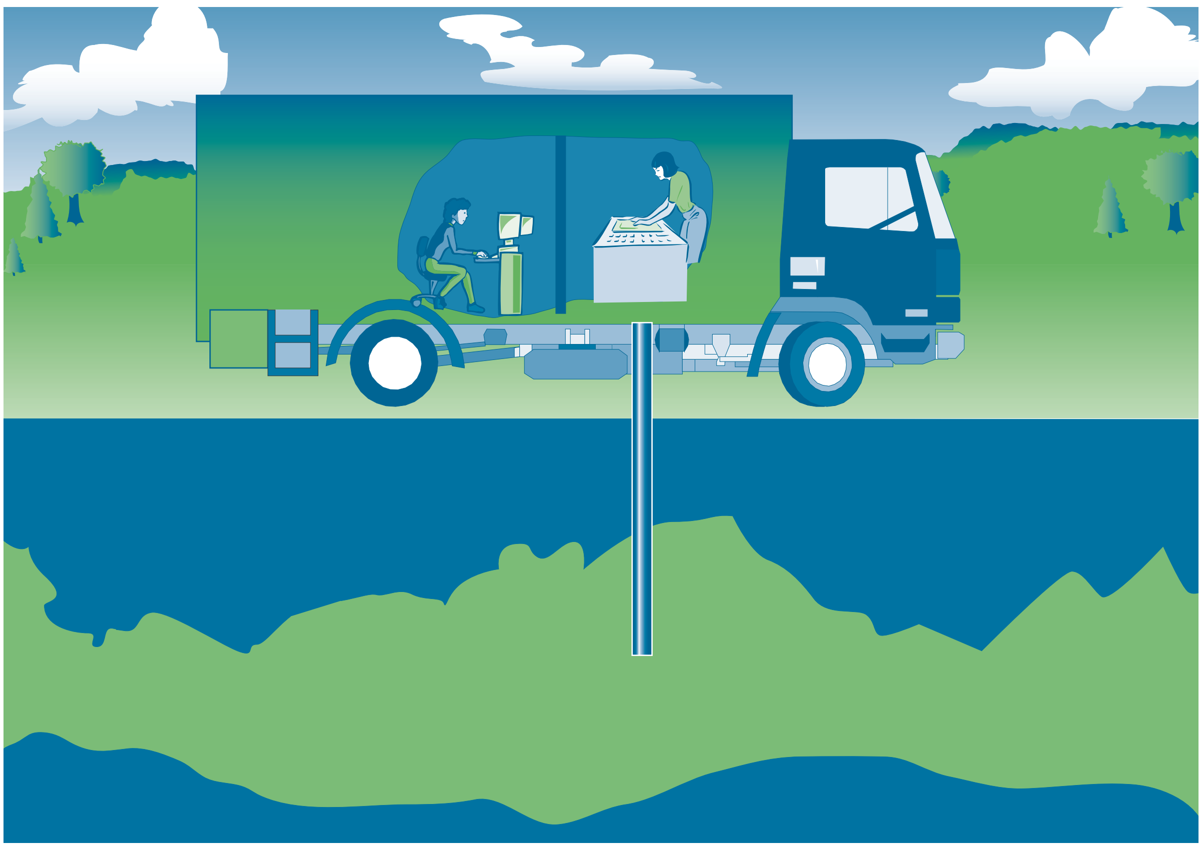
Technical/Regulatory Guidelines

Technical and Regulatory Guidance for the Triad Approach: A New Paradigm for Environmental Project Management



December 2003

Prepared by
The Interstate Technology & Regulatory Council
Sampling, Characterization and Monitoring Team

ABOUT ITRC

Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at **www.itrcweb.org.**

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Stuart Nagourney, New Jersey Department of Environmental Protection, Team Leader
Kimberlee Foster, Missouri Department of Natural Resources, Triad Subteam Leader
Brian Allen, Missouri Department of Natural Resources
Bradley Call, U.S. Army Corps of Engineers, Sacramento District
Hugo Martínez Cazón, Vermont Department of Environmental Conservation
Ruth Chang, California EPA Department of Toxic Substances Control
Ahad Chowdhury, Kentucky Department for Environmental Protection
Chris Clayton, Department of Energy
Steven Gelb, S2C2 Inc.
Richard LoCastro, Langan Engineering and Environmental Services, Inc.
Keisha Long, South Carolina Department of Health and Environmental Control
James Mack, New Jersey Institute of Technology
Denise MacMillan, U.S. Army Corps of Engineers Engineering Research and Development Center
Bill Major, Naval Facilities Engineering Service Center
John Pohl, McGuire Air Force Base, 305th Environmental Flight
Qazi Salahuddin, Delaware Department of Natural Resources and Environmental Control
Peter Shebell, Department of Energy, Environmental Measurements Laboratory
Jim Shirazi, Oklahoma Department of Agriculture
Shawn Wenzel, Wisconsin Department of Commerce

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EXECUTIVE SUMMARY

This technical/regulatory guidance document was prepared by the ITRC Sampling, Characterization and Monitoring (SCM) Team and serves to introduce new concepts regarding the manner in which environmental work is conducted. This document is atypical for the Interstate Technology & Regulatory Council in that it does not report on a new technology per se but introduces new concepts to the manner in which environmental work is conducted. These concepts can increase effectiveness and quality and save project money. These ideas aren't new but have been developed into a logical approach for environmental project management.

The concepts embodied in the three legs of the Triad approach are (1) systematic project planning, (2) dynamic work strategies, and (3) real-time measurement technologies. The Triad approach can be thought of as an initiative to update the environmental restoration process by providing a better union of scientific and societal factors involved in the resolution of contamination issues. It does this by emphasizing better investigation preparation (systematic project planning), greater flexibility while performing field work (dynamic work strategies), and advocacy of real-time measurement technologies, including field-generated data. The central concept that joins all of these ideas is the need to understand and manage uncertainties that affect decision making. The Triad approach consists of ideas that have been formulated previously but are now united to form a new paradigm for environmental project management.

The Triad approach relies on technological, scientific, and process advances that offer the potential for improvements in both quality and cost savings. The cost-saving potential is considered to be significant but is only now being documented by case studies. The challenges involved in changing from long-established procedures to any new method will be great, and there will be opposition to the Triad approach from those unfamiliar with its potential.

The SCM team has created this document as a first step to stimulate understanding and discussion of the ideas embodied in the Triad approach. It explains the relationship of the Triad to existing guidance such as the data quality objectives process. It lists the advantages and disadvantages of the Triad and notes regulatory and organizational barriers that may present obstacles to its use. New Jersey has only recently implemented a formal program to adopt the Triad approach, and a section is devoted to explanation of that program. Stakeholder issues are an important consideration for adoption of any technology or approach, and this document has a section dedicated to that end. Case studies revealing the advantages and potential success of using the Triad approach are summarized in the text and detailed in Appendix B.

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1.0 INTRODUCTION

The environmental cleanup profession has been in existence for more than 20 years and has developed a tremendous body of practical and scientific knowledge. However, despite this experience, environmental restoration remains a lengthy and expensive process. The U.S. Environmental Protection Agency (EPA) has combined the best elements from a number of initiatives designed to improve restoration effectiveness and calls the resulting synthesis the "Triad approach." This Interstate Technology & Regulatory Council (ITRC) document explains the advantages offered by the Triad approach and shows how it results in better restorations, accomplished faster and with less expense. These improvements benefit government regulators, the regulated community, and the public. Because there is often resistance to change from established procedures, it is important to involve the stakeholder community from the beginning of any project utilizing the Triad approach.

1.1 Evolution of the Current Investigation Paradigm

The current methodology for site characterization (created to support early cleanup programs) includes a multistage investigative process that was intended to provide sufficient understanding of site contamination issues to take remedial action. This process has proved to be very expensive and time-consuming. When this methodology was developed in the 1980s, there were good reasons to adopt a carefully staged approach to site characterization, ranging from the need to build a base of knowledge in this field to the tremendous complexity involved when predicting contaminant behavior in natural geologic settings. In addition, analytical methods required the controlled environment of static laboratories for proper implementation and quality control (QC) oversight. When this reality was combined with periodic budgeting cycles for government-funded work, it is not difficult to understand how multiple investigations—each with its own multiyear cycle of work plan preparation, field work, and report of findings—became the accepted approach.

Associated with the development of the multistage investigation process was the establishment of carefully documented analytical procedures (SW-846), which have become a standard in the environmental industry. Legal defensibility considerations have led to the widespread opinion that only SW-846 methods are suitable for site decision making. The importance of obtaining contaminant concentration data of known quality cannot be underestimated; however, the exclusive focus on analytical quality alone disregards other equally important considerations.

1.2 Why Change the Paradigm?

Many environmental professionals have recognized that the current approach is not always the most efficient in terms of either financial resources or technical sophistication. Despite this realization, it was not clear how to move away from multistage investigations. The fact remains that the complexity of contaminant distribution and geological heterogeneity requires a large number of costly samples to reduce uncertainty to acceptable levels. However, recent advances in field analytical methods, sample collection techniques, and geologic definition now offer the opportunity to dramatically improve investigation effectiveness. Yet, improvements in technology alone are not sufficient since they must be combined with changes in approach. Changes in approach include the following:

- better initial determination of investigation objectives,
- better use of conceptual site models (CSMs) during planning and project decision making,
- early agreement by all project team members and stakeholders on acceptable action concentrations,
- use of techniques to evaluate data uncertainty, and
- real-time management and analysis of data.

These ideals are now within reach of routine investigation, cleanup, and monitoring practices. All of these considerations revolve around one central concept: understanding and managing uncertainty. Environmental investigations are truly multidisciplinary endeavors, and this fact creates a management challenge. The project team must avoid a loss of focus on the specific investigation objectives while integrating different technical viewpoints. This goal is accomplished by achieving consensus on the investigation objectives prior to beginning generation of planning documents that support field work. This vital step of systematic planning is central to a successful investigation.

2.0 THE TRIAD APPROACH

This section begins by explaining the potential cost savings and quality improvements offered by the Triad approach. It next describes the type of projects to which this new system will be applicable. The underpinnings of the Triad approach are described, and the section goes on to provide additional information on each of the legs of the Triad: systematic project planning, dynamic work strategies, and real-time measurement technologies.

The primary product of the Triad approach is an accurate CSM that can support decisions about exposure to contaminants, site cleanup and reuse, and long-term monitoring. The Triad approach is grounded in science but recognizes that environmental restoration decision making considers policy, public debate, and negotiation. Because the Triad focuses on uncertainty management, it ensures that the unknowns impacting our ability to make good decisions are identified and documented so that all involved parties can openly evaluate the relative risks of each decision. The Triad encourages strategy and technology options that can lower project costs, while ensuring that the desired levels of environmental protection are achieved.

2.1 Overview of the Triad Approach

The Triad approach embraces scientific and process improvements in three areas: systematic project planning, dynamic work strategies, and real-time measurement technologies (Figure 1). The central principle of the Triad approach is the management of decision uncertainty. Systematic planning encompasses all tasks that produce clear project goals and decisions;

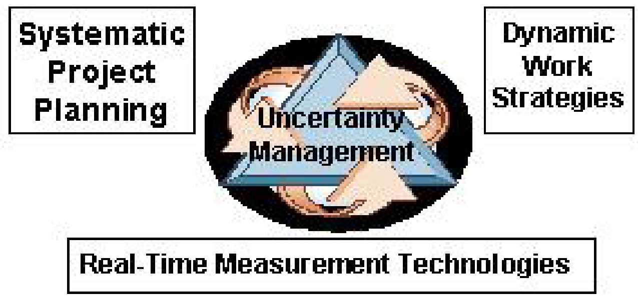

Figure 1. The Triad approach components.

describe unknowns (i.e., uncertainties) that could cause erroneous decisions; and foster clear communication, documentation, and coordination of all project activities. The adjective "dynamic" describes work strategies designed around consensus-derived decision logic so that real-time decision making can quickly refine field work as new information becomes available. Real-time measurement technologies include geophysics and other imaging techniques, on-site technologies and in situ detection techniques, and rapid turnaround from mobile and fixed labs, as well as software packages for processing, displaying, and sharing data so that the CSM can evolve while the work crew remains in the field (EPA 2001f).

The Triad focuses first on establishing clear project goals. That is why "systematic project planning" (sometimes called "strategic planning") is the single most important element in the Triad. After project goals are understood, then the uncertainties that stand in the way of achieving those goals will be addressed. Usually environmental data will be collected as one means to manage decision uncertainty. When data are used to make decisions, the sampling and analytical uncertainties inherent to environmental data generation must be managed to a level commensurate with project decision needs. Having clear project objectives spelled out up front improves the quality of investigation activities because data collection becomes more efficient.

The dynamic work strategies element of the Triad is based on real-time decision making. This element greatly reduces project lifetime costs and duration, making Triad life-cycle costs much less than traditional life-cycle costs. Project quality is improved because more data is acquired in exactly the right places to fill important data gaps in the CSM.

Real-time measurement technologies, the third element in the Triad, make real-time decision making possible. The state of the art is to use software tools that process and display or map data in real time. Together, real-time technologies and real-time work strategies work hand in hand so that data collection is focused and informative. Real-time decision making improves project decision confidence by providing higher-density sampling (more samples) and rapid feedback of information needed to efficiently mature the project CSM to sufficient accuracy so that exposure risk and remedial decisions are correct. It is critical to use the CSM to avoid sampling errors and to interpret results from various data sets, including lower-density (fewer samples) fixed-laboratory analysis in conjunction with the real-time measurements.

In the broadest sense, the Triad approach is a conceptual and strategic framework that explicitly recognizes the scientific and technical complexities of site characterization, risk estimation, and treatment design. In particular, the Triad approach acknowledges that environmental media are fundamentally heterogeneous at both larger and smaller scales. Heterogeneity can have important repercussions on sampling design, analytical method performance, spatial interpretation of data, toxicity and risk estimation, and remedy design and success. Most of the ideas found in the Triad approach are not new, and many in the environmental community both understand and support these concepts. What is new about the Triad is the effort to comprehensively incorporate all these ideas simultaneously into a next-generation model for cleanup practices supported by EPA. Table 1 lists the major components of the Triad and the questions answered by each component. Table 1 should be considered as a process that begins at the top with systematic planning and continues to decision making, perhaps iterating several times till complete.

Table 1. Triad process overview

SYSTEMATIC PROJECT PLANNING	**Project Initiation** • *Assemble project team* • *Define project objectives* • *Identify key decision makers* • *Define decisions to be made* • *Develop initial conceptual site model (CSM)*	**Answers:** • **Who** • **What** • **Why**
DYNAMIC WORK STRATEGY	**Project Start-Up** • *Ongoing revision of the CSM* • *Draft adaptive work plan and sampling strategy/decision logic* • *Develop detailed analytical strategy: field-based or fixed lab* • *Develop data management plan* • *Develop quality assurance plan* • *Develop health and safety plan*	**Answers:** • **What** • **Why** • **How** • **When** • **Where** • **Who**
ADAPTIVE WORK PLAN IMPLEMENTATION	**Plan Approval** • *Client/regulator/stakeholder review/approval* • *Refine project decision logic and finalize plans*	**Answers:** • **Who** • **What** • **Why** • **How**
REAL-TIME MEASUREMENT TECHNOLOGIES	**Field Program** • *Sampling and analysis to fill data gaps* • *Data validation, verification, and assessment*	**Answers:** • **When** • **Where** • **Who** • **What** • **How**
DECISION MAKING	**Are Project Objectives Met?** • *Evolve/refine CSM* • *Modify adaptive work plan* • *Client/stakeholder/regulatory review/approval*	• **Why** • **What** • **How** • **Who**

Central Concept = Uncertainty Management

The Triad approach explicitly focuses on the identification and management of sources of decision uncertainty that could lead to decision errors. The Triad explicitly manages the largest source of data uncertainty, which is data variability caused by the heterogeneity of chemical contaminants and the impacted environmental matrices.

The ideas contained within the Triad approach are a continuation and synthesis of efforts begun in the 1980s by the U.S. Department of Energy (DOE) to make site investigation and cleanup more cost-effective (Burton 1993). Over the years, a variety of governmental, academic, and private sector innovators continued to contribute to the theoretical and practical considerations that the Triad approach embraces (e.g., Robbat 1997). Similar efforts in Europe are also under way. A consortium of European academic and government institutions is pursuing an initiative (referred to as "Network Oriented Risk Investigation for Site Characterization," or "NORISC") to develop strategies for expediting site characterization that have some similarity to the Triad approach. NORISC emphasizes early and active stakeholder involvement in the establishment of cleanup goals and places strong emphasis upon the use of on-site analysis selection software (more information can be found at the NORISC Web site at http://www.norisc.com/).

2.2 Resource Savings and Investigation Quality

Reducing restoration costs and time are common goals for environmental professionals. The EPA and other practitioners have shown across a variety of project types that implementation of the Triad approach will result in significant improvements in both investigation quality and cost efficiency. Several examples of such projects are described in more detail in Section 9. Cost and time savings result primarily from reducing the number of investigation field mobilizations needed to complete the characterization. Significant cost and time savings can result because characterization can focus on uncertainties that impact appropriate remedial action selection, design, and associated cost estimation. Improved investigation quality arises from better focus on project goals, increased sample coverage of the site, fewer unexplored site uncertainties, flexibility for field activities to adjust to unexpected conditions, and sophisticated data management tools to analyze and communicate the findings.

The Triad Approach Is Efficient

The Triad approach offers the potential for significant **cost savings.** Cost savings up to 50% have been observed. The cost savings potential increases with site complexity.

Time savings can also be significant. Systematic project planning establishes clear project goals and the associated decision logic so that a dynamic work strategy can reduce the number of field mobilizations.

2.3 Applicability

In contrast to earlier efforts to improve quality and cost-effectiveness, the Triad approach is not narrowly focused on a single EPA remedial program. Rather, the Triad integrates the core principles behind many conceptually similar "expedited," "accelerated," or "streamlining" initiatives developed by federal and state agencies. The Triad approach is applicable to all EPA programs such as the Resource Conservation Recovery Act (RCRA), Superfund, brownfields, and the underground storage tank (UST) program, as well as similar state programs. Universal concepts underlying the Triad approach apply to any site, no matter what stage of investigation or remediation, and no matter what size or complexity of the site. These concepts include managing decision uncertainties and developing a conceptual site model accurate enough to support cost-effective, yet protective decisions.

The Triad Approach is Broadly Applicable

The Triad approach is a conceptual framework developed by synthesizing various strategic improvements to environmental investigation planning, execution and evaluation. It is applicable across all types of environmental programs.

2.4 Triad Approach Perspective

The Triad approach rests on the principle that the quality of an investigation depends on achieving a level of decision confidence that meets the customers' (including stakeholders') expectations for a successful project outcome. To reach the desired outcome, the project team makes specific regulatory, economic, and engineering decisions, each with inherent uncertainty. Detailed planning reveals cost-effective ways to ensure confidence in the project outcome despite the persistence of uncertainties with some of the decision inputs. Project planning always involves creating a preliminary or initial CSM. Planning with the "end" (i.e., the desired project outcome) in view reveals which knowledge gaps in the CSM are truly important. Data collection to fill those gaps should be tailored to be representative of the decision to be made. With its focus on managing decision uncertainty, Triad systematic planning allows projects to be done right the first time.

Significant components of project planning and execution are shown graphically in Figure 2. The general time order for tackling each of these components during the planning process is reversed during project implementation. Projects begin with the need to achieve a certain restoration or reuse outcome. A successful outcome depends on satisfactorily resolving regulatory and technical decisions about contaminant presence, exposure, and fate.

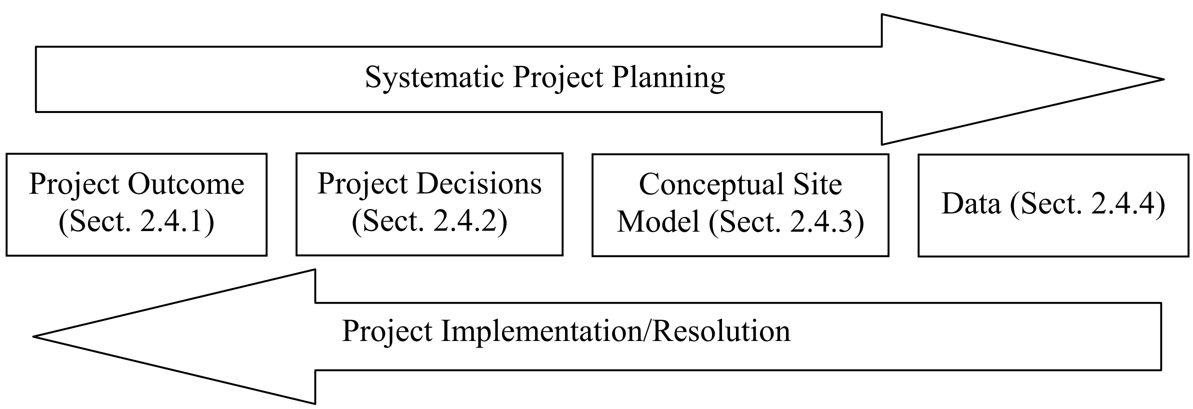

Figure 2. Project planning and execution relationships. Systematic planning tailors data collection by starting at the highest level (the desired outcome) and working downward into the details of sampling and analysis (arrow pointing right). As the work strategy is implemented, the generated data are used to mature the CSM, which is in turn used to make decisions about whether the outcome can be satisfactorily achieved (arrow pointing left).

The CSM integrates information about contaminant release, migration, and risk reduction options into a form that decision makers can use. Information gaps always exist in preliminary CSMs. Gaps are identified by comparing what is already known with what needs to be known to make appropriate regulatory and engineering decisions. Data-gathering strategies are then devised to fill CSM gaps. As the CSM progressively becomes more mature, decision uncertainty progressively decreases. These ideas are illustrated in Figure 2 and are more fully explained in the sections that follow.

2.4.1 Project Outcomes

A hypothetical example is used in the following paragraphs to illustrate the Triad approach. The desired project outcome is construction of a school at a former commercial parcel that is now being managed as a brownfields site. Project team members and stakeholders will be concerned about the certainty of a specific outcome, such as ensuring that if a school is built on the brownfields site, the children will not be exposed to site contaminants.

The decision about whether a school can be safely built is itself dependent on a number of specific regulatory and engineering decisions about whether contamination is present above regulatory thresholds, and if so, whether intact exposure pathways might exist after school construction is completed.

2.4.2 Project Decisions

To achieve the desired project outcome, a number of regulatory and technical decisions must be made along the way. In practice, project decisions are made using a combination of scientific data and other inputs. These other inputs include political, economic, and social considerations that may have local, regional, and national linkages. Different projects will have different lists of decisions. A partial list of example project decisions includes deciding whether

- contamination is greater than background;
- there is a threat to groundwater;
- the contamination has been adequately characterized;
- the extent and variability in contamination distribution has been adequately assessed;
- natural attenuation is occurring, and if so at what rate;
- people are exposed to the contamination, and if so by what pathways;
- environmental (ecological) receptors are exposed;
- contamination levels are greater than regulatory action level;
- there are cost-effective remedial options;
- it is possible to apply new and innovative remedial approaches;
- other institutional controls, such as land use restrictions, are appropriate for the site;
- a risk-based remedial strategy is appropriate for the site; and
- long-term monitoring will be required.

Making these decisions requires knowledge of site contamination issues, collectively referred to as a conceptual site model. The CSM will be discussed in more detail below, but at this point it is sufficient to understand that the CSM is constructed with information, much of which consists of environmental data for understanding how contaminants are distributed throughout the site, along with contaminant fate, migration, and exposure pathways.

The project team's confidence in making correct decisions depends on its ability to assemble an accurate CSM. To continue with the hypothetical brownfields school redevelopment site, when evaluating whether it is safe to build the school, the project team must determine whether there are unacceptable levels of contamination and complete exposure pathways. Assume that the project team must decide if lead contamination in near-surface soils would pose a risk to school children if a playground were built. A regulatory action level has been established, and the limited amount of available data and site history used to create the initial CSM suggests that lead may be unevenly distributed across the site. The project team must decide whether the average lead concentration and the concentration of any isolated hot spots exceeding a certain size in the playground soils exceed established regulatory action levels. To demonstrate with confidence whether lead concentrations could be high enough to pose a threat, a sampling program is needed. To have confidence that the sampling design can detect hot spots of concern and produce an accurate estimate of the mean, the project team needs to develop the sampling program that estimates contaminant variability and is dense enough to locate any significant hot spots. If there are doubts about the correctness of a regulatory decision because of excessive uncertainty in estimates of lead concentrations, then all team members will be in doubt regarding the success of the school development project from the standpoint of the children's safety. In other words, doubts about whether decisions are made correctly create doubts (i.e., uncertainty) about the success of the project outcome.

As mentioned earlier, it is sometimes possible to manage outcome uncertainty despite unresolved decision uncertainty. Continuing with the school example, this possibility can be illustrated by considering how a remedial option might render actual soil lead concentrations irrelevant by simply blocking the exposure pathway. For example, physically capping potentially contaminated soil at the playground ensures confidence in the desired outcome that children not be exposed to contaminated soil. This outcome is achieved without costly soil sampling to determine the actual lead concentrations. Exposure to any other nonmobile contaminant that may happen to be present in the subsurface is similarly blocked by this containment option. Selection of this option is conservative in the sense that all team members will have high confidence in the desired protective outcome, despite continued uncertainty about whether or not lead concentrations exceed regulatory thresholds. The benefits of this decision strategy are that regulatory agencies can quickly confirm the completion of remedial actions, financial institutions can confidently lend money for redevelopment to proceed, and insurance brokers can provide coverage at reasonable rates.

This type of decision uncertainty management may be appropriate for some sites but not for others. It depends on myriad site-specific, economic, social, and regulatory variables. While conservative protective options may be appropriate and cost-effective in some instances, in other cases the costs and consequences of overly conservative decisions may outweigh any perceived benefits. When cost-effective treatment options are available (such as precision removal and disposal of contamination hot spots followed by evaluating the hazard posed by any remaining contamination), sampling and analysis to support a cleanup strategy are generally preferable to preserve a wider range of land use options. In that case, developing a sampling plan that gives an accurate picture of lead concentrations becomes a critical component of the project planning. Tolerable levels of decision uncertainty (how much contamination can be missed by the sampling program without causing undue risk) must also be established in the work plan.

Decision Strategies Are Determined During Systematic Project Planning

Decision strategies are determined with the input of stakeholders and the approval of regulators. If too little information is available to know which decision strategy would be best, the factors driving the selection of one strategy over another (e.g., selecting a cleanup strategy rather than a containment option) are determined. These factors can be arrayed into a matrix or decision tree, which is resolved as the needed information is gathered during implementation of the dynamic work strategy.

An important task of Triad systematic planning is to consider which decision strategy is most appropriate for a particular project, weighing each strategy's pros and cons against budgetary and regulatory constraints and stakeholder interests. Early in the project life cycle there may not be enough knowledge to determine which decision strategy is best. In that case, systematic planning focuses on the information needed to decide which decision strategy makes the most sense. Selection of a decision strategy may be summarized as a series of "if-then" statements that capture the relationships between drivers such as costs, risk, cleanup versus containment options, and stakeholder concerns. For example, "If characterization finds that estimates of the highly contaminated soil requiring disposal (if removed) exceed 100 tons, then capping and restricted reuse is the only financially viable option. Further delineation of soil contamination will be aborted, and a decision strategy to support containment design will be instituted. However, if contamination is found to be low level and disposal is estimated at less than 100 tons, characterization will continue according to a decision strategy supporting complete cleanup and unrestricted site reuse." As long as all stakeholders agree on the decision logic, final selection of the decision strategy can be a seamless part of field implementation.

2.4.3 Conceptual Site Models (CSM)

Building a CSM begins with information about land use, records of chemical usage, other historical data, and expectations about how contaminants may have been released to the environment. Contaminant release mechanisms determine how variable contaminant concentrations are likely to be across the site. When new data are collected, CSM hypotheses are tested and confirmed, modified, or rejected. New data are used to "mature the CSM," that is, to build an accurate understanding of what contamination is present and where, whether the contamination can pose current or future risks to potential receptors, and if so, how that risk can be mitigated. The CSM and "data" are tightly coupled in a feedback loop: the CSM guides the collection of new data, but the CSM is also changed and refined as those new results are integrated into it. The updated CSM then guides the collection of more data, which further refines the CSM. Traditional approaches were forced to update the CSM in separate field mobilizations. Under the Triad, new technologies allow the CSM update cycle to proceed daily, with a fully matured CSM emerging in as little as a single field mobilization.

The CSM creates the setting within which the analytical contaminant data are evaluated and understood. The CSM consists of chemical, physical and biological data that are organized into text, graphics, tables, or some other useful representation (or "model") able to support site decision making. Key elements typically included in a CSM include the following, adapted from the Vermont Department of Environmental Conservation:

- General physical site description
- Regional environmental setting
  - Geology
  - Hydrogeology
  - Habitat description
- Land use description
  - Current land use
  - Proposed land use
  - Land use history
- Contaminant regime and site investigations
  - Results of previous site investigations
  - Contaminants of concern
  - Contaminant sources
  - Contaminant fate and transport
  - Contaminant susceptibility to various treatment or destruction options
  - Contaminant variability in time and space (at larger and smaller scales)
- Potential risks and potential receptors
  - Exposure pathways
  - Activities and risks
- Data evaluation
- Identification of data gaps and data needs to serve various exposure or remedial decisions

Different decisions may require different representations of the CSM. For example, decisions about groundwater contamination migration or cleanup need a CSM that emphasizes hydrogeology and contaminant concentrations and fate information; whereas decisions about contaminant exposure require a CSM that focuses on identifying all potential receptors and exposure pathways. Figure 3 shows a simple pictorial CSM representing geologic and hydrogeologic settings. A geologic cross section is an effective method to show manmade and natural features that affect contaminant transport and receptor exposure. A complex site may have several depictions of the CSM, each of which addresses a different medium or subset of the decisions to be made or represents one of multiple hypotheses that need to be clarified by getting more data (USACE 2003; ASTM 2002).

The CSM is updated as new information becomes available, generally after completion of each phase of investigation. Using a dynamic work strategy, a "phase" might be completed one day, the CSM updated overnight, and the next "phase" begun the next day without a break in field work. The CSM can be updated whenever new data suggest a significant change to a previous interpretation or to direct the next sampling or remedial effort. The revision/updating cycle of the CSM should be a group decision made by team members and stakeholders during the systematic

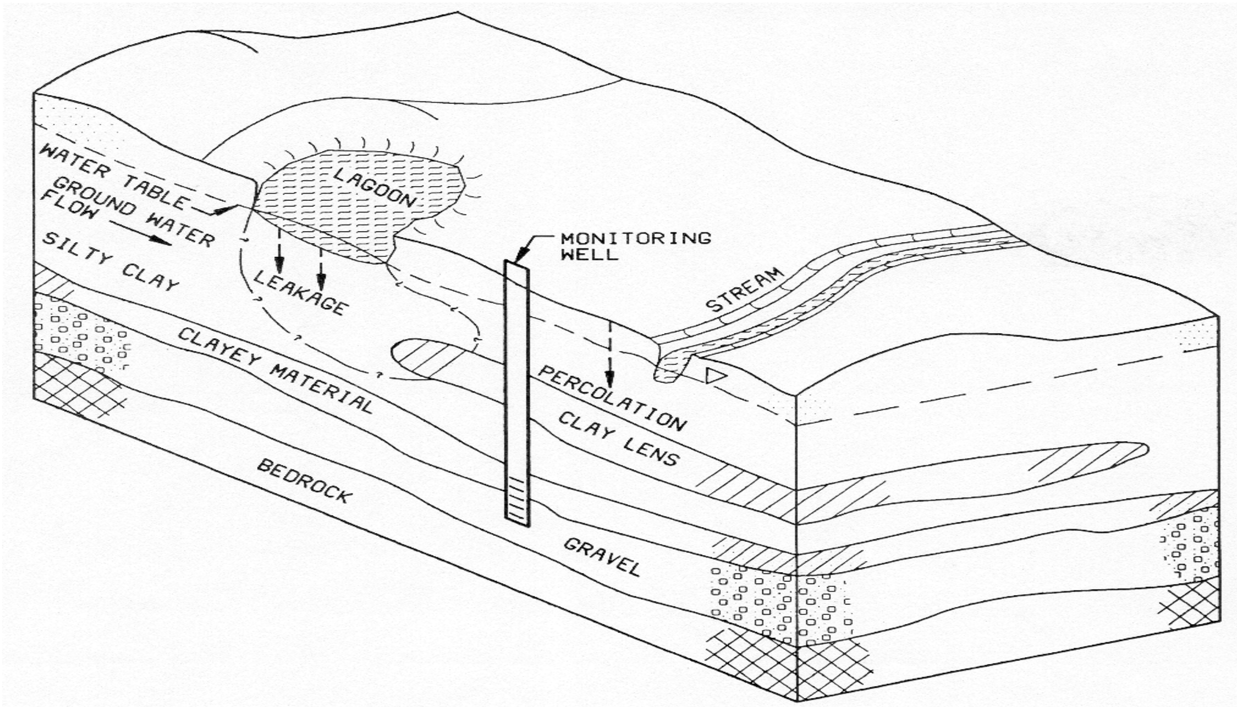

Figure 3. Simple hydrogeologic conceptual site model (USACE 2003).

planning. When not performing the CSM updates themselves, it is critical that field personnel be kept informed of any updates to the CSM.

The CSM becomes sufficiently accurate when there is confidence that the CSM represents actual site heterogeneity so that decisions about exposure and remediation can be correct and cost-effective. Spatial heterogeneity occurs because of differing release scenarios, the many diverse

fate and transport mechanisms that affect a contaminant, and the heterogeneity of geologic environments. Spatial heterogeneity creates areas that can differ widely in contaminant concentrations. These different areas may constitute different contaminant populations. Populations can be considered different if the mechanism creating them is different and/or if decisions are different. For example, for noncontaminated areas, the obvious decision is "no action required." For contaminated areas of sufficient size, with concentrations above the action level or large contaminant mass, the decision is to remediate.

A preliminary CSM considers the site history and physical characteristics to determine what type of spatial patterning might be expected. The same information can predict whether the concentrations from place to place within a single population are expected to be more or less uniform or whether they are likely to be highly variable. This knowledge is critical to designing cost-effective sampling plans. Statistical sampling plans, such as those used to estimate a mean for use in risk assessment (where an average concentration over an exposure unit is required), are much more powerful when data from different contaminant populations are kept separate. Successful remedial designs are entirely dependent on sampling plans that develop an understanding of spatial patterns and concentration extremes (e.g., finding a dense, nonaqueous-phase liquid [DNAPL] source area).

Heterogeneity Is Addressed in the CSM

The CSM is the primary tool used to

- predict the degree of contaminant heterogeneity and the nature of spatial patterning and migration pathways;
- verify whether those predictions were accurate;
- assess whether heterogeneity impacts the performance of statistical sampling plans;
- understand "data representativeness;" and
- integrate knowledge of heterogeneity and spatial patterning into decisions about exposure pathways, selecting remedies, designing treatment systems, and long-term monitoring strategies.

The term "data representativeness" is frequently used in a generic sense by environmental practitioners, but mechanisms to make the concept practical have not received sufficient attention. "Data representativeness" can be made more meaningful if it is evaluated in terms of the CSM and the project decisions. Data that are representative of the CSM will first enable delineation of distinct contaminant populations of interest to the project. Once the approximate boundaries of those populations are understood (i.e., the CSM is mature), data that are representative of specific project decisions are used to estimate the properties of interest for each population (for example, a risk assessment decision requires an estimate of the mean concentration over an exposure unit).

Generating representative data is not a simple matter when heterogeneous environmental matrices are involved. Although data may be correct in the sense that the analytical results are accurate for the tiny samples analyzed, extrapolating the results from those tiny samples to the much larger matrix volumes encompassed by the CSM may create a false picture. This is termed "sampling error." Sampling errors occur when the analysis is accurate but the sample analyzed is not representative of what the data user thinks it represents. Because environmental matrices are frequently heterogeneous at both macro and micro scales, sampling errors can contribute to very misleading CSMs, which in turn can lead to erroneous decisions about risk or cleanup strategies. As a group, the factors that contribute to sampling errors are termed "sampling uncertainties."

Spatial heterogeneity at the scale of many grid-based sampling designs is one contributor to sampling uncertainty. This case is illustrated in the top panel of Figure 4. This cartoon illustrates a sampling design where too few high–analytical quality samples miss important areas of contamination and fail to define the true extent of contaminant populations (such as hot spots). When few samples are collected, there is no choice but to extrapolate the result of a tiny sample analyzed in the laboratory (often as little as 1 gram) to volumes of matrix a million or more times larger. Statistical calculations (such as calculation of a mean) make the assumption that the result from a tiny sample in the center of a grid represents the contaminant concentration for the entire grid block. The degree to which this is a valid assumption depends on the CSM (i.e., how you think the contamination got there and whether the release mechanism is expected to produce uniform contaminant concentrations).

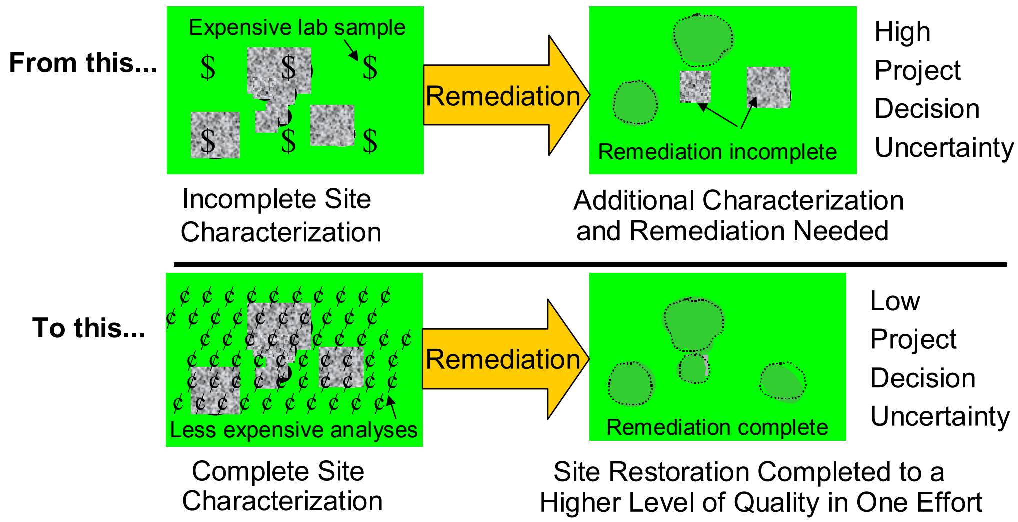

Figure 4. Sample representativeness and uncertainty. By collecting a larger number of less-expensive (¢) samples a more complete understanding of site conditions can be achieved.

Another source of uncertainty arises from errors in the statistics used to summarize the data and can be termed "statistical error." Such error may result from any of the following actions:

- The wrong distribution was assumed (normal versus abnormal).
- Assumptions concerning the statistic were violated (contamination may not be random or independent).
- The wrong statistic was used to describe the samples.
- Censored data was used incorrectly (how nondetects were interpreted).

Selecting correct statistical procedures is dependent on having a reasonably accurate CSM.

High-Density Sampling versus Analytical Perfection

Decision errors about risk and remediation are an unavoidable consequence of traditional work strategies that rely on fixed-laboratory analyses. Since such analyses are expensive, relatively few samples can be analyzed compared to the number needed to accurately characterize heterogeneous contaminant distributions. High analytical quality is seldom needed to refine the CSM. However, without a reliable CSM to support the representativeness of expensive, high–analytical quality data points, those data may be misleading and result in decision errors.

When the sampling density (number of samples per unit volume of environmental media) is insufficient to capture the effects of heterogeneity, incomplete or inaccurate CSMs are produced. Consequences include errors about risk and compliance. Estimates of contaminant nature and extent may be seriously biased. Decisions about exposure pathways may be wrong. Treatment designs may fail to achieve cleanup the first time, requiring another round of characterization and cleanup after remediation fails or when unexpected contamination is discovered. Poor characterization needlessly increases the costs of cleanup when "clean" matrix is inadvertently lumped together with the "dirty" matrix, unnecessarily increasing the volume to be treated or disposed while artificially decreasing treatment efficiency.

2.4.4 Data and Sources of Data Uncertainty

"Data uncertainty," in its broadest sense, can include the ideas that

- the necessary data are completely missing,
- accurate data exist but were not collected in sufficient quantities to provide confidence that the CSM is complete and accurate for decision-making purposes, and
- data exist but the accuracy or representativeness of the data is either in doubt or known to be inadequate.

All of these kinds of data uncertainty may be relevant for site cleanup projects. As noted previously, uncertainty is a hallmark of all environmental data, with contributions from both the sampling and the analytical components. Difficulties stem from the fact that environmental matrices are heterogeneous in composition and in contaminant distribution. Composition heterogeneity makes it impossible to devise cost-effective standardized sampling and analysis methods that will work equally well for all possible applications. Contaminant heterogeneity across larger and smaller spatial scales means that it is dangerous to assume that results from tiny samples can be extrapolated to represent larger matrix volumes. Environmental heterogeneity produces true variability in sample results. In other words, the actual concentration in one sample is truly different from the concentration in another sample, even though the samples may be taken only inches apart in the field or taken from the same sample jar. It has long been recognized that the largest source of data uncertainty is sampling variability associated with the heterogeneity of environmental matrices (Homsher 1991, Jenkins et al. 1997).

As mentioned earlier, factors associated with sampling variability can lead to sampling errors, where the analysis is accurate but the sample or subsample is not representative of the matrix volume to which the result is being applied. For solid environmental samples, such as soils, sediments, and waste materials, even the volume of a subsample taken from a "homogenized" sample introduces variability because it is impossible to completely homogenize solid environmental matrices so that the contaminant is uniformly distributed throughout the sample. For trace analyses of parts per million (ppm) and lower, models predict that matrix grains with attached contaminants distribute nonuniformly throughout a "sea" of grains that have few or no contaminant molecules attached. The smaller the subsample, the more likely it is that the number of contaminated grains will vary greatly from one subsample to the next. When analyzed, the subsample results will vary widely. Yet, current protocols unquestioningly extrapolate a single subsample result to represent the result for the entire jar, leading to erroneous conclusions.

A DOE study first published in 1978 demonstrated how subsample volume could produce misleading results. A site contaminated with americium-241 (Am-241, a radionuclide) was sampled to create a single large containerized soil sample (about 4–5 kg). That sample was carefully homogenized by drying, ball-milling, and sieving through a 10-mesh screen. The true mean for this large sample was determined to be 1.92 ppm. Twenty subsamples each of 1, 10, 50, and 100 volumes were taken and analyzed separately. The results are summarized in Table 2.

Table 2. Subsample variability

Subsample volume (g)	Range of results for 20 individual subsamples (ppm)
1	1.01–8.00
10	1.36–3.43
50	1.55–2.46
100	1.70–2.30

(Adapted from Gilbert and Doctor 1985.)

Obviously, the larger the subsample, the less variable the results, and the much more reliably any single subsample result estimated the true mean (1.92 ppm) for the original sample (Gilbert and Doctor 1985). A sampling error would occur if a data user got the result of 8 ppm (as reported by the laboratory on a 1-g subsample) and assumed that it represented the true concentration for the entire jar of sample (an error of over 400%). The error would be further compounded if that 8 ppm result were extrapolated to represent the concentration of Am-241 for a large portion (e.g., a 100-square-foot by 1-foot-deep grid volume) of the site.

This type of sampling error is a consequence of a "sample support" problem. The term "sample support" refers to the physical properties of the sample or subsample. In the environmental field, the concept of sample support includes (1) the sample or subsample volume, (2) the spatial orientation or dimensions of the sample collection device which determines the spatial dimensions of the sample, and (3) the particle sizes making up the sample. The concept of sample support is critical for both solids (such as soils) and water (such as groundwater). Analytical results can be different simply because the sample support is different, excluding any variability in the analytical method itself.

The concept of sample support was introduced into waste cleanup programs by EPA years ago, although the concept never received wide recognition. For example, *Data Quality Objectives Process for Superfund* guidance (EPA 1993, p. 41) lists sample support as one of the design elements required to be discussed in the Quality Assurance Project Plan (QAPP) or the Sampling and Analysis Plan (SAP). Controlling sampling variables (to ensure that sample results are truly representative of intended decisions) is a critical first step to managing data uncertainty for cleanup projects.

Figure 5 illustrates how variables governing the generation of decision quality data (i.e., data fully representative of the intended decision) can be coarsely grouped into sampling and analytical categories. Each of these categories is a step where serious data errors can occur, creating nonrepresentative or poor quality data. The four sampling-related categories are "sample support," which covers variables related to the volume, spatial orientation, and particle size of individual samples; "sampling design," which covers all those issues related to how many samples to take and where to take them; "sample preservation," which includes all those tasks involved with ensuring that analytes are not lost through degradation or volatilization, or gained through cross-contamination; and "subsampling," which covers sample homogenization and subsample support when a smaller portion is taken from a sample container for analysis. On the analytical side, "sample preparation method(s)" refer to extraction or digestion procedures used to remove targeted analytes from the original matrix of the sample or subsample. Extraction procedures inappropriate for the particular matrix or for individual analytes on a determinative method list will falsely bias results lower than the true value. "Extract cleanup method(s)" are used for removing coextracted interferences for analytes like pesticides and dioxins. Significant loss of target analyte can occur in this step. "Determinative method" refers to the instrumental method that determines the numerical result. "Result reporting" from the laboratory is the last link in the chain where clerical errors can be introduced before the data user receives the results.

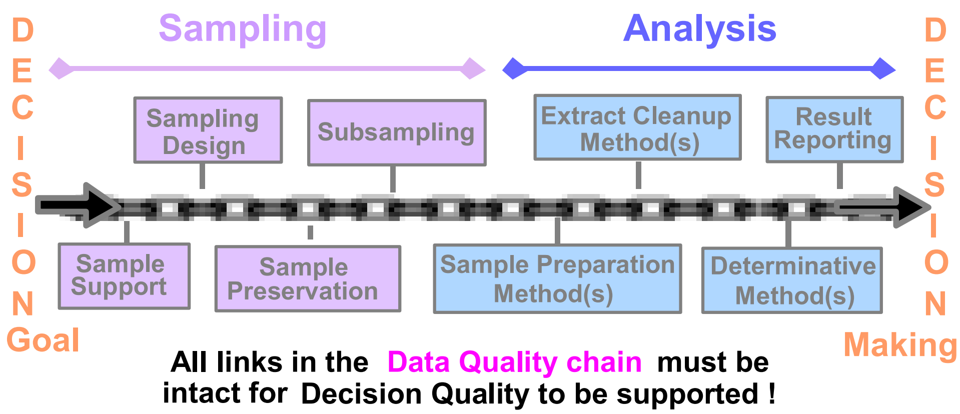

Figure 5. The data quality chain. Failure to control any of these variables can break the data quality chain, rendering the reported results nonrepresentative and misleading (Crumbling 2003b).

"Representative data" are generated when all these variables are controlled by selecting the appropriate procedures based on the intended use of the data. Depending on the analyte, the site type, the matrix, and the estimation procedure, sampling uncertainties can account for most to nearly all of the variability in a given data set. Even on just the analytical side, sample preparation methods and extract cleanup methods (separate method numbers in the SW-846 methods manual) can introduce significant variability into analytical results. Yet regulatory programs focus nearly all "data quality" oversight only on the last step, the analytical side of data generation: the determinative method. Most SW-846 methods familiar to practitioners designate only a determinative method. For example, SW-846 Method 8260 simply denotes that a gas chromatography–mass spectrometer (GC-MS) is used to measure volatile organic compounds (VOCs). The sample preparation method is not specified by referring to Method 8260 and needs to be designated separately. For example, the nearly universal purge-and-trap sample preparation method for VOCs is designated by Method 5030 (for water samples) and by Method 5035 (for solid samples). Selection of sample preparation method can impact the accuracy of the analysis. A generalized preparation method (such as Method 5030) will unavoidably perform better for some analytes than for others on the same (determinative) method list. At least five alternatives to the purge-and-trap sample preparation method for VOCs are referenced in SW-846 Method 8260 because the purge-and-trap method is not recommended for those VOC analytes that have low purging efficiency (EPA 2003d). Although the GC-MS may be able to measure any ethanol, for example, that gets into the instrument, the results will be falsely low if purging cannot move the ethanol out of the sample and into the GC-MS.

It should be clear that regulatory oversight for only SW-846 determinative methods leaves most of the data variability uncontrolled and unaddressed. In contrast, practitioners who use the Triad approach are expected to address all sources of data uncertainty that are of sufficient magnitude to cause decision errors. Within the Triad, there is no one-size-fits-all sampling and analysis program for a diverse range of site types and analytes. On the contrary, the Triad uses systematic planning to tailor all steps in the data generation chain to be representative of the exact decision goals articulated for the project.

As was illustrated in Figure 4, overall uncertainty in the data set used to develop the CSM is better managed using less-expensive analyses (such as field analyses) that can affordably increase the number of samples. Expensive laboratory analyses are reserved for samples of known representativeness to answer questions that the less-expensive analyses cannot address. High numbers of less-expensive analyses are used to develop the CSM and manage sampling uncertainties; fewer, carefully selected, fixed-laboratory analyses are used to manage analytical uncertainty (as illustrated later in Figure 7). In this way, the Triad approach uses a second-generation data quality model that breaks with the practice of using analytical uncertainty as a surrogate for overall data uncertainty. By explicitly managing sampling uncertainty, the Triad keeps the project team focused on all sources of data uncertainty and guides the selection of investigation techniques to keep decision errors within tolerable limits.

It is important to remember that all analytical methods contain some degree of purely analytical imprecision, even on a perfectly homogenous, well-behaved matrix. Repeated measurements of the same sample or extract will provide slightly different results, no matter how good the method. Analytical performance is further complicated when matrices are composed of mixtures of components that interfere with contaminant extraction or detection. The composition of typical site matrices (such as soil, groundwater, and wastes) is complex and variable in ways that affect the repeatability of the analysis. For example, soil analysis generally produces more measurement uncertainty than the analysis of water. The Triad approach encourages project teams to be realistic when determining during systematic planning the degree of analytical imprecision that can be tolerated in the decision-making process. The relevance of analytical imprecision should be balanced against the imprecision in the data set contributed by real-world heterogeneity. The goal is to generate data that are representative for their intended use. Judicious mixing and matching of sampling and analytical options allows data generation to be representative and economical. This approach to analytical method selection is equivalent to EPA's Performance-Based Measurement System (PBMS) initiative, which is discussed in more detail in Section 3.2.

The remainder of Section 2 provides additional information on the three legs of the Triad.

2.5 Systematic Project Planning

Many in the environmental community have recognized the need for systematic project planning as reflected in the EPA's data quality objective (DQO) process, the U.S. Army Corps of Engineers' (USACE) *Technical Project Planning (TPP) Guidance* (USACE 1998), and others. Too often during the course of performing environmental investigations, insufficient attention is directed to establishing clear objectives for the work, sometimes leading to unproductive investigations that fail to efficiently gather the information necessary for scientifically defensible decisions.

Systematic Project Planning Is the Key

The dynamic work strategy and real-time measurement technology components of the Triad approach may not be applicable to some sites. However, systematic project planning to establish clear objectives is essential for <u>all</u> environmental restoration projects.

Project teams should consider known or potential cleanup goals for a site from the earliest planning stages. Often cleanup goals will not yet be established or accepted, in which case values obtained from regulatory guidance (such as EPA Preliminary Remediation Goals [PRGs], maximum contaminant levels [MCLs], state action levels, etc.) or from preliminary site-specific screening risk assessments can be used Consideration of cleanup goals may need to be combined with discussion of potential institutional controls (deed restrictions, etc.) if consistent with the intended land use. Where possible and appropriate, the project planning should also identify potential remedial responses. Consideration of corrective action at this stage of the project allows for the earliest possible collection of specific data critical for evaluation of the potential remedial activity. Planning should detail how background conditions will be evaluated. For example, systematic planning can establish how background concentrations of naturally occurring metals will be calculated and used.

Optimization of data collection is a central theme of systematic project planning; however, it also includes many familiar tasks such as preparing for smooth workflow, ensuring the health and safety of field teams and local residents, procuring necessary contractor services, acquiring rights of entry, involving the public, and other related activities. Related to project workflow considerations is the early identification of key decision points that can result in significant alterations to the CSM. For example, discovery of a preferential pathway could result in a major reappraisal of likely contamination migration pathways and necessitate immediate modifications to the investigation strategy.

Another familiar theme that is emphasized in systematic project planning is the need for quality control. The project QC program must be comprehensive enough to detect deviations from expected performance and to allow for estimation of sampling and analytical uncertainties, as well as their impact on decision making. The actual quality will often vary by collection/ analytical technology and in accordance to the type of decision to be made. Varying the levels of analytical quality through the mixing and matching of methods offers potential cost and time savings, but the added complexity to the QC program must be carefully managed.

Sample collection and analysis methods must be shown appropriate to specific project conditions and applications. A pilot applicability study (called "demonstration of methods applicability" in SW-846) can be an important aspect of project QC that should be considered during the planning stage. This activity is recommended in Chapter 2 of SW-846 when using all analytical methods, including traditional fixed-laboratory methods, because of the complexity of waste-related matrices. A demonstration of methods applicability can be critical to determine whether a particular field method is appropriate to an intended application.

Establishing a project team with a cross section of necessary skills and experience is of fundamental importance to successful project planning. However, technical skills alone are not enough, and the team must include regulators and stakeholders from the outset to ensure that all parties participate in the development of the project goals.

The project team should begin its planning by gathering and organizing available site and regional data. The use of environmental data management systems (databases, geography information systems [GIS], etc.) will often be very helpful in accomplishing this task. Next the team will develop a CSM or various depictions of the site model to convey competing alternatives or complementary levels of site detail. For example, a small leaking UST site may need only a limited CSM focused on the shallow vadose zone and a small number of potential receptors. Conversely, at a complex site where large amounts of a very mobile contaminant have been released to the environment, development of a comprehensive CSM may require integration of geologic, hydrogeologic, geochemical, and potential receptor models.

For those situations where an environmental consultant will be retained to conduct the project, the earliest possible consideration should be given to preparing a scope of services that will ensure formation of a team with the necessary skills. The project scope of services should contain language highlighting the overall approach to the investigation, thereby requiring that some planning be conducted prior to contract award. In cases where new and innovative investigation technologies may be under consideration, it is especially useful to discuss options with potential vendors prior to finalizing the scope of services.

In summary, systematic project planning includes familiar project preparation activities combined with several important new tasks, such as early determination of action criteria and identification of key decision points. To successfully apply the Triad approach, these new tasks must be fully integrated into the planning process, and the project team must not abridge the planning process with the hope that problems can be corrected later. Failure to fully embrace all facets of systematic project planning can result in compromised projects that fail to achieve the desired project outcome.

2.6 Dynamic Work Strategies

Dynamic planning documents differ from conventional work planning documents in that they contain decision logic enabling the field team to change or modify site activities as required to achieve the project objectives in the face of potential confounding site complexities. This flexibility does not necessarily require that all decision makers be present in the field, only that they be accessible to support the field crew. Telecommunications advances permit the real-time sharing of data, diagrams, and maps anywhere. Many Triad projects are entirely successful even though various team members are scattered across the country. The rapid pace of Triad field projects means that work is fairly intensive while it is occurring, but it spans a shorter period of time. An implicit goal is to complete the field work in as few mobilizations as possible. Dynamic strategies do this by providing contingencies to actually change or modify the field activity quickly as the investigation proceeds. Since project cost is proportional to time invested, it is important that the adaptive work plan be developed to allow the investigation to proceed as quickly as possible. This approach requires close involvement by the project team and processes to allow for rapid data evaluation and decision making. The use of environmental data management systems can play a large role in making the investigation a success.

A critical feature of any work plan document prepared using Triad principles is clear articulation of project goals and the rationale behind each proposed activity. Work planning documents for Triad projects should include discussion of the following:

- decision goals,
- the initial CSM,
- decision uncertainties,
- mechanisms to manage decision uncertainties and refine the CSM,
- data needs to address decision goals, and
- mechanisms to address data (sampling and analytical) uncertainties.

The word "dynamic" describes the flexibility or adaptability of the intended flow of work activities. There is a tendency to use this term to title work documents, but that may not be a good idea. Work plan documents go by many different names, such as "field sampling plans" (FSPs), "sampling and analysis plans," "quality assurance project plans," "remedial action management plans" (RAMPs), and others. The naming convention for project planning and reporting documents is often specific to the program or the contractor. The Triad approach does not change that. It is inadvisable to title a document "Dynamic Work Plan" simply because it is written using a flexible or dynamic decision logic. Experience has shown that doing so causes confusion. It is not clear whether a reference to the "dynamic work plan" refers to a particular paper document or to the decision logic or strategy that underlie behind the written plan.

Remedial investigation plans, RAMPs, FSPs, QAPPs, SAPs, health and safety plans (HSPs), community relations plans, etc., may all be written to follow an adaptive or dynamic decision-making strategy. Keep in mind that each planning document (whether a RAMP, QAPP, or HSP) supporting a particular Triad project must be written to be harmonious with the overall dynamic work strategy. For example, simple wholesale adoption of an HSP from a previous non-Triad project into a Triad project will certainly create inconsistencies with the overall flow of work activities written into the SAP or RAMP and may cause planning documents for the same project to conflict with each other.

Triad Work Planning Documents

In addition to the usual elements that comprise a conventional work plan, flexibly written work planning documents supporting a dynamic work strategy contain

- decision logic that adapts the investigation approach to changing conditions,
- mechanisms for rapid project team communication and decision making, and
- real-time data management.

It is not a good idea to use "Dynamic Work Plan" as the title of a document.

The naming of documents or the parceling of activities between various documents is not important to the Triad approach. What is important is that planning documents discuss how overall decision uncertainty will be managed. When environmental data are collected, investigation elements that will address uncertainty should be detailed (such as what sample support will be representative of the decision or how to minimize variance by separating and delineating distinct contaminant populations). For those projects where statistical measures are compared to action levels, the statistical procedures must be identified in the work plan. In some cases multiple statistical procedures combined with professional interpretation may be necessary. QC considerations will include familiar checks on fixed-laboratory analysis but will be expanded to include all investigation techniques, such as geophysical methods, direct-push lithologic data evaluation, in situ contaminant measurements, and field-based analytical methods. "QC" is used here in the generic sense encompassing varied definitions of quality assurance (QA) and QC. The goal of the QC program will be to produce data of known quality that is commensurate with achieving project decision goals and helps the project team understand data variability.

A dynamic or adaptive work plan contains the same kind of QC measures associated with a conventional approach; however, the application may be more complex. Multiple field analytical technologies are typically used in conjunction with fixed-laboratory analysis techniques, with each managing different components of data uncertainty. It is often advisable to evaluate some QC data very early during the investigation. For example, it may be desirable to confirm that an on-site method is performing as expected soon after it is used because real-time decisions depend upon its performance. "Adaptive quality control" describes QC procedures that support higher frequencies of QC samples when the uncertainty is high and lower frequencies when there is greater confidence in the analytical performance.

Dynamic work strategies allow a sample-by-sample evaluation of results, if desired. Results can be assessed in real time for their value to CSM development and to project decisions. If there is a conflict between a result and the current CSM, there are two possibilities: either the result or the CSM is wrong. Within an adaptive work plan it is a simple matter to quickly double-check and resolve an incompatible data result. Something may have gone wrong with the analysis or the sampling. Perhaps an equipment problem has developed that needs to be rectified. If the result is confirmed to be correct, then the CSM needs to be modified. Incompatible results are valuable clues to detect errors or false assumptions in the CSM.

Better Quality Control

Triad systematic planning revolves around the identification and management of things that can cause decision errors. This is the essence of quality control.

Quality control within the context of a dynamic work strategy is much more effective at catching mistakes than traditional work strategies relying on static work plans and fixed-laboratory analyses. Results are immediately compared with the current CSM.

Real-time checks of data compatibility with the CSM are a powerful QC procedure seldom available to traditional projects using standard laboratory methods. Much of the QC performed with traditional analyses tries to compensate for the fact that the analyst must work blind, having little or no knowledge of the intended data use or project uncertainties. In turn, the data user interacts with the analyst only through written reports that may leave many questions unanswered. Traditional paradigms for regulatory oversight of analytical data were created based on this mass-production mode of most fixed-laboratory analyses. The operator seldom knows whether results make sense from the project standpoint, whether detection limits are too high, or whether simple method modifications (such as adding another calibration standard to extend the method's quantitation range) could produce much more useful data. Batch-based QC checks may not pick up sample-specific problems if the QC sample run with the batch was not from the same site or was 18 samples away in the analytical run. In contrast, Triad practitioners have greater opportunity to detect and rectify problems before errors lead to costly mistakes. For example, Triad projects sometimes have access to two different real-time methods that are able to cross-check and confirm each other's results. One example is using an on-site GC-MS primarily set up for polycyclic aromatic hydrocarbon (PAH) analyses to verify detections of polychlorinated biphenyls (PCBs) indicated by an immunoassay kit during the same project.

Providers of Triad Analytical Services

- Bring vital expertise and participate in the up-front systematic planning.
- Interact closely with data users during field implementation.
- Routinely adapt their method procedures and QC checks (maintaining accountability and documentation) to manage uncertainty to match the specific needs of the project at that moment in time.

Regulatory programs seeking to support Triad projects will be challenged to adapt their oversight procedures to acknowledge the power of CSM-data compatibility checks. Inflexible requirements for QC can be counterproductive. Rather, QC can have its own dynamic decision tree written into the QAPP for regulatory approval. Only unplanned deviations from the approved options would require additional regulatory oversight. Some QC checks based solely on the need to compensate for the limitations of routine fixed-laboratory analysis may be superfluous for Triad projects. Requiring certain QC checks simply because they appear on a one-size-fits-all fixed-laboratory checklist (but add no value toward managing data uncertainty at the project decision level) will waste resources that could be better used increasing the sampling density to perfect the CSM.

Dynamic Work Strategies Alone Are <u>Not</u> the Triad Approach

Using the Triad approach means that systematic planning clearly identifies project decision goals and that decision and data uncertainties are actively managed. Dynamic work strategies make this level of effort and project quality both achievable and affordable.

It is possible to use a dynamic approach without doing systematic project planning and focusing on uncertainty management, but that is not the Triad approach.

On the other hand, QC checks seldom used now (such as mechanisms to detect and control for sampling variables) are very important for Triad projects. When approving work plans for Triad projects, regulators should expect to see a concise list of planned QC checks, along with brief descriptions of the role each is intended to play in managing uncertainty in the data, the CSM, or the project decisions.

2.7 Real-Time Measurement Technologies

As mentioned before, the ability to gather a large number of samples at a site helps to reduce uncertainty in the CSM. To achieve this objective, the environmental community must provide greater acceptance of data generated in the field, which can produce more information in a shorter amount of time than fixed-based laboratories. The increased use of real-time analytical procedures, combined with changes in the emphasis in data quality procedures, will be a fundamental shift in thinking for many environmental professionals.

Field Methods Alone Do Not Make a Triad Project

Just as using a dynamic work strategy alone does not equate to using the Triad approach; nor does the sole use of field methods. Systematic project planning to select the right analytical methods and to develop proper QC protocols is essential to Triad's goal of managing uncertainty.

Real-time measurement technologies are the third element of the Triad because real-time data are necessary to support real-time decision making. Many people mistakenly believe this leg of the Triad refers only to things like test kits and x-ray fluorescence (XRF), but the term encompasses also the technologies that support data management, processing, interpretation, and sharing. Because the technologies used by Triad projects often generate very large numbers of data points, electronic tools to reliably handle and manipulate this volume of data are critical. For example, open-path air monitoring systems and subsurface geophysical detection tools deployed in situ via direct push 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 tools have become more available in recent years, and experienced Triad practitioners are already exploiting them.

QC for field-generated data and for data management tools is a critical aspect of the Triad approach. The wide range of available and emerging field analytical techniques and the uses to which they may be put make it impossible to prescribe blanket requirements for QC. Field techniques now range from simple yes-no detection of contaminant presence to highly sophisticated and quantitative mass spectrometers. The value of the information cannot be judged by the analytical rigor of the method, as even simple detection tools can be highly valuable for refining the CSM. The exact QC checks to be employed depend on the nature of the technique and the way the information generated will be used. Qualitative data uses, e.g., those that support a general site (screening) assessment or refine the CSM, may rely on the data's general agreement with expected CSM as a form of verification. However, in general, the validity of all in-field measurements should be established by QC procedures that demonstrate that instruments are calibrated (if appropriate) and functioning properly. When data uses are quantitative in nature, the assessment of the numerical values produced becomes more critical. QC protocols should include both instrumental and matrix-specific QC checks to verify the equipment is not only working properly, but that the method shows acceptable performance with the project matrices. Routine QC checks applied might include an evaluation of potential cross-contamination sources (e.g., various blanks), limits of quantitation (LOQ)/detection limits (DL) in the project matrix, or the bias from matrix interferences. Accuracy of the method should be checked at project decision levels to assess the need for establishing intervals of decision uncertainty and triggers for appropriate split sample analyses. A series of duplicate samples can be executed to evaluate sampling and analytical procedures, as well as characteristics of sample heterogeneity and other sample support issues. There are diverse ranges of options for documenting that a tool is performing as intended. Under the Triad approach, project planners are expected to determine which options make logistical and technical sense for their tools, their work plan, and their project constraints. They must be prepared to provide full justification and documentation for their choices.

A frequent QC technique that should be avoided is relying on an arbitrary, fixed percentage of split "confirmation" samples between the field and fixed-lab analysis as the sole QC to establish. reliability of the field data. In practice, this tactic may fail to manage data and decision uncertainties. It also creates an economic disincentive for increasing the sampling density by using the less-expensive methods. Another serious deficiency of this arbitrary confirmation sample approach can be the untimeliness of the comparison of data sets. In a traditional approach, many times the evaluation of comparability between field and fixed data sets actually waits until the final report. The Triad instead tries to work real time to optimize the methods/techniques, understand their limitations, trends, and effects on use. Even the term "confirmation sampling" is misleading because it assumes that the fixed-lab analysis is correct, and that may not be the case.

Avoid Requirements for Fixed Percentages of Split Samples

Arbitrary percentages of QC samples, such as "10% split sample confirmation," nearly always fail to provide convincing evidence to "confirm" that field data are reliable. Split sample evidence is usually equivocal. Split samples are not a substitute for in-field method QC to demonstrate the method is working properly. Split samples should be selected on the basis of the analytical information these samples provide to enable interpretation of nonspecific analyses and to provide the low reporting limits and analyte-specific data needed for risk assessment or to demonstrate regulatory closure compliance.

Relying on confirmation by the fixed lab ignores the many sampling and analytical variables that cause analytical results to vary (as discussed in Section 2.4.4.). Although split samples can provide important information, arbitrary percentages and arbitrary selection of those splits fail to manage uncertainty for both the field and fixed-lab data sets. Managing uncertainty with the Triad approach requires that a rationale for the number and selection of split samples be developed and followed. Field analyses are generally not a direct substitute for fixed-laboratory analysis and so cannot be expected to always achieve a one-to-one correspondence. They complement each other for the purpose of refining the accuracy of the CSM.

Figure 6 illustrates that both traditional fixed-laboratory methods and alternative, less-expensive methods have certain strengths and weaknesses. If used independently of each other, both method types produce data sets with significant amounts of uncertainty. The use of either laboratory or field analysis in isolation may result in "screening quality data," which equates to excessive decision uncertainty (Crumbling 2003b).

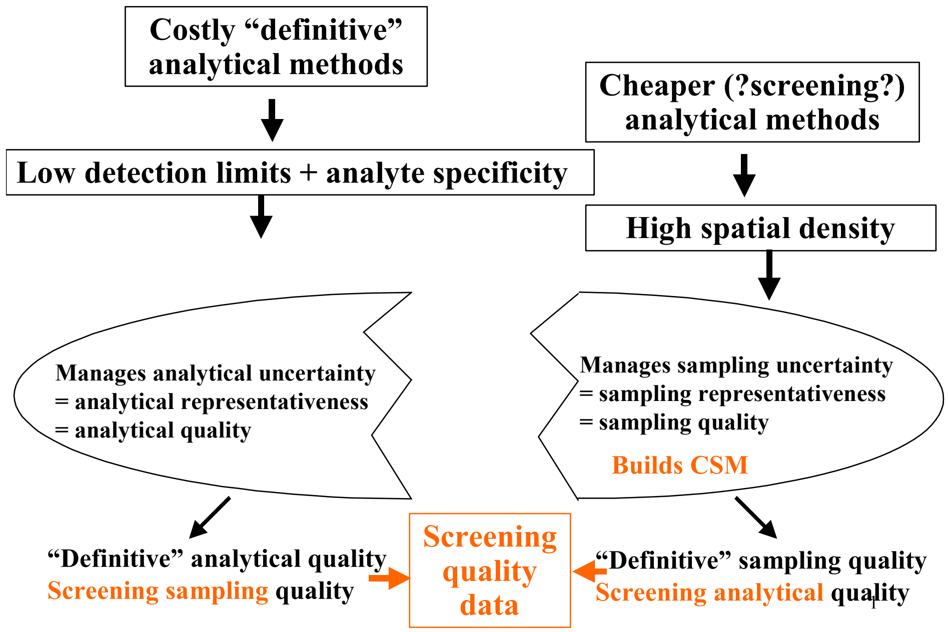

Figure 6. The strengths and limitations of analytical methods (Crumbling 2003b).

If used alone, fixed-laboratory methods are generally too expensive to get a high enough sampling density to characterize heterogeneous contamination and build confidence in the CSM. Therefore, the representativeness of those high-analytical quality data points is in doubt. On the other hand, a nonspecific and/or biased field method can be useful to understand contaminant distributions and spatial patterning to support the CSM. The data may even be useful for making some project decisions where there is confidence that the method correctly indicates areas either well above or well below a regulatory action level. However, there may be too much analytical uncertainty to support confident decision making near the action level or to support risk assessment or a demonstration of regulatory compliance. Note that this generalization may not be true for those field methods based on rigorous analytical techniques, such as field-portable GC-MS for VOCs, where the analytical quality may equal or surpass that of a fixed laboratory.

The solution to this dilemma is to use field and fixed-laboratory analyses in a collaborative effort that maximizes their respective strengths but compensates for their respective weaknesses. This approach is illustrated in Figure 7. Less-expensive methods are used to increase sampling density and build the CSM. Where unresolved analytical uncertainty remains, samples are selected for fixed-laboratory analysis. These samples are selected based on their representativeness (already established by the refined CSM) to support specific decisions for which more analyte-specific information or more accurate quantitation is required. Collaborative data sets complement each other by managing all sources of data uncertainty, both sampling and analytical, important to site decision making (Crumbling 2003b).

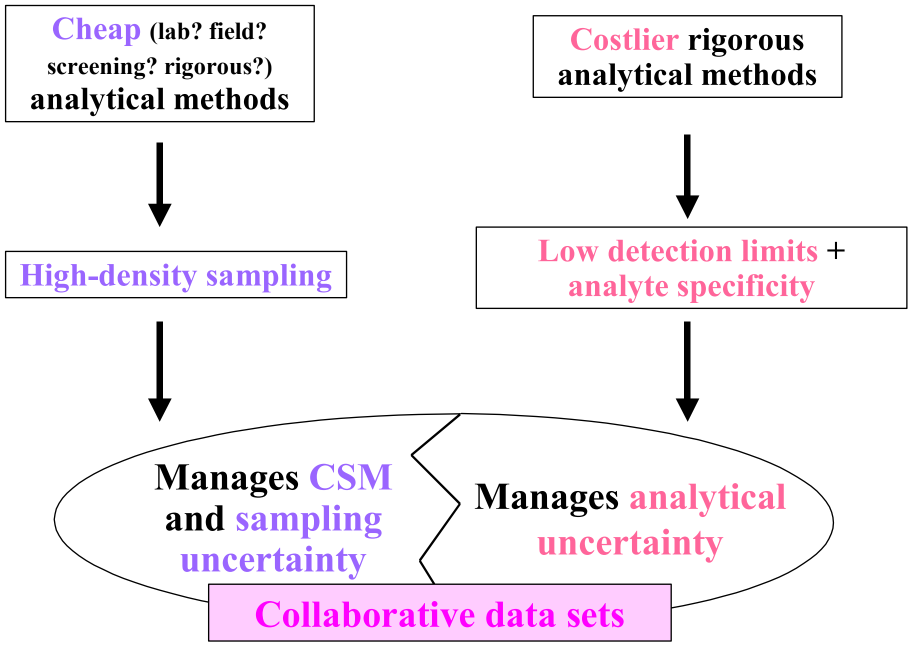

Figure 7. Collaborative data sets increase data quality in heterogeneous matrices (Crumbling 2003b).

Care should be exercised 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. Especially when nonspecific screening methods (such as immunoassay test kits for PCBs or pesticides) are used to build the CSM, results from the test kit are seldom numerically comparable to analyte-specific fixed-laboratory data. In other cases, differences in sample volume or processing may create noncomparable data sets. Blind merging of the two data sets, such as in statistical programs to calculate means and standard deviation, should be avoided. This situation does not in any way invalidate the usefulness or reliability of the data for making project decisions. One data set is used to build the CSM; the other is used to manage any lingering analytical uncertainties from the first data set. The confidence provided by collaborative data sets is much higher than can be achieved by either data set alone.

The increased impetus the Triad places on field analysis should not imply that laboratory analysis is of lesser importance. Data derived from fixed laboratories continue to play an important role in analysis of contaminants not currently amenable to field analysis and to evaluate the effectiveness of analytical data obtained in the field. Samples split between the field and fixed laboratory are required when comparison analysis is needed to help interpret results from nonspecific or biased analytical methods. Split samples, especially for solids, seldom match closely, however, for a number of important reasons. For example, different analytical techniques may be measuring different things, or the sample support may be different. Some matrices and analytes are more difficult to homogenize than others. For reasons covered in Section 2.4.4, heterogeneity at microscales makes it nearly impossible to split samples so that

> **Real-Time Measurement Technologies**
>
> - Faster decision making
> - Fewer uncertainties
> - Better conceptual site model
> - Better use of resources

each analytical method is presented with the exact same concentrations of analytes. This is another reason why confirmation sampling seldom works if a fixed percentage of splits is the only QC being performed to support the field data.

The terms "screening" and "confirmation" are used widely by the environmental community, especially in the context of sampling and analytical activities. The ambiguous use of both terms easily causes confusion. Confusion is avoided by being clear about what activity is being described. The word "confirmation" implies the intent to manage some aspect of uncertainty. When postremediation samples are analyzed at a fixed laboratory, these results are used to "confirm" that the cleanup was successful and that regulatory action levels are met (thus managing uncertainty regarding the completed cleanup action).

The term "confirmation" is also used to refer to reducing uncertainty regarding the performance of specific sampling and analytical procedures. Confirmation of analytical performance is often done by homogenizing samples that are then split between different laboratories or analyzed by different methods by the same laboratory. There are a variety of reasons why split sample analysis is performed:

- provide oversight of a laboratory or analyst performance;
- evaluate the comparability of different analytical, sample preparation, and extraction techniques; and
- provide analyte-specific results to guide the interpretation of results produced by test kits that do not produce analyte-specific data.

Because of the confusion that can arise when term "confirmation" is used ambiguously, Triad practitioners try to be very clear about what exactly is intended to be "confirmed" when split samples are used. More accurate phrases, such as "comparison analysis" or "establishing the comparability between data sets" are often used by Triad practitioners rather than the more vague "confirmation analysis." When performing any kind of "confirmation analyses" under the Triad approach, first be clear about what you intend to "confirm" and what uncertainties you are expecting to manage. Secondly, whenever split samples are used, consider the impact of heterogeneity on your ability to compare or interpret results from the splits. Control for that variability by careful homogenization if you can, but know that no homogenization procedure is perfect. It is a good idea to determine how much variability is occurring simply from imperfect homogenization. This can be done by doing "control splits." Control splits are prepared the same way as splits between the fixed lab and the field lab. However, the same analyst analyzes both splits at the same time in both the fixed lab and the field. Since the analytical variability is thus held constant, you will be able to estimate how much variability is due to imperfect sample splitting. The analytical results for splits between the field and fixed lab cannot be expected to match any better than this.

Field Methods Used in a Fixed Laboratory

There can be advantages to performing methods typically associated with the field in a fixed laboratory. If a fixed lab is nearby, the option exists for running real-time analyses in a controlled environment, thereby avoiding the costs of support facilities on site. This may improve method performance while retaining the advantages of rapid turnaround and greater sample numbers.

A detailed description of all available real-time measurement technologies is not within the scope of this document. A more comprehensive list and descriptions are available at the Web sites noted in Section 10. Following is a partial list of some of the categories of geophysical and analytical methods available:

Geophysical techniques:
- borehole techniques (gamma-gamma probe, for example)
- electrical (resistivity)
- electromagnetic (conductivity, ground-penetrating radar)
- magnetics
- magnetotellurics
- seismic (reflection, refraction)
- borehole tomography

Analytical techniques:
- DNAPL detection techniques such as hydrophobic dye and sheen tests
- mobile gas chromatography (SW-846 8000 methods series)
- mobile mass spectrometers (Draft SW-846 Method 8265)
- x-ray fluorescence (SW-846 Method 6200)
- immunoassay (SW-846 4000 methods series)
- colorimetric (a number of SW-846 methods in the 8500 and 9000 series)
- in situ probes such as laser-induced fluorescence (LIF), and the membrane interface probe (MIP)
- electrochemical methods (SW-846 Method 7472 and Method 9078)
- ion-specific electrodes (SW-846 9200 methods series)
- open-path techniques (ultraviolet differential optical absorption spectrometry, Fourier transform infrared spectroscopy, and tunable dye lasers) for atmospheric monitoring for fenceline, landfill, and vapor-intrusion detection (EPA 2003e)

Geological techniques:
- cone penetrometer test (CPT) logging
- direct-push down-hole video

2.8 Other Triad Approach Considerations

The use of the Triad approach to conduct a project may introduce a number of new concepts to project teams. In some cases these concepts will require changes to long-established business practices or acquisition of new capabilities. While departure from familiar procedures may be daunting, the potential improvements to quality and cost-effectiveness are significant. It should be noted that development of tools to facilitate Triad implementation is an ongoing process. Some of the considerations linked to application of the Triad approach are described below.

2.8.1 Need for Senior/Experienced Field Personnel

When applying the Triad approach, field teams are required to evaluate site data as they become available. This requires that experienced technical staff (geologists, chemists, engineers, etc.) be either in the field or available via telecommunications to guide the unfolding investigation in real time as directed by the preapproved decision logic and contingencies identified in the project work plans.

2.8.2 Change in Approach to Quality Control

Investigations conducted in accordance with traditional methods apply most of the QC effort towards the validation of chemistry data originating from fixed laboratories. The Triad approach advances the idea that a better investigation can be achieved by identifying all sources of uncertainty. The Triad approach emphasizes development of a QC plan that minimizes the overall uncertainty without undue emphasis on fixed-laboratory data at the expense of equally important considerations such as sample density, location, and representativeness. QC data are explicitly leveraged to address uncertainties in the data and in the CSM that are relevant to project decisions. Within the context of an adaptive sampling and analysis program, the intensity of QC checks is adjustable in real time (according to a preapproved rationale) depending on the kinds and levels of uncertainty present at each milestone of project implementation.

2.8.3 Greater Use of Multidisciplinary Investigation Teams

Traditional investigation processes allow generous amounts of time for various disciplines to be consulted during the course of data evaluation. Conducting an investigation using the Triad approach requires that significant data evaluation occur in the course of the field work, which necessitates that all needed disciplines be included on the project team from the earliest phases of the project.

2.8.4 Early Consideration of Land Use, Action Levels, Etc.

Successful systematic project planning requires project team and stakeholder consensus on objectives prior to conducting the field work. Future use of the site must be agreed upon so that the data obtained support evaluation against action levels consistent with that use. It is sometimes possible for the team to agree on a range of future land uses if the specific land use is not known. Data must be collected with a specific future land use (or range of uses) in mind. Later changes in land use may require reevaluation. Notwithstanding the foregoing discussion, some states have regulations that require sites to be remediated to residential use levels regardless of the future use. Consideration must be given to state regulations regarding future land use.

2.8.5 Need for Data Management Tools

Field teams often need tools for the management and evaluation of the increased amount of data generated during Triad investigations. These software tools may include some form of database, GIS, and data visualization applications (such as Surfer, RockWorks and EarthVision). The successful utilization of these applications may require database and computer data evaluation team members to be involved in both planning and implementation of the field work.

2.8.6 Research and Training Needed

A fundamental tenet of the Triad approach is to improve investigation quality by reducing decision uncertainty. Decision uncertainty can be reduced even further with improvements in statistical or visualization tools that display in real time and quantify geologic variability, contaminant fate and transport, preferential pathways, and human activities generating contamination. Additional training, guidance, and software tools (decision support applications) are needed to assist all project teams to successfully address these issues.

2.8.7 Not All Projects Are Amenable to Full Application of the Triad Approach

Although systematic planning has been mandated by EPA for years and managing the uncertainty in decisions and data are fundamental to any successful, science-based project, not every project is amenable to a real-time, accelerated approach. Legally contentious projects may be required to move very slowly and deliberately. There may be economic disincentives to spending more money in the short run to save money in the long run. When one party saves money on a cleanup, another party is losing money that would have otherwise been spent. As long as traditional approaches are considered satisfactory by regulatory agencies, non-Triad approaches are still available to anyone who wishes to use them. Since employing the Triad can require significant changes to familiar ways of doing business, adoption of Triad concepts might be phased in gradually to allow practitioners to become more proficient. Alternatively, staff could "practice" by using Triad strategies on smaller discrete tasks within larger projects that would be too complex if tackled whole. Lastly, dynamic work strategies and on-site methods are often used outside of the decision uncertainty management umbrella of the Triad approach.

2.9 Summary

The three legs of the Triad—systematic project planning, dynamic work strategies, and real-time measurement technologies—utilize both established and new ideas and methods. The key new components include the following:

- greater efforts to define project goals,
- a renewed emphasis on the CSM and sample representativeness,
- greater application of field analytical techniques to increase sample density,
- adaptive QC to ensure representative data of known quality,
- dynamic sample collection programs, and
- increased effort to define necessary analytical quality.

The goal of the Triad approach is to improve investigation effectiveness. This is achieved by focusing on clearly defined goals up front and incorporating recent technological advances. It provides the potential for more efficient, less-expensive site characterizations that generate data of improved quality and more definitive conceptual models, leading to more decision confidence. The Triad approach is an outgrowth of the natural evolution of the site restoration industry in response to imperatives that include evolving economic considerations (such as environmental insurance coverage and a community focus on redeveloping/reusing sites) and improved science and technology for both characterization and remediation. Many federal and state programs have recognized the impetus for change and improvement, as shown by the large number of program initiatives under development that reflect the universal principles embodied in the Triad approach.

3.0 RELATIONSHIPS TO EXISTING GUIDANCE

Knowing that EPA and other organizations have developed a number of process streamlining initiatives, environmental professionals may wonder how the Triad approach relates to these programs. This section addresses that issue both generally and for several specific programs. As discussed previously, the Triad approach is not a new environmental program. The Triad approach brings together into a single integrated package concepts articulated in a variety of prior initiatives. These include the Observational Approach, the DQO process, Technical Project Planning (TPP), Expedited Site Characterization (ESC), QuickSite, Accelerated Site Characterization (ASC), ESC using the M_3 Approach, Streamlined Approach for Environmental Restoration (SAFER), Expedited Site Assessment (ESA), and Superfund Accelerated Cleanup Model (SACM). These and other approaches have been described by various parties including EPA, DOE, ITRC, the Department of Defense, universities, and private-sector consulting firms (TetraTech EM, Inc. 1997). The Triad approach is consistent with any guidance or approach that recognizes the following:

- Site decisions are made based on scientific, economic, social, and political considerations.
- Data quality concepts need to emphasize sampling representativeness instead of focusing solely on laboratory analytical procedures.
- Good science requires that data be shown to be representative of the target populations at the same scales as the decision to be made about those populations.
- Good science also requires controlling variables that introduce data uncertainty.
- Data collection should be tailored to the specific decisions developed during the systematic planning process.
- Analytical and sampling plans are most efficient when they can adapt to unexpected conditions.
- Data representativeness both determines and is determined by the CSM and project decisions.
- Appropriate scientific/technical expertise is required throughout project planning and implementation to address complexities and direct activities. Otherwise, identification and management of relevant uncertainties does not occur, data quality is frequently mismatched to data use, sound science is not achieved, and decisions may be made in error, wasting time, resources, and public good will.

Acceptance of these concepts constitutes an ongoing evolution of regulatory thought and technical approach. At the birth of cleanup programs, explicit management of scientific sources of uncertainty was exceedingly expensive, if possible at all, because the scientific foundations and technological capabilities to do so were lacking. In recent years this situation has changed, and a number of practitioners have developed initiatives to address some of the same key concepts as the Triad. The sections that follow detail some of these other initiatives and related processes.

3.1 The Triad Approach and the DQO Process

One obvious question is whether the Triad approach differs from the data quality objective initiative also promoted by EPA. The answer is that the Triad approach is entirely consistent with the DQO process as articulated in EPA guidance. Both are methods to structure the project planning processes. There is a slight difference in that the DQO process focuses primarily on data collection, whereas systematic planning under the Triad approach is far broader in scope. Although data quality is an extremely important aspect of the Triad approach, it is but one aspect. The Triad approach explicitly considers remedial design, the flow of work tasks (such as implementing the dynamic strategy), stakeholder concerns, long-term monitoring designs, and all other types of site-related activities to be within the scope of "systematic project planning" and integral to the process of identifying and managing decision uncertainties. Within the broader scope of Triad project planning, an accurate CSM is used to decide how classical statistics and geostatistics will be used for evaluating data. Some practitioners may call this "the DQO process," whereas other practitioners might not. What the systematic planning process is called is less important than the fact that it is done (EPA 2000b).

It is important to acknowledge, however, that confusion has arisen because the DQO process has not been consistently applied by the environmental community. Many practitioners have been unclear about how to utilize some elements of the process, such as statistical hypothesis testing. Although the originators of the DQO process do not consider statistical hypothesis testing to be a requirement of using the systematic planning aspects of the DQO process, some DQO proponents have so strongly emphasized classical statistics and hypothesis testing that they have become inseparably linked to DQOs for many. While hypothesis testing can be a very valuable tool for some aspects of risk and compliance decision making, many professionals realize that not all environmental scenarios faced by project managers are amenable to classical statistical modeling. This idea has caused some to dismiss the DQO process in its entirety, an unfortunate reaction since the planning structure that the DQO process provides is very useful. Classical statistical models are important tools when applied properly and guided by a CSM.

Originally, the DQO process was named the "Data Quality Objectives for Environmental Decision-Making." Although much more intuitively meaningful, the name became truncated to "data quality objectives," and over time, the important conceptual linkage between data quality and the project-specific decision-making process was muted (Crumbling 2003a). The term "DQO" was originally intended to convey the idea that project objectives (i.e., decisions) determined what data quality was needed. In other words, DQOs were supposed to describe the project objectives that would drive the selection of sampling and analytical methods, when all of the factors impacting the relationship between data quality and decision quality were considered. The intent behind the DQO process is wholly consistent with the Triad approach.

When the DQO process was developed in the 1980s, there were few tools that could allow the DQO process to be executed as it was intended within available budgets. For example, statistical calculations that took true matrix heterogeneity (and thus sampling variability) into account determined that hundreds to thousands of samples were required to reach statistical confidence for site decisions. The cost of laboratory methods available at the time made large numbers of samples cost-prohibitive for most projects. Given real constraints on their ability to cope with sampling uncertainties, many began to think of DQOs in terms of strict control over analytical quality. This thinking has resulted in some practitioners now using the term "DQOs" to refer specifically to requirements for analytical methods and laboratory performance. Another prevalent outcome is that DQOs (as laboratory requirements) became defined at programmatic levels that are independent of project- and decision-specific data needs. This development has contributed to the pervasive misconception that "analytical quality = data quality." Attempts to clarify DQO terminology for the data user community have been so far unsuccessful at harmonizing DQO language and usage across the environmental industry (Crumbling et al. 2001). Because of the propensity for confusion and miscommunications, an interagency team coordinating Triad development avoids DQO language in favor of intuitively meaningful or descriptive words or terms for which the Triad usage has been clearly defined.

3.2 The Triad Approach and PBMS

The Performance-Based Measurement System initiative described by EPA several years ago and the Triad approach are completely consistent with each other. As articulated by EPA's waste programs, PBMS makes the policy statement that any analytical method may be used to generate data (whether or not it is currently published in SW-846) as long as it can be demonstrated

- to measure the constituent of concern
- in the matrix of concern,
- at the concentration level of concern, and
- at the degree of accuracy necessary to address the site decision.

In other words, PBMS is a formal articulation of the idea that analytical uncertainty should be managed to a degree commensurate with the overall project decision goals (EPA 2003a). It might be noted that this is also the intent of the DQO process. Although a PBMS strategy has always existed in the language of the SW-846 methods compendium, it has long been overlooked in favor of simpler one-size-fits-all prescriptive method requirements.

A primary factor contributing to confusion over EPA's analytical strategy is that EPA encompasses two distinct analytical method programs that function very differently. EPA's Office of Water programs has a very prescriptive, one-size-fits-all regulation-driven analytical strategy. While it may be debated whether this prescriptive approach has served the needs of water programs well, it is very clear that a prescriptive analytical strategy cannot meet the data quality needs of waste programs and risk-based decision making. Technical and logistical difficulties posed by the matrices encountered in waste programs render one-size-fits-all analytical approaches counterproductive to the goals of protective, yet efficient and economical site cleanup. Waste programs deal with some very difficult matrices and analytes subject to a wide variety of decisions about exposure, remediation, and long-term monitoring. Therefore, the value of analytical and sampling flexibility has long been recognized by the scientists who developed and maintain the SW-846 methods manual. The PBMS initiative was EPA's effort to elevate public awareness that the flexibility already inherent in SW-846 and EPA waste program policies is vital to good science and cost-effective waste programs. The Triad approach builds on these very same principles, and a PBMS approach is vital to the success of Triad-type projects.

3.3 The Triad Approach and the Dynamic Field Activities Guidance

From about 1998 to present, an interagency Triad team have been pooling their experiences from actual projects to formulate the Triad approach as a coherent framework. About the same time, EPA's Superfund program was interested in promoting dynamic work strategies since a number of innovative Superfund projects using this basic approach had demonstrated cost savings. Semi-independently of concurrent Triad efforts, the Superfund program prepared a document titled *Using Dynamic Field Activities for On-Site Decision Making: A Guide for Project Managers* (EPA 2003b). This guide includes descriptions of several projects conducted in the 1990s that used a dynamic field approach. Internet links to the online guide and to the endorsement memorandum from the Assistant Administrator for EPA's Office of Solid Waste and Emergency Response are found in Section 10.

Although this first release of the dynamic field activities (DFA) guide has many commonalities with the Triad approach, there are currently a few differences. In general these stem from the fact that the DFA guide focuses more on streamlining site activities and field analytical tools and less on the concepts of uncertainty management and systematic planning. Despite the differences, the DFA guide makes an important contribution that demonstrates the Superfund program's approval for dynamic work strategies. The fact that EPA accepts these strategies does not negate the fact that considerable time and coordination will be required (even within EPA) to restructure programmatic budget allocations, contracting, staffing, and logistical mechanisms to facilitate the routine implementation of dynamic work strategies. However, releasing the DFA guide is an important step in communicating EPA's intention to move in that direction.

3.4 The Triad Approach and MARSSIM

The Multi-Agency Radiation Surveys and Site Investigation Manual (MARSSIM) was developed by Departments of Defense and Energy, EPA, and the Nuclear Regulatory Commission. MARSSIM was created to provide guidance for planning, implementation, and evaluation of environmental and facility radiological surveys conducted to demonstrate compliance with either a dose- or risk-based regulation (EPA 2000a). The focus of MARSSIM is on demonstrating compliance during the final status survey, which follows scoping, characterization, and any necessary remedial actions. MARSSIM describes how to plan systematically and how to make planning decisions during the seven steps of the DQO process. Therefore, its connection to the Triad approach is through the DQO process. The Triad approach is tied to a CSM and is focused on characterization to support a full range of project decisions, while MARSSIM is prescriptive and focused on compliance.

3.5 The Triad Approach versus the "Sediment Quality Triad"

The word "triad" has been used by others in the environmental community. Its application to sediment risk evaluation may cause confusion with the term as used in this document. These two triads are completely unrelated. The sediment quality triad (SQT) was described by Chapman to comprehensively evaluate contamination effects on the health of sediment-exposed biota. SQT is an effect-based technique that involves three components: sediment chemistry, sediment toxicity testing, and in situ environmental receptor appraisals (Chapman 1996).

3.6 The Triad Approach and the Technical Project Planning Approach

USACE developed the TPP process to improve planning activities associated with hazardous, toxic, and radioactive waste (HTRW) site cleanup. The TPP process is an example of a Triad-consistent systematic planning process that involves four different phases of planning activities. The TPP process is meant to be initiated at the start of activities associated with a HTRW site and continue through the life cycle of cleanup. The expectation is that the application of the TPP process will ensure that the requisite type, quality, and quantity of information are obtained to satisfy project objectives.

3.7 The Triad Approach and Early ITRC Guidance

ITRC has been involved with "accelerated" efforts for site characterization since 1995. In May 1996 the ITRC Cone Penetrometer Site Characterization Task Group published a document titled *Multi-State Evaluation of an Expedited Site Characterization Technology: Site Characterization and Analysis Penetrometer System Laser-Induced Fluorescence (SCAPS-LIF)*.

Also in 1996, the American Society for Testing and Materials (ASTM) partnered with the Accelerated Site Characterization Task Team of ITRC to release a 1997 technology review summary report that reviewed the accelerated site characterization guide that ASTM was developing (ITRC 1997). In 1998, ASTM published its *Standard Practice for Expedited Site Characterization of Vadose Zone and Ground Water Contamination at Hazardous Waste Contaminated Sites* (ASTM D6235-98a). In 1997 the ITRC Cone Penetrometer Site Characterization Task Group published another document, *Multi-State Evaluation of the Site Characterization and Analysis Penetrometer System Volatile Organic Compound (SCAPS-VOC) Sensing Technologies*. ITRC had an ASC team in 1997, which formed a partnership with the EPA Consortium for Site Characterization Technology (CSCT) to verify technologies and publish an overview report in January 1998. The focus of the partnership was on verifying promising new technologies that might be used for rapid assessments in the field. The CSCT was one of the first pilot programs under the EPA Environmental Technology Verification program. These early efforts were building blocks that laid the foundation to help support today's Triad approach. Documents resulting from these earlier ITRC efforts are available on the ITRC Web site (www.itrcweb.org) and are included in Section 10.

4.0 ADVANTAGES AND DISADVANTAGES

This section discusses specific advantages and disadvantages associated with use of the Triad approach. Table 3 summarizes the potential benefits and disadvantages for practitioners to keep in mind when considering application of the Triad approach.

4.1 Advantages

The advantages discussed below can be documented from the case studies presented later in this document. Section 9 presents a summary of the case studies, and Appendix B contains more detailed information.

Table 3. Summary of advantages and disadvantages

Advantages	Disadvantages
Better investigation quality	Higher up-front costs
Faster investigations, restoration, and redevelopment	Change in approach to data quality
Lower life-cycle costs	Lack of tools to manage decision uncertainty
Improved stakeholder communication	Greater need for training about Triad
More effective cleanups	Negative bias towards field-generated data

4.1.1 Better Investigation Quality

As compared to using the traditional multistage investigation process, applying the Triad approach allows for the collection of more data supporting a more representative CSM for the site. Fewer site/data uncertainties will remain uninvestigated, resulting in a better understanding of site conditions, less decision uncertainty, and better project outcomes.

4.1.2 Faster Investigations

Dynamic work strategies reduce or eliminate repeated mobilizations to the field, with commensurate reduction in overall investigation costs. The repetitive production and review of work plans and reports of findings that consume large amounts of time and financial resources are thereby avoided.

4.1.3 Lower Life-Cycle Costs

Project teams can anticipate that most environmental projects will be successfully completed for a lower overall life-cycle cost. The Triad approach produces this effect by consistently using systematic project planning. Improved planning leads to fewer mobilizations to the field, fewer reports and work plans, rapid resolution of data gaps, and most importantly, shorter overall project schedules.

4.1.4 Improved Stakeholder Communication

Successful application of the Triad approach encourages involvement by the public from the earliest stages of systematic project planning. The project should not move to the field until all affected parties, including tribes and other stakeholders, reach consensus on goals. The CSM prepared during the planning is especially helpful in communicating complex aspects of the project to stakeholders.

4.1.5 More Effective Cleanups

Project teams arrive at more efficient remedial decisions when fewer site uncertainties remain. Contaminated areas requiring remediation are separated from clean areas not requiring action. In this way improved site characterizations produce more focused, more effective, and less costly remedial systems, ultimately achieving significant reductions in overall project costs.

4.2 Disadvantages

4.2.1 Higher Up-Front Costs

Preparation for, and execution of, an investigation using the Triad approach requires more effort and professional expertise than traditional methods. This difference shifts more funding to early phases but avoids spreading less effective investigative efforts over longer time periods. In the Triad approach, greater resources are invested in the initial (and perhaps only) field effort with the expectation of reduced overall project costs.

4.2.2 Change in Approach to Data Quality

Traditional investigation methods have long emphasized the importance of implementing the laboratory analytical procedures outlined in SW-846. In addition many environmental professionals are of the opinion that only traditional laboratory data will withstand legal scrutiny. The Triad approach recognizes that decision quality data can be obtained by nontraditional methods and by non-SW-846 methods as long as appropriate QC measures are in place. Some practitioners may be surprised to learn that many common field analytical methods have been included in SW-846 since the mid 1990s. Environmental professionals may be reluctant to depart from prescribed analytical expectations and validation/verification procedures. When procedures are evaluated for their usefulness and defensibility within the Triad approach, the overarching goal of managing uncertainty should be used as the touchstone to decide whether or not a given procedure adds value.

4.2.3 Greater Need for Triad Training

All environmental professionals will need some level of training to effectively implement the Triad approach. This training should include both general overviews and more specific technical training. Scientists and engineers involved in preparing or implementing these projects will especially benefit from training on understanding and managing uncertainty. Federal and state regulators must be trained to ensure that they can effectively oversee these faster-paced projects.

4.2.4 Negative Bias Towards Field Generated Data

Many environmental professionals consider data acquired in the field to be a lesser, "screening-level" quality and therefore unsuitable for site decision making. Actually, with proper QC procedures, data generated in the field can be demonstrated to be suitable for a wide range of project decision-making purposes.

5.0 REGULATORY AND OTHER BARRIERS

The Triad approach requires innovative thinking and a flexible approach to planning, work plan development, and application of analytical methodologies. Regulators are guided in their oversight work by agency business practices created to enforce state law and regulations. As a result they operate in a carefully prescribed manner when overseeing projects. These business practices are often difficult to change due to regulatory policies and/or organizational and cultural barriers. When implementing the Triad approach, it is important for regulators to remain aware of implementation issues and any real or perceived barriers. Identification and understanding of these barriers is a key issue for regulatory acceptance of the Triad approach. This section presents these obstacles in six categories:

- organizational barriers,
- concerns with real-time measurement technologies,
- conflicts with state law,
- lack of regulatory guidance,
- difficulties of establishing cleanup criteria during initial planning, and
- confusion in associating uncertainty to specific decisions.

The following states participated in the development of this guidance document and contributed to the following discussion regarding potential barriers: California (CA), Delaware (DE), Kentucky (KY), Missouri (MO), New Jersey (NJ), Oklahoma (OK), South Carolina (SC), Vermont (VT), and Wisconsin (WI).

5.1 Organizational Barriers

Regulatory agencies may have both organizational and institutional barriers to the use of a conceptual framework like the Triad approach. For a regulatory agency, the Triad approach may require changes in process, timing, and staffing as well as consideration of new technologies and ideas. The sections that follow describe some of these issues.

5.1.1 Business Practice Inertia

Regulatory agency procedures, like those in any large organization, can become institutionalized over time. As state environmental officials recognize the benefits associated with the Triad approach, it can be expected that more projects will be conducted this way and the concepts will become established and more widely applied. The New Jersey Department of Environmental

Protection has recently taken formal steps to allow the Triad approach to be applied to its projects. This change is discussed in more detail in Section 6.

A number of states (including CA, DE, KY, MO, NJ, SC, VT, and WI) indicated that business practice inertia is not necessarily foreseen as a barrier to implementation of the Triad approach. Although all of these states have guidance and procedures for site characterization and remediation, varying degrees of flexibility are allowed as long as QC procedures are followed. For example, these states all allow the use of several field analytical methods.

Comments from specific states are as follows:

- CA – California does not anticipate difficulties in implementing the Triad approach if (1) a proposed investigative technology has the capability to achieve data quality needs that meet project specific objectives, (2) QC is performed as specified in the QAPP, and (3) the state remedial project manager and technical staff approve the use of the Triad approach.
- DE – Delaware does have procedures and guidance in place for investigation and cleanup; however, some flexibility regarding sampling and analyses is allowed. Field methods like direct-push wells and field analyses are encouraged. Although application of parts of the Triad is currently taking place, a consistent application of all three aspects of Triad has not yet begun. Management recently began considering an approach similar to Triad.
- KY – Kentucky is open to new approaches and ideas. Project managers are yet to be convinced that field analytical methods can achieve the DQOs necessary to make the cleanup decisions based on human health and ecological risk assessments. Project managers recognize the benefits of the Triad approach, and in some cases the Triad approach has been applied within the constraints of agency procedures. Kentucky believes that integration of the Triad approach with regulatory agency procedures is the way to proceed for Triad acceptance and success.
- MO – The various environmental programs do have guidance and standard operating procedures in place and often have procedures for allowing some flexibility within the work plan. Creating new practices (like those needed for Triad success) is a challenge, especially for established staff members. The key to overcoming this challenge is to ensure that adequate QC procedures are documented.
- NJ – Some concern has been expressed among Department of Environmental Protection (DEP) personnel that it will be hard to change how staff "do business." For initial Triad implementation, the department is involving only those staff that are flexible and eager to try a new concept such as the Triad.
- OK – Oklahoma already uses some aspects of the Triad approach without using the term in a formal sense. It is not a barrier in programs dealing with voluntary closure and brownfield activities, but programs dealing with Superfund have not accepted this approach in total.
- SC – South Carolina does not anticipate difficulties in implementing the Triad approach. A proposed investigative technology must be able to attain project specific data quality needs and objectives, meet QC guidelines specified in the QAPP, and be approved by the project manager.
- VT – Consultants working in Vermont are primarily state-based, small consulting firms. Many of these firms are distinguished for the quality of the science they bring to site investigation. Part of that entrepreneurial spirit is shared at the Vermont Department of

Environmental Conservation (DEC), in that it manages a broad spectrum of projects with a relatively small team of scientist-regulators. These consulting firms have played a role in proposing innovative analytical approaches to site characterization, starting as early as 1991. Although some consultant clients are willing to undertake dynamic work plan projects, responsible party apprehension of seemingly uncontrollable (unpredictable) costs in a flexible work plan setting is a concern. Site manager (regulator) unfamiliarity or discomfort with the consultant's expertise in innovative investigation methodologies can act as a barrier to adoption.

- WI – Business practice inertia is not foreseen as a barrier. In some regards, Wisconsin already allows some flexibility with work plans and the use of field analytical methods.

5.1.2 Lack of Adequately Trained Staff for Triad Projects

The staffing flexibility and experience required to implement the Triad approach might be problematic for state regulatory agencies in some cases. Successful implementation of Triad requires environmental staff with considerable experience in the application of geochemistry, geology, analytical chemistry, statistics, and other disciplines. Many agencies have junior-level staff doing the majority of the oversight, while the more experienced and knowledgeable staff members are not always available to spend significant time on individual projects. This distribution of knowledge within an agency is a significant barrier to Triad approach implementation. Problems of this nature will be overcome as regulatory agencies align their staff for oversight of projects conducted using the Triad approach.

Oversight of Triad projects by junior staff is facilitated if regulators consistently and explicitly require detailed, transparent work plans and reports. These documents should provide

- a succinct list of project objectives or desired outcomes,
- a list of decisions that need to be made to achieve those objectives,
- a listing of the qualitative (and quantitative, if possible) unknowns that could lead to decision errors if the uncertainties are not managed or data gaps filled, and
- a clear discussion of the preliminary CSM or the more mature (after the investigation has occurred) CSM.

Comments from specific states are as follows:

- CA – A competent technical team available to direct the field activities during the project implementation phase is crucial in the success of Triad Approach. Only personnel who have the specific skill and knowledge on the related subject area and who have the necessary experience should implement the Triad, whether the regulatory agency or a consultant conducts the project. The personnel qualifications need to be defined. Every technical person involved in the project has the responsibility to carry out the field activities in accordance with the QAPP.
- DE – Delaware does have a technical team consisting of experienced staff from different disciplines that review technical documents including work plans. However, junior staff members are performing most of the field work, and there have been relatively few applications of dynamic work plans. For the most part regulators provide oversight on

projects performed by consultants. These consultants also use junior staff to perform field work. Use of a decision tree and communication with experienced staff in the office may offer some solution.

- KY – This problem is inherent in state government and can be overcome through training, proper planning, and cooperation from management.
- MO – Due to the nature of state government, the staff turnover rate is rather high. The majority of workers doing field work (and sometimes designing sampling plans) are somewhat inexperienced. While it's true that senior level staff oversee the work plans and procedures, this is often done as part of a review process rather than in the active planning process. Getting the most qualified staff in the field is often difficult due to administrative responsibilities that keep them in the office.
- NJ – Many staff within the New Jersey DEP are aware of Triad. The department is providing on-site education of Triad from EPA and USACE.
- OK – Contract consultants perform most of the work. A junior- or mid-level staff person may visit the site once a week for oversight purposes. Lack of staff is a real problem. Due to the cuts in the budget, the situation may not improve for quite some time.
- SC – In general, staff have a wide variety of knowledge and experience. Typically, an engineer and a hydrogeologist are assigned to each project (Superfund). Risk assessors are also available upon request. Senior-level staff oversee the review of work plans and procedures.
- VT – The experience that Vermont DEC has with oversight of projects similar to Triad has resulted in a cadre of professional regulators capable of keeping abreast of the innovations in the private sector. The insufficient number of staff at VTDEC remains a problem, and consequently some sites are currently unmanaged.
- WI – In general, staff have a wide variety of knowledge and experience to build upon. However, as indicated above, junior-level staff complete the majority of the site-specific work.

5.1.3 Requirement for Additional Commitment of Time and Effort

Regulators often manage a large number of sites and may feel that they are unable to devote the time necessary to both participate in detailed project planning or in the fast-paced evaluation of data generated using dynamic work strategies. While this may be the initial impression of some state regulators, in actuality the Triad approach can reduce regulator workload in the long run. Carefully planned and executed projects with clearly identified goals come to a conclusion faster and with less overall effort than work at the same site using traditional methods. However, there is no doubt that a learning curve requires an up-front investment of time and effort that could tax staff laboring under already heavy workloads.

Comments from specific states are as follows:

- CA – If the project goals are well defined and a technology or test method is properly selected, the overall costs with respect to time and money should be less than those of the traditional way of operation. Several successful case studies using the Triad approach for site projects, as described in Section 9, show the potential time savings.

- DE – Similar to that of other states, Delaware staff manages a large number of sites. Initially, Triad implementation will take more time especially during systematic planning. This need will cause an initial resistance to Triad implementation. However, as Triad implementation becomes routine the time and cost savings will become evident and the barriers will be removed.
- KY – This is a problem, but not a significant barrier. This problem will vary across the Kentucky DEP; however, with management cooperation and staff training, it can be managed.
- MO – The time factor will be a real barrier until staff are adequately trained in systematic project planning and evaluation of the data quality. Staff are already overworked, and adding additional time to a project will not be well received. Eventually, staff will gain experience and then time will not be an issue.
- NJ – This is a concern of New Jersey DEP management. The actual time commitment involved in managing a Triad project will need to be accurately calculated. The department is educating managers that although Triad projects may take more time initially because of the development of the CSM, overall time savings will accrue from lack of repeated mobilizations.
- OK – In Oklahoma, there is a need for more education and training at all levels. Initially, the time needed for systematic planning and dynamic work plan development may be difficult to achieve due to shortage of sufficiently qualified staff, but eventually the situation could improve.
- SC – South Carolina encourages project managers and/or their support team to have a presence on each site, particularly residential cleanup sites. However, since the Triad approach requires more commitment, time management is essential.
- VT – Triad approach projects require immediate regulatory attention at the initial stage. It is necessary for the responsible party's consultant to confer with the Vermont DEC so as to arrive at an approach that will lead in a regulator-acceptable direction.
- WI – This will be a barrier, at least during the first few years of allowing the use of such an approach. As with almost every other state, budget constraints have limited the number of staff available to work on sites (i.e., there is a need to do more work with fewer people). This problem will vary as state budgets fluctuate.

5.2 Concerns with Real-Time Measurement Technologies

The majority of the real and perceived state regulatory barriers revolve around the real-time analysis leg of the Triad, rather than the systematic planning or dynamic work strategy components. Most, if not all, of these concerns involve the use of field analytical data. These real and perceived barriers will most likely be the toughest to overcome for those proposing the use of the Triad approach. As previously mentioned, data quality is the key to successful utilization of Triad. Many regulators believe that data quality is equivalent to analytical quality, which sets limitations on the types of data that can be used for making site decisions. Traditionally, a significant amount of time and money have been spent on analytical quality control. However, the Triad approach recognizes that the majority of error in the site decision is not in the analytical data but rather the representativeness of the sampling. The regulatory culture must accept the significance of sample representativeness and the relationship between data quality and decisions. Analytical quality is important and should not be discounted; however, the overall data quality encompasses much more than just analytical methods, and the regulatory agencies should be encouraged to recognize this fact.

Comments from specific states are as follows:

- CA – As long as the data quality is validated by the associated QC results, the test method used is not an issue. This concept is consistent with the PBMS. However, to ensure the data quality, a fraction of split sample analysis by a reference method is usually recommended, specifically for samples with concentrations around the action level.
- DE – Significant barriers exist regarding the use of results of samples analyzed in the field for risk assessment and site closure.
- KY – This is a barrier, but it will ease when examples of site closure and risk decisions using field analytical methods from other states are presented to management and project managers.
- MO – The key to overcoming this barrier is a staff comprehension of the definition of "quality" for a given data set. The general belief is that data gathered in the field could not be of the same quality as that of data generated in a fixed lab. It's going to take a huge change in thinking about the true meaning of "quality" for any given data.
- NJ – NJ has accepted field analytical data for many years when used to define areas of contamination.
- OK – There is inherent bias against these technologies in the Superfund program. However, the voluntary cleanup and brownfield programs are generally more flexible. Field screening must still be verified by fixed-lab results.
- SC – Barriers exist regarding the use of results from samples analyzed in the field for risk assessment and site closure.
- VT – The Vermont DEC has a history of applying real-time analytical measurements with success.
- WI – The barriers stated later in this section do coincide with our current concerns. It is generally accepted in Wisconsin that the field "screening" analytical data is of lower quality and reliability than fixed-laboratory data.

5.2.1 Field Data Quality Concerns

Some regulatory agencies have expressed concern regarding the quality of data generated in the field. The Triad approach's success relies not only on defining the necessary data quality, but also on establishing QC procedures to verify the results. Application of QC procedures for precision and accuracy can establish that field data are of adequate quality. Therefore it is possible for field data to satisfy state guidelines and to be used for decision-making purposes.

Comments from specific states are as follows:

- CA – With the recent advancement in hardware and software, many field instruments have high specificity, sensitivity, and selectivity and are able to generate data in a more efficient manner. It depends on the project manager to select an appropriate field technology to meet the project-specific objectives. As a matter of fact, the data generated by a reference method may not always be appropriate for the project. A comprehensive QC program and complete documentations of field activities are crucial to the accountability of data quality.

- DE – Although Delaware does allow field analyses of samples, it is generally viewed as a screening tool and requires confirmatory samples analyzed by a fixed lab. Field analyses for some media and some contaminants such as soil contaminated with metals are accepted. Delaware has concerns regarding the reliability of the field methods and the training of field method operators.
- KY – This is a concern at the Kentucky DEP. Kentucky allows the use of field analytical methods for site closure and investigative work as long as certain percentages (10%–15%) of data are confirmed by laboratory analyses.
- MO – The belief that field data lacks quality is a real barrier. Having a work plan that defines the acceptability and use for the collected data is helpful, along with having significant QC procedures both in the design of the work plan and the collection of data. Again, experienced staff is the key to making this work, and that's a concern.
- NJ – The New Jersey DEP technical regulations have allowed the use of data obtained from field analytical measurements for years. This is not a concern at the DEP.
- OK – There is a perceived concern that the quality of field data is not as good as that of fixed-lab data. In certain programs, such as UST and enforcement activities, field data have been used for initial decision making, but final decisions are made after results from the fixed lab become available.
- SC – The belief that field data lacks quality is a real barrier. A work plan that defines the acceptability and use for the collected data is needed. The inclusion of significant QC procedures in the work plan would be helpful. Also, experienced professionals are key to making the Triad work.
- VT – Federal (EPA) QC requirements typically drive a site towards traditional iterative lab-based approaches. The EPA quality control requirements are only necessary to meet on federal sites (superfund, etc). On state-lead sites VT has much more flexibility regarding this issue.

5.2.2 Analytical Quality Versus Data Quality

As mentioned above, many environmental professionals have the misconception that only analytical methods listed in SW-846 can produce data of adequate quality for decision-making purposes. Many are not aware that many field analytical methods have been in the SW-846 methods manual for years. Section 2 details how uncertainty associated with sample representativeness has a much larger adverse effect on project decision making than that associated with analytical error. Therefore, regulatory agency efforts to control quality with method certification alone will never be sufficient. To ensure successful project outcomes, regulatory agencies must take a more holistic approach to managing uncertainty, which will mean much more attention devoted to goal development and QC measures, rather than exclusive focus on ensuring that specific analytical methods are referenced in SW-846.

Comments from specific states are as follows:

- CA – The concepts of "analytical quality" and "data quality" need to be clarified among the analytical chemistry community as well as the regulatory agencies. This message can be introduced through the training process.
- DE – Misconceptions and lack of knowledge about different field methods exist. Studies showing effectiveness of the use of field methods and acceptance by EPA and other states will help in the elimination of this barrier.
- KY – Certain misconception exists but will ease as case studies of acceptance of field data are available to the management and project managers. EPA's acceptance of the field analytical methods will go a long way in eliminating this barrier.
- MO – Many staff members greatly struggle with this concept of "data quality." The vast majority of QC auditing is conducted only on our fixed labs and the data that are generated by them. This process furthers the belief that "lab data = quality data" because it implies that if data are not generated in the lab, then they don't even warrant a QC review. This concept is further hindered by the misconception that all data gathered in the field are of "screening" quality and that confirmation of the result is needed prior to a decision.
- NJ – This concept has been explained to New Jersey DEP management and staff but is not yet well understood by either group. Further education on this issue is needed.
- OK – There is a lack of understanding about the accuracy and relevance of several field measurement techniques. Some regulators have taken a "wait and see" approach about certain emerging technologies. Established field measurement techniques are well received for screening purposes. State will accept real-time measurement technologies if EPA or other federal agency takes a lead in their acceptance.
- SC – Misconceptions and lack of knowledge about different field methods exist. Studies showing the effectiveness of field methods and acceptance by EPA and other states will help in the elimination of this barrier.

5.2.3 Legal Defensibility

There is a widespread opinion that data generated by real-time measurement technologies will not withstand legal scrutiny, and this argument is sometimes used as a reason not to consider these methods. The opinion that field generated data are not legally defensible is a misconception. The standards for the admissibility of scientific evidence by a state court may be different from a federal court. The admissibility of evidence in a federal court is based on two basic requirements: the evidence is relevant to the case, and the data and information are reliable. In addition, the U.S. Supreme Court expressed the following criteria: whether (1) the technique has been valid and tested, (2) the principle of the technology has been subjected to peer review and in publication, (3) the rates of potential error associated with the relevant testing are known, and (4) the technique has gained general acceptance in a relevant scientific community (William Daubert v. Merrell Dow Phamaceuticals, Inc. United States Supreme Court, 509 U.S. 579, 1993).

Comments from specific states are as follows:

- CA – For regulatory acceptance, environmental data must be legally defensible. The standards for analytical data to be accepted as evidence in California courts are based on three requirements (The People v. Kelly, 17 Cal.3d 14 ,1976):
  - A technology is generally recognized in the scientific community.

    - The test method is performed correctly.
    - The case is substantiated by an expert witness.
- DE – This barrier exists primarily due to perception.
- KY – This issue is a barrier mainly because of the misconception concerning the field analytical data. Acceptance of the field methods by EPA and other states will help toward the elimination of this barrier.
- MO – Whether or not a Missouri court has challenged field data is not known at this time. However, most site cases would not even be considered for litigation unless the data had been QC audited according to the standard operating procedures, which are mainly applicable to fixed labs.
- NJ –The New Jersey DEP Assistant Commissioner for Site Remediation has endorsed the Triad approach, and this issue is not expected to be a problem.
- OK – Real-time measurement technologies are generally looked upon as screening tool; therefore, their legality has been questioned in the court. However, in many cases these technologies such as electromagnetic surveys are used with follow-up data. In most cases the court has accepted the technique "for whatever it's worth" basis.
- SC – For regulatory acceptance, environmental data must be legally defensible. South Carolina has experienced a setback when the three principles listed by Simmons were applied. An analytical method not listed in SW-846 was used to analyze for hexavalent chromium at a site in Charleston. The use of this method resulted in a verdict against the South Carolina Department of Health and Environmental Center (DHEC) and the loss of some cost-recovery funds.
- VT – Legal predisposition towards establishing certainty is a barrier within the community of responsible parties in Vermont, particularly at large sites. However, the Vermont DEC has successfully implemented a number of state-lead real-time measurement site investigations and has successfully defended the validity of the data in state courts.

5.2.4 Validation or Certification of Field Analytical Methods or Operators

Real-time analysis is often achieved by field analytical methods, which could potentially be in conflict with a state's laboratory certification and/or data acceptability requirements. For most states, data acceptability is linked to laboratory certification, which does not currently apply to field analytical methods. Laboratory or operator certification does not guarantee understanding of all types of data uncertainty. With the Triad process, uncertainties not addressed (most prominently, the very large impact from sampling uncertainties) must be evaluated through other mechanisms.

The current EPA SW-846 compendium of analytical methods that apply to environmental measurements includes many, but not all, of the available and well-documented emerging field analytical technologies. In general, it takes several years to gather performance data, write, test, review, and edit the method information that is adopted into SW-846 by a consensus process. Resource limitations slow the inclusion of new technologies into SW-846. In the meantime, the fact that a particular field analytical method is not currently included in SW-846, does not mean that regulators should assume that the data do not have adequate precision and accuracy. Nor should they assume that they couldn't permit the use of non-SW-846 methods.

It should also be noted that the SW-846 manual has been "deregulated" by EPA under the Methods Innovation Rule. This means that many of the required uses of SW-846 methods that were written into some Resource Conservation and Recovery Act regulations years ago have been eliminated. Use of SW-846 methods would continue to be required only in those limited situations where the written test method itself defines the property being measured (e.g., the Toxicity Characteristics Leaching Procedure test). Deregulation of the SW-846 manual means that the process required for including new methods will be less resource- and time-intensive, which should result in faster incorporation of new technologies (EPA 2003c).

Comments from specific states are as follows:

- CA – The criteria for the selection of a field test method and standards for field measurements should be consistent with the standards approved by the National Environmental Laboratory Accreditation Conference (NELAC Chapter 7, Field activities approved July, 2002, effective July 1, 2004). To ensure the data quality, it is commonly specified in the QAPP that a fraction of samples be submitted to a certified laboratory for confirmatory analysis. Field data associated with proper QC results can be used for the regulatory purposes if data meet the project-specific objectives. Currently in California there is no requirement that an instrument operator be certified.
- DE – Delaware does have a laboratory certification program, and these labs have to be used for confirmatory samples. However, field analyses are allowed primarily as a screening tool.
- MO – Missouri does not have a laboratory certification program. In fact, although contractors often use the Contract Laboratory Program labs, the majority of samples collected by the department are sent to the Environmental Services Program or the State Health Laboratory—neither of which is certified as a CLP lab.
- NJ – The New Jersey DEP Office of Quality Assurance will be implementing a program to certify an entity providing field analytical measurements for the following types of field measurements:
  - immunoassay,
  - field-portable GC,
  - field-portable GC-MS, and
  - field-portable XRF.
- OK – Oklahoma has a lab certification program run by the Department of Environmental Quality (DEQ). All samples are to be analyzed by a certified laboratory. Field labs using real-time measurement technologies are not certified by DEQ.
- SC – South Carolina has a laboratory certification program, and confirmatory samples are sent to these labs. However, field analysis techniques are used often (e.g., site assessments).
- VT – The Vermont DEC does not have laboratory certification programs. For real-time analytical methodologies, we discuss with the consultant the need for a certain percentage of duplicate samples to go to a fixed laboratory for confirmation. DEC also works with the consultant and responsible party to establish the quality criteria for accepting or rejecting real-time analytical data.

5.3 Conflicts with State Law, Policy, or Guidance

Application of Triad approach concepts may be inconsistent with state law in a number of ways. Some states have prescriptive guidance on preparation of work plans, reports, and decision documents. A responsible party risks violation of state regulatory policy by proposing a dynamic work plan that may deviate from established law or guidance. In addition, some states also have stipulated specific analytical methods (such as SW-846) in environmental regulations and are hesitant to allow the use of field methods.

Comments from specific states are as follows:

- CA – CA Health and Safety Code Section 25198 indicates "the analysis of any materials shall be performed by a laboratory certified by the state Environmental Laboratory Accreditation Program (ELAP) in the Department of Health Services (DHS)." This statute appears to be a regulatory barrier for implementing Triad approach. In reality, this statute is a perceived barrier, because in many instances the test method is outside the scope of DHS accreditation and the project manager can make the decision in selecting the appropriate test methods for the project. To avoid this potential problem, changing state law or including the field test methods in the ELAP scope would be an alternative for eliminating this perceived regulatory barrier.
- DE – This is considered a procedural barrier because there is guidance on work plans and cleanup procedures. However, the laws are flexible to allow for example dynamic work plans. As mentioned earlier, field analyses are not accepted for certain decision such as site closures. As field analyses become more sophisticated and diverse, the acceptance will increase.
- MO – No barriers are known. Policies (like Voluntary Cleanup Program) indicate that field data may be used for site assessment; however, no guidance is specifically known to exclude field data for site closures, etc.
- NJ – No barriers are known.
- OK – There is no clear-cut barrier in Oklahoma. The Triad concept has been used by some agencies more than others. For closure purposes a fixed lab must verify field results.
- SC – No barriers are known. Field data may be used for site assessment; however, no guidance is specifically known to exclude field data for site closures, etc.
- VT – Vermont has no policy or guidance that precludes the use of real-time analytical methods or flexible work plans.
- WI – This is a barrier in Wisconsin. Current administrative codes require that a certain number of samples be submitted to a certified lab for analysis. Field analytical data are not to be used for closure decisions.

5.4 Lack of Guidance for State Regulators

The Triad approach has only recently taken shape, and therefore guidance is in the earliest stages of development. The lack of such guidance at either the federal or state level is a serious hindrance to applying the Triad approach. However, guidance is beginning to appear (see Sections 3.3, 6, and 10), and a number of peer-reviewed articles are available in environmental journals. It is expected that an increasing number of EPA and state regulatory agency technical/guidance documents will become available in the near future as efforts continue to put definition to Triad concepts. This document is the first phase of Triad guidance to be offered by ITRC. The next phase will consist of training sessions to transfer the technology worldwide to the environmental community. Other phases may follow, depending on the need.

However, it is impractical to produce a single guidance document that could address all of the programmatic procedures of 50 state agencies and 10 EPA regional offices. The choice of adapting state regulatory policies to support Triad implementation will rest with each state program. For that reason, adoption of the Triad into regulatory and engineering practice is expected to be gradual. State regulators might consider supporting one or two “pilot” Triad projects with assistance from experienced Triad implementers. As these pilot projects unfold, they should be observed by the program staff to gather lessons learned and pinpoint any constraints of the current regulatory structure. States wishing to try Triad pilots should coordinate through the ITRC to share lessons learned and supporting documentation as they is developed. This approach will allow states to share knowledge, experience. and materials, avoiding the time and expense of “reinventing the wheel” and promoting greater consistency across state and federal programs.

Comments from specific states are as follows:

- CA – The memorandum “Distribution of OSWER Guidance Using Dynamic Field Activities for On-Site Decision Making: A Guide to Project Managers” from EPA Assistant Administrator, Office of Solid Waste and Emergency Response, dated May 7, 2003 will have an impact on the implementation of Triad approach.
- DE – This is a temporary but significant barrier. Once detailed guidance and case studies are available, this barrier will be resolved.
- MO – There is a need for guidance to transition between the “old” ways and the new, innovative approach.
- NJ – The New Jersey DEP is developing written guidance for Triad implementation.
- OK – This is true. There are very few people out there who are aware of the Triad approach. But it could change if the guidance documents become available and regulator training starts.
- SC – As guidance is developed, this barrier will go away.
- VT – The Vermont DEC does not have internal Triad guidance documents for state regulators. A majority of our site staff have participated in the ITRC-sponsored Web-based training seminars. Our existing generic guidance documents have allowed us to successfully implement Triad-like investigations over the last 10 years.
- WI – This will be a barrier for at least a short while. Like anything else, if there are not enough people that know about an issue, it is hard to promote it. As guidance is developed, this barrier will go away.

5.5 Defining Action Levels During Systematic Project Planning

As described in earlier sections, it is important to define appropriate action levels during the earliest stages of systematic project planning. Some regulators are more accustomed to identifying appropriate action levels only after investigation data has been gathered and evaluated. The regulatory community must be encouraged to actively consider action levels very early in the systematic project planning process. Early identification of action levels will become more common as regulators are made integral members of project team decision making.

Comments from specific states are as follows:

- CA – The action level is one of the targets usually stated in the QAPP.
- DE – Action levels are determined based on risk to human health and environment. Guidance lists action levels for contaminants based on the end use of the site (i.e., residential, commercial, etc.). However, there may be a problem with finding field methods that can achieve the detection levels close to the action levels.
- MO – Site projects in Missouri mainly rely on the Cleanup Levels for Missouri (CALM) for site closures within the state. Even federal Superfund sites often defer to the CALM levels for cleanup goals. CALM was developed by the state Voluntary Cleanup Program with coordination from a variety of partners, including the health department and EPA. The levels are risk based and are dependent on future site use.
- NJ – This issue has yet to be addressed.
- OK – Action levels are arrived at after careful study of all applicable factors including the economics. They generally go through a public participation process. For closure and risk assessment purposes the field methods are used as preliminary data.
- SC – Current administration policy allows for this; however, the burden is on the consultant to prove that the levels are appropriate. Risk to human health and the environment determine action levels. Guidance lists action levels for contaminants based on the end use of the site (i.e., residential, commercial, etc.). However, problems may exist with finding field methods that can achieve the detection levels close to the action levels.
- VT – The Vermont DEC utilizes the Groundwater Enforcement Standards informally applies the Region IX and III PRGs and, where appropriate, site-specific goals for soils and sediments.
- WI – This is not foreseen as a barrier. Wisconsin's current administrative code allows for this; however, it will be the burden of the consultant to prove that the levels are appropriate (not simply state that the level should be OK).

5.6 Associating Uncertainty to Specific Decisions

Identifying and managing uncertainty are central to successful application of Triad approach concepts. Until guidance and computer application tools (like decision support software) become more widely distributed to assist in associating tolerable levels of uncertainty to sampling plans, this process will remain within the realm of professional judgment, and for this reason many regulators will be reluctant to consider proposals to manage projects in this way. EPA and the interagency Triad team are aware of the lack of guidance in this area and are working to overcome the lack of such technical assistance.

Comments from specific states are as follows:

- CA – This is one of the areas needing consensus among the regulators, technical teams, and responsible parties during the project planning step. This would be a complicated step for the implementation of Triad approach.

- DE – Delaware is moving towards associating uncertainty to a specific decision. Although several software programs are available, guidance on their proper use is very much needed.
- MO – This issue has yet to be addressed.
- NJ – This issue has yet to be addressed, although future state Triad guidance will comment on this issue.
- OK – The problem of associating uncertainty within the analytical methods and sampling method is critical. There is need for more discussion in this area. In Oklahoma this issue is discussed, but generally no action is taken.
- SC – The South Carolina DHEC administrative policy currently allows for some professional judgment in day-to-day decision-making efforts.
- WI – This should not be much of a barrier. Our administrative code currently allows for some professional judgment in our day-to-day decision-making efforts.

5.7 Recommendations for Overcoming Barriers

5.7.1 Organizational Barriers

- Establish a training program on the Triad approach, for both regulators and practitioners.
- Create a cadre of trained staff to respond to Triad-related projects.
- Publicize Triad experiences to encourage information sharing.
- Educate their senior managers about the advantages of Triad.
- Draw upon the experience of previous investigations to demonstrate the savings of time and money.
- Develop a state peer network of experienced Triad users.

5.7.2 Concerns Regarding Acceptance of Data Generated from Field Analytical Methods

- Expand existing state laboratory accreditation/certification programs to include field analytical methods. Consider granting certification for specific methods.
- Consider qualifying individuals performing selected real-time measurement technologies. Try to strike a balance between regulation and project-specific QC requirements.
- Remind staff that some field analytical methods are included in SW-846 (accepted EPA analytical methods).
- Educate national laboratory accreditation/certification programs on the benefits of field analytical methods.
- Dialogue with national analytical service providers regarding the benefits of field analytics.

5.7.3 Conflicts with State Law, Policy and Guidance

- Document problems as they arise during implementation of Triad projects.
- Utilize experience gained in other states to predict similar Triad implementation issues.
- Change state law, policy, and guidance to remove regulatory barriers

5.7.4 Lack of Written Guidance

- Create guidance on how to practice Triad with concurrence of state regulators.
- Compile successful Triad implementation case studies.

5.7.5 Defining Action Levels During Systematic Project Planning

- Publicize results of case studies where action levels were successfully defined prior to project implementation.

6.0 IMPLEMENTATION OF TRIAD IN A STATE REGULATORY AGENCY

New Jersey is the first state to initiate a formal program to use the Triad approach, and the program is still in its infancy. This section discusses the New Jersey Triad program and presents materials that may be beneficial to other states considering similar programs of their own. Information on the New Jersey Department of Environmental Protection (NJDEP) approach to Triad implementation can be found at http://www.nj.gov/dep/srp/triad/.

6.1 New Jersey Policy Statement Supporting the Triad Approach

NJDEP is committed to streamlining the site investigation and remediation process at contaminated sites without compromising data quality and reliability. This goal can sometimes be better achieved by implementing the Triad approach, a process that integrates systematic planning, dynamic work strategies, and real-time measurement technologies to achieve more timely and cost-effective site characterization and cleanup. The Triad approach seeks to recognize and manage the uncertainties involved in generating representative data from heterogeneous environmental matrices.

NJDEP supports and encourages the use of Triad for sites undergoing investigation and remediation within the Site Remediation and Waste Management Program where feasible. NJDEP has evaluated the Technical Requirements for Site Remediation, New Jersey Administrative Code (N.J.A.C.) 7:26E, in the context of Triad and has determined that the concepts embodied in Triad can be implemented within the framework of the rules. NJDEP encourages persons interested in using the Triad approach to enter into memoranda of agreement, as described in N.J.A.C. 7:26C, because successful implementation of the Triad approach requires close interaction with NJDEP to ensure that appropriate considerations have been addressed. NJDEP will continue to consider whether modification of applicable rules would facilitate or further encourage use of the Triad method.

6.2 New Jersey Triad Approach Training

As of September 2003 NJDEP had conducted three training sessions for its managers, staff, and consultants on Triad. EPA also supports this approach and is very interested in promoting this approach nationally. EPA has partnered with NJDEP and the New Jersey Institute of Technology (NJIT) to use the Triad approach to expedite site characterization and cleanup of contaminated sites in New Jersey. Speakers have included NJDEP program managers and case managers, Deana Crumbling of EPA's Technology Innovation Office, Kira Lynch of the Army Corps of Engineers, and Jim Mack of NJIT. As of September 2003, more than 200 people had been trained.

6.3 New Jersey Regulations Pertinent to the Triad Approach

NJDEP has published rules governing the remediation of contaminated sites in N.J.A.C. 7:26E. These rules are titled "Technical Requirements for Site Remediation" (also known as the "Tech Rules"). The latest version of N.J.A.C. 7:26E was adopted in 2003.

The Triad approach can be implemented within the framework of the technical rules. For example, N.J.A.C. 7:26E 2.1(b) provides for liberal use of real-time analyses when conducting investigation and remediation, and 3.3(d) provides that "It is often appropriate to phase the site investigation so that the areas of concern most likely to be contaminated above the applicable remediation standards are sampled first. If at any time during the site investigation, any contamination is found above the applicable remediation standards, then the site investigation may be discontinued and the remediation continued at either the remedial investigation or remedial action phase." There are certain provisions in the technical rules that require department oversight or notification, and other provisions that the department has determined are often associated with complex aspects of investigation and remediation. It is critical that these provisions be considered during the systematic project planning phase of the Triad process. These provisions from N.J.A.C. 7:26E are as follows:

1. Department Oversight Required

   1.12 – Requirement for department oversight of remediation (for sites suspected or known to be contaminated with anthropogenic radionuclide contamination of any media; and sites with immediate environmental concern (IEC) conditions.

   5.2 – Remedial action selection report (oversight required for certain types of remedies).

   6.1(d) – Free and/or residual product (oversight required for containment remedies).

   6.2(b) – Soil reuse (oversight required).

   6.7 – Remedial action report (oversight required).

   7 – Permit identification and application schedule (oversight required).

   8 – Engineering and institutional controls (oversight required; note: if the need for a deed notice is reasonably anticipated, plan for time delays in obtaining property owner approval).

2. Department Notification

   1.4 – Required

- prior to the initiation of any sampling activities at a contaminated site which is not already known to the department,
- if immediate environmental concern conditions are identified, and
- if an interim response action in response to an IEC is to be conducted.

3.7(e)3.ii – Potable well search (plan for possible time delays at this stage).

3.7(g)5 – Up-gradient groundwater contamination.

3. Potentially Complex Aspects of Investigation and Remediation

2.1(a)5 – Proposing an alternative analytical method.

3.7(g) – Background groundwater investigation.

3.10 – Background investigation in soil.

3.11 – Ecological evaluation .

3.12 – Investigation of historic fill material.

4.1 – If off-site contamination of soil, groundwater, or other media is reasonably anticipated, plan for time delays in obtaining off-site access.

4.8 (c)3i – Sampling results summary table and averaging requirements. Using field analytical method data to calculate average contaminant concentrations for contaminated areas should be conducted only in consultation with the department.

NJDEP is strongly encouraging the application of Triad to site remediation activities. The plan for NJDEP Triad implementation includes the following components:

- Articulation of strong support by senior NJDEP management.
- Creation of an interdisciplinary Triad implementation work group of NJDEP staff.
- Identification of subset of NJDEP case managers, technical coordinators, and project geologists who have expressed an interest in utilizing the Triad approach. These are the staff members who will be working on Triad-related projects.
- Training for these NJDEP staff including presentations by the leading practitioners of the Triad approach including the EPA, USACE, as well as engineering firms and consultants.
- Development of a Triad implementation guide for NJDEP staff.
- Inclusion of field analytical measurement technologies in the NJDEP laboratory certification program by the Office of Quality Assurance (OQA) at N.J.A.C. 7:18, Regulations Governing the Certification of Laboratories and Environmental Measurements. Four categories of field analytical methods will be included:
  - immunoassay,
  - field-portable gas chromatography,
  - field-portable gas chromatography mass spectrometry, and

  - field-portable X-ray fluorescence spectroscopy.
- Once implemented, any laboratory, engineering firm, or consultant employing these field analytical measurements will need to be certified by the OQA before providing these data to NJDEP on any Triad project. The OQA will require submission of standard operating procedures, experience of analysts, performance criteria, and other documentation prior to certification. Certified entities will be subject to future audits and/or proficiency demonstrations in order to maintain their certification(s).
- Continuing training for NJDEP Triad staff.

7.0 STAKEHOLDER CONCERNS

For the purposes of this document, “stakeholders” are affected tribes, community members, representatives of environmental and community advocacy groups, and the public. Stakeholders generally show great interest in the nature and extent of the contamination problem, in the means by which the site will be remediated, and in the cost of the restoration effort. Given the financial, technical, and regulatory complexities inherent in the remediation process, it is essential that affected stakeholders are involved in all phases of the cleanup. Only through meaningful and substantial participation will the stakeholders support the difficult policy, budget, and technical choices that will have to be made (WGA 1994).

It is important to note that affected stakeholders are not necessarily limited to adjacent property owners. For instance, those who live downstream of a contaminated site may be affected even if they are not in the immediate vicinity of the site. Furthermore, tribes may have treaties or other pacts with the federal government that grant them fishing, hunting, or access rights in places that are not necessarily near their present-day reservations. In other words, nonadjacent tribes may have legal rights involving the contaminated site or other property affected by the contamination, even though they do not own the property or live adjacent to the site.

All interested stakeholders must have access to critical information and the opportunity to provide input to technology development decisions at all stages of the evaluation, planning, and implementation processes. It is particularly important at the site level to involve stakeholders in collaborative decision making. Stakeholder and regulator interactions with the technology developers, including examination of data and evaluation of demonstration results, increases the credibility of predicted outcomes and decreases the likelihood that barriers to the implementation of a technology will be encountered (WGA 1996a). Effective stakeholder participation can promote a more accurate understanding of the relative risks of various technologies and remediation options. Participants gain a greater understanding of the regulatory requirements and processes, as well as a greater understanding of the technologies and/or remediation techniques, are thus more likely to accept less costly environmental solutions. At the Oxnard Plain site in Port Huneme, California, for example, the Restoration Advisory Board members recommended a less-expensive remediation alternative than the plan originally proposed by the Navy (WGA 1996b). In addition, stakeholders often have valuable, in-depth knowledge of the site characteristics and site history that enhances the effectiveness of the evaluation, planning, and implementation processes.

The three components of the Triad approach—systematic project planning, dynamic work strategies, and real-time measurement technologies—are designed to facilitate early and ongoing participation of stakeholders. A project team controls all three phases, and this team includes stakeholder representation. From the stakeholder perspective, the systematic planning phase of the Triad is most critical. This phase involves the development of project goals and objectives. Once the project goals and objectives are defined, a CSM is developed to integrate what is already known about the site and what is necessary to fill data gaps to achieve those goals. The CSM is the organizing tool for communication among the project team, the decision makers, and the field personnel. The systematic planning process "allows the CSM to evolve and mature as site work progresses and data gaps are filled" (EPA 2001a). It is important that the stakeholder members of the project team be drawn from a representative cross section of the affected community and surrounding regions, including representation from each of the affected tribes.

The dynamic work strategy phase of the Triad approach is directed at field activities and is designed to allow the project team to make decisions in the field on how subsequent site activities will progress. Field staff maintain close communication with regulators or others overseeing the project during implementation of the dynamic work plan. The success of this phase of the Triad approach hinges on experienced field staff who have been "empowered to call the shots based on decision logic developed during the systematic planning phase" (EPA 2001a). It is anticipated that the representative stakeholders with regulatory and technical roles on the project team will be more active during this phase and that other stakeholders and the general public will be indirectly involved through progress reports and periodic meetings.

The third phase of the Triad approach, real-time measurement technologies, makes the dynamic work strategy possible. During the dynamic work plan phase of the project, the project team (including the stakeholders) identifies the type, rigor, and quantity of data needed to answer the questions raised in the CSM. Those decisions guide the design of sampling regimens and the selection of analytical tools and methods for providing relevant information (EPA 2001a).

Throughout the three phases of the Triad, it is important to maintain the rigor of the project team dynamics through ongoing communication via progress reports and live interaction via facilitated site visits and periodic meetings.

8.0 HEALTH AND SAFETY CONSIDERATIONS

State and federal environmental programs require that an HSP be developed for characterization and/or remediation projects. As a conceptual framework, rather than a specific technology, the Triad approach does not necessarily require specific health and safety recommendations. However, because of the flexibility inherent in the Triad approach, the HSP must also be flexible and able to incorporate the specifics for a variety of analytical methods and site conditions.

The HSP should be developed and implemented in accordance with the Occupational Safety and Health Administration (OSHA) regulations, Hazardous Waste Operations and Emergency Response 29 CFR 1910.120 (b). In addition to the HSP, standard operating procedures (SOPs) should be developed and implemented, and the collection and handling of samples should follow such procedures. The SOP should be developed in such a manner that allows for flexibility to fit the site conditions as they may change.

The solvents and chemicals involved in using some field analytical methods may pose exposure hazards. Proper procedures regarding the use of field methods will be addressed in each project HSP, but as a general reminder, practitioners should not utilize these field analytical methods off site in hotel rooms or similar public places. Always ensure that all contamination remains on site so that it cannot endanger unsuspecting members of the public. When used according to the HSP, field real-time measurement technologies will not pose a significant safety concern and will be a beneficial tool for making on-site decisions.

9.0 CASE STUDY SUMMARIES

This section briefly describes environmental restoration activities where the Triad approach or substantive elements have been utilized. Not all of these projects were conducted as a true Triad project; however, they all highlight important aspects of the three components: systematic project planning, dynamic work strategies, and real-time measurement technologies. Each case study is briefly summarized here, and more detailed information is available in Appendix B and from sources provided in the reference section.

9.1 Fernald Uranium Processing Facility

Type of Facility:	Former DOE uranium processing plant
Contaminants:	Radionuclides
Project Team Lead:	Fluor Fernald
Technologies Used:	Integrated Technology Suite (rad detectors, global positioning system [GPS], GIS)
Triad Advantages:	$34 million cost savings
Point of Contact:	Rich Abitz, Rich.Abitz@fernald.gov

9.2 Varsity Cleaners

Type of Facility:	Former dry cleaners
Contaminants:	Perchloroethylene (PCE)
Project Team Lead:	HAS scientists and engineers
Technologies Used:	Field-portable GC
Triad Advantages:	Approximately $300–450K cost savings, substantial time savings
Point of Contact:	Beth Walker, beth.walker@dep.state.fl.us

9.3 Wenatchee Tree Fruit Research and Extension Center Test Plot

Type of Facility:	EPA Agricultural Research Center
Contaminants:	Pesticides
Project Team Lead:	U.S. Army Corps of Engineers
Technologies Used:	Immunoassay test kits

Triad Advantages: +$500K cost savings, time savings
Point of Contact: Howard Wilson, 202-564-1646

9.4 Assunpink Creek Brownfields

Type of Facility: Brownfields
Contaminants: PCBs, Metals, PAHs, total petroleum hydrocarbons (TPH)
Project Team Lead: Langan Engineering and Environmental Services, Inc.
Technologies Used: Field GC-MS, XRF, immunoassay test kits, petro flag test kit
Triad Advantages: Unquantified time and cost savings
Point of Contact: John Musco, jmusco@langan.com

9.5 McGuire Air Force Base C-17 Hangar Site

Type of Facility: Air Force Base
Contaminants: Solvents
Project Team Lead: Hayworth Engineering Science
Technologies Used: CPT, MIP, direct sampling ion trap mass spectrometer (DSITMS), XRF, GPS, GIS
Triad Advantages: 18–24 months saved, $1.34 million cost savings
Point of Contact: John Pohl, john.pohl@mcguire.af.mil

9.6 Pine Street Barge Canal

Type of Facility: Superfund, former lumber and coal yard, former manufactured gas plant
Contaminants: Coal tars, metals
Project Team Lead: The Johnson Company
Technologies Used: Immunoassay test kits, XRF
Triad Advantages: $45 million savings, site reduced from 70 to 38 acres
Point of Contact: Michael Smith, michael.smith@anr.state.vt.us

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11.0 ADDITIONAL SOURCES OF INFORMATION

Guidance for practical application of the Triad approach is in the early stages of development. However, there is a gathering body of knowledge concerning these issues. Available resources can be grouped into Web-based technical resources, regulatory guidance, and peer-reviewed articles (also see Section 10).

Web-Based Resources:

EPA Triad Resource Center

The EPA is currently working with an interagency Triad team to prepare a "Triad Resource Center" on the Internet that compiles technical resources and case study information to assist practitioners in applying these concepts. This resource will both facilitate the dissemination of the information and allow for the updating of the center as the body of knowledge grows. This Triad Resource Center should be available in late 2003/early 2004. Information on availability can be obtained through the EPA "Clu-in" Web site http://clu-in.org/

Field Analytical Technologies Encyclopedia (FATE)

Another valuable resource available on the EPA Clu-in Web site is a compilation of on-site technology information. This section of the Clu-in Web site contains articles and technical information on the theory of operation, strengths/weaknesses, and general operating costs for a large variety of analytical procedures that can be implemented in the field. This information can be accessed through the EPA "Clu-in" Web site http://clu-in.org/. Guidance concerning CSMs, sampling designs, sampling handling, and similar topics can be accessed through the site characterization menus of the Clu-in Web site.

Technical Project Planning, USACE

The Corps of Engineers has produced a guidance manual for technical project planning (the Corps' terminology for "systematic project planning"). The document is titled *Technical Project Planning (TPP) Process*, Engineer Manual EM 200-1-2, and is dated August 31, 1998. It can be accessed online at the Corps of Engineers guidance Web site http://www.usace.army.mil/inet/usace-docs/eng-manuals/em.htm.

NORISC

A European consortium developing an approach with some similarities to Triad http://www.norisc.com.

Regulatory Guidance

Using Dynamic Field Activities for On-Site Decision Making: A Guide for Project Managers, EPA

This guide encourages consideration of some of the concepts central to the Triad approach; systematic project planning, flexible (or dynamic) work plans, and quick-turnaround analytical methods. The manual also includes example case studies. This document can be found at the EPA Superfund Dynamic Field Activity Web site: http://www.epa.gov/superfund/programs/dfa/

Vermont Site Investigation Guidance Document

http://www.anr.state.vt.us/dec/wastediv/sms/pubs/SI Guidance 96.pdf

APPENDIX A

Acronyms

Acronyms

AFB	Air Force Base
AOC	area of concern
ASC	Accelerated Site Characterization
ASTM	American Society of Testing and Materials
CALM	Cleanup Levels for Missouri
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
COC	contaminant of concern
CPT	cone penetrometer test
CSM	conceptual site model
DEC	Department of Environmental Conservation
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality
DFA	dynamic field activities
DHEC	Department of Health and Environmental Center
DL	detection limit
DNAPL	dense, nonaqueous-phase liquid
DOE	Department of Energy
DOIT	(Committee to) Develop On-Site Innovative Technologies
DSITMS	direct sampling ion trap mass spectrometer
DTSC	Department of Toxic Substances Control (CA)
DQO	data quality objective
ECOS	Environmental Council of the States
ELAP	Environmental Laboratory Accreditation Program
EM	electromagnetic
EPA	Environmental Protection Agency
ERIS	Environmental Research Institute of the States
ESA	Expedited Site Assessment
ESC	Expedited Site Characterization
FATE	Field Analytical Technologies Encyclopedia
FFD	fuel fluorescence detector
FSP	field sampling plan
GC	gas chromatograph
GIS	geographical information system
GPS	global positioning system
HSP	health and safety plan
HTRW	hazardous, toxic, and radioactive waste
ICRU	International Commission on Radiation Units and Measurements
ITRC	Interstate Technology & Regulatory Council
ITS	Integrated Technology Suite
LIF	laser-induced fluorescence
LOQ	limits of quantitation
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCL	maximum contaminant level

MIP	membrane interface probe
MTU	metric tons uranium
MS	mass spectrometer
NAPL	nonaqueous phase liquid
NELAC	National Environmental Laboratory Accreditation Conference
N.J.A.C.	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJIT	New Jersey Institute of Technology
NORISC	Network Oriented Risk Investigation for Site Characterization
OQA	Office of Quality Assurance
OSHA	Occupational Safety and Health Administration
PAH	polynuclear aromatic hydrocarbon
PBMS	Performance-Based Measurement System
PCB	polychlorinated biphenyl
PCE	perchloroethylene (tetrachloroethene)
PPM	parts per million
PRG	Preliminary Remediation Goal
PRP	potentially responsible party
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
RAMP	Remedial Action Management Plan
RCRA	Resource Conservation and Recovery Act
RTDF	Remediation Technology Development Forum
SACM	Superfund Accelerated Cleanup Model
SAFER	Streamlined Approach for Environmental Restoration
SAP	sampling and analysis plan
SCM	Sampling, Characterization and Monitoring
SOP	standard operating procedure
SSEB	Southern States Energy Board
SQT	Sediment Quality Triad
TCLP	Toxicity Characteristic Leaching Procedure
TPH	total petroleum hydrocarbons
TPP	technical project planning
USACE	U.S. Army Corps of Engineers
UST	underground storage tank
VOC	volatile organic compound
WGA	Western Governors Association
XRF	x-ray fluorescence

APPENDIX B

Case Studies

B.1 Fernald Uranium Processing Facility

B.1.1 Background Summary

Originally named the Feed Material Production Center, this Ohio facility's primary mission was to produce high-purity uranium metal products in the form of ingots, derbies, billets, and fuel cores for other sites within the nuclear weapons complex. Some sites used the products as fuel for nuclear reactors to produce plutonium. The Fernald site was a uranium processing facility; it did not contain a nuclear reactor, nor did it produce or handle explosive devices, nuclear weapons, or highly radioactive material. During its 38 years of operations, the Fernald site played a critical role in the nuclear weapons complex, delivering nearly 170,000 metric tons uranium (MTU) metal products and 35,000 MTU of intermediate compounds, such as uranium trioxide and uranium tetrafluoride. In 1989, after 37 years of operations to support the U.S. weapons program, site management shut down uranium metal production to concentrate on environmental compliance, waste management, and remediation.

B.1.2 Significant Project Issues

Many U.S. Department of Energy (DOE) sites are involved in a cleanup and closure process. The surface soils (e.g., the top 10 cm) of many of these sites are contaminated with gamma-emitting fission products (e.g., cesium, Cs-137 and cobalt, Co-60) and product material (e.g., uranium). The site investigative process involves many soil surveys:

- an initial characterization survey to delineate radionuclide contamination,
- a remedial action surveys that support remediation activities and determine when a site or survey unit is ready for a final status survey, and
- a final status survey that is used to verify that a site or survey unit has met its cleanup goals.

At the time that Fernald began site remediation, regulatory guidance addressing protocols for soil sampling and sample collection was provided by the EPA (EPA 1992). In general, the approach to a characterization survey for surface soil involves the collection of discrete soil cores, typically to a depth of about 10 cm. While the number and location of the samples depend on the nature of the contamination coupled with a limit on the sampling uncertainty, a conservative estimate for an initial characterization survey might be one soil sample for every 100 m^2. To illustrate the economic impact of any sampling protocol adopted by the DOE, consider the fact that the DOE's Office of Environmental Management has identified 36 sites in 14 states that need remediation. The total area of these 36 sites covers approximately 1590 square miles. If one soil sample were collected for every 100 m^2, then over 41 million samples would be needed. The cost of such an effort would likely run into the billions of dollars. Faced with these numbers site managers are forced to look for alternative or innovative approaches to soil characterization to reduce the effort and cost involved in soil measurements.

B.1.3 Project Team

Fluor Fernald has managed the cleanup of the Fernald site for DOE. Rob Janke was the DOE project manager responsible for the soil remediation effort. Fernald formed a Real-Time

Measurement Work Group, which consisted of DOE management, contractors, technical experts, and regulators, to examine the use of emerging real-time soil characterization technologies (e.g., in situ gamma ray spectrometry) as a means of providing a cost-effective, technically defensible approach to site characterization

B.1.4 Implementation of Triad Approach

- Systematic Project Planning – The project team met to identify project goals, necessary decisions, and the regulatory process. It was possible to reach agreement among the team regarding many issues. For example, while it was acceptable to utilize real-time measurement technologies for initial characterization surveys, it was agreed that final status surveys would be done using the conventional radionuclide-sampling techniques.

- Dynamic Work Strategies – Using a field-portable gamma-ray spectrometer, a global positioning system (GPS), and geographic information system (GIS) software the position and concentrations of contaminants in the near surface were mapped at the conclusion of each day in the field. This approach allowed contaminant distributions to be measured in a study area. The available maps, in turn, allowed for dynamic work plans where decisions on further remedial action were made while field teams were deployed or while closure verification processes were started using the final in situ data and/or a statistical sampling plan for collecting physical samples.

- Real-Time Measurement Technologies – The technology used at Fernald consisted of field-based gamma-ray spectrometers and corresponding platforms, along with GPS and GIS. The GPS and GIS systems provided the ability to map contamination. The system is referred to as the Integrated Technology Suite (ITS) and is not commercially available. A detailed description of in situ gamma-ray spectrometry and the ITS may be found in papers and reports documenting activities at Fernald (Mille, Shebell, and Klemic 1993; ICRU 1994; DOE 2001).

B.1.5 Project Improvements due to the Triad Approach

Early in the project (June 1998) a detailed estimate was prepared that addressed expected costs and cost saving associated with using real-time soil characterization techniques. Cost savings were estimated as the difference between the estimated cost of characterization activities during remedial activities using real-time methods and the estimated cost of accomplishing a similar level of characterization using conventional sampling and analysis methods. The estimated savings were $34M (1998$) for the period FY1998 to FY2006 (DOE 2000).

B.1.6 Project Outcome and Lessons Learned

Regulatory approval can be an obstacle to the use of in situ characterization methods.

Regulatory approval can be an obstacle to the use of in situ characterization methods. Regulators (state and federal) did not approve the use of in situ methods for certifying that the soil meets the appropriate cleanup criteria. The regulators did approve in situ methods for use in all phases of characterization during soil remediation except for the final certification phase. When only a limited numbers of soil samples collected, the conventional approach is subject to substantial uncertainty due to sampling error. However, for regulators the technical advantage of in situ measurements may be of less importance than the perceived risk associated with approving the use of a nonstandard approach.

The major cost savings that result from the use of the ITS at Fernald are associated with precertification.

The major cost savings associated with the use of the ITS occur when mobile detectors are used to scan large areas, as is done during precertification. Such scans greatly increase the probability of locating significant hot spots and allow the average soil concentrations of the primary radiological contaminants in the area to be determined. These averages can be compared to cleanup levels to determine whether any additional soil excavation is necessary. To obtain comparable results using a conventional sampling and analysis approach would require the collection and analysis of a large number of samples, at a cost of approximately $44K per acre. Average field costs for use of the ITS during precertification, based on several years of experience, are about $1.2K per acre.

The detectors require calibration under controlled conditions.

The detectors (sodium iodide scintillators coupled to photomultiplier tubes) used on mobile platforms were initially calibrated in the field using location having contaminated soil that has been characterized independently using other more reliable detectors (i.e., high-purity germanium detectors). However, the contamination in such areas is heterogeneous and occurrences of different types of contamination may be correlated. Also, the calibration locations are lost as contaminated soil is excavated. Therefore, a permanent calibration pad was constructed, and the detectors were calibrated under controlled conditions using the pad.

B.1.7 Contacts

Fluor Fernald, Inc.
Richard Abitz
Phone: (513) 648-4629
E-mail: Rich.Abitz@fernald.gov

B.2 Varsity Cleaners

B.2.1 Background Summary

The Florida legislature established a voluntary state-funded program in 1996 to clean up properties that are contaminated as a result of operations of a dry cleaning facility, prioritizing sites with potential impacts to drinking water supplies. The Florida Dry Cleaning Solvent Cleanup Program is funded through a gross receipts tax on dry cleaner operations and a tax on the sale of perchloroethylene (PCE). Remediation of sites is performed by state-approved contractors who employ a Triad-like approach utilizing systematic planning, dynamic work strategies, and real-time measurement technologies for site evaluation and cleanup (HSA 2002)

Varsity Cleaners, located in Tampa Florida, is in a mixed commercial/residential setting where a dry cleaning business operated from 1960 to 1998. A service station was formerly located on an adjacent property, and a water supply well is 0.5 miles northeast of the site. It was suspected that groundwater was contaminated with various organic solvents. PCE was found to be the contaminant with the highest concentration, 4,940 µg/L in a groundwater plume estimated to be 420 by 300 feet in size. The highest concentration of PCE found in soil was 2,260 µg/kg. The cleanup goals were established prior to remediation and for PCE were set at 3.0 µg/L for groundwater and 30 µg/kg for soil. These values were achieved during the cleanup.

B.2.2 Significant Project Issues

Construction of a large drugstore adjacent to this site demanded that the work be performed as quickly as possible. The most important issues in this investigation were potential impacts to groundwater and the desire of developers to reuse the site as soon as possible. The use of the Triad approach minimized multiple mobilizations and greatly reduced the time required for project completion.

Florida DEP worked with the contractor to define cleanup goals and approaches through systematic project planning, and the contractor was allowed flexibility in means to perform site remediation. This interactive approach encouraged trust between regulator and contractor and allowed HSA Engineers and Scientists, the contractor, the flexibility to employ their expertise as required to achieve the project goals.

B.2.3 Project Team

HSA Engineers and Scientists (HSA) – a Florida DEP-approved contractor
Elizabeth Walker, Florida DEP, Drycleaner Solvent Cleanup Program, Contract Manager

B.2.4 Implementation of the Triad Approach

- Systematic Project Planning – Despite the short time frame to initiate the project, the project team met to develop project goals. The project team had considerable experience with dry cleaning sites in similar geologic settings, which facilitated the creation of the CSM. Due to financial reasons the owner of the site requested that the remediation of the former dry cleaning site be completed quickly.

- Dynamic Work Strategies – The work began on September 14, 1998 and concluded less than two months later on November 4, 1998. The decision logic created during systematic project planning was used to guide the investigation and remediation of the site. The entire project was completed in one mobilization.

- Real-Time Measurement Technologies – A variety of analytical parameters were examined including volatile organic compounds (VOCs), nitrate/nitrite, ammonia, total Kjeldahl nitrogen, total organic carbon, iron, sulfate, and chloride. All field measurements were performed in accordance with HSA's Florida DEP–approved quality assurance plan and included blind and duplicate samples at prescribed frequencies. Comparisons of VOC samples analyzed by a Photovac field-portable GC and by SW-846 methodology were made to confirm data quality and to guide project decisions. The extensive use of field-portable GC analyses and the reduced turnaround time from sample acquisition to data availability greatly contributed to the reduction of time and cost for this Triad approach as compared to conventional remediations involving only the use of analyses generated by fixed off-site laboratories.

B.2.5 Project Improvements due to the Triad Approach

Total project costs were $690,600, of which only $148,000 was attributable to site assessment activities. It is impossible to quantify how much this remediation would have cost if a non-Triad approach had been employed, but conservative estimates are that 2–3 times the cost would have been incurred.

B.2.6 Project Outcome and Lessons Learned

Adaptive field activities

Use of field GC measurements enabled specific sources of PCE contamination to be delineated, including a concrete vault and drain field that, if not identified, would have acted as a continuing contaminant source.

Refinement of soil excavation quantities

Thorough characterization using field analysis minimized the amount of soil that needed to be removed. This could not have been accomplished using fixed-laboratory methods alone.

Acquisition of both characterization and remedial design data

After the site was investigated and the soil hot spots removed, a pump-and-treat system was installed to remediate residual contamination in the clay and limestone.

Final confirmation samples

Regulatory-approved analytical methods were employed to confirm final contaminant levels.

B.2.7 Contacts

Florida Department of Environmental Protection
Elizabeth Walker, Contract/Project Manager
Phone: (850) 245-8927
E-mail: beth.walker@dep.state.fl.us

B.3 Wenatchee Tree Fruit Research and Extension Center Test Plot

B.3.1 Background Summary

The Wenatchee Tree Fruit Research and Extension Center located in Wenatchee, Washington, contained soils contaminated with organochlorine pesticides (which include DDT, endrin, and dieldrin, among others), organophosphorus pesticides, and other pesticides due to agriculture-related research activities conducted from 1966 until the mid-1980s. In 1997, the U.S. Army Corps of Engineers (USACE) implemented an integrated site characterization and remediation project at the site. The Triad approach was used to facilitate quick cleanup and included systematic project planning, on-site remedial decision making using dynamic work strategies, and on-site measurements with immunoassay methods. This approach permitted characterization, excavation, and segregation of soil based on the result of rapid on-site analyses employing commercially available immunoassay testing products (EPA 2000c).

B.3.2 Significant Project Issues

The determination of the suitability for the on-site analytical methods was a major project issue. Therefore, a pilot test was performed to compare the immunoassay field method and traditional fixed-laboratory methods. The test demonstrated the applicability of immunoassay and laid the grounds for method modification, and provided data for development of site-specific action levels. No significant problems were encountered throughout the project, primarily due to the systematic planning that had identified potential issues and reached consensus on the course of actions.

B.3.3 Project Team

Planning and field teams were created to include the appropriate mix of skill and regulatory authorities needed to plan and implement cleanup. The planning team comprised representatives from EPA ORD (responsible party), the regulator (Washington State Department of Ecology), stakeholders (Washington State University), USACE project manager, chemist, heath and safety hygienist, and construction engineer. The field team comprised of USACE project manager, chemist, construction engineer, field QA/QC and health and safety officer; the prime contractor (project manager, field engineer, project chemist/QC officer); and subcontractors to perform excavation, IA, operate Geoprobe, and manage soil disposal activities.

B.3.4 Implementation of the Triad Approach

- Systematic Project Planning – Systematic planning for the project was accomplished by a team representing the USACE, EPA, the site owners, and state regulators with appropriate mix of skills and decision-making authority. An initial conceptual site model (CSM) was developed after reviewing existing information. The primary purpose for the project was to clean up contaminated soil. The team during the systematic planning phase identified the specific goals:

  - focused removal of concentrated pesticide product,
  - gross removal of pesticide-contaminated soil,

- o restoration of the site to achieve the cleanup level, and
- o characterization, classification, and disposal of contaminated materials.

The decisions to achieve these goals were identified. The first decision was to determine whether the soil within each unit was contaminated above the action levels for each contaminant of concern (COC). After removal, a second decision was required to determine if the remaining soil attained the cleanup standard. Once the soil and other wastes were removed, a third decision was to define appropriate classification of the waste for disposal purpose.

Inputs to the decisions were identified, for example, to make remedial decisions (i.e., to remove or not to remove the soil) the necessary inputs included, at a minimum, a list of COCs and cleanup levels, target quantitation limit, candidate analytical method of achieving the quantitation limits, and measurement performance criteria. The limits of the decision errors were also specified in the planning stage.

- Dynamic Work Strategies – The use of data generated on site allowed relatively quick decision making regarding subsequent steps in accordance to the decision rule established during the planning stage. Field-generated data were used to update the CSM to direct subsequent steps. This approach permitted rapid location and definition of hot areas, guided removal of contaminated soil, and quickly identified when enough information had been collected. This approach minimized the collection and analysis of uninformative samples, avoided unnecessary removal of soil, avoided multiple rounds of mobilization, and effectively identified when the project was done.

- Real-Time Measurement Technologies – Immunoassay test kits were used to analyze contaminated soil in the field. A pilot test was performed by analyzing contaminated soil by immunoassay methods and by traditional fixed-laboratory methods. The result of the pilot test demonstrated the applicability of the field methods, guided method modification to streamline field analyses, and enabled establishment of site-specific action levels. The adaptive work plan permitted field team to make real-time decisions on the basis of data generated in the field.

B.3.5 Project Improvements due to Triad Approach

The use of the Triad approach for this project resulted in savings of about 50% (over $500,000) over traditional site characterization and remediation methods. The project was completed in one mobilization, which allowed significant cost savings over multiple mobilizations that would have otherwise occurred. The systematic project planning and use of dynamic work strategies saved significant time by allowing on-site decision making and reduction in multiple regulatory reviews. Costs of waste disposal were significantly reduced by using field analyses to characterize and segregate wastes that required costly incineration from other waste that were suitable for less-expensive disposal methods.

B.3.6 Project Outcome and Lessons Learned

Unexpected conditions

There was some uncertainty regarding the actual project boundaries. This was confirmed during the course of the field work, and the uncertainty was easily resolved with the immunoassay test kits.

Use of immunoassay test kits

Immunoassay analysis is not specific to a single compound but reacts to a range of structurally similar chemicals. Thus, it is important to ensure that the investigation QC program addresses potential immunoassay cross-reactivity. In addition, the immunoassay test kits are manufactured to have a high bias to ensure against false negative decision errors. It may be necessary to determine the actual bias for a specific project.

B.3.7 Contacts

Responsible Party: Howard Wilson, U.S. Environmental Protection Agency, Office of Research and Development, 1200 Pennsylvania Avenue, NW, Washington, DC 20406, (202) 564-1646

Contractor: Ralph Totorica, Project Manager and Greg Gervais, QA Representative, Kira Lynch, Project Environmental Scientist, USACE, Seattle District, 4735 East Marginal Way South, Seattle, WA 98134, (206) 764-6837

State Regulatory Contact: Thomas L. Mackie, Washington State Department of Ecology, Central Regional Office, 15 West Yakima Avenue, Suite 200, Yakima, WA 98902-3401, (509) 454-7834

Technology Demonstrator: Mike Webb, Garry Struthers Associates, Inc., 3150 Richards Road, Suite 100, Bellevue, WA 98005-4446, (425) 519-0300

B.4 Assunpink Creek Brownfields

B.4.1 Background Summary

The Triad approach was utilized to investigate two brownfields sites that are part of the Assunpink Creek Greenway Project in Trenton, New Jersey. The project is an initiative by the City of Trenton to redevelop abandoned brownfields properties along the Assunpink Creek into a recreational area and greenway. The City of Trenton entered into a memorandum of agreement with the New Jersey Department of Environmental Protection (NJDEP) to investigate portions of the Crescent Wire site and the Freight Yards site. The Crescent Wire site is an approximately 2-acre vacant lot that is currently owned by the city and was formerly used for the manufacturing of high-tension cables and wires. Operations at the site ceased prior to 1995, and the former building was destroyed by fire in 1996. The site is presently vacant and covered primarily by concrete. The city owns a portion of the Freight Yards site, which was historically used as railroad freight depot. Operations at this site ceased in the mid-1980s. The Freight Yards site comprises an area of approximately 37 acres and presently includes paved roadways and unpaved areas that are primarily covered by rails.

Preliminary assessment activities were performed, and limited sampling was initially conducted at both properties to provide initial characterization of environmental conditions. Several areas of concern (AOCs) were identified at each site that required further delineation. This information was utilized to support development of the preliminary conceptual site model (CSM) and to initiate the systematic planning step. The Triad approach was selected to complete the delineation of PCB impacts that were identified in soil at the Crescent Wire site and to complete the investigation of several AOCs at the Freight Yards site including sitewide soil impacts across the rail area, an existing aboveground storage tank area, fuel oil spills, and areas of distressed vegetation. Dynamic work strategies were incorporated into project planning documents to codify the investigative objectives and approach, for approval by all stakeholders prior to initiating the field investigation.

B.4.2 Significant Project Issues

The City of Trenton was interested in accelerating the site characterization phase so that the scope and cost of remedial actions could be developed in a short time frame. The Triad approach was selected in an attempt to complete the characterization of identified impacts in one mobilization.

The project was undertaken in cooperation with several stakeholders to evaluate an innovative approach for reducing the cost and timeframe for environmental investigations at brownfields sites.

The use of field analytical methods required preapproval by NJDEP, which participated in the systematic planning process along with the other stakeholders.

B.4.3 Project Team

- City of Trenton, N.J.
- Langan Engineering & Environmental Services, Inc. – Doylestown, Pa.
- S2C2 Inc. – Raritan, N.J.
- New Jersey Department of Environmental Protection
- New Jersey Institute of Technology
- U.S. Environmental Protection Agency, Technology Innovation Office

B.4.4 Implementation of the Triad Approach

- Systematic Project Planning – The systematic planning process involved a careful review of existing environmental data for the sites, the generation of a CSM, and several meetings with stakeholders to identify project objectives and reach a consensus on an investigative approach. A project kick-off meeting was held to discuss project objectives and stakeholder concerns. Two additional meetings were then conducted to discuss the investigative approach and finalize the adaptive work plan.

- Dynamic Work Strategies – The work planning documents laid out the investigative objectives and the approach and clearly articulated the investigative decision logic. The work plan contained a review of existing environmental data and a presentation of the CSM. A crucial element of the adaptive work plan was a series of decision rules, which directed continued sampling until project objectives were met. Stakeholders' comments on draft work plans were incorporated into the final NJDEP-approved adaptive work plan.

- Real-Time Measurement Technologies – A variety of analytical methods were utilized in the field to obtain real-time data that were evaluated and used to direct the field program until the investigative objectives were achieved. A modified version of EPA SW-846 gas chromatograph – mass spectrometer (GC-MS) Method 8270C was used for the analysis of individual polynuclear aromatic hydrocarbons (PAHs) and total petroleum hydrocarbons (TPH) in soil. A Spectrace 600 x-ray fluorescence (XRF) was used for the analysis of metals in soil. An immunoassay RaPID Assay test kit by EPA SW-846 Method 4020 was used for the analysis of PCBs in soil. PCB detections by the RaPID Assay were confirmed in real time by the on-site GC-MS (modified 8270C). A Petro Flag test kit was used for the analysis of TPH in soil.

B.4.5 Project Improvements due to the Triad Approach

The most significant benefit resulting from the use of the Triad approach was the reduction in investigative phases and overall time for the characterization of environmental impacts at the site. The investigation of the Crescent Wire site was completed within one week, and the investigation of the Freight Yards site was completed within four weeks. The increased sampling density afforded by the lower cost field analyses enabled a more detailed characterization of the site, thereby reducing the uncertainty of environmental conditions. Although the overall cost savings using the Triad approach has not been quantified, the completion of site characterization objectives within one mobilization and the use of field analytical methods resulted in a cost benefit to the City of Trenton.

B.4.6 Project Outcome and Lessons Learned

Accelerated site characterization

The Triad approach was successfully applied to accelerate the characterization and delineation of environmental contamination at two brownfields sites.

Fewer unresolved site uncertainties

The high sampling density utilized as part of the Triad approach identified a PCB "hot spot" at the Freight Yards site that would have likely been missed by a conventional investigative approach.

Greater initial effort required of the regulators

The systematic planning and dynamic work strategy steps of the Triad approach required a considerable amount of NJDEP resources on this high-profile project that may not always be as readily available. However, as the Triad approach becomes better understood and more widely accepted, it is anticipated that less up-front involvement would be required of the regulators.

B.4.7 Contacts

John Musco and Katherine Linnell
Langan Engineering & Environmental Services, Inc.
500 Hyde Park
Doylestown, PA 18901
Phone: (215) 348-7101
E-mail: jmusco@langan.com and klinnell@langan.com

B.5 McGuire Air Force Base C-17 Hangar Site

B.5.1 Background Summary

McGuire Air Force Base (AFB) in New Jersey was selected to receive a new transport aircraft, the C-17, to support United States military operations. The C-17 aircraft required a new hangar that was to be constructed on the location of former base maintenance buildings. The limited investigation data available for the new hangar location suggested that chlorinated solvent contamination was present at concentrations requiring remedial action.

B.5.2 Significant Project Issues

Construction had started on the $28 million C-17 hangar when contamination issues required that the work be halted. Preliminary work on the hangar was stopped in March 2003. The Air Force determined that construction must resume no later than July 2003 to enable the deployment of the C-17 to remain on schedule. To accomplish this goal, the investigation of the site had to be completed in only three months. An interim remedial action would follow shortly thereafter. The environmental restoration team at McGuire AFB realized that only an innovative process—the Triad approach—would allow the hangar project to remain on schedule. McGuire AFB formed a core technical team from environmental consultants with the necessary experience to implement Triad.

B.5.3 Project Team

Christopher Archer, McGuire AFB Environmental Flight, Chief
Bryan O'Ferrall, Air Force Center for Environmental Excellence, Project Manager
John Pohl, McGuire AFB Environmental Flight, Restoration Project Manager
Paul Ingrisano, U.S. Environmental Protection Agency, Region II Remedial Project Manager
Phil Cole, New Jersey Department of Environmental Protection, Case Manager

Scott Beckman, Science Applications International Corporation (SAIC), Project Manager
Joel Hayworth, Hayworth Engineering Science (HES), Inc., Core Technical Team Leader
William Davis, TriCorder Environmental, Core Technical Team member

B.5.4 Implementation of the Triad Approach

- Systematic Project Planning – After the team was assembled, specific project objectives were established: (1) locate the source of the solvent contamination, (2) characterize the groundwater solvent contamination, (3) determine whether other contaminants were present, (4) obtain appropriate data to support an interim remedial action, if needed, and (5) conduct any needed removal actions beneath the footprint of the hangar. A CSM was created based on historical information and the limited available contaminant data. The regulatory agencies were included from the very earliest stages of planning. The project team agreed to contaminant action levels and to decision logic guiding investigation and remedial activities.

- Dynamic Work Strategies – The project work plan included sampling contingencies based on the decision logic established earlier. Data collection was sequenced to efficiently determine the hydrogeology as well as the magnitude and extent of the contamination. Experienced members of the Core Technical Team guided the field work. The CSM was updated frequently using data from a variety of real-time collection technologies. All site uncertainties were investigated and resolved during the course of the fieldwork.

- Real-Time Measurement Technologies – To ensure that the site was completely characterized within the available three-week field work schedule, direct-push equipment equipped with advanced sensor technology was used. A cone penetrometer test (CPT) rig with both a membrane interface probe (MIP) and fuel florescence detector (FFD) was deployed to the site. This was supplemented with a drilling rig combining direct push with a hollow-stem auger system. Volatile organic chemical analysis in soil and groundwater was accomplished with a direct sampling ion trap mass spectrometer (DSITMS) running EPA Method 8265. A Niton XLT/500 x-ray florescence (XRF) unit was used for analysis of metals in soil. Sample collection locations were surveyed with a global positioning system (GPS) with submeter accuracy. Data was managed/evaluated in the field using geographical information system (GIS) and analysis software applications.

B.5.5 Project Improvements due to the Triad Approach

No cost estimates were prepared comparing a hypothetical traditional process to the actual approach (Triad). However, it was estimated that the cost of the investigation was comparable to a more traditional investigation that would have taken longer, provided less contaminant data, and would have likely left significant site uncertainties unresolved. The most significant benefits to the project were the time savings—on the order of 18–24 months—which allowed the pending hangar construction to proceed on schedule.

B.5.6 Project Outcome and Lessons Learned

Early involvement of the regulators in planning

Faced with the abbreviated schedule for the project the McGuire AFB environmental restoration team recognized that the regulators must be involved from the beginning of project planning. The project team including the regulators was successful in quickly identifying objectives and agreeing on responses to a variety of potential contaminant scenarios.

The benefit of experienced environmental professionals

It would not have been possible to plan and successfully execute the investigation within the available time without the use of experienced environmental professionals. The Core Technical Team consisted of senior engineers and scientists accustomed to working in a multidisciplinary fashion.

The use of environmental data management software

The real-time measurement technologies employed for this project generated large amounts of data. It would not have been possible to rapidly manage, visualize, and use these data without the use of database, GIS, and contaminant analysis software.

B.5.7 Contacts

John Pohl, Restoration Project Manager
McGuire Air Force Base, New Jersey 08641
Phone: (609) 754-3495
E-mail: john.pohl@mcguire.af.mil

B.6 Pine Street Barge Canal

B.6.1 Background Summary

The Pine Street Barge Canal is located in Burlington Vermont and was constructed in 1868. The Canal presented an environmental risk where the contaminants of concern were coal tars and metals. Historical site uses included a lumber and coal shipping yard and a manufactured gas plant that operated from 1895 through 1966. Waste from the plant, including coal tar, was released to the site, where it was absorbed into natural peat and layers of wood chip fill in the subsurface. Over the decades, coal tar constituents from the gas plant accumulated in the sediments in the canal. Oil spills, other industrial discharges and disposal activities, and urban storm-water runoff also have impacted the site.

Burlington is a lakeside community that values highly its past and present relationship with Lake Champlain. The Pine Street Barge Canal was a 70-acre site in the downtown area and on Burlington’s waterfront to Lake Champlain.

In 1983 the site was listed as a Superfund site, and in 1991 the EPA arrived at a proposed remedy. That proposal called for a $50 million remedial plan that involved dredging and the construction of a containment unit that would have become one of the most salient elements in the city's landscape. In response to public concern about the proposed remedy, EPA withdrew its proposed remedial plan in 1992 and accepted an initiative to develop an alternative plan. In 1992 the Pine Street Barge Canal Coordinating Council was formed. The potentially responsible parties (PRPs) agreed to undertake an additional RI/FS in 1993 that was performed with the active participation of the Coordinating Council.

Elements of the Triad approach (systematic planning and real-time measurement) were applied to plan and implement the additional RI/FS, leading to substantial investigation time and remediation cost savings.

B.6.2 Significant Project Issues

- Acceptance of real-time measurements as decision quality data, without involving EPA Level IV QAPP protocols. This was at a time when real-time measurement methods were in an early phase of acceptance. The Pine Street Barge Canal Coordinating Council overcame that hurdle by undertaking a correlation study, which compared full laboratory protocol to immunoassay measurement.

- The project was the first to involve a coordinating council of the PRPs and active community representatives in the work plan development and decision-making process.

B.6.3 Project Team

The project team included

Pine Street Barge Canal Coordinating Council
Vermont Department of Environmental Conservation
The Johnson Company, consulting engineers, Montpelier, Vermont
EPA Superfund Program

B.6.4 Implementation of the Triad Approach

- Systematic Project Planning – The systematic project planning process was achieved through the development of an exhaustive CSM, based on the data developed in the previous years of investigation, which identified the before undescribed hydrogeologic equilibrium processes with the adjacent Lake Champlain. The Coordinating Council produced a work plan through consensus, which clearly identified the goals and objectives for the Additional RI/FS and established the remedial option decision selection process.

- Dynamic Work Strategies – The work plan involved the identification in the field of different bioregions of the Pine Street Barge Canal wetland and provided a detailed description of the sampling protocols and the decision-making procedure for further sampling, based on the field-identified soil matrix conditions. Those soils meeting the work plan criteria were submitted to real-time measurement.

- Real-time Measurement Technologies – In the RI/FS investigations that ensued after 1992, the focus was to characterize the contaminant distribution within the shallow soil and sediments. The consultant proposed a Phase I ARI that applied real-time measurement of PAHs via immunoassay screening and on-site XRF for metals with a 10% analytical laboratory confirmation. The per sample costs for these screening analyses were a fraction of the laboratory analytical costs. The plan also called for the establishment of a field lab with a QAPP. During the implementation of the Phase I ARI sampling plan, 146 shallow upland/wetland soil samples and 87 canal sediment samples were collected and analyzed for PAHs. Forty-five more surface soils were analyzed to characterize areas for human health risk assessment that had not been sampled earlier. Twenty-five confirmation samples were submitted for PAHs and metals. The data developed during this phase of the investigation allowed the study area to be divided into eight distinct areas of similar features for subsequent toxicity testing. The correlation between the real-time measurements and the commercial analytical laboratory supported the use of the real-time measurements for the overall site characterization. This characterization identified areas most likely to pose unacceptable ecological risk. The toxicity testing and other ecological sampling programs were then designed to evaluate these areas. During a Phase II ARI the real-time measurement techniques were again applied to identify the sample points that would be submitted for toxicity testing. The results of this phase established that five of the eight distinct areas required risk management measures. This process effectively reduced the 70-acre Superfund site area to 38 acres.

B.6.5 Project Improvements due to Triad Approach

The selection of a remedial strategy was a collaborative effort between the PRPs, EPA, the State of Vermont, the U.S. Fish and Wildlife Service, the City of Burlington, the Lake Champlain Committee (a local environmental group), and local public and business representatives. This process was the first such collaborative process for the EPA Superfund Program. EPA New England Administrator at the time, John P. DeVillars, said that the consensus-building model used at the Pine Street Barge Canal stands as a national model for community-based decision making.

The findings from these real time–based investigations led to the selection of an innovative, much less intrusive, remedial approach that was accepted by regulatory agencies and the public, costing less than $5M. A $45M cost savings was realized, along with the implementation of a less intrusive and more protective remedial option that preserved the city’s landscape. The primary feature of the revised approach was a subaqueous silt/sand cap over the coal tar–contaminated sediments to isolate them from ecological receptors.

Also significant to this effort was that the site definition was reduced from 70 acres to 38 acres, allowing the PRPs and the city to better manage the future use and development of the site.

B.6.6 Project Outcome and Lessons Learned

Faster site characterization

Real-time in-field analysis successfully accelerated the characterization and delineation of environmental impacts at the Pine Street Barge Canal.

Better quality investigations

Greater number of sample points for a comparable investigative cost allowed a more thorough description of site conditions and a higher level of development of the CSM.

Correlation study facilitated use of field analytical methods

The correlation study was a fundamental threshold in the acceptance of real-time measurements as decision quality data in environmental investigations.

B.6.7 Contacts

Sonja Schuyler, Senior Scientist
The Johnson Company, Inc.
100 State Street
Montpelier, VT 05406
(802) 229-4600
E-mail: sas@jcomail.com

Michael B. Smith, Hydrogeologist
Waste Management Division
103 South Main Street West Building
Waterbury, VT 05671-0404
(802) 241-3879
E-mail: michael.smith@anr.state.vt.us

APPENDIX C

Response to Comments

SCM Team Response to Review Comments

SPECIAL NOTE; The ITRC Sampling, Characterization, and Monitoring team is especially grateful to members of the USACE ITA program who reviewed and commented on the document. Of particular note, Kira Lynch and Cheryl Groenjes provided constructive comments that helped improve the document. Jeff Breckenridge is the former coordinator of the USACE ITA program, and Greg Mellema became the program coordinator during the time of this review. The team is grateful to both for allowing participation in the review.

The SCM team is also grateful to those states that responded with comments about the draft document. Of particular note, the team would like to thank the very thoughtful and thorough review made by the Nebraska DEQ. Comments from the various reviewers follow.

Reviewer; US Army Corps of Engineers Innovative Technology Advocates Program

The document provides excellent guidance and will help to lay the groundwork for change in our industry and improvements in the execution of the Triad projects. Thank you for the opportunity to comment.

We concur, and thank you.

1. p. 2, Penultimate sentence of 1.2 (& p. 27, 2.8.4-similar text). Suggest, "…achieving consensus on the investigation objectives prior to beginning **generation of planning documents, which support** fieldwork**."** *Clarification will focus this being accomplished before the writing, review and approval of project planning documents. This can increase the cost effectiveness of these tasks by all parties – for they have been discussed during planning and are in agreement with the basic concepts and objectives with which they are based.*

We concur – the suggested wording was added to the sentence.

2. p. 4, (2.1) 1st paragraph of pg., last sentence. Suggest, "It is crucial to use the CSM to avoid sampling errors and to interpret results from **various data sets, including** lower density fixed-laboratory analysis **in conjunction with the real-time measurements.**

We concur – the suggested wording was added to the sentence.

3. p. 4, (2.1) 2nd paragraph of pg., 3rd sentence. Suggest, "Heterogeneity can have important repercussions on sampling design, analytical method performance, **spatial interpretation of data,** toxicity and risk estimation, and remedy design and success."

We concur – the suggested wording was added to the sentence.

4. p. 4, Outlined box, last sentence. Suggest, "The Triad explicitly manages the largest source of data uncertainty, which is data variability caused by the heterogeneity of **chemical contaminants and the impacted** environmental matrices."

We concur – the suggested wording was added to the sentence.

5. p. 11–15, 2.4.3 and 2.4.4. Some of the text in these sections could be better focused. Suggest rework of text in light of the following.

- p.11, 2nd paragraph. The first sentence's message - which the CSM is generally updated after the completion of each 'phase' of work and then seems to have to clarify that a 'phase' can be 'daily' is odd. Suggest as an alternative, that the revision/updating cycle for the CSM(s) be noted as a project-specific decision(s) made during planning, that is linked to the data being produced (how much, how fast) and how the data is being used (are their daily decisions being made based on it, or is less frequency acceptable). The motto should be the more data and more real-time the needs, the more frequent the CSM should be updated. Daily is about as frequent as you can achieve / maintain. Suggest emphasizing this as a group decision(s) by team members and project stakeholders. It should be noted as a key aspect of the data management and project communication strategies developed. Retain the sentence that states that the CSM be updated whenever a significant change in previous interpretations. The last sentence seems confusing, for the field personnel are normally the ones doing the CSM updating. Suggest, "**When not performing the CSM updates themselves, it is critical that** field personnel be kept informed of any updates to the CSM that occur during data collection activities."

We concur – similar wording was added to the sentence and paragraph.

- p.11, 2.4.3, 3rd paragraph. The text noted here and on p.14 in section 2.4.4 (1st and 2nd paragraphs) lack a logical foundation to describe many of the terms used (i.e., various heterogeneities, errors, and uncertainties), their sources, associations, or how to mitigate them. Text on heterogeneities is disjointed across the 2 sections. Suggest these topics be gleaned together and reworked to concisely introduce these topics with some of the principals below for clarification.

    - Heterogeneity is a state of nature that causes all sampling error. There are two types of heterogeneity affecting environmental sampling: compositional and distributional.
    - Compositional heterogeneity applies predominantly to solids or suspended particles, and can be defined as the difference in composition of particles for an analyte of interest within a population. With compositional heterogeneity, because all particles do not have the same concentration (i.e., contamination may be greater in the fines or larger particles), this induces fundamental error, which can exacerbate other sampling errors. The means for controlling compositional heterogeneity and fundamental error is by collecting sufficient sample mass (based on particle size of matrix, etc.).
    - Distributional heterogeneity is defined as nonrandom distribution of particles, which lead to grouping and segregation errors. *The environmental causes for this should be linked to existing text on p.11 under spatial heterogeneity.* Mitigation of these can be done by collecting many random increments, segregating CSM (and managing related data sets) into groups with similar characteristics, using sampling

tools that minimize sample bias, and thorough mixing of the samples. The Triad approach focuses on this type of heterogeneity and its associated sources of error by initial segregation of the CSM into different populations based on suspected contamination spatial patterns and project decisions associated with them (*see examples on bottom of p.11)*, providing greater sample density with the use of real-time measurement technologies, and ensuring thorough evaluation during planning phases of the key sampling and analytical factors that impact the representativeness of that sample and its data (fig.5).

- o If existing project data shows high RPD values between duplicate samples (indicating an incompatibility in results), this should trigger additional evaluation of these matrix heterogeneity issues (and how they impact decisions). Research work by T. Jenkins of CRREL, Chuck Ramsey of Envirostat, Inc., etc. on the impact these heterogeneities have on soil sampling have identified the acquisition of short-range (multi-aliquot) composite samples as a means to provide a more representative field sample. Additionally, employing steps to dry, grind, and sieve the sample matrix prior to sample preparation / analyses can also improve analytical performance. *Suggest linking this topic to text on p.15 1st – 3rd paragraphs (DOE study), which apply to compositional heterogeneity and its measured uncertainty/variability.*

We concur that heterogeneity could be better explained in the document; however, we believe that most of the readers of this document will already have a basic understanding of the subject. The suggested addition is an excellent discussion, and we will use it as part of the planned internet and classroom training seminars to better explain environmental heterogeneity.

- p. 12, 4th paragraph, last sentence. Once the approximate boundaries…(i.e., the CSM is mature), data that are representative of specific project decisions **is used** will be collected to estimate the properties of interest…..(stet).

We concur – the suggested wording was added to the sentence.

- p. 13, 2nd paragraph, last 2 sentences. Suggest this discussion be associated with another type of error, i.e., statistical error. Some aspects influencing the amount of statistical error are noted below, which in turn can lead to incorrect inferences about the population from the data.
  - o Assume the wrong distribution (normal vs. abnormal)
  - o Violate assumptions of that statistic or distributions (contamination is not typically random or independent)
  - o Use of the wrong statistic
  - o Incorrect use of censored data (how to interpret the nondetects)

We concur – similar wording was added.

6. p. 18, 2.5, 3rd paragraph, last sentence. Suggest, "For example, systematic planning can establish how background concentrations of naturally occurring metals will be calculated **and used.**

We concur – the suggested wording was added to the sentence.

7. p. 19, 2.5, 2nd paragraph. Suggest noting this step is recommended when field data's use is quantitative in nature. For instance, a numerical value will be generated that will be evaluated against a project decision level, e.g., when used to monitor removal actions or other remedial response actions. Also, include a reference to later sections (p. 27) 2.7 and the discussion of confirmation samples / split sample analysis (2nd bullet). Another task commonly performed time (during a pilot study, or initial start-up) is the modification / adaptation of preparatory procedures and analyses to improve extraction efficiency, or improve performance in the project matrices.

We concur with the concept, but do not believe it is necessary to develop the paragraph to this level of detail. No change was made.

8. p. 24, 2.7, 2nd paragraph. Suggest nominal clarification be provided to guide the application of a quality control program. After the discussion on "the way the information generated will be used", suggest introducing the concept of qualitative and quantitative data uses: **Qualitative data uses, e.g., those that support a general site (screening) assessment or refine the CSM, may rely on the data's general agreement with expected CSM as a form of verification**. **However i**n general, the validity of **all** in-field measurements should be established by **instrumental** QC checks that demonstrate that the instruments calibrated (if appropriate.) and functioning properly. **When data uses are quantitative in nature, the assessment of the numerical values produced becomes more critical. QC protocols should include both instrumental and matrix-specific QC checks to verify the equipment is not only working properly, but that the method shows acceptable performance with the project matrices. Routine QC checks applied might include an evaluation of cross-contamination potential sources (e.g., various blanks), limits of quantitation (LOQ) / detection limits (DL) in the project matrix, or the bias from matrix interferences. Accuracy of the method should be checked at project decision levels to assess the need for establishing 'gray regions' and triggers for appropriate (split sample) (redundant) more definitive analyses. A series of duplicate samples can be executed to evaluate sampling and analytical procedures, as well as characteristics of sample heterogeneity and other sample support issues.** There is a diverse…(stet)

We concur – similar wording was added.

9. p. 24, 2.7, 3rd paragraph. Another serious deficiency of this arbitrary, rote confirmation sample approach can be the untimeliness of the comparison of data sets. Although the option to evaluate near real time is available, a traditional approach has been applied many times - where the evaluation of comparability between field and fixed data sets actually waits until the final report. When the correlation was not as expected or hoped, whole data sets were discarded. The Triad instead tries to work real time to optimize the methods/techniques, understand their limitations, trends, and effects on use. Suggest the "timing" of this data evaluation be emphasized, if any benefit is to be assured from these data sets.

We concur – similar wording was added.

10. p. 27, 2.7, last paragraph. Suggest associating this (confirmation) QC with data uses that are quantitative in nature. Also recommend a minimum of 6 split samples be done to ensure nominal validity of statistics performed.

We concur in general but do not believe the additional wording is needed. Because each site is unique, we hesitate to recommend 6 (or any number) as a minimum for split samples.

11. p. 27, Field Methods can be used in a Fixed Lab box, 2nd sentence. Suggest, "If a **fixed** lab is nearby a site, **the option exists for** running real-time analyses in **a** controlled environment**, thereby avoiding the costs of support facilities onsite**. **This** may improve method performance while retaining the advantages of rapid turnaround and greater sample numbers.

We concur – similar wording was added.

12. p. 28, 3rd and 6th Analytical bullets. Suggest dropping the "Draft" designation from Method 8265. *(I know it is in draft form right now, but this will be removed soon*.) Suggest adding 8510, 8515, (85** others?) to the current reference of the 9000-series colorimetric methods.

We concur and made the addition to the colorimetric bullet but left the "draft" on Method 8265 as it is draft at the time of this document publication.

The technical/regulatory guidelines document is very well written and will go a long way toward helping to educate the environmental remediation community regarding the use of Triad work strategies. Thank you for the opportunity to comment.

We concur, and thank you.

1. p. v, Executive Summary, I recommend changing the language in the second paragraph that references "advocacy of field generated data" to "advocacy of use of near real-time data". The reason for recommending this change is that far to many people think that the Triad equates to using field analytical methods. The Triad does not specifically advocate the use of field generated data but rather encourages people to consider the wide variety of analytical techniques available and to design data collection strategies to make use of the numerous innovative measurement and data visualization techniques available.

We concur. The wording was changed as suggested.

2. p. 5, first paragraph, Significant cost and time savings can result because characterization can focus on uncertainties that impact appropriate remedial action selection, design, and associated cost estimation. This is a key issue that should be documented in this paragraph and in the box.

We concur. The wording was changed as suggested.

3. p. 8, third paragraph, Fix typographical errors.

We concur; typographical errors have been fixed during the document review.

4. p. 19, fifth paragraph, I suggest referencing the EPA Triad Procurement Guide since in this guide we discuss issues when procuring Triad services at length. Consider adding “logistical planning” to the new tasks that must be fully integrated into the planning process. The logistical planning (i.e. access agreements, sequencing of tasks so that the data builds on the CSM, contracting issues for back up equipment and services, etc.) is critical to the success of Triad projects and is significantly different then standard phased projects.

We concur but think that the existing language broadly covers all planning issues. The team may prepare a Triad “How – To” document in the future, and if so will consider adding logistical planning as a separate discussion item.

5. p. 21, second paragraph, QC programs should also be designed to help the project team understand data variability. Fix typo in third paragraph.

We concur – similar language was added to the end of the paragraph. Typo was fixed.

6. p. 22, the box at the bottom of this page, I suggest deleting the bullet “produce better data and better project outcomes for less cost”.

We concur; the bullet was removed.

7. p. 29, section 2.8.4, It is possible for the team to agree on a range of uses if the specific land use is not known.

We concur – the statement “It is sometimes possible for the team to agree on a range of land uses if the specific land use is not known,” was added.

8. Table 2, This table needs to have an arrow or something that makes it clear that “decision making” and the top box “systematic planning” are connected and must be considered iteratively. Development of a communication strategy should be part of the dynamic work strategy.

We concur and added this sentence; As shown in Table 2, the final step “Decision Making” is related to the first step “Systematic Planning,” and the 2 must be considered iteratively.

9. p. 32, second paragraph, Fix typographical error.

We concur; the typo was fixed.

10. p. 32, This section should really include a comparison to the Corps Technical Project Planning Process. I could write this section if you would like.

We concur. The suggested addition was included in the document.

11. p. 36, Table 3, The use of the word disadvantages is misleading since many of the issues raised under this category are not what I would call “disadvantages”.

We do not concur. There are some negative aspects involved with implementing a Triad project, especially for untrained personnel. The ITRC team has attempted to present all the pros and cons in an unbiased manner so that a reader can consider all aspects.

Reviewer; Nevada DEP

I did not find any regulations or policies that would prevent NDEP from using the Triad concepts. Both NAC 445A and NAC 459 state a specific test method or an equivalent test method approved by the Division. This language allows NDEP the flexibility to use the Triad approach.

Good to know.

In regards to the presentation of the document, I suggest that table 2 (Triad Process Overview) which is a road map be included up front in the document behind the Executive Summary. As I was reading the document, I kept saying they need an outline or road map so the reader can keep the different section and subsections in context as to where it fits in the process. I finally ran into it on Page 31.

We concur. Table 2 was moved toward the front of the document and renamed as Table 1.

This approach will be successful due to the emphasis placed on strategic, systematic planning, and the flexibility in work strategies. Triad will definitely remove the vast confusion pertaining to the DQO process that is many times improperly applied.

We concur.

Specific comments and suggestions:

Page 1 Introduction:

> Rephrase? In the last 20 years, tremendous strides, both practical and scientific, have been made in the environmental restoration industry.

The sentence was rephrased.

Second sentence: change this experience to these improvements

Either approach would work. The sentence was not changed.

Fourth sentence: change gathered to combine

We concur and changed the sentence.

Rephrase? Six sentence: This ITRC document highlights the advantages of the Triad approach with regards to achieving higher quality and more cost-effective environmental remedies.

Either approach would work. The sentence was not changed.

Page 2: Bullet item four: standard techniques or mutually accepted techniques

We don't think this would help clarify the issue. Many of the Triad techniques are not "standard," but the assumption is that all techniques were mutually agreed upon by the involved parties.

Page 3: first paragraph: explain lower density fixed laboratory analysis**.**

We concur. The phrase "fewer samples" was added in parentheses after the term "lower-density" to explain its meaning, and the phrase "more samples" was added similarly after the term "higher-density."

Page 8: third paragraph third sentence typo: simple should be simply

We concur. The typo was fixed.

Page 21: fourth paragraph sixth sentence: typo (itused)

We concur. The typo was fixed.

Page 32: second paragraph first sentence: typo (anew)

We concur. The typo was fixed.

Reviewer; Illinois EPA

NOTE: IEPA personnel indicated that they use the Triad approach and find it very useful. They had no comments on the document.

Good to know they already use the approach.

Reviewer; Vermont DEC

Page 10: The document references the VT DEC conceptual site model process. The references should include the VT Site Investigation Guidance Document (available on the web: http://www.anr.state.vt.us/dec/wastediv/sms/pubs/SI Guidance 96.pdf

We concur. The reference was included in section 11 "Additional Sources of Information."

Page 17: Figure 5: Please re-work these colors, they make it very difficult (for me anyway) to read the left side of the document on my color printout. This should also be checked to see what it looks like in black and white.

We concur. We changed these colors.

Page 17: 2nd paragraph: The third sentence in this paragraph states "High numbers of **cheaper** analyses…" This term is also used elsewhere in the document. As "**cheaper**" holds a certain connotation that it is poor quality, I would suggest that the word cheaper be replaces with "less expensive" where appropriate.

We concur. The change was made throughout the document.

Page 20: Section 2.6: This section states that an implicit goal of triad is to complete the field work in one mobilization. I would generally dispute this and say that even with the most efficient triad process, at large sites, you will generally need more than one mobilization (if not for anything else for monitoring environmental quality over time versus the single snapshot in time that one field phase will provide). I would suggest replacing "one mobilization" with "minimize mobilizations".

We concur. The change was made throughout the document.

Page 28: List showing analytical methods. There should be a category for field screening using less analytical techniques. We have found (and defended successfully in court) that both the PID and FID can play a very important role in site investigations and can supply important data.

Good point. The list isn't intended to be exhaustive and include all possible methods, just provide a general sampling to the reader. No change was made.

Page 29: Section 2.8.4: I have some concerns about this section. While future land use can be important in making remedial decisions, this must be coupled with relevant state regulations. Some states require a site to be cleaned up to residential use no matter what the actual future use of the site will be. This section should be revised to incorporate the concept of regulations in land use decisions.

We concur. The following text was added to that section; "Notwithstanding the foregoing discussion, some states have regulations that require sites to be remediated to residential use levels regardless of the future use. Consideration must be given to state regulations regarding future land use."

Page 30: Section 2.8.7 title: The title currently reads: "**All Projects are not Amenable to the Triad Approach**". Should this read "**Not all Projects are Amenable to the Triad Approach**"?

We concur. The language was changed.

Page 39: Section 5.1 and on: This section lists certain states and their comments. I think that the states should be placed in alphabetical order. While this is not a big issue, it will just appear more logical if, in this list and the following lists, there is a rational for the ordering of the state comments.

We concur. The states were listed in alphabetical order.

Page 44: Section 5.2.1: The comment from Vermont should be revised to state the EPA quality control requirements are only necessary to meet on federal sites (superfund, etc). On state lead sites we have much more flexibility I this issue.

The comment was revised as requested.

Page 51: Section 5.5" The comment for VT should be revised to include "informally applies the Region IX and III PRGs and where appropriate, site specific goals for soils and sediments"

The comment was revised as requested.

Thanks for giving VT the opportunity to comment on this document.

Reviewer; California DTSC

1. The issue of changing the term "Performance-Based Measurement System (PBMS)" to "Performance – Based System (PBS)" has been discussed and finalized in the Method and Data Comparability Board (MDCB) meeting recently held in Albany, NY.

Good information to know. However, at the time of this printing the term that has been used to date is the term that should be used in this document.

2. Conflict with State Law, Policy or Guidance

CA - CA Health and Safety Code Section 25198 indicates "The analysis of any materials shall be performed by a laboratory certified by the state Environmental Laboratory Accreditation Program (CA ELAP) in the Department of Health Services (DHS). This statute appears to be a regulatory barrier for implementing Triad approach. In reality, this statute is a perceived barrier, because in many instances the test method is outside the scope of DHS accreditation and the project manager can make the decision in selecting the appropriate test methods for the project. To avoid this potential problem, changing state law or including the field test methods in the ELAP scope would be an alternative for eliminating this perceived regulatory barrier.

The wording above was substituted for the original wording from California

- Recommendations for Overcoming Barriers

5.7.2 Concerns regarding acceptance of data generated from field analytical methods

Due to budget and time constraints, gathering all the involved parties in making systematic project planning can be a problem. A video conference call would be an alternative solution.

We concur that this is a worthwhile approach, but don't think this wording fits well in this section.

Reviewer; Nebraska DEQ

Technical & Regulatory Guidance for the Triad Approach; A new Paradigm for Environmental Project Management

Review Comments (based on 11/10/03 version)

General Comment: Consider changing the title of the document to include mention of the fact that the Tech & Reg Guidance is on Understanding the Triad Approach.

We concur. The Title was changed to be more indicative of the document's content.

General Comment: The material presented in Sections 2.6, 2.7, 5.2 and other parts of Sections 5.0, and portions of Section 6.0 was straight forward and very informative with enough detail to grasp the Triad concept.

We concur.

Key Issue-Question/Concern from the Sampling, Characterization, and Monitoring (SCM) team: Are there any regulations or policies in your state that would prevent you from using the concepts discussed in the document? Response: Our CERCLA/Superfund program and some voluntary clean-up sub-programs are Federally funded and the sampling protocol for those programs is in accordance with a generic QAPP that is based on Region 7 EPA policy and practice. We don't have our own CERCLA/Superfund laws and we use EPA guidance documents for sampling and analysis and related QA/QC requirements. Thus, we would need regional Region 7 EPA to make changes in their procedures or accept an alternate procedure, before we could implement such changes for site characterization and investigative work for these Federally funded projects.

Good to know. However, since the Triad development has been led and sponsored by the EPA, it is likely that the EPA Regions are willing to be flexible in this regard.

SCM Team Question: Does our approach in describing and presenting the Triad approach help you understand it? Response: Yes, however, the document can be improved by eliminating repetitive discussions about each of the three legs of the Triad and their associated pros and cons. Also suggest limiting the number of comments from states, used as support information in Section 5, to about 3 or 4 comments per issue (choose the most representative ones), instead of listing 7 to 9 comments per item.

The document has been rewritten to eliminate some of the repetitive discussions. The states that provided comments in Section 5 are states that had a representative on the SCM team.

SCM Team Question: Would you be willing to suggest its (the Triad approach) use on particular projects in your state? Response: I believe that the Triad approach has merit on medium to large site assessment, characterization, and remedial investigation/remedial action projects. I believe we have been utilizing many of the key aspects of the Triad's three components. We encourage the use of on-site labs and direct push technology for sampling and other exploratory/pilot studies (hence, real-time measurement aspect), with confirmation spilt samples as appropriate for federally funded projects. Work plans are designed to accommodate selection of samples (type, number and location) during later rounds of a mobilization, based on the results/feed-back from the field lab results of earlier rounds of samples collected during the same event (hence, the dynamic work strategies aspect). Additionally, we determine how extensive the planning requirements are for each project based on the level complexity. We apply experience gained in previous similar planning situations, assemble team members with varying backgrounds/multi-disciplines when deemed necessary, and coordinate with other agencies early on, to the extent that I believe we do apply elements of the "systematic project planning" process at varying degrees. However, I do think that we can benefit from the following:

Access training on the elements of the Triad approach for personnel
at various levels of involvement with site assessment/remediation.
Make changes in our work plans and QA/QC procedure documents (perhaps as part of our internal program development efforts and also in
response to regional EPA shifts in requirements) to include various
elements of the Triad approach, like using the Conceptual Site Model
(and all the dynamics that surround its development) to help guide project decisions.
Seeking greater use (meaning regulatory
acceptance/certification/implementation) of real-time
measurement/field methods when deemed appropriate.

Good to know. The SCM team will develop internet training for the Triad early in 2004, and this will help with the training needs mentioned above.

Section 1.0, suggest combining the last two sentences of text into a single improved sentence reading: "Because there is often resistance to change from established procedures, it is important to involve the stakeholder community from the beginning of any project utilizing the Triad approach."

We concur. The change was made.

Section 1.1, fourth sentence of the first paragraph: The sentence reads "These reasons ranged from the need to build a basis of knowledge in the field ..." Suggest replacing the word "basis" with the word "base"

We concur. The change was made.

Section 2.1, last sentence of the third paragraph of text after Figure 1: The sentence reads "It is critical to use the CSM to avoid sampling errors and to interpret results from lower density fixed laboratory analysis." This sentence is confusing and sounds like the low density terminology is part of the fixed laboratory analysis; please clarify.

We concur. The term "low-density" was clarified.

Section 2.3, first sentence of second paragraph: Spell out/introduce the acronym RCRA since this is the first time it appears in the document. There are other acronyms that need to be spelled out when first introduced, including DNAPL in Section 2.4.3, GIS in Section 2.5, DL in Figure 6 (Section 2.7), TCLP and CLP in Section 5.2.4, PRG in Section 5.5, and N.J.A.C. in Section 6.1 (please note that N.J.A.C. is spelled out later in Sect. 6.3).

We concur. The changes were made.

Section 4.0, Table 3: There is awkward wording used for some of the advantages & disadvantages with using Triad listed in the table, please consider rewording. Also, to avoid confusion, the table listings should be the identical wording used in the sub-titles for Sections 4.1.1 through 4.2.4.

We concur. The listings and/or table contents were changed to be similar.

Beginning within Table 3 and elsewhere in the document, there are terms like up-front, lifecycle, and clean-ups that are sometimes hyphenated and not at other times; recommend being consistent and hyphenate.

We concur. The terms were made uniform throughout.

Section 4.2.3, second sentence of text: The sentence reads "This training should include both general overviews to more specific technical training." Perhaps the word "to" should be changed to "and."

We concur. The change was made.

Section 5.1.2, under specific states comments, the last sentence of the California entry: The sentence reads "... the ethical and legal responsibility to carry out the field activities in according to the QAPP." Suggest changing "in according to" to "in accordance with"

The CA entry was modified such that this is no longer an issue.

Section 7.0, last sentence of the second paragraph: The sentence reads "Furthermore, tribes may have treaties or other pacts with the federal government that grant them fishing, hunting, or access rights in places that are not necessarily near their present-day reservations." This sentence may need some clarification or closure by adding another sentence after it because I can not make the complete connection on just how it supports the previous information in that paragraph.

We concur. An additional sentence was added to clarify the meaning.

Section 7.0, first sentence in the fifth paragraph: The sentence reads “The dynamic work strategy phase of the Triad approach is more directed at field activities.” Suggest deleting the word “more.”

We concur. The change was made.

Section 7.0, last sentence of the sixth paragraph: The sentence reads “Those decisions guide the design of sampling regimens and the selection of analytical tools and methods ...” Correct the spelling of the word regiments.

Either spelling may be used based on the definition of the words. No change was made.

APPENDIX D

ITRC Contacts, Fact Sheet, and Product List

ITRC Sampling, Characterization and Monitoring Team Contact List

Brian Allen
Environmental Specialist
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102
P: (573) 526-3380
F: (573) 526-3350
nralleb@mail.dnr.state.mo.us

Bradley Call P.E.
Senior Environmental Engineer
U.S. Army Corps of Engineers
1325 J Street (Attn: CESPK-ED-EE)
Sacramento, CA 95814
P: (916) 557-6649
F: (916) 557-5307
Bradley.A.Call@usace.army.mil

Rick Carlson
Bus: (775) 831-9468
E-mail: rick@groundtruthenvironment.com

Hugo Martínez Cazón
Environmental Engineer
Vermont Department of Environmental Conservation
103 South Main St., West Building
Waterbury, VT
P: (802) 241-3892
F: (802) 241-3896
hugom@dec.anr.state.vt.us

Ruth Chang, Ph.D.
Senior Hazardous Substances Scientist
California Department of Toxic Substances Control, Hazardous Materials Laboratory
2151 Berkeley Way
Berkeley, CA 94704
P: (510) 540-2651
F: (510) 540-2305
rchang@dtsc.ca.gov

Ahad Chowdhury, Ph.D., P.G.
Registered Geologist
Kentucky Department for Environmental Protection
14 Reilly Road
Frankfort, KY 40601
P: (502) 564-6716 ext. 208
F: (502) 564-2705
ahad.chowdhury@mail.state.ky.us

Chris Clayton
Physical Scientist
U.S. Department of Energy
LM-40/Forrestal Building
1000 Independence Ave., SW
Washington, DC 20585
P: (202) 586-9034
F: (202) 586-1241
christopher.clayton@em.doe.gov

Deana Crumbling
Environmental Scientist
U.S. Environmental Protection Agency
Mail Code 5102G
1200 Pennsylvania Ave., NW
Washington, DC 20460
P: (703) 603-0643
F: (703) 603-9135
crumbling.deana@epa.gov

William Davis
Tri-Corder Environmental, Inc.
1800 Old Meadow Road, Suite 102
McLean, VA 22102
P: (703) 201-6064
F: (703) 448-1010
mmbdavis@bellsouth.net

DeFina, John
New Jersey Department of Environmental Protection
9 Ewing Street
Trenton, NJ 08625

Kimberlee Foster
Environmental Specialist
Missouri Department of Natural Resources
4750 Troost Avenue
Kansas City, MO 64118
P: (816) 759-7313
F: (816) 759-7317
nrfostk@dnr.state.mo.us

Steven B. Gelb
President/Principal Hydrogeologist
S2C2 Inc.
5 Johnson Drive, Suite 12
Raritan, NJ 08869
P: (908) 253-3200 ext. 11
F: (908) 253-9797
sgelb@s2c2inc.com

George J. Hall, P.E.
ITRC Program Advisor
Hall Consulting, P.L.L.C.
4217 W. 91 St.
Tulsa, OK 74132-3739
P: (918) 446-7288
F: (918) 446-9232
TechnologyConsultant@prodigy.net

Richard P. LoCastro, P.G.
Project Manager
Langan Engineering and Environmental Services, Inc.
500 Hyde Park
Doylestown, PN, 18901
P: (215) 348-7110
F: (215) 348-7125
rlocastro@langan.com

Keisha D. Long
Environmental Engineer Associate
South Carolina Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
P: (803) 896-4073
F: (803) 896-4292
longkd@dhec.sc.gov

Mack, Jim
P: (973) 596-5887
mack@adm.njit.edu

Denise MacMillan
Environmental Laboratory, Engineering Research and Development Center
420 S. 18th Street
Omaha, NE 68102
P: (402) 444-4304
F: (402) 341-5448
Denise.K.Macmillan@nwo02.usace.army.mil

Bill Major
Naval Facilities Engineering Service Center
1100 23rd Ave.
Port Hueneme, CA 93043-4370
P: (805) 982-1808
F: (805) 982-4304
majorwr@nfesc.navy.mil

Stuart Nagourney
Research Scientist
New Jersey Department of Environmental Protection
9 Ewing Street
Trenton, NJ 08625
P: (609) 292-4945
F: (609) 777-1774
stu.nagourney@dep.state.nj.us

Mary Jo Ondrechen
Professor
Northeastern University
Department of Chemistry
360 Huntington Avenue
Boston, MA 02115
P: (617) 373-2856
F: (617) 373-8795
mjo@neu.edu

Katherine Owens
Community Stakeholder
1278 Riviera Drive
Idaho Falls, ID 83404
P: (208) 522-0513
F: (208) 522-3151
paragon@ida.net

John G. Pohl
Restoration Program Manager
305th Environmental Flight
2403 Vandenberg Ave.
McGuire Air Force Base, NJ 08642
P: (609) 754-3495
F: (609) 754-2096
John.pohl@mcguire.af.mil

Roelant, David
Florida International University
10555 W. Flagler Street, Suite 2100
Miami, FL 33174
Bus: (305) 348-6625
Bus Fax: (305) 348-1852
roelant@heet.fiu.edu

Qazi Salahuddin Ph.D.
Environmental Scientist
Delaware Department of Natural Resources and Environmental Control
391 Lukens Drive
New Castle, DE 19720-2774
P: (302) 395-2640
F: (302) 395-2641
qazi.salahuddin@state.de.us

Peter Shebell
Environmental Measurements Laboratory
201 Varick St. 5th Floor
New York, NY 10014-4811
P: (212) 620-3568
F: (212) 620-3600
pshebell@eml.doe.gov

G.A. (Jim) Shirazi, Ph.D., P.G., PSSc Hydrologist/Soil Scientist
Oklahoma Department of Agriculture
Oklahoma City, OK 73105
P: (405) 522-6144
F: (405) 522-0909
gashirazi@aol.com

Shawn Wenzel
Hydrogeologist
Wisconsin Department of Commerce, Bureau of PECFA
201 W. Washington Ave.
Madison, WI 53708-8044
P: (608) 261-5401
F: (608) 267-1381
swenzel@commerce.state.wi.us