



Management and Interpretation of Data Under a Triad Approach – Technology Bulletin May 2007



INTRODUCTION

Since its inception in 1995, the U.S. Environmental Protection Agency's (EPA) Brownfields Initiative and other revitalization efforts have grown into major national programs that have changed the way contaminated property is perceived, addressed, and managed in the United States. In addition, over time, there has been a shift within EPA and state regulatory agencies in the way that hazardous waste site cleanups are managed.

Project managers, regulators, technology providers, and other stakeholders are increasingly recognizing the value of implementing a more dynamic approach to site cleanup that is flexible and focuses on real-time decision-making in the field to reduce costs, improve decision certainty, and expedite site closeout. As shown in Figure 1, the Triad approach uses (1) systematic project planning, (2) dynamic work strategies (DWS), and (3) real-time measurement technologies to reduce decision uncertainty and increase project efficiency (Source: EPA 2003).

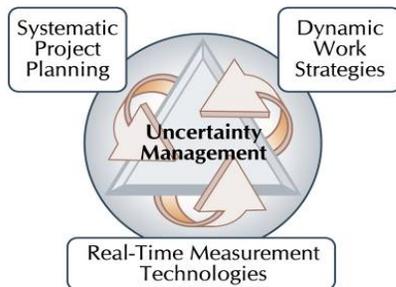


Figure 1: The Triad Approach.

The approaches used in Triad projects require specific procedures and tools for data interpretation and management. For example, technologies such as open-path air monitoring systems and subsurface geophysical detection tools can generate thousands of individual data points that must be assimilated and manipulated by computer to provide the full benefit of their real-time imaging capabilities. Fortunately, data management and decision support tools (DST) have become more available in recent years, and

experienced Triad practitioners are already exploiting them (ITRC 2003).

About the Brownfields and Land Revitalization Technology Support Center (BTSC)

EPA established BTSC (www.brownfieldstsc.org) to ensure that brownfields and other land revitalization decision-makers are aware of the full range of technologies available for conducting site assessments and cleanups and can make informed decisions about their sites. The center can help federal, state, local, and tribal officials evaluate strategies to streamline the site assessment and cleanup process at specific sites; identify, review and communicate information about complex technology options; evaluate contractor capabilities and recommendations; and plan technology demonstrations.

Localities can submit requests for assistance through their EPA Regional Brownfields Coordinators (<http://www.epa.gov/swerosps/bf/corcncnt.htm>) or by calling 1-877-838-7220 toll free. For more information about BTSC, contact Carlos Pachon at (703) 603-9904 or pachon.carlos@epa.gov.

The Brownfields and Land Revitalization Technology Support Center (BTSC) created this bulletin to focus on implementing a data management program for a Triad project, and includes:

1. A brief introduction to the Triad approach
2. Answers to frequently asked questions about data management on Triad projects, such as the following:
 - How do Triad practitioners plan for data management and interpretation?
 - Who prepares the dynamic work strategy (DWS) and data management plan, and what are the essential elements of the data management plan?
 - How are data collected and used in a Triad investigation?

- What types of tools are used to manage, interpret, and communicate data?
 - How do Triad practitioners balance the need for data review with the need for rapid data turnaround?
3. Three examples of data management are addressed, with state agencies as the primary regulatory body:
 - Milltown Redevelopment Site, Milltown, New Jersey
 - Metal Etching Site, Freeport, New York
 - Underground Storage Tank (UST) Sites, South Dakota
 4. Sources of additional information for project teams and stakeholders who develop or provide input on a data management program in support of a Triad project

THE TRIAD APPROACH

Triad is a three-pronged approach for improving decision-making and streamlining environmental cleanup projects. The Triad approach draws on advancing science, technology, and practitioner experience to develop strategies for making site work more defensible, resource-effective, and responsive to stakeholder concerns.

Data management is an essential cross-cutting component to the three elements of the Triad approach: systematic project planning, dynamic work strategies, and real-time measurement technologies.

Systematic project planning provides the overarching framework for project planning, contracting, and stakeholder communication. The systematic planning process compels the stakeholder group (which consists of regulators, landowners, civic leaders, public participants, and their representatives) to reach consensus on critical issues, such as schedule, milestones, data management, communication, and — most importantly — exit strategy as early as possible in the project's life cycle. Although stakeholder participation is necessary for all hazardous waste site remediation and closure efforts, it plays a particularly important role in the Triad approach. Stakeholder participation is particularly important because of the Triad's reliance on non-standard analysis to support real-time decision-making and its use of dynamic work strategies that often defer significant sampling program decisions to

the field (Triad Resource Center 2006). Developing data flow plans, and gaining an understanding of the data user's needs are essential tasks during systematic planning.

Dynamic work strategies (DWS) are embodied in dynamic (flexible) planning documents. The key aspect of a dynamic work strategy is a defined *decision logic* that members of the field team can follow as they collect and evaluate data. The decision logic is a set of guidelines or decision rules that provide a logical framework the project team will use to make decisions on how, when, where, and why sampling and analysis will be conducted. The DWS informs field team members and project stakeholders on the amount and type of data to be collected initially and as the investigation progresses. The DWS, with the decision logic at its core, is incorporated into project planning documents and may be summarized in a flow chart or diagram (Figure 2).

The Triad approach differs from conventional investigations in its emphasis on collecting data using *real-time measurement technologies*. These technologies allow data to be collected or analyzed at a much greater density or rate than is typically obtained through a conventional remedial investigation (RI) or other site characterization project. The Triad approach uses real-time measurement technologies to increase the amount of data available to support decision-making and to provide these data to the project team in a matter of minutes or hours. Thus, decision-making for many projects can occur in real time while equipment is mobilized to the site and samples are being collected, rather than after months of data review, report preparation, and approval. It is no surprise then, that management and communication of data is of utmost importance to the success of a dynamically managed project.

The primary tool that guides a Triad project is the *conceptual site model (CSM)*. The CSM is a planning tool that organizes what is known about a site and helps the project team identify what more must be known to make defensible project decisions. The CSM unifies existing data into a concise description of a site's physical setting, contaminant release, transport mechanisms, and exposure points that describe the problem. The CSM is treated as a working hypothesis of site conditions that will be refined and improved over the course of the project.

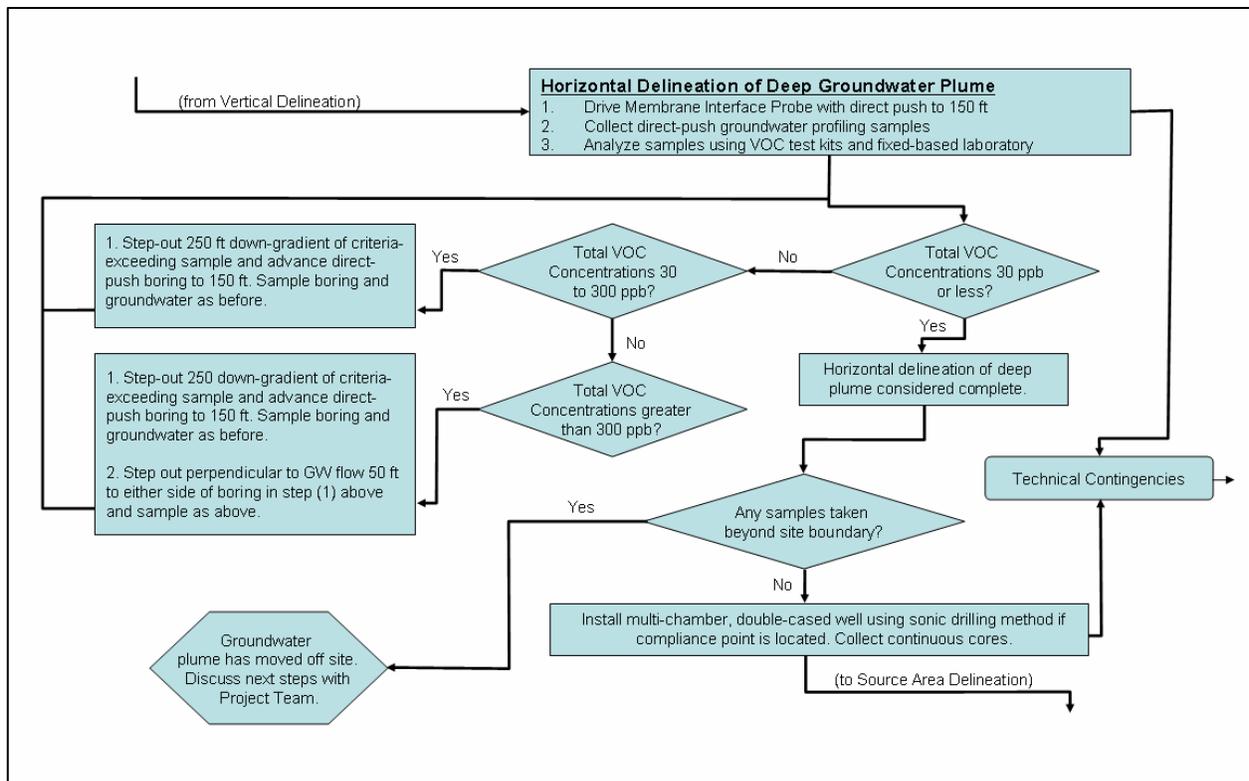


Figure 2. Example of a Subset of a Decision-logic Diagram. The decision-logic subset depicted in these diagrams forms part of a dynamic work strategy (DWS) plan, and was created during systematic planning. Enormous amounts of data from parallel sampling schemes may be generated once field work begins, and a data management plan is critical to allow quick information dissemination and presentation so that the project team can interact and make decisions in real time.

A well-implemented Triad project must use data management procedures that promote clear visualization of the CSM and encourage participation of all stakeholders in its development and refinement. Furthermore, data management and collection procedures should allow for review and refinement of the CSM in nearly real time. This distinction is a critical difference between the Triad and more conventional approaches to site investigation and poses the central data management challenge for Triad projects.

Triad practitioners recognize that the uncertainty inherent in site characterizations results largely from (1) sampling uncertainties, which are minimized by high-density, sometimes lower-quality sampling of heterogeneous media using real-time sampling and analytical methods, and (2) analytical uncertainties, which are minimized by higher-quality, lower-density laboratory analysis. The Triad practitioner combines both types of data into a *collaborative data set* that

maximizes the strengths of each data type to minimize overall uncertainty. Collaborative data sets combine information from multiple data collection tools, ranging from test kits and hand-held meters to survey information and analytical laboratory data. It is essential that the data management system of a Triad project provides an efficient means for assembling and using collaborative data sets.

The Triad practitioner also looks for tools and techniques that allow the core technical team — the environmental professionals who conduct the project — to share and interpret data as rapidly as possible without compromising overall data quality. Tools such as relational databases, data reduction or visualization software (also called “decision support tools” [DST]), and project Web sites or file sharing sites improve the ability of the core technical team to share data and new insights with project stakeholders. As a result, all interested parties may meaningfully participate in refining the CSM and

adjusting the sampling plan. Further information about the Triad approach is available at www.triadcentral.org.

FREQUENTLY ASKED QUESTIONS

Five frequently asked questions are answered below to help potential Triad practitioners understand how familiar data management issues are handled under the Triad approach.

How do Triad practitioners plan for data management and interpretation?

Triad investigations are dynamic. A DWS is developed before the project team mobilizes to the field, and the DWS rather than a static grid-based sampling plan is used to guide the investigation. The DWS may identify a number of initial sampling locations, but subsequent (referred to as “adaptive”) sampling locations are based on predetermined criteria and are driven by collection and interpretation of real-time data.

The DWS must have a parallel data management strategy that allows real-time data interpretation and decision-making by project stakeholders. For this reason, it is important for project planning documents to include a data management plan that contains a detailed discussion of data management procedures, equipment (software and hardware), lines of communication, reporting guidelines, and time frames. Careful planning further allows the project team to adequately assess costs and resource needs associated with data management.

Who prepares the DWS and data management plan, and what are the essential elements of the data management plan?

Preparation of the DWS and data management plan is usually the responsibility of the core technical team; however, these plans should not be prepared until stakeholder input and concerns are obtained during a series of systematic planning meetings. As the Triad methodology is applied to a broader class of environmental projects and programs, some may initially view its principles as conflicting with regulatory standards and approaches. Thus, it is critical to the success of a Triad project to encourage the participation of regulators, landowners, and the public

from the outset and to maintain a spirit of transparency and cooperation throughout the project. The Triad approach can incur more costs upfront because critical issues are addressed at the outset of the project; however, the initial expenditure should be more than offset by the savings that will result from fewer mobilizations and phases of work, with less conflict and more efficient coordination between stakeholders later in the project.

A successful data management strategy depends on input not only from data management specialists but also from those who will be generating and using the data, including vendors, geoscientists, chemists, and other technical specialists. The data management plan must address how data from different sources will be integrated to support decisions by considering the following elements:

- **Origin of data streams:** Data may be generated by a variety of field or laboratory instruments, and results may be documented using various manual and electronic formats. The quality and format of the various data streams must be understood so that they may be merged effectively into a common database.
- **Data pathways and communication:** Project managers must recognize that a number of key participants in project decision-making may be remote from the site during significant periods of time. The data management plan for the project should recognize this issue as important and provide for the rapid turnaround and distribution of results and data analysis to stakeholders. The data management plan should also assign responsibility for all aspects of the management and security of the data throughout the project life cycle.
- **Level and timing of quality assurance and quality control (QA/QC):** Triad-based programs often include QA/QC components that are either unique or significantly different in scope and nature from what a conventional program would require. Fewer QC requirements are typically pre-defined for real-time measurement systems that are deployed in the field. This lack of pre-defined requirements offers the opportunity to develop QC protocols that are customized to the site-specific needs and performance goals of a project. The concept of customized QC requirements is consistent with EPA's

Performance Based Measurement System (PBMS) initiative (<http://www.clu-in.org/search/t.focus/id/195>).

- **Data analyses (visualization and statistical):** Triad practitioners should have a clear idea of the statistical analyses, geostatistical programs, and visualization software that will be appropriate to interpret and evaluate the data at early planning stages of the project. Planning for data evaluation up front assures that the data are formatted appropriately for the analytical tool and that the analytical suite is appropriate for the project's objective and the site's characteristics.
- **Data stream integration:** Care is required if databases are used to store collaborative data sets. The two separate data sets should not be indiscriminately mixed together because they often will not be statistically comparable. Blind merging of data sets with different QC protocols, (such as in statistical programs to calculate means and standard deviations) should be avoided, and clear, consistent data identification protocols should be used to minimize time-consuming errors in identifying and managing data.
- **Correspondence between data and the decisions they support:** It is important to understand how the data will be used to support different decisions as the project progresses. The linkage between data and decisions may be best summarized in a table or matrix format, providing a direct means to assess whether data collection and analysis techniques are being used appropriately.
- **Data archive and repository:** As part of the systematic planning process, it is important for project managers to be aware of the records that must be included in the project archives and make sure the mechanisms are in place to capture the appropriate documentation.

How are data collected and used in a Triad investigation?

The key to using data to drive decision-making in the field is to ensure that the data are readily available as the investigation is being conducted. Real-time data collection and analysis methods may yield immediate graphical results. For instance, subsurface investigations increasingly rely on characterization tools that use direct-push drilling equipment. One

example is the cone penetrometer test (CPT), which generates a lithologic profile as a sensor is pushed through soil. Other tools create profiles of organic contaminants as the sensors are advanced through the subsurface environment, such as the membrane interface probe (MIP) or the laser-induced fluorescence (LIF) sensor.

Vendors of these services can usually plot the profiles as the sensors are advanced, giving the field team a hard-copy graphic depiction of subsurface characteristics of interest, such as a continuous-profile CPT tip resistance (indicating soil type), dynamic pore pressure (indicating permeability), or MIP response (indicating contamination by volatile organic compounds [VOCs]). Many vendors can quickly generate additional visualizations, such as modeled plan view or three-dimensional plume maps. The team can select the following day's sampling locations after they have reviewed these work products and by following the predetermined decision logic established during systematic project planning.

Similarly, a variety of instruments and tests kits are available to rapidly analyze samples for metals, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and other classes of chemicals. Test kit results are usually recorded in logbooks but may be logged electronically using a personal data assistant (PDA). Other hand-held instruments such as the photoionization detector (PID) and X-ray fluorescence (XRF) detector include data loggers or more comprehensive data systems with electronic data porting capabilities. Location data, such as locations of surface sampling or boreholes, can be recorded electronically using global positioning system (GPS) equipment.

Although many decisions can be made using graphical printouts or data recorded in log books, a Triad investigation is most efficient when data can be captured electronically and then downloaded in a seamless manner to a relational database (a database where relationships between data items are organized in tables that can be linked through a common field). As noted previously, many vendors of real-time analytical technologies can quickly generate representations of electronic data in the field. Alternatively, different types of data can be transferred to a central on-site or off-site location for incorporation into the relational database and for

further analysis using widely available software. Numerical detector responses can be tabulated and correlated with laboratory data within a relational database.

What types of tools are used to manage, interpret, and communicate data?

The streamlined manner used to acquire data during a Triad project is mirrored by the tools and techniques used for data management and interpretation. DSTs are interactive software tools decision-makers use to answer questions, solve problems, and support or refute conclusions. They may have a single function, but more often incorporate multiple functions, such as data acquisition, spatial data management, modeling, and cost estimation. DSTs are designed to bring data management and interpretation capabilities as close (in both time and space) to data collection activities and decision-making as possible while still maintaining the integrity of the work products they develop.

The *DST matrix* (<http://www.frtr.gov/decisionsupport/>) is a Web-based resource EPA created to assist Triad practitioners in selecting a DST to meet project objectives. The matrix provides detailed information for 25 DSTs. Additional information about the DST matrix is provided at the end of this bulletin. Examples of data management, interpretation, and communication tools are presented below. Links to specific programs are provided in the DST matrix.

Examples of available tools include:

Scribe (http://www.ertsupport.org/scribe_home.htm) is a data management DST developed by EPA's Environmental Response Team (ERT) that allows a greater number of project teams working at small to medium sites to realize the benefits of maintaining data in a relational database. Scribe can import electronic data, including analytical laboratory results in electronic data deliverable (EDD) format and sampling location data such as GPS coordinates. Scribe can print sample labels and chain-of-custody documents. Scribe is integrated with a software extension called "Scriblets" to capture and import sampling and monitoring data collected using hand-held PDAs during field work. The ability to sort, query, post, and plot data in the field frees project teams from the need to load data in an office setting.

On Triad projects, this ability means that the field team can conduct an initial evaluation of the data moments after a measurement is made using a real-time tool.

Spatial Analysis and Decision Assistance (SADA) is a package of data analysis tools developed by the University of Tennessee using grants provided by EPA. SADA incorporates tools for visualization, geospatial analysis, statistical analysis, human health risk assessment, ecological risk assessment, cost/benefit analysis, and design of sampling plans. It includes a data import module that allows the user to incorporate electronic data rapidly, thus making it ideal for use in the field.

The need to distribute real-time data to geographically remote stakeholders and members of the project team has increased the use of *project-specific Web pages*. Sample results and maps can be posted to the Internet almost as soon as they are generated. Electronic access encourages greater participation among stakeholder groups, which leads to an enhanced sense of ownership among group members.

How do Triad practitioners balance the need for data review with the need for rapid data turnaround?

Triad practitioners use a variety of techniques to maintain data quality while expediting processing, reviewing, and reporting field data. Before the project team designs a sampling program around a real-time sampling and analysis technique, it should be tested during a *demonstration of methods applicability (DMA)*. Confirmation is often provided by collecting *collaborative data sets*.

A DMA is an initial site-specific performance evaluation for a method, a series of related methods, or a data collection tool. Investigations that use the Triad approach depend more heavily on field-based analytical equipment and emerging technologies. A DMA usually consists of using the real-time technology on a limited suite of samples while sending paired samples to an off-site laboratory for standard laboratory analysis for the same analytes or parameters. The DMA sample results are evaluated using statistical methods such as regression analysis and analysis of variance to (1) evaluate the adequacy

of the real-time method for achieving the project's data quality objectives (DQO), (2) establish appropriate sampling and analysis procedures, and (3) develop action levels for the real-time methods. By conducting the DMA before the field sampling program, many problems and data "bottlenecks" that may arise during the sampling program can be anticipated and corrective measures can be established proactively.

Making full use of collaborative data sets is another key to balancing rapid generation of data with thorough review. As noted previously, collaborative data sets integrate data obtained rapidly using real-time techniques with analytical data from an off-site laboratory. A subset of samples that were analyzed using real-time measurement technologies may be split, with the other portion sent to an off-site laboratory to manage uncertainty in real-time measurements. These samples are selected based on their representativeness (already established by the refined CSM) to support specific decisions that require more analyte-specific information or more accurate quantitation (ITRC 2003).

The real-time data can be used to support most aspects of the DWS, as long as the adequacy of the real-time techniques is established ahead of time during the DMA. If the DMA is not completed before the field program begins, quick data reporting turnaround (24 or 48 hours) is required for a portion of the samples analyzed off site to allow timely evaluation of the data adequacy.

Similar to conventional investigations, data review requirements should be documented in the quality assurance project plan (QAPP). It is important that the provisions of the QAPP be carefully followed during the investigation (Triad Resource Center 2006).

EXAMPLES OF DATA MANAGEMENT AND INTERPRETATION UNDER THE TRIAD APPROACH

The three examples below illustrate the use of procedures and tools for data management and interpretation for Triad projects.

Example 1: Milltown Redevelopment Site, Milltown, New Jersey

Milltown Redevelopment is a Brownfields site in Milltown, New Jersey. A large, diverse stakeholder group was formed to plan, conduct, and oversee the project. The stakeholder group included representatives from federal, state, and local agencies, as well as a potential site developer.

The primary project goals were to (1) develop and revise a CSM of site geology, hydrology, and contaminant fate and transport by collecting soil, sediment, and ground water samples and geologic logs on a regular grid, and (2) delineate potential areas of concern (AOC) on a closer grid spacing of adaptive sampling locations.

Site Facts

- The 22-acre Brownfields site is in the heart of downtown Milltown, New Jersey. More than 50 percent of the site is covered with warehouses and industrial buildings.
- Industrial use of the site began with a rubber manufacturing plant in the late 1800s, succeeded by numerous other industries.
- The Milltown Redevelopment Authority and Middlesex County Improvement Agency entered into an agreement with a developer to improve the parcel for mixed uses, including more than 300 age-restricted residential units, commercial space, and open space along Mill Pond, the main waterway through central Milltown.
- Principal contaminants of concern (COC) included VOCs (particularly chlorobenzene), PAHs, PCBs, pesticides, and total petroleum hydrocarbons (TPH).

The stakeholder group identified several concerns through a series of systematic planning meetings, including the management of the large volume of data that would be generated by field analytical methods over a relatively short, 2-month time frame (Mack 2006a). EPA's Brownfields Technical Support Center (BTSC) identified Scribe and Scriplets (see "Scribe" on page 6) as DSTs that would meet the project team's needs for data management (Figure 3) and address the stakeholder concerns. Another outcome of systematic planning was the development of a DWS for selecting successive rounds of sampling locations in real time, thus allowing rapid delineation of potential AOCs.

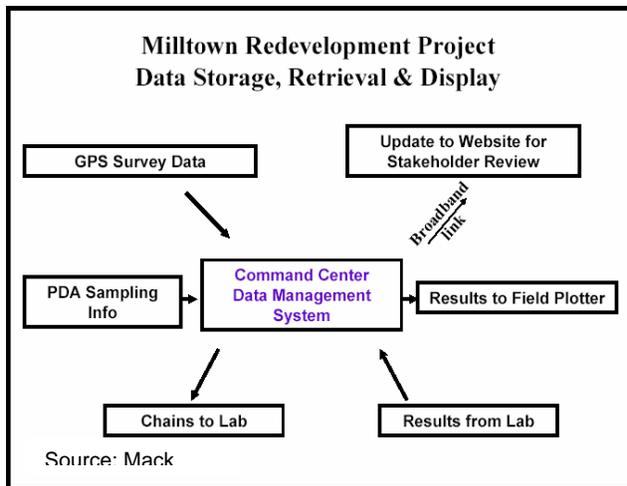


Figure 3: Generalized Schematic Diagram of Data Pathways. At Milltown, Scribe was used as the central data management software, with Scribblets used on PDAs to feed field data to Scribe. This allowed the project team to make real-time decisions during the sampling mobilization.

Data Management Tools and Procedures

Scribblets allows the user to set up a sampling template before field work begins; a field technician uses the template to enter data electronically as they are generated in the field. A sample numbering sequence was assigned in Scribblets before sampling began, providing sample numbers automatically as the sampling event progressed. Sample data, real-time analytical results, and sampling location data (coordinates generated using GPS survey equipment) were entered into Scribblets in the field and then imported to the Scribe database by connecting the PDA to a laptop computer with a USB cable. The result was an all-electronic data pathway that minimized the potential for transcription errors.

Scribe facilitated “in the trailer” review of data and enabled the project team to plan the next day’s sampling locations before team members left the site for the day. After each round of sampling, the data were imported to Scribe, reviewed, queried, and exported to AutoCAD (visualization software) through an electronic data format the project team created in Scribe. Most importantly, Scribe made available in real time many of the features and advantages of a relational database while the team was still in the field.

Data Interpretation Tools and Procedures

The DWS anticipated the need for rapid delineation of AOCs, and so it provided decision logic diagrams in the work plan. Decision logic diagrams facilitate delineation of contaminated zones in the field because they provide general rules, rather than predetermined sample locations. (An example of a decision rule would be, “step out 5 feet in each cardinal direction from each grid location where the field instrument’s action level was exceeded and collect an additional instrument reading at each new location.”) Scribe provided quick turnaround of preliminary sample results; as a result, optimal adaptive sampling locations were identified shortly after sample results collected previously were reviewed in Scribe and plotted in AutoCAD. Scribe’s data querying capabilities allowed sample results to be sorted by analyte or depth and plotted with any associated data item (such as data qualifier) that was entered to the database through Scribblets, while still assuring the relational integrity of the data were maintained. In this manner, the ground water plume delineation was expedited, and the CSM was developed to explain the likely source of the plume and mechanisms that contributed to its spread.

Data Communication Tools and Procedures

A project-specific Web site was set up on the EPA ERT’s Web server. Passwords were issued to all stakeholders to provide access to the Web site. Maps were posted to the Web site daily, along with progress reports and information about meeting times and places. The Web site allowed stakeholders, including any who were not present at the site, to review tables and maps summarizing the project team’s updated understanding of the distribution of COCs at the end of each day and then provide input for the next day’s sampling.

Project Results

The field team was able to sample more than 400 locations in approximately 5 weeks. The field team collected more than 130 ground water samples and 600 soil samples, generating 30,000 analytical results that were loaded into the database and that underwent QC review in a short time.

The benefits of streamlined data acquisition and processing using Scribe were evident during the dynamic investigation of the chlorobenzene plume. During a site walk-through immediately preceding the Triad investigation, a vat was discovered under a formerly used loading dock that had been obscured by heavy brush. A sample from the vat verified the presence of chlorobenzene. Although the vat would likely have been discovered during a conventional study, the Triad DWS provided a flexible means to adapt the sampling strategy immediately after the discovery was made in the field, without modifying the written plans. The DWS provided clear direction to the sampling teams and the means for quick concurrence on the sampling strategy from project stakeholders. The plume was delineated in approximately 4 days after 63 ground water and 28 soil samples were collected from 46 sampling locations (shown as black dots on Figure 4).

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Example 2: Metal Etching Site, Freeport, New York

The Metal Etching Site is a New York State Superfund site in Freeport, Nassau County, New York, adjacent to Freeport Creek. The New York State Department of Environmental Conservation (NYSDEC) conducted an RI of the site to identify and delineate contamination in surface and subsurface soil, sediment, soil gas; source areas; ground water contamination; and impacts to surface water.

Site Facts

- The 2-acre site is currently used for commercial boat storage, sales, and maintenance.
- The site operated from 1966 through 1999, and products were printed or etched using anodization, chromate conversion, and chrome or nickel plating processes.
- The primary method for disposal of sanitary and industrial wastewater at the site was through sanitary sewer lines. AOCs identified at the site included the former plating area, chemical and waste storage areas, wastewater treatment operations, failed sewer lines and connections, waste storage areas, and historical spill areas.
- Site-related COCs included chromium, cadmium, nickel, and chlorinated hydrocarbons such as tetrachloroethene (PCE), and trichloroethene (TCE).

NYSDEC required that the Triad approach be used for the RI. The goal of using the Triad approach was to complete the RI during one mobilization effort, thereby decreasing time and costs for the investigation, while increasing confidence in project decisions through a greater sampling density.

Data Acquisition Tools and Procedures

Surface soil, subsurface soil, and ground water samples were collected on a grid with a borehole spacing of 70 feet throughout much of the site, with a more focused grid (20-foot spacing) in areas of particular interest. The DWS called for adaptive samples to be collected at two new locations offset 10 feet from areas where contaminants were detected at concentrations above cleanup goals.

The team evaluated the use of field analytical methods (XRF for metals and a field gas chromatograph [GC] for VOCs) but decided against them because of concerns regarding the high number of confirmation samples that would be required to collaborate the XRF with the field GC measurements. Furthermore, elevated detection limits would restrict the usefulness of the XRF to sources and other high-concentration areas. In the case of VOC analysis, the sample throughput for the field GC would be too low to support the cost of the instrument and analyst. Instead, a nearby laboratory was used to analyze samples using modified EPA SW-846 methods, which

required less QA/QC and could be completed overnight. Samples were delivered to the laboratory by noon of each day, and the results were returned to the field team by 11:00 a.m. the next day, thus providing data almost as quickly as on-site analytical methods.

A collaborative data set was collected to support the objectives of the project; real-time data was combined with data collected using standard methods and each type of data had a specific purpose. The advantage gained by collecting data in real time was in obtaining the most complete "snapshot" of contaminant distribution that time and budget would allow. Confirmation sampling, using standard (SW-846) laboratory methods, indicated that the real-time data for soil and ground water could be used to prepare contaminant distribution plots and plume maps, which were used to refine the CSM in real time and select locations for ground water wells. The confirmation sampling indicated real-time ground water data did not meet all of the DQOs for making decisions about the need for remediation; therefore, ground water monitoring wells were installed and samples collected for analysis using EPA SW-846 methods. The locations of the wells, however, were based on contaminant distributions plotted from the real-time data.

Data Management Tools and Procedures

A relational database was constructed using geographical information system (GIS) software. The database contained chemical data, water levels, and survey data. Tables presenting the analytical results as well as maps of contaminant distribution and ground water flow were all prepared from the database using the GIS software interface. Because field personnel obtained electronic data deliverables (EDDs) from the laboratory daily, updated contaminant distribution maps were quickly prepared and the field program was redirected as indicated by the DWS.

The GIS software was used to automatically integrate the collaborative data set, which included real-time and compliance data. Real-time data were used to delineate the extent the media were contaminated and to develop the CSM; compliance data were used to quantify the level of contamination to facilitate

comparison with regulatory standards and guidance values.

As discussed above, the database queries were used to prepare graphical representations of contaminant distributions, which were used in the RI report to identify areas that would require remediation. Ground water flow and the impacts of tidal fluctuations were evaluated using spreadsheets containing data exported from the database.

Data Communication Tools and Procedures

Data were shared with the stakeholders through e-mail messages. Contaminant distribution maps and tables were prepared in .pdf format and transmitted in the e-mail messages.

Project Results

The real-time analysis required by the Triad approach (daily redox potential [Eh] measurements using a downhole Eh sensor) quickly revealed that a strongly reducing environment predominated the site subsurface. The reducing environment had immobilized metals, and metal contamination was limited to former waste storage and disposal areas. Furthermore, it was established that tidal recharge promoted biodegradation of the VOC plume.

Daily analysis permitted early elimination of hexavalent chromium as a COC, which resulted in significant cost savings because ground water samples did not require analysis for hexavalent chromium. The real-time data defined a plume of chlorinated VOCs extending across the site, with the reducing environment in the shallow aquifer effectively degrading PCE to TCE to cis-1,2-dichloroethene and finally to vinyl chloride (Figure 4). The chlorinated solvents in the deeper portions of the aquifer, however, did not appear to be degrading under existing conditions.

Real-time analysis coupled with the GIS software permitted stakeholder input in redirecting sample collection to more accurately define the affected areas. Without real-time analysis and visualization, the chlorinated VOC plume may have been incompletely characterized because installation of the monitoring well network would have been based more on ground water flow than on chemistry. Finally, the

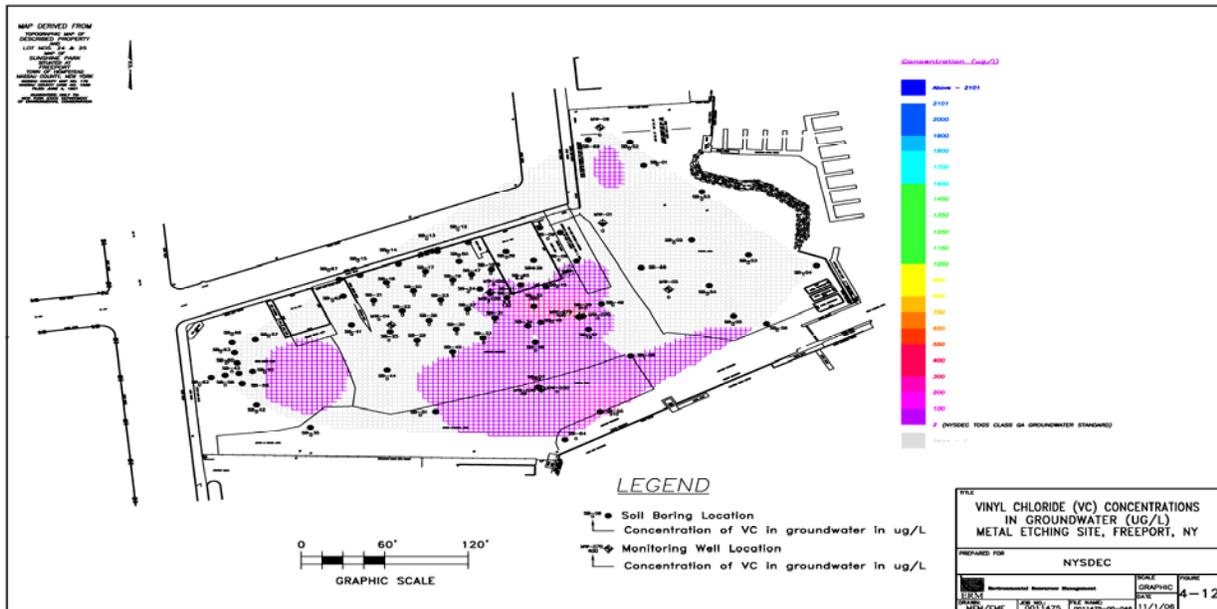


Figure 4: Vinyl Chloride contaminant distribution map, Metal Etching site, Freeport, NY. For rapid, economic results, an off-site laboratory returned analytical results by 11 AM the day after samples were taken. The project team utilized GIS software to visualize data and direct sampling efforts to accurately define affected areas. The team communicated the contaminant distribution maps and tables to all stakeholders via e-mail. Source: Shkuda and others 2006

identification of chlorinated VOCs as COCs allowed the timely delineation of a soil vapor plume and identified the potential for soil vapor intrusion.

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Example 3: “Legacy” UST Sites, South Dakota

The South Dakota Petroleum Release Compensation Fund (PRCF) conducted a pilot program in the fall of 2004 to evaluate the effectiveness of the Triad

approach to expedite closure of “legacy” UST sites. Specifically, the PRCF wanted to evaluate whether the Triad approach could be used to reduce decision uncertainties associated with petroleum release sites on a real-time basis.

Site Facts

- Five sites were chosen for the study, including three active gas stations, one closed gas station, and a railroad fueling site.
- The time since the petroleum releases had been first discovered on the sites ranged from 1 to 14 years.
- All the sites were considered “legacy” sites because, although the petroleum releases had been known about for years, none of the sites was moving toward regulatory closure.
- Three of the sites had been previously assessed at costs ranging from \$35,000 to \$103,000 (including field work and report preparation), but the results did little to reduce decision uncertainty.

- COCs included benzene-toluene-ethylbenzene-xylene (BTEX), methyl tert butyl ether (MTBE), diesel fuel, gasoline, ethylene dibromide (EDB), naphthalene, terephthalic acid (TPA), and total petroleum hydrocarbons (TPH).

The Triad pilot program sought to reduce decision uncertainty by increasing data density through the use of the MIP as the primary investigation tool. The MIP is a direct-sensing tool that enables investigators to obtain rapid, continuous profiles of subsurface characteristics and display logs of results in real time. These capabilities promote a fast, iterative investigation process that minimizes mobilizations and ideally can collapse multiple phases of assessment under a conventional approach into a single event. These events can generate huge amounts of data, and require a pre-plan to organize and utilize the data in real time. The PRCF estimates that a UST site assessment using a conventional approach would require 12 to 18 weeks from the time the samples were sent to an off-site lab to when stakeholders are notified additional information is needed (South Dakota PRCF, 2005). A primary goal of this pilot program was to shorten that time frame to a few days.

Legacy Data and Systematic Planning

A systematic planning meeting presided over by an independent facilitator was held before the beginning of the field program and was essential to the project's success. Existing assessment data were made available to all stakeholders at the meeting, along with three-dimensional models of each site's subsurface geology and chemistry. This process provided all stakeholders with a single representation of the preliminary CSM of existing conditions to promote a common understanding at the outset of the problems to be solved. The stakeholders were able to establish objectives and ground rules (such as the required participation of all project team members at the site every day) and to develop a generic protocol for use at each site to obtain data. All data that were needed to comply with South Dakota Department of Environment and Natural Resources (DENR) Tier 1 petroleum release reporting requirements were acquired within 4 days per site.

Data Acquisition Tools and Procedures

Confirmation samples (including VOC contamination in both soil and ground water matrices because MIP sensors are not matrix-specific) were collected from all sites to establish the site-specific sensitivity of the MIP sensors to fuel hydrocarbons. The development of this collaborative data set mitigated regulatory concerns that decisions were being made based on data that had not been analyzed at a fixed laboratory.

Logs of sensor response were printed immediately after the MIP profile was conducted. In many cases, the log itself can be used to identify contaminated intervals and target depths for confirmation soil sample collection and to select locations and depths for subsequent borings. Direct-sensing methods are ideal for use in conjunction with a DWS and usually allow for new sample or boring locations to be selected in real time as the work progresses. The MIP borehole location was established on the site coordinate system within minutes after it was completed using GPS survey equipment.

Data Interpretation and Communication Tools and Procedures

The project team uploaded the MIP results and the GPS survey data to the vendor's proprietary data processing and contouring program twice daily to update the existing three-dimensional model of the site. On-site, three-dimensional renderings of the geologic structure and the plume extents (Figure 5) allowed the project team to identify data gaps immediately and fill them before the team demobilized from the site.

Each morning, results from the previous day were evaluated by team members and compared to project objectives. These results were also uploaded to a project Web site daily. The Web site allowed project team members who could not be present in the field to fully participate in the ongoing evaluation of data. The quick data turnaround time enabled the project team to follow through on one of the ground rules established from the start of the project – that all parties be satisfied that the objectives were met before the team demobilized from the site.

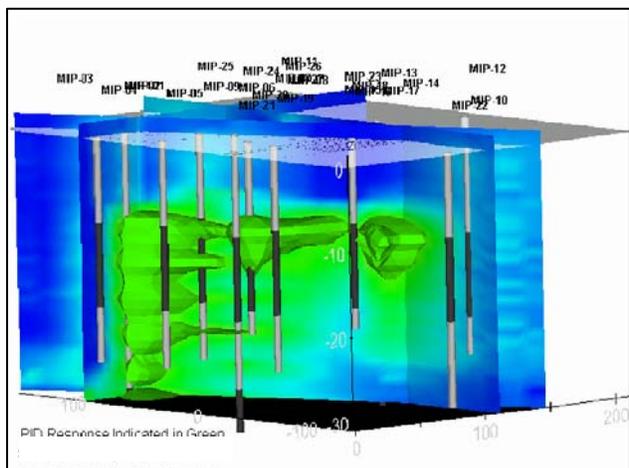


Figure 5. Example of a rendering of petroleum plumes and high conductivity values, for the South Dakota UST Sites. The Project team fed newly-acquired data into a 3-D visualization program in order to make decisions about where sample next. Source: PRCF 2005

Project Results

Throughout the course of the project, 133 borings were advanced, generating almost 350,000 MIP data points. In contrast, only about 1,400 data points would have been generated if conventional drilling methods had been used at the same number of boreholes (assuming one PID reading for every 2.5 feet of core and one discrete sample per borehole). The greater data density not only reduced the potential for data gaps, but three previously unknown USTs were found during the project. All three USTs were believed to have contributed to the plumes, and have been removed.

Stakeholders met after the assessment to select the next course of action. Additional corrective action is planned for two of the sites, consisting of monitored natural attenuation, and it is expected that another site will be eligible for a no further action (NFA) determination.

The possible NFA determination at one site highlights the value of increased data density and the benefits of continuous evolution of the CSM. The ground water plume was believed to be located within a source water protection zone and therefore needed to meet EPA maximum contaminant levels (MCL). High-density geologic delineation using the soil conductivity probe revealed that the plume lay within a geologic unit that was not hydraulically connected to

the aquifer. Thus, MCLs did not apply; depending on the results of a soil vapor survey, the site may be closed with an NFA determination.

The costs of the Triad investigations at the two sites that had not been previously investigated were \$25,000 and \$32,000. The costs of the Triad investigation are difficult to compare with the conventional investigations at the other three sites because the Triad investigations built on knowledge gained from the conventional assessments. However, the conventional assessments left the investigators with uncertainty regarding the CSM, while the Triad assessments tended to remove those uncertainties. More information about the costs and results of all five assessments can be obtained from the Triad profile for this site (Triad Resource Center 2006).

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SOURCES OF ADDITIONAL INFORMATION

The Triad approach is gaining ever greater acceptance by EPA and other federal and state agencies, as well as professional and industrial organizations. Communities and project teams interested in implementing the Triad approach are encouraged to contact the BTSC for more information and for successful examples of Triad applications. More detailed information about data management and interpretation and on the Triad approach is available in the Brownfields Technology Primer Series document titled "Using the Triad Approach to Streamline Brownfields Site Assessment and Cleanup," which is available at <http://www.brownfieldstsc.org>.

Project profiles, case studies, and other information on applying the Triad approach are available at <http://www.triadcentral.org>. As additional bulletins about other aspects of the Triad approach are developed, the BTSC will make them made available through these Web sites.

The DWS is the element of the Triad approach that provides the mechanism for making real-time decisions in the field. It consists of stakeholder-approved decision trees and decision logic that are tied to the CSM. A guide to developing a DWS is provided at:

http://www.triadcentral.org/tech/dsp_sub.cfm?id=23

Further information about DSTs is provided at <http://www.frtr.gov/decisionsupport/index.htm>. This Web site provides information on 25 DSTs in a matrix format. The Web site describes the DSTs, input and output file requirements, and user comments and provides a link to a software home page providing a free copy of the DST.

DMAs can be critical for a better understanding and management of decision-related uncertainty. DMAs are discussed in technical bulletins on the Triad approach available from the Triad Resource Center: http://www.triadcentral.org/tech/dsp_sub.cfm?id=4.

Performance-based Management System (PBMS) provides the site investigator, regulators, and stakeholders the leeway to adjust method specifications (including QC) to address site-specific needs and issues. A discussion of how PBMS may be integrated with the Triad systematic planning process is provided at:

<http://www.clu-in.org/search/t.focus/id/195/>

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This bulletin can be downloaded from EPA's Brownfields and Land Revitalization Technology Support Center at www.brownfieldstsc.org. For further information about this bulletin or about the Triad approach, please contact Dan Powell of EPA at (703) 603-7196 or powell.dan@epa.gov.