# IMPROVING THE COST-EFFECTIVENESS OF HAZARDOUS WASTE SITE CHARACTERIZATION AND MONITORING

by Deana M. Crumbling, M.S.
USEPA Technology Innovation Office
Mail Code 5102G, 401 M Street, SW, Washington, DC 20460

## Executive Summary

U.S. EPA's Office of Solid Waste and Emergency Response is promoting more effective strategies for characterizing and monitoring hazardous waste sites. In particular, the wide-spread adoption of a new paradigm which uses an integrated triad of systematic planning, dynamic work plans, and on-site analysis for data collection and technical decision-making at hazardous waste sites is recommended.

## The Need for Change

EPA's Office of Solid Waste and Emergency Response (OSWER) manages the Superfund, RCRA Corrective Action, Federal Facilities, Underground Storage Tank, and Brownfields programs, all dealing with issues related to the management of wastes, hazardous materials, and site contamination. Within OSWER, the Technology Innovation Office (TIO) is charged with advocating for more effective, less costly approaches by government and industry to assess and clean up contaminated waste sites through federal, state, and local programs. TIO disseminates technical and market information in an effort to remove policy and institutional impediments to adopting "smarter solutions" for investigating and remediating contaminated sites.

"Smarter solutions" may take two major forms. One is through the adoption of new tools; the other is to revolutionize the strategy by which tools are deployed. Both are connected in a feedback loop, since strategy shifts are both fueled by and fuel the evolution of innovative technology. In the area of hazardous waste site monitoring and measurement, new technologies are already available with documented performance showing them capable of substantially improving the cost-effectiveness of site characterization. Yet hazardous waste practice clings tenaciously to the familiar habits developed during its infancy.

The current traditional phased engineering approach to site investigation (mobilize staff and equipment to a site, take samples to send off to a lab, wait for results to come back and be interpreted, then re-mobilize to collect additional samples, and repeat one or more times) can be incrementally improved by the occasional use of on-site analysis to screen samples so that expensive off-site analysis is reserved for more critical samples. Yet, for a wide variety of reasons covered in depth elsewhere [1], even such limited acceptance of new analytical tools within the existing engineering paradigm is slow. A conservative regulatory and engineering atmosphere strongly influences hazardous waste site management to the point where even clearly demonstrated success is often powerless before the diffuse institutional, legal, and inertial forces that buttress the status quo. Vendors and developers sometimes go bankrupt waiting for innovative ideas to percolate through the site remediation community where it seems no one wants to be the first to try something new.

A fundamental change in thinking is needed. Faster acceptance of cost-effective new characterization tools among practitioners is even more important now that Brownfields and Voluntary Cleanup Programs are gaining importance with Congress, localities, and the public. For programs that focus on site redevelopment and reuse, factors such as time, cost, and quality are of prime concern. Although litigation is not usually a driver in these programs, it could become so if the public had reason to believe that its safety might be compromised through non-transparent or faulty decision-making at these sites.

A paradigm shift would allow realization of the benefits accrued from public and private investments in research and development. When new knowledge and technologies borne from these investment dollars "wilt on the vine" because they cannot find entree into daily practice, we waste the invested dollars, we sacrifice the cost savings and re-development opportunities possible through their application, and we forfeit the incremental progress inherent in the "stepping-stone" effect basic to technological progress. A paradigm shift could also aid hazardous waste site professionals to resist stagnation and advance to more productive models for characterizing and cleaning up sites.

The idealized model for an innovation-friendly system that produces defensible site decisions at an affordable cost would have the following characteristics:

- it would be driven by achieving performance, rather than by complying with arbitrary policies or procedural checklists that do not add value;
- it would use transparent, logical reasoning to articulate project goals, state assumptions, plan site activities, derive conclusions, and make defensible decisions;
- it would value technical and scientific proficiency, understanding the need for technical experts in the scientific, mathematical, and engineering disciplines required to competently manage the complex issues of hazardous waste sites;
- it would require regular continuing education of its practitioners, especially in rapidly evolving areas of practice;
- its practitioners would be able to logically evaluate the appropriateness of an innovative technology with respect to project-specific conditions and prior technology performance, with residual areas of uncertainty being identified and addressed;
- it would reward responsible risk-taking by practitioners who would not fear to ask, "why don't we look into...?" or "what if we tried...?"

What form might such an optimized paradigm take? TIO advocates a paradigm shift that would involve institutionalizing **the triad of systematic planning, dynamic work plans, and on-site analysis** as the foundation upon which cost-effective, defensible site decisions and actions are built. None of the concepts in the triad are new, but the boost given by computerization to technology advancement in recent years provides options that did not exist before. Pockets of forward-thinking practitioners are already successfully using this triad; the concept is proven. What remains is for engineering practice and regulatory policy to catch up.

**The Triad's First Component: Systematic Planning**

Most organizational mission statements pledge a commitment to quality. The U.S. EPA is no different. EPA Order 5360.1 CHG 1 requires that work performed by, or on behalf of, EPA be governed by a mandatory quality system to ensure the technical validity of products or services [2]. A fundamental aspect of the mandatory quality system is thoughtful, advance planning. The *EPA Quality Manual for Environmental Programs* explains that "environmental data operations shall be planned using a systematic planning process that is based on the scientific method. The planning process shall be based on a common sense, graded approach to ensure that the level of detail in planning is commensurate with the importance and intended use of the work and the available resources" [3].

Systematic planning is the scaffold around which defensible site decisions are constructed. The essence of systematic planning is asking the right questions and strategizing how best to answer them. It requires that for every planned action the responsible individual can clearly answer the question, "Why am I doing this?" First and foremost, planning requires that key decision-makers collaborate with stakeholders to resolve clear goals for a project. A team of *multi-disciplinary, experienced technical staff* then works to translate those goals into realistic technical objectives. The need for appropriately educated, knowledgeable practitioners from *all* disciplines relevant to the site's needs is vital to cost-effective project success. When the value offered by non-engineering technical experts is ignored under the traditional phased engineering approach, the outcome is often avoidable mistakes that are costly as well as embarrassing.

Using all available information, the technical team develops a conceptual site model (CSM) that crystallizes what is already known about the site and identifies what more must be known in order to achieve the project's goals. The team then uses the CSM to direct field work that gathers the necessary information. Data not needed to inform specific site decisions will not be collected. (Although this sounds elementary, the one-size-fits-all approach used by many practitioners routinely collects costly data which are ultimately irrelevant to the project's outcome.) The CSM will evolve as site work progresses and data gaps are filled. The CSM thus serves several purposes: as a planning instrument, as a modeling and data interpretation tool, and as a communication device among the team, the decision-makers, the stakeholders, and the field personnel.

During the planning phase, the most resource-effective characterization tools for collecting data are identified by technically qualified staff who are familiar with both the established and innovative technology tools of their discipline. The hydrogeologist will be conversant not only with the performance and cost issues of well drilling techniques, but also with the more innovative and (generally) less costly direct push technologies entering common use. The team's analytical chemist will not only know the relative merits of various traditional sample collection, preservation, preparation, and analysis methods, but also the strengths and weaknesses of innovative techniques, including on-site analytical options. The chemist's responsibilities include designing the quality control (QC) protocols that reconcile project-specific data needs with the abilities of the selected analytical tools.

Systematic planning provides the structure through which foresight and multi-disciplinary technical expertise improves the scientific quality of the work and avoids the blunders that sacrifice time, money, and the public trust. It guides careful, precise communication among participants and compels them to move beyond the ambiguities of vague, error-prone generalizations. Systematic planning requires unspoken assumptions to be openly acknowledged and tested in the context of site-specific constraints and goals. Its use should be a *sine qua non* for all projects requiring the generation or use of environmental data, even those performed under the current phased engineering approach [4].

**The Second Component of the Triad: Dynamic Work Plans**

When systematic planning is combined with practitioner experience, with scientific understanding about the fate of pollutants in the environment, and with advanced technology, an extremely powerful strategy emerges for the effective execution of field activities. Terms associated with this strategy include expedited, accelerated, rapid, or streamlined site characterization. Its cornerstone is the use of dynamic work plans. Formulated as a decision tree during the planning phase, the dynamic work plan adapts site activities to track the maturing conceptual site model, usually on a daily basis. Dynamic work plans have been championed and successfully demonstrated for over 10 years by various parties [5, 6]. Success hinges on the presence of senior staff in the field to "call the shots" based on the decision logic developed during the planning stage and to cope with any unanticipated issues. For small uncomplicated sites, or for discrete tasks within complex sites, project management can be streamlined so smoothly that characterization activities blend seamlessly into cleanup activities.

Just as the design of a dynamic work plan requires the first component of the triad (systematic planning) to choreograph activities and build contingencies, implementation of a dynamic work plan generally requires the third member of the triad (on-site generation and interpretation of site data) so that data results are available fast enough to support the rapidly evolving on-site decision-making inherent to dynamic work plans.

**The Third Component: On-Site Analysis**

On-site analysis can be performed within the standard phased engineering approach; however, it does not achieve its full potential for cost- and time-savings except in the context of dynamic work plans. Like dynamic work plans, sampling and analysis designs require thoughtful technical input from systematic planning to ensure that the most appropriate sampling and measurement tools are selected and suitably operated.

Data collection is not an end in itself: its purpose is to supply information. There has been a counter-productive tendency to fixate solely upon the quality of data **points**, without asking whether the **information quality and representativeness** of the data set was either sufficient or matched to the planned uses of the data. On-site analysis can never eliminate the need for traditional laboratory services; but the judicious blending of intelligent sampling design, dynamic work plans, and on-site analysis, supplemented by traditional laboratory testing as necessary, can assemble information-rich data sets much more effectively than total reliance on fixed lab analyses. When the gathering of reliable information to guide defensible site decisions is a clear priority, field analytical technologies offer a much more valuable contribution than is implied when the concept is downplayed as “field screening.” The cost advantages of on-site analysis extend well beyond possible “per sample” savings, since the use of the integrated triad approach maximizes the chances that the project will be done right the first time over the shortest possible time frame.

Informative data sets that accurately represent true site conditions across the project’s lifetime (from assessment to characterization through remediation and close-out) never happen by accident. No matter whether the on-site generated data are expected to be used for “screening” purposes or for “definitive” purposes, good analytical chemistry practice must be followed and QC protocols must be designed carefully. Analytical chemists are the trained professionals best able to construct valid QC protocols that will integrate 1) the site-specific data needs and uses, 2) any site-specific matrix issues, and 3) the strengths and weaknesses of a particular analytical technology. Ignoring these considerations risks a chain of errors that waste effort and money: faulty data sets lead to erroneous conclusions, that, in turn, lead to flawed site decisions and/or ineffectual remedial actions. Good decisions rely on good data sets. Therefore, when the decision is made to take an analytical method to the field, the expertise of an analytical chemist must go along, whether in absentia as a written site-specific Standard Operating Procedure (SOP) that a technician will follow, or in person as an instrument operator or supervising field chemist.

Field analytical chemistry has made significant advances in scientific rigor and credibility. Computerization, miniaturization, photonics (e.g., lasers and fiber optics), materials research, immunochemistry, microwave technologies and a host of other chemical, biological, and physical science disciplines are contributing to a multiplicity of technology improvements and innovations for analytical chemistry in general, and for the specialized practice of on-site analytical chemistry in particular. When compared to the convenience and control offered by fixed laboratory analysis, field analysis offers unique challenges to its practitioners, leading to the blossoming of a recognized subdiscipline. Field analysis now has its own dedicated international conferences, a peer-reviewed journal (*Field Analytical Chemistry and Technology,* published by Wiley InterScience), and university-based research centers. There is a small but growing number of companies offering specialized on-site analytical services and consulting expertise to the environmental community, and their professional standards and practices will be addressed by the newly formalized Field Activities Committee within the National Environmental Laboratory Accreditation Counsel (NELAC).

Environmental chemists are not alone in recognizing the potential of field analysis. Even the pharmaceutical industry is taking their analytical methods to the field to screen for new drugs in marine and terrestrial ecosystems. “Who would have thought we could do this much *in situ* now? When we first started, people said we were crazy,” marveled a University of Illinois chemistry professor. While acknowledging that on-site analysis may seem the stuff of science fiction, he predicted that the pace of technological advances will make it commonplace for the pharmaceutical industry within five years [7]. Will the same be true for the environmental remediation industry?

On-site interpretation of data is greatly facilitated by decisions support software tools using classical statistical analysis and geostatistical mapping algorithms. Laptop PCs may be used to manage data and produce 2- or 3-dimensional images representing contaminant distributions, including an assessment of the statistical reliability of the projections. Cost-benefit and risk-management analyses produced within minutes can allow decision-makers to weigh options at branch points of the dynamic work plan, or to select optimum sampling locations that can give the "most bang for the characterization buck" by minimizing decision uncertainty. The graphical output of the software greatly facilitates meaningful communication of site issues and decisions with regulators and the public. As with all tools, users need to understand possible pitfalls and consult with experts as necessary to avoid misapplications that could lead to faulty outputs.

**The Triad as a Successful Paradigm**

The integrated triad of systematic planning, dynamic work plans, and on-site analysis has been demonstrated to complete projects faster, cheaper, and with greater regulatory and client satisfaction than the traditional phased engineering approach. One Department of Energy (DOE) version of the triad is called Expedited Site Characterization (ESC), which focuses heavily on characterizing the hydrogeological nature of the subsurface [8]. DOE has linked dynamic work plans with systematic planning to speed up Superfund site investigations and feasibility studies at DOE sites in an approach called SAFER (Streamlined Approach for Environmental Restoration). Showing the acceptance of this paradigm among remediation experts, ASTM has issued three guides describing various applications of expedited or accelerated approaches [9, 10, 11].

The U.S. Army Corps of Engineers has begun institutionalizing this integrated approach under the name "Technical Project Planning (TPP) Process." To date, 12 of the Corps' 15 Hazardous, Toxic, and Radioactive Waste (HTRW) design districts have completed initial training. The TPP manual, EM 200-1-2, is available to the public over the Internet, and it stresses the importance of a multi-disciplinary team that performs the "comprehensive and systematic planning that will accelerate progress to site closeout within all project constraints" [12]. A review of 11 initial projects performed under the TPP approach demonstrated the following successes:

- Met all schedules (and "train-wreck" and "break-neck" milestones);
- Improved project focus and communications;
- Improved defensibility and implementability of technical plans;
- Eliminated "excessive" data needs and identified "basic" data needs;
- Increased satisfaction of USACE's Customers;
- Improved relations and communication with regulators; and
- Documented cost savings of at least $4,430,000 (total for all 11 projects) [13].

A few state programs are beginning to use field-based site characterization in limited applications. For example, the Florida Department of Environmental Protection created the Drycleaning Solvent Cleanup Program (DSCP) to address contamination related to small dry cleaner shops. Under the DSCP, rapid site assessments are performed using on-site mobile laboratories and direct push technologies to characterize soil and ground water contamination, assess cleanup options, and install permanent monitoring wells, all in an average of 10 days per site. Site assessment costs have been lowered by an estimated 30 to 50 percent when compared to conventional assessments. [14].

Whether the focus of a site investigation is ground water, surface water, sediment, soil, or waste characterization, or a combination thereof, the triad approach has been shown to achieve site closeout faster and cheaper than traditional phased approaches. The question becomes: Why has this approach not yet caught on as the established paradigm for site investigation and cleanup?

Past reasons no doubt included the limited selection of rapid turnaround field analytical and software tools so vital for implementing dynamic work plans efficiently. As described earlier however, recent years have seen a growing array of analytical options able to meet many types of data quality needs. Technology advancement would be even more brisk if a paradigm of logical evaluation, acceptance, and use by practitioners and regulators were the norm. Benefitting from the tools we currently have and boosting our available options require that we modernize habits that were established during the infancy of the environmental remediation industry. Since those habits are thoroughly ingrained in most practitioners, regulators, and members of the legal community, it will take a concerted effort on many fronts to introduce new attitudes and practices.

**The Time Is Right!**

EPA's OSWER is launching that concerted effort through existing and new EPA guidance documents, training courses, outreach mechanisms, and technology demonstration programs. These activities are integral to regulatory reinvention efforts that focus on achieving quantifiable results. For example, the Government Performance and Results Act of 1993 (GPRA) encourages management for results with a focus on outcomes rather than process-oriented outputs [15]. Furthermore, EPA's Strategic Plan for the Agency commits EPA to "better waste management [and] restoration of contaminated waste sites" (Item No. 5), and to the application of "sound science, improved understanding of environmental risk, and greater innovation to address environmental problems" (Item No. 8) [16]. Key regulatory support for these efforts is provided by EPA's recent adoption of a formal agency-wide Performance-Based Measurement System (PBMS) approach.

More than an EPA commitment is needed, however, to reinvent site characterization practice. The collaboration of all players in the hazardous waste arena will be required to effect the adoption of the triad approach as the standard paradigm for managing environmental data. For example, academic institutions will need to teach these concepts to their students, and support local regulators, practitioners, and communities with the scientific, mathematical, and engineering technical expertise they may need to produce and interpret scientifically valid data sets. Upper management in both the regulatory and private sectors will have to support their staff with efforts to purge outdated institutional patterns that reinforce antiquated habits. Practitioners must be open to new tools and to updating their professional habits and skills. Legal and contracting departments must be willing to adapt their procedures to prudently accommodate the flexibility crucial to results-based decision-making. Intransigence by any group will make progress by the others very difficult. All must show greater appreciation for the range of technical and creative skills needed to cooperatively formulate the right questions and then resourcefully find the best answers. All must be willing to own their role in implementing their organization's written commitments to quality environmental results.

The National Academy of Public Administration concluded in a 1995 report to Congress [17]: "To continue to make environmental progress, the [United States] will have to develop a more rational, less costly strategy for protecting the environment, one that achieves its goals more efficiently, using more creativity and less bureaucracy." The concerted use of an integrated triad of systematic planning, dynamic work plans, and on-site analysis would greatly assist achievement of this aspiration when managing hazardous waste sites. This is a goal that the hazardous waste community should seriously begin to work toward.

**References**

[1] National Research Council. 1997. Committee on Innovative Remediation Technologies. *Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization*, National Academy Press, Washington, DC, pp. 40-75. *http://www.nap.edu*

[2] U.S. EPA. 1998. EPA Order 5360.1 CHG 1: *Policy and Program Requirements to Implement the Mandatory Quality Assurance Progra*m, U.S. Environmental Protection Agency, Washington, DC, July 1998. *http://es.epa.gov/ncerqa/qa/qa_docs.html*

[3] U.S. EPA. 1998. EPA Order 5360*: EPA Quality Manual for Environmental Program*s, U.S. Environmental Protection Agency, Washington, DC, July 1998. *http://es.epa.gov/ncerqa/qa/qa_docs.html*

[4] U.S. EPA. 1998. EPA Office of Inspector General Audit Report: *EPA Had Not Effectively Implemented Its Superfund Quality Assurance Program*, Report No. E1SKF7-08-0011-8100240, September 30, 1998 *http://www.epa.gov:80/oigearth/audit/list998/8100240.pdf*

[5] Burton, J.C. 1993. *Expedited Site Characterization: A Rapid, Cost-Effective Process for Preremedial Site Characterization*, Superfund XIV, Vol. II, Hazardous Materials Research and Control Institute, Greenbelt, MD, pp. 809-826.

[6] Robbat, A. 1997. *A Guideline for Dynamic Workplans and Field Analytics: The Keys to Cost-Effective Site Characterization and Cleanup*, sponsored by President Clinton's Environmental Technology Initiative, through the U.S. Environmental Protection Agency, Washington, DC. *http://clu-in.org/download/char/dynwkpln.pdf*

[7] Drollette, D. 1999. Adventures in drug discovery. In *Photonics Spectra*, September 1999, pp. 86 - 95.

[8] DOE. 1998. *Expedited Site Characterization.* Innovative Technology Summary Report, OST Reference #77. Office of Environmental Management, U.S. Department of Energy, December 1998. *http://ost.em.doe.gov/ifd/ost/pubs/cmstitsr.htm*
see also *http://www.etd.ameslab.gov/etd/technologies/projects/esc/index.html*

[9] ASTM. 1998. *Standard Practice for Expedited Site Characterization of Vadose Zone and Ground Water Contamination at Hazardous Waste Contaminated Sites*, D6235-98. Conshohocken, PA. *www.astm.org*

[10] ASTM. 1998b. *Standard Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases,* E1912-98. Conshohocken, PA. *www.astm.org*

[11] ASTM. 1996. *Standard Provisional Guide for Expedited Site Characterization of Hazardous Waste Contaminated Sites*, PS85-96. Conshohocken, PA. *www.astm.org*

[12] USACE. 1998. *Environmental Quality: Technical Project Planning (TPP) Process* (Engineering Manual 200-1-2), Washington, DC. August 1998. *http://www.usace.army.mil/inet/usace-docs/eng-manuals/em200-1-2/toc.htm*

[13] USACE. 1999. Personal communication with Heidi Novotny, PE., Technical Liaison Manager, U.S. Army Corps of Engineers HTRW Center of Expertise, July 22, 1999.

[14] Applegate, J.L. and D.M. Fitton. 1998. *Rapid Site Assessment Applied to the Florida Department of Environmental Protection's Drycleaning Solvent Cleanup Program*, in Proceedings Volume for the First International Symposium on Integrated Technical Approaches to Site Characterization, Argonne National Laboratory. pp. 77-92. *http://www.anl.gov:80/ITASC/index.html*

[15] U.S. EPA. 1999. EPA's Office of the Chief Financial Officer Webpage: *http://www.epa.gov/ocfopage/planning/gpra.htm*. See also *http://www.epa.gov/reinvention/*

[16] U.S. EPA. 1999. *An Overview of EPA's Strategic Plan*. Washington, DC. EPA 190-F-99-001. See also *http://www.epa.gov/ocfopage/planning/strate.htm*

[17] National Academy of Public Administration. 1995. *Setting Priorities, Getting Results.* Washington, DC: NAPA.