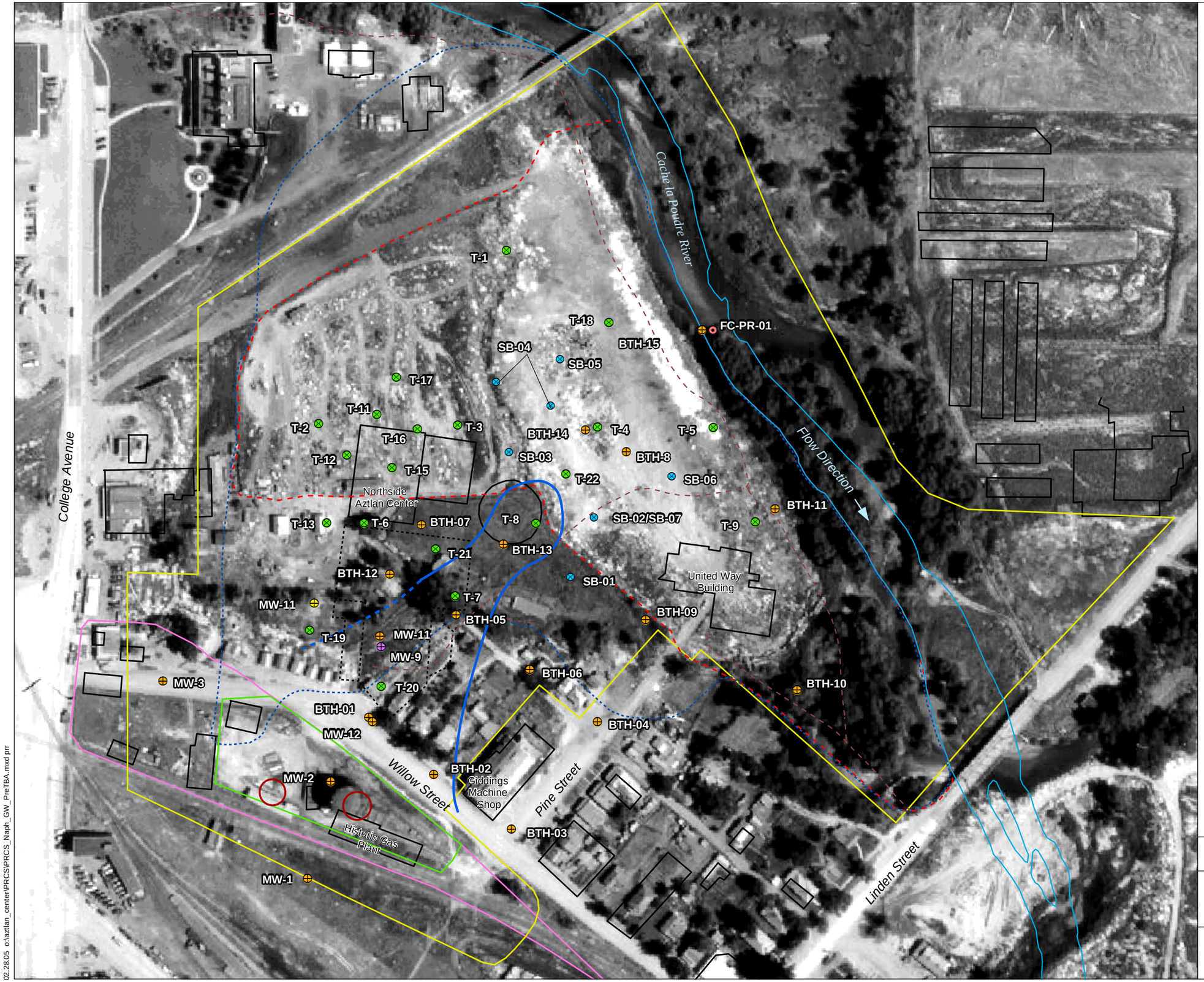
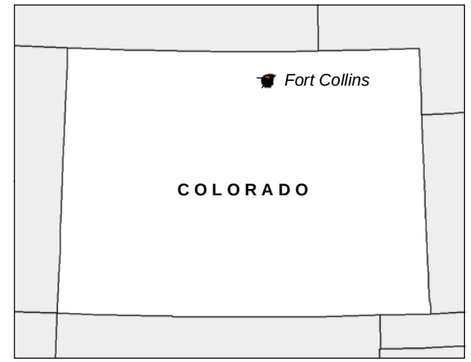
FIGURE 6
Pathway Receptor Diagram
Atzlan Center, Fort Collins



● Completed pathway
⊙ Possible complete pathway (data required)
○ Incomplete pathway





Location Map

Legend

- T-1: Terracon Bore Hole Location
- Product Sample Location
- Paragon Monitoring Well Location
- Schrader Monitoring Well Location
- Soil Boring Location
- BTH-14: Walsh Well Location
- Recreation Path
- Current River Channel
- Estimated Extent of Napthalene in Groundwater, dashed where approximate (Walsh)
- Building
- Proposed Aztlan Recreation Center
- Approximate Extent of Observed Fill and Trash Debris
- Approximate Extent of Former Landfill
- Site Outline
- Previous Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property
- Approximate Boundary of Historic Gas Holder

Note: Aerial Photo from USGS, July 14, 1951.

N

0 75 150 300

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 7

NAPHTHALENE CONCENTRATIONS IN GROUNDWATER, PRE-TBA

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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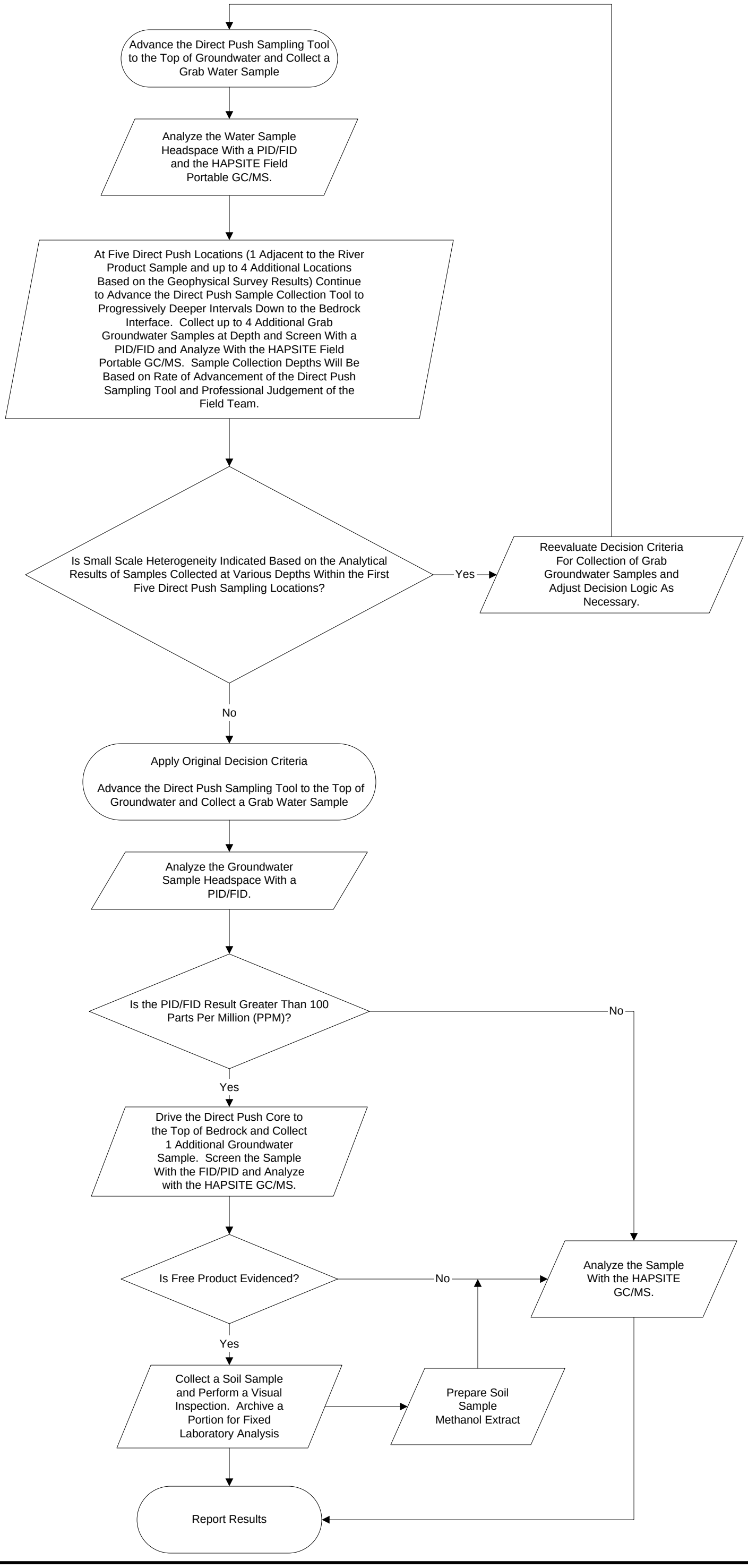
Figure 8
TBA - Sample Collection Decision Logic Diagram



Cache la Poudre River

Flow Direction

College Avenue

Northside Aztlan Center

United Way Building

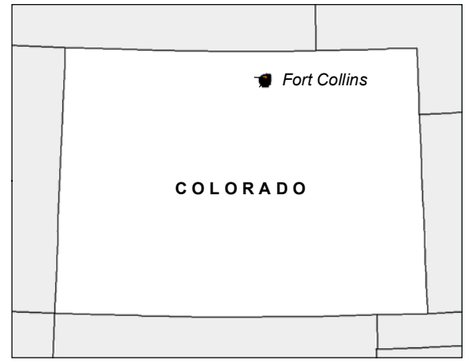
Giddings Machine Shop

Willow Street

Pine Street

Linden Street

Historic Gas Plant



Location Map

Legend

- Recreation Path
- Geophysical Surveyed Transect Lines
- Building
- Proposed Aztlan Recreation Center
- Approximate Extent of Observed Fill and Trash Debris
- Approximate Extent of Former Landfill
- Site Outline
- Previous Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property

N

0 75 150 300

Feet

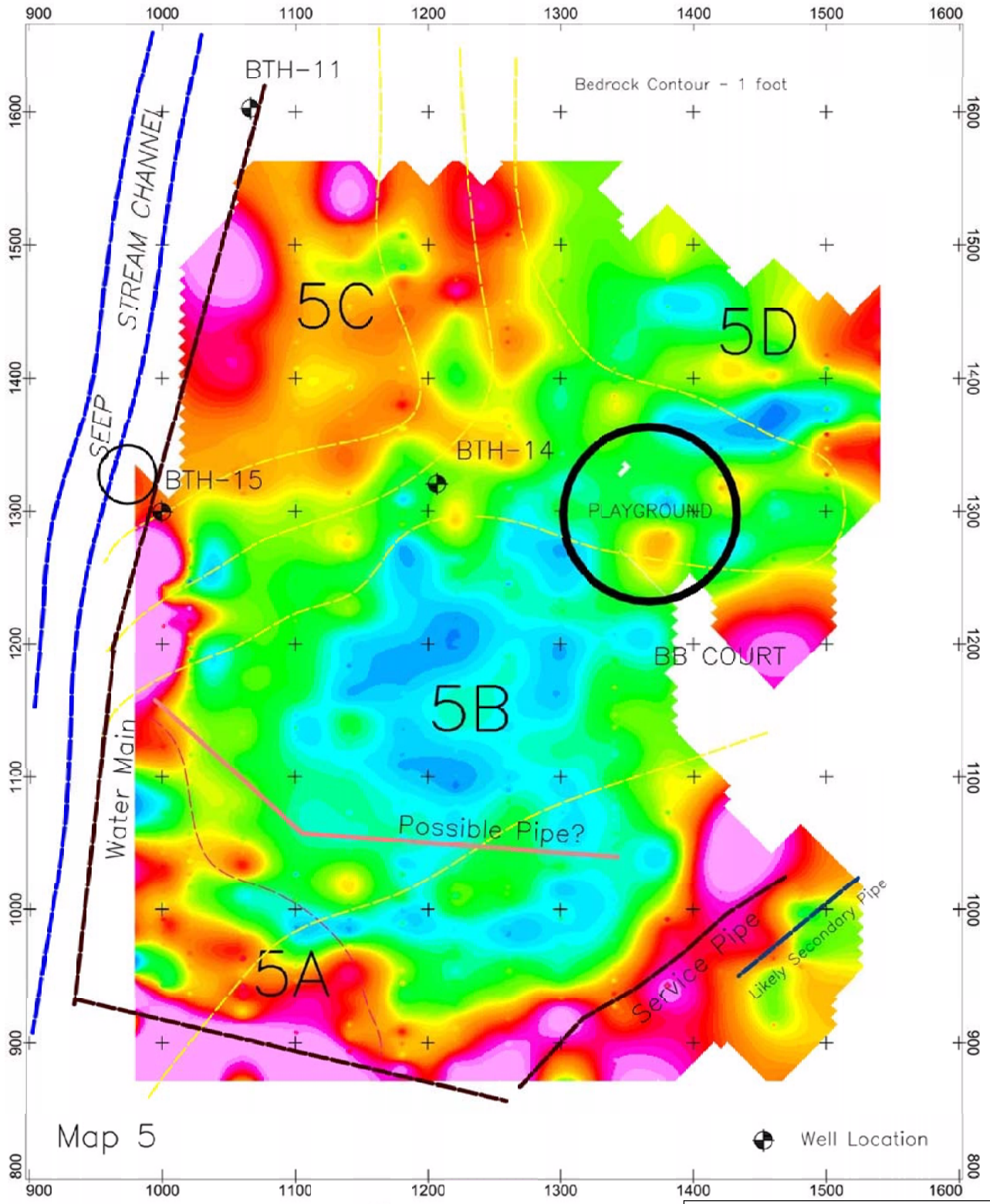
POUDRE RIVER SITE
FORT COLLINS, COLORADO

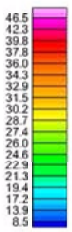
FIGURE 9

TBA – GEOPHYSICAL GRID SPACING

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

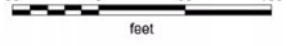
03.01.05 o:\aztlan_center\PRCS\PRCS_Geophys_Grid_Spacing.mxd prr





milliSiemens/meter

Bedrock Contour - 1 foot

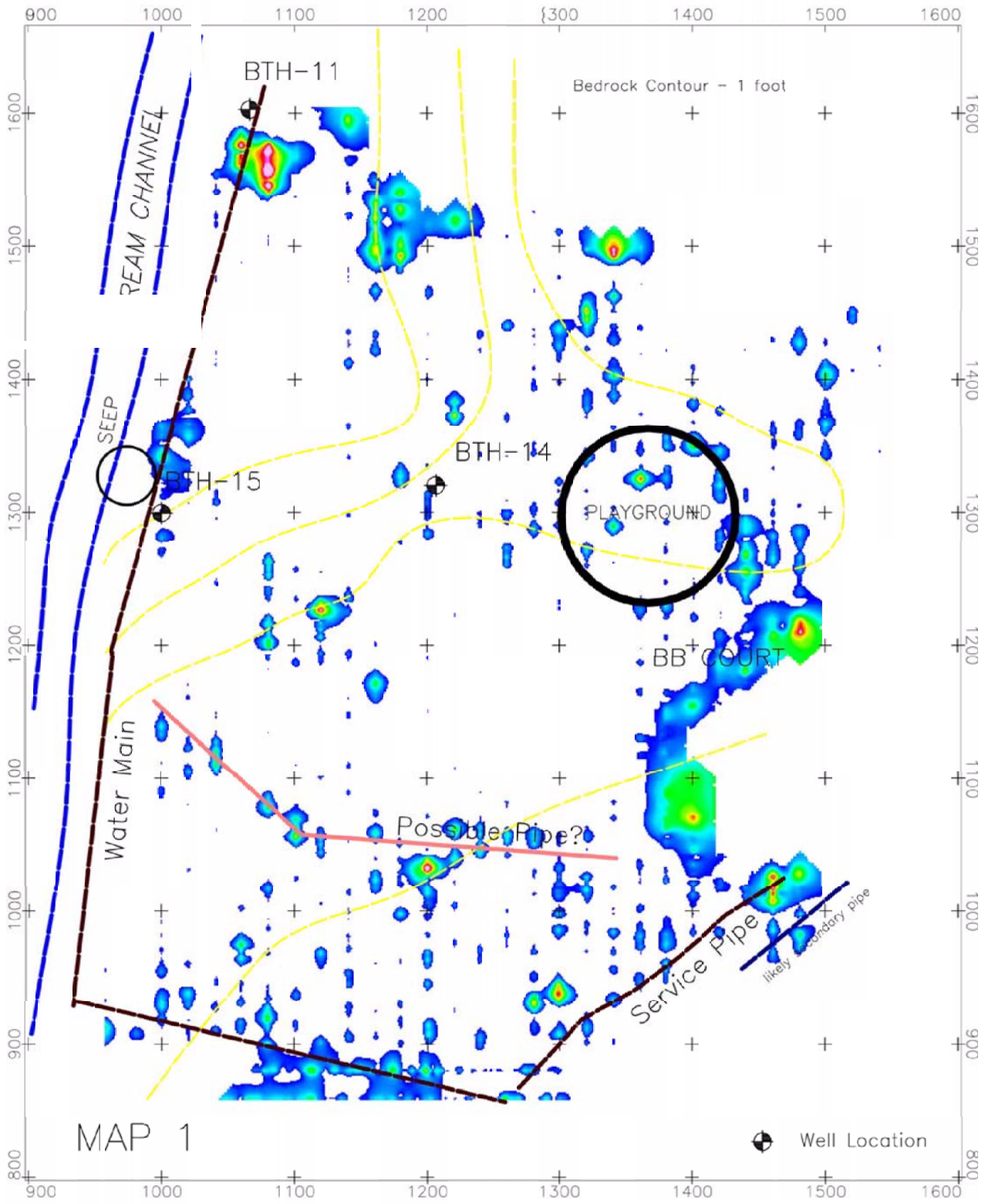


POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 10
TBA – GEOPHYSICAL ELECTROMAGNETIC SURVEY RESULTS MAP

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

03.01.05 o:\aztlan_center\PRCS\PRCS_Geophys_Results_TBA.mxd prr



Relative Response

Bedrock Contour - 1 foot

Scale 1:1000

50 0 50 100

feet

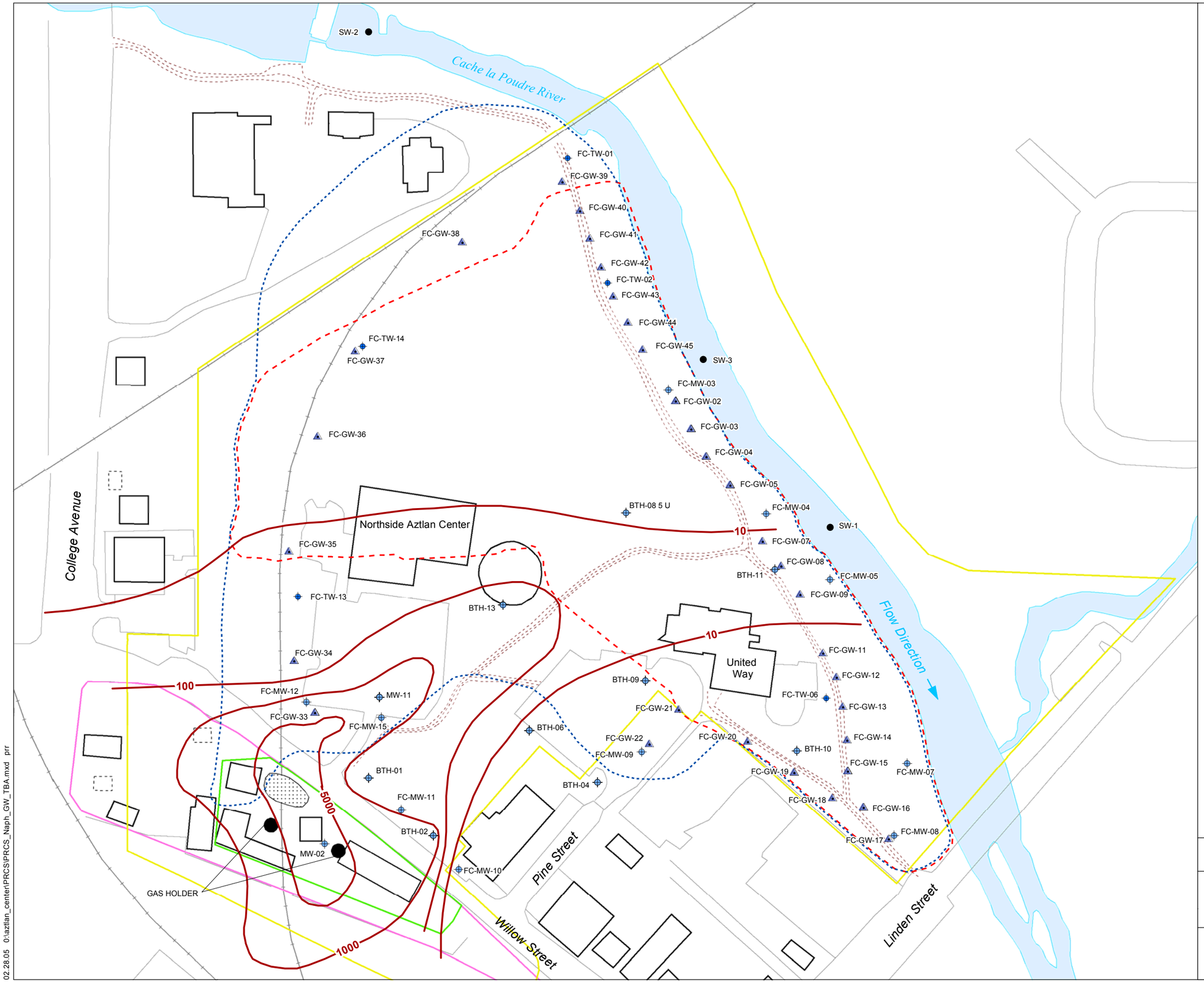
POUDRE RIVER SITE
FORT COLLINS, COLORADO

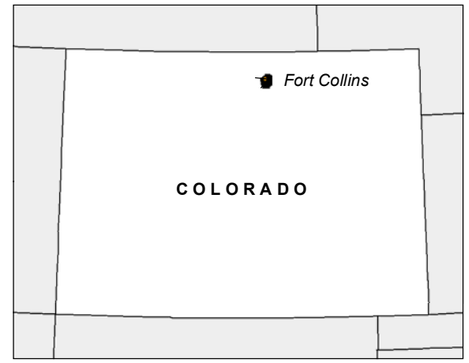
FIGURE 11

TBA – GEOPHYSICAL METAL DETECTION SURVEY RESULTS MAP

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

08.08.06 o:\aztlan_center\PRCS\PRCS_Buried_Metals_TBA.mxd prr





Location Map

Legend

- Direct Push Groundwater Grab Sample Location
- Tetra Tech EMI Inc. Small Gauge Temporary Monitoring Well
- Monitoring Well
- Surface Water Sample Location
- Naphthalene Contour
- Recreation Path
- Paved Area
- Railroad
- Building
- Approximate Extent of Observed Fill and Trash Debris
- Approximate Extent of Former Landfill
- Site Outline
- Former Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property
- Former Tar Pit
- Former Underground Storage Tank

N

0 75 150 300

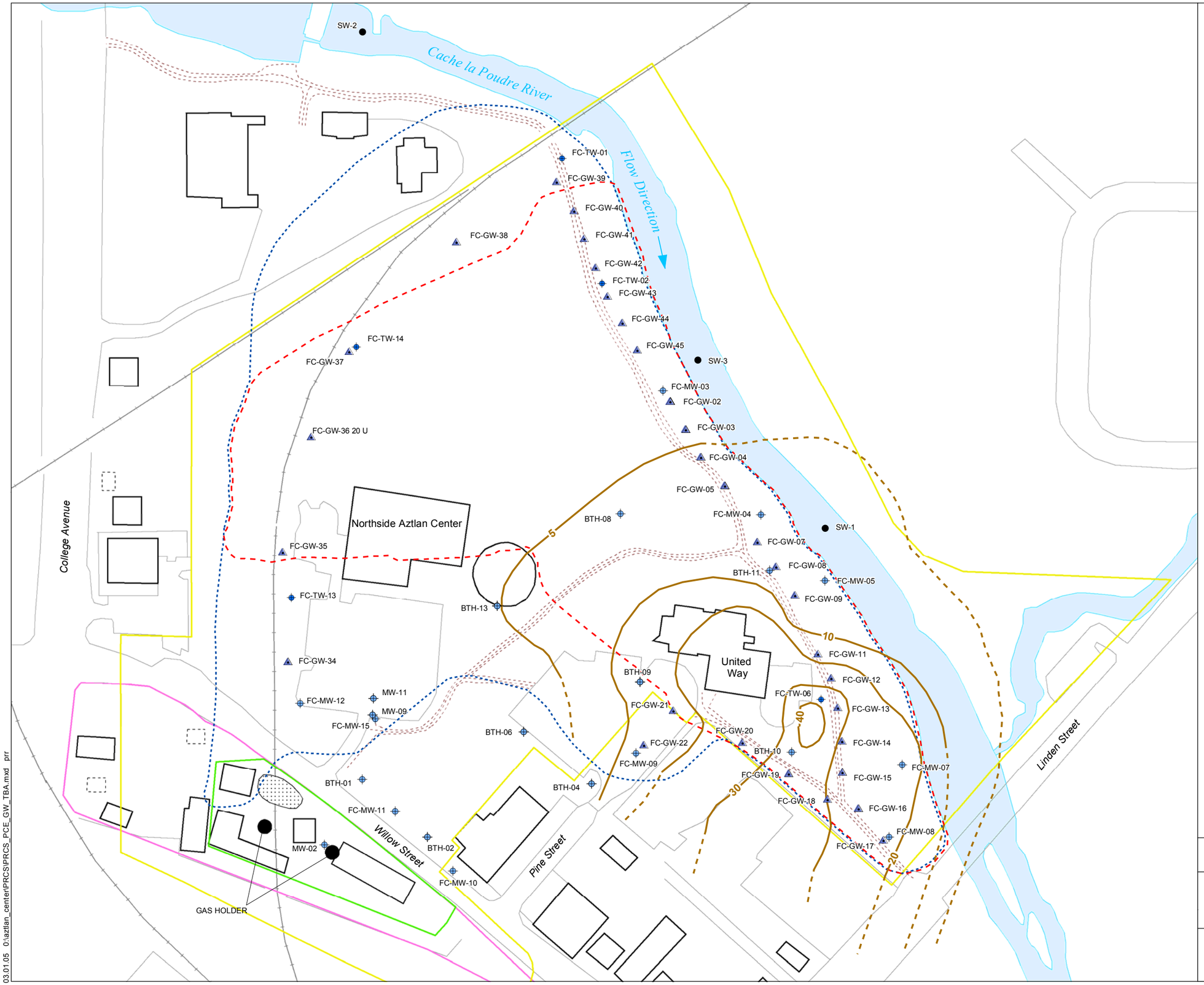
Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 12
TBA – NAPHTHALENE CONCENTRATIONS IN GROUNDWATER

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

02.28.05 0:\aztlan_center\PRCS\PRCS_Naph_GW_TBA.mxd prr



Fort Collins

COLORADO

Location Map

Legend

- Direct Push Groundwater Grab Sample Location
- Tetra Tech EM Inc. Small Gauge Temporary Monitoring Well
- Monitoring Well
- Surface Water Sample Location
- PCE Contour (dashed where approximate) 5 feet contour interval
- Recreation Path
- Paved Area
- Railroad
- Building
- Approximate Extent of Observed Fill and Trash Debris
- Approximate Extent of Former Landfill
- Site Outline
- Former Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property
- Former Tar Pit
- Former Underground Storage Tank

N

0 75 150 300

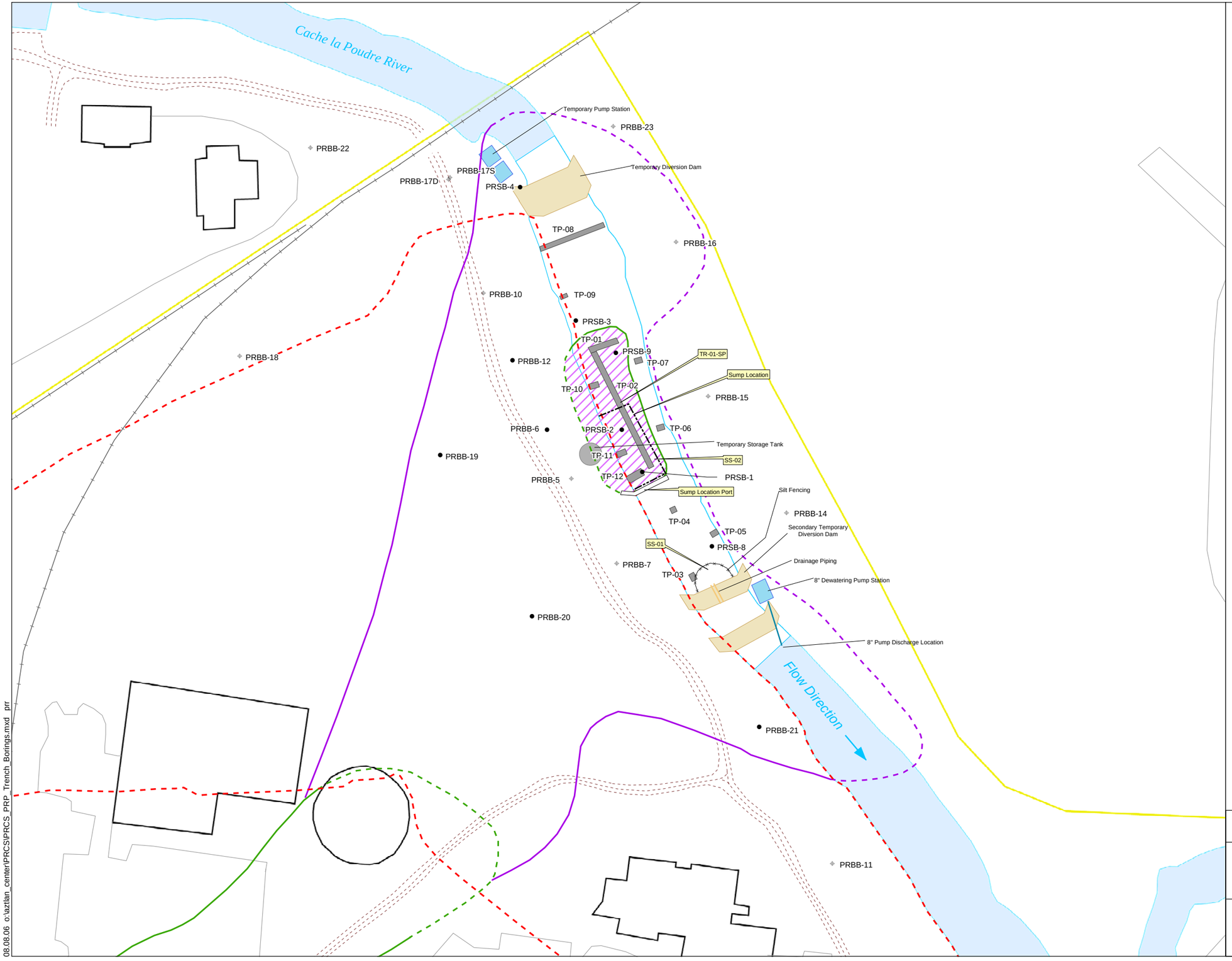
Feet

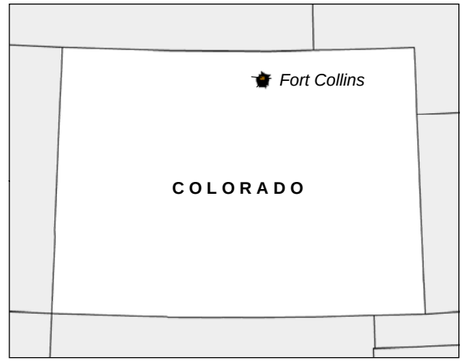
POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 13
TBA – PCE CONCENTRATIONS IN GROUNDWATER

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

03.01.05 0:\aztlan_center\PRCS\PRCS_PCE_GW_TBA.mxd prr





Location Map

Legend

- Soil Boring
- Monitoring Well
- Excel (RETEC) Test Pit
- Recreation Path
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts in Bedrock (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium (dashed where inferred)
- Paved Area
- Railroad
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium and Bedrock (dashed where inferred)
- Building
- Approximate Extent of Old Landfill
- Site Outline

N

0 100 200

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

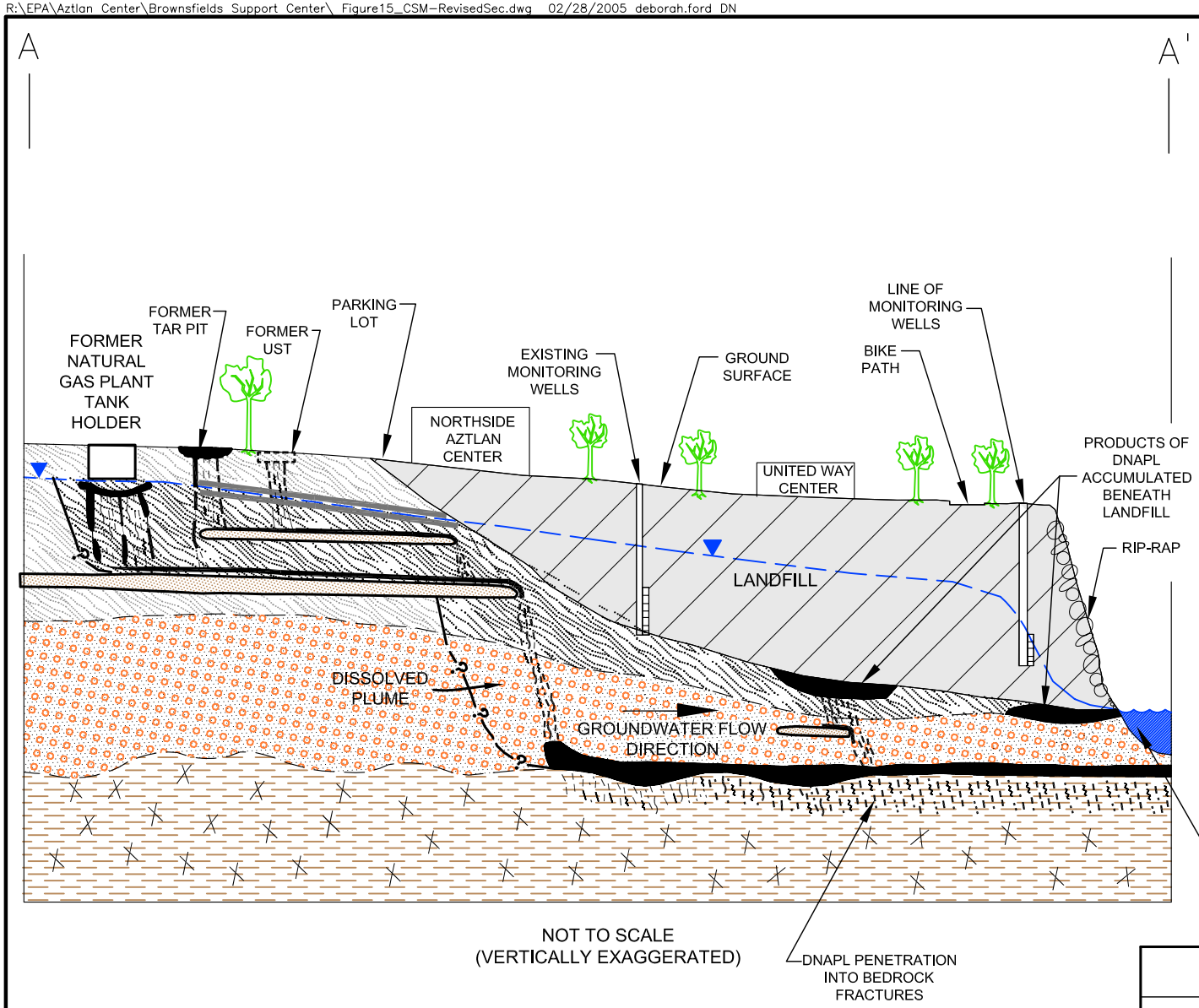
FIGURE 14

RIVER CHANNEL INVESTIGATION TRENCHING AND BORING LOCATIONS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

08.08.06 o:\aztlan_center\PRCS\PRCS_PRP_Trench_Borings.mxd prr

R:\EPA\Aztlan Center\Brownsfields Support Center\ Figure15_CSM-RevisedSec.dwg 02/28/2005 deborah.ford DN



NOT TO SCALE
(VERTICALLY EXAGGERATED)

LEGEND

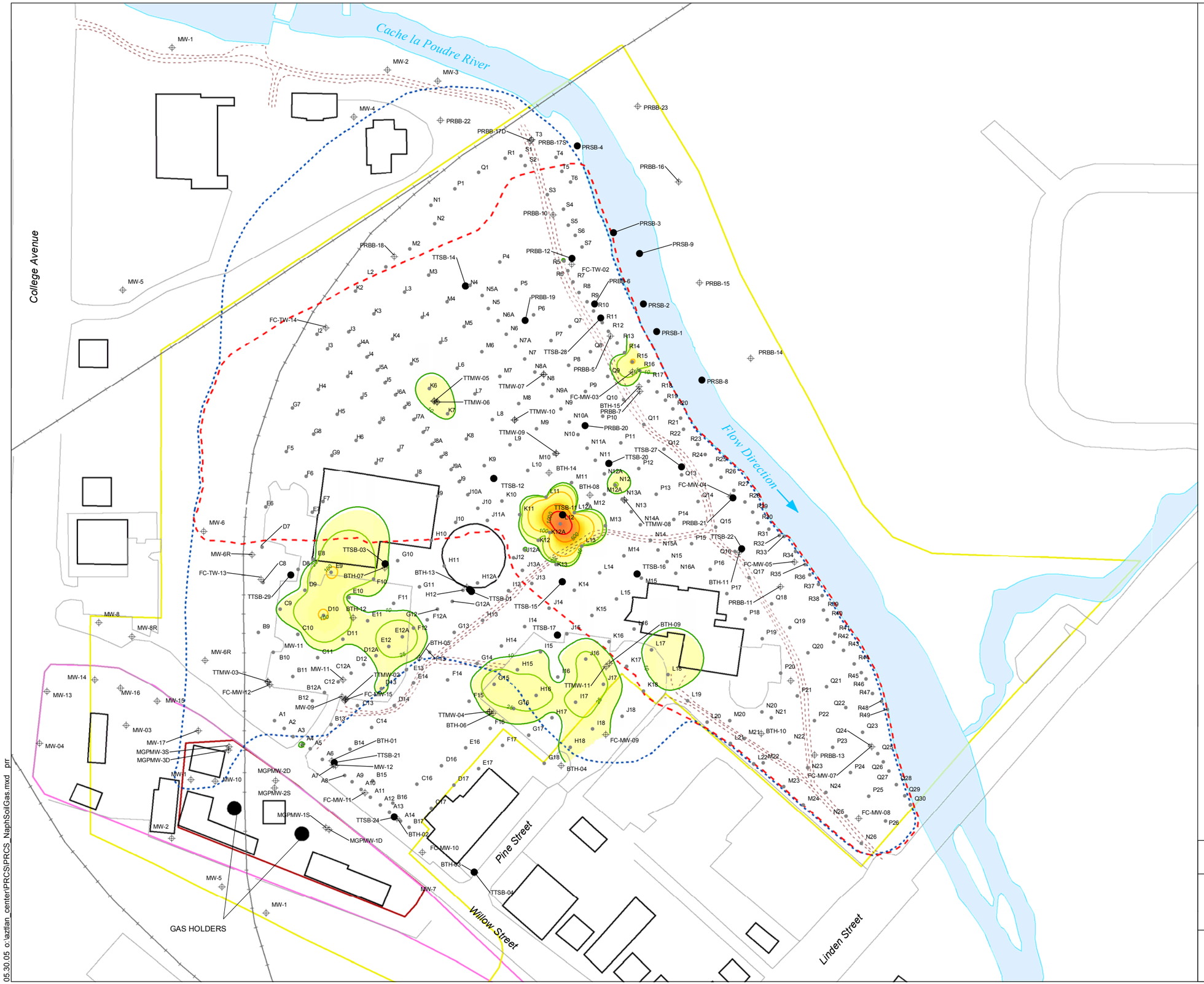
- POST-PINEY CREEK ALLUVIUM (UPPER HOLOCENE)
- BROADWAY ALLUVIUM (PLEISTOCENE)
- WEATHERED AND FRACTURED PIERRE SHALE
- LANDFILL
- INTERBEDDED CALICHE/CEMENTED SANDSTONE LAYERS
- PETROLEUM HYDROCARBONS AND NAPTHALENE PLUME BOUNDARY
- DENSE NON-AQUEOUS PHASE LIQUIDS (DNAPL)
- LIGHT NON-AQUEOUS PHASE LIQUIDS (LNAPL)
- WATER TABLE (APPROXIMATE)
- WELL SCREEN INTERVAL

Note: Line of Cross-Section shown on Figure 2.

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 15
REVISED PRELIMINARY CONCEPTUAL SITE MODEL

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM. INC.

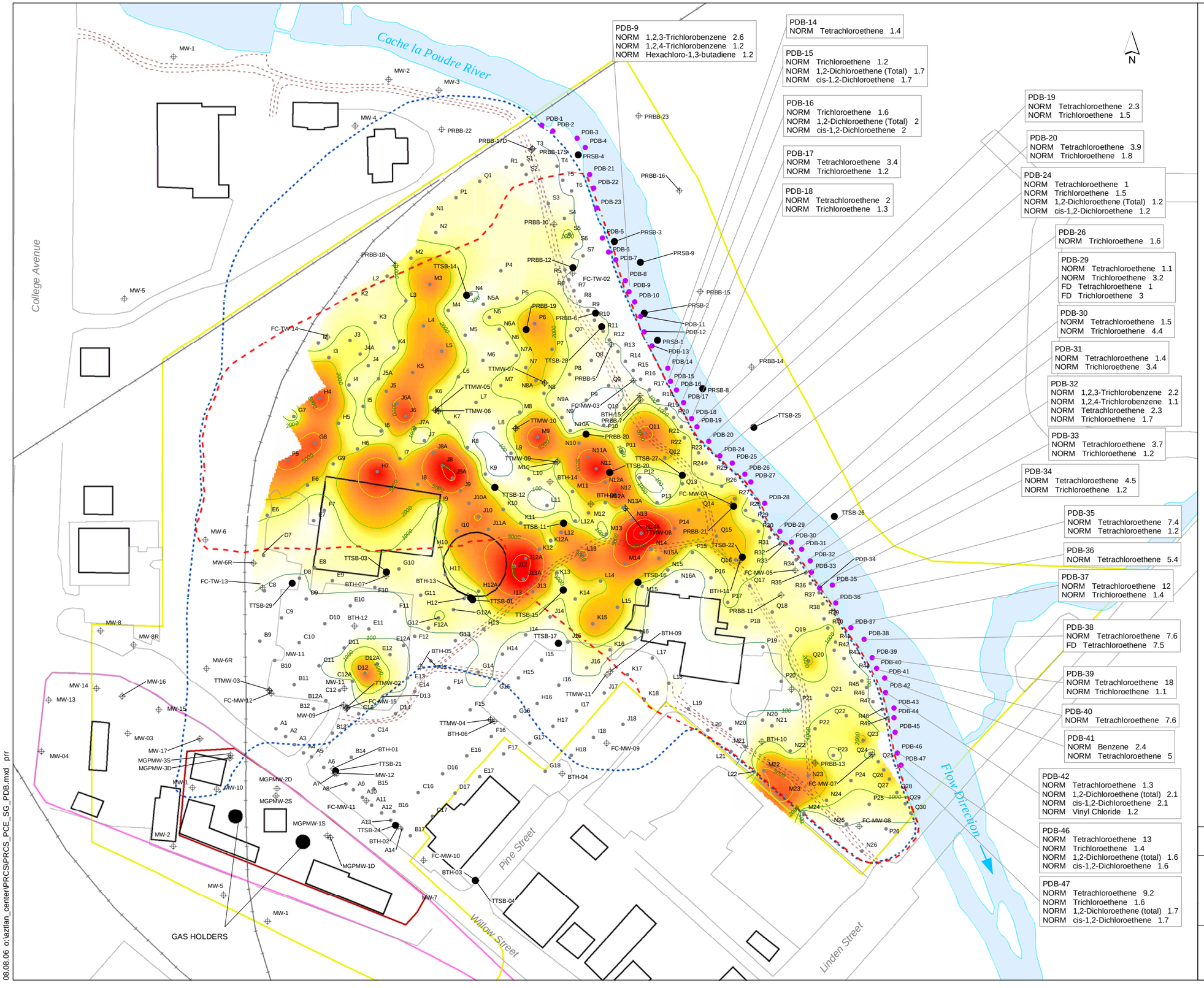


POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 16
SA – NAPHTHALENE DETECTED IN SOIL GAS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

05.30.05 o:\aztlan_center\PRCS\PRCS_NaphSoilGas.mxd prr



POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 17

SA – TETRACHLOROETHENE DETECTED IN SOIL GAS AND PASSIVE DIFFUSION BAG SAMPLE LOCATIONS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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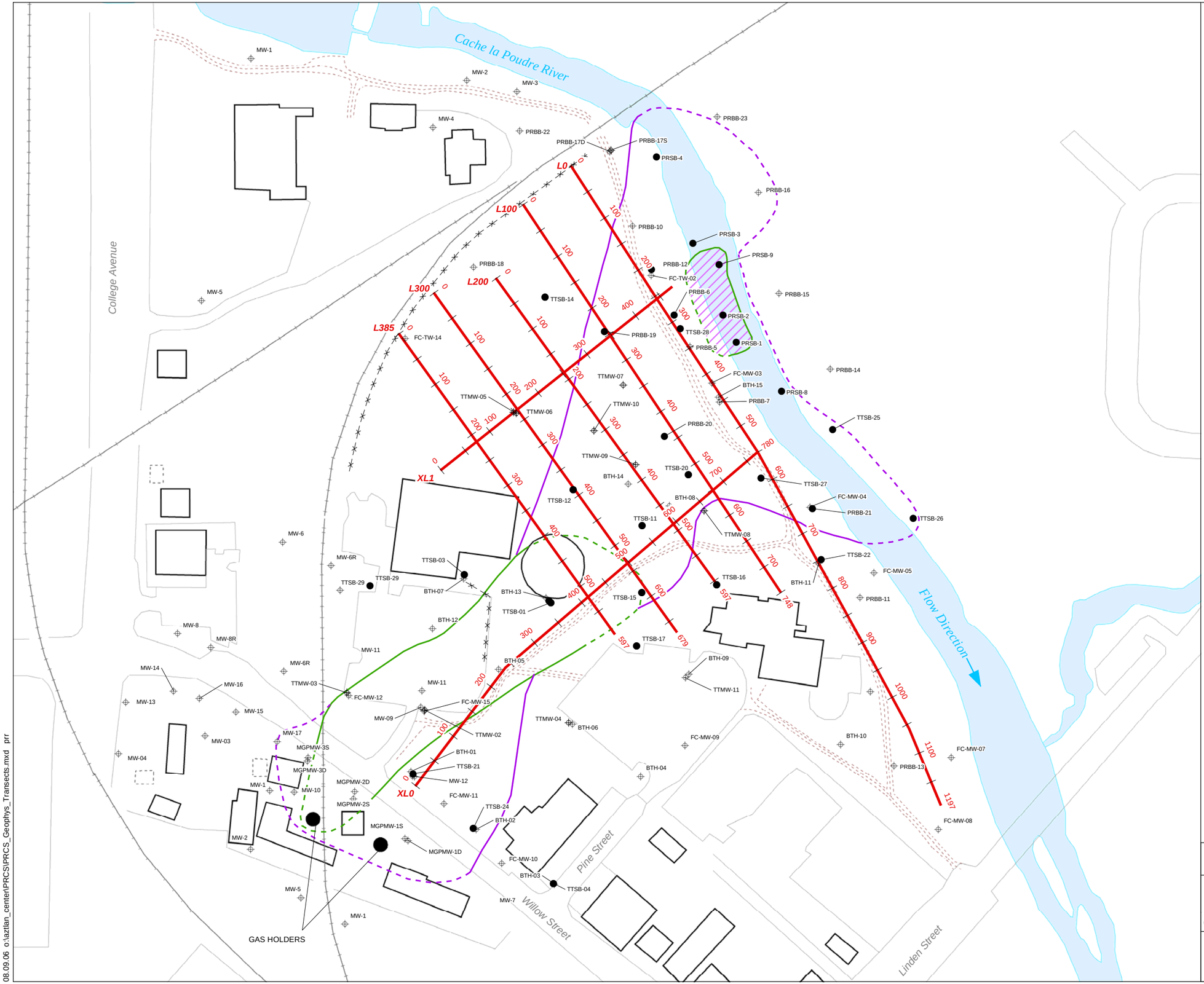

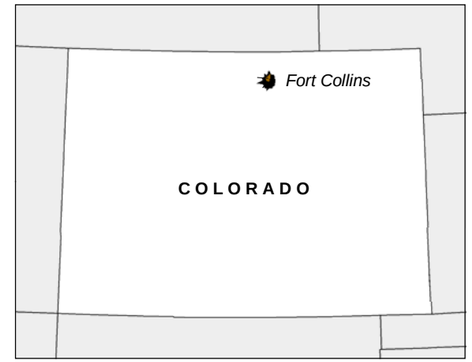

Location Map

Legend

- Soil Boring
- Monitoring Well
- High Resolution Resistivity Line
- Geophysical Survey "Railroad Fence"
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts in Bedrock (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium and Bedrock (dashed where inferred)
- Recreation Path
- Paved Area
- Railroad
- Building

N

0 150 300

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 18

SA – HIGH RESOLUTION RESISTIVITY GEOPHYSICAL SURVEY TRANSECT LOCATIONS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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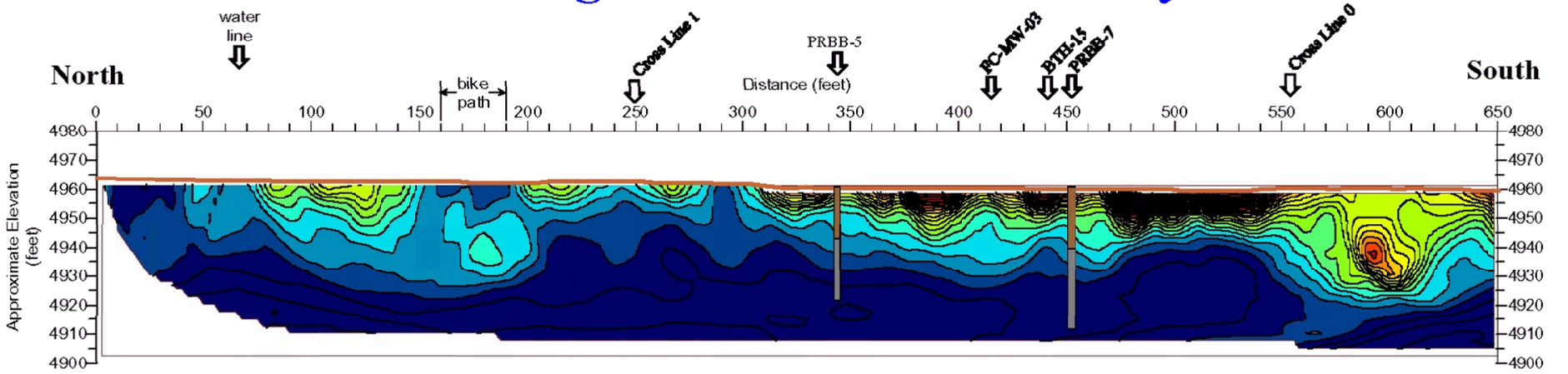
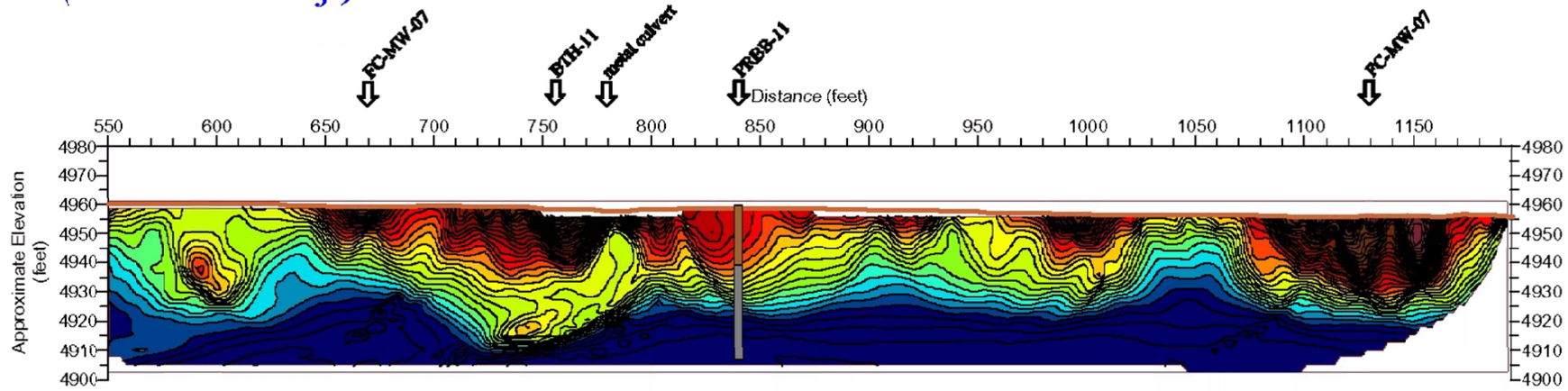
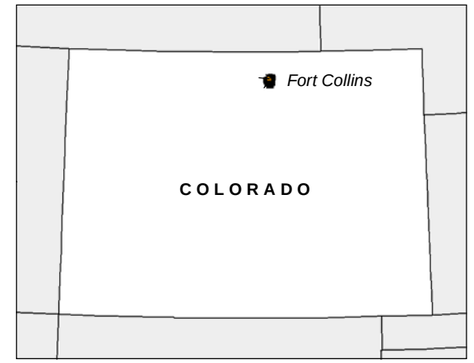
High Resolution Resistivity



HRR Line 0 (Station 0 - 650 ft)



HRR Line 0 (Station 550-1195 ft)



Location Map

Landfill/Alluvium

Bedrock

EQUIPMENT	
Rx:	AGI Sting R8
Tx:	AGI Sting R8
Array:	Pole-Pole
Spacing:	5 - 360 ft
Electrodes:	Stainless Steel

PROCESSING	
Filter:	None
Gridding Method:	Kriging
Cell Size:	2.5 x 2.5
Trend Bias:	None
Coordinate System:	Local (feet)

Apparent Resistivity (Ohm-m)

0 150 300 450 600 750 900 1050 1200 1350 1500

Vertical Exaggeration: 1.5 : 1

0 25 50 75 100

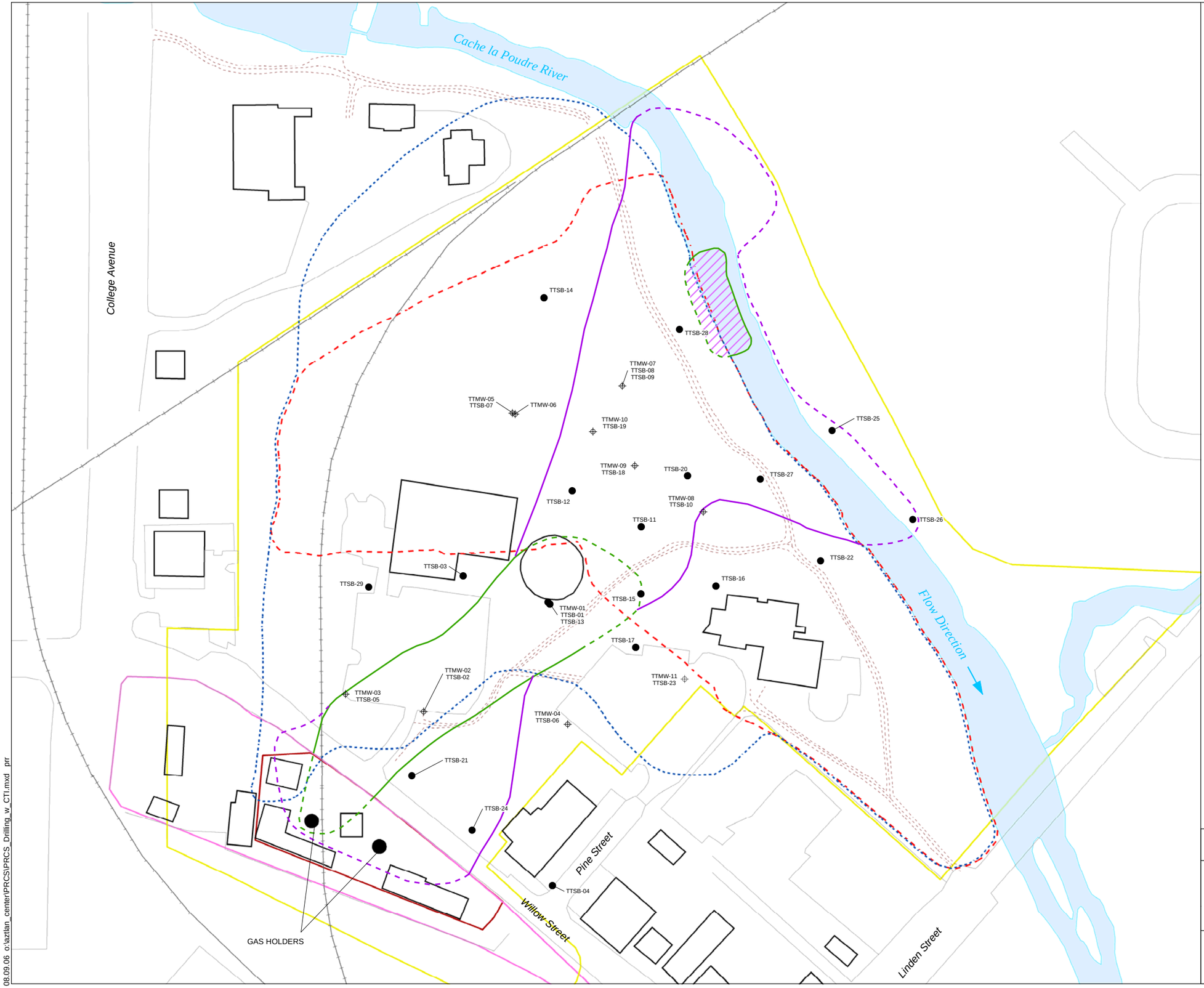
Scale: 1 inch = 60 feet

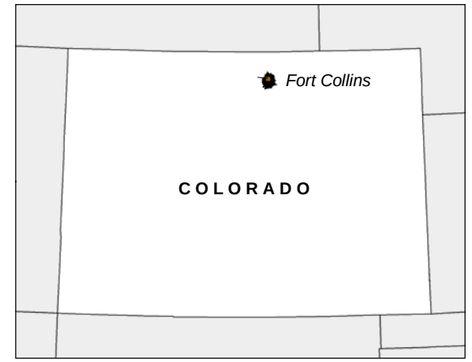
POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 19
SA – GEOPHYSICAL RESULTS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

08.09.06 o:\aztlan_center\PRCS\PRCS_Geophys_Results_SA.mxd prr





Location Map

Legend

- Soil Boring
- Monitoring Well
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts in Bedrock (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium and Bedrock (dashed where inferred)
- Recreation Path
- Paved Area
- Railroad
- Building
- Approximate Extent of Observed Fill and Trash Debris
- Approximate Extent of Former Landfill
- Site Outline
- Former Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property

N

0 150 300

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 20
SA – BORING AND MONITORING WELL LOCATIONS WITH EXTENT OF COAL TAR IMPACTS

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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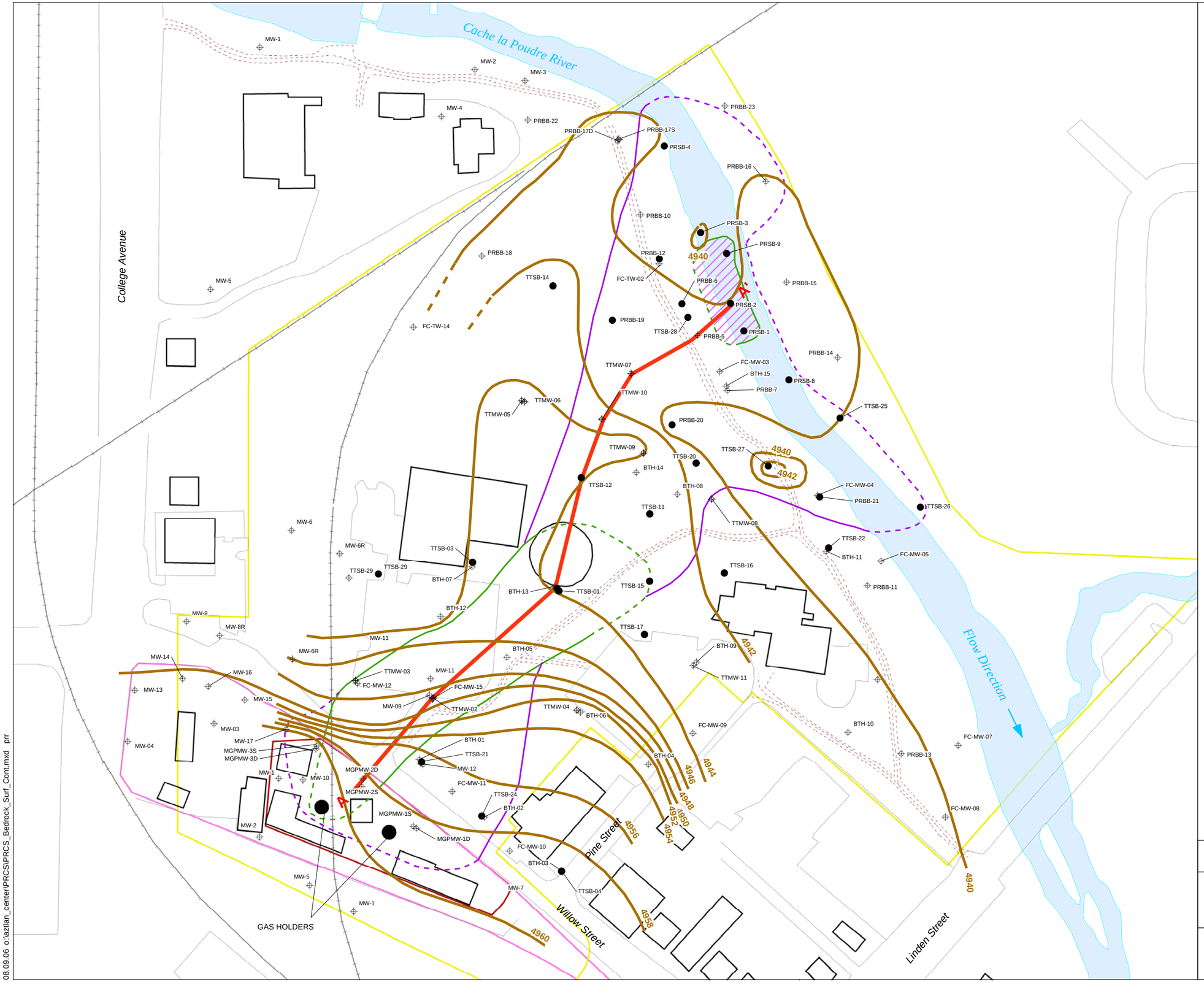

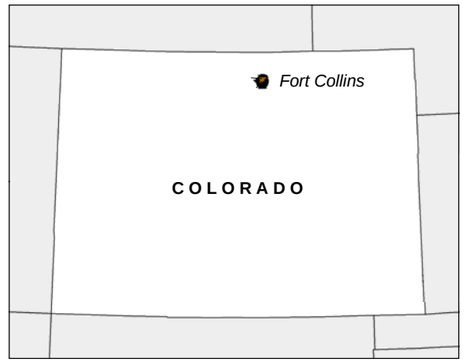

Location Map

Legend

- Soil Boring
- Monitoring Well
- Bedrock Contour (dashed where inferred)
- Cross-Section Transect (A – A')
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts in Bedrock (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium (dashed where inferred)
- Approximate Boundary of Non-Aqueous Phase Liquid Impacts Observed in Unconsolidated Alluvium (dashed where inferred)
- Recreation Path
- Paved Area
- Railroad
- Building
- Site Outline
- Former Location of Poudre Valley Gas Company
- Schrader Oil or Public Service Company Property

N

0 150 300

Feet

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 21
SA – FINAL BEDROCK SURFACE CONTOUR MAP

U.S. EPA REGION VIII IN COOPERATION WITH BROWNFIELDS TECHNOLOGY SUPPORT CENTER AND TETRA TECH EM, INC.

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SW
A

NE
A'

FORMER NATURAL GAS PLANT TANK HOLDER

MGPMW-2D

WILLOW STREET

FC-MW-15
TTMW-02

PARKING LOT

SOIL GAS SAMPLE (e.g. E12A)

NORTHSIDE AZTLAN CENTER

TTSB-01

PLAYGROUND

TTSB-12

UNITED WAY BUILDING

TTMW-10

SOIL GAS SAMPLE (e.g. N13)

TTMW-07

GRAVELY FILL

CACHE LA POUDRE RIVER

RIP-RAP

BIKE PATH

FC-MW-03
PRBB-5

PDBS
SEEPAGE FACE

SOIL/GAS ACCUMULATION BENEATH PARKING LOT

SOIL/GAS PREFERENTIAL PATHWAY

GROUNDWATER FLOW DIRECTION

4965
4950
4935
4920

LEGEND

- WATER TABLE (APPROXIMATE)
- POST-PINEY CREEK ALLUVIUM (UPPER HOLOCENE)
- BROADWAY ALLUVIUM (PLEISTOCENE)
- MASSIVE GLAUCANITIC SANDSTONE (PIERRE SHALE)
- LAMINATED SILTY SANDSTONE/SILTSTONE (PIERRE SHALE)
- LAMINATED, FRACTURED SILTY SANDSTONE (PIERRE SHALE)
- LANDFILL MATERIAL
- DNAPL-COAL TAR
- HIGHLY WEATHERED FRACTURED SANDSTONE (PIERRE SHALE)
- DENSE NON-AQUEOUS PHASE LIQUID (DNAPL)
- PDBS — PASSIVE DIFUSSION BAG SAMPLER
- WELL SCREEN INTERVAL
- COAL TAR

NO SCALE
HORIZONTAL VERTICAL
1:5 APPROXIMATE VERTICAL EXAGGERATION

POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 22

FINAL CONCEPTUAL SITE MODEL AND CROSS-SECTION

U.S. EPA REGION VIII
IN COOPERATION WITH
BROWNFIELDS TECHNOLOGY SUPPORT CENTER

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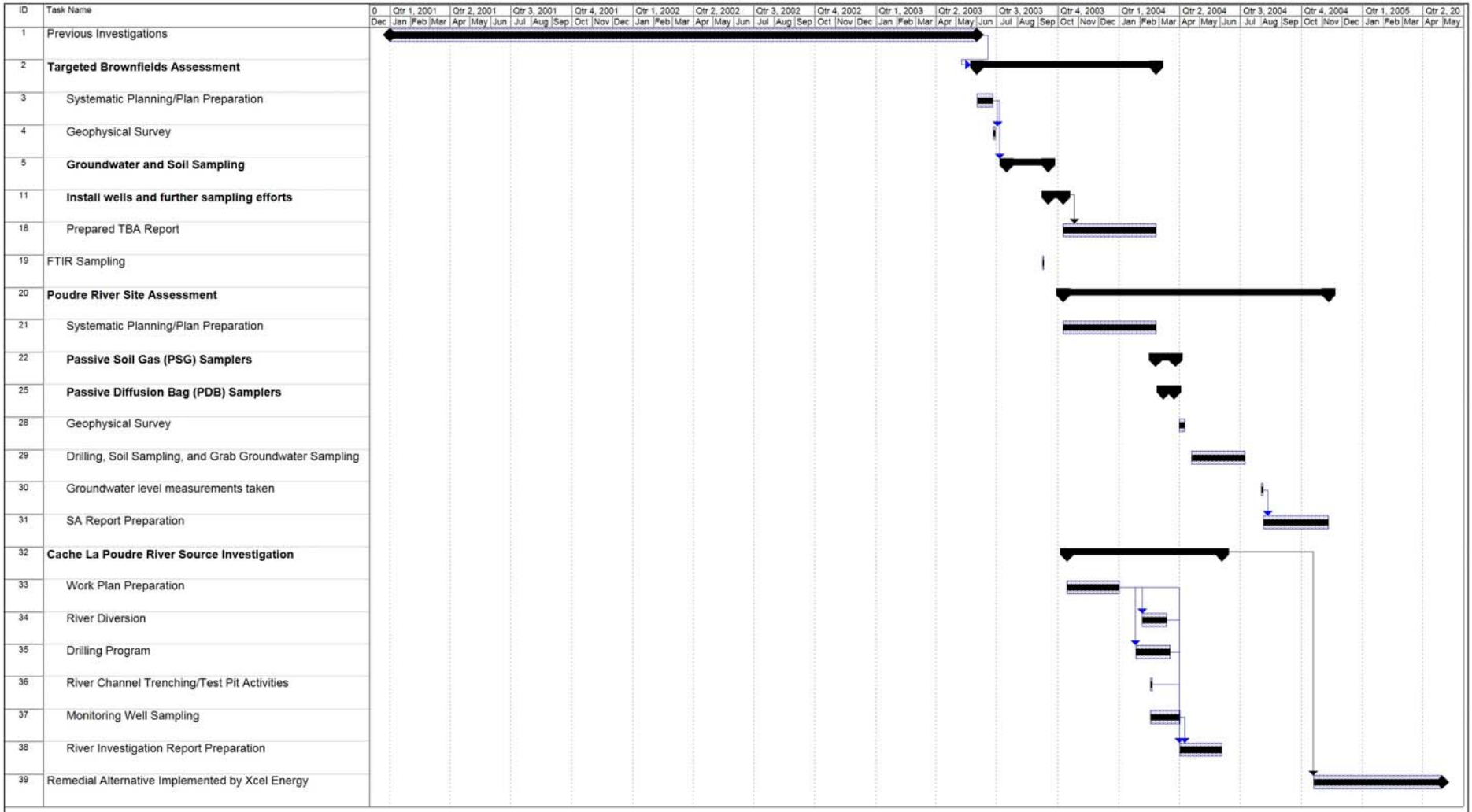


POUDRE RIVER SITE
FORT COLLINS, COLORADO

FIGURE 23
INVESTIGATION HISTORY

U.S. EPA REGION VIII IN
COOPERATION WITH BROWNFIELDS
TECHNOLOGY SUPPORT CENTER

APPENDICES

APPENDIX 1

TECHNOLOGY QUICK REFERENCE SHEETS

TECHNOLOGY QUICK REFERENCE SHEET #1
VOLATILE ORGANIC COMPOUNDS (VOC)
BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY (GC/MS)

Summary of Project-Specific Performance Information

Project Role:
Provide real time results to guide dynamic sampling activities for a Triad investigation. GC/MS results were used to identify potential coal tar related contaminants, delineate dissolved plumes, and place temporary and permanent monitoring wells.

Analytical Information Provided:

A total of 68 analyses were performed over 6 days using a Hewlett Packard 5970 series GC/MS. The unit was provided in a mobile laboratory vehicle by EPA Region 8 at no charge to the project. Equipment included all necessary peripherals (computer, HP chemstation software), auto-sampler, and Tekmar/Dohrman purge and trap unit. Analysis followed a modified EPA SW-846 Method 8260 process using a 5-point initial calibration curve, daily continuing calibration checks and blank analyses.

Qualified analytical chemists were provided by Tetra Tech to process samples, obtain analytical results, evaluate sample quantitation and calibrations, and provide real time results to the field crew for dynamic sampling activities. Additionally, samples were provided to EPA Region 8 for comparative analysis by EPA SW-846 Method 8260. The analyses were able to identify a significantly large dissolved plume of low level trichloroethene and tetrachloroethene contamination not previously identified or delineated at the site.

PROJECT COST AND TIME SAVINGS

Total Cost (includes GC/MS, autosampler, purge and trap unit, consumables, and labor): Approximately $3,600. Mobile laboratory, instrument, and peripherals were provided free of charge by EPA Region 8. Cost only includes labor and some consumables.

Total Cost Per Sample (only includes labor and consumables): $53

Estimated Total Cost Per Sample (including labor, consumables, laboratory, instrument, and peripheral charges): $95

Instrument Cost:

HP5970 GC/MS Purchase Price: Approximately $45,000 to $50,000 new

Used units including auto-sampler and purge and trap unit can be purchased from $25,000 to $35,000 depending on age and configuration.

Rental Costs: Not applicable for this project.

A certified mobile laboratory providing Method 8260 analyses can be procured as a service for approximately $1,500-$2,000/day.

Consumables Cost:

Most consumables (standards, methanol, helium 99.999% pure, were provide free of charge by EPA Region 8).

DI water for blanks:

$5/ gallon, 2 gallons used = $10

Ice $2/ bag, 20 bags used = $40

Labor Cost:

$52/ sample

Waste Disposal Cost:
Not available. Samples were disposed of with site purge water. Disposal cost for small amounts of sample, methanol, and site contaminants are assumed to be minimal.

Time Savings:

1 Year

Site characterization activities using a dynamic work strategy were completed in several weeks. Sufficient data to place monitoring wells and complete the Targeted Brownfields Assessment (TBA) were completed in a single funding cycle (1 year). Site characterization following a traditional phased approach would have required multiple mobilizations taking place over 2 years, which encompasses 2 cycles of Brownfields funding.

Site-Specific Precision and Accuracy Achieved:

Duplicate Samples evaluated using

Relative Percent Difference (RPD): $$RPD = \frac{|A-B|}{(A-B)/2} \times 100$$

Duplicate RPDs for detected compounds ranged from 0.56% to 33%

Comparability = (Field Result/ EPA Region 8 Fixed Laboratory Result) X 100

Comparability results ranged from 4% to 38%

Throughput Achieved:
68 Analyses

TECHNOLOGY QUICK REFERENCE SHEET #1 (CONTINUED)
VOLATILE ORGANIC COMPOUNDS (VOC)
BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY (GC/MS)

General Commercial Information (Information valid as of September 2003)

Vendor Contact:

Rene Beleau
(303) 312-7713

Vendor Information:

EPA Region 8 Laboratory
16194 W 45th Drive
Golden, Colorado 80403
U.S.A.
303-312-7700

Limitations on Performance:
The system employed a purge and trap configuration and auto-sampler with the GC/MS. An initial 5-point calibration curve was developed and spiked surrogates, daily continuing calibration checks, blanks, and duplicate analyses were performed as part of the QA/QC program. Samples were analyzed following a modified SW-846 Method 8260 process (limited QC); however, results were verified by comparative analysis of samples using a complete SW-846 method at the EPA Region 8 laboratory.

Principle of Analytical Operation:

This analysis is based on a 5 milliliter sample purge using an inert gas followed by collection on a trap system. Contaminants are then desorbed from the trap and are injected directly onto the gas chromatograph column using an auto-sampler system. The system is flushed after each sample analysis.

The entire purge and trap sampling system is automated and results were graphed electronically by using HP CHEMSTATION software. Dilutions were made as necessary to samples that exceeded the calibration range.

Availability/Rates:
The EPA Region 8 mobile laboratory is available to assist in analysis of samples for investigations at START, Brownfields, and Superfund site cleanups. Requests should be submitted to the EPA Region 8 Laboratory.

Power Requirements:
The mobile laboratory provides all of its own power and is completely self-contained. The mobile laboratory comes complete with all the tools to perform purge and trap collection with a Hewlett Packard GC for analysis.

Instrument Weight and/or Footprint:
Bench-top GCs weigh between 100 and 200 pounds, but can be less than 100 pounds. Laboratory space required is controlled by the need for sample preparation and extraction. Documentation can also increase the need for additional space in the laboratory.

GENERAL PERFORMANCE INFORMATION

Interferences are limited to matrix effects. The method was conducted according to specifications provided under EPA SW-846 Method 8260.

Applicable Media/Matrices:
Soil/Water

Wastes Generated Requiring Special Disposal:
Low level contaminated water samples from sample contaminants, surrogates, and matrix spikes.

Analytes Measurable with Expected Detection Limits:

SW-846 target analytes
Detected compounds were quantitated above the lowest standard (20µg/L) and reported as estimated to the detection limit (1µg/L).

Other General Accuracy/Precision Information:
Quantitative and qualitative results are provided by GC/MS analysis.
The method was conducted according to specifications provided under EPA SW-846 Method 8260.

Rate of Throughput:
Sample preparation (purge and trap) is about 5 to 8 minutes per sample. Analysis of individual samples can be completed in approximately 20 minutes.

TECHNOLOGY QUICK REFERENCE SHEET #2
EMFLUX PASSIVE SOIL GAS SAMPLING SYSTEM
ANALYSIS BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY (GC/MS)

Summary of Project-Specific Performance Information

Project Role:

Guide dynamic sampling activities for a Triad investigation. Provide full site coverage for soil gas analysis. GC/MS results were used to identify potential coal tar related contaminants, refine dynamic sampling strategies for drilling activities, delineate soil gas plumes, and refine placement of temporary and permanent monitoring wells.

Analytical Information Provided:

Of the 333 EMFLUX soil gas samplers installed, 329 were recovered and analyzed following procedures outlined in EPA SW-846 Method 8260. Several target compounds beyond the typical Method 8260 list were also requested for analysis. Additional reported compounds included 2-methylnaphthalene and total aliphatic hydrocarbons. The EMFLUX System uses state-of-the-art, hydrophobic adsorbent materials that have a strong affinity for the targeted compounds and do not have to compete with water molecules.

EMFLUX samplers were installed according to Beacon Analytical guidelines http://www.emflux.com/default.htm and left in sampling locations for approximately 25 days. The extended sampling time was used to increase sensitivity associated with less volatile target compounds expected at the site. Relative results were provided in nanograms per trap units and concentrations were estimated using the EMFLUX timing model. Relative results in the form of isopleth maps were developed by Beacon Analytical based on sorbent analysis, sampling time, earth tidal influence, and the EMFLUX timing model.

Project Cost and Time Savings

Total Cost (includes sampling labor, consumables, and analyses):
Installation labor= $6,480
Removal labor= $3,780
Samplers plus analysis= $140/sample= $46,620
Prepare and ship samples= $2,450
Total= $59,330

Total Cost Per Sample (includes labor, analysis and consumables): $180

Instrument Cost:

Not applicable for this technology as analysis costs are included in sampler purchase price.

Samples analyzed following procedures outlined in EPA SW-846 Method 8260.

Rental Costs: Not applicable for this project

Consumables Cost:

Not applicable. Consumable costs were included in sampler and analysis price.

Labor Cost:
$31/ sample

Waste Disposal Cost:
Not applicable. All samples were disposed of at Beacon Analytical laboratory at no additional cost. Copper pipes used during sample deployment and equilibration were recycled and other associated waste was disposed of in a trash bin provided at the site.

Time Savings:
1 Year

Site characterization activities using a dynamic work strategy were completed in several weeks. Sufficient data to place monitoring wells and complete the Targeted Brownfields Assessment (TBA) were completed in a single funding cycle (1 year). Site characterization following a traditional phased approach would have required multiple mobilizations taking place over 2 years, which encompasses 2 cycles of Brownfields funding.

Site-Specific Precision and Accuracy Achieved:
Duplicate Samples evaluated using Relative Percent Difference (RPD) $RPD = \frac{|A-B|}{(A+B)/2} \times 100$

Duplicate RPDs for detected compounds range from 4.5 % to 28%

Throughput Achieved:
329 Analyses

TECHNOLOGY QUICK REFERENCE SHEET #2 (CONTINUED)
EMFLUX PASSIVE SOIL GAS SAMPLING SYSTEM
ANALYSIS BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY (GC/MS)

General Commercial Information (Information valid as of September 2003)

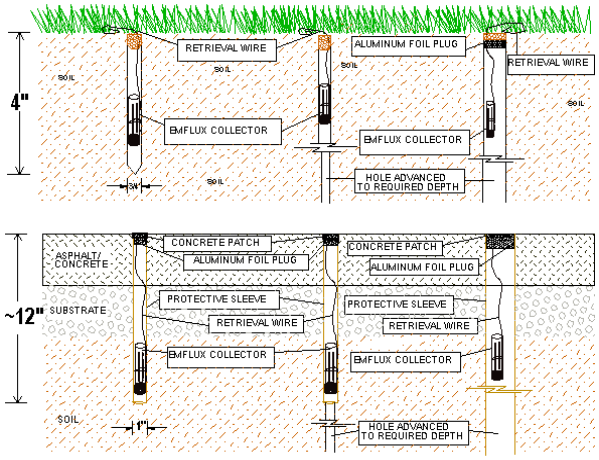
Vendor Contact:	**Vendor Information:**	**Limitations on Performance:**
Harry O'Neill 800-878-5510	Beacon Environmental Services, Inc. Telephone: 800-878-5510 info@emflux.com	Because the EMFLUX® system relies on diffusion of soil gas from subsurface sources such as contaminated soil or groundwater, the performance range for the EMFLUX® system may be controlled by factors such as depth to the contaminant source, contaminant concentrations and diffusion rates, soil type and organic content, and the detection limits of the methods used to analyze the samples. It should be noted that the EMFLUX® system is a field screening technique useful for identifying compounds of potential concern and potential contaminant hotspots. Analytical results only provide an estimate (relative concentration in nanograms per trap) of the actual concentration of contaminants in soil gas.

Principle of Analytical Operation:
The EMFLUX ® system is a passive soil gas sampling technology designed for use in shallow deployment to identify and estimate relative concentrations of a broad range of VOCs and SVOCs, including halogenated compounds, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, and other compounds present at depths to more than 200 feet. For this project, the EMFLUX® system consisted of 2 EMFLUX® sample cartridges, sample insertion tools, and developer-provided sample analysis. Each EMFLUX® cartridge consists of 100 milligrams of sorbent sealed in a fine-mesh screen, which is placed in a glass vial. This assembly is inserted into the soil, but only the cartridge is thermally desorbed and analyzed in the laboratory. The EMFLUX® field collector was installed by drilling a three foot deep hole using a hammer drill, inserting a copper pipe in the upper foot of the hole, and inserting the sampler manually inside the pipe. The sampler is covered with tin foil and then surface soil (or cement in asphalt applications) to reduce the potential for sorption of airborne contaminants. The cartridge was retrieved by hand and analyzed by the developer. The EMFLUX ® system also includes computer modeling by Beacon using a proprietary model to predict periods of maximum soil gas emission for geographic locations and optimize sampling.

Availability/Rates:
EMFLUX soil gas sampling system is available through Beacon Environmental Services, Inc. $85.00 to $195.00 per sample.

Power Requirements:
Electricity or diesel generators are required to power drills for installation of EMFLUX samplers.

Instrument Weight and/or Footprint:
Not applicable.



GENERAL PERFORMANCE INFORMATION

Interferences are limited to matrix effects. The method was conducted according to specifications provided under EPA SW-846 Method 8260.

Applicable Media/Matrices:Soil gas	**Analytes Measurable with Expected Detection Limits:** A broad range of VOCs and SVOCs, including halogenated compounds, petroleum hydrocarbons, polynuclear aromatic hydrocarbons, and other compounds.	**Other General Accuracy/Precision Information:** Concentrations returned are relative and reported in nanograms per trap (sorbent).
Wastes Generated Requiring Special Disposal: None		**Rate of Throughput:** Rate of installation ranged from 8 to 15 minutes. Retrieval times were typically less than 5 minutes.

TECHNOLOGY QUICK REFERENCE SHEET #3
PASSIVE DIFFUSION BAG SAMPLERS
ANALYSIS BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY (GC/MS)

Summary of Project-Specific Performance Information

Project Role:
Guide dynamic sampling activities for a Triad investigation. Provide an evaluation of contaminant concentrations for groundwater discharge reaching site surface water (Cache La Poudre River). GC/MS results were used to identify potential coal tar related contaminants and chlorinated solvents entering surface water from site groundwater.

Analytical Information Provided:
Forty seven passive diffusion bag (PDB) samplers were installed along the west bank of the Cache La Poudre River and an additional 3 samplers were placed in permanent monitoring wells along the river to correlate up-gradient groundwater concentrations with those detected along the river bank. PDB samplers installed in the monitoring wells were evaluated to ensure concentrations detected in nearby riverbank samples could be considered representative of groundwater reaching surface water discharge points. Five field duplicate samples were also collected from riverbank PDB samplers. Samplers were allowed to equilibrate for 2 weeks, then removed and placed in VOA vials for analysis following procedures outlined in EPA SW-846 Method 8260.

PDB samplers installed in the monitoring wells were placed near the top of the well screen and close to the groundwater surface while samplers placed in the riverbank were installed in shallow (approximately 2-4 feet) hand dug holes where groundwater was visually observed entering the hole from an up-gradient direction.

Project Cost and Time Savings

Total Cost (includes sampling labor, consumables, and analyses): Installation labor= $3,600
Removal labor= $1,200
Samplers $28/sample= $1,540 (includes field duplicates)
Sample analysis $120/sample= $6,600
Total= $12,940

Total Cost Per Sample (includes labor, analysis and consumables): $235

Instrument Cost:

Not applicable for this technology as analysis costs are included in sampler purchase price.

Samples analyzed following procedures outlined in EPA SW-846 Method 8260.

Rental Costs: Not applicable for this project

Consumables Cost:

Not applicable. Consumables were not required. Costs were included in sampler and analysis price.

Labor Cost:
$87/ sample

Waste Disposal Cost:
Waste disposal costs were not applicable for this technology. All samples were disposed of at Pace Analytical laboratory at not additional cost. Used PDB samplers were disposed of in a trash bin provided at the site.

Time Savings:
1 Year

Site characterization activities using a dynamic work strategy were completed in several weeks. Sufficient data to place monitoring wells and complete the Targeted Brownfields Assessment (TBA) were completed in a single funding cycle (1 year). Site characterization following a traditional phased approach would have required multiple mobilizations taking place over 2 Brownfields funding cycles (2 years).

Site-Specific Precision and Accuracy Achieved:
Duplicate Samples evaluated using Relative Percent Difference (RPD) $RPD = \frac{|A-B|}{(A+B)/2} \times 100$

Duplicate RPDs for detected compounds range from 6% to 15%

Throughput Achieved:
55 Analyses

TECHNOLOGY QUICK REFERENCE SHEET #3 (Continued)
PASSIVE DIFFUSION BAG SAMPLERS
ANALYSIS BY GAS CHROMATOGRAPHY/ MASS SPECTROMETRY (GC/MS)

General Commercial Information (Information valid as of September 2003)

Vendor Information:

Columbia Analytical Services
Telephone: 800-695-7222
www@caslab.com

Eon Products
Telephone: 800-474-2490
www.eonpro.com

Limitations on Performance:
Passive diffusion bag (PDB) samplers integrate concentrations over time. This can be a limitation if the goal is to collect a representative sample at a point of time in an aquifer where VOC concentrations change substantially over time faster than the PBD samplers can equilibrate. PDB samplers are not appropriate for all compounds. VOC concentrations in the PDB samplers may not reflect those of the surrounding aquifer if the well screen or sand-pack are less permeable than the surrounding aquifer and divert flow lines around the well. VOC concentrations in PDB samplers represent ground-water concentrations in the vicinity of the screened or open well interval that move to the sampler under ambient flow conditions. This is a limitation if the ground-water contamination lies above or below the well screen or open interval. In cases where the well screen or open interval transects zones of differing hydraulic head and variable contaminant concentrations, VOC concentrations obtained using a PDB sampler may not reflect the concentrations in the aquifer directly adjacent to the sampler because of vertical transport in the well. This can be mitigated by using a vertical array of PDB samplers.

Principle of Analytical Operation:
A typical PDB sampler consists of a low-density polyethylene (LDPE) tube closed at both ends and containing deionized water. VOCs travel across the membrane and equilibrate with groundwater or surface water concentrations. The sampler is positioned at the target horizon of the well or surface water by attachment to a weighted line or fixed pipe. The rate that the water within the PDB sampler equilibrates with ambient water depends on multiple factors, including the type of compounds being sampled and the water temperature. The samplers should be left in place long enough for the water, contaminant distribution, and flow dynamics to re-stabilize following sampler deployment. Laboratory and field data suggest that 2 weeks of equilibration is adequate for most applications. In less permeable formations, longer equilibration times may be required. After the equilibration period the PDB sampler is extracted and the water inside immediately drained into VOA vials and sent to the laboratory for analysis.

Availability/Rates:
Passive diffusion bag samplers are currently available through the two distributors provided above. Costs vary from approximately $17.00 to $32.00 per unit depending on the type and quantity purchased.

Power Requirements:
Not applicable.

Instrument Weight and/or Footprint:

Not applicable.

GENERAL PERFORMANCE INFORMATION

Interferences are limited to matrix effects. The method was conducted according to specifications provided under EPA SW-846 Method 8260.

Applicable Media/Matrices:

Water

Wastes Generated Requiring Special Disposal:

None

Analytes Measurable with Expected Detection Limits:

Volatile organic compounds. Detection limits are determined in accordance with EPA SW-846 Method 8260.

Other General Accuracy/Precision Information:
Quantitative and qualitative results are provided by GC/MS analysis.

Rate of Throughput:
Installation and retrieval times are minimal. Equilibration period is approximately 2 weeks.

TECHNOLOGY QUICK REFERENCE SHEET #4
GEONICS LIMITED EM31 AND EM34
TERRAIN CONDUCTIVITY METERS

Summary of Project-Specific Performance Information

Project Role:	**Analytical Information Provided:**
Guide dynamic sampling activities for a Triad investigation. Provide an evaluation of shallow subsurface geology to refine the conceptual site model. Results can also be interpreted to assist in identification of preferential contaminant migration pathways as well as locate potential site contaminants.	The EM31 was used to investigate the shallow subsurface, or unsaturated zone since it has an effective exploration depth of approximately 12 feet using the fixed coil spacing of 3.7 meters. The EM34 was used to investigate subsequent deeper intervals because the coil space can be varied and essentially tuned to specific target depths. The survey used a 10 meter coil spacing to investigate the saturated zone of the site, since the instrument set in the vertical dipole mode (coils placed horizontally on the ground) has a peak response from materials from approximately 3 to 7 meters below the ground surface (10 to 20 feet). The average groundwater depth at the site is approximately 15 feet. A 20 meter coil spacing to investigate possible bedrock features, since in this configuration, the instrument has a peak response for materials from approximately 6 to 12 meters below the ground surface (20 to 30 feet). Bedrock at the site is up to 21 feet below ground surface (below ground surface (bgs), and possible target features such as bedrock channeling, may be deeper.

Project Cost and Time Savings

Total Cost (includes grid setup, data collection, data analysis and report generation): Total= $3,500		**Total Cost Per Sample (includes labor, analysis and consumables):** Approximately $0.23 per EM31 reading and $1.13 per EM34 reading, based on 31 survey lines with 250 (or 50) data points on each line for 7750 (or 1550) measurements.	
Instrument Cost: Rental Costs: $3,500 for 4 days.	**Consumables Cost:** Not applicable. Consumables were not required.	**Labor Cost:** Not applicable **Waste Disposal Cost:** Waste disposal costs were not applicable for this technology. No waste was generated as a result of the geophysical surveys.	**Time Savings:** 1 Year Site characterization activities using a dynamic work strategy were completed in several weeks. Sufficient data to place monitoring wells and complete the Targeted Brownfields Assessment (TBA) were completed in a single funding cycle (1 year). Site characterization following a traditional phased approach would have required multiple mobilizations taking place over 2 Brownfields funding cycles (2 years).
Site-Specific Precision and Accuracy Achieved: Not applicable for this technology			**Throughput Achieved:** Survey lines with wood stakes and flagging spaced 20 feet apart in an area measuring approximately 500 feet by 600 feet, parallel to the Cache La Poudre River. Measurements were recorded in a data logger along the survey lines approximately every two feet with the EM31 and every 10 feet with the EM34 for good lateral resolution, giving a throughput of ~500 readings/hr for the EM31 and ~100 readings/hr for the EM34

TECHNOLOGY QUICK REFERENCE SHEET #4 (CONTINUED)
GEONICS LIMITED EM31 AND EM34
TERRAIN CONDUCTIVITY METERS

General Commercial Information (Information valid as of September 2003)

Vendor Contact:

JD McNeill

905-670-9580

Vendor Information:

Geonics Limited
1745 Meyerside Drive, Unit 8
Mississauga, Ontario
Canada
L5T 1C6
Telephone: 905 670 9580
Telefax: 905 670 9204

Limitations on Performance:

Each instrument has limited vertical sounding capabilities. The EM31 can effectively map terrain conductivity to about 18 feet below ground surface (bgs) using a 3.7 meter coil spacing. The EM34 can be tuned to specific depths. With an effective total depth of approximately 180 feet bgs.

Inductive electromagnetic techniques have a limited dynamic range. At low values of terrain conductivity it becomes increasingly difficult to magnetically induce a detectable magnetic field at the receiver coil. At very high values the received magnetic field is no longer linearly proportional to the terrain conductivity. Setting and maintaining the instrument zero can be difficult, although over most terrain conductivities the zero error is negligible. At locations where the instruments are being used to measure highly resistive ground the zero error can be significant.

Principle of Analytical Operation:

A time varying magnetic field arising from alternating current in the transmitter coil induces very small currents in the earth. These currents generate a secondary magnetic field that is sensed by the receiver coil in conjunction with the primary field. The secondary magnetic field is a complicated function of intercoil spacing, the operating frequency, and the ground conductivity.

Using a complicated formula, the instrument software generates a ratio of the secondary current to the primary magnetic field that is linearly proportional to the terrain conductivity. This allows the instruments to be a direct reading linear terrain conductivity meter simply by measuring this ratio.

Availability/Rates:

The EM31 and EM34 terrain conductivity meters are available through Geonics Limited. These instruments can also be procured as a service through various geophysical survey companies.

Power Requirements:

The instruments are field portable and supply their own power via rechargeable batteries.

Instrument Weight and/or Footprint:

Both the EM31 and EM34 weigh less than 30 pounds and are easily transported into the field. The data loggers are readily removed from the console for easy data downloading. Additional space may be required for laptops employing terrain mapping software.

EM 31 **EM34**

GENERAL PERFORMANCE INFORMATION

Potential interferences include:

Applicable Media/Matrices:

Soil/Groundwater

Wastes Generated Requiring Special Disposal:

None

Analytes Measurable with Expected Detection Limits:

Terrain conductivity in Siemen/meter or millimho/meter. Results can also be converted to resistivity values in ohmmeters. Dynamic range 1-1,000 millimho/meter

Other General Accuracy/Precision Information:

Data interpretation is aided through the use of known geology from boreholes or other benchmarks.

Rate of Throughput:

Large grid surveys (approximately 750 nodes) can be completed in 1 day. Additional time is needed for data interpretation and mapping.

TECHNOLOGY QUICK REFERENCE SHEET #5
ADVANCED GEOSCIENCES INC. (AGI)
SUPERSTING RESISTIVITY CONTROL UNIT
(HIGH RESOLUTION RESISTIVITY GEOPHYSICAL SURVEY)

Summary of Project-Specific Performance Information

Project Role:
Guide dynamic sampling activities for a Triad investigation. Provide an evaluation of shallow subsurface geology to refine the conceptual site model. Results can also be interpreted to assist in identification of preferential contaminant migration pathways as well as locate potential site contaminants.

Analytical Information Provided:

High Resolution Resistivity (HRR) was used to characterize shallow bedrock and other subsurface conditions. Seven survey lines were used to grid the site and a total of 5,110 feet of HRR data was acquired (mostly over unpaved areas) over 9 days. The HRR survey used the SuperSting resistivity control unit, a battery powered programmable unit capable of acquiring resistivity and induced polarization geophysical data. Data collected included bedrock surface and other shallow geologic information to assist in refinement of the conceptual site model (CSM). Information correlated extremely well with visually observed drilling cores obtained during the subsequent limited drilling program. Maps obtained were used to provide site-wide coverage of the bedrock surface, refine and focus the drilling program, and to evaluate potential preferential pathways of contaminant migration.

Project Cost and Time Savings

Total Cost (includes grid setup, data collection, data analysis and report generation):
Total= $24,800

Total Cost Per Sample (includes labor, analysis and consumables): Not applicable.

Instrument Cost:

Not applicable for this technology as analyses were not performed.

Rental Costs: Not applicable for this project, technology was procured through a geophysical vendor.

Consumables Cost:

Not applicable. Consumables were not required.

Labor Cost:
Not applicable

Waste Disposal Cost:
Waste disposal costs were not applicable for this technology. No waste was generated as a result of the geophysical surveys.

Time Savings:
1 Year

Site characterization activities using a dynamic work strategy were completed in several weeks. Sufficient data to place monitoring wells and complete the Targeted Brownfields Assessment (TBA) were completed in a single funding cycle (1 year). Site characterization following a traditional phased approach would have required multiple mobilizations taking place over 2 Brownfields funding cycles (2 years).

Site-Specific Precision and Accuracy Achieved:

Not applicable for this technology

Throughput Achieved:
5,110 feet of HRR information was obtained.

Four figures depicting subsurface geology at the site were developed and a comprehensive report was provided by the vendor.

TECHNOLOGY QUICK REFERENCE SHEET #5 (CONTINUED)
ADVANCED GEOSCIENCES INC. (AGI)
SUPERSTING RESISTIVITY CONTROL UNIT
(HIGH RESOLUTION RESISTIVITY GEOPHYSICAL SURVEY)

General Commercial Information (Information valid as of September 2004)

Vendor Contact:

General Information:
info@agiusa.com
Sales info & order:
sales@agiusa.com
Customer Support:
support@agiusa.com

Vendor Information:

Advanced Geosciences Inc.
12700 Volente Rd.
(FM2769), Bldg. A, Austin,
TX 78726, USA
Telephone: 512-335-3338
Telefax: 512-258-9958

Limitations on Performance:

Electrical resistivity techniques are more labor intensive and time consuming than ground penetrating radar (GPR) techniques. The resistivity method is strongly sensitive to changes in moisture content but can also be affected by changes in grain size distributions, clay content, and other geologic properties. Apparent resistivity values are influenced by the amount of interstitial moisture content and the type of geologic media.

Principle of Analytical Operation:

The survey consisted of a four-electrode array with two electrodes forming a transmitting pair or "dipole" whereby electrical current is injected into the earth. Two electrodes form a receiving pair, or "dipole", and measure the voltage difference due to the impressed current. HRR generally uses a "pole-pole" array whereby two of the four electrodes are placed at a predetermined distance away (effectively at an infinite distance) from the survey area so that they do not affect survey data, leaving two "active" electrodes for survey line data acquisition. The "active" electrodes in a pole-pole array are a single current source electrode and a nearby potential measuring electrode. The remote or "infinite" electrode locations normally remain fixed during surveys unless larger areas are involved. The two "active" electrodes are arranged collinearly so that the distances between them vary in an incremental manner. For conventional shallow investigations, the distance between the two active electrodes typically varies between five and 200 feet. Survey line locations and spacing are determined by objective, target size, and depth of burial. Since topography will distort resistivity profiles, changes in elevation along the geophysical lines are surveyed to be used for subsequent data processing. Recorded apparent resistivity data can be processed and inverted using software that allows topographic correction and provides robust depth estimates. The resulting image is a contoured section.

Availability/Rates:

The AGI Supersting resistivity control unit is available through Advanced Geosciences Inc. (AGI). These instruments can also be procured as a service through various geophysical survey companies.

Power Requirements:

The instruments are field portable and supply their own power via 12V or 2x12V DC external batteries.

Instrument Weight and/or Footprint:

The SuperSting R1 IP (instrument only) weighs 10.9 kg (24 lb). Width 184 mm (7.25"), length 406 mm (16") and height 273 mm (10.75").

TECHNOLOGY QUICK REFERENCE SHEET #5 (CONTINUED)
Advanced Geosciences Inc. (AGI)
SUPERSTING RESISTIVITY CONTROL UNIT
(HIGH RESOLUTION RESISTIVITY GEOPHYSICAL SURVEY)

<table>
<tr><th colspan="3">GENERAL PERFORMANCE INFORMATION</th></tr>
<tr><td colspan="3">Potential interferences include: Overhead and buried utilities.</td></tr>
<tr><td>Applicable Media/Matrices:

Soil/Groundwater</td><td rowspan="2">Analytes Measurable with Expected Detection Limits:

Measurement modes: Apparent resistivity, resistance, self potential (SP), induced polarization (IP), battery voltage

Measurement range: +/- 10VMeasuring resolution: Max 30 nV, depends on voltage level

Screen resolution: 4 digits in engineering notation.</td><td>Other General Accuracy/Precision Information:
Data interpretation is aided through the use of known geology from boreholes or other benchmarks.</td></tr>
<tr><td>Wastes Generated Requiring Special Disposal:

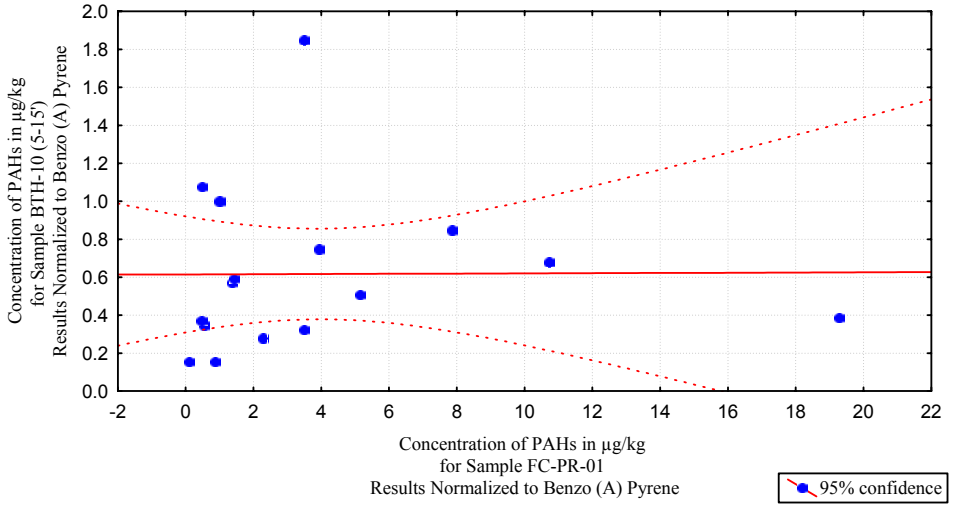
None</td><td>Rate of Throughput:
Large line surveys can be completed in 1 day. Additional time is needed for data interpretation and mapping.</td></tr>
</table>

APPENDIX 2

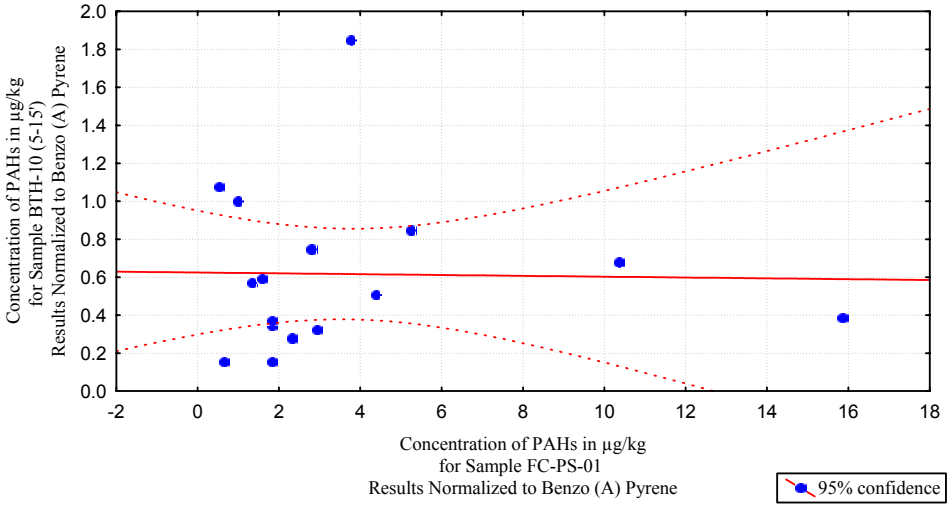
MANUFACTURED GAS PLANT COAL TAR FINGERPRINTING USING POLYNUCLEAR AROMATIC HYDROCARBONS

Correlations of PAH Concentrations in µg/kg
Normalized to Benzo (A) Pyrene
Cache La Poudre River Samples vs. Sample BTH-10 (5-15')

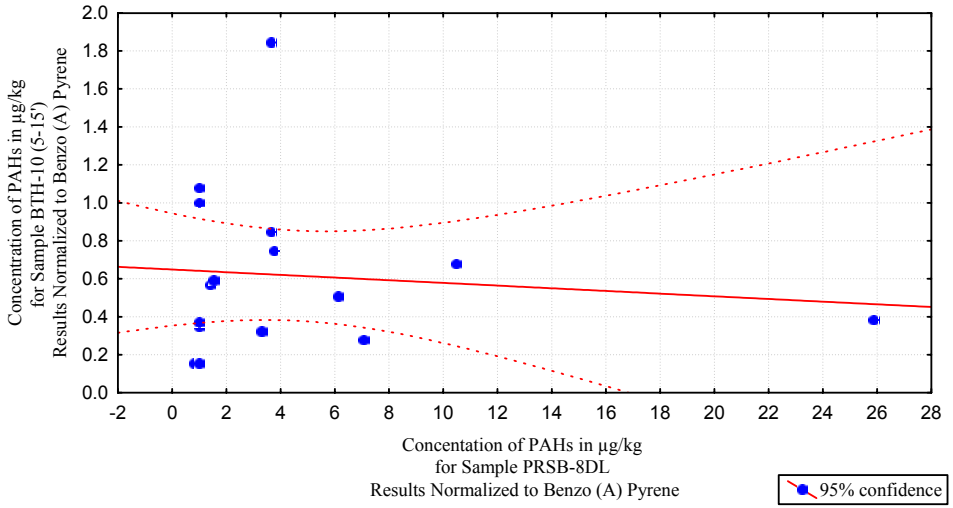
Scatterplot: FC-PR-01 vs. BTH-10 (5-15')
Results Normalized to Benzo (A) Pyrene
BTH-10 (5-15') = .61469 + .55E-3 * FC-PR-01
Correlation: r = .00641



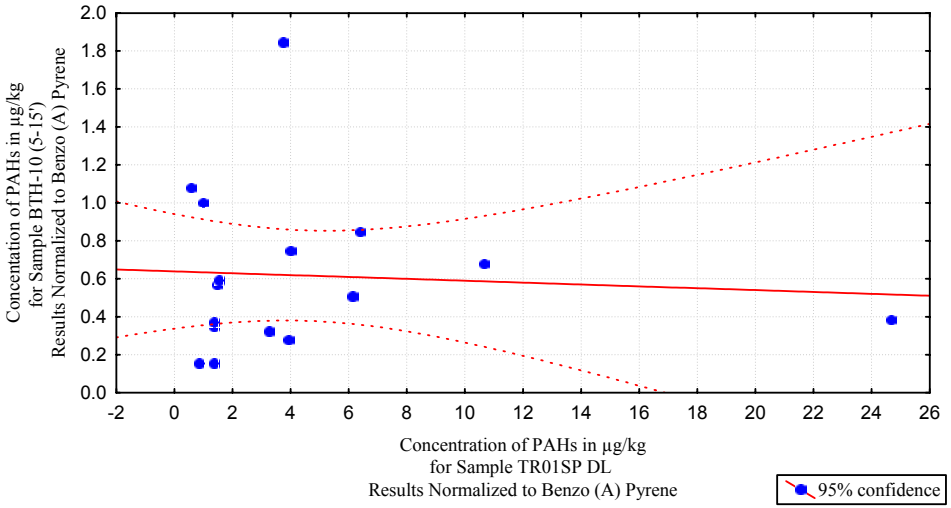
Scatterplot: FC-PS-01 vs. BTH-10 (5-15')
Results Normalized to Benzo (A) Pyrene
BTH-10 (5-15') = .62483 - .0022 * FC-PS-01
Correlation: r = -.0206



Scatterplot: PRSB-8DL vs. BTH-10 (5-15')
Results Normalized to Benzo (A) Pyrene
BTH-10 (5-15') NormBAP = .64883 - .0071 * PRSB-8DL NormBAP
Correlation: r = -.1035

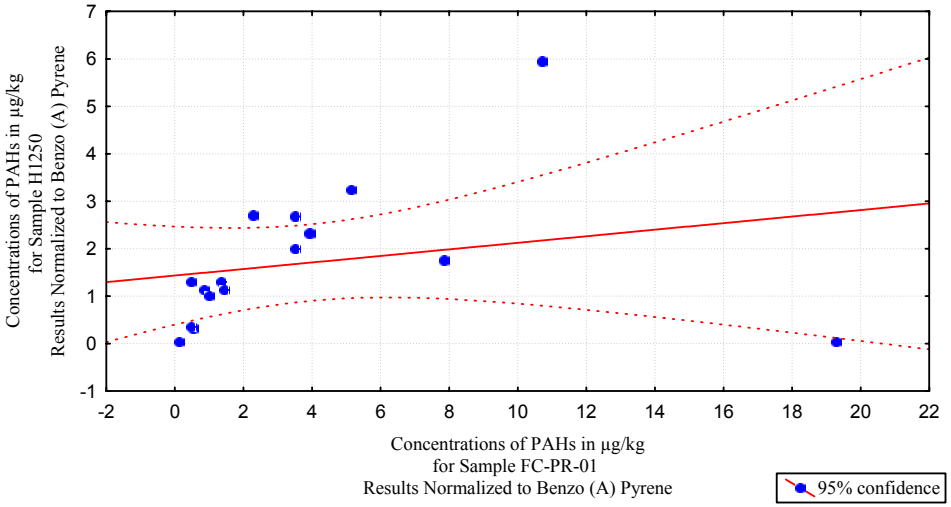


Scatterplot: TR01SP DL vs. BTH-10 (5-15')
Results Normalized to Benzo (A) Pyrene
BTH-10 (5-15') = .63915 - .0049 * TR01SP DL
Correlation: r = -.0690

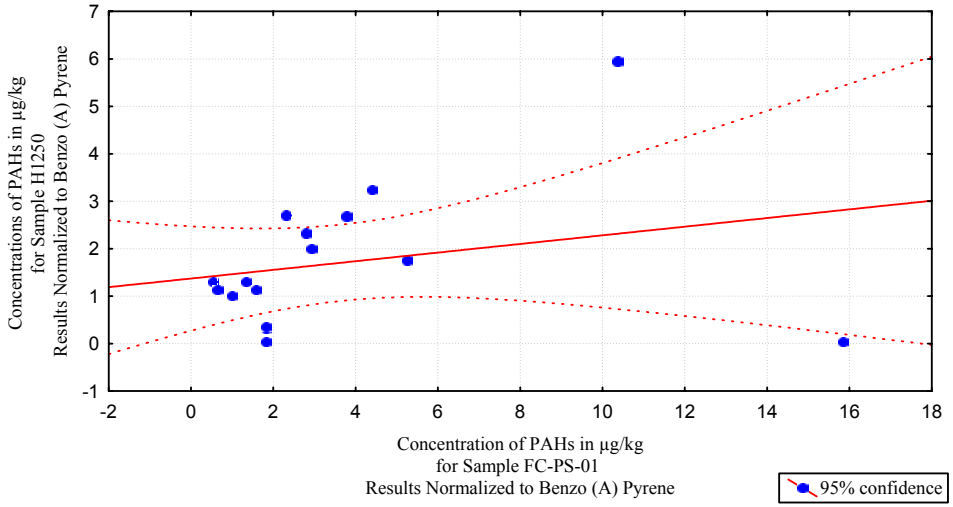


Correlations of PAH Concentations in µg/kg
Normalized to Benzo (A) Pyrene
Cache La Poudre River Samples vs. Sample H1250

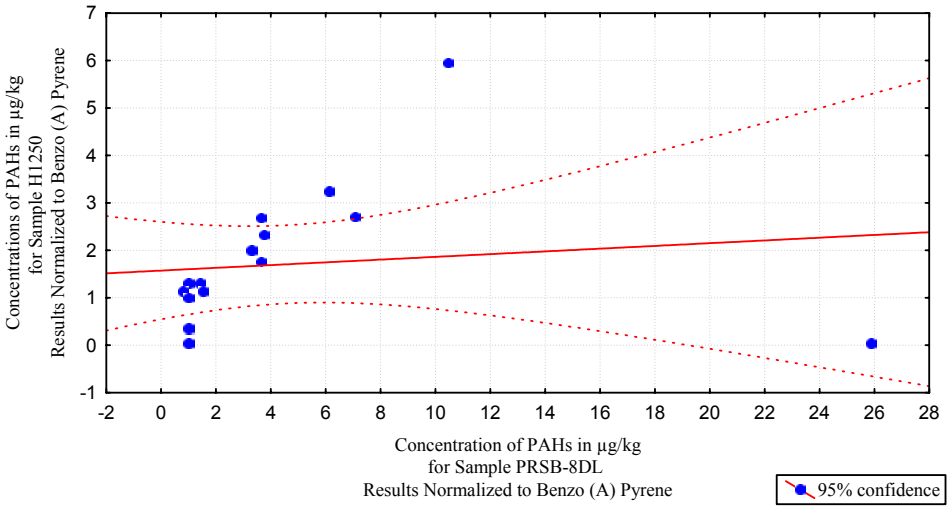
Scatterplot: FC-PR-01 vs. H1250
Results Normalized to Benzo (A) Pyrene
H1250 = 1.4345 + .06906 * FC-PR-01
Correlation: r = .23327



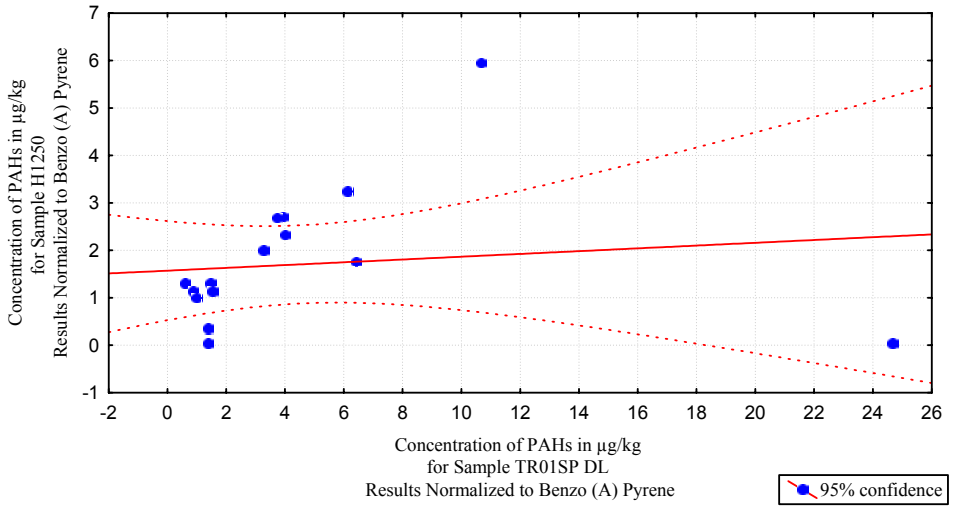
Scatterplot: FC-PS-01 vs. H1250
Results Normalized to Benzo (A) Pyrene
H1250 = 1.3724 + .09104 * FC-PS-01
Correlation: r = .24626



Scatterplot: PRSB-8DL vs. H1250
Results Normalized to Benzo (A) Pyrene
H1250 = 1.5729 + .02889 * PRSB-8DL
Correlation: r = .12204

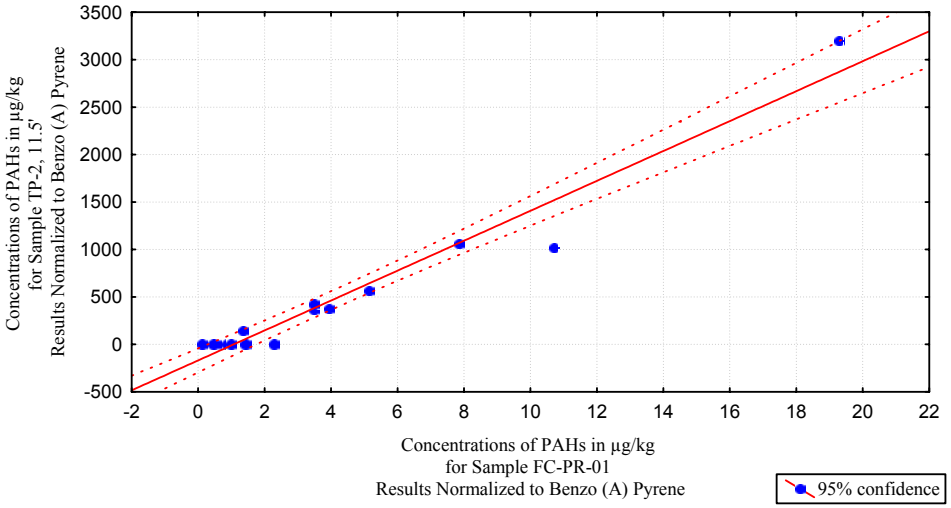


Scatterplot: TR01SP DL vs. H1250
Results Normalized to Benzo (A) Pyrene
H1250 = 1.5711 + .02938 * TR01SP DL
Correlation: r = .11809

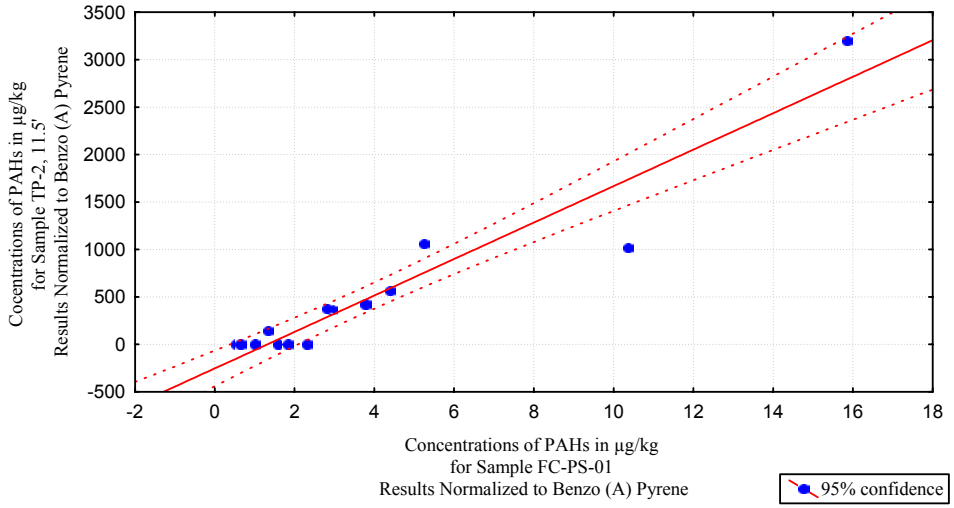


Correlations of PAH Concentrations in µg/kg
Normalized to Benzo (A) Pyrene
Cache La Poudre River Samples vs. Sample TP-2 11.5'

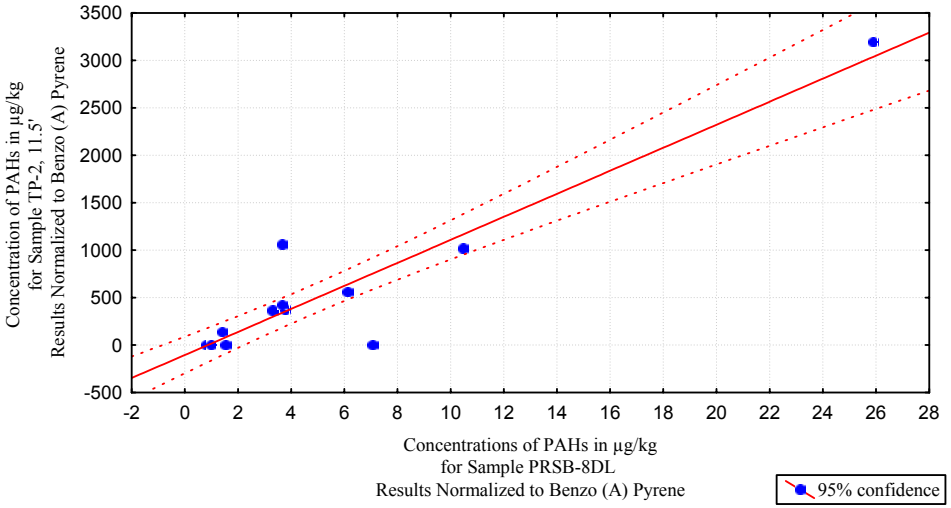
Scatterplot: FC-PR-01 vs. TP-2, 11.5'
Results Normalized to Benzo (A) Pyrene
TP-2, 11.5' = -168.4 + 157.56 * FC-PR-01
Correlation: r = .97603



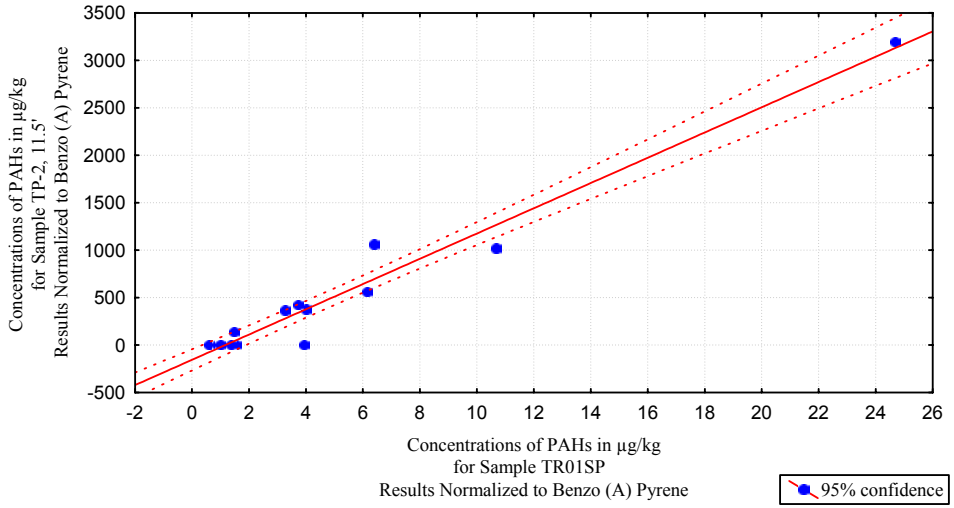
Scatterplot: FC-PS-01 vs. TP-2, 11.5'
Results Normalized to Benzo (A) Pyrene
TP-2, 11.5' = -253.1 + 192.05 * FC-PS-01
Correlation: r = .95265



Scatterplot: PRSB-8DL vs. TP-2, 11.5'
Results Normalized to Benzo (A) Pyrene
TP-2, 11.5' = -104.1 + 121.29 * PRSB-8DL
Correlation: r = .93976

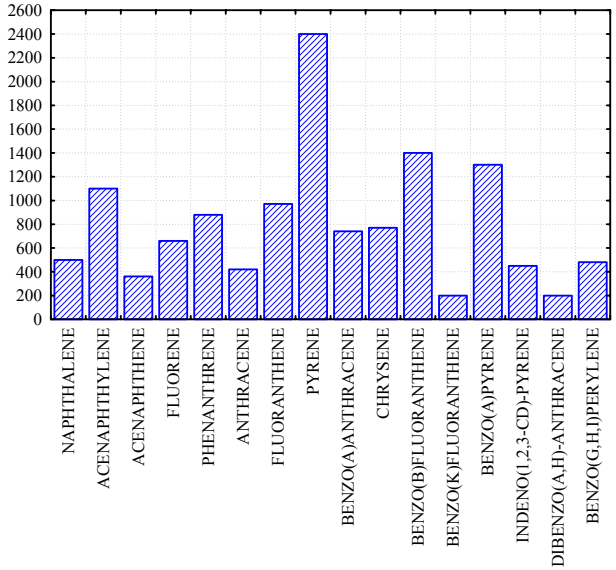


Scatterplot: TR01SP vs. TP-2, 11.5'
Results Normalized to Benzo (A) Pyrene
TP-2, 11.5' = -155.2 + 133.06 * TR01SP
Correlation: r = .98078

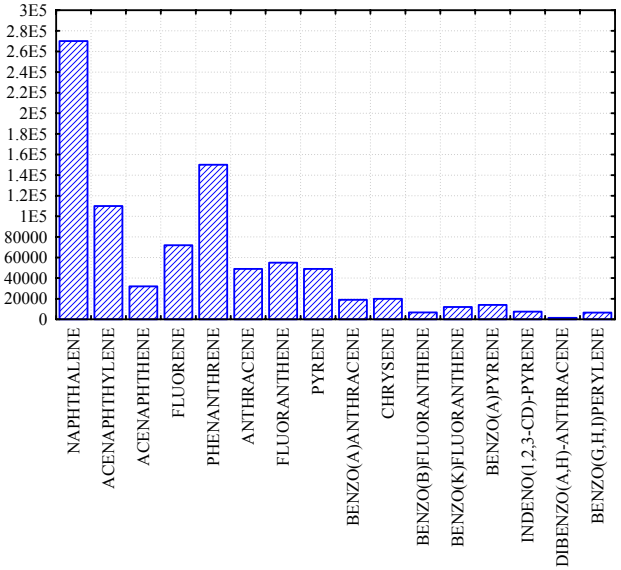


PAH Ratios for Cache La Poudre
River Samples vs. Sample BTH-10 (5-15')

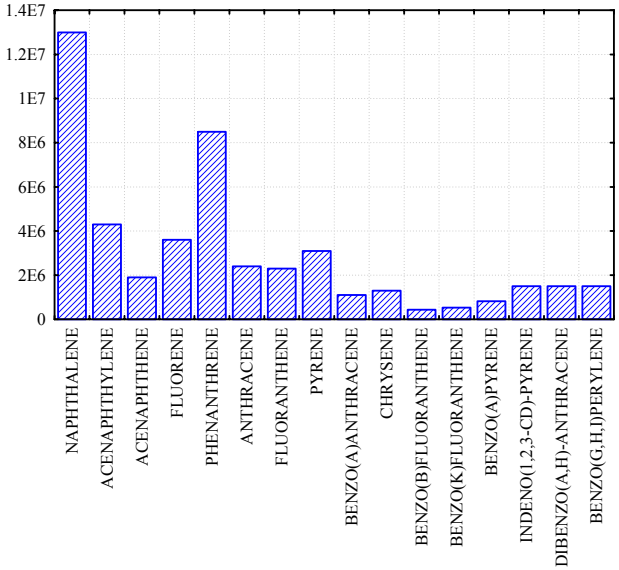
Bar/Column Plot for Sample BTH-10 (5-15')
PAH Concentrations in µg/kg



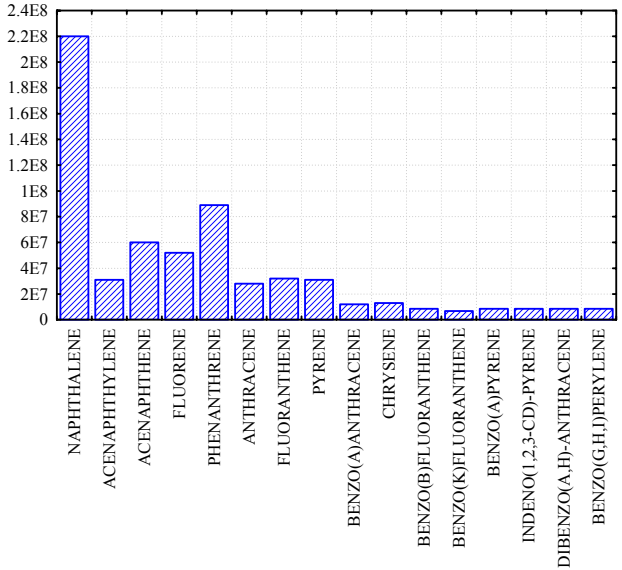
Bar/Column Plot for Sample FC-PR-01
PAH Concentrations in µg/kg



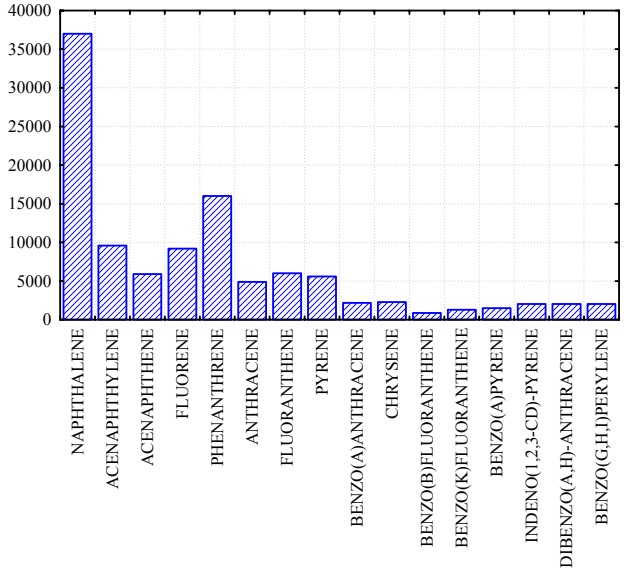
Bar/Column Plot for Sample FC-PS-01
PAH Concentrations in µg/kg



Bar/Column Plot for Sample PRSB-8DL
PAH Concentrations in µg/kg

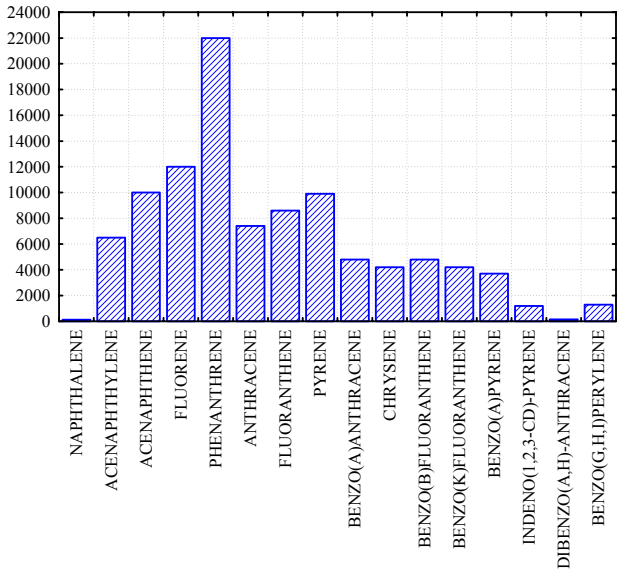


Bar/Column Plot for Sample TR01SP
PAH Concentrations in µg/kg

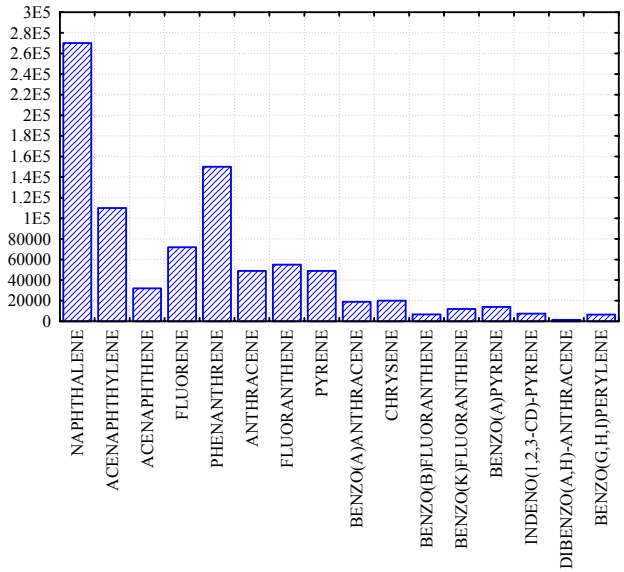


PAH Ratios for Cach La Poudre River Samples vs. Sample H1250

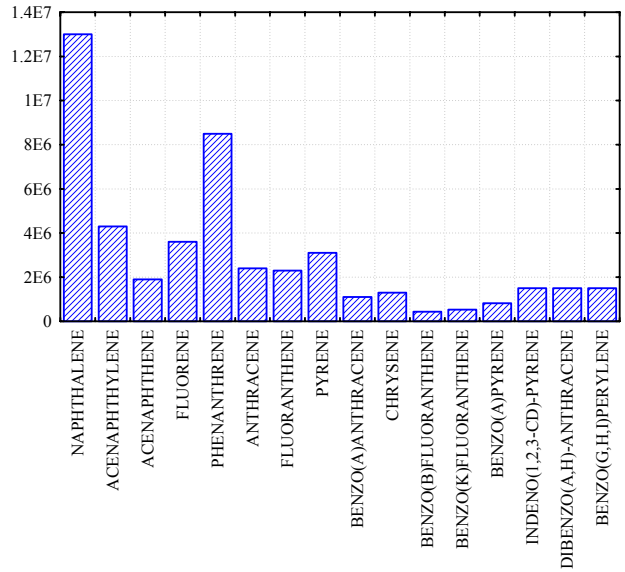
Bar/Column Plot for Sample H1250
PAH Concentrations in µg/kg



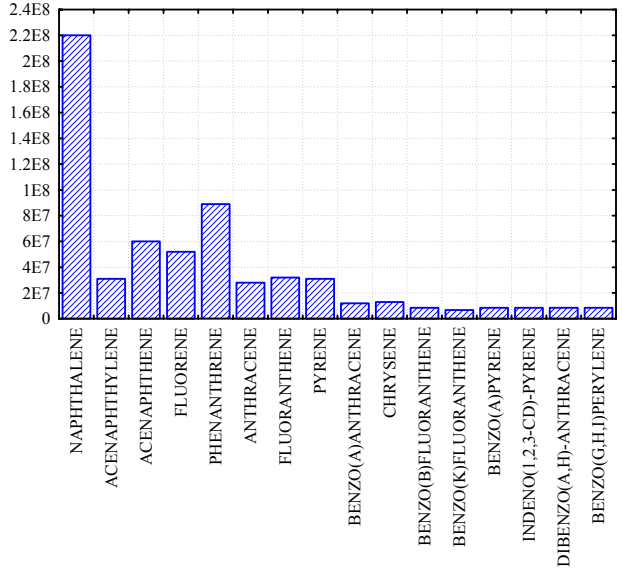
Bar/Column Plot for Sample FC-PR-01
PAH Concentrations in µg/kg



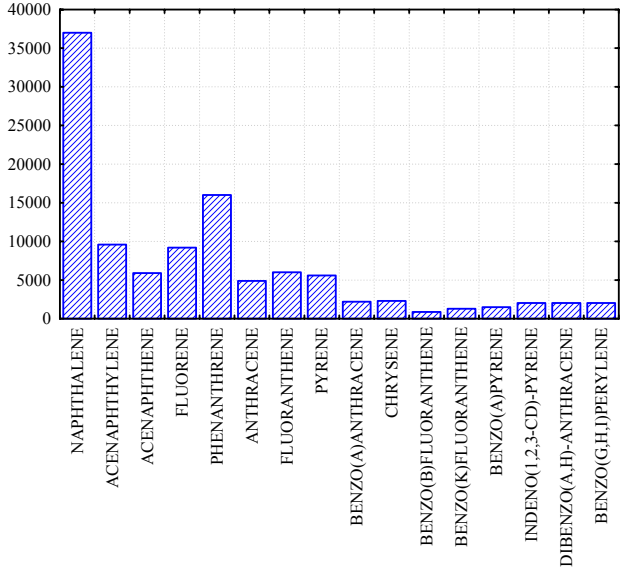
Bar/Column Plot for Sample FC-PS-01
PAH Concentrations in µg/kg



Bar/Column Plot for Sample PRSB-8DL
PAH Concentrations in µg/kg

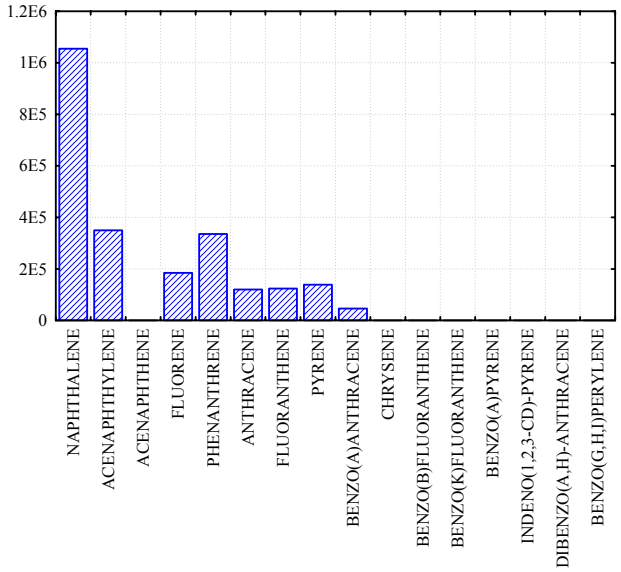


Bar/Column Plot for Sample TR01SP
PAH Concentrations in µg/kg

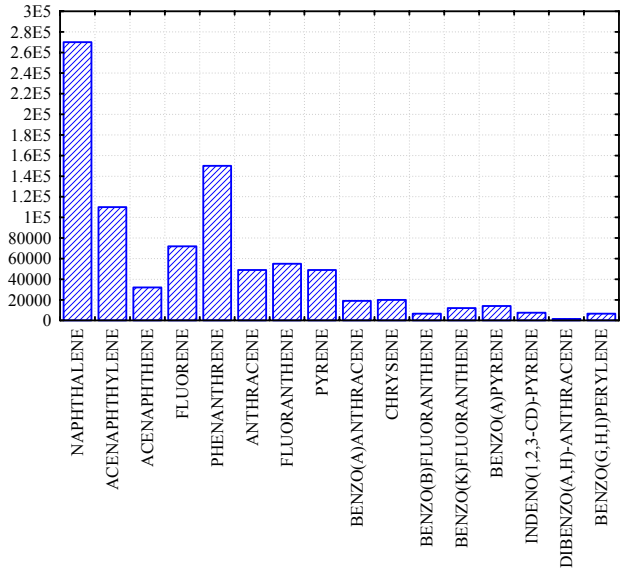


PAH Ratios for Cache La Poudre River Samples vs.Sample TP-2, 11.5'

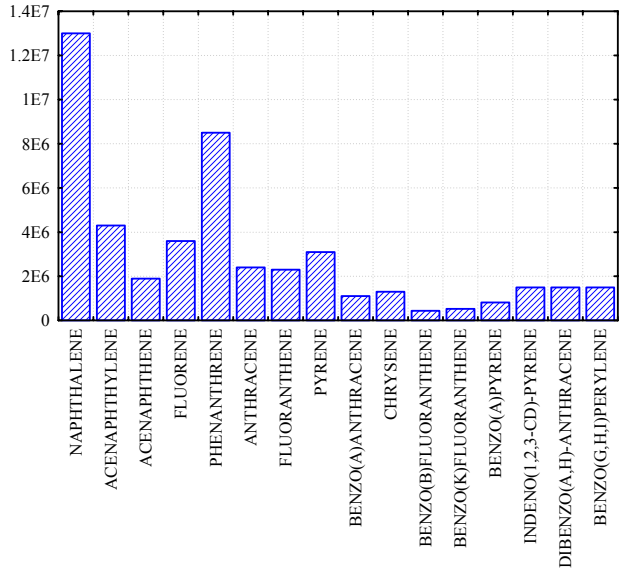
Bar/Column Plot for Sample TP-2, 11.5'
PAH Concentrations in µg/kg



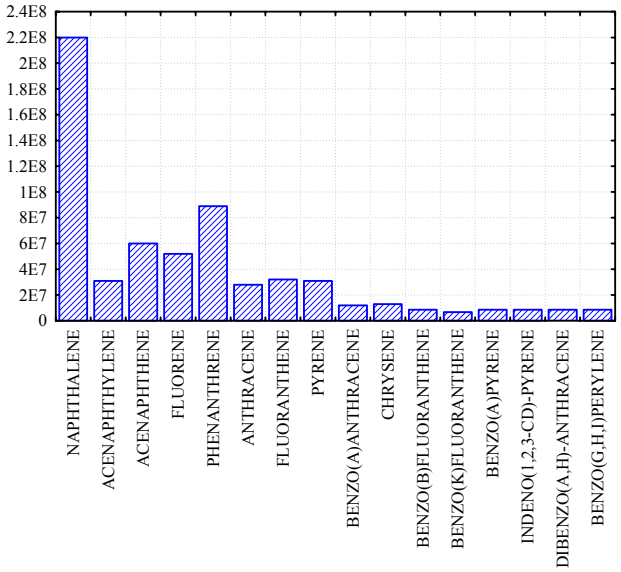
Bar/Column Plot for Sample FC-PR-01
PAH Concentrations in µg/kg



Bar/Column Plot for Sample FC-PS-01
PAH Concentrations in µg/kg



Bar/Column Plot for Sample PRSB-8DL
PAH Concentrations in µg/kg



Bar/Column Plot for Sample TR01SP
PAH Concentrations in µg/kg