EPA United States Environmental Protection Agency

A Resource for MGP Site Characterization and Remediation

Expedited Site Characterization and Source Remediation at Former Manufactured Gas Plant Sites

Office of Solid Waste and
Emergency Response (5102G)
EPA 542-R-99-005
www.epa.gov/tio
clu-in.org
May 1999

A Resource for MGP Site Characterization and Remediation

Expedited Site Characterization and Source Remediation at Former Manufactured Gas Plant Sites

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

Notice

This report was prepared by Environmental Management Support, Inc., 8601 Georgia Avenue, Suite 500, Silver Spring, MD 20910 under contract 68-W6-0014, work assignment 87, with the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Abstract

The United States Environmental Protection Agency (USEPA), in conjunction with states, industry trade associations (the Edison Electric Institute [EEI], the Utility Solid Waste Activities Group [USWAG], and American Gas Association [AGA]), and individual utilities, has compiled a summary of innovative strategies and technical approaches for expediting site characterization and source material remediation at former manufactured gas plant (MGP) sites. Former MGP sites, as a category of inactive industrial waste disposal sites, contain many similarities in historical industrial activities and the types and distribution of MGP wastes and related contaminants. This trend, coupled with the fact that today's utilities are often the primary owners of (or accept remedial responsibility for) these sites, allows both the regulatory agencies and the utilities to develop approaches to achieving economies of scale and effort in addressing contamination at former MGP sites. Unlike remediation sites of other industries, MGP sites are typically not found at locations where utilities operate today, are often located in the midst of residential communities that have developed around these abandoned industrial locations, and are owned by entities unrelated to the modern utility.

This document was prepared by the USEPA to provide current information on useful approaches and tools being applied at former MGP sites to the regulators and utilities characterizing and remediating these sites. The document outlines site management strategies and field tools for expediting site characterization at MGP sites; presents a summary of existing technologies for remediating MGP wastes in soils; provides sufficient information on the benefits, limitations, and costs of each technology, tool, or strategy for comparison and evaluation; and provides, by way of case studies, examples of the ways these tools and strategies can be implemented at MGP sites.

Innovative strategies for managing former MGP sites, as discussed in Chapter 3 of this document, include multi-site agreements, dynamic work planning, teaming approaches to expedite remedial action planning and execution, and methods for dealing with uncertainty at these sites. Technical innovations for site characterization (Chapter 4) include the availability of direct push and other field screening technologies to complement traditional analytical approaches. Finally, a variety of approaches and technologies have been employed to provide cost-effective solutions to treating the wastes remaining at former MGP sites (Chapter 5).

The information presented in this document is applicable to the characterization and remediation of former MGP sites conducted under traditional remediation programs as well as the large number of MGP sites which are likely to be addressed under voluntary cleanup programs.

Contents

Foreword i

Abstract ii

Contents iii

List of Acronyms and Abbreviations v

1 Introduction 1-1

1.1 Background 1-1

1.2 Purpose and Scope of Document 1-2

2 Creating an Expedited Site Characterization and Remediation Program 2-1

2.1 Introduction 2-1

2.2 Expedited Site Characterization and Remediation 2-1

2.3 Creating the Expedited Site Characterization and Remediation Program 2-5

2.4 Management Tools for Expediting Characterization and Remediation 2-7

2.5 Tools for Site Characterization 2-8

2.6 Technologies for Cleaning up MGP Wastes 2-8

2.7 Conclusion 2-9

3 Management for Expediting Site Characterization and Remediation . . . 3-1

3.1 Introduction 3-1

3.2 Management Tools for Expediting Site Characterization and Remediation 3-4

3.2.1 Site Bundling 3-4

3.2.2 Multi-Site Agreements 3-8

3.2.3 Generic Work Plans and Reports 3-13

3.2.4 Program / High Performance / Design Plan 3-15

3.2.5 Early Land Use Determination / Brownfields 3-20

3.2.6 Managing Uncertainty (Observational Approach) 3-24

3.2.7 Expedited Site Characterization 3-30

3.2.8 Legislative Innovation 3-36

3.2.9 Dovetailing Business Decisionmaking and Remediation Planning 3-40

3.2.10 Establishing Background PAH Concentrations 3-43

3.2.11 Generic Administrative Orders 3-49

4 Tools and Techniques for Expediting Site Characterization 4-1
4.1 Introduction 4-1
4.2 Tools and Techniques for Expediting Site Characterization 4-10
4.2.1 Direct-Push Methods / Limited Access Drilling 4-10
4.2.2 Analytical Field Screening 4-26
4.2.3 Geophysical Surveys 4-36
4.2.4 Soil Gas Surveys 4-52
4.2.5 Contaminant Migration Evaluation 4-56
4.2.6 Other Tools 4-61

5 Technologies for Source Material Treatment 5-1
5.1 Introduction 5-1
5.2 Technologies for Source Material Treatment 5-1
5.2.1 Co-Burning 5-5
5.2.2 Thermal Treatment Processes 5-8
5.2.3 Asphalt Batching 5-24
5.2.4 Bioremediation / Chemically Enhanced Bioremediation 5-32
5.2.5 Containment 5-45
5.2.6 Stabilization / Solidification 5-49
5.2.7 Soil Washing 5-55
5.2.8 Soil Vapor Extraction 5-61

6 References 6-1

7 Additional Sources of Information 7-1

List of Acronyms and Abbreviations

AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
ASTM	American Society of Testing and Materials
atm	atmospheres
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
Btu	British thermal unit
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CERCLIS	Comprehensive Environmental Response Compensation, and Liability Act Information Systems
cis-1,2-DCE	cis-1,2-dichloroethylene
CO	carbon monoxide
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CPT	cone penetrometer
CROW™	Contained Recovery of Oily Wastes
CWM	Chico / Willows / Marysville
DCE	dichloroethylene
DCI	Dust Coating, Inc.
DEC	Department of Environmental Conservation
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality
DMLS™	diffusion multi-layer sampler
DNAPL	dense non-aqueous phase liquid
DNR	Department of Natural Resources
DQO	data quality objective
DRE	destruction removal efficiency
DTSC	Department of Toxic Substance Control
DUS	dynamic underground stripping
EEI	Edison Electric Institute
ELISA	enzyme-linked immunosorbent assay
EMS	electromagnetic survey
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERAP	Expedited Remedial Action Program
ESC	expedited site characterization

FS	feasibility study
ft/min	feet per minute
GC	gas chromatography
GCL	geosynthetic clay liner
GIS	geographic information system
gpm	gallons per minute
GPR	ground-penetrating radar
GRI	Gas Research Institute
ha	hectare
HASP	health and safety plan
HCl	hydrogen chloride
HDPE	high-density polyethylene
HPO	hydrous pyrolysis oxidation
HPT	high-performance team
IDW	investigation-derived waste
IGT	Institute of Gas Technology
ISM	in situ bio-geochemical monitor
ISTD	in situ thermal desorption
ISU	Iowa State University
kg	kilogram
LIF	laser-induced fluorescence
LNAPL	light nonaqueous phase liquids
LTTD	low-temperature thermal desorption
LTU	land treatment unit
MART	Mid Atlantic Recycling Technologies, Inc.
MCL	Maximum Contaminant Level
MEC	MidAmerican Energy Corporation
MEW	Missouri Electric Works
µg/L	micrograms per liter
µm	micrometer
mg	milligram
mg/kg	milligrams per kilogram
MGP	manufactured gas plant
mm	millimeter
MSE	microscale solvent extraction
NAPL	nonaqueous phase liquid
NCP	National Contingency Plan
NJDEP	New Jersey Department of the Environment
NMPC	Niagra Mohawk Power Corporation
NO_x	nitrogen oxide
NPL	National Priorities List

NTU	nephelometric turbidity unit
NYSDEC	New York State Department of Environmental Conservation
OUR	oxygen uptake rate
PAH	polycyclic aromatic hydrocarbon
PA	preliminary assessment
PCB	polychlorinated biphenyl
PCE	perchloroethylene
PCP	pentachlorophenol
PEA	preliminary endangerment assessment
PGE	Portland General Electric
PG&E	Pacific Gas and Electric Company
PITT	Partitioning Interwell Tracer Test
PNA	polynuclear aromatic hydrocarbon
ppb	parts per billion
PP&L	Pennsylvania Power & Light Company
ppm	parts per million
PQL	practical quantitation limit
PSE&G	Public Service Electric and Gas Company
psi	pounds per square inch
PVC	polyvinyl chloride
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
RA	remedial action
RAGS	Risk Assessment Guidance for Superfund
RAP	remedial action plan
RCRA	Resource Conservation and Recovery Act of 1976
RD	remedial design
RG&E	Rochester Gas and Electric
RI	remedial investigation
ROD	Record of Decision
ROST™	Rapid Optical Screening Tool
RP	responsible party
SCAPS	site characterization analysis penetrometer system
SI	site investigation
SITE	Superfund Innovative Technology Evaluation
SoCal Gas	Southern California Gas Company
SO_2	Sulfur dioxide
SPLP	synthetic precipitation leaching procedure
SRP	site remediation program
S/S	solidification and stabilization

SVE	soil vapor extraction
SVOC	semivolatile organic compound
TCE	trichloroethylene
TCLP	toxicity characteristic leaching procedure
TEPH	total extractable petroleum hydrocarbons
3-D/3-C	three-dimensional, three-component
TPH	total petroleum hydrocarbons
TSCA	Toxic Substance Control Act
2D	two-dimensional
UCS	ultimate compressive strength
USEPA	United States Environmental Protection Agency
USWAG	Utility Solid Waste Activities Group
VOC	volatile organic compound
WEPCO	Wisconsin Energy Power Company
WRI	Western Research Institute
XRF	X-ray fluorescence

Chapter 1

Introduction

1.1 Background

From the early 1800s through the mid-1900s, manufactured gas plants (MGPs) were operated nationwide to provide gas from coal or oil for lighting, heating, and cooking. The gas manufacturing and purification processes at these plants yielded by-products or gas plant residues that included tars, sludges, lampblack, light oils, spent oxide wastes, and other hydrocarbon products. Although many of these by-products were recycled, excess residues remained at MGP sites. These residues contain polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, benzene, cyanide, metals, and phenols.

Almost every city in the United States had an MGP; an estimated 3,000 to 5,000 former MGP sites exist across the country, some of which are still owned by the successors to the utilities that founded them. MGPs were typically built on the outskirts of cities that have since grown. As a result, the sites are now often located in inner city areas that are being redeveloped.

MGPs were constructed nationwide with similar facilities and generated similar wastes using defined manufacturing processes. In general, MGPs produced gas by cracking the hydrocarbon chains of feedstocks, primarily oil and coal, and releasing lighter carbon products. These lighter products were given off in the form of gas that was used for household needs. MGP residues were solid or liquid and included creosote, tars, spent oxide residues, and lampblack. The feedstocks and manufacturing processes used at a site, the size of the manufacturing operations, and a site's physical constraints (e.g., proximity to wetlands or vacant lots) were some of the factors that governed the manufacturing and disposal practices at each site.

Although many former MGP sites have been or are currently being investigated and/or remediated, a large number remain unaddressed. In some cases, the same party may be responsible for numerous former MGP sites in a region. The similarities in the configuration and contaminants at these sites provide opportunities to apply innovative approaches that benefit from economies of scale. Former MGP sites offer an ideal opportunity to apply tools and technologies that expedite site characterization and source remediation.

Residues often occur in the same locations at former MGP sites, e.g., near the former gas holders, tar sumps, and lampblack separators. These wastes contain a number of known or suspected carcinogens and other potentially hazardous chemicals. Because of the nature of these residues, there is a limited subset of technologies that are likely to be effective in treating them.

For additional background and historical information on the operations of former manufactured gas plants, the reader is referred to the Additional Sources of Information listed in Chapter 7 of this document.

1.2 Purpose and Scope of Document

There is a general awareness, both in the public and private sectors, of the need for faster, better, and cheaper methods for site characterization and remediation. MGP sites as a class provide opportunities to try new methods of site characterization and waste treatment, and to relate the resulting experiences to other MGP sites. Utilities and other regulatory agencies are recognizing the advantages of such programs, and are currently putting these experiences to use.

Three aspects of former MGP site characterization and remediation are addressed in this document:

- Management tools for expediting site characterization and remediation (Chapter 3)
- Tools and techniques for expediting site characterization (Chapter 4)
- Technologies for treatment of MGP-related wastes in soil (Chapter 5)

Chapter 3, Management Tools for Expediting Site Characterization, describes innovative strategies and gives examples of their use at former MGP sites. Because many of the examples come from ongoing projects, references are provided so readers can contact representatives for follow-up information.

Chapter 4, Tools and Techniques for Expediting Site Characterization, presents information on "tried and true" as well as innovative tools that can be used to expedite characterization of former MGP sites. The following categories of information are presented for each tool or technique:

- Tool or Technique Description
- Operational Considerations
- Applications and Cost
- Benefits and Limitations
- Case Studies
- Contacts

Chapter 5, Technologies for Source Treatment, focuses on the technologies currently available for MGP source (soil and/or MGP residue) treatment. The following information is presented for each technology:

- Tool or Technique Description
- Operation Considerations
- Applications and Cost
- Benefits and Limitations
- Case Studies
- Contacts

The costs provided in this document are based on limited data and are dynamic. Many variables will affect the cost of a tool or technology as applied to a specific site or set of sites. The cost information provided herein reflects an order-of-magnitude guide to costs, and is provided on an informational basis.

Case studies are provided, where available. Additional examples of the application of these strategies, tools, and treatment technologies likely exist. Typical regional variations in MGP sites are identified where relevant or where additional information is available.

Detailed information on the history of former MGPs and their disposal practices is not included in this document. For background and historical information, the reader is referred to Chapter 7, Additional Sources of Information.

Finally, this document specifically does not address groundwater remediation technologies. A limited amount of information is provided on restoration of non-aqueous phase liquid (NAPL) zones at or below the water table. This is an area of considerable technological development. These issues may be addressed in future guidance document volumes.

Chapter 2

Creating an Expedited Site Characterization and Remediation Program

2.1 Introduction

The process of characterizing and remediating an MGP site or sites involves first determining what contamination is present and where. Once it is clear what wastes are present and at what locations, a selection of treatment and / or management alternatives can be evaluated to identify a preferred remedial approach. Familiarity with the historical operation of MGPs, which was similar at almost all sites, can further expedite the characterization and remediation process. This process typically follows that which is outlined by the National Contingency Plan (NCP) and is often modified by other federal, state, and / or local regulations.

The primary modes by which the site characterization and remediation process can be modified to save time and costs are:

- How the site is "administered" (i.e., how investigations and cleanups are organized and managed)
- The use of innovative and survey-level tools and approaches for expediting the site characterization
- Awareness of and familiarity with the subset of treatment technologies that are proven or promising for the particular types of wastes found at MGP sites

This chapter summarizes the process of streamlining the site characterization and remediation process, by tying together approaches to site management and contamination assessment (described in Chapters 3 and 4) with proven or promising treatment technologies for MGP residues and wastes in soil (Chapter 5).

2.2 Expedited Site Characterization and Remediation

Twenty to twenty-five years ago, in the early days of site characterization and environmental remediation, contaminated site work was scientific study as new disciplines were created and refined to address the work at hand. Typically, site work would begin with the preparation of work plans, followed by a round of field investigations. Samples collected during the field programs were sent to analytical laboratories for analyses, and after about a month, laboratory results were returned and subjected to tabulation, mapping, and other types of data evaluations. The results of the data analyses were documented in a draft report which was distributed to the responsible party and regulatory agencies for review. Meetings typically followed in which detailed discussions were held as to the "correct" interpretation of the data. Eventually, a revised report was prepared and submitted, the conclusion of which typically included recommendations for additional sampling. And so the whole process of work planning-sampling-laboratory analyses-data interpretation-reporting would continue until multiple phases and many years would pass. In all, very large sums of money were spent on "studying" the site before cleanup activities were planned, much less implemented.

In response to outside economic influences (including experience with the economic impacts of site characterization and remediation on businesses), the need for additional urban lands for redevelopment (bringing the Brownfields-type initiative to the forefront), and the maturation of the environmental marketplace, new pressures have been brought to bear to accomplish the same tasks in a smarter, cheaper, and more expeditious manner. For certain types of sites, including former MGP sites, practitioners now have enough experience that they can anticipate the nature of work to be accomplished, foresee the problems that may arise, and select an appropriate remedy from a known subset of treatment technologies. From a menu of technology options, practitioners can select the site characterization and analytical methods that are most likely to yield useful information to support site decisionmaking and remedy selection. When remedial design options are anticipated during the planning stage, data supportive of remedy considerations can be gathered concurrently with characterization information. By involving stakeholders at critical junctures, community and regulator satisfaction can be increased, decreasing the likelihood of legal battles that may delay remedial action and consume financial resources.

Work at former MGP sites can proceed seamlessly from investigation to remediation and closeout. With careful advance planning and the use of rapid turnaround on-site analytical technologies, investigation and cleanup objectives can be achieved in a fraction of the time (and thus at a lower cost) as compared to traditional approaches which rely on a prescriptive, linear progression of phases and tasks. Considerable time savings over the life of the project can be realized by reducing the number of mobilizations to the field and by performing multiple task simultaneously.

There are a number of key elements that comprise new approaches to performing site characterization. The most critical is the need for systematic planning prior to initiating site work. Systematic planning is one of the most cost-effective tasks in environmental remediation. It markedly increases the likelihood that a project will be successfully completed the *first* time, and within budget. It markedly decreases the probability of unpleasant and costly surprises.

Planning should be performed by a core technical team that contains all the expertise needed to adequately address the needs of the site, and that will incorporate the interests and concerns of stakeholders. Expertise vital to nearly all sites, but frequently overlooked, includes the services of a knowledgeable analytical chemist and a statistician familiar with the special concerns of environmental sampling. Planning involves the use of a site conceptual model which identifies the historical uses of the site, potential exposure pathways, cleanup concerns, and future land-use options. Clear articulation of the decision(s) or question(s) that drive the site work is imperative to the planning process. An appreciation for how much uncertainty or risk is acceptable in site decisions is also crucial (i.e., how sure must the decisionmaker be that wrong decisions will not be made). A great deal of time and effort may be consumed reaching consensus on these two issues, but once done, planning of the actual work to be performed at the site can begin and proceed without interruption.

Planning then proceeds in an orderly progression: When the site decision(s) is known, the *type* of information (data) which is required to inform the decisionmakers can be identified. When the amount of uncertainty has been decided, the *quality* of the data needed to meet the uncertainty goals can be determined. Once the type of data and the data quality needs have been determined, then a menu of analytical chemistry methods (for contaminant data) or sampling tools and techniques (for hydrogeological or contaminant information) can be surveyed for a cost-effective means of gathering information. If, during the planning process, it is found that the expense of collecting a data point to meet very stringent uncertainty goals exceeds available resources, the team can “go back to the drawing board,” and negotiate with stakeholders over future land use alternatives and the degree of allowable uncertainty.

Selecting an analytical method(s) involves balancing a number of considerations: the data needs, any regulatory requirements, costs, the ability to optimize sample throughput to provide real-time decisionmaking and to match the speed of sample collection, and any anticipated site-specific issues (such as matrix interference). Method selection should be done by a qualified chemist who can weigh the costs and benefits of various methods against site-specific data needs.

Field analytical methods hold a significant potential for cost and/or time savings, and should be included in the pool of analytical options under consideration. The rapid turnaround time supports a dynamic work plan which can decrease the collection and analysis of uninformative samples. Again, a knowledgeable chemist is crucial to avoiding the potential pitfall of the undiscerning use of field analytics.

It is the responsibility of the chemist member of the technical team to stay on top of rapid advancements being made in analytical environmental chemistry, especially as they relate to field methods. Depending on the method, the skill of the operator, and the kinds of calibrations and quality control used, some currently available field technologies can produce results that are just as quantitative as those expected from traditional laboratory services. The ability of field analytical methods to address certain issues, such as defining spatial variability across the site and minimizing the loss of volatile contaminants during sample collection and transport, means that field analytical data can sometimes be *more* reliable and representative than those generated under traditional scenarios.

Of course, the big question about the use of innovative analytical methods and sampling tools is “Will the regulators accept the results?” In general, regulators will often accept results from less-traditional technologies if the rationale for the collection and use of the data has been clearly documented. It is unfortunately true, however, that a heavy reliance has been placed on accepted methods, sometimes to the extent that these methods are viewed as “approved methods” that *must* be used to generate analytical data at contaminated sites. However, as part of their Performance-Based Measurement System initiative, the U.S. Environmental Protection Agency (USEPA) is attempting to change the focus to *what* data quality is required, leaving it up to the regulated entity to select the analytical method to be used.

Finally, by blending advance planning with field analytical methods capable of “immediately” available results, it is possible to implement dynamic work plans to accomplish site work much more efficiently than under traditional approaches. Dynamic work plans offer structured decision logic, such as decision trees or contingency planning, that guides the performance of field activities. A key feature is on-site decisionmaking and direction of field efforts by the technical team based on an evolving site conceptual model which is constantly updated with new information as it becomes available. Dynamic work plans use an adaptive sampling and analysis strategy where subsequent sampling is directly contingent on the interpretation of earlier results, which permits the collection of samples or the installation of wells in locations where the data are truly needed to decrease uncertainty.

To successfully implement a dynamic work plan, more experienced team members must take charge of field work. Increased expense is justified by the increased productivity of field work. For example, there is a decreased need for multiple mobilizations to the field to redirect work after interpretation of results turned around from the laboratory three to four weeks later indicate that important data gaps (and thus uncertainty) still remain; or when it is discovered that some critical analyses failed quality assurance checks and samples must be recollected if the data set is to be complete. Most importantly, the quandary of whether to spend more money on another sampling round to decrease uncertainty or whether to “make do” with the available data is avoided. “Making do” generally means that site decisions or remedial design will be based on inadequate information which increases the risk that the project will ultimately fail to achieve its objectives.

Adequate site characterization is essential to define the nature and extent of contamination so that decisions regarding site cleanup will be done in a scientific and legally defensible yet cost-effective manner. The range of experience and knowledge gained over the past decade is permitting the environmental remediation field to capitalize on new technologies and new ideas. To maintain momentum, practitioners must make the effort required to stay current with developments in their field of expertise. As the pool of available knowledge and technology tools continues to expand, it also becomes important to recognize that a single person cannot be relied upon to do it all – a technical team approach which acknowledges that contributions of geologists, engineers, chemists, biologists, quality assurance experts, risk assessors, statisticians, and regulatory experts is crucial to successful projects.

2.3 Creating the Expedited Site Characterization and Remediation Program

A successful expedited site characterization and remediation program is formed by careful and thoughtful advance planning. As a whole, the program can be broken down into the following four steps or phases. Although these steps appear to be the same basic steps as currently applied at Resource Conversion and Recovery Act of 1976 (RCRA) or Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) sites, the intent is to do the project in a better, faster, and less expensive manner. During each step described below, project implementation and management can be enhanced through the development of relationships (and trust) between stakeholders, frequent and effective communication, flexibility, and contingency planning.

Step 1: Preliminary Conceptual Model Formation
The first vital step in expediting site characterization and remediation is to conduct an initial site evaluation (also known as a Phase I environmental assessment or Preliminary Assessment) to establish baseline conditions at the site. In this assessment, historical information about the site's former operations are gleaned from documents such as:

- Historical aerial photographs
- Sanborn Fire Insurance maps
- As-built site drawings
- Historical operations records
- Historical topographic maps
- Real estate records and title information

Regulatory agency site listings and files are also reviewed as are current site practices. From this assessment, a preliminary site conceptual model is formed, identifying what types of contaminants (if any) may be present at the site (e.g., petroleum hydrocarbons, PAHs, heavy metals), the possible locations of wastes (e.g., gas holders, lampblack separators, tar pits and wells), and any immediate health risks or threats to the environment.

Step 2: Survey-Level Field Program Formulation
Following completion of the preliminary site conceptual model, all possible stakeholders in the project should be identified, briefed with the preliminary conceptual model, and interviewed to obtain their input on the overall project goals and objectives. Possible stakeholders include senior members of the responsible parties' organizations, regulatory agency representatives, third-party owners, public officials, and representatives of the public as required for future land use determination. A survey-level field program is then formulated to collect analytical data to answer the following questions:

- What contaminants are present at the site, if any?

- What are the relative concentrations of the detected contaminants?
- What is the approximate extent of contamination at the site?

It is here the 80/20 rule should prevail; that is, practitioners should aim at getting 80 percent of the information ultimately needed for the project in this round of sampling. The survey-level field program should take advantage of the site characterization and management tools listed in Chapters 3 and 4 to gather a large amount of relatively good quality data in order to determine where the majority of the contamination is located and its chemical composition. A limited site investigation (SI) is usually required to collect this information.

Dynamic work planning is essential to the successful completion of this phase of the project. Sampling and field decisionmaking protocols — rather than specific boring locations — should be outlined in the work plan, allowing an experienced field team to move and sample at those locations dictated by each previous sampling point. Innovative tools should be paired and implemented to allow for real-time on-site analytical data feedback; for example, using direct-push drilling with grab groundwater samplers and immunoassay or colorimetric testing to identify the presence/absence and relative concentrations of subsurface and groundwater contamination, where practicable.

Step 3: Preliminary Treatment Technology Screening, and Focused Field Investigation Formulation and Implementation

Following completion of the survey-level field investigation, the sampling program's results are analyzed with an eye toward site remediation. Those remediation technologies that are the most promising for the site are identified, as are the additional data points necessary to:

- Further refine estimates of contamination volume
- Gather the additional data necessary to aid in evaluation and selection of the best remedial alternative(s) for the site (e.g., geochemical indicators of natural attenuation to see if active groundwater remediation is necessary, soil sieve analyses to determine grain size, soil moisture measurements to determine effectiveness of thermal desorption, etc.)
- Collect additional site-specific data to evaluate uncertainties that may have a significant effect on the remedy selection (e.g., Is shallow groundwater in connection with deeper groundwater-bearing zones? May drinking water be affected?)

From this exercise, one or more focused field investigations are formulated and subsequently implemented to gather only those data necessary to reduce uncertainty to a pre-determined level of comfort and as required to complete remedy selection. Again, work planning should allow for flexibility in the field, permitting additional data collection as deemed necessary by the experienced project team.

Step 4: Remedy Selection and Contingency Planning
Using the results from the focused field investigations or a full-scale subsequent remedial investigation (RI), remediation remedies for the site are evaluated. Taking all factors into account, a remediation selection is made. As part of the remedy selection and remedial design process, contingency planning is conducted to prepare for unexpected changes in site conditions during remediation. The selected remedial program is then implemented and modified as needed to adapt to changing site conditions in order to achieve pre-determined performance-based standards.

The four steps described above are intended to provide a skeleton for an expedited site characterization and remediation program. It is the responsibility of the practitioner to use this as a guide, amending, modifying, and adapting as needed to meet site- or project-specific conditions. There are many variables that will influence the form, scope, and level of effort involved for a site characterization and remediation program. For example, site attributes that may affect the tools used to characterize the site include:

- Site size
- Hydrogeology complexity
- MGP feedstocks used
- Availability of background and historical information

The tools described in general below and in detail in subsequent sections of this document have been selected as those most applicable and available for formulating an expedited program at former MGP sites. Logic and experience will aid in formulation of an appropriate site-specific program.

2.4 Management Tools for Expediting Characterization and Remediation

The process of MGP site characterization and remediation can be expedited by a number of management or administrative approaches. Underlying all these approaches is the need for trust and communication among those with an interest in the site: the site owner, responsible party, regulators, consultants, the public, area residents, etc. Actively involving all stakeholders in the process and creating teams under conditions that foster genuine cooperation are key to facilitating cleanup. If there is trust among all parties involved, there can be flexibility to make decisions in the field as new information is uncovered about the site, without slowing the process down for repeated reviews of new documentation. Effective, cooperative relationships can be fostered by establishing administrative structures and procedures, and / or by chartering teams of stakeholder representatives on a project-by-project basis.

Practical strategies for streamlining MGP site characterizations and remediations are discussed in Chapter 3 and include grouping together nearby or similar sites and negotiating agreements for groups of sites rather than on a site-by-site basis; creating templates for work plans, reports and administrative orders; and knowing early in the process what the eventual use of a site will be so cleanup can be targeted to levels appropriate to that future use. Risk analyses, in the form of tiered or probabilistic risk assessments, can also be used to help establish appropriate cleanup objectives and to aid in the comparison of risks and liability that could remain if various remedial alternatives were implemented. In addition, use of the observational approach to site management can help focus the project on targeting the information needed to assess contamination, getting only as much information as needed to evaluate remedial alternatives, and planning for new information that might emerge about the site as cleanup proceeds rather than trying to eliminate all uncertainties before remediation can begin.

2.5 Tools for Site Characterization

All of the management strategies summarized above rely on targeted field investigations in which sampling locations are chosen based on knowledge of a site's past layout, and on the use of tools that are generally faster and give more immediate results than those used in the past for assessment and cleanup of wastes. Many samples can be collected, and a large amount of survey-level data can be generated in a short time using these innovative tools.

Field surveying tools described in Chapter 4, from direct-push drilling to methods for rapidly sampling soil and groundwater to the use of imaging techniques to locate underground structures, make the process of collecting data on the types, concentrations, and locations of MGP wastes much more rapid than in the past. If management strategies such as site bundling are also used, multiple sites can be assessed together or sequentially, taking advantages of economies of scale.

After the first phase of an investigation has been completed using field surveying tools, further, focused investigations can supply additional data about areas of contamination or uncertainty. This document focuses on tools for rapid field surveys. In some cases, regulators may require data that these tools cannot provide (e.g., low concentrations of PAHs in groundwater). However, because effective field surveying can determine where the majority of the contamination occurs at a site, traditional, time-intensive monitoring (e.g., fixed monitoring wells) to gather additional data can be used only where necessary, saving time and money compared to using these traditional methods to assess the whole site.

2.6 Technologies for Cleaning Up MGP Wastes

Familiarity with the technologies that have proven effective for treating MGP wastes (as described in Chapter 5) may save time in identifying those candidates most applicable to a specific former MGP site. Consider the choice between on-site or off-site asphalt batching and thermal desorption as a treatment for contaminated soil. Since both technologies will produce approximately the same result, considerations such as the amount and types of soil to be treated, the proximity of the MGP site to an off-site fixed facility, and the costs associated with these factors will likely motivate the decision.

2.7 Conclusion

The ability to craft an effective, streamlined site characterization and remediation program comes from both experience and knowledge. Understanding how MGPs were operated and dismantled is the first step — gaining an understanding of what might be below the surface of a site is extremely important. Flexibility, combined with careful planning and the willingness to try something new, can aid in the formulation and successful implementation of an innovative and streamlined investigation and remediation program.

The management strategies and field-survey tools described in this guide will provide information necessary to expedite the site characterization and remediation process. The technologies described are those most likely to be effective in remediating MGP wastes in soils, delineated by this streamlined process.

Chapter 3

Management Tools for Expediting Site Characterization and Remediation

3.1 Introduction

Because of the similarity of former MGP sites nationwide, innovative site management tools have been developed to streamline the characterization and remediation of wastes found at these sites. Using these techniques can reduce the timescale that has been typical for remedial investigation, feasibility study, remedial design, and remedial action (RI/FS/RD/RA) cleanup projects at sites being addressed under traditional programs. These innovative approaches, described below, have two key features: they take advantage of economies of scale, emphasizing ways to address multiple sites simultaneously; and they focus on facilitating communication among the parties involved in cleanup as well as promoting each party's "ownership" of the process. The table on the following pages summarizes the components of these programs.

These site management innovations are currently being applied at MGP sites. Case studies are included below where available. Not every tool will be appropriate in every situation. Parties responsible for former MGP sites can modify the approaches to fit their sites. Similarly, responsible parties can select more than one of the tools discussed below and merge them to tailor a program to a site or set of sites. Reference information is supplied so that readers can contact representatives involved in the specific projects.

Management Tools for Expediting Site Characterization and Remediation

Name	Description	Economies of Scale Advantages	Communication Facilitation
Site Bundling	Bundling multiple MGP sites into one "package" which is then managed, investigated, and as appropriate, remediated as a single entity.	• Saves time and money by reducing the volume of paperwork • Allows for negotiation of lower unit pricing with vendors • Reduces project management and accounting costs through reduction in project administration labor hours • Reduces regulatory agency oversight costs by negotiation one order for multiple sites and having one regulatory project manager	• One regulatory project manager for multiple sites minimizes downtime from lack of education/project understanding • Minimizes duplication in RI/FS/RD/RA program development • Builds trust/relationship between stakeholders by prolonged, multi-site contact
Multi-Site Agreements	Single agreement providing responsible party(ies) and regulatory agency(ies) the opportunity to address environmental conditions under a single, cooperative, mutually beneficial, statewide agreement.	• Comprehensive and consistent statewide strategies • Reduced costs of negotiating agreements/orders • Control of year-to-year costs • Optimized risk reduction	• Agreements tailored to company-specific needs • Central point of contact(s) established within regulatory agency(ies) • Proactive environmental mitigation • Emphasis on cooperation and common sense
Generic Work Plans and Reports	Preparation of generic documents, such as work plans and reports, that can be tailored to a specific site or set of sites.	• Savings from having to prepare only the site-specific sections of a document • Reduced regulatory oversight costs and review time from having all documents from a single entity be organized similarly	• Streamlined decisionmaking from "prequalifying" remediation technologies with local regulatory agencies • Consistent site characterization and application of quality assurance project plans and Health and Safety Plan across multiple sites • Consistent decisionmaking rationales applied to multiple MGP sites
Program/ High Performance/ Design Teams	A team or set of teams formed and chartered to work towards a common goal, promoting communication, expediting decisionmaking, streamlining deliverable preparation, and remediating a site in the most cost- and time-effective manner possible with agreement among all parties involved.	• Shared project vision, mission, and goals for all sites addressed by the team • Reduces overall costs by minimizing document handling and review and project downtime • Reduces overall regulatory oversight costs • Minimizes downtime and backsliding resulting from consultant or regulatory management turnover	• Chartering and common sense of purpose and set of goals promotes communication • Success of team(s) based on development of relationship and trust • Nature of team reduces stakeholder conflict • Team charter formalizes communication process
Early Land-use Determination/ Brownfields	Identification of future site beneficial use prior to site characterization, and integration of the proposed future land use with the planned site remediation.	• Reduces site characterization costs by identifying only those data necessary for evaluation of remediation alternatives to meet proposed future site use • Minimizes remediation costs by focusing on alternatives that can successfully meet future beneficial use needs • Can turn a challenged property into a money-making enterprise	• Focuses regulatory agency(ies) and responsible parties on the project's ultimate goal (site remediation and redevelopment)

Management Tools for Expediting Site Characterization and Remediation

Name	Description	Economies of Scale Advantages	Communication Facilitation
Managing Uncertainty	A method providing a way to determine when sufficient site characterization data have been collected and involving managing uncertainties through the identification of reasonable deviations from original plans and the preparation of contingency plans to address changed site conditions.	• Minimizes downtime during site characterization and/or remediation through upfront contingency planning to address potential changes in site conditions	• Requires flexibility to alter a site investigation and/or remediation in the field based on pre-determined contingency plans. This requires trust and consistent communications between regulatory agency(ies) and responsible party(ies)
Expedited Site Characterization	The combination of tools, strategies, and processes that interlink and synergistically help streamline investigation and remediation processes.	• Reduced costs through streamlined document preparation and review • Reduced costs through the use of field screening and analysis tools • Minimizes project downtime by allowing flexibility in the overall site characterization and remediation processes and through the active management of uncertainty	• Communication and cooperation among responsible parties, regulatory agencies, and third party stakeholders through mediation, facilitation, and high-performance teams • Uses onsite or rapid decisionmaking capabilities • Includes a process for reducing team member turnover and minimizing effects of team member replacement
Legislative Innovation	Alternative regulatory policies for the remediation of contaminated properties by providing for a comprehensive program that includes revised liability, indemnification processes, risk-based cleanups, streamlined remediation processes, and dispute resolution.	• Allows risk-based decisionmaking to optimize remediation alternatives • Apportionment of liability based on fair and equitable principles and orphan share funding • Saves cost by expediting site remediation	• Lead agency designation streamlines regulatory agency communication • Requires public participation per state regulatory guidelines
Dovetailing Business Decisionmaking and Remediation Planning	Combining site remediation with business ventures such as developing affiliate companies or developing joint venture to create a mobile treatment facility.	• Optimize treatment costs by investing in risk-sharing treatment ventures	N/A
Establishing Background PAH Concentrations	Establishing the portion of PAHs at a site that are the result of non-MGP processes such as automobile exhaust, crude oil processing, etc.	• Optimizes volume of soil to be remediated by addressing only those portions of PAH-contaminated soil that are the result of historical MGP processes	N/A
Generic Administrative Orders	Preparation of a single generic administrative order that can be adapted for multiple sites.	• Streamlines the administrative order preparation process • Reduces costs in preparing and negotiating administrative orders	• Familiarity with the generic order allows for site-specific communications/ negotiations on an as-needed basis

3.2 Management Tools for Expediting Site Characterization and Remediation

The following sections describe each site management tool for expediting site characterization and remediation. Because different tools will be appropriate for different sites, no attempt has been made to rank the tools according to their effectiveness.

3.2.1 Site Bundling

Tool Description

Utility companies typically own or are liable for multiple MGP sites. There are many methods that can save time and money during site characterization and remediation. One simple but effective method is bundling multiple MGP sites into one "package," which is then managed, investigated, and remediated as a single entity. Site bundling saves time and costs by:

- Reduction in the volume of paper documentation (e.g., one work plan may be prepared for multiple sites)
- Reduction in project management and accounting costs through a reduction in the number of labor hours required for project administration
- Reduction in regulatory agency oversight costs by negotiating one order for multiple sites and by requiring only one regulatory agency representative for the sites

Additional savings can be achieved by coordinating site investigation and remediation activities for multiple sites located relatively close together. Mobilization costs can be reduced by conducting sampling (e.g., quarterly groundwater monitoring) sequentially at all sites and by purchasing sampling materials in bulk. When the preferred remedial alternative is the same for multiple sites and especially in situations where the sites are located near one another, treatment costs can be reduced by staging treatment processes for all the sites at one location. Savings result from reduced transportation costs and lower unit costs for treating larger volumes of material than would be generated by a single site.

Case Study

MidAmerican Energy Company Multi-Site Thermal Desorption

At the end of 1996, MidAmerican Energy Company (MEC) was preparing to conduct remedial activities at a number of former MGP sites that were relatively close to each other. These sites had fairly small quantities of waste to be treated and were of limited size, which posed potential problems for locating treatment technologies on-site. Because of the sites' proximity, small size, and ownership by one utility, innovative administrative and technical approaches were chosen.

On-site thermal desorption by a mobile treatment unit was identified as a viable remedial alternative for all of the sites. MidAmerican Energy worked with the Iowa Department of Natural Resources (DNR) and USEPA Region VII to locate a thermal desorber at a National Priorities List (NPL) site in Waterloo, Iowa.

Following completion of a rigorous trial burn, the thermal desorption unit was used to treat MGP wastes at the Waterloo site and from three additional sites in Charles City, Hampton, and Independence, Iowa.

Project Milestones

Initially, Independence, Iowa, was the only MEC site where contaminated soils were to be excavated and thermally treated. As the planning for this project proceeded, it became apparent the thermal desorption unit could not be set up on-site because of lack of space. A search began to find a treatment location. An industrial park in Independence appeared to be the first choice. However, the high costs of this choice meant that another option had to be considered. The Waterloo former MGP site in Waterloo, Iowa, already had 12,000 cubic yards of soil removed for treatment, and this site was located 30 miles from Independence. An open excavation existed at Waterloo, and more soil required excavation. Concurrently, MEC determined that removal actions at the Charles City and Hampton former MGP sites would also be beneficial if soil treatment could be arranged. MEC therefore concluded that treatment of excavated contaminated soils from all four sites at one on-site location could be a tremendously cost-effective way to conduct removal actions at all four former MGP sites.

Site	Waterloo	Hampton	Charles City	Independence
Size (acres)	3.4	0.6	1	0.4
Service Years	1901 - 1954	1906 - 1937	1909 - 1949	1880 - 1947
Current Site Use	vacant	electric substation/ storage area	electric substation	vacant
Gas Process Used	coal carbonization, water gas, carbureted water gas	Lowe Water Gas System	Lowe Water Gas System	J.D. Patton Oil Gas Process, Tenney Water Gas Process
Regulatory Status	Under consent order with USEPA Region VII	Under consent order with Iowa DNR	Under consent order with Iowa DNR	Under consent order with Iowa DNR

A summary of the projects milestones is shown below:

- January and February of 1997 - MEC contacts the city managers of Independence, Charles City, and Hampton, Iowa, to discuss the potential remediation of the former MGP sites.
- March and April 1997 - Additional meetings with Iowa DNR and USEPA take place to discuss the possibility of locating a thermal desorption unit at the Waterloo site and thermally treating soils from the other three sites, thermally desorbing the remaining soil at the Waterloo site, and using all the thermally treated soil as backfill at Waterloo.

- May 1997 - MEC adds the Hampton, Charles City, Waverly, and Waterloo sites to the Independence thermal desorption project, and initiates community relations activities in preparation for the project.
- July 1997 - A Thermal Desorption Scope of Work and Contract Documents package is completed. MEC continues to work with the Iowa DNR to develop work plans for the sites under state regulatory oversight and with the USEPA concerning the scope of work at the Waterloo site.
- October 1997 - Final changes are made to the work plans for Hampton, Charles City, and Independence sites. Site preparation begins at Waterloo, with soil excavation initiated at the Hampton site and soil shipping to Waterloo.
- December 1997 - Thermal desorption operations begin in January 1998. Soil excavation continues at all four sites, with thermal desorption operations continuing at the Waterloo site.
- February 1998 - All work, including backfilling, is completed.

Remedial Action Implementation

The cleanup objective at these sites was to remove visibly contaminated soil and to excavate to physical limits, which were determined by site conditions such as buildings, property boundaries, railroad tracks, etc. The criteria for stopping the excavation short of a physical boundary were less than 500 milligrams per kilogram (mg/kg) total PAHs or less than 100 mg/kg total cPAHs (cPAHs) in the 0- to 6-foot range, or less than 3,000 mg/kg total PAHs or less than 200 mg/kg cPAHs at depths greater than 6 feet. The cleanup criterion for the thermally treated soil was less than or equal to 5 mg/kg total PAHs.

The following table shows the amount of soil excavated and treated for each of the four sites:

Site	Tons of Soil Treated
Hampton	3,651
Charles City	2,138
Independence	4,734
Waterloo	14,167
Total	24,690

Treated soils from all four sites were used to backfill a previous excavation at the Waterloo site. All contaminated oversized debris was crushed and thermally treated. Some exceptionally large debris, such as foundations, was decontaminated in place and left in the excavation. All scrap steel was cleaned and sent to a recycler. As a result, nearly all materials removed were thermally desorbed or recycled. A small amount of material, primarily wood debris and tree roots, was taken to the local landfill.

The total cost of the project was $2 million. This cost includes site preparation and installation of utilities; excavation at all the sites; hauling excavated material from Hampton, Charles City, and Independence to Waterloo; backfill and labor to place the fill; and the thermal desorption services including the cost of fuel.

The average cost per ton of soil treated was calculated for the project and is shown in the table below:

Item	Average cost per ton ($)*
Excavation	4.83
Thermal Treatment	47.87
Transportation	12.53
Backfill	4.83
Miscellaneous*	8.62
Total	78.68

* This includes the cost of analysis, engineering services, air monitoring, etc.

Conclusions

Site bundling resulted in total savings of more than $1 million on this project. The use of a single, central location for treatment of contaminated materials resulted in significant savings compared to the cost of completing the four projects separately; MEC has estimated a savings in excess of $150,000 in costs related to project management. Additional savings of approximately $205,000 were realized by using the treated soil as backfill at the Waterloo site rather than landfilling the treated soil and purchasing clean backfill. Setting up the thermal treatment unit in Waterloo, a central location relative to the other sites remediated, reduced shipping costs. Previous work at the Waterloo site had included shipping soil to the Neal Generating Station near Sioux City, Iowa. By setting up the thermal desorber in Waterloo, MEC saved approximately $575,000 in soil shipping costs. Reduced regulatory oversight and engineering costs were estimated to be in excess of $100,000.

Teamwork was a key component to the successful completion of this project. Iowa DNR and USEPA Region VII personnel reviewed and commented on documents for this project. Because MEC wrote the work plans in-house, the time required to make a change to a work plan and send an updated copy to the regulators was very short. At times a change would be suggested, the pages of the work plan were modified, and copies of the changes were faxed within hours of the discussion. This fast pace kept everyone involved focused on completing the task. Joint effort by state and federal agencies resulted in achieving the goals of site source removal, thermal treatment, and backfill at four sites in a short time.

Contacts

Johanshir Golchin, Iowa Department of Natural Resources, (515) 281-8925

Jim Colbert, USEPA Region VII, (913) 551-7489
Sam Nelson, MidAmerican Energy Company, (712) 277-7851
Dan Klimek, MidAmerican Energy Company, (712) 277-7930

3.2.2 Multi-Site Agreements

Tool Description

Former MGP sites lend themselves to multi-site agreements. Much like strategic plans, multi-site agreements provide both the responsible party(ies) and the state in which the properties are located the opportunity to address environmental conditions under a single, cooperative, mutually beneficial, statewide agreement. Benefits of multi-site agreements include:

- Comprehensive and consistent statewide strategies
- Reduced costs of negotiating agreements/orders
- Agreements tailored to company-specific needs
- Control of year-to-year costs
- A central point of contact that may be established within the state regulatory agency
- Proactive environmental mitigation
- Optimized risk reduction
- Emphasis on cooperation and common sense

Multi-site agreements have currently been implemented in California, Iowa, New York, and Pennsylvania. In all cases, multi-site agreements are developed through negotiations among utilities/companies and regulatory agency(ies) and include a strategic plan for addressing and completing site investigation and remediation.

The Pennsylvania Department of Environmental Protection Multi-Site Agreement Program

The state of Pennsylvania has developed a statewide program for multi-site remediation agreements under the Department of Environmental Protection, Bureau of Land Recycling and Waste Management. Under the Pennsylvania Department of Environmental Protection (DEP) Multi-Site Remediation Agreement program, utilities and other private parties may enter into a form of consent agreement that is fundamentally different than the agreements enforced for parcels owned by individual owners. Instead of imposing requirements with respect to each individual site, the Pennsylvania multi-site agreements require that a specific minimum increment of work be performed each year at the covered sites taken as a whole. A point system is used to measure the work completed, thereby ensuring permit compliance. To a large extent, the volume and type of work performed during a particular year is within the discretion of the business owner. The Pennsylvania multi-site agreements include seven primary elements that distinguish them from other DEP-enforceable remediation agreements:

Element 1: Planning Process—Under the Pennsylvania DEP Multi-Site Remediation Agreement program, a company entering into an agreement with DEP is required to submit an annual and 5-year plan incorporating the following items:

- Identification of anticipated work during the next 1- and 5-year periods
- A list prioritizing the sites covered by the agreement
- The number of points to be earned by the anticipated work
- The estimated costs to be incurred during the next year of work

Under this program, it is the DEP's responsibility to assemble a team including representatives from both regional and central DEP offices, to disseminate information among this team during the course of the agreement, and to respond to submittals with a single set of comments. Any disagreement within the DEP team for the sites must be resolved internally to provide consistent regulatory review and oversight.

An annual planning meeting is held between the party responsible for the sites and the DEP, providing an opportunity to review the proposed plans in a cooperative manner, resolve outstanding issues, and discuss implementation of the agreement.

Element 2: Prioritization of Sites—As noted above, the annual plan is required to prioritize the sites to be covered by the agreement. This prioritization is conducted by evaluating the environmental and human health risks posed by each site and assigning points based on a scoring system that identifies the features that potentially pose the greatest risks. The scoring system varies by agreement and is included as an attachment to the multi-site agreement. This method of risk-based scoring promotes DEP's goal of risk reduction and helps the party responsible for the sites address its areas of highest liability first.

Element 3: Point System/Minimum Annual Point Requirement—The key feature of Pennsylvania DEP's Multi-Site Remediation Agreement program is the point system that measures success in completing remediation activities. Rather than dictating which sites require which activities, the DEP and the party responsible for the site create a list of anticipated components of work required to investigate and remediate the sites covered by the agreement. Points are assigned to each component based on various criteria (or combinations of criteria), including level of effort, cost, environmental benefit, and risk reduction. The DEP and the responsible party then determine the minimum number of points to be completed annually under the agreement, which allows the responsible party the freedom to determine which activities will be conducted in any given year. Failure to meet the minimum annual point requirements may result in penalties and the requirement to "make up" the shortfall in a specified period of time. Conversely, if the responsible party achieves more than the minimum annual point requirement in a given year, it may bank or save the "extra" points and apply them in a subsequent year.

Element 4: Cost Cap—The Pennsylvania DEP is willing to include a cost cap in its multi-site agreements, allowing a responsible party to fall short of its minimum annual point requirement should its total annual costs meet or exceed the cap. The costs that are included in this cap are open to negotiation. The cap gives the responsible party fiscal protection should remediation activities at one particular site turn out to be significantly more expensive than anticipated. In order to include the cost cap in a multi-site agreement, the responsible party must make a financial disclosure.

Element 5: Uniform Process for Review and Approval of Submittals — Pennsylvania's multi-site agreements, like all enforceable agreements in the state, must identify the type and contents of plans and reports to be submitted. Because Multi-Site Remediation Agreement documents require review by a DEP team, a uniform process for review and approval of submittals is also included in the multi-site agreement. Establishing this process during the agreement preparation means that requirements can be applied consistently. The review process can also be streamlined and potentially contentious issues can be resolved up front.

Element 6: Termination —All multi-site agreements prepared by the DEP allow for termination of the agreement by either party upon the agreement's fifth anniversary and every fifth anniversary thereafter. The agreement is limited to a minimum of 5 years, which allows the responsible party to "test the waters" without committing to a long-term process.

Element 7: Interaction with Act 2—Act 2, Pennsylvania's Land Recycling and Environmental Remediation Standards Act, establishes environmental remediation standards to provide a uniform framework for cleanups. Under this act, responsible parties can choose from three types of cleanup standards: background standard, statewide health standard, or site-specific standard. Act 2 describes submission and review procedures to be used under each of the three cleanup standards and provides releases from liability for owners or developers where the site has been remediated according to the standards and procedures of the Act. Under the Pennsylvania DEP's Multi-Site Remediation Agreement program, interaction with Act 2 has, to date, been agreement specific. The Penn Fuel Multi-Site Agreement (discussed below) required the achievement of an Act 2 standard but also allowed DEP to issue a no-further-action letter in lieu of an Act 2 release, thereby relieving Penn Fuel from some of the administrative requirements of Act 2 (Rader, 1997).

Benefits achieved under the Pennsylvania DEP Multi-Site Remediation Agreement program include (Commonwealth of Pennsylvania, 1996a):

- Development of case loads that are manageable by both the DEP and the responsible party
- Reduction of review time and inconsistent responses through the development of the uniform process for review and approval of submissions
- Cost savings from managing multiple sites simultaneously and reducing redundant administrative tasks

- Creation of good will among DEP regions and central office and with the regulated community

The primary disadvantage of the program is the potential deferral of remediation at some of the covered sites. However, by actively managing the sites requiring investigation and remediation and providing credits for work completed ahead of schedule, both DEP and the responsible parties can minimize risk within the context of limited resources.

Case Studies

Pennsylvania Power & Light Co. Multi-Site Agreement

In 1995, Pennsylvania Power & Light Company (PP&L) entered into a multi-site agreement with the Pennsylvania DEP. This agreement formed part of the foundation of Pennsylvania DEP's current Multi-Site Remediation Agreement program. Under this multi-site agreement, PP&L and DEP agreed to develop a model to rank almost 130 potential contaminated sites, including utility poles, substations, power plants, and former MGP sites. To create this model, PP&L and DEP first developed a uniform polychlorinated biphenyl (PCB) standard for all the sites so PP&L could manage the project with consistent interpretations from different DEP regional offices. Next, a system for prioritizing the sites was devised, and a method for tracking progress was designed. A point system was developed to ensure that PP&L kept its cleanup efforts on schedule, and an annual financial cap was set, allowing the company to allocate financial resources over several years (Winsor, 1996).

An example of a former MGP site remediated under the PP&L multi-site agreement is the Lycoming College redevelopment project. At this site, PP&L worked with the college and DEP to remove coal tar left from two large underground holders remaining from the original MGP (PP&L, 1996).

Contact

Don Stringfellow, PP&L, (717) 769-7535

Penn Fuel Multi-Site Agreement

Penn Fuel Gas, Inc., (Penn Fuel) and North Penn Gas Company (North Penn) entered into a multi-site agreement with the Pennsylvania DEP to investigate, and, where necessary, remediate 20 former MGP sites using standards from the Land Recycling Program (Act 2) and to plug 340 abandoned natural gas wells (Commonwealth of Pennsylvania, 1996b). Signed on March 27, 1997, the agreement between DEP, Penn Fuel, and North Penn Gas Company stipulated that, during the following 15 years, Penn Fuel would investigate all 20 of the sites, cleaning up those that require remediation following a schedule based on the potential environmental and health risks, if any, posed by each site. North Penn has also agreed to plug a minimum of 16 abandoned wells per year, with all 340 plugged by the year 2011. Penn Fuel and North Penn have agreed to spend up to a total of $1.75 million a year on investigation and cleanup operations and well plugging.

The Lewistown former MGP site was remediated by Penn Fuel under a multi-site agreement. Built in the early 1800s, this large MGP stood on the southern end of Lewistown, Pennsylvania. At the end of 1996, only two of the former MGP's gas holders remained. Under the multi-site agreement, Penn Fuel removed 100,000 gallons of coal tar and 625,000 gallons of water from inside the two gas holders and then dismantled the tanks. Water from the gas holders was pumped through an oil-water separator and treated with a dual carbon treatment system before disposal. The coal tar was pumped into treatment tanks and blended with a polymer to dewater the tar. The steel from the gas holders was recycled in a steel foundry.

Niagara Mohawk Multi-Site Agreement

Niagara Mohawk Power Corporation (NMPC) currently owns 24 former MGP sites, all inherited from predecessor companies when it was founded in 1950. Twenty-two of the former MGP sites are subject to two consent orders between NMPC and the New York Department of Environmental Conservation (DEC); the two other sites are being addressed separately.

The first of two DEC orders between NMPC and DEC calls for NMPC to:

- Investigate, between 1992 and 1999, coal tar and other wastes at 21 of the former MGP sites currently owned by the company to determine whether any hazardous substances are present and whether they pose a significant threat to the environment or to public health.
- Remediate each site where DEC determines that remedial process is required. Where deemed appropriate, interim measures may be undertaken to remove or control sources of contamination.

Under the second consent order, NMPC will expand and complete the cleanup already under way at the Harbor Point former MGP site in Utica, New York, to include adjacent parcels containing MGP wastes. In addition, the company committed to operate a research center at Harbor Point to evaluate several new technologies for remediation of waste-contaminated materials and to fund in advance DEC's expenses for environmental monitoring, oversight, and administrative costs (New York State Department of Environmental Conservation, 1992).

Under a third consent order that was executed in 1997, NMPC and the DEC expanded the first and second orders to include remedial programs for certain additional sites (including non-MGP sites) to:

- Level future annual costs to be incurred for site investigation and remediation (SIR) activities
- Minimize the impact upon ratepayers of excessive short-term expenditures for concentrated SIR activities
- Minimize potentially excessive burdens on staffing and administrative resources of both NMPC and the DEC

NMPC and the DEC agreed to implement an annual cost cap for SIR activities based on the level of annual costs incurred in recent years.

Contacts

Michael Sherman, Niagara Mohawk Power Corporation, (315) 428-6624

Jim Harrington, NY State Department of Environmental Conservation, (518) 457-0337

3.2.3 Generic Work Plans and Reports

Tool Description

In the site investigation and remediation process, documentation costs leading up to the remediation can be very high. The traditional RI/FS/RD/RA approach typically requires the preparation of one or more versions of a work plan and investigation report (often multiple work plans and reports for multiple phases of work), feasibility study reports, RA plans, removal action work plans, and closure reports. For utilities or private parties with portfolios containing multiple MGP sites, significant savings can come from reducing the costs of documenting and reporting. These savings can result from either preparing single submittals for multiple sites and/or multiple phases of work, or from preparing generic documents that can easily be tailored to a specific site or sites.

Most generic submittal development efforts have focused on field investigative work plans and feasibility studies. Benefits that can be achieved through the preparation of generic templates for these documents include:

- Savings from having to prepare only the site-specific sections of a work plan or feasibility study
- Reduced regulatory oversight costs and review time from having all documents from a single entity be organized similarly
- Streamlined decisionmaking from “prequalifying” remediation technologies with local regulatory agencies (e.g., development of presumptive remedies)
- Consistent site characterization and application of quality assurance project plans (QAPPs) and Health and Safety Plans (HASPs) across multiple MGP sites
- Consistent decisionmaking rationales applied to multiple MGP sites

A key factor in the successful application of generic work plans and feasibility studies is allowing flexibility to move outside the template as necessary for site-specific conditions. Combined with other streamlining strategies (e.g., multi-site agreements), the use of generic deliverables can provide a great time and cost savings to responsible parties and regulatory agencies.

Case Studies

Public Service Electric & Gas Company Generic Remedial Investigation Work Plan

In April and May of 1995, Public Service Electric & Gas Company (PSE&G) met with the New Jersey Department of Environmental Protection (NJDEP) to discuss the potential to work with the NJDEP Site Remediation Program (SRP) to streamline the MGP site remediation process. As a result, an NJDEP / PSE&G Streamlining Team was established. In partnership, the two organizations defined and evaluated the process of investigating and remediating MGP sites and identified opportunities for improvement, consistency of approach, and cost effectiveness. The Streamlining Team identified the quality of the RI workplan submittal as a major area for improvement. The inadequacy of the documents coupled with the separate review and approval cycles of the two organizations considerably lengthened the RI process. The Streamlining Team's solution was to develop a boilerplate RI work plan that met or exceeded NJDEP's technical regulations and guidelines.

In November 1997, PSE&G published a Generic Remedial Investigation Work Plan (PSE&G, 1997). This work plan outlined a data quality objective (DQO) process designed to gather and evaluate all the data necessary to complete an RI in one phase. The DQO process consists of six steps that, when completed, should provide all the data necessary to meet NJDEP's requirements. The six steps are:

Step 1: Understand the MGP facility's history, construction, and operations as they relate to the production and disposition of MGP residuals and the potential for release(s) to the environment.

Step 2: Use the results of Step 1 and the preliminary assessment and site investigation (PA / SI) to develop a preliminary site conceptual model.

Step 3: Develop a vision for future land use, preferably supported by a well-researched, site-specific plan.

Step 4: Develop risk-based RA objectives that define the purpose of the remediation and avoid expenditures on remedial activities that do not meet these objectives.

Step 5: Identify potential remedial methods, proven to be effective at former MGP facilities, that will achieve the RA objectives.

Step 6: Identify applicable regulatory requirements.

The Generic Remedial Investigation Work Plan prepared by PSE&G consists of three volumes. The first volume is the generic work plan itself, containing boiler plates for the descriptive portion of the work plan (e.g., site background, environmental setting, and scope of work). Volume 2 of the work plan contains the QAPP, Standard Operating Procedures for many field activities (e.g., cone penetrometer surveys, rock coring, and aquifer testing), and a list of the minimum safety and health plan requirements and specifications. PSE&G is currently planning to publish a generic RI report in concert with NJDEP.

Contacts

Rich Blackman, Public Service Electric & Gas, (973) 430-8278

Chris Kanakis, New Jersey Department of Environmental Protection, (609) 633-1460

Woerner Max, Public Service Electric & Gas, (973) 430-6413

Southern California Edison Generic Feasibility Study

Faced with investigation and remediation of multiple MGP sites, Southern California Edison (Edison) prepared a "generic FS" to help streamline preparation of site-specific feasibility studies for their MGP sites. This generic FS template is organized like a site-specific FS and contains text that can remain in a site-specific FS, but it also allows the user to "plug-in" site-specific information as appropriate. For example, the document provides a general history of MGP facilities and then prompts the user to add site-specific historical information. The generic FS also provides numerous examples of text and tables to further assist users in preparing a site-specific FS. In all cases, the generic FS assumes:

- The MGP waste is nonhazardous.
- Onsite ex situ remediation is not feasible because of space limitations at the sites.
- The cleanup level is 1 ppm total cPAHs (benzo[a]pyrene equivalent).

Contact

Terry Sciarotta, Southern California Edison, (626) 302-9723

3.2.4 Program/High Performance/Design Team

Tool Description

A Program, High Performance, or Design Team is a team of stakeholders brought together with the intention of creating trust, communication, motivation, and cooperation to collectively solve a problem. Site characterization and remediation is one of many fields in which the use of such a team can expedite, streamline, and reduce the cost of completing a project, with the project being site-specific (as for an MGP site characterization and remediation) or programmatic (e.g., to establish methodologies for dealing with multiple MGP sites) in nature.

A team approach is useful because characterization and remediation of sites:

- Is often too complex for any one person to be able to know of or handle multiple variables.
- Typically has no single solution. The best solution is often one that balances the needs of all stakeholders involved in the site with federal, state, and local regulations.
- Requires multiple areas of expertise to reach a preferred solution.
- Requires that all stakeholders work together to efficiently achieve an acceptable solution.

A High Performance Team (HPT) must concentrate on three major areas where team development typically occurs: problem-solving skills, process improvement, and behavioral performance. The team must learn to work together, be flexible, and be willing to understand and develop team-related problem-solving skills (such as Total Quality Management techniques including causal loop diagraming, popcorn brainstorming, and decision science models). The rules of conduct laid out in the charter must be followed, and the team must regularly revisit its purpose, goals, and methods, seeking individual and team feedback for continuous improvement. At times, a trained facilitator may be required to manage the team-building process and/or to assist the team in overcoming road blocks in the consensus-making process.

Building a team requires time and energy. Effective teams create synergistic results. Beyond pooling skills and understanding, an HPT can speed the remediation process, reduce overall project costs, minimize conflict and misunderstanding with regulators, promote acceptance and support in the local community, minimize downtime and back sliding resulting from consultant or regulatory management turnover, and create relationships and trust between the utility and regulators that extend beyond any single site characterization and remediation. The upfront costs of building the team are typically offset by savings realized later in the project after the team is formed and trust has been built between the team members.

Case Studies

Pacific Gas and Electric Company Chico/Willows/Marysville High Performance Team

In 1994, Pacific Gas and Electric Company (PG&E) initiated the RI/FS/RD/RA process for three former MGP sites in Chico, Willows, and Marysville, California. Recognizing the advantages of streamlining the RI/FS process, PG&E combined or "bundled" the sites into one project. PG&E negotiated one order for the three sites with California Department of Toxic Substances Control (DTSC) and identified representatives from PG&E, each of California's primary regulatory agencies (DTSC and the Regional Water Quality Control Board), along with a PG&E consultant to serve as primary case managers for all three sites. In 1996, PG&E initiated a unique streamlining program, the backbone of which was the Chico/Willows/Marysville (CWM) HPT.

The CWM HPT, as with most similar teams, was made up of a series of focus groups or sub-teams formed solely to promote the project's successful completion. The organization of the CWM HPT comprised all potential project stakeholders (in this case, PG&E, state regulatory agencies, and PG&E's consultant).

The Sponsorship Team was composed of stakeholder representatives with the authority to "sign on the dotted line." These included persons in charge of policymaking and budget authorization. Members of this team included DTSC's Site Mitigation Section Chief and PG&E's vice-president, who oversees all environmental operations. These are the ultimate "owners" of the project.

For the CWM project, a Leadership Team was also formed, consisting of senior representatives from PG&E and the regulatory agencies. California regulatory agencies generally experience a frequent turnover in project managers. Involving senior staff in the HPT process helps ensure continuity of project decisionmaking and regulatory interpretation despite personnel changes. Representatives on this team included PG&E's Director of Site Remediation and DTSC's Site Mitigation Unit Chief.

The Management Team of the CWM HPT is composed of persons charged with actually carrying out the project. Members are PG&E's consultant and regulatory project managers. Separate Task Teams were also formed to address specific issues or problems. For example, Task Teams were formed for community relations and risk assessment.

The first task of the HPT was its charter. This exercise formed the basis for the team's operations. Steps conducted by the HPT during chartering included: identifying unifying goals, objectives, and measures by which the team could evaluate whether it was meeting goals; preparing guidelines for meetings and communications; and identifying the fundamental rules by which the team(s) would operate. Because several HPT members were not familiar with either the RI/FS process or MGP sites, education was also required to ensure that all team members were comfortable with the process and would support decisions. This education was conducted during workshops where HPT members reviewed the operational history and historical documents (MGP facility plans, Sanborn maps, etc.) available for each site. Applicable state and federal regulations and HPT member expectations were also discussed.

The second HPT task was the development of conceptual models for each site to ensure that all HPT members had the same view of site physical conditions, source delineation, transport pathways, and exposure pathways. The team then jointly initiated the first steps of the FS, identifying all possible remedial technologies and screening them to form what all team members (including regulatory agencies) agreed to as a subset of technologies that could be reasonably applied at the three sites (i.e., ex situ thermal desorption and asphalt batching). At this time, the HPT identified two key questions that still needed to be resolved and defined the scope of an additional focused field investigation designed to collect only the data necessary for the HPT to complete the FS with a high degree of confidence.

As of July 1998, the CWM HPT completed site investigations and was in the middle of preparing FSs for the three sites. Although the CWM HPT has been operating for only approximately one year, significant gains (both fiscal and non-fiscal) have been made both on the CWM project and on other PG&E projects with the same regulatory agency oversight. Specifically, the HPT format has promoted better communication among the team members and a notable increase in trust between PG&E and the regulatory agencies. By the completion of the project, the CWM HPT will have:

- Expedited completion and review of the FS for all three sites. As each step of the FS process is completed by the HPT, a technical memorandum is prepared and reviewed by the team. When the FS is complete, these memoranda will be compiled along with an introduction to form the body of the FS. Because each memorandum is reviewed and approved by the HPT as it is prepared, final review of the FS will be a formality.

- Developed an advisory cleanup standard for remediation. This cleanup standard is developed with the recognition that it is a target that the HPT is trying to achieve, and that, given the uncertainties inherent in site remediation, this target may change. The paradigm shift of recognizing the cleanup standard as a target and not an absolute gives the HPT "permission" to be flexible in its remediation and to do what is best for the site, most protective of human health and the environment, and cost and time effective.
- Evaluated a greater array of remedial alternatives and cost savings, by evaluating remediation at three sites at once, than would have been possible for each site if taken individually (i.e., taking advantage of cost savings by negotiating contracts for work at all three sites rather than for each individual site).
- Promoted management of uncertainty through contingency planning prior to remediation, and through HPT communication during remediation to allow for expedited decisionmaking.

Contacts

Robert Doss, Director of Site Remediation, Pacific Gas and Electric Company, (415) 973-7601

Francis Anderson, California EPA, Department of Toxic Substances Control, (916) 255-3733

NJDEP/PSE&G MGP Site Remediation Streamlining Team

In April and May of 1995, PSE&G met with the NJDEP to discuss the potential to work with the NJDEP SRP to streamline the MGP site remediation program. As the result of discussions between the two organizations, the NJDEP / PSE&G Streamlining Team was established with executive sponsors and co-chairs from each organization. The goals of the Streamlining Team were stated as:

In partnership, NJDEP and PSE&G will identify and evaluate the process of MGP site investigation and remediation with the objective of streamlining the process. The Streamlining Team will identify opportunities for improvement, consistency of approach, and cost effectiveness. The Streamlining Team will develop a model that will reflect increased cooperation and teamwork between NJDEP and PSE&G and should provide measurement and oversight of improvement initiatives. Impediments that exist in achieving the above will be identified with improvements recommended (NJDEP / PSE&G, 1996).

The Streamlining Team initially defined major "issues" that are barriers to efficient and effective site remediation, identifying causes and developing solutions for each. The solutions were subsequently grouped by relative ease of implementation and potential for cost and/or time savings. Two basic categories of recommended solutions resulted:

- Solutions that were within the control and authority of the Streamlining Team to implement and would result in relatively greater cost or time savings while ensuring protection of human health and the environment
- Solutions that were beyond the control and authority of the Streamlining Team to implement but would provide relatively greater cost or time savings while ensuring protection of human health and the environment

The Streamlining Team then produced detailed implementation plans for the recommended solutions that were within the control and authority of the team to implement. Solutions that were beyond the control or authority of the Team were sent as recommendations to the NJDEP Green & Gold Task Force Site Remediation Subcommittee.

Using the detailed implementation plan prepared by the Streamlining Team, it was estimated that the time for the RI phase could be shortened by 30 percent and costs for RI work plans could be reduced by approximately 40 percent, that remedial investigation costs could be reduced by 30 to 50 percent, and that remedial investigation report approval time could be shortened by 30 percent to 40 percent.

Solutions included:

- Establish a dedicated NJDEP case team for PSE&G projects to enhance communications, encourage empowerment, enhance consistency of application of regulatory requirements, facilitate increased availability of regulatory staff, and streamline regulatory agency oversight.
- Establish periodic executive level reviews of program initiatives and results.
- Develop standard report "terms and conditions" for all PSE&G sites.
- Establish standard procedures to ensure proper treatment/disposal of wastes and/or contamination.
- Establish joint cycle time targets for delivery and approval of plans, reports, and work-related activities.
- Develop a generic RI work plan, including standard operating procedures, to streamline site-specific work plan preparation and review.

Contacts

Rich Blackman, Public Service Electric & Gas, (973) 430-8278

Woerner Max, Public Service Electric & Gas, (973) 430-6413

Chris Kanakis, New Jersey Department of Environmental Protection, (609) 633-1460

3.2.5 Early Land-Use Determination/Brownfields

Whether an environmentally distressed MGP site is a long-abandoned brownfield or is still owned and operated by a public or private utility, remediation can be expedited by developing an appropriate, beneficial reuse strategy. The remedial approach can then focus on cleaning the site up to a level acceptable for its future use (e.g., residential, industrial or commercial). Early land-use determination usually requires a multi-faceted team (including real estate professionals, land-use planners, local redevelopment agencies and environmental groups, financial analysts, community relations specialists, regulators, insurance professionals, remediation engineers, and others) and depends, ultimately, on the opportunity for local real estate development. Successful projects have identified a beneficial use for former MGP sites that increased their asset value and / or offered multiple other benefits to the local community. This strategy only works when the economics of the project are adequate to support both remedial cleanup and development of the site after cleanup.

The USEPA has recognized that restoring a contaminated property can bring strength and life to a community. They have defined brownfields as abandoned, idle, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. To promote brownfields redevelopment, the USEPA announced its Brownfields Action Agenda in January of 1995. This agenda outlined four key areas of action for returning brownfields to productive use:

- Awarding Brownfields Pilot Grants
- Clarifying liability and cleanup issues
- Building partnerships with all brownfields stakeholders
- Fostering local workforce development and job training initiatives

In May of 1997, the USEPA expanded its Brownfields Initiative by announcing the *Brownfields National Partnership Action Agenda* which provided a framework for cooperation among governments, businesses, and non-governmental organizations. The Brownfields Partnership addressed all aspects of the brownfields processes with monetary commitments from federal agencies and non-governmental organizations. To date, USEPA has funded more than 120 brownfields pilot projects.

A key to the success of the Brownfields program is the clarification of liability and cleanup issues. To address these issues, USEPA developed guidance promoting early land-use planning discussions and the use of Prospective Purchasers of Contaminated Property Agreements under which USEPA agrees not to sue the buyer of a property for existing contamination. USEPA also developed and issued policies on:

- The issuance of comfort letters (letters sent to stakeholders who need information on USEPA’s involvement at potentially contaminated properties)

- Circumstances under which USEPA will not pursue the owners of property where groundwater contamination has migrated to their property in instances where the owner did not contribute to the contamination
- Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA) enforcement against lenders and government entities that acquire property involuntarily
- The Underground Storage Tank Lender Liability Rule

Tool Description

The intent of the early land-use strategy is to evaluate a variety of potential land reuse options (for one site or a portfolio of sites) and to select reuse options that meet the following criteria:

- Local market need
  - Availability of potential developers interested in the reuse option
- Profitable financial analysis
  - Financial analysis including cost of remediation and liability management
  - Reasonable profit and return on investment
  - Insurance products
- Environmental compatibility
  - Regulatory agencies willing to provide “comfort letters” or “covenants not to sue” after remediation is complete
  - Cleanup levels based on reuse approach, limited remediation risks
- Physical feasibility
- Political acceptability (if local community approval is required)
  - Support of community and local government
  - Assurance that zoning changes can be achieved for the planned property use

Typically, real estate reuse specialists evaluate potential reuse options and work with remedial engineers and regulatory analysts to consider the level of cleanup and redevelopment necessary for these options. For options with merit, a financial analysis is developed. The analysis may indicate that the cost of remediation for a given site exceeds the potential revenue for all reuse options considered. When this is the case, early land-use determination will no longer be appropriate unless the owner can include the site within a portfolio of sites that, together, make up a financially feasible reuse package. There are developers who specialize in evaluating and purchasing portfolios of environmentally distressed properties. They evaluate the economics of a portfolio as a whole. If there is sufficient return on investment from the whole portfolio, the loss associated with individual sites that cannot be cost effectively redeveloped is acceptable.

When a site is being considered for a reuse option, the project's success rests on acceptance and buy-in of all parties. Once all affected parties accept the reuse option, a reuse-specific risk-based management plan can be developed and supported by the regulatory agencies with authority over the project. There is significant support within the USEPA and many state environmental regulatory agencies for risk-based approaches to remediation and reuse of historically contaminated industrial properties.

Assuming that stakeholders in the property all accept a recommended reuse option, a development plan and marketing package can be prepared to solicit bids, or the site owner can choose a specific developer for the entire process. Once the developer is selected, insurance can also be used to limit the remediation cost and to specify how remaining or future environmental liability will be apportioned (Daddario, 1997; Voorhees, 1997; Barnett Alexander, 1997).

Case Studies

Bangor Gas Works, Bangor, Maine (Adaptive Reuse of Coal Gasification Superfund Facility to Supermarket)

Coal gasification processing occurred from 1853 to 1963 at the Bangor Gas Works, resulting in widespread coal tar contamination of soil and groundwater at the site. Large quantities of viscous tar had been stored in on-site underground storage tanks. The property was eventually abandoned. The City of Bangor purchased the 4-acre property, located in a mixed residential and commercial area, in 1978. After the purchase, the city discovered an underground tank containing 45,000 gallons of coal tar as well as other underground contamination consisting of subsurface pools of coal tar and related substances. Within 1 mile of the site there are wetlands and the Penobscot River, which supports salmon, rainbow trout, and spring smelt.

In 1978, the City of Bangor alerted the Maine DEP to the site contamination. The Maine DEP oversaw initial remedial actions, which included:

- Filling the underground tank with clay
- Demolishing the old gasification buildings
- Paving over the site to create a parking lot

Subsequent investigations confirmed that these actions would prevent the coal tar from migrating off site.

In 1990, USEPA placed the site on the Comprehensive Environmental Response, Compensation and Liability Act Information Systems (CERCLIS) list. Maine DEP accessed Superfund monies and performed a preliminary assessment of the contamination and a site inspection. The studies concluded that the previous asphalt paving had adequately reduced the potential for migration or direct contact with the contaminated soil through an airborne release. In 1994, after the study results were made public, the City of Bangor, Shaw's Supermarket, and Boulos Developers agreed to build a 60,000-square-foot supermarket on the site and adjacent properties. The project cost was $9.5 million.

A partnership was formed between the City of Bangor, USEPA, and Maine DEP to develop a plan that would permit concurrent cleanup and redevelopment. In 1996, a multi-layer cap was constructed over the areas where coal tar by-products remained, so all sources of contamination would be isolated prior to building. The new supermarket was intended to be the largest in the area and thus would spur economic expansion and downtown redevelopment (USEPA, 1998a).

The Bangor gas works site consists of a number of parcels. In addition to the portion that has been the subject of redevelopment to date, a number of parcels are still being investigated, and as appropriate, remediated.

Site remediation/redevelopment involved a number of actions to address contamination. In the 1970s, with Maine DEP approval, 430,000 gallons of coal tar were removed from the site and burned in a paper mill boiler. Analysis of location, characteristics, and fate and transport aspects of residual contamination indicated that further excavation was not warranted at the time. The site currently has a cap and a passive venting system and is subject to deed restrictions. If conditions warrant, the passive venting can be converted to active extraction.

Contacts

Stan Moses, City of Bangor, Department of Economic Development, (207) 945-4400

John Harris, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, (703) 603-9075

Wisconsin Electric Power Company, Racine, Wisconsin (Adaptive Reuse of Manufactured Gas Plant Site to Mixed Use Development)

Wisconsin Electric Power Company (WEPCO) historically operated a coal gasification plant on 11 waterfront acres in downtown Racine, Wisconsin. Contamination requiring remediation was identified at the site.

Prior to initiating remediation, WEPCO decided to hire a consultant to evaluate potential reuse options for the site. The consultant performed both a physical and marketing analysis. The analysis determined that the property had significant value with potential for a variety of multiple uses that would also assist in revitalization of the city. The reuse option selected was a waterfront community, now known as Gaslight Pointe.

Remedial actions conducted on the Racine site prior to redevelopment included the removal of tar holders and highly contaminated soil. The site was then capped, and a groundwater extraction and treatment system was installed to address groundwater contamination. A soil venting and vapor extraction system was also installed to prevent fume buildup in buildings to be constructed on the site. Gaslight Pointe now includes a marina, townhouses, a hotel, and retail stores.

The development team agreed on a divestment to a specific developer/builder. WEPCO assumed no risk and did not need to invest new capital. The remediation and regulatory approval process focused on the newly recommended redevelopment use.

Gaslight Pointe has been a qualified success. It has resulted in reasonable returns for Wisconsin Energy Corporation as well as providing a source of new jobs and tax revenues for the community (Barnett Alexander, 1997). Most importantly, it has completely transformed a previously blighted property into a significant focal point in the community.

Contact

James W. Lingle, Wisconsin Electric Power Company, (414) 221-2156

3.2.6 Managing Uncertainty (Observational Approach)

Tool Description

Uncertainty is pervasive in the characterization and remediation of all kinds of contaminated sites, including MGP sites. One approach to managing uncertainty is the observational method. This method provides a way to determine when sufficient site characterization data have been collected and involves managing uncertainties through the identification of reasonable deviations from original plans if changed conditions materialize, and contingency plans to address these deviations. The observational approach entails monitoring site conditions during remediation and implementing contingency plans as needed. Using the observational method gives the flexibility to modify an RA to address conditions as they are discovered while still completing the action on time and under budget.

Managing uncertainties when applying one or more remedial technologies at a manufactured gas plant site requires two important pieces of information:

- The input, process, or environmental variables (e.g., contaminant composition, temperature, soil structure, moisture content) that affect a remedy's success
- The values of those variables throughout the implementation of the remedy

For ex situ remedial processes (e.g., thermal desorption, catalytic oxidation), this information can be obtained with relative ease. Process designers can incorporate the instrumentation and controls necessary to measure the critical process variables and perform adjustments to optimize process performance.

In situ remedial processes are more difficult. Unless a site is very small and/or the process is incredibly adaptive and robust, it is difficult to have all the information needed about the values of critical process variables (e.g., soil moisture). For example, the heterogeneity of subsurface soils and the lack of good subsurface analytical technologies make it virtually impossible to map the values of process variables throughout a site. With today's technology, the best achievable result is a reasonable estimate of the range of these variables.

Scientists and engineers working on subsurface construction problems (e.g., foundations, dams, tunnels) have found a way to manage the uncertainties associated with in situ remediation. Geotechnical engineers have addressed problems of this nature for decades using the observational method (Peck, 1969). Karl Terzaghi described the conditions for this application almost 50 years ago:

> "In the engineering for such works as large foundations, tunnels, cuts and earth dams, a vast amount of effort goes into securing only rough approximate values for the physical constants that appear in the equations. Many variables, such as the degree of continuity of important strata or the pressure conditions of water contained in the soils, remain unknown. Therefore, the results of computations are not more than working hypotheses, subject to confirmation or modification during construction" (quoted by Peck, 1969).

The table on the fofllowing page summarizes the key elements of the observational approach applied to hazardous waste sites.

Elements of the Observational Approach
■ Explore to establish general conditions ■ Assess probable conditions and reasonable deviations - Depends on remedial technology ■ Design for probable conditions - Define remedial end point(s) and how to measure - Select design/implementation modification for each potential deviation - Select parameters to observe and define how to measure - Determine expected values of parameters for remedial technology under probable conditions and deviations ■ Implement remedial technology - Observe parameters and compare to anticipated values - Implement preplanned actions if deviations detected

Hazardous waste sites involve uncertain subsurface conditions such as those found by geotechnical engineers at any site but also entail uncertain chemical and biological parameters. The principal differences from the traditional linear study-design-build model and the observational methods are the explicit recognition of uncertainty, characterization of states of uncertainty via scenario development (i.e., deviations), monitoring for deviations, and preplanning for contingencies. This is a management approach with feedback loops and preplanned responses.

The success of the observational approach depends upon the ability to alter a site investigation and / or remediation in the field based on pre-determined contingency plans. Therefore, the observational approach is not suitable for sites where there are no available contingent actions for site conditions within an allowable response time (e.g., a release of contaminants to the atmosphere that cannot be detected in time to implement a contingency plan).

During the past eight years, the observational method has been increasingly used for the remediation of hazardous waste sites because it offers two key benefits:

- ■ The method provides a means to determine when sufficient site characterization data have been collected.

- The method makes it possible to continue the project by managing uncertainty through contingency planning rather than trying to overcome it through additional study or highly conservative remedial design.

Case Studies

An Observational Approach to Removing Light Non-Aqueous Phase Liquids (LNAPLS)

Background

An operating bulk petroleum products storage and transfer facility, 43 hectares in size, contained approximately 11 million liters of light non-aqueous phase liquid (LNAPL) in the vadose zone beneath the site. The LNAPL was composed of approximately 70 percent gasoline-range hydrocarbons and 30 percent diesel-range hydrocarbons and had been located under the site for approximately 68 years. The hydrogeology underlying the site was composed of discontinuous alluvial and eolian Pleistocene deposits of sand, silty sands, silts, clayey silts, and dense clays. Depth to groundwater was approximately 3 to 6 meters below grade, and a cyclic rising and lowering water table resulted in LNAPL being trapped below the water table at some locations and perched above the water table at other locations, depending upon the small-scale subsurface stratigraphy.

During 10 years of site characterization, more than 100 borings and wells were installed at the site. Based on the information gathered from these borings, 60 product-extraction wells were installed to remediate the site. Numerous piezometers and groundwater monitoring wells were also installed to monitoring the performance of the extraction system.

The extraction system installed following the site characterization operated ineffectively because of the site’s stratigraphic heterogeneities. Some wells in the system produced LNAPL beyond expectations while other wells extracted practically no product. After several years of operation, the site owner wanted to expand the LNAPL removal system to increase overall extraction efficiency, but, because of the stratigraphic heterogeneities, there was significant uncertainty regarding how a particular LNAPL removal technology or design would perform in different portions of the site (Haimann, 1996).

Probable Site Conditions

LNAPL flow in the subsurface occurs in the vadose or unsaturated zone and is therefore dominated by capillary forces. Capillary forces are, in turn, highly dependent upon soil type, specifically on pore-throat diameters. Pore-throat diameters vary substantially among different soil types; in alluvial deposits, diameters can vary by nearly the scale of the soil particles themselves. In addition, the soil types above and below LNAPL layer(s) can significantly affect the efficiency of a removal technology by influencing soil moisture and the ability of the LNAPL to move within the vadose zone. At this site, a conventional site remediation approach, where a final remedy with a high likelihood of success is selected, designed, and implemented, would be unlikely to succeed because of the small-scale heterogeneities observed in the subsurface. At a site such as this, the cost and time required to gather sufficient data to fully understand the scale and location of these heterogeneities could exceed the actual cost for several rounds of remediation. Recognizing that such a conventional approach was not an efficient use of resources, those managing the site selected the observational approach.

In a phased observational approach, remediation is implemented in distinct phases, without investigating the entire site, to the extent that sufficiently detailed information is available to design a site-wide system. In effect, each phase of remediation occurs simultaneously as a phase of investigation. In this case, the operation of the system and the response of the subsurface to LNAPL removal were monitored, and data were collected and used to interpret subsurface stratigraphic features. These features were then used to update the subsurface stratigraphic model and to design expansions and/or modifications to the LNAPL removal system.

Remedial Technology Design and Implementation

The initial phases of the project were focused on portions of the site where subsurface stratigraphy was understood well enough to design an LNAPL removal system. The subsurface stratigraphic information used to design this initial extraction phase had been gathered during the field investigations and operations of the early LNAPL removal systems. The effectiveness of the initial extractions was then monitored using subsurface monitoring points located at the edges of the extraction zone to determine reasonable deviations in the monitoring parameters (indicating the relative success of the treatment setup). Subsurface monitoring points included monitoring wells, piezometers, and soil vapor probes, and the types and locations of the monitoring points were varied depending upon the LNAPL removal technology implemented at the specific area (e.g., liquids extraction, vapor extraction, dual-phase extraction, bioslurping). Data collected and evaluated during monitoring included drawdown, product thickness, subsurface vacuum pressures, and vapor concentrations.

The results of the first phases of LNAPL extraction were used to select and design the extraction system for the second phase; the results of the second phase used to design a third, and so on (Haimann, 1996). Continuous monitoring of data during remedial implementation allowed for the implementation of preplanned actions (e.g., increasing number of extraction points) as needed to address site-specific subsurface conditions and uncertainties.

Conclusion

One of the key benefits of the phased approach was the immediate implementation of remediation. Early extraction of the LNAPL prevented further migration from the source. Under a conventional scenario, the elapsed time that would have been lost during an extended site characterization could have led to the additional spread of LNAPL and therefore increased remediation costs. Several other cost savings were realized by implementing the phased observational approach, including (Haimann, 1996):

- A significant reduction in investigation costs. Combining remediation and investigation into one field effort reduced the need for multiple mobilizations and management costs from an extended project schedule.

- Savings resulting from a reduction in liabilities. Early and proactive removal of LNAPL prevented migration in the subsurface and reduced expenses relating to litigation and additional cleanups from off-site contamination.

A reduction in overall project costs resulting from a shortened project duration. Combining remediation with investigation reduced the overall number of phases of field work and reduced the remediation schedule because LNAPL migration was restricted as a result of early remediation.

Application of the Observational Method to the Cleanup of a PCB Spill

Portland General Electric (PGE) operated a steam-powered electricity generating plant on a 28-acre site known as the Station L facility between the early 1900s and 1975. The Station L facility is located in Portland, Oregon, on the east bank of the Willamette River.

As part of a transfer of a portion of the Station L property, PGE initiated an investigation to identify areas where PCBs might have been released. This investigation led to the discovery of a historical PCB spill in the Willamette River. A review of company records showed that a transformer next to the generating plant had failed in 1971. PGE collected sediment samples to determine the extent of contamination and found that an approximately 80- by 120-foot area contained PCB concentrations ranging from non-detect to 286 mg/kg.

During a 2-year period, PGE evaluated different remedial alternatives, submitted RA plans to the Oregon Department of Environmental Quality (DEQ), and conducted a limited action to remove near-shore contaminated sediments exposed during low-flow conditions in the river. In February 1990, DEQ issued a Record of Decision (ROD) that stated that low-volume, diver-operated, performance-standard dredging was the preferred remedial alternative. The performance standard in the ROD was to remove, if practical, up to 2 feet of sediment in areas with PCB concentrations greater than 10 mg/kg. Dredging was to be conducted in a manner that would minimize sediment resuspension. The ROD provided for dewatering and disposal of dredged sediments in an approved disposal facility and water treatment to applicable standards prior to discharge to the Willamette River. Following dredging, the spill area was to be isolated by placing a 6-foot sand, gravel, and rock cap over sediments containing PCB concentrations greater than 1 mg/kg; the cap was to be constructed in a way that would also minimize sediment resuspension (Brown, 1988).

Early in the remedial design, it was recognized that a conventional engineering approach could not be used because the following were highly uncertain:

- Sediment characteristics
- Dredging equipment flow rates required for removing two feet of sediment
- The amount of sediment resuspension associated with low-volume, diver-operated dredging

- Water treatment system flow rate and influent sediment and PCB concentrations
- The amount of sediment resuspension associated with cap construction methods

To manage these uncertainties and meet an the extremely tight project schedule, the observational method was selected.

The observational method was used to manage virtually all areas of uncertainty. The most likely outcome, based on available site characterization data and previous diving contractor experience, was that the suction created by the low-volume, diver-operated dredge would be sufficient to contain any resuspended sediment. Further, it was assumed that the suction action of the dredge would prevent PCB concentrations downstream from the site from rising above the acute aquatic criterion. A reasonable deviation was that dredging would cause conditions that exceeded the acute aquatic criterion for PCBs.

The parameter selected for observation was turbidity because it could be measured in the field in time to implement a contingency plan if a deviation was detected. Direct measurement of PCB concentrations was not selected because sample results could not be obtained in time to implement a contingency plan. To satisfy DEQ's concern for aquatic protection, a correlation between turbidity and PCB concentration in water was developed before dredging was initiated. This correlation was developed by relating suspended sediment concentrations (using site-specific sediments) to turbidity, on the basis of the average PCB concentration in sediments at the site.

Potential contingency plans included increasing the dredge flow rate to increase the capture of resuspended sediments, modifying diver operations to reduce sediment resuspension, and, if neither of these plans worked, stopping dredging and construction of the sand, gravel, and rock cap.

Monitoring conducted during dredging demonstrated that the turbidity did not increase downstream of the site and the acute aquatic criterion was not exceeded. Because no deviation was observed, none of the contingency plans was implemented (Brown, 1988).

Conclusion

The observational method made it possible to implement a relatively innovative RA and still complete the project on time and under budget. During a 4-week period, 22 tons of sediment were removed and more than 500,000 gallons of water were treated. The average depth of sediment removal was 1 foot. PCB concentrations were reduced from an average of 12 mg/kg before dredging to 7 mg/kg after dredging. All of this work was conducted without any observable increase in turbidity, without exceeding the acute aquatic criterion for PCB, and without any contractor change orders. PGE, DEQ, and the contractor considered the project a success (Brown, 1988).

Contact
Dennis M. Norton, Manager, Environmental Services, Portland General Electric, (503) 464-8522

3.2.7 Expedited Site Characterization

Tool Description
The traditional RI/FS process, as commonly practiced during the 1980s and early 1990s, is a phased approach. It consists of an RI requiring iterations of work plan preparation, review, and approval; field work; and report preparation, review, and approval. These steps are all designed to characterize the horizontal and vertical extent of contamination at a site. This phased RI is then followed by the FS to determine an appropriate remedial scenario and often includes additional phases of field investigation to acquire additional data. Following the NCP regulations, the FS leads to preparation of a Remedial Action Plan (RAP) and RD, culminating in the actual RA, which often uncovers unexpected conditions and/or contamination, sending the whole process spiraling back to supplemental RIs and revised FSs. The result is lengthy and costly site investigation/remediation cycles.

Changing regulatory and economic environments requires new strategies to meet the same needs. Private and public entities must now meet environmental responsibilities in a time of tightening budgets and greater pressure to work in a faster and cheaper manner. Thus, processes are being developed to expedite the way RI/FS/RD/RAs are being conducted.

Expedited site characterization and closure involves a number of tools, strategies, and processes that interlink and synergistically help streamline investigation and remediation processes. Components of an expedited site characterization and closure can include the following:

- On-site or rapid decision-making capabilities
- Use of field sampling and analysis tools (such as mobile laboratories and field screening methods) to facilitate real-time data collection and interpretation
- Use of nonintrusive or minimally intrusive geophysical and/or sample techniques
- Communication and cooperation among responsible parties, regulatory agencies, and third-party stakeholders through mediation, facilitation, and HPTs
- Flexibility in the overall site characterization and remediation processes (e.g., setting flexible DQOs)
- Active management of uncertainties regarding the location of former MGP residues and their effects on remediation costs and technologies, through modeling and contingency planning
- A streamlined document preparation and review process

- A process for reducing team member turnover and minimizing the effects of team member replacement

Not all components may be necessary to expedite site characterization. Selections of those component most directly applicable to a site or set of sites can still yield cost and time savings**.**

Argonne National Laboratory Expedited Site Characterization Process

In 1994, Argonne National Laboratory developed an innovative, cost- and time-effective process for preremedial site characterization. The Expedited Site Characterization (ESC) process was developed to optimize site characterization field activities.

The Argonne ESC process:

- Is a process and not a single or specific technology or tool.
- Is flexible and neither site- nor contaminant-dependent.
- Demands the highest levels of accuracy.
- Is scientifically driven within a regulatory framework (i.e., regulatory guidance does not drive the program without science).
- Requires that all field activities potentially affecting the quality of results be addressed in a quality assurance and quality control (QA / QC) plan**.**

The basic steps of the Argonne ESC are:

Step 1: A team is formed, composed of an experienced technical manager with a broad base of experience and a team of scientists (including geologists, geochemists, hydrogeologists, biologists, health and safety personnel, computer scientists, etc.) with diverse expertise and strong field experience.

Step 2: The technical team critically reviews and interprets existing data for the site and its contaminants to determine which data sets are technically valid and can be used in initial design of the field program.

Step 3: After assembling and interpreting the existing data for the site, the technical team visits the site to identify the site characteristics that may prohibit or call for any particular technological approach.

Step 4: After the field visit, the team selects a suite of technologies appropriate to the problem and completes the design of the field program. Nonintrusive and minimally intrusive technologies are emphasized to minimize risk to the environment and public health.

Step 5: A dynamic work plan is prepared, outlining the technical program to be followed. The work plan must allow flexibility; therefore the HASP and QA / QC plan must encompass a broad range of possible work plan alterations.

Step 6: The team implements the field program. Data are collected, reduced, and interpreted each day. At the end of each day, the team meets, reviews results, and modifies the next day's program as necessary to optimize activities that generate overlapping or confirming site details.

Step 7: Daily results and modifications are transmitted to the project sponsor and regulators, allowing both to participate in early data review and decisionmaking for the site.

The ESC is an iterative process that optimizes field activities to produce a high-quality technical result in a time- and cost-effective manner. Because both on-site analytical and multiple hydrogeologic techniques are used, there is very little need to send nearly all samples off-site and to perform massive subsurface sampling in the absence of local hydrogeologic information. By including on-site decisionmaking, the ESC process can significantly reduce the probability of having to return to the site to fill data gaps. As a result, the current multiphase sequence of environmental data acquisition becomes compressed into a single real-time phase typically requiring only months to complete (Burton, 1994).

The Argonne ESC process is not the ideal process for all sites. However, the basic components of the ESC have been applied at other former MGP sites to expedite site characterization and remediation. These basic components are also included in the American Society for Testing and Materials' (ASTM) provisional standard guide for Accelerated Site Characterization for Confirmed and Suspected Petroleum Releases (PS 3-95) (ASTM, 1996). Although the types of contaminants found at former MGP sites are typically more complicated than those found at sites with only petroleum releases, the general process published by ASTM in their provisional standard guide is similar to that outlined for Argonne's ESC program. Both published programs involve review of existing site information and development of a conceptual model prior to sample collection, followed by an on-site iterative process designed to collect, analyze, and interpret all data in a single field program.

Case Studies

Marshalltown Former MGP Site

In 1994 and 1995, USEPA's Ames Laboratory adopted the Argonne National Laboratory's ESC process for demonstration at the Marshalltown former MGP site in Marshalltown, Iowa. The Marshalltown former MGP site was owned by IES Utilities, Inc., and was located in an old industrial area adjacent to an active railroad switching yard and main lines. Gas manufacturing operations occurred between the 1880s and 1950s, resulting in the release of a variety of MGP wastes, including coal tar, petroleum hydrocarbons, condensates, and oxides.

Before the ESC at the Marshalltown site, five rounds of field investigation and/or reporting had been conducted. Data collected during these investigations provided the historical and technical information necessary to select technologies and develop scopes of work for the ESC demonstration.

The ESC methodology applied at the Marshalltown former MGP site incorporated on-site decision-support technologies that enabled site characterizations to be completed in a consolidated package.

The principal characteristics of the Ames ESC were:

- Emphasis on geologic structure and hydrogeology to determine contaminant fate and transport
- Use of technologies by expert operators with flexible data quality objectives
- On-site data processing using mobile laboratories
- On-site decisionmaking
- Preference for nonintrusive or minimally intrusive geophysical techniques
- Minimization of intrusive sampling techniques
- A single team for planning and managing site work

The use of minimally intrusive survey techniques, on-site analytical technologies, and innovative sampling and screening technologies (such as the Site Characterization and Analysis Penetrometer System cone penetrometer unit and GeoProbe™ soil conductivity probe) to determine the local hydrogeologic setting, supported the potential for significant time and cost savings. For example, geophysical survey techniques including ground-penetrating radar, seismic reflection and refraction, electromagnetic offset logging, and borehole logging were applied at the site to define the surface of the bedrock and significant stratigraphic interfaces above the bedrock and to provide information regarding the distribution of PAH contamination (Bevolo, 1996). By including on-site decisionmaking, the Ames ESC process significantly reduced the number of iterations of field investigations that otherwise would have been necessary to fill data gaps. As a result, the typical cycles of work planning, field investigation, and reporting, which often take years to complete, were compressed into months.

Site Characterization

The Site Characterization and Analysis Penetrometer System (SCAPS) cone penetrometer unit, GeoProbe™ soil conductivity probe, and geophysical survey technologies provided very useful and reliable stratigraphic data. Side-by-side comparisons of the direct-push technology logs with previous investigation borehole logs indicated stratigraphic correspondence to within about 1 to 2 feet. It should be noted, however, that the previous data tended to provide a slightly deeper granular/lower cohesive unit contact than direct-push data. Usually, the major unit stratigraphic contacts were easily picked off of both the cone penetrometer testing (CPT) and soil conductivity logs, and were used to create a database from which a three-dimensional site stratigraphic model was generated.

Based on previous site characterization work, the lateral and vertical distribution of the dissolved PAHs and residual NAPL contamination was estimated. Assessment of the nature and distribution of the PAH contaminants was carried out using three types of technologies: Phase I screening technologies (immunoassays, passive and active soil gas, and chemiluminescence), Phase II screening technologies (laser-induced fluorescence probe, soil conductivity probe), and Phase II quantitative technologies (chemical analysis of soil samples with gas chromatography mass spectrometry instruments in field laboratories).

The Phase I contaminant screening technologies were applied in an effort to evaluate their ability to identify the approximate boundaries of the contaminated area. Duplicate soil samples were collected from different depths and analyzed using three different immunoassay techniques and the chemiluminescence system. In addition, passive and active soil gas samples were collected and analyzed from the approximate depths of the soil samples.

The presence or absence of detectable PAHs and the data from each of the three immunoassay analyses correlated fairly well with each other. Results from the chemiluminescence did not correlate as well. Active soil gas measurements for aromatic hydrocarbons and naphthalene showed good agreement with passive soil gas and immunoassay measurements. Overall, the results of the Phase I contaminant screening technologies generally compared well with the previous investigation results. One significant finding of the screening was that PAH contamination existed farther to the west than appeared from previous data.

Phase II contaminant screening was performed using the cone penetrometer laser-induced fluorescence (LIF) sensor system and the GeoProbe™ soil conductivity profiles. Chemical analysis of soil samples collected adjacent to LIF "hits" indicated that although the LIF sensor data could not be considered quantitative, it could reliably detect regions of low, medium, or high contamination. The LIF may be considered the most direct qualitative methodology for indicating regions of PAH contamination.

Phase II quantitative plume delineation efforts were planned and implemented based on results of previous investigations, Phase I and Phase II screening, and an updated site geologic model. The primary technology evaluation function of this part of Phase II was the comparison and assessment of five on-site extraction methods for PAHs in soil (sonication, microscale, microwave-enhanced extraction, thermal desorption, and supercritical fluid extraction).

Conclusion

A significant finding of the study was the potential for inconsistencies in procedures and results even with strict adherence to SW846 methods. The application, versatility, and high quality of data from direct-push technologies were demonstrated at the site.

The study also indicated the potential for significant variation of chemical analysis results for PAHs in soils. The uncertainty and potential variability associated with soil matrix effects, sample selection, and preparation and extraction procedures far outweigh inaccuracies in the chemical analysis methodologies themselves. The Phase I and Phase II screening results, including olfactory and visual data, gave a far better picture of the distribution and extent of contamination than the quantitative analysis results.

The Ames ESC team implemented the ESC model using many of the tools that are essential to ESC, such as a dynamic work plan real-time data analysis and incorporation of stakeholders in the decisionmaking process. Establishing and maintaining close communications with the regulators was viewed as critically important, and significant efforts were made to invite participation from stakeholder groups including local residents, community organizations, educators, students, trade press, local media, etc. (Bevolo, 1996).

Contacts

Dr. Al Bevolo, Ames Laboratory, Iowa State University, (515) 294-5992

Bruce Greer, Alliant Energy, (608) 252-3948

Johanshir Golchin, Iowa Department of Natural Resources, (515) 281-8925

Pacific Gas and Electric Company Chico/Willows/Marysville Former MGPs

In 1994, Pacific Gas and Electric Company (PG&E) initiated the RI/FS/RD/RA process for three of its former MGP sites where Preliminary Endangerment Assessments (PEAs) had been completed in 1991. PG&E chose the former MGP sites in Chico, Willows, and Marysville, California, because they had similar operating histories and MGP-related contaminants, similar geologic settings, and were in close geographic proximity. Recognizing the advantages of streamlining the RI/FS process, PG&E initially combined or "bundled" the sites into one project, negotiating one order for the three sites with the California EPA Department of Toxic Substances Control (DTSC). Representatives from PG&E and its consultant as well as the state's primary regulatory agencies (DTSC and the Regional Water Quality Control Board) were identified to serve as primary case managers for all three sites. In 1996, an alternative, streamlined approach to the RI/FS was proposed and adopted in addition to the site bundling implemented earlier.

Streamlining the RI

By bundling three sites into one "package," PG&E observed immediate cost savings from reducing the volume of paper documentation and negotiating lower unit pricing as a result of larger volumes of laboratory analyses and work than would have applied to a single site. Further cost savings were achieved by negotiating one order with regulatory agencies and incurring oversight costs for only one regulatory agency caseworker for all three sites and by preparing one HASP and one RI work plan for the three sites. This work plan outlined the field sampling protocols and described the decision process by which field crews would identify and justify field sampling locations. These protocols were then used along with a field sampling flowchart in lieu of figures identifying specific locations for sampling. Such predetermined processes for decisionmaking and communications enabled the team to actively manage uncertainty about the extent of onsite contamination. Therefore, the number of field investigations required to adequately characterize the sites was significantly reduced.

The RI field programs developed for the three former MGP sites were further tailored so that field crews went from site to site (Willows and Chico are 45 minutes apart by automobile; Chico and Marysville are approximately one hour apart), circling back after well seals had cured and wells could be developed and sampled. Thus, well development and sampling took place in a short time. As part of the streamlined field program, lower unit pricing was negotiated with subcontractors (drilling and analytical laboratory) by offering larger volumes of work than would have been the case for a single site. Field personnel used in situ samplers (e.g., Hydropunch™ and Simulprobe™ samplers) and field screening tools (Handby colorimetric kits and Petrosense™ probes) to further aid in field evaluations of the extent of contamination. Through site bundling and field decisionmaking (aided by in situ and field screening tools), PG&E saved an estimated $120,000 during the preliminary phase of the RI/FS alone.

Streamlining the FS

As the Chico/Willows/Marysville (CWM) project continued into the FS stage, the project team adopted additional measures to streamline the project. The backbone of these measures was the formation of an HPT, discussed previously in greater detail in Section 3.2.4.

Significant gains have been made to date as a result of the streamlining at the CWM sites. Expenditures have been decreased by bundling of sites and by allowing flexibility to modify field programs during implementation. This flexibility has reduced the number of phases of field sampling required to determine the extent of contamination. In addition, both the CWM project and other PG&E projects with the same regulatory agency oversight have benefitted from the improved communication and trust between PG&E and the regulatory agencies as a result of the HPT's work.

Contact

Robert C. Doss, Pacific Gas and Electric Company, (415) 973-7601

3.2.8 Legislative Innovation

Tool Description

Recognition of the need to change the RI/FS/RD/RA process is not limited to consultants and private organizations; regulatory agencies have also seen the need to streamline site characterization and remediation. Legislative innovations have created a range of programs for regulatory agencies to streamline site remediations in the hope of significantly lessening current and future threats to human health and the environment in a much shorter time period than possible using the traditional RI/FS/RD/RA process. An example is the pilot Expedited Remedial Action Program currently being implemented by the State of California.

California Expedited Remedial Action Program

The California Expedited Remedial Action Program (ERAP) was established under the authority of the Expedited Remedial Action Reform Act of 1994. Its purpose is to test alternative regulatory policies for the remediation of contaminated properties by providing for a comprehensive program that includes revised liability based on fair and equitable standards, indemnification protection through a covenant not to sue, risk-based cleanups based on the ultimate use of sites, streamlined remediation processes, and a dispute resolution process. Because sites involved in the ERAP process follow the California Uniform Agency Review Hazardous Materials Release Sites (California Health and Safety Code Division 20, Chapter 6.65), permits and certification are issued through one lead oversight agency, which minimizes duplicate efforts among regulatory agencies (Cambridge, 1998).

Only 30 sites may participate in the pilot project; participation is voluntary by responsible parties (RPs) for sites. Participants must agree to pay for all oversight costs not paid by another RP or the trust fund designated for “orphan shares;” response costs apportioned to parties that cannot be located, identified, or are insolvent are considered orphan shares. If monies are available in the trust fund established for ERAP, these are refunded to the RPs once a site is certified. Only 10 sites in the pilot program may be designated as orphan share sites (Cambridge, 1998).

Case Study

Alhambra Former MGP Site

In Alhambra, California, Southern California Gas Company (SoCal Gas) elected to participate in the California EPA DTSC and ERAP to expedite cleanup of the Alhambra MGP site.

Site Background

SoCal Gas entered into a Remedial Action Consent Order with the DTSC on May 5, 1994, to perform remedial investigations at the Alhambra MGP. On September 22, 1995, SoCal Gas submitted to DTSC a Notice of Intent to have the site participate in ERAP. The site was admitted into ERAP on November 27, 1995, and thus was no longer subject to the Remedial Action Consent Order. In March 1996, DTSC and SoCal Gas signed an Enforceable Agreement for performing a site investigation and remediation. DTSC became the lead agency for the site cleanup.

The site consists of 20 residential lots on 2.4 acres. An MGP operated at the site from 1906 to 1913. SoCal Gas acquired the property, which had had two previous owners, in March 1939 after the gas plant had been dismantled, and sold the property to an individual in September 1939. This owner then subdivided the property and sold the lots for residential development beginning in 1940.

Investigations prior to the site’s inclusion in ERAP had shown MGP residues—arsenic, lead, and cPAHs—might be present in on-site soils at levels that would exceed risk-based soil concentration goals. Therefore, a site inspection was conducted after the site’s admission into ERAP.

The SI concluded that there was significant, widespread contamination in soils at the site. The level of contamination required excavation and removal to eliminate threats to public health and the environment. The SI also determined that groundwater had not been affected by MGP wastes.

The RA goal for the Alhambra site was to restore the levels of chemical exposure to background conditions. Values were established using a statistical evaluation of a background data set, which consisted of 184 samples collected over 20 different locations in Southern California. The remedial action plan (RAP) proposed the excavation and removal of all contaminated soil from the front and backyards of 18 of the 20 homes located on-site. The RAP also proposed removing all contaminated soil in the crawlspaces underneath each home.

A number of public meetings and other community outreach efforts were undertaken. The site's residential community was multicultural, with the languages spoken among 20 property owners including English, Spanish, Vietnamese, Cantonese, and Mandarin. All fact sheets and public notices were translated into those languages. At the public meeting for the RAP, four translators were present to address questions from the audience. All one-on-one meetings held between on-site residents and DTSC and SoCal Gas representatives had an interpreter present, if needed.

The final RA for the site began on July 23, 1997. The excavation portion of the project was done in phases. Four families would be relocated at a time, and excavation and removal activities would focus on those four properties. A relocation company handled details of moving residents. After completion of excavation activities at each house, backfilling and restoration activities included replacement of all landscaping and hardscaping removed as a result of the remedial activities. Remedial activities at the site were completed on February 13, 1998. The total volume of contaminated soil removed was 9,000 tons. DTSC issued a certificate of completion to SoCal Gas on February 27, 1998. The site evaluation and cleanup under ERAP took just over two years.

Benefits of ERAP

Sites posing the greatest public health or environmental threat are the highest priority for remediation. The Alhambra property was a natural priority because the presence of on-site residents created a high probability of direct exposure. SoCal Gas had reservations about proceeding with remediation in view of uncertainties about the requirements and effectiveness of the cleanup, the interruption to residents' lives, the possible liability resulting from cleanup, and the time and cost involved. The ERAP pilot project provided some assurance that the cleanup would be efficient and made explicit the potential risks and liabilities of remediation. SoCal Gas viewed the most beneficial aspects of ERAP as:

- **"Lead" Agency Designation—**DTSC, as lead agency, communicated with the other state and local agencies involved with the site. Contacts occurred early, during the preparation of the application package for the program. At this stage, DTSC contacted each affected agency to determine its concerns and anticipated level of involvement so these could be incorporated up front. Once the site was selected, DTSC invited these agencies to participate in the site conference that was required within 90 days of site designation. This provided other agencies with an opportunity to raise issues that could then be incorporated into work plans. Once site remediation was completed, DTSC issued a certificate of completion, which provides regulatory clearance from all other state and local agencies regarding hazardous substances issues. This certificate indicates that SoCal Gas's remediation of the site is complete.

- **Guidelines for Public Participation and Involvement**— ERAP provides that the party responsible for a site must comply with DTSC's public participation manual. Public participation was essential to the success of this project. In addition to fact sheets and an information repository, many public meetings, both formal and informal, were conducted to facilitate ongoing discussions. Most notable were the one-on-one discussions with residents. These contacts meant that the project managers considered residents' perspectives when making decisions, such as what types of trees or grass to replant during the landscaping activities and the timing of each activity. The result of the public participation efforts was positive community response to the cleanup.

- **Risk-Based Decisionmaking**—Any remedial action proposed by an RP must leave a site in a condition appropriate to its planned use without any significant risk to human health or the environment. Under ERAP, RPs are provided flexibility when selecting the remedial action; the DTSC does not give special preference to any particular actions. Evaluation of the remedial actions is based on their individual merit in light of site-specific conditions. Although this provision is most applicable to sites that will be used for commercial or industrial purposes, SoCal Gas demonstrated it could be applied to residential sites.

- **Apportionment of Liability Based on Fair and Equitable Principles and Orphan Share Funding** —The process for apportioning liability among parties potentially responsible for a site (e.g., previous and current owners) involves assigning to each a percentage of liability for necessary remedial action at a site. As an alternative to liability determination through judicial process (cost recovery under CERCLA), ERAP provides for DTSC to apportion liability to each RP. For this site, SoCal Gas was able to recover some cleanup costs through DTSC's apportionment of liability to orphan shares.

- **Indemnification through a Covenant Not to Sue** — Within the ERAP enforceable agreement is a requirement for a covenant not to sue under CERCLA between DTSC and the RPs who are signatories to the agreement. This covenant is conditional on performance of all obligations of CERCLA and the conditions outlined in the enforceable agreement. This covenant becomes effective upon completion of the RAP and receipt of the certificate of completion. Because the certificate of completion for the site is issued under the provisions of the Unified Agency Review Law, the RP can qualify for immunity and protection from future liability. However, the covenant not to sue does not apply to natural resource damage claims filed pursuant to CERCLA. SoCal Gas valued the protections afforded by this covenant, which significantly reduced the risk of future claims being made against the company because of the Alhambra site. The ERAP process also provides assurance that other agencies will not take additional enforcement actions in the future.

Conclusion

The Alhambra former MGP site is an example of a site remediated after a residential community was established there. Because residents live on-site, direct exposure to MGP residues was the greatest health risk. The focus of the project was to restore the site to background exposure levels and return the residents to their homes in the shortest amount of time with the least amount of disruption. Of most importance to SoCal Gas was the definition of the time and costs associated with the project and the determination of the company's liability. The ERAP program provided SoCal Gas with assurances regarding risks as well as monetary relief from the ERAP trust fund, which will reimburse costs assigned to orphan shares.

Contact

Megan Cambridge and Adam Palmer, California EPA DTSC, (916) 255-3773

3.2.9 Dovetailing Business Decisionmaking and Remediation Planning

Tool Description

Combining remediation strategies with business decisions can, when the circumstances are appropriate, provide additional opportunities for significant savings in total remedial cost, the effort required to secure permits, or time required to complete the project. The greatest cost and time savings are realized when remediation, land use / reuse, and business considerations can be aligned.

Depending on factors such as the numbers of MGP sites requiring remediation in a given area and the types of wastes involved, a number of business strategies may make sense. Parties responsible for one or more MGP sites may want to consider options such as: entering into a business venture with a local facility that could treat the MGP wastes; purchasing rather than renting remediation equipment; developing an affiliate company that markets cleaned and treated soil and / or provides cleanup services to others after MGP site remediation is complete; or undertaking a joint venture to create a mobile or fixed treatment facility. These options may offer significant savings in total time and cost of a remediation project.

The following list of questions is designed to help determine whether undertaking a remediation business venture might expedite and reduce the long-term costs of remediation:

(1) Are there multiple MGP sites in close proximity that have large volumes of contaminated materials that could be treated using the same remediation technology? (The sites may have multiple owners as long as they have similar wastes.)

(2) Are there other sites in the area with large volumes of similar waste that could also be treated with this remediation technology?

(3) Are there local political, community, and land reuse / redevelopment conditions that would predispose regulators to approve a remediation approach targeting multiple sites?

(4) What are the actual contaminants and their concentration levels?

(5) Do these contaminants lend themselves to off-site remedial treatment that would meet regulatory cleanup criteria? (e.g., non-hazardous vs. hazardous)

(6) Are there conveniently located facilities that could accept the contaminated material as supplemental fuel for blending? Examples include utility boilers, cement kilns, and asphalt batching facilities. Alternatively, is there a local waste treatment facility that could treat these wastes or incorporate a process to do so? If so, could this facility readily expand its permit to incorporate the new treatment process? Does this facility have adequate room to add such a treatment process?

(7) Has the local state environmental regulatory agency approved a permit for the treatment approach of interest in the past?

(8) Is there a regulatory process in place that would allow testing and approving the treatment process for the MGP application?

(9) Is the local operating facility or disposal / treatment company willing to assume financial and other risks in exchange for a guarantee to be given a specific amount of material for treatment?

(10) If there is no local facility in a position to accept the wastes in question, what are the economics of purchasing rather than renting remediation equipment (e.g., thermal desorbers, asphalt batchers)? This analysis should take into consideration the long-term costs of treating all MGP sites for which the party in question is responsible.

(11) Is there a market for cleaned or treated soil from the site(s) (e.g., for clean fill, asphalt, etc.)?

(12) Is there a market at other sites for the same remediation services required at the MGP site(s)?

(13) Are there local operating facilities or disposal treatment companies that are entrepreneurially oriented and willing to assume financial and other risks in exchange for a guaranteed volume of material for treatment?

Reviewing the answers to these questions can help clarify the opportunities to combine remediation efforts for several sites and / or to undertake new business efforts that can continue after remediation of a company's own sites is complete. Opportunities for off-site remedial treatment at fixed treatment facilities are ideal because the process of obtaining environmental permits is simplified if the waste materials are treated at one location. In addition, a fixed facility can draw input (contaminated materials) from a larger area and operate more efficiently than a mobile facility, thereby offering its customers a unit cost reduction borne from the economics of scale. However, it is also possible to form successful business ventures to treat wastes using mobile facilities at multiple sites.

Remediation business ventures are most promising in a geographical area where there has been considerable past utility / industrial activity, so large quantities of contaminated materials requiring remediation are likely to be present. Such areas are likely to already have waste or hazardous waste treatment / disposal facilities, co-burning boilers, cement kilns, and / or asphalt batch plants nearby with whom joint ventures can be undertaken. If off-site (fixed) treatment facilities are not readily accessible, however, there is the possibility of purchasing treatment equipment, developing a mobile facility or entering into a business agreement to construct an off-site facility. The success of a project like this often hinges on the local regulatory agency's willingness to consider such ventures. Whenever there is a local need for redevelopment of several contaminated sites, the area's long-term cleanup needs can be used as an argument to support a proposal for a remediation business venture.

Case Study

Several related case examples are provided for co-burning (Section 5.2.1) and asphalt batching (Section 5.2.3)**.**

Mid Atlantic Recycling Technologies Inc. (MART)

A New Jersey utility owned multiple MGP sites contaminated with typical MGP wastes. Ten of these sites were scheduled for eventual remediation. In considering options to reduce overall remediation costs, the utility evaluated its business options in light of the upcoming remediations. Because the company owned multiple sites with large volumes of contaminated soil, it sought options that would take advantage of economies of scale during remediation. The utility also hoped to return treated soil to the original sites.

In response to the utility's need, two environmental service companies, Casie Protank and American Eco Corporation, formed Mid Atlantic Recycling Technologies Inc. (MART). (Casie Protank owns and operates a waste transportation, transfer, and treatment facility in New Jersey. American Eco Corporation provides environmental, construction, and industrial services.) The utility and its remediation contractor negotiated a 5-year agreement with MART that committed MART to providing financing and then constructing and operating a thermal desorption facility specifically to treat MGP-contaminated soil. The facility is located in Vineland, New Jersey. The intent was that the thermal desorber would also be able to remediate other soils, specifically those contaminated with total petroleum hydrocarbons (TPHs). Construction of the facility cost $9 million and took 7 months; it began accepting MGP soils in July, 1997.

The NJDEP approved a permit for the facility's Astec / SPI low-temperature thermal desorber, requiring it to process contaminated soil to meet risk-based Residential Direct Contact Soil Cleanup Criteria. The desorber system can treat up to 45 metric tons / hour and reaches a treatment temperature of 540° C. After treatment, the soil is analyzed to demonstrate that Residential Direct Contact Soil Cleanup Criteria have been met. The treated soil can then either be returned to the generator or kept on-site and reused.

The first MGP site remediation undertaken by the utility was in an urban area. The site was vacant. Local community leaders wanted to see it converted to a new office complex. The project started in July, 1997, and was completed in 16 weeks.

Although 27,000 metric tons of soil and debris were transported to MART for remediation and the former MGP site is in a high-traffic area, the project did not disrupt local traffic or create an environmental or health hazard. The desorption treatment approach was successful; on the first pass all treated materials met the cleanup criteria specified by NJDEP. Treated soil was returned to the site, and the land was turned over to the community for beneficial use after treatment was complete and the site had been seeded (DiAngelo, 1998).

Contact

Brian Horne, Mid Atlantic Recycling Technologies Inc., Vineland, New Jersey, (609) 696-3435

3.2.10 Establishing Background PAH Concentrations

Tool Description

PAHs are a by-product of the incomplete combustion of organic material, and are found in everything from grilled meats to waste oil to MGP wastes. In today's society, the incomplete combustion of fossil fuels from heating systems, automobile exhausts, garbage incineration, crude oil processing, and many other practices release PAHs into the atmosphere where they tend to adhere to particles in suspension. Some of these suspended particles ultimately fall back on surface soils or aquatic environments. Establishing the background concentration of PAHs at MGP sites is therefore a significant challenge because it is necessary to distinguish the proportion of PAHs that come from MGP site wastes from those produced elsewhere.

In risk assessment, sample concentrations from a site are compared to background concentrations to identify non-site-related chemicals that are found at or near a site. If background risk is a possible concern, it is typically calculated separately in order to accurately evaluate the additional risk to public health or the environment posed by contaminants from a site. According to the Risk Assessment Guidance for Superfund (RAGS), (USEPA, 1989) information collected during a site characterization can be used to screen for two types of background chemicals: naturally occurring chemicals (i.e., those that have not been influenced by humans) and anthropogenic chemicals (i.e., those that are present because of human activity).

However, RAGS goes on to recommend that anthropogenic background chemicals not be eliminated from risk calculations as it is typically difficult to show that the chemicals are present at the site because of operations not related to the site or surrounding area. This presents a dilemma to those remediating MGP sites located in urban areas as the risks associated with background PAH concentrations are often quantified at concentrations above the incremental cancer risk of 10^{-4} to 10^{-6}, the criterion the USEPA most often uses for site restoration.

An alternative to the development of RA objectives based on traditional risk assessment practices is the establishment of background levels of anthropogenic materials and the application of those levels as a standard for site cleanup. This methodology has been applied at MGP sites and is gaining more acceptance as the cost and difficulty of cleaning up to pristine levels, sometimes beyond background concentrations, becomes clear.

Relatively few studies have been published in which PAH concentrations in soil have been quantified. According to one review of literature published in the Journal of Environmental Quality (Edwards, 1983), typical concentrations of benzo(a)pyrene (a known cPAH) in soils of the world range from 100 to 1,000 micrograms per kilogram (µg/kg). A typical range for total PAHs was about 10 times the value for benzo(a)pyrene alone, with the actual measured concentration of benzo(a)pyrene ranging from 0.4 µg/kg in remote regions to 650,000 µg/kg in very highly polluted areas. A second study on the background concentrations of PAHs in New England urban soils (Bradley, 1994) determined that the upper 95 percent confidence interval on the mean was 3 mg/kg for benzo(a)pyrene toxic equivalents, 12 mg/kg for total potentially cPAHs, and 25 mg/kg for total PAHs. The lack of adequate studies on background concentrations of PAHs, along with the need for site-specific information, indicates the demand for the development of a standardized procedure for establishing background PAH concentrations, rather than a single numerical value against which all other PAH values are measured.

A primary consideration in characterizing background levels of anthropogenic materials is the establishment of what constitutes background. In some cases, background has been functionally defined. For example, at CERCLA sites, background is defined as off-site locations that are comparable to the cleanup site in outward environmental characteristics such as geological setting and meteorological conditions. At RCRA sites, background is typically an on-site location where no facility processing or disposal has been known to occur. At any site, this definition is subject to opinion, based upon evaluation of the best available information. Proximity to the facility is a key consideration in specifying the locations that represent background conditions. Clearly, nearby locations are optimal in terms of similarities of geological conditions and deposition of anthropogenic materials, but these locations are also, because of their proximity to the facility, potentially subject to low-grade contamination from the facility. Distant locations may result in differing levels, not so much as a function of facility versus nonfacility contamination but rather as a function of major differences in native conditions and/or proximity to other sources. Definition of appropriate background locations must balance these distances based upon available site history. Once locations are selected to represent background levels, sampling results from those locations can be evaluated to corroborate expectations or to identify locations that do not meet assumptions about background conditions.

The total number of background samples to be collected is the next major consideration. Sample sizes can be directly estimated to achieve prespecified statistical power and confidence by making reasonable assumptions about the two expected "populations" of chemical concentrations (i.e., the site and background). Alternatively, sample size can be indirectly determined by defining a desired spatial coverage, then calculating the total number of samples to be collected by dividing the entire area to be sampled by the predetermined coverage or surface area per sample (e.g., collecting samples using a 25-foot grid with one sample collected per grid element).

The sample size for background characterization should be considered in the context of the sample size for the site being characterized. Statistical power for most comparative tests is optimized with a balanced design. That is, to maximize the ability to differentiate two populations (site versus background), similarly detailed information is necessary about contaminant distributions from the two areas. Optimizing statistical power must be balanced against the practical reality that sampling on the site may already be extensive.

Following collection of samples from background locations or consolidation of data from various sources, the frequency distribution of observed values can be examined. Intuitively, background data are expected to be relatively consistent or at least not to exhibit obviously bi- or multi-modal distributions of observations over the concentration range observed. Probability plots and statistical testing for adherence to commonly observed distributions (e.g., Shapiro-Wilk or Shapiro-Francia for normal or log normal distributions) are common methods to ascertain that data meet these basic assumptions about background conditions. Where data are composited from various sources and/or represent different methods or conditions, preliminary evaluations should also include examining the extent to which sampling factors (e.g., soil sample depths, analytical methods, specific locations) could be reasonably expected to result in different levels of the constituent. Spatial differences are the primary factors in considering background soils. Tests for trend (e.g., Cox or Sen tests) are useful to detect the presence of seasonal cycles and/or increasing or decreasing trends which would either eliminate the location from background designation or indicate the presence of upgradient effects independent of the site under investigation. If there are no significant differences among factor levels, data can be considered to represent a single population that represents background levels of naturally occurring or anthropogenic constituents.

The issue then becomes how to apply the available background information to determine which areas of a site represent incremental potential risk. Sample results from background locations are commonly used to estimate some agreed-upon proportion of the background population (such as an upper bound tolerance limit that defines the concentration corresponding to the 95th of 100 observations, ranked from lowest to highest concentration). That point estimate is then used as an upper limit to identify sample results from the site being investigated that exceed background and therefore require remedial action. The advantage of point comparisons is the relative simplicity of the method and calculations.

Disadvantages to point comparisons are numerous. First, contrary to the recommendations on sample size in the discussion above, the number of observations from background locations is typically smaller than the number of observations from the site. With the exception of uniform distribution, the probability of a sample containing extreme values relative to the overall population is lower than the more commonly occurring values from the center of the distribution. In other words, less commonly occurring values require increased sampling. A reduced sample size may result in an underestimate of variability in background levels. Because the calculated variance of the sampled population is integral in the calculation of the tolerance limit, the reduced sample size may result in a substantial underestimate of the upper concentration levels within the background population. Second, even when applying an upper bound estimate from a background sample, a certain proportion of values that truly represents background will exceed that estimate. For example, 5 percent of background values would be expected to exceed a 95 percent tolerance limit based upon true knowledge of the population. Finally, the statistical power of point-to-point comparisons is limited.

Alternative methods are population-to-population comparisons. For example, t-tests, Kruskal-Wallis tests, or Wilcoxon Ranks Sum tests in which the mean or median from on-site samples are compared to the mean or median from background samples; or the Quantile test which compares the upper end of the two populations (background and site) for statistically significant differences. Because no single statistical method is adequate to definitively define background conditions, a combination of tools (population-to-population and point comparisons) is recommended. Population-to-population comparisons, focusing on the entire distribution as well as upper portions of the observations, provide a more sensitive indication of the extent to which background and site populations compare. Used in conjunction with point estimates (such as tolerance limits or prediction limits), which establish an upper bound for a sample of a prespecified size (as would be established in post-remedy verification sampling), these comparisons optimize application of results from the background sampling effort.

Case Study

Alhambra Former MGP Site

In 1996, SoCal embarked upon the remediation of PAHs at a former MGP site in Alhambra, California. Because background concentrations of PAHs exceeded concentrations corresponding to a one-in-one-hundred-thousand cancer risk, the California EPA agreed that remediation to levels lower than background would not be practical. The first challenge associated with remediating to background included building a database of background PAH concentrations that could be used to characterize background concentrations. In addition, statistical methods had to be selected to support the site characterization and site remediation decisions made in the restoration of the site to background conditions.

Site Background

The Alhambra site had only operated as a MGP from 1906 through 1913. Because oil was the most likely feedstock, the predominant residual expected to be found was lampblack. Aerial graphs showed that the site sat vacant until about 1940, when the first house was built. By about 1948, the site had been subdivided into 20 lots, each with a separate residence.

Site investigations revealed the presence of PAHs in shallow soils. Other chemicals often associated with MGP operations such as metals, cyanides, reduced sulfur compounds, phenolics, and benzene, however, were not detected in soil above local background levels, or were present at levels below those that posed a health threat. Groundwater and soil investigations demonstrated that chemicals had not migrated into groundwater. Based on these findings, the remediation of the site focused on PAHs in soil.

Site remediation was performed under the supervision of the California EPA DTSC. As a risk management policy, the DTSC generally requires post-remediation cancer risks to be closer to the 10^{-6} end of the 10^{-4} to 10^{-6} acceptable risk range recommended in the National Contingency Plan (NCP). Most remediations approved by the DTSC achieve cleanup to a residual cancer risk of 10^{-5} or lower.

Background Database

The database of background PAH concentrations includes analyses of 184 surface soil samples collected from 20 different sites throughout Southern California. The data set was subjected to several statistical tests to determine if the data comprised a homogeneous population. Among the variables probed to explain variations in the data were urban versus rural setting, analytical method, and sample collection technique. After evaluating several different variables that might account for variability in the data, it was concluded that the data could be considered a single data set with a log normal distribution.

Developing the Remedial Action Goal

Using cancer slope factors recommended by California EPA for cPAHs, the concentrations of cPAHs (expressed as benzo(a)pyrene [B(a)P] equivalents) corresponding to 10^{-6}, 10^{-5}, and 10^{-4} cancer risks for a residential exposure scenario are 0.02, 0.2, 2.0 mg/kg, respectively. Using the database of background PAH concentrations in Southern California soils developed as part of this project, the 95% upper confidence level estimate of the mean concentration of cPAHs (expressed as B(a)P equivalents) in soil is 0.24 mg/kg. This concentration does not correspond to a cancer risk above the 10^{-4} upper end of the acceptable risk level recommended in the NCP, but it does correspond to risks in excess of 10^{-6} and 10^{-5}.

Remediating soils in Southern California to PAH concentrations corresponding to cancer risks in the 10^{-6} to 10^{-5} range would require reducing concentrations to levels below background, an impractical goal. Remediating the site to background concentrations would produce a site that posed no incremental risk to humans or the environment beyond that posed by background PAHs. The remediation goal adopted for the site was to restore each residential lot to a condition such that people living at the site would have no more exposure to PAHs than they would have had in the absence of the MGP operations.

Achieving the Remedial Action Goal

Given the objective of restoring the site to background conditions, the ideal remediation would have involved removing all PAHs that originated from the former MGP operations. Over time, however, some of the PAHs from the MGP operations had mixed with soil to such an extent that while the PAH concentrations were elevated above background levels, the soil across much of the site was not visually distinct. The practical approach developed for remediating the site relied on field observation to visually identify lampblack and on statistical evaluations of sampling data to identify areas with PAH concentrations above background levels.

Because there is no single statistical test that could be applied to soil concentration data to determine if the PAHs measured in a particular sample exceed background concentrations, SoCal applied a few different statistical tests to identify areas where concentrations probably exceeded background levels. The statistical tests include both comparisons of point estimates as well as distributions. To evaluate point estimates, the 95^{th} percentile, the upper tolerance limit, and the upper prediction limit were considered. The appropriate test for comparing distributions depended on the nature of the background distribution and the site data. Visual comparisons of plots of the background data set to the data from each lot were revealing, as were more rigorous statistical tests such as a t-test or a Mann-Whitney test. Using these statistical tests, an initial excavation target of 0.9 mg/kg of B(a)P equivalents for the cPAHs was identified. Using the initial site characterization data, soils with B(a)P equivalent concentrations above 0.9 mg/kg were initially identified to be excavated.

Because approximately 5 percent of background soil samples had B(a)P equivalent concentrations above 0.9 mg/kg, leaving some soil with PAH concentrations above this level did not necessarily mean that the PAH concentrations remaining after site remediation exceeded background levels. This was an important practical consideration because some soil with elevated PAHs level were in areas where excavation was not practical (e.g., beneath foundations).

The evaluation of data distributions was particularly important in the determination of whether contamination had spread off-site. Because there is a wide range of PAH concentrations in the background, the occasional detection of a relatively high concentration of PAHs in boundary or off-site samples did not necessarily mean that contamination had spread off-site. The use of a single point estimate (e.g., two standard deviations above the mean, the upper tolerance limit, etc.) as a test for determining whether any single data point represents contamination beyond background can lead to false conclusions.

Demonstrating Achievement of the Remedial Action Goal

Based on the initial evaluation of the distribution of PAHs in soil at the site, the excavation of soils meeting the two initial excavation criteria described above (i.e., visible lampblack and B(a)P equivalent concentrations above 0.9 mg/kg) was predicted to effectively restore each lot to background conditions. Excavation was required on 18 of the 20 lots down to an average depth of 4 to 5 feet, including under crawl spaces and concrete slabs. Following excavation, soil samples were collected from the side walls and bottoms of excavated areas and statistical analyses were performed to determine if each lot had been restored to background conditions. Post-remediation concentrations were also compared to risk-based concentration limits designed to prevent acute or sub-chronic health effects to ensure that none of the material left behind would pose such health risks. The same statistical tests described above for determining whether and where remediation was needed were applied to the post-remediation data to confirm that remediation was complete.

Conclusions

Because risk-based remediation goals for cPAHs were below background levels, a method for developing background-based remediation goals was needed. The traditional reliance on a single point estimate of background (e.g., two standard deviations above the mean), however, can provide false indications of contamination, particularly if there is a substantial overlap in the range of background concentrations and the range of incremental concentrations attributable to MGP operations.

By having a database representative of background concentrations over a sizable geographic region, the characterization of background concentrations coming from the database can be used at the many sites in the region. The size of the database (i.e., 184 data points) allows for a high degree of statistical power in distinguishing background concentrations from elevated concentrations that are presumably related to MGP operations. In addition, through the use of distributional comparisons to supplement point estimate definitions of background levels, this approach can minimize the false identification of background concentration samples as representing contamination.

Contact

Bob Vogel, Southern California Gas Company, (213) 244-5880

3.2.11 Generic Administrative Orders

Tool Description

Generic administrative orders have been developed to streamline the regulatory administrative process. Former MGP sites, as a subset of site characterization and remediation experiences, lend themselves to generic administrative orders and provide the opportunity to address environmental conditions under a consistent, cooperative, mutually beneficial statewide agreement. Benefits of generic administrative orders include:

- Comprehensive and consistent statewide strategies
- Reduced costs in negotiating agreements/orders
- Proactive environmental mitigation
- Emphasis on cooperation and common sense

Case Study

North Carolina MGP Group Generic Administrative Order

In the late 1990s, the North Carolina Manufactured Gas Plant Group (NCMGPG) entered into a memorandum of understanding (MOU) with the North Carolina Department of Environment, Health, and Natural Resources, Division of Solid Waste Management (DSWM) to establish a uniform program and framework for addressing manufactured gas plant sites in North Carolina. Under the MOU, all investigations and, if required, remediation of specific MGP sties are to be addressed pursuant to one or more administrative orders of consent. The MOU did not commit the NCMGPG to investigation and / or remediation any particular former MGP site; rather it simply set in place the framework to be followed should such an investigation / remediation be implemented. Implementation is formalized through the execution of one or more of the generic administrative orders of consent.

In establishing the generic administrative orders and preparing the MOU, the NCMGPG and DSWM agreed to coordinate all North Carolina MGP site investigations and remediations under the authority and jurisdiction of the DSWM in order to ensure that all characterization activities were completed in a uniform manner and to ensure that a single, regulatory agency (DSWM) would take control of oversight of North Carolina former MGP sites. In executing the MOU, the NCMGPG and DSWM agreed to:

- Negotiate in good faith to develop a uniform program and framework for the investigation and, if required, remediation of former MGP sites within the state
- Prioritize MGP sites in the state using the Site Screening and Prioritization System (SSPS) developed by the Electric Power Research Institute
- Discuss and obtain regulatory acceptance of the most nearly applicable cleanup standards that would be applied under CERCLA and Superfund Amendments and Reauthorization Act of 1986, recognizing the need for flexibility in addressing site-specific conditions
- Negotiate in good faith to develop appropriate alternatives to the site assessment and remediation methodologies outlined in the generic administrative orders
- Organize and sponsor group-funded technical seminar(s) and conference(s) highlighting state-of-the-art technologies involving assessment and remediation of former MGP sites

Contact

Brian Nicholson, North Carolina Department of Environment, Health, and Natural Resources, (917) 733-2801 x353

Chapter 4

Tools and Techniques for Expediting Site Characterization

4.1 Introduction

Expedited site characterization (as described in Section 3.2.7) encompasses the use of tools and methodologies that streamline data collection, increase field program flexibility, and allow for real-time on-site access to results. Fundamentals key to an expedited site characterization include:

- On-site or rapid decision-making capabilities
- Use of field and analytical tools that facilitate real-time data collection and interpretation.
- Use of non-intrusive or minimally intrusive geophysical and/or sampling techniques
- Flexibility in the overall site characterization and remediation process

The tools and techniques described in this chapter offer alternatives to, and in some cases, advantages over more traditional approaches to environmental assessment of sites. These tools and techniques are less intrusive, and generally allow completion of data collection in a more expeditious manner. In addition, the majority of these tools allow practitioners immediate, on-site access to results rather than requiring samples be sent to analytical laboratories for analysis. Having the data available in real time while implementing the sampling program allows the investigator to modify the sampling program based on early results. The investigator can then make informed decisions about subsequent sampling locations to cover an area of interest or to define the boundaries of identified problem areas.

In addition to being faster and less intrusive, these tools and techniques are cost-effective, taking many samples and producing a large amount of data in a short time. This is especially useful in expedited site characterizations, where the goal is to first collect more data points of lesser quality in order to focus resources on those areas of greatest concern. Subsequent phases of field work can then be implemented to collect fewer data points of better quality at predetermined locations, if necessary, to complete the site characterization.

These tools and techniques can be combined to form a site-specific expedited field program. Prior to developing such a program, however, thought must be given to the project's data needs and the ways in which the data will be used. Once these DQOs have been formulated, different site characterization tools and techniques can then be brought together, as appropriate for different site conditions. Flexibility in decision-making during the field program will also be required to ensure that only necessary and useable data points are collected. Each tool and technique in this chapter has strengths and weaknesses. The following table summarizes available information. Additional information is presented in the chapter proper for use by the practitioner. The order in which the tools and techniques discussed in this chapter does not reflect any ranking of their relative effectiveness.

Expedited Site Characterization Tools and Techniques

Name	Description	Benefits	Limitations	Approximate Cost
Direct Push Methods/Limited Access Drilling				
Direct Push/Limited Access Drilling (Geoprobe, Power Punch, Strataprobe, Precision Sampling, and others)	Used to collect soil, groundwater and soil gas samples and for identifying stratigraphy and nonaqueous phase liquids.	• Faster, cheaper way to explore subsurface characteristics • Can be linked to on-site analysis for real time mapping • Widely available • Can install small diameter wells and vapor extraction points • Less intrusive • Produces small volume of investigation-derived waste	• Limited range of use (with refusal/depth limited to <100 ft max; typically 25 to 30 feet) • Does not allow for large well installations • Limited use at locations with buried obstructions (e.g., foundations and coarse grain materials) • Potential for cross-contamination from single-tube rigs.	$1,000 - $1,500 per day; typical production 10-15 shallow (<40 ft) pushes per day
Cone Penetrometer	Push sampler used for geologic logging and to collect in situ measurements of geologic properties and pore pressure. Can be used to collect soil gas and groundwater samples.	• Rapid collection of objective stratigraphic information • Can penetrate harder zones than most direct push methods • Produces small volume of investigation-derived wastes	• Does not collect soil samples for analysis or inspection • Large, heavy rig may limit access • Cannot install wells • Potential for cross contamination from single-tube rigs	Typically one-third that of conventional soil borings, on per foot basis
Simulprobe	Driven sampler used to collect soil, groundwater, and soil gas samples through a casing or auger advanced to desired sampling depth.	• Collects soil and either groundwater or soil gas samples at same stratigraphic interval on the same push • Can be used with field instrument to screen for VOCs while pushing • Can be used in conjunction with a variety of drilling methods	• Limited availability • Multiple moving parts increases potential for breakage or sticking • Depth to which sampler can be pushed limited	Tools rent for $150/day or $650/week, plus rig cost of about $1,500 per day.
Hydropunch	Direct push tool used to collect depth-discrete groundwater samples at a discrete level in a single push.	• Collects groundwater sample at a discrete depth • Can be used with field instrument to screen various depths	• Data subject to interference from turbidity • Potential for cross-contamination if sampler is driven across hydrostratigraphic zones	Tools rent for $150/day or $650/week, plus rig cost of about $1500 per day.
Waterloo Profiler	Direct push sampler used to collect depth-discrete groundwater samples at various levels in a single push. Useful in identifying thin, high-concentration plumes that may be missed or underestimated (via dilution) with monitoring well sampling.	• Generates a vertical profile of groundwater quality on a single push (typical vertical separation of about 2 to 5 feet) • Faster and less prone to cross-contamination (vertically) than multiple pushes with conventional push samplers	• Sampling depth generally limited by drilling method • Not applicable to low-permeability settings • Tool available through limited number of vendors	$1,500 to $2,000 per day (2-person crew, including all decon and support equipment); typical production is 150 - 200 ft per day. Waterloo sampler equipment may be purchased from Solinst Canada, Inc., for $US 2,700.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Multi-Level Groundwater Samplers				
Westbay System	Fixed multi-level sampler built for a specific well installation. Access is through a single standpipe with mechanical "ports" that are opened and closed during sampling. Used to provide multi-level sampling and hydraulic head measurements.	• Provides direct samples of formation water • Allows head measurements	• Mechanically complex • Not adjustable or portable between wells • Requires specially constructed wells	Approximately $30,000 for a 5-level system ranging from 50 feet to 200 feet in depth. Includes installation but not sample analysis.
Waterloo Sampler	Fixed multi-level sampler built for a specific well installation. Access is through bundled flexible tubes that are accessible at the surface. Used to provide multi-level sampling and hydraulic head measurements in specially-constructed well. Smaller "drive point" units available for shallow installation.	• Provides direct samples of formation water • Reduces purge volumes • Removable or permanent systems available	• Mechanically complex • Specially-ordered materials necessary • Removable packer system sometimes difficult to cost-effectively reuse • Requires trained technician for installation	Approximately $25,000 for a 5-level system ranging from 50 feet to 200 feet in depth. Includes installation but not sample analysis.
Diffusion Multi-Layer Sampler (DMLS)	Portable multi-layer dialysis cell passive groundwater sampler. Used to characterize vertical variation in groundwater quality in either open rock boreholes or in wells with long well screens. Can be used to estimate groundwater flow velocity using borehole dilution method.	• Portable between wells • Allows vertical characterization of groundwater in a single borehole or well • Requires no purging	• Not widely used • Does not allow head measurements • May not be appropriate for zones with strong vertical gradients	About $3,000 for 2- to 3-meter-long units. Cost increases with increasing length. Need to add additional costs related to sample analysis and equipment installation.
Discrete Point Samplers				
Discrete Point Samplers	Discrete point sampler used to collect representative groundwater sample at a distinct elevation or points of inflow in either open boreholes or screened wells.	• Permits groundwater sampling from discrete vertical depth • Minimizes mixing of water from different levels during sample collection • Portable	• May require training to operate sampler • May be difficult to obtain complete seal	$150-$2,000 for purchased sampler.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Analytical Field Screening				
Rapid Optical Screening Tool (ROST)	Sampling and screening technology used to field screen for petroleum hydrocarbons and other contaminants.	• Rapid, real-time geologic and hydrocarbon data • Can be used to converge on area of interest • Works for both fuel (aromatic) hydrocarbons and creosote (polycyclic aromatic hydrocarbons) • Generates little investigation-derived wastes during sampling	• Limited availability • Limited to unconsolidated geology (same as CPT) • Provides only relative concentration data	$4,000 to $4,500 per day (reflects recent cost reduction). Production up to 300 feet per day.
X-Ray Fluorescence (XRF)	Field screening tool used to analyze trace metals in soil, sludges, and groundwater.	• No waste generated • Little sample preparation required • Easily transported to the field	• Limited penetration depths • Susceptible to interference from water, petroleum, and soil variability • Poor detection limits for some metals • Radioactive source in analyzer	$2,000/week.
Colorimetric Field Test Kits	Field test kits used to detect the presence or determine the concentrations of contaminants in soil and water.	• Inexpensive and easy to use • Available for a wide range of concentrations for hundreds of chemicals • Can be used for remote sampling	• Relatively high detection limits • Possible interference by naturally occurring chemicals and other contaminants • Possible difficulty in reading colorimetric matches in low light	Handby Kits - $1300/30 samples PetroFLAG - $800/10 samples Petrosense - $150/week Quick Testr - $275/week
Immunoassay Field Screening	Field test kit used to detect target chemicals in soil and other samplers. Most kits use competitive enzyme-linked immunosorbent assay (ELISA) type.	• Produces rapid, real-time analytical data onsite • Can be used to select samples for laboratory analysis and to define limits of contamination	• Requires site-specific calibration • Does not speciate individual PAHs • Does not work effectively at MGP sites where crude oil was used • Does not produce quantified concentrations of target chemicals • Requires test runs to ensure adequacy	Approximately $20 - $55/sample excluding labor
Mobile Laboratory	Mobile facility providing onsite soil, water, and air analyses.	• Rapid onsite detection of contaminants • May reduce mobilization/demobilization charges for field projects • Can rapidly perform time-critical analyses	• More expensive for standard turn-around analysis • Not all mobile laboratories use USEPA analytical methods	$2,500 to $3,000 for rental; $13 to $30/sample for expendables.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Geophysical Surveys				
Electromagnetics	Non-intrusive electromagnetic geophysical tool used to locate buried drums, landfills, bulk buried materials, etc. Can be used to determine depth to the water table and to delineate electrically-conductive (high dissolved solids) contaminant plumes.	• Non-intrusive • Can provide large quantities of detailed data in short time	• Need expert subconsultant to plan survey and interpret data • Data affected by power lines and metal buildings, cars, or other large metal items • Problematic in iron-rich soils and fill with large amounts of diffused metal wastes	Approximately $3,500, including data collection and interpretation for a one-acre site.
Seismic Refraction	Non-intrusive geophysical surveying tool used to determine depth to bedrock and/or water table. Can be used to define bedrock surface, buried channels, etc.	• Non-intrusive • Can provide large quantities of detailed data in short time	• Need expert subconsultant to plan, collect, and interpret data • Data subject to interference from complex geologic strata • Needs to be correlated with other site-specific subsurface data • Heavy traffic or numerous surface obstructions may be problematic	Approximately $10,000 including data collection and interpretation for a one week survey.
Ground Penetrating Radar (GPR)	Non-intrusive geophysical surveying tool used to locate buried waste, drums, tanks and voids, and to determine the depth and thickness of soil and bedrock.	• Non-intrusive source and detectors • Can provide large quantities of detailed data in short time	• Need expert subconsultant to plan, collect, and interpret data • Data deteriorates with increasing surface moisture or clay in subsurface • Problematic in iron-rich, deeply weathered soils	$10,000/week for 5 to 7 line miles of interpreted data.
Magnetometry/Metal Detection	Non-intrusive geophysical survey tool used to detect and map buried drums, metallic pipes, utilities and cables, tanks and piping. Also used to delineate trenches and landfills with metal debris.	• Non-intrusive • Relatively easy for non-expert to use • Can provide large quantities of detailed data in short time	• Depth and detail not obtainable • Cannot distinguish between types of metallic objects • Nonferrous metallic objects are invisible	$500/month for equipment rental costs only.
Electric Logging	Includes electrical resistivity methods, induction logs, self-potential logs, and fluid conductivity logs. Uses electrical resistivity to identify different hydrogeologic zones around a borehole.	• Rental equipment available • Specialized training not required • Quantitative data may require corrections	• Requires uncased borehole • Electrical resistivity and self-potential techniques require conductive borehole fluids • No quantitative measurements (other than depth) • Induction logging requires a dry borehole or borehole with non-conductive fluids	$1,200 - $2,500 day. (Can log 5-7 100-foot wells per day.)

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Geophysical Surveys, cont.				
Mechanical Logging	Includes flow-meter and caliper logging. Used to identify water-producing zones. Flow-meter logging provides semi-quantitative flow measurements when used in conjunction with caliper log (which measures borehole size and roughness and locates fractures and washouts).	• Provides direct measurement of vertical flow in well bore	• Flow-meter logging is relative insensitive at low velocities • Most applications of flow-meter logging requires a pumping or flowing well • Caliper logging is required for interpretation of flow-meter log	$500 - $600 per well, when run as part of multiple log suite. Flow-meter only (with caliper) is approximately $1,500 - $2,500 per well.
Acoustic (Sonic) Logging	Uses acoustic energy to determine the relative porosity of different formations. May be used to identify the top of the water table, locate perched zones, and assess the seal between a casing and formation material.	• Useful for characterizing rock aquifers • Allows porosity determination without use of radioactive source	• Not applicable in shallow wells or in unsaturated conditions • Relatively complex test; requires skilled operator for reliable results	$1,500 - $4,500 per well.
Radiometric Logging	Includes neutron logging and natural gamma logging. Used to estimate the porosity and bulk density of a formation and to locate saturated zones outside casing. Gamma logging is used to evaluate downhole lithology, stratigraphic correlation, and clay or shale content.	• Rental equipment available • Specialized training not required • Good tool for performing infiltration studies	• Neutron logging requires handling radioactive source and may be limited to case boreholes • Natural gamma logging may provide a non-unique response • Natural gamma logging may respond to the presence of phosphate minerals of micas or may mistake feldspar for clay or shale	For neutron logging, $2,500 to $5,000 per well depending on well depth and number of other logs run in conjunction. For natural gamma logging, $1,200 - $2,500 day. (Can log 5 - 7 100-foot wells per day).
Thermal Logging	Uses temperature differentials for flow and injectivity profiling, in conjunction with flow-meter logging.	• Supplements flow-meter log for identification of producing zones	• Requires fluid-filled borehole for testing • Interpretation of log complicated if internal borehole flow is present	$500 - $600 per well, when run as part of multiple log suite. Temperature log only $1,500 - $2,500 per well.
Video Logging	Downhole videotaping to provide visual inspection of a well interior, detecting damaged sections of screen and casing, and to detect fractures, solution cracks and geologic contacts in uncased holes.	• Allows visual inspection of the interior of the well	• Requires very clear water for successful survey • Not suitable for open boreholes in unconsolidated formations	$400 to $3,000 per well.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Soil Gas Surveys				
Passive Soil Gas	Measures relative concentration of contaminants through subsurface detectors sensitive to diffusion.	• Can be more sensitive than active soil gas, soil, or groundwater sampling for detecting presence of trace contaminants • Can be used in areas of low-permeability soil	• Does not measure direct concentration • May be difficult to collect data at depth for vertical characterization • Requires 2 to 4 weeks for sample collection	Approximately $250 per sample location, including analysis and reporting; about $50 - $100 per location installation and retrieval.
Active Soil Gas	Uses a vacuum pump to induce vapor transport in the subsurface and to instantaneously collect samples of contaminants in the vapor phase.	• Provides real-time data • Rapid results allows user to converge on areas of interest • Provides direct measure of vapor concentration • Can be used to evaluate vertical changes in soil gas concentrations	• Samples must be collected at least 10 to 20 feet bgs • Cannot be used in areas of relatively low permeability • May be adversely affected by transient processes (e.g., barometric pressure) and stationary features (e.g., pavement)	Approximately $3,000 to $4,000 per day
Contaminant Migration Evaluation				
Push-Pull Natural Attenuation Test	Injection/withdrawal test (single well) to document and quantify microbial metabolism.	• Can document microbial metabolism, loss of degraded contaminants, production of degradation products, and yield estimates of zero- and first-order decay constants • Can use wells already installed • Provides in situ data	• Not widely used • Can have difficulty when decay rate is slow relative to groundwater flow rates	$12,000 to $15,000 for 2 to 3 wells at one site for BTEX. Costs may be higher for other contaminants (because of more expensive analysis).
Partitioning Interwell Tracer Test (PITT)	Injection/withdrawal test (2 wells) to quantify volume and estimate distribution of nonaqueous phase liquids (NAPLs).	• Can provide quantitative estimates of NAPL volume • Can be used to design remediation methods targeting a NAPL source • Is relatively accurate compared with other in situ tests that utilize point values or small aquifer volumes	• Expensive • Technology is patented • Most experience is with solvents	$100,000 to $400,000 depending on scale of test.
In Situ Bio/Geochemical Monitor (ISM)	Allows for in situ measurement of biochemical reaction rates and retardation factors for both organic and inorganic compounds through the subsurface introduction and monitoring of tracers and reactants.	• Reduces the time and cost of obtaining site-specific biological and geochemical data • Provides in situ measurements of biochemical reaction rates • Provides estimated rates of denitrification during biodegradation • Provides estimated retardation rates for organic and inorganic compounds	• Testing is complex and requires trained personnel • Small aquifer volume tested means results may be affected by small-scale variations in aquifer properties • Typically applicable only with permeabilities $>10^{-4}$ cm/sec	$3,000 for equipment only.

Expedited Site Characterization Tools and Techniques, continued

Name	Description	Benefits	Limitations	Approximate Cost
Other Tools				
Micro-Scale Extraction (for PAHs)	Alternative laboratory extraction procedure for mono- and polycyclic aromatic hydrocarbons, chlorinated phenols, PCBs, mineral oil, and selected nitrogen- and sulfur-containing aromatic hydrocarbons prior to analysis.	• Small sample volumes required • Fast laboratory turnaround times • Minimal laboratory wastes • Quantitative results for individual components	• Relatively new procedure	Dependent upon analysis. Can reduce costs by over 50% in certain situations.
PAH Sample Filtration	In-field or laboratory filtration of water samples prior to PAH analysis to estimate the 'true' dissolved concentration by removing potential for colloidal contribution of PAHs.	• Eliminates high bias in PAH concentration measurements introduced by artificial colloidal entrainment • Inexpensive • Requires minimal training to implement	• Low bias resulting from elimination of naturally-occurring colloidal transport of PAHs • Dissolved or colloidal contaminants may adsorb onto the filter or apparatus	Minimal cost when compared to overall analytical costs. (Typical PAH analysis costs $200 to $300/sample.)
Inverse Specific Capacity Method	Specific application of push sampler (Geoprobe and others) to link groundwater quality data obtained from push sampler with an estimate of hydraulic conductivity in the sampled zone	• Allows vertical profiling of variations in horizontal hydraulic conductivity to be assessed	• Provides hydraulic conductivity for only small volume of aquifer • Need site-specific permeability data from conventional means (pumping or slug tests in wells) to convert specific capacity to hydraulic conductivity • Only appropriate for zones having permeability ranging from 10^{-1} to 10^{-5} cm/sec	Negligible cost, assuming that a peristaltic pump and push sampler already are in use at the site (assumes typical time for test ranges from 5 to 10 minutes).
Hand Augering/Trenching/ Pot Holing	Field surveying and sampling technique.	• Inexpensive where labor is cheap • Can be used to expose buried objects • Discrete and can get into tight locations	• Hand augering and test pits are depth limited • Pot holing and test pits are visible to public • Borehole/slope stability problems • Waste management may be a problem	Materials and equipment costs are minor. Cost is dependent on local labor costs.
Noise and Fugitive Emissions Controls	Barriers and controls to minimize noise and fugitive emissions during site characterization and remediation.	• Protects community and workers • Limits noise and air pollution • Minimizes the migration/transport of contaminants	• May be cost- and effort-prohibitive on a large scale • Controls may make field work logistically more complex and/or limit rate of completion	Ranges from $200-$500/day for water sweeping to >$10,000 for complete site enclosure.

4.2 Tools and Techniques for Expediting Site Characterization

Described below are 13 categories of new and existing tools and techniques that are currently available for expediting characterization of former MGP sites. The cost of using the tools and techniques and the results generated will vary from site to site depending upon accessibility, cost of labor, types and concentrations of contaminants found, hydrogeology, and other characteristics. Although many of these tools and techniques have been used successfully at former MGP sites, practitioners should choose tools based on the particular conditions at their site(s). Where possible, references are listed so that readers can contact representatives of projects where the tools and techniques have been used.

4.2.1 Direct-Push Methods/Limited Access Drilling

Tools in this category provide faster and cheaper ways to explore subsurface characteristics than have been available in the past. These methods are typically less intrusive, generate fewer investigation-derived wastes than past techniques, and permit sample collection in areas with limited clearance. When combined with on-site data analysis, these tools provide a powerful way to survey soil (and groundwater) for contaminants.

Some of the tools described herein may be limited to depths of 25 to 30 feet; others, however, are not depth-constrained. These tools generally create small-diameter boreholes and therefore do not allow for the installation of large wells. In addition, they may only allow for one-time “snapshot” or “grab” sampling. Tools included in this category are:

- Direct-Push Limited Access Drilling Techniques (such as GeoProbe™, Power Punch™, Strataprobe™, and Precision Sampling™)
- Cone Penetrometer
- Simulprobe™ Sampler
- Hydropunch™
- Waterloo Profiler
- Westbay System
- Diffusion Multi-Layer Sampler
- Waterloo System
- Point Sampler or Dual Packer Sampling

4.2.1.1 Direct-Push/Limited Access Drilling

Tool Description

A wide range of direct-push and limited access drilling techniques is available for collecting soil, vapor, and groundwater samples and for identifying stratigraphy or NAPLs. Some vendors, such as GeoProbe™, have also developed specific application probes (e.g., the conductivity probe) that can be used in conjunction with a drilling rig to survey a site or install small-diameter wells. These drilling methods have been successfully applied at former MGP sites for delineating source areas, screening aquifers for plumes before well installation, and collecting subsurface information in hard-to-access areas.

Direct-push drilling rigs typically consist of hydraulic-powered percussion/probing machines designed specifically for use in the environmental industry. "Direct push" describes the tools and sensors that are inserted into the ground without the use of drilling to remove soil and make a path for the sampling tool. These drilling rigs rely on a relatively small amount of static (vehicle) weight combined with percussion for the energy to advance a tool string. The small rig size allows work in limited access areas. Below is a photograph showing a typical direct-push drilling rig.

Operational Considerations

Direct-push drilling rigs, such as the GeoProbe™, are more efficient at drilling in shallow, soft areas but are not typically capable of drilling through a thick subsurface structure such as a gas holder foundation. Although limited in depth and often unable to drill through buried foundations at an MGP site, this technology can provide useful information about the location and depth of buried structures without puncturing them, which would create a route for cross contamination. In addition, this technique is effective for collecting soil, groundwater, and soil vapor grab samples. It is most efficient to depths of approximately 30 to 50 feet (depending on soil type).

Applications and Cost

Vendors of direct-push drilling rigs include GeoProbe™, Power Punch™, Strataprobe™, and Precision Sampling™. This drilling technology is well understood and provides reliable results. The cost of a direct-push drilling rig is approximately $1,000 to $1,500 per day, not including sampling tools and related expenses.

Benefit

- Small rig size suitable for tight spaces around aboveground structures or utility areas such as substations
- Small volume of investigation-derived waste (IDW) produced
- Continuous coring or discrete soil samples both possible
- Sampling of soil, groundwater, and vapor possible along with installation of small-diameter wells

Limitations

- Limited use at locations with buried obstructions (e.g., foundations)
- Potential for cross contamination from single-tube rigs
- Rods can get lost in tight soils
- Small diameter wells installed using these direct-push rigs may be difficult to develop
- Water samples collected from direct-push tubes typically contain considerable suspended sediment; may yield biased results for turbidity-sensitive constituents such as lead and PAHs
- Repeated pushes required from ground surface in order to vertically profile a site (i.e., collect water samples at different depths at the same location) unless special equipment (i.e., Waterloo system) is used
- Impractical (because of slow sample collection) in low-permeability soil or when attempting to collect samples at relatively shallow depths below water table

Case Study

Chico/Willows/Marysville (CWM) Former MGP Sites

Both GeoProbe™ and Precision Sampling™ direct-push drilling rigs were used at PG&E's CWM former MGP sites. The rigs were used to:

- Collect deep soil and grab groundwater samples from within active substations
- Collect grab groundwater samples to delineate the extent of offsite groundwater contamination so that downgradient monitoring wells could be placed at the edges of plumes (to act as sentry wells against continued downgradient plume migration)

- Quickly establish the extent of lampblack and coal tar in shallow soils at the locations of former lampblack separators, lampblack dumps, and tar pits

When the rigs were unable to drill through obstructions, this helped verify the location, depth, and extent of buried foundations. Soil samples from depths beneath former foundations (collected when the drilling rig was able to push through the former foundations) provided information about the types and volume of buried MGP wastes. At locations where cross contamination was a significant concern, Precision Sampling's dual-tube direct-push drilling rig was used to minimize the amount of soil and/or waste that may be transported downward by the driving rod.

4.2.1.2 Cone Penetrometer (CPT)

Tool Description

CPTs were initially developed as engineering tools for determining the capacity of soils to support foundations and pilings. These tools are a quick, reliable, and well-tested means to determine the continuity of stratigraphy, the depth to the water table, and the thickness of stratigraphic layers. More recently, the hydraulic pushing equipment on a modern CPT rig has been used to advance probes and samplers into subsurface soils. Examples of such probes/samplers include vapor samplers, soil samplers, the Hydropunch™, LIF probes, and resistivity probes.

A traditional CPT survey is a continuous penetration test in which a cone-shaped rod is forcibly pushed into the soil with hydraulic rams. Sensors electronically measure the resistance at the cone's tip and along the cone's sides. The function of the relative density of the sediment is then correlated to the soil textures to determine the site's stratigraphy. A schematic figure of a CPT rig is shown below.

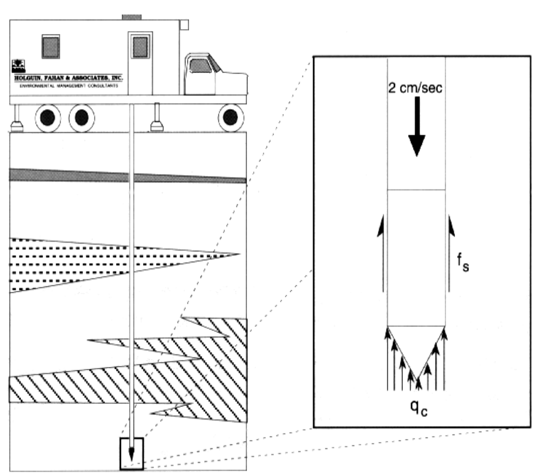


FIGURE 1 - SCHEMATIC DIAGRAM OF CPT
(qc = tip stress, fs = friction stress)

Reference: Holguin, Fahan & Associates, Inc.

Operational Considerations

Modern CPT rigs are capable of collecting the same data as conventional drilling rigs. CPT data are high quality, most often meeting DQOs, cost effective, and typically pose minimal health and safety concerns. In addition, CPT testing does not generate any drill cuttings. CPT drilling rigs can generally penetrate to depths of 100 to 150 feet below ground surface (bgs) in normally consolidated soils. The principal disadvantage of CPT rigs is that they cannot penetrate as deeply as conventional drilling rigs.

Applications and Cost

There are several CPT vendors in the United States, most of whom support both traditional geotechnical CPT projects and modern environmental investigations. The types of CPT-mounted sampling equipment and probes vary, however, among vendors. Costs for CPT are typically about 30 percent (on a per-foot basis) of the cost of conventional soil borings installed using traditional methods such as hollow-stem auger drilling. CPT costs are comparable with the modern direct-push drilling technologies offered by GeoProbe™, Precision Sampling, Inc., and others.

Benefits

- Can penetrate harder zones better than most direct-push methods
- Produces small volume of IDW
- Can be used for sampling groundwater and soil gas

Limitations

- Potential for cross-contamination from single-tube rigs
- Does not allow continuous coring or discrete soil samples
- Cannot be used to install wells
- Large, heavy rig may preclude access to some locations

4.2.1.3 Simulprobe™ Sampler

Tool Description

The Simulprobe™ sampler is a soil, soil gas, and groundwater sampling tool designed to be driven by either push or drive sampling technology. The sampler reduces the potential for cross-contamination by precharging its sample canister with nitrogen and by covering the sampler with a latex condom. Precharging the sampler with nitrogen prevents water from entering the sample canister until the sample is collected. The condom ensures that the sampler remains uncontaminated until driven into undisturbed soil.

One significant advantage of the Simulprobe™ sampler is the ability to obtain a soil core sample at the exact depth where the grab groundwater or soil gas sample was obtained. This allows the user to determine the lithology at the point of sampling. In addition, the Simulprobe™ sample chamber fills at a slower rate than other samplers (controlled by the rate at which the nitrogen is bled off), thereby reducing turbidity. The sampler also has a settling chamber so that any excess sediments that enter the chamber settle out before the water sample is transferred. The adjacent photograph shows a Simulprobe™ sampler.

The Simulprobe™ provides continuous sampling of soil gas in the vadose zone. When the probe is pushed through the vadose zone, soil gas is extracted under the vacuum and measured continuously in an organic vapor analyzer located above ground surface. If desired, a syringe can be inserted and a sample of soil gas can be extracted and analyzed by gas chromatography (GC) at any time.

Operational Considerations

Sampling with the Simulprobe™, as with other similar tools, is limited by the depth to which the tool can be driven. Other geologic conditions, such as flowing sands, also limit the tool's effectiveness and range.

When a grab groundwater sample is collected using the Simulprobe™ sampler, the water canister is first charged with nitrogen (usually 60 pounds per square inch [psi]/100 feet of hydrostatic head), and the entire sample device is covered with a latex condom. The Simulprobe™ is then slowly lowered to the bottom of a borehole and hammered 21 inches into the subsurface to collect a soil core. The device is then pulled back 2 to 3 inches to retract the sliding drive shoe and expose the circular screen. A valve is opened to allow the nitrogen pressure to bleed off from the water canister so water can enter the sample chamber under ambient hydrostatic pressure. After the water sample has been collected, the water canister is repressurized to prevent leakage into the sampling device, pulled out of the borehole, and emptied into appropriate sample containers.

Applications and Cost

The latex condom covering the Simulprobe™ sampler is designed to minimize cross-contamination during sampling, therefore making the Simulprobe™ a tool for grabbing groundwater samples before well installation, especially in areas where cross-contamination is of concern. Combined with push- or hammer-driven sampling (such as GeoProbe™) and in-field analysis, it provides a fast, effective method for obtaining survey-level data for refining monitoring well and groundwater plume locations. In addition, collecting soil samples at the same interval as the sampled groundwater allows for better linkage between hydrostratigraphy and groundwater and contaminant movement in the subsurface.

The rental cost of the Simulprobe™ sampler alone (direct from the vendor) is approximately $150 per day or $650 per week. Drilling costs can add approximately $1,500 per day to total sample collection costs. Sampling depth and frequency, site hydrostratigraphy, and buried obstructions can significantly impact the tool's effectiveness.

Benefits

- Collects soil and either groundwater or soil gas samples at the same stratigraphic interval in the same push
- Can be used with field instruments to screen for volatile organic compounds while pushing
- Field tested and proven
- Can be used in conjunction with a variety of drilling tools
- Latex condom minimizes cross-contamination during sampling
- Nitrogen or helium can be used to purge the canister to create an inert atmosphere before sample collection, thereby improving the quality of chemical parameters for natural attenuation monitoring
- Canister attachments can be used as pneumatic bailers inside wells or boreholes (e.g., for sampling below NAPL layers)

Limitations

- Limited availability (though may be available through local drilling firms)
- Multiple moving parts increase potential for breakage or sticking
- Depth to which the sampler can be pushed / driven limited

Case Study

Chico Former MGP Site

Field investigations conducted at PG&E's Chico former MGP site identified PAHs and petroleum hydrocarbons in the shallow water-bearing zone. However, the hydrostratigraphy below the water-bearing zone was not known, nor was information available on the water quality of deeper water-bearing zones. In order to determine the vertical extent of MGP-related constituents in groundwater and to identify the next deeper, unimpacted zone for monitoring (as a sentry well), the Simulprobe™ sampler was used with resonant sonic drilling. Grab groundwater samples were then collected from the two water-bearing zones directly underlying the shallow groundwater.

The first, deeper water-bearing zone was identified at 47 feet bgs. Grab groundwater samples were successfully collected from this zone using the

Simulprobe™. Because naphthalene-like odors were detected in the field from this groundwater zone, the Simulprobe™ was advanced to the next deeper water-bearing zone, identified at 97 feet bgs. Flowing sands encountered at this depth combined with the vibrations from the resonant sonic drilling jammed the sampler and prevented collection of a grab groundwater sample. Use of the Simulprobe™ is not recommended with a resonant sonic drilling rig or where flowing sands are present.

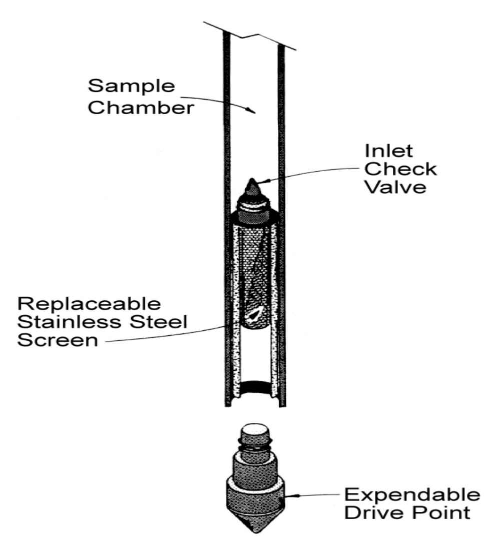
4.2.1.4 Hydropunch™

Tool Description

The Hydropunch™ is a direct-push tool for collecting a depth-discrete groundwater sample inside a boring without installing a well. The Hydropunch™ has been successfully used for collecting grab groundwater samples at former MGP sites to quickly delineate the extent of a groundwater plume without well installation or to quickly determine the best location or depth for screening a monitoring well.

The Hydropunch™ sampler is advanced with a hammer-driven tool to collect a groundwater sample from a particular depth. The sampler is pushed to the proper groundwater sampling zone and then withdrawn to expose an inlet screen. The screened interval is approximately 3 to 5 feet long. Groundwater can be collected from multiple depths within a single borehole although the tool must be withdrawn between samples. The following figure is a schematic diagram of the Hydropunch™ sampler.

Operational Considerations



The key factor affecting the accuracy of groundwater analytical results collected via the Hydropunch™ sampler is the turbidity of the grab sample. Because the sample is collected from a borehole instead of a developed well, the sample may be turbid. If the sample is not filtered before laboratory analysis, hydrophobic chemicals (such as PAHs and metals) sorbed onto the suspended sediments may cause erroneously high concentrations. In addition, the Hydropunch™ sampler limits the sample volume collected per push, so this tool is best used in a permeable zone where there is reasonable recharge into an area 3 to 5 inches thick. It is possible to attach a peristaltic pump to the Hydropunch™ sampler to pump larger volumes of samples if volatilization is not an issue. Finally, as with any single-tube direct-push probe or sampler, there is a potential for cross-contamination between groundwater zones. However this concern can be mitigated by using conductor casings. Floating-layer hydrocarbons may be sampled with a small-diameter bailer lowered through the push rods in one of the Hydropunch™ tools.

Applications and Cost

The Hydropunch™ sampler is a fast and inexpensive method for collecting a groundwater sample without installing a well. The Hydropunch™ is well understood and provides reliable results.

The cost of a Hydropunch™ sampler is approximately $150 per day, in addition to the drilling rig and associated equipment.

Benefits

- Provides reliable data
- Field tested and proven

Limitations

- Data subject to interference from turbidity
- Potential for cross-contamination if sampler is driven across hydrostratigraphic zones

Case Study

Stockton Former MGP Site

Grab groundwater sampling at the Stockton former MGP site was performed using the Hydropunch™ sampling tool for field screening to determine monitoring well locations at the edge of the plume. Samples were collected from two depths and sent to a laboratory for rapid analyses. Sample results were used successfully to determine whether the proposed well locations were at the edge of the groundwater plume (analytical results showed no detectable levels of contamination). Alternate well locations were identified when the Hydropunch™ samples showed detectable levels of contaminants.

4.2.1.5 Waterloo Profiler

Tool Description

The Waterloo Profiler (patent pending) is a groundwater sampling tool designed to collect depth-discrete groundwater samples in a single borehole with one probe entry. The Profiler consists of a tip containing multiple screened ports located around it. The Profiler tip is connected to 3-foot lengths of heavy-duty threaded steel pipe that extends to the ground surface. The Profiler is advanced by pushing, pounding, or vibrating the steel pipe into the ground using one of Precision Sampling, Inc.'s custom-made sampling rigs. Groundwater samples are conveyed to the surface via small-diameter tubing that is attached to a fitting inside the Profiler tip. The internal tubing, made of stainless steel or Teflon, passes up through the inside of the pipes to a pump and sample collection station located at the ground surface (Precision Sampling, 1998). Chemical concentrations in highly stratified formations can vary by several orders of magnitude over vertical distances of 1 foot. One significant advantage of the Waterloo Profiler is its ability to vertically profile contaminants in microstratigraphy without having to withdraw and reinsert the probe. This minimizes cross-contamination and the need for frequent tool decontamination between sample collection. The Profiler can be pushed through clay and silt beds without plugging, which makes vertical profiling easy.

Operational Considerations

Sampling with the Waterloo Profiler, as with similar tools, is limited by the depth to which the tool can be driven. Other geologic conditions, such as fine-grained sediments, also limit the tool's effectiveness and range.

Sample collection with the Waterloo Profiler is the most time-consuming part of sampling operations. Sample collection can vary from 10 minutes per sample in coarse-grained sand and gravel to 30 minutes in fine- to medium-grained sand. Groundwater sampling with the Waterloo Profiler is not recommended for lithology with sediments finer than fine-grained sands because of the lengthy sampling time required.

Applications and Cost

The Waterloo Profiler is a useful tool for rapid vertical profiling of hydrostratigraphy down to a maximum of 100 feet bgs. (Actual maximum depth is dependent on site-specific conditions and is typically shallower than 100 feet). The tool allows for delineation of contaminants in highly stratified formations where microstratigraphy plays a significant role in contaminant migration.

The cost of the Waterloo Profiler plus direct-push rig adds approximately $1,600 per day to total sample collection costs. Sampling depth and frequency, site hydrostratigraphy, and buried obstructions can have significant impact on the tool's effectiveness.

Reference: Precision Sampling, Inc.

Benefits

- Allows multiple depth-discrete groundwater sampling in a single borehole (i.e., sampler does not have to be withdrawn between samples)
- Less prone to cross-contamination than multiple pushes with conventional push sampler

- Can be used with field instruments to screen for volatile organic compounds while pushing
- Field tested and proven
- Allows for delineation of contaminant pathways in microstratigraphy

Limitations

- Profiler available only through a limited number of vendors
- Limited by depth to which the sampler can be pushed / driven
- Shallow groundwater sampling via peristaltic suction-lift pump may cause volatilization of some contaminants during sampling
- Groundwater sample collection recommended only for fine-grain sands and coarser materials

4.2.1.6 Multi-Level Groundwater Samplers

Multi-level groundwater samplers are used to collect groundwater samples at multiple, discrete levels within a single monitoring well. These types of groundwater samplers are equivalent to a series of nested monitoring wells but require only one casing in a single borehole.

The tools discussed below include several types of multi-level groundwater samplers:

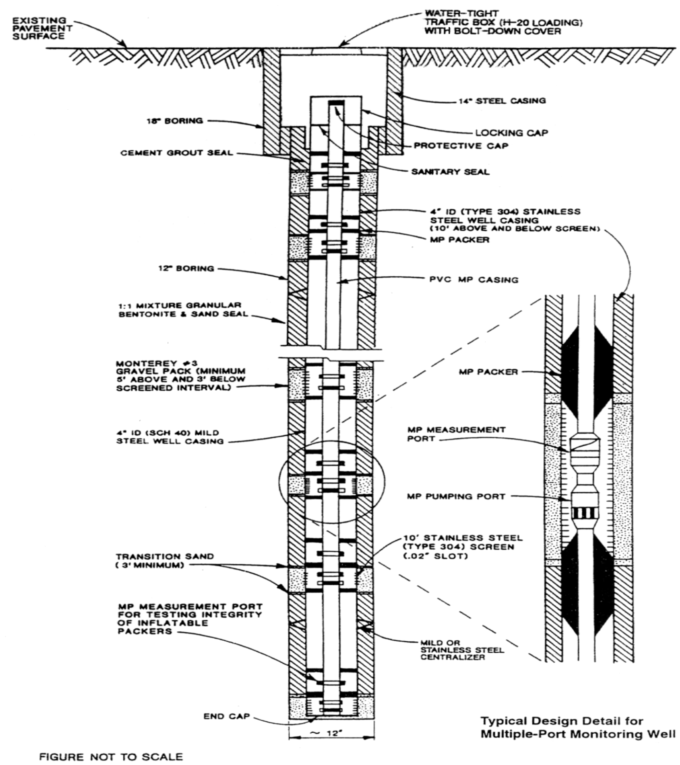
- Westbay System
- Waterloo System
- Diffusion Multi-Layer Sampler (DMLS)

4.2.1.6.1 Westbay System

Tool Description

The Westbay System is a fixed, multi-level sampler built for installation in a multi-port monitoring well. It is designed to collect groundwater samples and hydraulic head measurements at multiple, discrete levels in a single monitoring well. Multi-port monitoring wells are like a series of nested monitoring wells but require only one casing in a single borehole. The Westbay System incorporates valved couplings, casings, and permanently inflated packers into a single instrumentation string that is installed inside a cased borehole with multiple screened intervals, allowing multi-level groundwater monitoring for a fraction of the installation cost of nested monitoring wells.

The following figure shows the typical design detail for a Westbay System multi-port monitoring well.



Typical Design Detail for Multiple-Port Monitoring Well

Operational Considerations

Westbay System multi-port monitoring systems are complex and require trained technicians to install. Monitoring wells must be designed specifically to conform with the Westbay System requirements. Field quality control procedures enable verification of the quality of the well installation and operation of the testing and sampling equipment.

Groundwater samples from Westbay monitoring wells are collected without repeated purging. In addition, Westbay is currently developing instruments to enable the use of in situ sensors to monitor various chemical parameters.

Applications and Cost

The Westbay System is useful for MGP sites where multiple groundwater zones exist and discrete monitoring of multiple screened zones is required.

One of the primary cost savings with the Westbay System is that several discrete groundwater zones can be sampled by installing only one well. Fewer boreholes mean lower drilling costs, a shorter project schedule, and less IDW (e.g., drill cuttings and fluid). This can result in substantial savings in waste management, site access approval, noise abatement, and project management. In addition, fluid samples are collected from the Westbay monitoring wells without repeated purging (the groundwater in each zone is not in contact with the atmosphere), which can lead to significant cost reductions at sites where purge water must be stored, transported, and treated before disposal**.** The cost of installing a Westbay System is approximately $30,000 for a five-level system that can range from 50 to 200 feet in depth. The price does not include the cost of installing the monitoring well and does not include sample collection or analysis.

Benefits

- Reduces the amount of drilling

- Provides reliable data
- Field tested and proven

Limitations

- Mechanically complex
- Requires well construction to specific Westbay specifications
- Not portable between wells

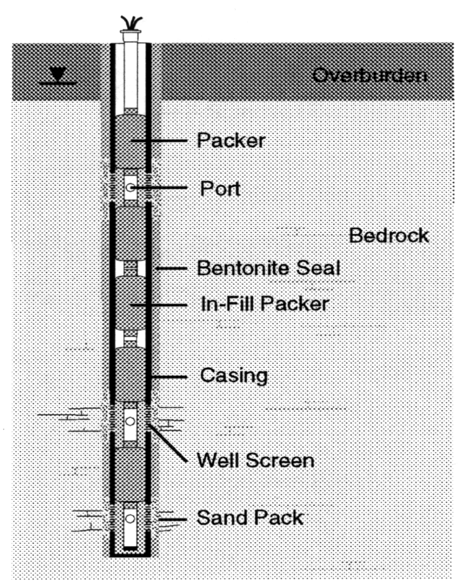
4.2.1.6.2 Waterloo System

Tool Description

The Waterloo System is used to obtain groundwater samples, hydraulic head measurements, and permeability measurements from multiple isolated zones in a single monitoring well. The Waterloo System uses modular components held firmly together to form a sealed casing string composed of casing, packers, ports, a base plug, and a surface manifold. Monitoring ports are isolated by packers at each desired monitoring zone and are individually connected to the surface manifold with narrow-diameter tubing. Formation water enters the port, passes into the stem, and rises to its static level in the monitoring tube attached to the stem. A sampling pump or pressure transducer may be dedicated to each monitoring zone by attachment to the port stem, or the monitoring tubes may be left open to allow sampling and hydraulic head measurements with portable equipment. A section of the sampler is shown in the following figure.

Operational Considerations

A typical Waterloo System can be installed in a few hours by one trained technician and an assistant. Purge volumes are small, and dedicated pumps for all zones can be purged simultaneously. Because the groundwater in each zone is not in contact with the atmosphere, formation water may be sampled without repeated purging. The Waterloo System may be used in hollow-stem augers, temporary casing, or cased and screened wells.



Permanent or Removeable Packers in Casing or Well Screen

Applications and Cost

The Waterloo System is useful for MGP sites with multiple groundwater zones when discrete monitoring of the zones is required. Project costs may be reduced by limiting the number of wells installed and maximizing the number of groundwater zones sampled. The purge volumes necessary for groundwater sampling using the Waterloo System are likely to be smaller than those from conventional nested monitoring wells.

The cost of installing the Waterloo System is approximately $25,000 for a five-level system that can range from 50 to 200 feet in depth. This price does not include the costs of monitoring well installation or sample collection or analysis.

Benefits

- Reduces the number of wells needed for multiple-zone monitoring
- Reduces purge volumes and may reduce time required for purging/sampling relative to conventional monitoring well requirements
- Provides reliable data
- Removable or permanent systems available

Limitations

- Mechanically complex
- Specially ordered materials necessary
- Removable packer system sometimes difficult to cost-effectively reuse
- Requires trained technician for installation

Contact

Solinst Canada Ltd., (800) 661-2023, www.solinst.com

4.2.1.6.3 Diffusion Multi-Layer Sampler (DMLS™)

Tool Description

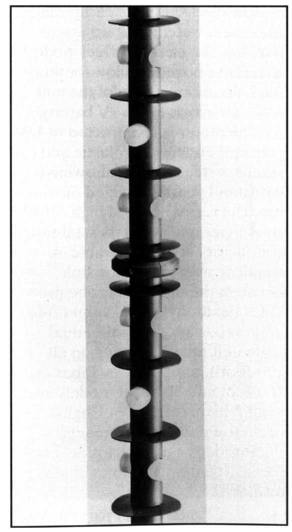
DMLS ™ is portable, multi-layer device that can collect groundwater samples at multiple intervals in the same monitoring well. The DMLS ™ uses dialysis cells separated by seals that fit the inner diameter of the well. This arrangement allows natural diffusion of groundwater into the unit at different elevations. Once the DMLS ™ is lowered into either an open rock borehole or a groundwater monitoring well with a long screen, the dialysis cells are exposed to water in the borehole and natural diffusion gradients permit external formation water to reach equilibrium with the water in the dialysis cells. The water flowing from the formation into the stratified dialysis cells is separated by seals; therefore, each dialysis cell contains a groundwater sample from a different layer.

The basic unit of the DMLS ™ is a 5-foot-long polyvinyl chloride (PVC) rod with a variable number of dialysis cells and nylon membranes separated from each other by seals. A string of up to five rods can be formed. Vertical layers of groundwater as narrow as 3 inches can be segregated and sampled. The rods fit into 2-inch-diameter and larger wells.

The following figure shows the typical design detail for a DMLS ™ multi-level groundwater sampler.

Operational Considerations

Once the DMLS™ is lowered into a well, it should remain undisturbed for 7 to 10 days to allow stratification of the water flowing from the formation. Once stratification of the formation water is complete and the water in the sampling cells is representative of ambient conditions, the rods are pulled to the surface and the sampling cells are removed and sent to a laboratory for analysis. The sampling cells in the rods can then be replaced, and the process can be repeated. The DMLS™ may be left in the water for periods of time that conform to individual sampling schedules. For example,DMLS™ sampling cells may be collected and replaced every three months.



Because the DMLS™ relies on natural groundwater diffusion principles, no purging is required. The DMLS™ does not permit head measurements.

Applications and Cost

The DMLS™ is useful for MGP sites where monitoring wells have long screens and a vertical characterization of the screened aquifer is desired.

The DMLS™ reduces costs because several vertical groundwater zones can be sampled by installing only one well. Having fewer boreholes reduces drilling costs, shortens project schedules, and produces less secondary waste (e.g., drill cuttings and fluid). The result is substantial cost savings in waste management, site access approval, noise abatement, and project management. Groundwater samples are collected from DMLS™ monitoring wells without repeated purging (the groundwater in each zone is in direct contact with the formation water), which can significantly reduce costs at sites where purge water must be stored, transported, and treated before disposal.

The cost of the DMLS™ is approximately $3,000 for a 10-foot-long unit. The price does not include labor costs for installing the DMLS™ rods, nor does it include costs for sample collection or analysis.

Benefits

- Allows vertical characterization of groundwater in a single borehole or well
- Requires minimal training for installation
- Requires no purging

Limitations

- Not widely used

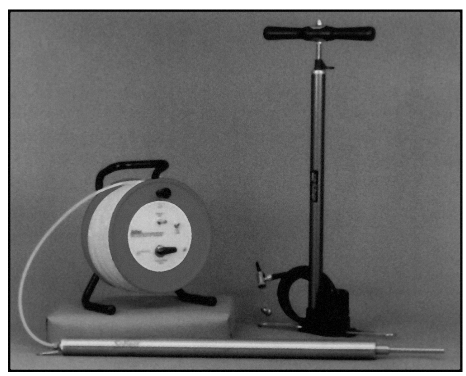
- Does not permit head measurements
- May not be appropriate for zones with strong vertical gradients

4.2.1.7 Discrete Point Samplers

Tool Description

Floating product layers (e.g., LNAPL) or sinking product layers (e.g., DNAPL) may cause stratification of contaminant concentrations in groundwater. Discrete point samplers are used to represent groundwater at distinct elevations or points of inflow in either open boreholes or screened wells. Discrete point samplers are designed to minimize disturbance and/or mixing that would be caused by pumping and purging water from different zones.

Several tools are available that have been designed to collect groundwater samples at discrete points in either open boreholes or in screened wells. Solinst Canada, Ltd., manufactures a number of samplers designed for use in wells screened over multiple water-bearing zones. Two examples are the Model 429 Point Source Bailer and the Model 425 Discrete Interval Sampler. The Model 429 Point Source is a stainless steel bailer with dual ball valves that prevent the mixing of water from multiple depths during retrieval of a sample from a specific depth. The Solinst Model 425 Discrete Interval sampler (shown in the figure below) is a stainless steel sampler connected by tubing that is pressurized before the device is lowered into a well; pressurization prevents water from entering the sampler until the sampling zone is reached. When the desired sampling depth is reached, pressure is released, and hydrostatic pressure fills the sampler and tubing with water directly from the sampling zone. When the sampler is filled, it is repressurized and raised to the surface; the sample is decanted using the sample release device provided, which avoids degassing of the sample (Solinst, 1998).



Solinst also manufactures a Triple Tube Sampler that uses a narrow-diameter pump and packer assembly to seal off a discrete interval in groundwater. A nitrogen-inflated packer is placed just above the desired sampling point within the sampling tube. The packer seals against the walls of the sampling tube and isolates the formation water standing in the tube. A second nitrogen line applies pressure down the sampling tube. The water is pushed to the surface through the coaxial tubing. The cycle is repeated until purging and sampling are complete.

The Solinst Triple Tube Sampler is similar to the Waterloo Profiler multi-level groundwater sampler discussed in Section 4.2.1.5 except that the Solinst sampler is designed to sample from wells whereas the Waterloo Profiler is a direct-push sampler designed to collect grab groundwater samples without boreholes or wells (Solinst, 1998).

Operational Considerations

The Solinst Model 429 Point Source Bailer and the Solinst Model 425 Discrete Interval Sampler do not require or allow purging prior to sampling. It is assumed that a sample collected at a discrete depth is representative of the formation water flowing through the well at that depth. The Solinst Triple Tube Sampler does permit purging of the discrete interval being sampled.

Applications and Cost

Discrete point samplers are useful for field scenarios where heterogeneities exist in the vertical distribution of contaminant concentrations in groundwater in an open borehole or screened well.

The purchase costs for Solinst Model 429 Point Source Bailer, Solinst Model 425 Discrete Interval Sampler, and the Solinst Triple Tube Sampler are approximately $150, $675, and $2,000, respectively.

Benefits

- Permits groundwater sampling from a discrete vertical point in a well or borehole
- Minimizes mixing of water from different levels during sample collection
- Fits in small-diameter wells/boreholes
- Is portable (the Triple Tube Sampler may be dedicated)
- Solinst Triple Tube Sampler is usable for purging in addition to sampling

Limitations

- May require limited training to operate equipment (especially the Triple Tube Sampler)
- May be difficult to obtain a complete seal with the Solinst Triple Tube Sampler

Contact

Solinst Canada Ltd., (800) 661-2023, www.solinst.com

4.2.2 Analytical Field Screening

Field screening tools allow practitioners to detect the presence and determine the estimated concentrations of chemical constituents in the field. As noted above, combining these tools with direct-push grab sampling techniques allows rapid and cost-effective preliminary screening of former MGP sites by pinpointing areas of contamination that require further, focused field investigations. Once these areas are identified, field screening tools can be used to gather further data so that remediation alternatives can be evaluated. In some cases, the tools can also be used to gather confirmatory data during remediation.

Tools included in this category are:

- Laser Induced Fluorescence (LIF) (such as ROST™)
- X-ray fluorescence (XRF) (such as the Spectrace 9000, SEFA-P, or X-MET 880)
- Colorimetric testing (such as Hach Kits, Draeger Tubes, Sensidyne, Handby Kits, PetroSense™, and PetroFLAG™)
- Immunoassay testing (such as Strategic Diagnostics)
- Portable laboratories

4.2.2.1 Rapid Optical Screening Tool (ROST™)

Tool Description

The ROST™ is a sampling and screening technology used to field screen for petroleum hydrocarbons and other contaminants. Like its military sister, the SCAPS, ROST™ is designed to offer a suite of CPT tools on a single platform. Using fiber-optic technology with LIF, ROST™ provides rapid, real-time, in situ delineation of subsurface petroleum hydrocarbon contamination down to depths of 150 feet.

The ROST™ consists of a sensor-tipped, hydraulically advanced, penetrometer probe with a self-contained data collection and analysis system housed within a CPT truck. Additional probes incorporate video imaging technology and soil moisture measurements while the latest CPT sampling devices allow for the collection of soil, water, or gas samples with analytical confirmation or other measurements. A diagram of ROST™/SCAPS is shown in the figure on the following page.

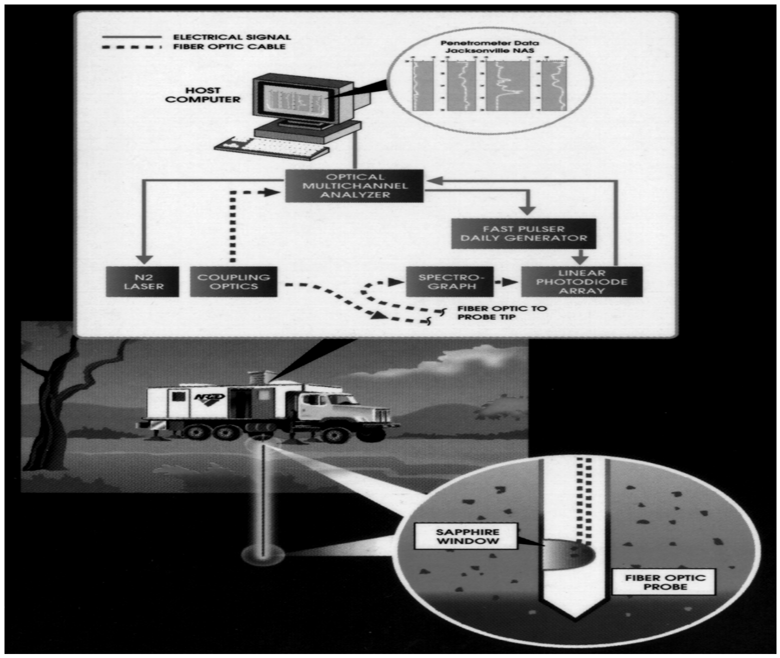
Operational Considerations

Operational considerations with ROST™ sampling technology are similar to those of cone penetrometers. Depths are limited to 100 to 150 feet bgs in normally consolidated soils, shallower in coarser materials. The ROST™ sampling technology does not produce soil cuttings and can provide real-time, in situ field screening for petroleum hydrocarbons. The ROST™ can also detect small deviations in concentrations, thereby making it useful in mapping areas with significant subsurface structures/materials. Microwells can also be installed using this tool.

Applications and Cost

The ROST™ sampling technology is useful for field surveys and initial characterization of sites, and for post-remediation confirmation for petroleum hydrocarbons. The system is limited to the depths of the CPT and by the sensors currently available.

ROST™ costs approximately $4,000 to $4,500 per day with production up to 300 feet (around 10 pushes) per day.



Benefits

- Provides rapid, real-time geology and hydrocarbon data
- Can be used to converge on an area of interest
- Works for both fuel (aromatic) hydrocarbons and PAHs
- Generates little waste during testing/sampling
- Verified by USEPA and certified by California EPA

Limitations

- Limited availability (only two commercial licenses currently held)
- Limited to unconsolidated geology (same as CPT)
- Only relative concentration data provided

Case Study

North Cavalcade Superfund Site, Houston Texas

The North Cavalcade Street Superfund Site is a former wood treating facility, located in northeastern Houston, Texas. The site encompasses approximately 21 acres, and was used for treating wood from 1946 to 1964. Initially, creosote was employed as the primary wood preservative, but later operations also included pentachlorophenol. Operations included wood storage and pole peeling, and a treatment plant with pressure vessels, storage tanks, and drip racks.

The site is relatively flat with elevations ranging from 43.2 feet to 53.8 feet above mean sea level. The water table occurs at depths ranging from approximately 2 to 5 feet bgs. Surficial soils are part of the Beaumont Formation, which is composed of clays, silts, and silty sands. The depositional environment was fluvial and deltaic, and the deposits can be characterized as stream channel, point bar, mud flat, and coastal marsh. The majority of the soils are composed of continuous and noncontinuous clay to silty clay layers with two principal sand to silty-sand layers located at average depths of 15 feet and 30 feet bgs. The various clay layers are known to be fractured to various degrees. The site is intersected by at least three and possibly four relatively minor surface faults with displacements of 2 to 5 feet. At least one of these faults is known to be active.

The site was divided into separate soil and groundwater operable units during the feasibility study. The soil operable unit consists of approximately 10,000 cubic yards of contaminated soil that was excavated and stockpiled into a bioremediation cell. The groundwater operable unit was addressed through a pump-and-treat system consisting of 19 wells, pumps, a treatment plant, and three groundwater infiltration galleries. The pump-and-treat system operated at an average flow rate of 12 gallons per minute for 24 months. It removed approximately 7,000 gallons of DNAPL out of approximately 11,500,000 total gallons of extracted water. The pump-and-treat system was subsequently discontinued due to a drastic decline in the amount of DNAPL recovered.

Previous information sources of subsurface data consisted mainly of a limited number of boring logs and soil samples. In order to gather more information on the horizontal and vertical extent of DNAPL that exists in the subsurface and to refine the site conceptual model, the CPT/ROST™ technology was selected as the most cost effective option for data collection. A total of 101 pushes were completed at an average depth of approximately 45 feet for data collection. The data from the cone penetrometer portion of the tool, which is displayed similar to well logs, were used in the construction of isopach and structure maps and fence diagrams to aid in the characterization of the subsurface. Based on an extensive correlation of the pushes, it was determined that the tool's lithologic determinations were internally consistent and correlated well with the existing data. Also, due to the greatly increased number of data points, two and possibly three additional faults were located.

The ROST™ data, like that from the CPT portion of the tool, was provided in a format similar to a well log with total fluorescence graphed versus depth. Windows of the "waveform," which consisted of a graphical presentation of the breakdown of the total fluorescence into four wavelengths, were also presented on this log for various peak fluorescence values. This enabled a quick identification of the type of hydrocarbon contamination present at a given depth. Additionally, another log was provided which displayed the total fluorescence signature and a continuous breakdown of this signal into the four component wavelengths, which allowed more detailed analyses of the different types of hydrocarbons.

The data from the ROST™ portion of the tool was used to gain an understanding of the vertical and horizontal extent of creosote contamination, and the relative concentration of the creosote contamination in three dimensions. Due to the tool's ability to detect a wide range of hydrocarbon contamination, other sources of hydrocarbon, such as diesel, gasoline, and oil, were also discovered. Interestingly, four of the pushes, which are located adjacent to a known pipeline easement exhibit a relatively strong oil-like signature at shallow depths. It is postulated that this represents leaks in the pipeline. Because the focus of the investigation was creosote, these signals were filtered out from the total fluorescence signal by running the data through a FORTRAN program written specifically for that purpose. Refinement of this filtering methodology, although effective, is currently somewhat primitive and is undergoing further development.

When creosote was encountered, it was usually found at several depths within a given push. The tops of the creosote occurrences were tabulated by depth and by whether they occurred in a sand or a clay. It was determined that almost all of the creosote hits occurred within the two sands zones, with the lower sand zone registering the majority of the hits. The deepest creosote contamination that was observed occurred at a depth of approximately 50 feet bgs. Based on these data, the remediation strategy of the site has re-focused on the lower sand zone.

CPT/ROST™ has proven cost-effective for the determination of lithology and the delineation of creosote contamination at the North Cavalcade Superfund site. Also, based on its performance at the site, its effectiveness appears to extend to the identification of other less dense hydrocarbon signatures. The CPT/ROST™ offers advantages in both price and the rapidity with which the data can be acquired. This technology is being evaluated for use at two additional creosote sites.

Contact

Joe Kordzi, USEPA Region VI, 214-665-7186

4.2.2.2 X-Ray Fluorescence (XRF)

Tool Description

Energy dispersive XRF is used to analyze trace metals (e.g., mercury, chromium, lead, cadmium, copper, nickel, and arsenic) in soils, sludges, and groundwater. The technique uses x-rays (high-energy electromagnetic radiation) to penetrate the soil matrix and excite metals. Radiation emitted from fluorescence of the metals is measured to quantify the concentrations of metals present in the soil.

XRF analyzers yield semiquantitative results with detection from a few to a few hundred parts per million (ppm) depending on the soil matrix and the metals being analyzed. XRF is generally considered a screening tool because of its relatively high reporting limits. The XRF analyzer is easily transported to the field and very fast (reportedly 5 to 40 samples per hour can be analyzed depending on sample preparation and measurement times).

Operational Considerations

Several manufacturers supply XRF analyzers including TN Spectrace (the Spectrace 9000) and Metorex Inc. (the HAZ-MET 920, HAZ-MET 940, and the X-MET series). XRF analyzers contain a radioactive source that may require special handling. Although XRF methods do not require soil samples to be digested (as do conventional analytical methods), some sample preparation (e.g., drying and homogenization) may be required. XRF analyzers are susceptible to interference from water, petroleum, and soil heterogeneity. Nontechnical personnel may operate XRF analyzers with minimal training.

Applications and Cost

XRF methods are mostly used as screening tools for trace metals. Because of their relatively high detection limits, these methods are best suited to site characterizations requiring metal screening at relatively high levels.

The cost to rent an XRF analyzer is approximately $2,000/week. A comparative conventional analytical method (inductively coupled plasma) is 30 to 40 percent more expensive and requires that samples be digested.

Benefits

- No IDWs generated
- Easily transportable to the field
- Does not require digestion of soil samples

Limitations

- Sample preparation required (e.g., drying and homogenization)
- Poor detection limits on some metals, especially as a result of matrix interference
- Limited penetration depth
- Not well suited to measure liquid samples
- Radioactive source in the analyzer

Contacts

Jim Moore, TN Spectrace, (512) 388-9100, x208

James R. Pasmore, Metorex Inc., (541) 385-6748 or (800) 229-9209

4.2.2.3 Colorimetric Field Test Kits

Tool Description

Colorimetric field test kits are used to detect the presence or determine the concentrations of contaminants in soil and water. Because detection limits are generally in the low ppm range, field test kits are primarily used as a screening tool for site characterization. Colorimetric field test kits may be used to screen for a broad range of inorganic parameters, total hydrocarbons, selected organic compounds, and selected explosive compounds.

Colorimetry is generally performed by mixing reagents in specified amounts with the water or soil sample to be tested and observing the color change in the solution. The intensity of the color change is an indicator of the concentration of the chemical of interest. The color change is either observed visually (compared with color charts) or electronically with a handheld colorimeter.

It is important to understand the limitations of the specific test kit being used, including the chemicals it can detect. Some kits are susceptible to interference from both naturally occurring organic matter and other co-contaminants.

Specific vendor technologies discussed below include Handby, PetroFLAG™, PetroSense™, and Quick Testr field test kits. Handby field test kits are generally used to screen for petroleum-derived substances in soil and water. Results are quantified by comparison to substance-specific calibration photographs. Handby kits are also available to quantify PAHs. The PetroFLAG™ test kit for soil is primarily used to detect petroleum hydrocarbons with detection limits ranging from 20 to 2,000 ppm. The PetroFLAG™ test kit can use either a conservative calibration to estimate total hydrocarbons present or it can be calibrated to specific hydrocarbons. The Dexsil Corporation, which markets the PetroFLAG™ test kit, indicates that PAHs can be measured using the technology. The PetroSense™ PHA-100 Petroleum Hydrocarbon Analyzer (PetroSense™), marketed by FCI Environmental Inc., combines fiber optic chemical sensor technology and digital electronics to measure the vapor concentration of TPHs in soil and benzene, toluene, ethylbenzene, and xylenes (BTEX) in water. Envirol Inc., markets Quick Testr field test kits, which can estimate total cPAHs in soil. Quantitative results are obtained by establishing a site-specific correlation between test kit and laboratory results.

Operational Considerations

The Handby Kit is susceptible to positive interference if extremely large quantities of organic matter (e.g., peat) are present. The PetroFLAG™ is sensitive to a wide range of hydrocarbons including natural waxes and oils. For both the Handby Kit and PetroFLAG™, the user must test background samples and calibrate the equipment to detect only foreign (i.e., not naturally occurring) substances.

The Handby Kit analyzes a sample in less than 10 minutes; detection limits typically range from 1 to 1,000 ppm for soil and 0.1 to 20 ppm for water. Approximately 25 samples per hour can analyzed using the PetroFLAG™ field test kit. The PetroSense™ analyzer is very sensitive to turbidity and temperature in water samples. Preconditioning and calibration for the PetroSense™ take approximately 30 minutes; sample analysis takes less than 10 minutes. The PetroSense™ probe may be lowered directly into a borehole for analyzing in situ groundwater. The Quick Testr field test kit for cPAHs in soil reportedly takes less than 20 minutes per sample to analyze. The Quick Testr must be used in temperatures ranging from 40 to 110°F.

Applications and Cost

Test kits are most useful as screening tools. Colorimetric test kits are available for different media and contaminants. Prices vary with the type of kit. Most test kits include some of the following equipment: hand-held analyzer, glassware, reagents, and scales. The more expensive units use electronic colorimeters, and the less expensive units usually use visual colorimetric matches. Handby kits for soil or groundwater cost about $1,300 including enough reagent for 30 samples, and $550 for an additional 30 samples. The PetroFLAG™ kit for soil costs about $800 with enough reagent for 10 samples, and $250 for an additional 10 samples. The Petrosense™ rents for about $150/week plus minimal costs for calibration standards. The Quick Testr analyzer rents for about $275/week plus $40 per sample for consumables.

Benefits

- Rapid on-site screening tool
- Kits available for petroleum-derived substances and polynuclear aromatic hydrocarbon (PNAs)
- Useful for remote sampling
- Generally requires minimal training

Limitations

- Relatively high detection limits
- Possible interference by naturally occurring chemicals and other contaminants
- Possible difficulty reading colorimetric matches under low light conditions

Contacts

Dexsil Corporation (PetroFLAG™), (203) 288-3509, www.dexsil.com

Envirol, Inc. (Quick Testr), (801) 753-7946 or (435) 753-7946, www.environl.com

FCI Environmental Inc. (PetroSense™), (702) 361-7921

Handby Environmental Laboratory Procedures, Inc., (Handby Kit), (512) 847-1212

4.2.2.4 Immunoassay Screening

Tool Description

Immunoassay testing can be used in the field to detect target chemicals in soil and other samples. Most immunoassay-based test kits for analyzing environmental contaminants are of the competitive enzyme-linked immunosorbent assay (ELISA) type. In competitive ELISAs, the sample to be tested is combined with a labeled enzyme and an antibody to which both the contaminant in the sample and the enzyme will bind. The contaminant and the enzyme compete for the limited number of antibody binding sites that are available. Each will bind to a number of sites that is proportional to its concentration in the mixture, so the relative concentration of the contaminant can be determined.

The relative concentrations of enzymes and contaminants are indicated by color-producing reagents, which are added after the antibody with contaminants and enzymes bound to it is separated from whatever material is left over. Color development is catalyzed by the enzymes and then terminated by a stopping reagent. A spectrophotometer reads the absorbance or reflectance of the antibody-contaminant-enzyme complex; the color detected by the spectrophotometer is proportional to the enzyme's concentration and inversely proportional to the contaminant's concentration. Thus, the concentration of contaminant in the soil or other sample tested can be inferred.

Operational Considerations

Field immunoassay test kits can operate in temperature ranges from 40 to 100°F. Soil moisture content in excess of 30 percent can decrease extraction efficiency. Reactivity and/or interference from the surrounding soil matrix can have either a positive or negative effect on results. A work environment protected from sunlight and wind is recommended, and operator training by the manufacturer is encouraged.

To effectively use immunoassay test kits for field screening at MGP sites, a site-specific correlation study should be performed first. PAH immunoassay test methods measure PAH compounds based on molecular structure. Laboratories use gas chromotography/mass spectrometry (GC/MS) for ion identification to quantify 16 different PAHs. The presence of any of the more than 30 PAHs can be detected, but without identifying specific types or quantifying concentrations.

Immunoassay test kits should not be used at MGP sites where crude oil was used as a fuel source because the widely varied composition of feedstocks for oil-fired plants does not allow correlation to a standard based on simple feedstock. MGP sites where coal was used as a fuel source yield much better correlation factors between analytical laboratory data and immunoassay test kit data in field tests.

Applications and Cost

Immunoassay test kits may be an effective screening tool for PAHs, TPHs, and other chemicals typically detected at coal-fueled MGP sites. Immunoassay test kit cost per sample is $25-55 (excluding labor) depending on batch size and product line. Field lab instrumentation can be rented for $450/week or purchased for $1,700-2,000.

Benefits

- Rapid, real-time analytical data on-site
- Can be used to select samples for laboratory analysis and to define limits of contamination during an investigation

Limitations

- Requires site-specific calibration

- Does not speciate individual PAHs
- Does not work effectively on MGP sites where crude oil was used as fuel
- Does not produce quantified concentrations of target substance being analyzed
- Requires a trial period or test runs to confirm satisfactory performance

Contact

Dwight Denham, Strategic Diagnostics, Inc., (714) 644-8650

Case Study

Georgetown Former MGP Site

In 1930, the Georgetown Coal Gas plant was demolished after about 20 years of operation. The objectives of using immunoassay kits at the Georgetown Former MGP Site were to evaluate the entire site quickly and to find areas with actionable levels of PAHs, determine the extent and depth of each contaminated area, and compare in-laboratory methods with immunoassay results in terms of accuracy, cost, and time. Of the 36 samples analyzed at the site, the PAH immunoassay test kits were consistent with in-laboratory results with the exception of five false positives from the immunoassay test method. By not performing laboratory analysis of the samples determined to be negative via immunoassay (as defined by a concentration less than 1 ppm), a savings of approximately $4,000 would have been realized. Used as a screening tool, the immunoassay results can be very useful in determining which samples to send to a lab (immunoassay costs were approximately one tenth of laboratory analysis).

4.2.2.5 Mobile Laboratories

Tool Description

Under the right conditions for field programs in which rapid site assessment is necessary, mobile laboratories can provide rapid on-site, soil, air, and water sample analyses.

Field characterization programs are often conducted in phases of field sample collection and analysis. The results from the first phase are used to plan the sampling strategy of the second phase. The results from the second phase are used to plan sampling for a third phase, and so on until delineation of contaminants is complete. The time spent between phases waiting for analytical results from standard offsite laboratories translates into additional costs for repeated mobilization / demobilization of drilling equipment and field personnel. Mobile laboratories can provide same-day results for field sampling, allowing field personnel to make quick decisions about the locations of subsequent sampling. It is not necessary to demobilize then remobilize the sampling effort.

Operational Considerations

The analytical capabilities of mobile laboratories vary considerably among companies. However, several laboratories are equipped to analyze PAHs in addition to petroleum hydrocarbons and other common contaminants. Some mobile laboratories are also equipped to analyze natural attenuation parameters in the field. Many natural attenuation parameters (e.g., dissolved oxygen, oxidation-reduction potential, ferrous iron, hydrogen, methane, ethane, and ethene) require rapid analysis for accurate reporting, so mobile laboratories can be very effective for analyzing these parameters.

Several mobile laboratories can identify and quantify PAHs by SW846 Methods 8100, 8270, and 8310. Prior to selecting a mobile laboratory, it is important to determine the quality of data required (e.g., are results from immunoassay methods acceptable, or are gas chromatography / mass spectrometry procedures warranted). Similar to offsite laboratories, mobile laboratories require trained chemists to run analyses and perform QA / QC functions.

Applications and Cost

The decision to use a mobile rather than an offsite laboratory depends on a number of factors, including quality of data required, number of samples to be analyzed, types of analyses required, possibility of access to a fixed laboratory, and cost of onsite versus offsite analysis.

If the mobile laboratory does not require specialized instrumentation, the cost of sample analysis may be 10 to 15 percent less than the cost of sending samples offsite and requesting rapid turnaround (Onsite Laboratories, 1998). It is important to note that the cost of laboratory analyses at both onsite and offsite situations varies markedly among laboratories and that unit costs depend on the number of samples to be analyzed. Approximate laboratory rental costs are $2,500 to $3,000 plus $13 to $30 per sample for expenditures.

Benefits

- Extremely rapid turnaround analytical results
- May reduce mobilization / demobilization charges for drilling and field personnel
- Can rapidly perform time-critical analyses, such as for natural attenuation parameters

Limitations

- May be more efficient to send samples for rapid turnaround at an offsite laboratory
- More expensive than standard turnaround analysis
- Not all mobile laboratories use USEPA analytical methods

4.2.3 Geophysical Surveys

Geophysical surveys encompass a broad group of tools historically used by the geophysical, mining, and petroleum industries for mapping geological formations. All of these tools operate from the surface to sense buried obstructions and objects, changes in geologic formations, and / or the location of groundwater, thus minimizing uncertainty about what might be unearthed during excavations and giving additional information to conceptual and numerical modeling of groundwater flow. These tools are generally grouped into one of two categories: surface geophysical and borehole geophysical.

Surface geophysical tools are nonintrusive and include:

- Electromagnetics
- Seismic Refraction
- Ground-Penetrating Radar
- Magnetometry / Metal Detection

Borehole geophysical tools are designed to be put into a well or borehole. They include:

- Electrical Logging (including single-point and multi-electrodes)
- Mechanical Logging
- Sonic Logging
- Radiometric Logging
- Thermal Logging
- Video Logging

In general, all geophysical tools work on a "preponderance of evidence" basis. That is, an individual geophysical method does not typically provide definite results. Rather, several methods are used in conjunction at a site to provide information concurrently through their results.

4.2.3.1 Electromagnetics

Tool Description

Electromagnetic surveys (EMS) comprise two subclasses of surveys: magnetometer surveys and terrain conductivity electromagnetic surveys. Both types of surveys are nonintrusive geophysical surveying techniques that have traditionally been used to detect geologic features (e.g., formations with magnetic properties). More recently, EMS has been successfully applied with ground-penetrating radar (GPR) surveys at former MGP sites to locate buried obstructions and objects such as old underground storage tanks, buried sumps and pits, and current and abandoned utility lines.

Magnetometer surveys are conducted by using an instrument that measures the varying intensity of magnetic fields produced by natural objects (e.g., rocks) and man-made objects (e.g., utility lines). Interpreting the magnetic readings produced by the magnetometer allows conclusions to be drawn about the location of the buried objects.

Terrain conductivity electromagnetic surveys are conducted by remote seismic inductive electric measurements made at the surface. The apparent conductivity of subsurface formations and objects is measured by a conductivity meter consisting of a receiver coil and a separate transmitter coil that induces an electric source field in the ground. Lateral variations in conductivity values generally indicate a change in subsurface conditions. The figure below is an example of an output from a terrain conductivity electromagnetic survey.

Operational Considerations

Soil factors that affect the accuracy of EMS include moisture content, iron content, and dissolved salts and ions. EMS results can also be affected by electromagnetic interference. Overall, EMS results are best interpreted in parallel with other geophysical survey techniques, such as ground-penetrating radar surveys, that provide correlating information.

Applications and Cost

EMS uses a nonintrusive source and detectors and is therefore ideal for screening sites for buried objects. It is a fast, relatively inexpensive method to obtain "ballpark" data. Under favorable conditions (low moisture, low iron content, low electromagnetic interference), EMS's resolution and accuracy improve. EMS is well understood and provides reliable results.

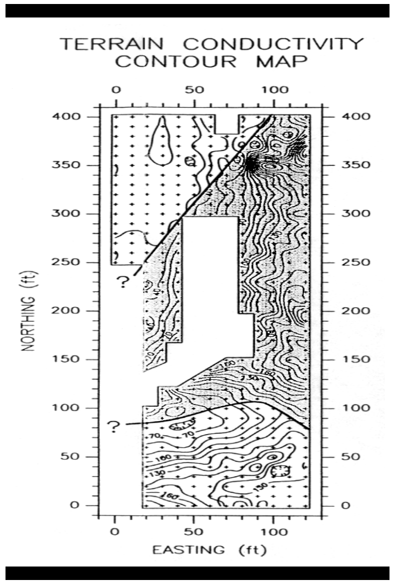
The cost of an EMS survey varies depending upon access to the site (directly related to the time required to perform the field work) and detail desired (e.g., the target depth to which a survey is to be conducted). Typically, an EMS survey on a 1-acre site will take 3 to 4 days to complete, costing around $3,500.

Benefits

- Provides reliable data
- Field tested and proven

Limitations

- Requires expertise to plan, collect, and interpret data
- Data subject to interference from soil moisture or clay in the subsurface and nearby electromagnetic sources (e.g., power lines)
- May be problematic in iron-rich, deeply weathered soils



Case Studies

Chico Former MGP Site

Available historical information for PG&E's Chico former MGP site indicated multiple locations for the historical buried feedstock tank. Terrain conductivity electromagnetic surveys were performed in conjunction with GPR to determine whether the tank still existed and, if so, to better estimate the tank's location (thereby determining if soil contamination observed in the general area might be from the tank or from a different former MGP structure). At the time of the surveys, the site consisted of the former MGP sheet-metal generating building and an adjacent substation. There was significant interference in the EMS survey from the adjacent substation, but the GPR survey was able to place the location of the former buried feedstock tank farther west than the location estimated from historical Sanborn Fire Insurance maps.

Stockton Former MGP Site

Terrain conductivity electromagnetic surveys were also used at PG&E's Stockton former MGP site to delineate debris-filled areas, covered pits and sumps, and concealed foundations associated with the former MGP. The terrain conductivity electromagnetic surveys correlated well with the estimated locations of former MGP structures as determined by a GPR survey.

Contact

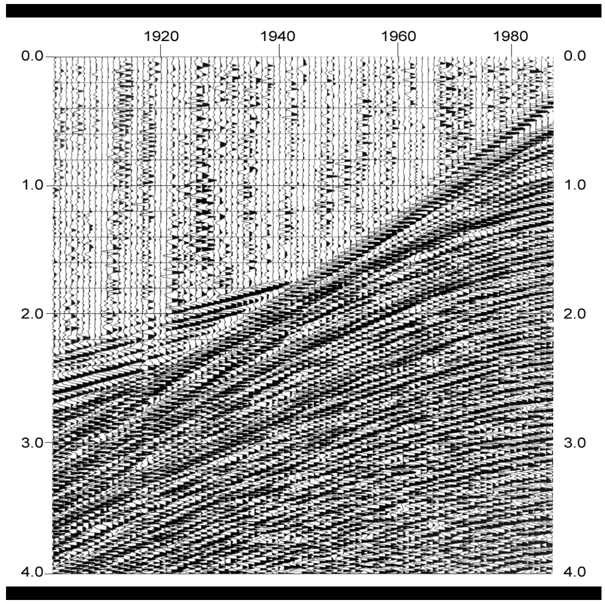
Robert Doss, Pacific Gas and Electric Company, (415) 973-7601

4.2.3.2 Seismic Refraction

Tool Description

Seismic refraction is a nonintrusive geophysical surveying technique that can be used to determine depth to bedrock, thickness of surficial fracture zones in crystalline rock, extent of potential aquifers, and depth of the water table.

Seismic refraction surveys are conducted by measuring the velocity of elastic waves in the subsurface. Elastic waves are generated by a source (hammer blow or small explosion) at the ground surface, and a set of receivers is placed in a line radiating outward from the energy source to measure the time between the shock and the arrival. The velocity of the elastic waves in the subsurface increases with increasing bulk density and water content. The depth of various strata and objects may be calculated if their wave velocities are sufficiently different. The survey data are processed and interpreted, typically along with other geologic information and geophysical surveys, to provide a picture of subsurface conditions. The following figure exemplifies the output from a seismic refraction survey.



Three-dimensional / three-component (3-D / 3-C) seismic imaging can be an extremely powerful tool for characterizing the hydrogeological framework in which contaminants are found at MGP sites. 3-D / 3-C seismic imaging is a nonintrusive geophysical surveying technique that can delineate subsurface geophysical features including: bedrock channels, clay layers, faults, fractures, and porosity. In addition, 3-D / 3-C seismic imaging can identify trench / pit boundaries and differences in soils and wastes (Hasbrouck et al., 1996).

3-C imaging entails analysis of one-component compression-wave and two-component shear-wave data. Two-dimensional (2-D) seismic refraction surveys use only one–component compression-wave data. The 3-D / 3-C seismic imaging uses shear-wave data to map much thinner features than can be detected with 2-D surveys; 3-D / 3-C imaging can determine anisotropy (i.e., preferred grain orientation, periodic layering, and depositional or erosional lineation), which may correlate to preferential contaminant transport pathways (Hasbrouck et al., 1996).

Operational Considerations

Interpretations of seismic refraction surveys are most reliable in cases where there is a simple two- or three-layer subsurface in which the layers exhibit a strong contrast in seismic velocity. For shallow investigations (i.e., up to approximately 10 feet deep), the energy source for the elastic waves is a hammer blow on a metal plate set on the ground surface. For a deeper investigation or at sites with noise interference (heavy machinery or highways), an explosive source is necessary. High gravel content in the soil matrix may diminish the quality of the data.

3-D / 3-C seismic imaging data can be processed so that cross sections are oriented from any angle and specific zones of interest can be displayed and interpreted. Specially developed 3-D / 3-C software is necessary to process the data, and skilled data interpretation is required (Hasbrouck et al., 1996).

Overall, seismic refraction results are best interpreted in parallel with other geophysical survey techniques (such as magnetometer surveys and electromagnetic terrain surveys) or well logs, which provide correlating information.

Applications and Cost

Where deep groundwater, consolidated materials, or both make test drilling relatively expensive, it may be advantageous to get as much information as possible by seismic refraction. Seismic refraction is a nonintrusive survey method that is well understood and provides reliable results.

3-D/3-C seismic imaging can be used for subsurface characterization. The relatively high cost of 3-D/3-C seismic imaging may be justified in situations where site entry is restricted because of high levels of subsurface contaminants and a three-dimensional picture of the sites's subsurface is required without intrusive sampling.

The cost of a seismic refraction survey varies depending upon access to the site (directly related to the time required to perform the field work) and the level of detail desired (e.g., the target depth to which the survey is to be conducted). Typically, one week of seismic refraction surveys may yield 3 to 5 line miles of interpreted data for approximately $10,000.

Benefits

- Provides reliable data
- Field tested and proven
- Minimizes the number of times an area must be accessed for subsurface characterization and maximizes the amount of information gathered
- 3D/3C seismic refraction provides greater level of detail (e.g., thinner features) than traditional 2-D seismic surveying results

Limitations

- Requires expertise to plan, collect and interpret data
- Data subject to interference from complex geological strata
- 3D-3C seismic refraction relatively expensive
- Needs to be correlated with other site-specific subsurface data such as drilling logs
- Heavy traffic or numerous surface obstructions can be problematic

Contact

Dennis Olona, U.S. Department of Energy, Albuquerque, NM, (505) 845-4296

4.2.3.3 Ground-Penetrating Radar (GPR)

Tool Description

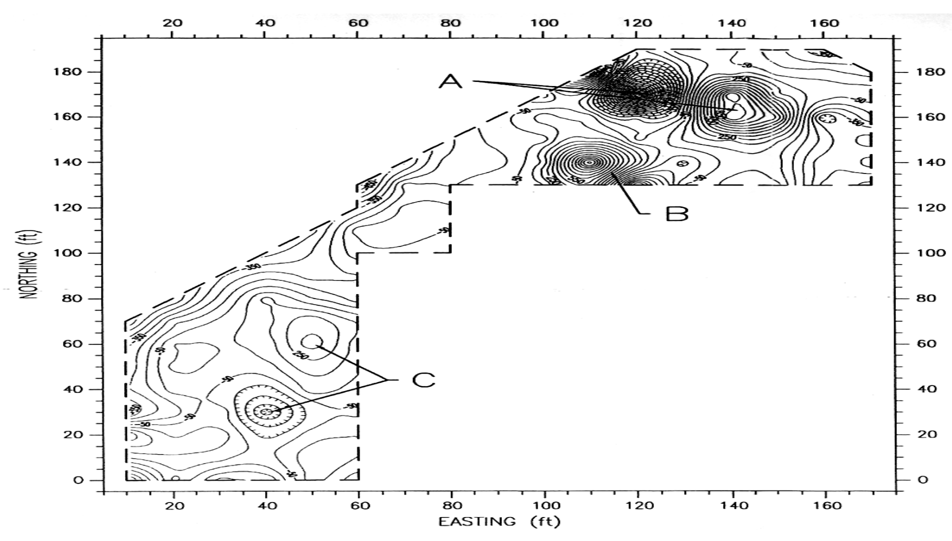
GPR is a nonintrusive geophysical surveying technique that has traditionally been used to detect geologic features (e.g., fractures and faults). More recently, GPR has been successfully applied with EMSs at former MGP sites to locate buried obstructions and objects such as old foundations, underground storage tanks, buried sumps and pits, current and abandoned utility lines, and concrete rubble.

GPR surveying emits high-frequency electromagnetic waves into the subsurface. The electromagnetic energy that is reflected by buried obstructions is received by an antenna at the surface and recorded as a function of time. The recorded patterns are interpreted, typically along with other geologic information and geophysical surveys, to provide a picture of subsurface conditions. The following figure is an example of an output from a GPR. Results are best interpreted in parallel with other geophysical survey techniques, such as magnetometer surveys and EMSs, which provide correlating information.

Applications and Cost

GPR uses a nonintrusive source and detectors and is therefore ideal for screening sites for buried objects. It is a fast, relatively inexpensive method to obtain "ballpark" data. Under favorable conditions (low moisture, low iron content, low electromagnetic interference), GPR's resolution and accuracy is best. GPR is well understood and provides reliable results.

The cost of a GPR survey varies depending upon access to the site (directly related to the time required to perform the field work) and the level of detail desired (e.g., the target depth to which the survey is to be conducted). Typically, one week of GPR surveys yields 5 to 7 line miles of interpreted data for around $10,000.



Benefits

- Field tested and proven

Limitations

- Requires expertise to plan, collect, and interpret data
- Data subject to interference from soil moisture or clay in the subsurface
- May be problematic in iron-rich, deeply weathered soils

Case Study

Chico Former MGP Site

Historical information for PG&E's Chico former MGP site indicated multiple locations for the buried former feedstock tank. Ground-penetrating radar was used in conjunction with EMS to determine whether the tank still existed and to verify its location (in order to determine whether soil contamination observed in an area might be from the tank or from a different former MGP structure). Although there was significant interference in the EMS survey from an adjacent substation, the GPR survey placed the location of the former buried feedstock tank farther west than the location estimated from historical Sanborn Fire Insurance maps. Interpretation of the survey data identified the location of the tank excavation but was not able to confirm whether or not the tank was still in place.

Contact

Robert Doss, Pacific Gas and Electric Company, (415) 973-7601

4.2.3.4 Magnetometry/Metal Detection

Tool Description

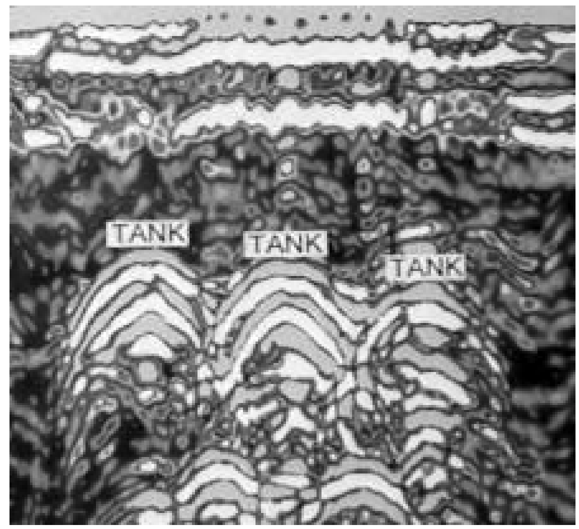
Magnetometry is a nonintrusive electromagnetic geophysical surveying technique commonly used in the construction industry to detect and map buried drums, metallic pipes, utilities, cables, and piping before excavation, demolition and/or construction. This technology has also been applied to former MGP sites to identify buried utilities before drilling and to survey and map historical MGP structures such as buried piping, tanks, and other metal structures.

Magnetometer surveys use an instrument that measures the varying intensity of magnetic fields produced by buried metallic objects. The magnetic readings produced by the magnetometer can be interpreted so that conclusions can be drawn about the location of the buried objects. The following figure is an example output from a magnetometer survey.

Operational Considerations

Soil factors that affect the accuracy of magnetometry include moisture content, iron content, and dissolved salts and ions. In addition, magnetometry surveys are typically depth limited and cannot distinguish among types of metallic objects. Nonferrous objects are invisible to magnetometry survey instruments.

Applications and Cost



Magnetometry uses a nonintrusive source and detectors and is therefore ideal for screening sites for buried objects. It is a fast, inexpensive method to obtain "ballpark" data on the location of buried metallic objects. Under favorable conditions (low moisture, low iron content, low electromagnetic interference), magnetometry resolution and accuracy is best. Magnetometry is well understood, well accepted, and provides reliable results.

The cost of a magnetometry survey varies depending upon access to the site (directly related to the time required to perform the field work), the size of the area to be surveyed, and the level of detail desired (e.g., the target depth to which the survey is to be conducted). Typically, a magnetometry survey on a 1-acre site with 10-foot grid spacing will take 3 to 4 days to complete. Equipment rental may cost approximately $500 per month, exclusive of labor (for both testing and data interpretation) and other related expenses.

Benefits

- Field tested and proven
- Widely accepted

Limitations

- Details obtainable only at relatively shallow depths
- Cannot distinguish among metallic objects
- May be problematic in iron-rich, deeply weathered soils or where there is a lot of scattered metal debris
- Nonferrous objects will not be visible to the technology

4.2.3.5 Borehole Geophysical Methods

Borehole geophysical methods are used to physically characterize sediments, rocks, and fluids in boreholes and wells. Data are acquired by moving a string of instruments up or down a borehole and measuring the response. Depending on the specific information required, one or more borehole geophysics techniques may be used in a single well. The radius of the investigation depends on the particular instrument used.

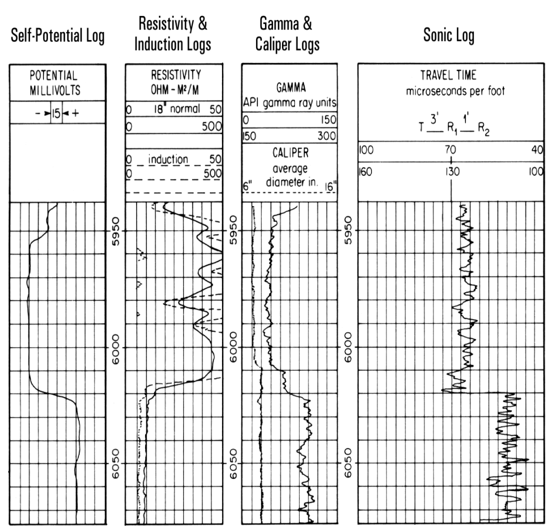
The tools discussed below include several categories of borehole survey techniques:

- Electrical
- Mechanical
- Sonic
- Radiometric
- Thermal
- Video

Borehole geophysical logging is a useful tool for site characterization. Because of the mobilization effort required and because multiple logging techniques can be used simultaneously, borehole geophysical surveys are most cost effective when performed as part of a multiple-log suite.

Geophysical logs provide a continuous profile of response versus depth in a well or boring. Typically, direct soil sampling is undertaken only at 5-foot intervals. A substantial amount of information can be obtained from a few logging runs into a well. In addition, data can be correlated between adjacent wells. Examples of some of the well logs that may be produced with the techniques discussed herein is shown below.

In general, borehole logging is relatively expensive (including actual logging and post processing), and equipment must be transported to the site. In addition, the radius of the investigation may be small and may not be representative of the bulk formation.



4.2.3.5.1 Electrical Logging

Tool Description

Electrical logging includes electrical resistivity methods, induction logs, self-potential logs, and fluid conductivity logs. Electrical resistivity relies on different electrode configurations to give information on different zones around the borehole. The characteristics (e.g., thickness, permeability, salinity) of a region energized by particular current electrode configuration can be estimated by measuring variations in current among electrodes. Many variations of electrical resistivity logging exist in which different electrode configurations are used including: normal logs, lateral logs, guard logs, and micrologs. Using empirical constants specific to the particular rocks in the area and the drilling fluid, electrical resistivity is also used to estimate porosity, water and hydrocarbon saturation, and permeability.

An induction log is a profile of resistivity obtained by utilizing electromagnetic waves. This technique is used in dry holes or boreholes that contain nonconductive drilling fluid. Lithologic boundaries show up on induction logs as gradual changes in apparent resistivity.

On self-potential logs, measurements of potential differences between an electrode on the sonde (probe) and a grounded electrode at the surface are made in boreholes filled with conductive drilling fluid. The self-potential effect originates from the movement of ions at different speeds between two fluids of differing concentration, in this case groundwater and drilling fluid. Self-potential logging can be used to identify the boundaries between geological beds based on the differing rates of penetration of drilling mud into the lithology. In hydrocarbon-bearing zones, self-potential logs show less deflection than normal.

Fluid conductivity logging uses an electrical conductivity probe to profile water quality by depth. It is used to select sampling depths and also used in conjunction with a flow-meter log (see Section 4.2.3.5.2, Mechanical Logging) to identify water-producing zones.

Operational Considerations

The electrical logging techniques described here require an open borehole. Borehole fluids must be electrically conducting if electrical resistivity and self-potential logging are to be used. Induction logging, however, requires either a dry borehole or nonconducting fluids in the borehole. Single-electrode logging yields a poor response in saltwater aquifers and provides qualitative data elsewhere. Multi-electrode logging permits quantitative data and estimates of formation water salinity. Fluid conductivity logging yields less precise information in highly saline waters.

Applications and Costs

The cost of electrical logging is approximately $1,200-$2,500 per day. Five to seven wells can be logged per day. Fluid conductivity logging is approximately $500-$600 per well when performed as part of a multiple-log suite and approximately $1,500-$2,500 per well when done alone.

Benefits

- Quantitative data may require corrections

Limitations

- The electrical logging techniques described require an uncased borehole
- Electrical resistivity and self-potential techniques require conductive borehole fluids
- Induction logging requires a dry borehole or borehole with nonconductive fluids
- Induction logging may be complex and provide poor results in situations of high-resistance formations, thin beds, and shallow wells
- Poor response in saltwater aquifers

4.2.3.5.2 Mechanical Logging

Tool Description

Flow-meter and caliper logging are two different types of mechanical logging. Flow-meter or spinner logging incorporates mechanical flow meters to measure horizontal and vertical groundwater flow rates. These flow rates can be used to identify permeable zones in a formation. When used in conjunction with the caliper log, the flow meter yields semiquantitative measurements of groundwater into the borehole.

A mechanical flow meter measures the velocity of fluid in a borehole by means of low-inertia impellers that are turned by the fluid flow. Turning of the impellers causes a magnet mounted on the impeller shaft to rotate and generate electrical signals. Mechanical flow meters are capable of measuring flow rates down to about 2 feet per minute (ft/min). A newer electromagnetic flow meter uses thermal principles to measure flow rates as low as 0.1 ft/min.

Mechanical flow-meter logging can be done under natural (non-pumping) or forced-flow (pumping) conditions. Pumping flow-meter logs can be used to estimate the relative transmissivity of different water-bearing zones; non-pumping flow-meter logs can be used to identify the direction and magnitude of vertical well-bore flow caused by vertical gradients.

Another common type of mechanical logging uses the caliper log, which measures borehole diameter and roughness. The tool itself has a number of feelers (usually four) attached. The feelers are electromechanical devices, held by springs against the wall of the hole, that send information to the surface. The information from the log is used mainly to estimate the volume of cement that might be required to seal around a collapsed region, to verify well-construction details, and to provide lithologic information. Information gained from the caliper log is used to estimate velocity losses in the gap between the borehole wall and the flow-meter impeller, thereby correcting velocity measured by the flow-meter log. The key use of the caliper log data is to correlate vertical velocity data to vertical flow data by allowing the area of the borehole to be factored into the vertical profile.

Operational Considerations
Flow-meter logging requires a minimum flow of approximately 2 ft/min. Caliper logging requires an open borehole, which may be difficult to achieve in deep, unconsolidated deposits. Conductor casing may be necessary to contain unconsolidated sediments near the top of the well.

Applications and Costs
The cost of flow-meter logging is roughly $500 to $600 per well when performed as part of a multiple-log suite. The cost of flow-meter logging (with recommended caliper logging) is $1,500 to $2,500 per well.

Benefits
- Caliper log is widely available, rapid, and inexpensive
- Flow meter logging is relatively simple and inexpensive

Limitations
- Flow-meter logging is relatively insensitive at low velocities
- Most applications of flow-meter logging require a pumping or flowing well during the survey
- A caliper log is needed for interpretation of flow-meter logs

4.2.3.5.3 Sonic Logging

Tool Description
Sonic logging, also known as continuous velocity or acoustic logging, is used to determine the relative porosity of different formations. Sonic logging may also be used to determine the top of the water table, to locate perched water-bearing zones, and to assess the seal between a casing and formation material.

A probe containing one or more transmitters that convert electrical energy to acoustic energy is lowered into the borehole on a cable. The acoustic energy travels through the formation and back to one or more receivers also located on the tool. The acoustic energy is converted back to an electrical signal, which is transmitted back to the surface by the receivers and recorded.

Sonic logging determines the seismic velocities of the formations traversed. The average velocity of the acoustic wave passing through the formation depends on the matrix material and the presence of fluid in the pore space. The speed of the wave is slowed by the presence of pore fluid; therefore, sonic logging provides a measure of fluid-filled pore space. The velocity of the solid matrix can be determined by laboratory analysis of core samples.

Operational Considerations
Sonic logging can be performed in a borehole cased with metal; however, the results are most representative of formation properties if logging is performed in an open borehole. The borehole must be fluid-filled for signal transmission to

occur. Obtaining meaningful results in unconsolidated materials with low groundwater velocities may be difficult.

Applications and Costs

Sonic logging may be used for site characterization where information is needed on the relative porosity of different formations and the location of water-bearing zones. The cost of sonic logging is approximately $1,500 to $4,500 per well.

Benefits

- Widely available
- Suitable for uncased or cased boreholes although the results are more representative of the formation if the borehole is uncased
- Useful for characterizing rock aquifers to identify high-porosity zones that may transmit water
- Allows porosity determination without use of radioactive source

Limitations

- Interpretation of the data may require expertise
- The borehole must be fluid-filled
- Not applicable in shallow wells or in unsaturated conditions

4.2.3.5.4 Radiometric Logging

Tool Description

The radiometric logging techniques discussed here include neutron logging and natural gamma (or gamma) logging. Neutron logging is used to estimate porosity and bulk density, and, in the vadose zone, to locate saturated zones outside a borehole or well casing. Natural gamma logs are used to evaluate downhole lithology, stratigraphic correlation, and clay content of sedimentary rocks.

Both logging techniques are based on the process by which particles of mass or energy are spontaneously emitted from an atom. These emissions consist of protons, neutrons, electrons, and photons of electromagnetic energy that are called gamma rays. Radiometric logs either make use of the natural radioactivity produced by the unstable elements U^{238}, Th^{232}, and K^{40}, or radioactivity induced by the bombardment of stable nuclei with gamma rays or neutrons.

In neutron logging, nonradioactive elements are bombarded with neutrons and stimulated to emit gamma rays. The sonde (probe) contains a neutron source, and the neutrons collide with atomic nuclei in the wall rock and emit gamma rays, which are measured by a gamma-ray detector also on the sonde. The amount of gamma radiation from neutron logging correlates directly with the proportion of water-filled pore space in a rock unit.

Natural gamma radiation logging uses a detector mounted on a sonde to measure the gamma rays produced by radioactive elements in a formation. Because different types of formations contain different amounts of radioactive elements, gamma logging is used primarily to determine lithology, stratigraphy, and the clay or shale content of a rock.

Operational Considerations

Neutron and gamma logging techniques can be used in cased holes, which means they offer a distinct advantage under some circumstances. Neutron logging requires handling of a radioactive source.

Applications and Costs

Neutron logging costs approximately $2,500 to $5,000 per well (depending on well depth and the number of other logs run at the same time). Gamma logging costs are on the order of $1,200 to $2,500 per well; approximately five to seven 100-foot wells can be logged per day.

Benefits

- Radiometric logging is suitable for both uncased and cased boreholes
- Specialized training is not required for gamma logging
- Radiometric logging is useful in characterizing rock aquifers to identify high-porosity zones that may transmit water.

Limitations

- Gamma rays detected using neutron and natural gamma logging come from the formation only within a few feet from the well
- Lithology must be determined by other logs before porosity estimates can be made using the neutron logging technique
- Neutron logging requires special training, transportation, and permits to allow handling of a radioactive source; its availability is also limited
- Neutron logging may only be allowed in cased holes in some states (e.g., Oregon)

4.2.3.5.5 Thermal Logging

Tool Description

Thermal logging is primarily used to locate water-bearing zones. It can also be used to estimate seasonal recharge or a source of groundwater. A temperature sensor, usually a thermistor mounted inside a protective cage, is lowered down a water-filled borehole. The probe is lowered at a constant rate and transmits data related to the temperature change with change of depth to surface. The natural variation of temperature with depth is called the geothermal gradient. Water-bearing zones intersected by the borehole may cause changes in the geothermal gradient, which is shown on the temperature log. Seasonal recharge effects may also be detected because the influx of recharge water changes the natural temperature regime. It is also possible to assess the source of groundwater if the regional sources have characteristic temperatures.

Operational Considerations

Thermal logging may be performed in an open or cased borehole; however, the borehole must be fluid-filled. Thermal logging should be performed several days after drilling is complete to ensure that water in the boring is representative of ambient conditions.

Applications and Costs

Thermal logging is often combined with other borehole geophysical methods. The cost of thermal logging is approximately $500 to $600 per well (depending on the total depth logged) as part of a multiple-log suite. The cost of temperature logging when no other borehole geophysical methods are used is approximately $1,500 to $2,000 per well.

Benefits

- Thermal logging is widely available, rapid, and inexpensive
- Data are easy to interpret unless internal borehole flow is present

Limitations

- Temperature measured is that of borehole fluid, which may not be representative of surrounding formation
- This technique requires a fluid-filled borehole
- Interpretation of log is complicated if internal borehole flow is present

4.2.3.5.6 Video Logging

Tool Description

Video logging a borehole can provide visual inspection of the interior of a well, detecting damaged sections of screen and confirming well construction details. In uncased boreholes, video logs can detect fractures, solution cracks, and geological contacts if turbidity in the well is low.

Operational Considerations

Video logging requires very low turbidity in the well for a successful survey. Both monochrome and color videography are available; however, color is preferred because interpretation of images is easier.

Applications and Cost

Video logging is primarily used to detect fractured bedrock and the integrity of screens and casing. Video logging may cost from $400 to $3,000 per well.

Benefits

- Video logging allows visual inspection of well interior
- Video logging is useful for troubleshooting potentially damaged casings

Limitations

- Video logging requires an open borehole and is therefore not useable with unconsolidated formations

- The borehole walls must be clean and the groundwater relatively clear

4.2.4 Soil Gas Surveys

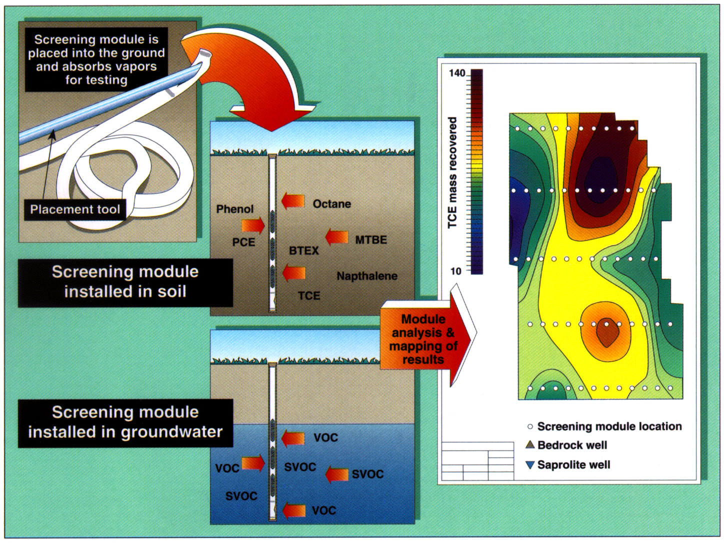
Soil gas measurements can successfully predict actual concentrations of MGP residues in soil and water. MGP residues are present in the soil as a gas because of their vapor pressure and solubility. Measuring the amount and composition of these gases can indicate the extent of source areas and groundwater plumes. Soil gas investigations, used in conjunction with physical soil and groundwater sampling, can provide a more thorough and cost-effective site investigation than borings and well samples alone. Soil gas surveys are grouped in two categories: passive and active. Passive soil gas surveys measure the relative concentration of contaminants through subsurface detectors sensitive to diffusion. Active soil gas surveys relatively quickly withdraw soil vapors using a vacuum pump system to analyze the concentration of contaminants in the vapor phase. The active gas soil gas technique provides real-time concentration data; the passive soil gas technique provides a time-integrated relative concentration that may detect less volatile compounds. Each of these methods of soil gas sampling is discussed in more detail below.

4.2.4.1 Passive Soil Gas Survey

Tool Description

Passive soil gas surveys use subsurface detectors sensitive to diffusion to measure the relative concentration of contaminants. Passive methods involve integrated sampling over time and collection of the sample on an absorbent material. Because sampling is integrated over time, fluctuations in soil gas availability resulting from changing ambient and subsurface conditions are minimized. Passive soil gas sampling does not disrupt the natural equilibrium of vapors in the subsurface as is the case with active sampling methods. Passive gas sampling only provides qualitative results because it does not measure the specific amount of contamination per unit of contaminated material. Because passive soil gas sampling occurs over a period of at least a few days, it can detect heavy organic compounds with lower vapor pressures, such as PAHs.

Gore-Sorbers® and Emflux® are both patented technologies that use passive soil gas principles. The Gore-Sorbers® Module uses a granular absorbent within an inert Gore-Tex® membrane that only permits vapor transfer into the module. Each thin, cord-like, module is placed in the shallow subsurface for a period of 2 to 4 weeks and then removed and shipped to a laboratory for analysis. Emflux® samples consist of a sampler vial containing an adsorbent cartridge. The samplers are placed at a depth of approximately 3 inches below grade for 72 hours, after which they are removed and sent to a laboratory for thermal desorption and analysis. Results of a passive gas survey is shown below.



Operational Considerations
As opposed to active gas sampling, passive soil gas sampling can be used in areas with relatively low soil permeability. Installation and retrieval of samples can be accomplished with minimal training and equipment. Soil gas samples should be taken at points deep enough to avoid background contamination from surface spills or exhaust. Installations directly beneath concrete or paved surfaces should be to a depth below the zone of lateral migration of soil gas to avoid misleading results. Depths of at least 2 to 3 feet are typically sufficient to insure good sampling. It may be difficult to obtain passive soil gas data for vertical characterization; active soil gas sampling is often used to vertically characterize contamination. Passive gas sampling may be applied directly in a saturated zone.

Application and Cost
Passive gas testing has been used for many different types of contaminants (including MGP residues) and is becoming more popular because of its low cost and flexibility in different types of soil. Using soil gas sampling data in conjunction with other site-specific data can be a cost-effective method for delineating MGP residues.

Passive soil gas testing is approximately $250 per sample location (including analysis and reporting) and $50 to $100 per location for installation and retrieval.

Benefits
- Easy to use
- Can be used in areas of relatively low permeability
- Can be more sensitive than active soil gas, soil, or groundwater sampling

Limitations

- May not correlate well with active soil sampling results
- Does not measure direct concentration
- Data at depth for vertical characterization may be difficult to collect
- Gore Sorber® passive detector must remain in situ for 14 days, whereas Emflux® passive detector must remain in situ for only 3 days

Case Study

McClellan Air Force Base (AFB)

Past disposal practices at McClellan AFB, located near Sacramento, California, from 1936 to the late 1970s, contaminated the soil and groundwater of more than 3,000 acres. Contaminants include caustic cleaners, electroplating chemicals, heavy metals, industrial solvents, low-level radioactive wastes, PCBs, and a variety of fuel oils and lubricants.

As part of a test location for innovative technologies, McClellan AFB tested the Gore-Sorber® Module, primarily to monitor VOCs (perchloroethylene [PCE] , trichloroethylene [TCE], and cis-1,2-dichloroethylene [CIS-1, 2-DCE]). A very good correlation was observed between the relative contamination levels measured by the survey and actual levels determined using active soil gas sampling (Elsevier Sciences, 1997).

Contacts

Paul Henning, Quadrel Services (Emflux® Module), (800) 878-5510

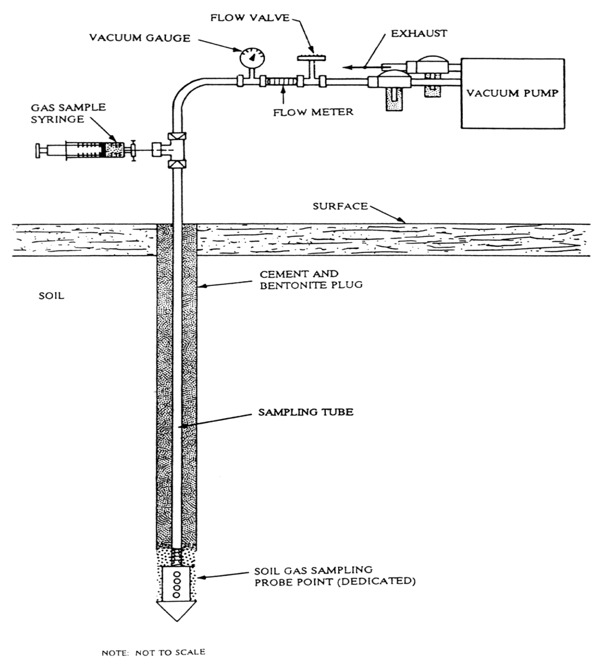
Gore Technologies (Gore-Sorber®), Mark Wrigley (410) 392-3406 and Andre Brown (415) 648-0438

4.2.4.2 Active Soil Gas Survey

Tool Description

Active soil gas surveys use a vacuum pump to induce vapor transport in the subsurface and to instantaneously collect samples of contaminants in the vapor phase. Active soil gas surveys provide a snapshot of vapor concentration in the subsurface, in contrast to passive soil gas surveys, which provide time-integrated sampling data.

Because active soil gas sampling provides real-time data, a relatively coarse sampling grid is initially used; this grid can be refined in areas of interest (e.g., areas with relatively high contaminant concentrations) for additional sample collection. The following figure shows a schematic of one type of active soil gas sampling device. (Adapted from "Handbook of Vadose Zone Characterization and Monitoring" by L.G. Wilson, et al., 1995.)



Other active soil gas sampling methods also use a vacuum pump; however, a gas sampling bag, an evacuated canister/vial, or a solid adsorbent may be used instead of a gas sampling syringe. The active soil gas sampling method that uses a solid adsorbent is similar to passive soil gas sampling techniques except that active soil gas sampling uses vacuum pressure instead of diffusion to pull the vapor sample through the solid adsorbent.

Operational Considerations

The vacuum used in active soil gas sampling disrupts the equilibrium soil gas vapor in the subsurface by forcibly drawing the vapor and soil gas from the soil matrix surrounding the sampling point. Active soil gas sampling typically must be done at least 10 to 20 feet bgs; passive soil gas sampling, by contrast, typically occurs at 3 feet bgs. It may be difficult to collect an active soil gas sample in an area of relatively low soil permeability. Active soil gas surveys may not be used in the saturated zone and may result in false negative or low soil gas concentration measurements in areas of elevated soil moisture.

Active soil gas sampling may be adversely affected by transient processes such as barometric pressure changes, earth tides, and precipitation, as well as by stationary features such as buried foundations. Active soil gas sampling data should be interpreted to account for the fluctuations these transient processes may create in the data.

Laboratory sample holding/extraction times are dependent on the specific active soil gas sampling method used. The solid adsorbent active gas sampling method requires relatively long sample holding/extraction times. The gas syringe active gas sampling method (shown in the figure above) requires relatively short sample holding/extraction times.

Applications and Cost

Active soil gas sampling is well suited to delineating areas of higher and lower VOC concentrations. Passive soil gas sampling may be better suited to measuring lower contaminant concentrations and less volatile compounds such as PAHs because of the time-integrated nature of the sampling methodology. Active soil gas sampling costs approximately $3,000 to 4,000 per day.

Benefits

- Provides real-time data
- Provides rapid results that allow the user to converge on areas of interest
- Provides a direct measure of vapor concentration
- Can be used to evaluate vertical changes in soil gas concentrations

Limitations

- Requires samples collected at least 10 to 20 feet bgs
- Cannot be effectively used in areas of relatively low permeability
- May not be effective in detecting semivolatiles (e.g., PAHs)
- May be affected by barometric and other transient processes
- Subsurface equilibrium vapor conditions disrupted by vacuum

Contacts

Tracer Research, (800) 989-9929

Transglobal Environmental Geosciences, (800) 300-6010

4.2.5 Contaminant Migration Evaluation

Three techniques for evaluating the movement and degradation of contaminants in aquifers include a Push-Pull Natural Attenuation Test, a Partitioning Interwell Tracer Test (PITT), and an In Situ Bio / Geochemical Monitor (ISM) test. Each of these are discussed in more detail below.

4.2.5.1 Push-Pull Natural Attenuation Test

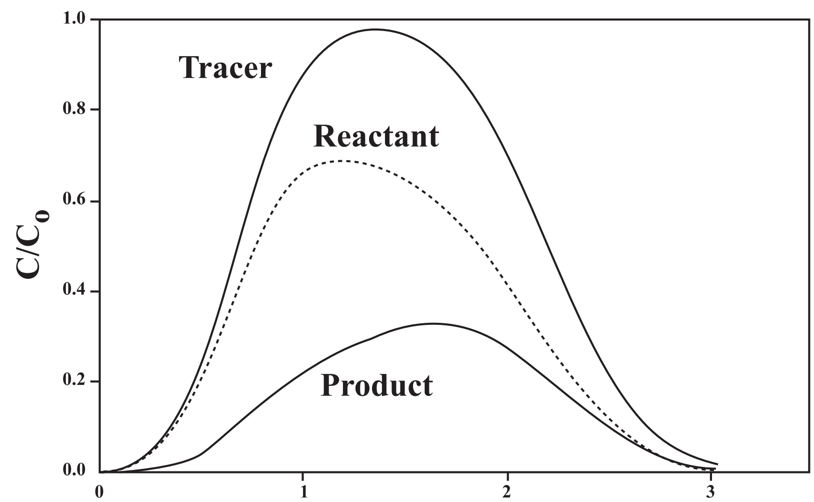
Tool Description

The push-pull natural attenuation test is an infrequently used single-well injection / extraction test used to obtain quantitative information on in situ microbial metabolic activity. A push-pull test is conducted in three steps:

1. Inject in an existing monitoring well a pulse of test solution consisting of water, a conservative tracer, and microbial substrates (electron acceptors and donors).
2. Allow the test solution to interact with indigenous microorganisms and then extract a slug of water / tracer / microbial substrates from the same well.
3. Measure the tracer, substrate, and product concentrations from the extracted slug of the test solution / groundwater mixture, and use measurements to calculate rates of microbial activities.

This method provides direct estimates of rates for microbial activity and mass balances for reactants.

The following figure shows an idealized breakthrough curve for a process generating a single product from a single reactant. The curves show the typical relationship between contaminant concentration and time, providing information on the way advection, dispersion, diffusion, and biodegradation affect contaminant movement within the aquifer.



Operational Considerations

Push-pull tests require specially trained field personnel although an individual test typically only requires a few hours, so several tests can be completed by a single operator in a day. The test solution used during the injection phase of a push-pull test is composed of various electron acceptors and donors (e.g., sodium bromide) that depend on the objectives of the sampling. The tracer selected should have a decay rate similar to or greater than the groundwater flow rate.

Applications and Cost

Push-pull tests are ideal for situations in which quantifiable estimates of microbial activity are desired for potential natural attenuation scenarios.

The cost of push-pull tests for a site contaminated with BTEX is approximately $12,000 to $15,000 for two to three wells, including analytical costs. The costs are very dependent on the specific analyses required.

Benefits

- Can document microbial metabolism, loss of degraded contaminants, production of degradation products, and estimates of zero- and first-order decay constants
- Provides in situ data (versus in an artificial laboratory environment)

- Can be used in wells that are already installed
- Can assay a wide variety of processes
- Is field tested

Limitations

- Is a fairly new test; not widely used
- Can be difficult to use when decay rate is slow relative to groundwater flow rate

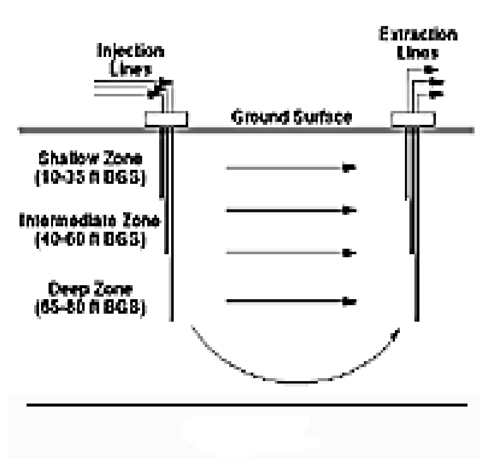
4.2.5.2 Partitioning Interwell Tracer Test (PITT)

Tool Description

The PITT is an in situ technology that measures the volume and percent saturation of NAPL contamination trapped in water-saturated and vadose zone sediments. The PITT technology is primarily used to:

- Quantify and locate NAPL contamination
- Assess the performance of remediation activities
- Quantify water saturation in the vadose zone

The technique is essentially a large-scale application of chromatography. The migration of a partitioning tracer between an injection well and an extraction well is retarded relative to a nonpartitioning tracer because it spends a portion of its residence time in the immobile residual NAPL. The chromatographic separation of the tracers indicates the presence of NAPL in the interwell zone and is used to determine the volume of NAPL present. The figure below shows a typical injection-extraction system.



The PITT technique can be used before and after an in situ remedial activity, such as surfactant flooding, to estimate the fraction of NAPL removed and the volume of NAPL remaining.

Operational Considerations

The PITT technique requires wells situated so that the potential NAPL source is within the radius of influence of the wells used to inject/withdraw the conservative and nonconservative tracers. It is important for the tracers to be nontoxic and to have nondetectable background concentrations and for the partitioning tracer to have an affinity for the particular NAPL found at the site.

Applications and Cost

The PITT technique is ideal for in situ characterization of NAPL and is limited by the well network available to perform the injection / withdrawal tests and the project budget.

The cost of PITT technology may range from $100,000 to $400,000 depending on the scale of the test.

Benefits

- Provides quantitative estimates of NAPL volume
- Can be used to design remediation methods targeting a NAPL source
- Is relatively accurate compared with other in situ tests that utilize point values or small aquifer volumes

Limitations

- Expensive
- Technology is patented
- Not economical for smaller sites
- Most application experience is with solvents

Case Study

Hill Air Force Base, Utah

The PITT technique was used at Hill AFB in 1996 to demonstrate surfactant remediation of a DNAPL-contaminated site. Partitioning interwell tracer tests were used to estimate the volume of DNAPL in place and to assess the performance of the surfactant remediation. Three constituents make up more than 95 percent of the DNAPL present at the site: TCE; 1,1,1-trichloroethane (1,1,1-TCA); and PCE. Approximately 99 percent of the DNAPL source within the test volume was recovered by the surfactant remediation leaving a residual DNAPL saturation of only approximately 0.0004. The PITT technique successfully provided quantitative estimates of DNAPL volume before and after an in situ remedial activity at this site.

4.2.5.3 In Situ Bio/Geochemical Monitor (ISM)

Tool Description

Chemical and biochemical reactions affect the geochemical composition of groundwater and the migration and persistence of inorganic and organic contaminants. The ISM allows in situ measurement of biochemical reaction rates and retardation factors for both soluble organic and inorganic compounds. The ISM maintains the geochemical integrity of sediment and groundwater and may be less expensive than collecting similar data via conventional tracer tests.

Installed below the water table, the ISM isolates a small section of the aquifer with minimal disturbance of the geological medium. Groundwater is removed from the test chamber, reactants and tracers are added, and it is reinjected into the test chamber. Samples are then collected for laboratory analysis to monitor the biological and geochemical reactions occurring within the test chamber (Solinst, 1998).

Operational Considerations

The ISM requires saturated aquifers with a hydraulic conductivity greater than 10^{-4} centimeters per second (cm/sec). The monitor is installed through the center of a hollow-stem auger with a special "trap door" cutting head and pushed into the soil using either a hydraulic ram or vibrating hammer. The ISM consists of a stainless steel test chamber, open at the bottom and bounded at the top by a set of coarse and fine mesh screens. These screens are used to draw groundwater into the test chamber. A depth-adjustable central spike with a fine mesh screen extends into the test chamber. In biodegradation studies, groundwater samples are collected via the spike. To create a one-dimensional flow system in retardation studies, water is injected through the spike and collected from the outer screens (Nielsen, 1996; Solinst, 1998).

The ISM has a relatively complex design and requires knowledgeable personnel to design, implement, and interpret tests. A numerical model may be necessary to estimate degradation rate constants from test data (Neilsen, 1996).

Applications and Cost

The ISM can be used in aquifers with a hydraulic conductivity greater than 10^{-4} cm/s where in situ biochemical reaction rates and retardation factors must be determined. The cost of ISM is approximately $3,000 for equipment purchase only, not including installation, analyses, and trained personnel (Solinst, 1998).

Benefits

- Reduces the time and cost of obtaining site-specific biological and geochemical data (as compared with injection-withdrawal and field tracer tests)
- Provides in situ measurement of biochemical reaction rates
- Provides estimated rates of denitrification during biodegradation
- Provides estimated retardation factors for organic and inorganic compounds

Limitations

- Design, implementation, and interpretation of ISM tests are complex and require knowledgeable personnel
- A numerical model may be necessary to help estimate the degradation rate constant
- Typically applicable only with permeability greater than 10^{-4} cm/sec
- Small aquifer volume tested means results may be affected by small-scale variations in aquifer properties

Contact

Solinst Canada Ltd., (800) 661-2023, www.solinst.com

4.2.6 Other Tools

Listed below are other tools and techniques that offer a range of advantages for expediting site characterization but do not fit in one of the categories previously described. These tools include:

- Microscale solvent extraction
- PAH sample filtration
- Inverse specific capacity method
- Hand-augering / trenching / pot holing
- Noise and fugitive emission controls
- Information management

4.2.6.1 Microscale Solvent Extraction

Tool Description

Conventional laboratory analysis of PAHs in soil and water matrices may take 2 weeks from the time samples are received to the time the results are released. Current EPA-approved Methods 8240, 8270, and 8310 require a 24-hour extraction period before analysis can be run. EPRI has developed a technique for analysis that requires smaller sample volumes and shorter laboratory turnaround times than conventional techniques. Because microscale solvent extraction (MSE) methods require smaller sample volumes, MSE analytical methods are ideal for alternative collection methods that yield smaller sample volumes (e.g., Geoprobe™ and Hydropunch™) (EPRI, undated).

MSE methods are microextraction techniques used by a lab to prepare samples for analysis by gas chromatography. Microextraction is defined as a single-step extraction process with a high liquid-sample-to-solvent ratio. Historically, microextraction techniques have been limited by extraction inefficiencies, in precision, and elevated detection limits. However, recent MSE methods involve multiple microextraction steps as needed to improve analyte recovery and reduce detection limits. EPRI reports that the comparison of MSE results to standard USEPA methods ranges from good to excellent.

As a screening tool, MSE methods provide quantitative results for individual PAH components at the site characterization or remediation stages of a project. Several states have approved MSE methods for specific projects either in lieu of certified laboratory analysis or as a percentage of samples being submitted to a certified laboratory for confirmation analysis.

Operational Considerations

MSE methods were originally developed for use at an on-site laboratory; therefore, these methods can easily be used in an on-site laboratory to perform expedited characterization of PAHs.

Soil sample volumes required for MSE analytical methods can be up to six times smaller than those for conventional laboratory analysis. Turnaround times for MSE methods range from 12 hours to 2 weeks; in contrast, laboratories following conventional EPA protocol may have turnaround times ranging from 24 hours to 4 weeks.

Many conventional laboratories may not have instrumentation and protocol readily available for MSE methods. Analytical laboratories chosen to use MSE methods should be interviewed and audited prior to contracting and use.

Applications and Cost

MSE methods are applicable during the site characterization or remediation stages of a project where quantified concentrations of PAHs are needed.

The cost of MSE depends on the laboratory (prices vary widely) and the types and numbers of samples to be analyzed. Analytical costs can be as much as 50 percent lower than costs for conventional analyses. In addition, using MSE methods may significantly reduce overall project costs because of rapid turnaround times on lab results (which could translate into fewer mobilizations/demobilizations of field crews) and lower sample volumes (which permit alternative drilling/sampling techniques to be implemented).

Benefits

- Small sample volumes
- Fast laboratory turnaround times
- Minimal laboratory waste
- Quantitative results for individual components

Limitations

- Relatively new procedure

Contact

Electric Power Research Institute, (800) 313-3774

4.2.6.2 PAH Sample Filtration

Tool Description

When monitoring wells are constructed or aquifers are disturbed (e.g., pumped at rates higher than natural groundwater flow), small particles called colloids are mobilized in the groundwater. Although it is common practice to require turbidity during sampling to be less than 5 nephelometric turbidity units (NTUs), in practice it may be difficult to acheive (unless low-flow sampling techniques are employed). Artificially suspended particles become entrained in groundwater at flow rates higher than the natural groundwater flow rate and these suspended particles may bias concentration data higher than true concentration levels. PAHs are relatively immobile, hydrophobic compounds that tend to sorb onto soil particles. Because PAHs have low aqueous solubility values and a high affinity to sorb onto artificially mobilized suspended particles, it may be more representative to filter

PAH samples that are collected under high turbidity conditions (Backus, 1993; and Saar, 1997).

A standard environmental filter has a pore diameter of 0.45 micrometers (mm). Research has shown that naturally transported colloids may have diameters up to 2 mm. Therefore, a drawback to sample filtering is that naturally transported colloids may be filtered, in addition to the artificially mobilized colloids, and contaminant concentrations may be understated depending on the importance of natural colloid transport at a particular site (Backus, 1993).

In deciding whether to filter groundwater samples or not, the potential for natural and artificial colloid transport should be considered. Because sampling turbid groundwater often necessitates the use of field filters, it is recommended that all attempts be made to lower the turbidity (e.g., low-flow sampling) and thereby avoid filtering altogether. Analysis of both filtered and unfiltered samples from the same location may provide an indication of the relative impact of colloidal transport; however, it cannot distinguish between natural and artificial colloidal transport.

Operational Considerations

Turbidity is often highest in formations characterized by reducing conditions and fine-grained or poorly sorted lithologies. Typically, filtering is not an issue with samples collected from higher permeability (and presumably lower turbidity) formations. For groundwater samples collected in a temporary monitoring well or borehole, turbidity will most likely be relatively high, so it may be justifiable to field filter because of the large amount of artificially entrained colloids (Backus, 1993).

The ultimate use of the sampling data should also be considered when deciding whether or not to filter a groundwater sample. In general, the following guidelines may be used in making this decision:

- Filtered samples should be used whenever groundwater samples are collected to determine whether water quality has been affected by a hazardous substances release that includes metals or chemicals susceptible to colloidal transport.
- Samples should not be filtered when a water supply well is sampled.
- For data to be used in risk assessment, unfiltered samples should also be considered if the hydrogeologist suspects that colloidal transport could be significant.
- It is generally recommended that both filtered and unfiltered samples be collected at the same time for comparison.

Several different filter types are available at equipment supply stores. Filtration may occur in an open filter funnel with filter discs (the sample is pulled through the filter with a vacuum system) or by using an in-line filter where the sample is pushed through a self-contained, enclosed filter. Many different filter sizes are available. A 0.45-mm filter should be used unless some information is known regarding the distribution of natural and artificial colloids at a particular site.

Applications and Cost

Field filtering of PAH samples is applicable to groundwater samples that have relatively high turbidity levels (e.g., greater than 5 NTUs). One key drawback, however, is that filtering also removes naturally transported colloids. The presence of naturally transported colloids should be taken into consideration when analyzing the results.

The cost of field filtering equipment is nominal compared with the cost of sample analysis and may add a small labor cost to complete the field filtering. Analyzing both filtered and unfiltered samples doubles analytical costs and raises the labor costs associated with groundwater sampling.

Benefits

- Eliminates the high bias in PAH concentration measurements introduced by artificial colloidal entrainment
- A simple technology requiring minimal training

Limitations

- PAH concentrations determined from filtered samples may not include naturally transported colloids and create a low bias
- Dissolved or colloidal contaminants may adsorb onto the filter or apparatus

4.2.6.3 Inverse Specific Capacity Method

Tool Description

The hydraulic conductivity of the interval yielding water to permanent monitoring wells is routinely estimated by pumping tests or slug tests conducted in a well. The inverse specific capacity method estimates the hydraulic conductivity of the depth interval that provides the water sample in a temporary monitoring well.

Specific capacity refers to the flow of water yielded by a well at a drawdown or drop in the water surface. The specific capacity test is usually estimated by pumping a well at a fixed rate and monitoring the drop in the level of water in the well over time. The inverse specific capacity method sets the drawdown at a predetermined level and then measures the yield required to maintain this predetermined drawdown (Wilson, 1997).

Operational Considerations

The inverse specific capacity test is conducted using the GeoProbe™ as a temporary monitoring well. Once the GeoProbe™ (or similar technology) rods are pushed to the desired depth, ¼" plastic tubing, a peristaltic pump, and a measuring cup collect the inverse specific capacity data. Typically, a peristaltic pump can lift up to 40 feet of head; therefore, when groundwater is more than approximately 40 feet bgs, the inverse specific capacity method is not feasible.

Site-specific permeability data from conventional means (pumping or slug tests) are needed to calibrate the inverse specific capacity data if quantitative data are desired. In addition, the inverse specific capacity method is only appropriate for zones with hydraulic conductivities ranging from 10^{-1} to 10^{-5} cm / sec (Wilson, 1997).

Applications and Cost

The inverse specific capacity method can be used with any direct-push drilling technique where groundwater can be sampled via suction lift using a pump on the surface. The cost is negligible assuming that a peristaltic pump and push sampler are already in use at the site. The typical time for a test ranges from 5 to 10 minutes.

Benefits

- Provides quantitative estimates of hydraulic conductivity in a temporary monitoring well
- Allows variation in horizontal hydraulic conductivity to be assessed in the vertical direction for preferential pathway identification

Limitations

- Provides hydraulic conductivity estimates for a small volume of aquifer
- Requires hydraulic conductivity values from conventional monitoring wells on site for calibration
- Only approved for zones having permeability ranging from 10^{-1} to 10^{-5} cm / sec

4.2.6.4 Hand Augering/Trenching/Pot Holing

Tool Description

Hand augering, trenching, and pot holing are well-accepted, simple techniques for gathering shallow geologic information and for surveying and delineating wastes from former MGP sites. All three methods require minimum equipment and result in the gross collection of geologic and analytical information.

Hand augers are thin-tube cylinders that are driven by hand into the ground. Typically 18 inches in length, hand augers split lengthwise to allow insertion of three stainless steel or brass rings. When driven into the ground, soil is pushed into the rings, which are then removed and used for sample analysis.

Trenching and pot holing both use equipment such as shovels or backhoes to excavate soil. Trenching is basically excavation along a single axis, often designed to create vertical walls that can then be mapped for geologic strata. Pot holing incorporates the random or sequential digging of pits and is typically used to grossly delineate the extent of MGP residues. A photograph of a typical trench is shown below.

Operational Considerations

Trenching and pot holing are easy exploratory techniques that often do not require regulatory (e.g., boring) permits. They are especially effective at large sites with few above- or underground obstructions and where labor is inexpensive. Both techniques will, however, create significant quantities of waste, which can be costly to handle and dispose of if found to be hazardous.

Similar to trenching and pot holing, hand augering is effective at sites where labor is inexpensive. In contrast to trenching and pot holing, hand augering is effective for sites where there are significant above- or underground obstructions and/or at sites where generation of wastes is a significant concern. In contrast to trenching and pot holing, hand augering is limited to the depth to which the sampler can be driven, often a maximum of 3 to 5 feet bgs.

Applications and Cost

As noted above, trenching, pot holing, and hand augering are inexpensive if labor is inexpensive. The costs for the techniques vary directly with local labor costs.

Benefits

- Can be used to expose buried objects
- Discrete and can get into tight locations (hand augering)

Limitations

- Hand augering and pot holing are depth limited
- Trenching and pot holing are visible to the public
- Borehole and slope stability may be a problem
- Waste management may be a problem with trenching and pot holing

Case Study

Marysville-1 Former MGP Site

The MGP formerly operating at PG&E's Marysville Service Center was originally located in what is now an operating substation. Because of clearance restrictions and operating limitations, standard drilling methods (e.g., hollow-stem auger drilling) could not be conducted within the substation. Hand auger sampling was initially performed within the substation in areas historically thought to contain some former MGP structures (e.g., the generating and scrubbing building, lampblack dump, and gas holder). Soil samples collected via hand augering indicated that MGP residues did exist in soil within the substation. Partial substation de-energizing was subsequently arranged, and limited access drilling (via Precision Sampling's limited-access direct-push drilling rig) was conducted to approximately 28 feet bgs within the substation.

Contact

Robert Doss, Pacific Gas and Electric Company, (415) 973-7601

4.2.6.5 Noise and Fugitive Emission Controls

Tool Description

During site characterization and remediation, noise and / or emission controls may be required for regulatory, political, and safety reasons. Sound barriers, such as curtains or berming, may be necessary to minimize noise in residential areas during 24-hour drilling or near school / community centers during the day. One primary disadvantage of sound barriers and tenting to control noise is that decreased air flow may result in the work area, so emission controls (such as ventilation blowers) may have to be increased.

Construction activities such as grading, excavation, material handling, and travel on unpaved surfaces can generate substantial amounts of dust. Water sweeping or soil stabilization may be necessary at sites where airborne dust could pose a health and safety risk. Foam suppressants and chemical applicants such as magnesium chloride are also used to control dust. A site can be completely enclosed (tented) to prevent dust migration off-site; however, ventilation of work areas may be required.

Operational Considerations

All alternatives to control noise and fugitive emissions should be considered. If, for example, several days of 24-hour construction in a residential area are required, it may be more cost effective to forgo noise control and place nearby residents in hotels during the noisiest construction. Seasonal and diurnal constraints such as cooler weather or the calmest periods of the day should be factored into the remediation schedule. To control noise from generators and other construction equipment, one alternative is to use an electrical power source or advanced muffler systems. Monitoring the effectiveness of the controls is critical. Noise monitors are readily available from field equipment catalogs and provide constant-readout, time-averaged, or peak sound levels. Airborne emission levels are often monitored visually or with the use of a hand-held meter that gives real-time measurements of dust, aerosols, fumes, and mists. Monitoring of noise or dust levels may occur at the project site perimeter if off-site migration is the primary concern; monitoring may take place close to sources if worker safety is the primary concern.

Applications and Cost
Noise and / or fugitive emission controls should be used at any site where regulatory, health, or community concerns dictate action. The cost and level of effort to implement noise and / or emission controls vary widely. Water sweeping at a smaller construction site may cost from $200 to $500 per day; renting and installing a sound barrier around a drilling operation may cost $5,000; and complete enclosure of a site could easily add tens of thousand of dollars to project costs.

Benefits

- Protects community and workers
- May satisfy regulatory requirements
- Limits noise and air pollution
- Minimizes migration / transport of contaminants during remediation

Limitations

- Noise emission control on a large scale may involve prohibitive cost and effort
- Controls may make investigations / remediations logistically more complex and / or may limit the rate of completion

4.2.6.6 Information Management

Tool Description
There is a growing awareness of the importance of information management in expediting and streamlining remedial action planning, coordination, and execution. In particular, information management tools can:

- Ensure that the quality and integrity of environmental data are maintained throughout the site investigation process.
- Facilitate data interpretation and remedial selection.

At the project level, information management tools allow geologists, engineers and project managers to plot and view site characterization data quickly and efficiently. At a management level, a database management system may provide a “big picture” of critical issues, significantly improving an environmental manager’s communications with decision makers both within their organizations and with regulatory agencies. The efficiencies gained through the effective use of database and information management systems allows resources to be shifted from labor-intensive data manipulation to analyzing data through efficient management and focusing on solutions and project closure.

A variety of commercial software packages are available to support this type of initiative. The most common characteristic of these systems is that the system architecture is designed around a common premise that all project information can be assigned a spatial address, converted to electronic formats, and entered into a geographic information system (GIS) project database.

The architecture of a GIS-based information management system must allow for multi-level participation in information use since all information is derived from a common database. Once construction of the database architecture is complete, any portion of the database can be accessed depending on user needs but not changed. This approach allows all information to be available in one location significantly reducing time spent searching for information — a common challenge without effective data management tools. The features and benefits of using a GIS-based information management system are as follows:

Feature	Benefit
Data associated with unique spatial address	High quality data integrity
Information available electronically in one location	Time accessing information reduced
Elimination of manual data handling	Reduction in data transcription errors and compounding of errors over the remainder of the project

If correctly utilized, GIS-based information management systems can reduce cycle times for completing site characterization and remediation activities.

Operational Considerations

Prior to the purchase and/or development of an information or database management system, specific project needs must be evaluated. Questions to be answered include the following:

- What kind of data may be expected?
- How much data may be expected?
- Who will be the direct users of the package (e.g., one computer operator, multiple personnel)?
- How would prospective system users interact with the system (e.g., read-only access)?
- What is the level of the users' computer literacy?
- How would the data be manipulated (e.g., tables, boring logs, cross-sections, figures, interaction with groundwater flow models)?
- How much would the client need to spend?
- What are the software's system requirements (e.g., memory, coprocessor speed)?

The answers to these questions will aid the manager in selecting the right package for the project. Options will range from sophisticated GIS packages such as ArcInfo, to less sophisticated software packages built on common computer software such as ACCESS and AutoCAD.

Applications and Cost

Data and information management packages are applicable to all projects that generate data. The level of sophistication required will vary, however, from site to site. Smaller sites may be able to use common software packages such as ACCESS, DBASE, LOTUS, and EXCESS to easily tabulate and sort data. Larger projects may look towards more sophisticated, expensive software such as ArcInfo or BOSS GMS. Costs, too, will vary considerably depending on the management system purchase, associated hardware costs, and labor costs for data entry and system maintenance.

Benefits

- Helps ensures data quality and integrity
- Facilitates data use and interpretation
- Combined with electronic deliverables from analytical laboratories, may reduce data entry costs
- May reduce labor costs associated with report preparation

Limitations

- System may act only as data repository
- No single system may be able to fulfill all project requirements

Case Study

Bordentown Gas Works, Bordentown, New Jersey

The Public Service Electric and Gas Company (PSE&G) former Bordentown Gas Works site is located in a mixed commercial and residential area in Bordentown, New Jersey. The site was used as an MGP from approximately 1853 to 1900 and as a gas distribution regulating station until 1960. Since the demolition and clearing of structures, the site has remained vacant and remains the property of PSE&G.

A pilot project was initiated by PSE&G as part of an ongoing joint effort between PSE&G and the New Jersey Department of Environmental Protection (NJDEP) to continue to streamline remedial processes associated with MGP cleanups. A remedial investigation was previously conducted at the site, indicating that remedial actions were required:

- Collect additional site characterization data to support PSE&G's remedial objective
- Conduct a remedial alternative analysis

- Prepare and submit a remedial action selection report to NJDEP. The report included a comprehensive evaluation of environmental conditions at the site using a GIS-based data management system developed and applied by Woodard & Curran, Inc.

The Woodard & Curran environmental data management system was selected to aid in data evaluation to understand the site's environmental conditions; facilitate real-time interpretation of subsequent field work activities to complete site characterization; streamline mapping and interpretation of geologic and contaminant profiles; and assist in the evaluation of viable remedial options. The system consisted of a customized software platform based on ESRI's ArcView® as the overall platform and GIS\Solutions' GIS\Key™ as the application software for environmental data. The key benefit of utilizing ArcView® is that the software has the ability to import information from a variety of software packages (including those specifically designed for environmental data management) increasing the robust performance of this system.

The data management work performed by Woodard & Curran, Inc., on this project consisted of the following tasks:

- Electronic loading of environmental data (approximately 10,000 records) into the system
- Querying of data to understand site conditions and identify data gaps in concert with the NJDEP
- Development of a supplemental investigation work plan to address data gaps
- Input of supplemental data (approximately 4,000 records) for use in mapping, assessment of environmental conditions at the site, and identification of areas of concern for evaluation of remedial alternatives
- Review of findings in a series of workshops with the NJDEP prior to preparation of the remedial action selection report

This project resulted in improvements in the overall site investigation process, including reductions in cycle time for data collection, compilation and interpretation. Supplemental field work activities filled in the data gaps and allowed the project team to focus on remedial alternatives. Field and laboratory data were in the system within one week of completion and were available to the project team for interpretation and analysis immediately thereafter. The project team conducted technical workshops to keep NJDEP apprised of results throughout the process. The data management system was used at project meetings to conduct "what if" scenarios, creating contaminant isopleths and assisting in understanding hydrogeologic features at the site. The final report included a summary of findings and conclusions that were developed in concert with NJDEP throughout the project. In summary, the application of the information management system assisted the project team and resulted in the following:

- Reductions in time and cost required to complete the site investigation
- Increased reliability of data interpretation
- A simplified way of presenting site environmental data to NJDEP and permitted them to be part of the project team evaluating site conditions and remedial alternatives in real time

Contacts

Woerner Max, Public Service Electric and Gas Company, (973) 430-6413

Matt Turner, New Jersey Department of Environmental Protection, (609) 984-1742

Chapter 5

Technologies for Source Material Treatment

5.1 Introduction

This chapter describes technologies for treating former MGP residues. These technologies have either been proven successful and cost effective or are new and promising for use at former MGP sites. The technologies described below destroy or encapsulate MGP residuals in the vadose zone, reducing or eliminating the threat that chemicals from these materials will reach groundwater or human populations and thus limiting or reducing the responsible party's liability. (This is in contrast to past methods of disposal that often involved sending wastes to landfills where the responsible parties continue to bear long-term responsibility for the waste's environmental and health effects.)

The technologies discussed in this chapter are summarized in the following table. Although each technology is discussed independently, multiple treatment technologies may be applied at a site to address the various chemical components. For example, soil vapor extraction (SVE) may be applied at a former MGP site to remediate the volatile components of the MGP residues concurrent with or prior to in situ stabilization (which will treat the heavier, less mobile chemical compounds). Multiple technologies applied concurrently or sequentially are often referred to as treatment trains, and are often formed to address an overall site remediation.

The costs provided in this section are based on limited data and are dynamic. Many variables will affect the cost of a remediation technology as applied to a specific site or set of sites. The cost information provided herein reflects an order-of-magnitude guide to cost, and is provided on an informational basis.

This document does not address the treatment of NAPLs or MGP contaminants in groundwater. These issues may be addressed in a future volume of this document. However, remediation at a site should address all the site's contaminants, including those present in both soil and groundwater.

5.2 Technologies for Source Material Treatment

The following sections contain specific information pertaining to each of the technologies for treating residuals and contaminated soil from former MGP sites.

Source Material Treatment Technologies

Name	Description	Benefits	Limitations	Approximate Cost *
Co-Burning	Combustion of MGP residues with coal in utility boilers and cement kilns.	• Recycles wastes • Destroys organic contaminants • Cost effective	• Long-term impacts on boiler efficiency, maintenance, and operation is unknown	$44-$309/ton
Thermal Treatment Processes				
Ex Situ Thermal Desorption	Desorption and/or destruction of organic contaminants in excavated soil by heating.	• Demonstrated PAH and organic contaminant reduction • Moveable units available for onsite treatment	• Hazardous levels of contaminants may not be accepted at offsite facilities • Wet or saturated media requires dewatering prior to treatment • Soil with high organic content is unsuitable for treatment • Air emissions control may be required	$100-$200/ton
In Situ Thermal Processes				
Dynamic Underground Stripping (DUS)	Injection of steam into subsurface contaminants to volatilize and mobilize contaminants.	• Minimal disruption to site operations • Removes contaminants under existing structures • Works well under wide range of soil types	• Utility costs may be high • Sufficient contaminant mass may not be removed during treatment	$110/cy
In Situ Thermal Desorption (ISTD)	Soil heating via in-well heater or electrodes to vaporize/volatilize fluids and contaminants.	• Minimal disruption to site operations • Removes contaminants under existing structures • Works well under wide range of soil types	• Utility costs may be high • Works best in unsaturated conditions	$120-$300/cy
Contained Recovery of Oily Wastes (CROW)	Hot water flushing/displacement and extraction of subsurface contaminants.	• Minimal disruption to site operations • Removes contaminants under existing structures • Works well under wide range of soil types	• Utility costs may be high • Sufficient contaminant mass may not be removed during treatment	N/A

Source Material Treatment Technologies, continued

Name	Description	Benefits	Limitations	Approximate Cost *
Asphalt Batching				
Cold-Mix Asphalt Batching	Encapsulation of contaminant by blending residues, wet aggregate and asphalt emulsion at ambient temperature.	• Reuses materials • Immobilizes PAHs • Viable treatment technology for coal tars	• Curing times can be affected by temperature • Not viable for fine-grained materials (e.g., clays) • Physical properties of final product not always appropriate for traffic reuse	$40-$70/ton
Hot-Mix Asphalt Batching	Encapsulation of contaminant by blending residues, wet aggregate and asphalt emulsion at high temperature.	• Reuses materials • Immobilizes PAHs • Viable treatment technology for coal tars	• Curing times can be affected by temperature • Not viable for fine-grained materials (e.g., clays) • Physical properties of final product not always appropriate for traffic reuse	$40-$70/ton
Bioremediation/ Chemically Enhanced Bioremediation				
Ex Situ Bioremediation				
Landfarming	Destruction of organic compounds in contaminated soil by microorganisms. Treatment occurs on lined beds during contaminated soil tilling and irrigation.	• Shorter treatment periods than in situ bioremediation alternatives • Reduces contaminant concentrations	• Not effective for higher molecular-weight hydrocarbons • May be slower than alternative treatment technologies	$75/cy exclusive of lab and pilot studies
Biopiles	Destruction of organic compounds in contaminated soil by microorganisms. Treatment occurs through soil amendment and stockpiling.	• Shorter treatment periods than in situ bioremediation alternatives • Reduces contaminant concentrations	• Not effective for higher molecular-weight hydrocarbons • May be slower than alternative treatment technologies	$100-$200/cy exclusive of lab and pilot studies
Bioreactor	Destruction of organic compounds in contaminated soil by microorganisms. Treatment occurs in an enclosed reactor vessel.	• Shorter treatment periods than in situ bioremediation alternatives • Reduces contaminant concentrations	• Not effective for higher molecular-weight hydrocarbons • May be slower than alternative treatment technologies	$216/cy exclusive of lab and pilot studies
In Situ Bioremediation/ Bioventing	Destruction of organic compounds in subsurface contaminated soil by microorganisms.	• Generally inexpensive • Minimal disruption of existing operations • Removes contaminants from under existing structures	• Verification of destruction is sometimes difficult • Not effective for higher molecular-weight hydrocarbons • Treatment uniformity uncertain because of subsurface variables	$10-$70/cy exclusive of lab and pilot studies

Source Material Treatment Technologies, continued

Name	Description	Benefits	Limitations	Approximate Cost *
Containment	Containment or capping of contaminated soil to prevent or significantly reduce contaminant migration and to prevent human and animal exposure.	• Quick installation • Does not require soil excavation • Prevents vertical infiltration of water • Prevents human and animal exposure	• Contains wastes; does not reduce contaminant concentration • Requires operation and maintenance program • Typically requires institutional controls (e.g., deed restriction)	$45,000- $170,000/ac
Stabilization/Solidification				
In Situ S/S	Encapsulation of contaminant by in situ blending with chemical binders to immobilize contaminant of concern.	• Immobilizes contaminants • Neutralizes soil • Improves bearing capacity or shear strength of treated area	• Possible leaching of volatile or mobile contaminants • Creation of concrete-like material in subsurface • Effective in situ mixing may be difficult	$40-$60/cy in shallow applications, exclusive of lab and pilot studies
Ex Situ S/S	Encapsulation of contaminants in excavated soil by blending with chemical binders to immobilize contaminant of concern.	• Immobilizes contaminants	• Performance dependent upon chemical composition of wastes • Long-term immobilization of contaminant may be affected by environmental conditions	$100/ton exclusive of lab and pilot studies
Soil Washing	Physical/chemical process for scrubbing soils ex situ to remove contaminants.	• High degree of certainty regarding treatment performance	• Material handling possibly expensive • Effectiveness limited by complex waste mixtures and high humic content	$170/ton
Soil Vapor Extraction	Extraction of air from subsurface to remove volatile compounds from vadose zone soils.	• Removes contaminant from under existing structures • Promotes in situ biodegradation • Well established treatment technology • Minimal disruption to site operations	• Not effective for low-volatility compounds • May not be effective in areas with water tables shallower than 5 to 10 feet bgs or in fine-grain soils • Limited effectiveness on pools of contaminants	$2-$450/cy

* Approximate costs do not include cost of excavation, transportation, material handling, etc.

5.2.1 Co-Burning

Technology Description

Co-burning is the process by which MGP residues such as coal tar and tar-contaminated soils are combusted along with coal in utility boilers. Developed by the Edison Electric Institute's (EEI) subcommittee for MGP sites with technical support from the Electric Power Research Institute (EPRI), this technology blends remediation waste recovered during site excavation with coal so as to render it nonhazardous for co-burning in utility boilers. EPRI also developed a sampling approach that is consistent with EPA test methods for characterizing soils and wastes and for developing blending ratios for treating soils. This strategy is intended to ensure that only nonhazardous MGP wastes are co-burned in utility boilers, and allows utilities to burn this waste without entering the RCRA hazardous waste permit program or paying the high cost of commercial incineration (EPRI, 1995).

Operational Considerations

Utilities have co-burned MGP site wastes in a variety of utility boilers, including stokers, cyclones, and those fired by pulverized coal. Preparation consists of screening waste to remove oversized material and rendering the material nonhazardous under RCRA if necessary (GRI, 1996). MGP materials are typically blended with coal feedstock in the range of 5 to 10 percent coal or wastes. Co-burning increases the amount of ash requiring management. For example, a 10 percent co-burning mixture doubles the amount of ash generated by a boiler (GRI, 1996).

Applications and Cost

As of 1996, co-burning was used as part of full-scale remediation at five MGP sites; four other demonstration tests have been completed (GRI, 1996). Media that have been treated include coal tars, purifier box wastes, and contaminated soils. Co-burning is currently offered as a commercial service by one utility in the northeast United States. The cost of co-burning in a case study in Rochester, New York, ranged from $44 to $142 per ton for soil and from $134 to $309 per ton for tars.

The utility company currently offering co-burning charges a tipping fee of approximately $90 per ton to incorporate the MGP site residuals into its boiler feed, but this cost does not include any preprocessing, transportation, or analytical work necessary for disposal (GRI, 1996).

Benefits

- Reuses/recycles waste into a usable product
- Has demonstrated technical feasibility to destroy organic contaminants
- Allows utilities to expedite flexible, cost-effective remediation at MGP sites

Limitations

- Long-term impact of co-burning on boiler efficiency, maintenance, and operation is unknown

Case Studies

Rochester, New York

Rochester Gas and Electric (RG&E) with the assistance of EPRI, the Gas Research Institute (GRI) and the New York Gas Group evaluated co-burning for use at their plant. RG&E operates an 80-megawatt, tangentially fired, pulverized coal unit built in 1959 by Combustion Engineering. It is located on the same site as the former West Station MGP. Residues in the form of "neat" coal tar and soil with major amounts of rock, brick, coke, concrete, and other demolition debris remain at the West Station site. The soil contains from 40,000 to 70,000 ppm of PAHs. Although preprocessing was needed to remove large rocks and other debris, the tar and soil were easily blended with coal to make two distinct fuel products. One fuel product contained 4 percent tar, and the other contained 5 percent soil, with the balance in both cases made up of coal.

The test burn program contained a series of inspection and evaluation protocols directed at monitoring the effects of these mixed fuels on the boiler and ancillary systems. In a program that lasted approximately 12 weeks (4 weeks of which were dedicated to actual co-burning), the boiler performed without significant performance losses, PAH removal efficiency exceeded 99 percent, electrostatic precipitator performance was unchanged, and emissions appeared unaffected (air emissions were actually significantly reduced for certain parameters).

Two factors that arose in this demonstration could greatly affect the feasibility and cost of co-burning. The first factor is that the state environmental agency required ash leachate to meet drinking water standards before it would grant RG&E permission to reuse the ash. Because drinking water standards are set below the method detection limit for many parameters, the ash could not meet these standards, and the state denied permission to reuse it. If not resolved, this prohibition on reuse will add more than $50 per ton to the cost of the residues to be treated. (One bottom ash sample also showed PAH concentrations of 800 ppb, attributed to spillover from the mill reject system.) The second factor that affects co-burning is the potential physical damage to a boiler using this technology. Mill abrasion was measured during the test and one measurement indicated a rate of wear about eight times that from processing ordinary coal. If this measurement and test are representative, maintenance costs of co-burning could increase proportionally.

Contact

Kevin L. Hylton, Rochester Gas and Electric Corporation, (716) 546-2700

Greenville, South Carolina

Co-burning of MGP residues was demonstrated in a pulverized-coal, tangentially fired utility boiler at the Duke Power Company in South Carolina. The remediation site was the Broad Street MGP in Greenville, where a 1.2-acre, carbureted water gas plant operated from 1875 until 1951. The co-burn facility was Duke Power Company's Lee Steam Station, located in Pelzer, South Carolina. The MGP residues were co-burned in unit No. 3, which has a capacity of 175 MW and was constructed in 1956.

The project's remediation goals were to prepare the site for future sale as an industrial/commercial property. A cleanup level of 200 ppm total PAHs was required. The matrix treated consisted of soil impacted with MGP residues. Prior to co-burning, soil was screened to ½ inch and then blended with coal at a maximum rate of 5 percent. Plant operations preferred a 2 percent blend.

This was a full-scale operation. The plant had a permit for 19,000 tons of soil per year, but the actual amount treated was estimated at 3,000 tons per year. Before treatment, total PAH concentrations in site soils ranged up to 1,600 ppm. After treatment, BTEX and PAH concentrations were below the detection limit in all bottom ash and fly ash samples. Stack gas concentrations were the same as when co-burning was not taking place. The project is now complete, with 3,000 tons of material treated and managed; a destruction and removal efficiency (DRE) of 100 percent was obtained. No additional co-burns of MGP residues are planned at this time.

Contacts

Ralph Roberts, Duke Power Company, (704) 875-5536, rcrobert@duke-energy.com

Lori Murtaugh, South Carolina Department of Health and Environmental Control, (803) 734-4668

Illinois Power Company/Illinova Resource Recovery

Illinois Power and Illinova Resource Recovery, Inc. operate a commercial waste management facility at Illinois Power's Baldwin Power Station. The program is designed to co-burn MGP remediation wastes from the utility industry. These wastes are blended with coal and burned in the Baldwin Power Station's two cyclone boilers.

Power Station Description

The Baldwin Power Station is located outside the village of Baldwin, Illinois, approximately one hour southeast of St. Louis, Missouri. The area is primarily rural agricultural property.

Two 600-megawatt cyclone boilers are utilized to co-burn remediation wastes. The cyclone units are especially suited to burning these wastes due to the fact that materials can be fed at up to a one-inch size, without the need of pulverization to 200 mesh as is required in some coal-fired power plants. In addition, 90 percent of the ash generated from cyclone boilers is in the form of a vitrified, inert slag material. All this slag is sold commercially as sandblast grit and roofing shingle aggregate. Both power station boilers are base-load units, meaning that they operate 24 hours per day, 7 days per week at full-load. This allows co-burning to be conducted on a steady basis and maximizes the capacity of the program. The Baldwin units are equipped with electrostatic precipitators and continuous emission monitors. The units are fueled with Illinois Basin coal.

Waste Management Facility

A dedicated waste management facility has been constructed at the Baldwin Power Station specifically designed to receive, store, and process remediation wastes. All waste storage and processing activities are conducted in a 30,000 square foot water-tight concrete and steel containment pad. The containment pad can store 8,000 cubic yards of contaminated soil. Baldwin is allowed to load waste at a rate of 5 percent of the coal loaded daily. This corresponds to approximately 450 tons per day capacity. Baldwin has demonstrated a 300-ton-per-day sustained rate capacity. The practical annual capacity is currently about 100,000 tons per year. The waste materials are delivered by dump trailer and off-loaded directly into the containment pad. The materials are then crushed, screened, and blended with coal to produce a final product that is homogenous, less than two inches in size, and free of metal, plastic and other unprocessable debris. Rock, gravel, and masonry are accepted and crushed with the other materials and burned in the boilers. The processed material is delivered to the power plant coal conveyors using an enclosed conveyor system.

Environmental Permits
The Baldwin facility is fully permitted by the Illinois Environmental Protection Agency as a commercial waste treatment and storage facility. Solid waste permits limit types and quantities of acceptable waste, and define the management practices, documentation and inspection requirements, and quality control procedures. Water discharge permits require collection, treatment, and analysis of runoff water prior to discharge to the environment. Air permits limit the amount of dust generated and the emissions from the boiler stacks. The Illinois Environmental Protection Agency has been very supportive of the program as a safe and effective means of permanently eliminating the hazards and liabilities associated with these wastes, which previously were disposed of in landfills almost exclusively. Three USEPA Regions have approved the operation for receipt of coal tar and petroleum contaminated soil and debris for federal Superfund sites.

Operating History
A test burn in March of 1994 convinced Illinois Power that the power plant systems could handle the contaminated soils effectively with acceptable impacts to boiler operations and efficiencies. The costs, however, indicated that the process would not be cost effective for only Illinois Power's quantities of waste. It was determined that a commercial operation could be supported by the quantities of waste market, thereby providing the economies of scale required to make the project feasible.

Since the initiation of operations in June of 1996, over 135,000 tons of waste have been accepted and treated at Baldwin. Materials have been received from as far as 1,200 miles away. Baldwin has been an integral contributor to the remediation of over 40 contaminated sites for more than 20 customers.

5.2.2 Thermal Treatment Processes

Thermal desorption is a treatment technology in which organic chemical constituents contained within a contaminated soil matrix volatilize as a result of heating. The volatilized constituents are then extracted from nonvolatile materials, such as soil, and treated prior to release. Thermal desorption can be grouped into in situ and ex situ practices. Both technologies are described below.

5.2.2.1 Ex Situ Thermal Desorption

Technological Description

Full-scale thermal desorption has been successfully used to remediate soils containing MGP wastes (e.g., lampblack, coal tar) since the early 1980s, achieving concentration reductions of more than 98 percent for TPHs, BTEX compounds, PAHs, and cyanide. Thermal desorption has been used in many non-MGP applications, and is a common remediation technology for MGP sites. The technology can be applied on site with a mobile unit or at an off-site facility. Below is a photograph of a thermal desorption unit.

Thermal desorption uses temperatures ranging from 400°F to 1,200°F to desorb chemicals from the soil. Soil is fed into a material dryer where heated air causes chemicals to volatilize. In general, temperatures between 200° F and 900°F are required to desorb VOCs and many PAH compounds. Higher temperatures (up to 1,200°F) are required to desorb high-molecular-weight PAHs (Barr, 1996). After chemicals in the offgas are treated, the cleaned air is vented to the atmosphere. The dry, hot soil is then discharged to a pug mixer where water is introduced to reduce dust and lower the soil temperature. The quenched soil is discharged and transported to a stockpile. Each day's production volume of soil is held separately while residual concentrations are determined. The treated soil is then returned to the excavation, transported to an off-site facility for disposal, or reused at a different location. A typical thermal desorption unit can treat approximately 8 to 45 tons per hour, depending on soil conditions (e.g., water content, waste concentrations, etc.) and the size of the dryer unit used.

Operational Considerations

The thermal desorber's operational characteristics depend on soil type and properties, contaminant type and concentrations, moisture content, organic material content, pH, compound volatility, and temperature and residence time during drying. This technology may require a pilot test demonstration. Blending is recommended to reduce variations in organic concentrations.

Application and Cost

Full-scale systems have achieved a DRE of 99 percent when treating contaminated soils from MGP sites at temperatures of 750°F to 850°F with residence times of approximately 10 minutes (GRI, 1996). A summary of costs from six remediation efforts conducted to date in California (see the table below) shows on-site treatment costs ranging from approximately $110 to $130 per ton for 16,000 and 9,000 tons of soil, respectively, and offsite treatment costs ranging from approximately $100 to $200 per ton for 11,000 and 1,000 tons of soil, respectively. All estimates include costs for general contracting, confirmation sampling, construction management, permits, and transportation for offsite treatment (GRI, 1996). Recent projects suggest the potential for even more favorable pricing.

Summary of Total Project Costs for Thermal Desorption at six California Former MGP Sites

(Cost/Ton ($))	Santa Barbara	Dinuba	Covina	Inglewood	Orange	Visalia
Thermal Treatment	$52	$49	$45	$38	$44	$32
Transportation	--	--	$18	$19	$20	$30
General Contractor	$42	$25	$31	$35	$62	$24
Confirmation Sampling	$10	$4	$7	$5	$19	$2
Construction Management	$30	$21	$17	$11	$45	$7
Miscellaneous Costs (Agency oversight, air permitting)	$14	$4	$8	$8	$13	$3
Adjusted Total Cost	**$131**	**$106**	**$120**	**$115**	**$202**	**$96**
Total Cost	**$178**	**$140**	**$130**	**$133**	**$202**	**$96**
Total Project Costs	**$1,556,974**	**$2,257,630**	**$906,735**	**$666,416**	**$212,384**	**$1,055,950**
Tons Soil Excavated	**8,745**	**16,120**	**7,000**	**5,024**	**1,050**	**10,775**

Source: Southern California Gas Company

Benefits

- Demonstrated PAH reduction to less than 1 mg/kg under optimal conditions
- 80 to 99 percent removal of carcinogenic PAHs
- 90 to 99.7 percent removal of total PAHs (Barr Engineering, 1996)
- Production rates of 8 to 15 tons per hour for small units and 25 to 45 tons per hour for large units

Limitations

- Very wet or saturated media must be dewatered prior to treatment
- Soil with high organic content (peat) is unsuitable
- Air emissions of chlorinated compounds, sulfur, etc. may need to be abated

Case Studies

Huron, South Dakota, Former MGP Site

The Huron MGP site is a 3-acre parcel that once housed a process plant for the production of carburetor water gas. Site geology consists of a surficial fill unit underlain by a clayey lacustrine deposit and a glacial till unit. Depth to bedrock beneath the site is approximately 100 feet. The glacial till unit acts as a barrier to the vertical migration of MGP residuals.

The requirements under which the ex situ thermal desorption project was conducted were negotiated with the state regulatory agency. These included excavation criteria, a treatment performance criterion, and an operating permit for thermal treatment. Field demonstration activities consisted of excavating and staging soils containing MGP residuals, preparing the staged soils, treating the prepared soils, backfilling and compacting the treated soils, and managing wastewater.

The Huron MGP site used a low-temperature thermal desorption (LTTD) system, a two-stage counter-flow direct-fired rotary desorber capable of heating contaminated soils to 1,200 °F. The system is equipped with an oxidizer that can operate at 1,800 °F. Field demonstration costs included mobilization/ demobilization, material excavation and handling, thermal treatment, soil and water analyses, utilities, backfilling and compaction, dewatering and wastewater management, and project oversight. The total cost of the project was $3,819,000. Approximately 47,000 tons of soil containing total PAH concentrations ranging from 84 to 3,733 mg/kg were treated to below the treatment performance criterion of 43 mg/kg for the sum of cPAHs, at a cost of $82 per ton.

Conclusions from the Huron MGP site field project are summarized as follows:

- The thermal desorption system achieved removal/destruction rates of greater than 79 percent to greater than 99 percent for cPAH compounds, and greater than 89 percent to 99.7 percent for total PAH compounds.
- The system showed good operating stability; critical operating parameters, shown below, were relatively constant:
  - Feed rate of 20 to 31 tons per hour with an average rate of 26 tons per hour
  - Desorber temperature of 1,050 °F to 1,200 °F with a residence time of 18 minutes
  - Oxidizer temperature of 1,741 °F to 1,773 °F with a residence time of 2 to 2.5 seconds

- Stack emissions, which were in compliance with the operating permit requirements, were as follows:

Opacity	<20 percent
Sulfur Dioxide	2.4 pounds per million Btu of heat input
Oxides of Nitrogen	10.7 pounds per hour
Total Hydrocarbons	0.07 pounds carbon per hour
Naphthalene	<926 micrograms per second

- Soil type and moisture content affected total cost. Had the clay and moisture content of the site soils been lower, soil preparation time would have been shorter, and unit treatment costs would have been lower.
- Inclement weather significantly affected project costs. Approximately 20 days out of a 6-month period were lost to rain delays. The rain delays increased soil preparation time and costs associated with dewatering, wastewater management, and project oversight.

Contact

Ed Highland, Northwest Public Service Co., (605) 353-7510

Waterloo, Iowa, Former MGP Site

A two-stage thermal desorption unit was installed on the Waterloo, Iowa, former MGP site. The treatment used natural gas as a fuel. In the first stage of the two-stage desorber, the soil was mixed in a rotating drum and heated to approximately 300 °F to 500 °F by a 40-million-Btu-per-hour burner. In the second stage, the soil was further heated to between 1,100 °F and 1,200 °F by three additional 6-million-Btu-per-hour burners. The first stage was used to drive off moisture and the more volatile hydrocarbons; the second stage desorbed the contaminants from the soil.

All heating conducted by the two-stage desorber was direct fired and oriented counter to soil flow. The vapors from the desorption stage were passed through an oxidizer (secondary burner) and heated to between 1,750 °F and 1,800 °F to destroy hydrocarbon contaminants. The desorber unit used at the Waterloo site was specifically modified for treatment of coal tar compounds and operated at a higher temperature in the high-temperature stage of the two-stage desorber than some thermal desorption units. This was necessary to desorb higher-molecular-weight coal tar compounds. The desorber used at the Waterloo site was capable of thermally treating soil at a rate of 25 to 40 tons per hour, depending upon the concentration of contaminants, and soil type and moisture content. During the trial burn conducted at the site, soil was treated at a rate of 31.6 tons per hour.

The minimum space required for setup and operation of the Waterloo desorber unit was approximately 140 feet by 120 feet, not including space for storage of soils prior to and after treatment. The thermal desorption unit and all auxiliary equipment were transported to and from the temporary locations with 14 tractor trailers. It took approximately 7 days to complete setup of the equipment and an additional 5 days for startup and fine tuning of the equipment in preparation for trial burn or routine treatment of soils. Natural gas (or propane), electricity, and water were required to operate the system. In addition, water was required for rehydration of the treated soil and other cooling operations.

The remediation goal for the project was to treat the soil to less than 5 mg/kg total PAHs. Routine sampling of treated soil showed concentrations well below 5 mg/kg. A total of 83 samples of treated soil (one sample for every 300 tons of soil) had an average concentration of 0.59 mg/kg total PAHs. The media treated included clay, sand, and silt.

A trial burn of coal tar materials was conducted to determine the DRE for the organic contaminants in the excavated coal tar materials. A grab sample of soil was collected for every 100 tons of treated soil, composited with two other 100-ton representative samples, and analyzed for PAHs. Routine thermal treatment of soil began as soon as the Iowa DNR and USEPA approved the results of the DRE testing. The treated soil could not be backfilled, however, until laboratory analysis was received and the results were shown to be below the treatment criterion of less than 5 mg/kg total PAHs.

The specific operating conditions observed during the trial burn were used as the operating criteria for the remainder of the soil to be treated. Continuous monitoring included waste feed rate, system treatment temperatures, carbon monoxide concentration in stack gas, and other parameters. Of the 83 samples of treated soil that were collected and analyzed throughout the project, three lots of 300 tons each did not pass. These values were not included in the average above because the soil was blended with other soil and retreated.

The following table shows the amount of soil excavated and treated for each of the four sites:

Site	Tons of Soil Treated
Hampton	3,651
Charles City	2,138
Independence	4,734
Waterloo	14,167
Total	**24,690**

Treated soils from all sites were used to backfill an earlier excavation on the Waterloo site. All contaminated oversized debris was crushed and thermally treated. Some exceptionally large debris, such as foundations, was decontaminated in place and left in the excavation. All scrap steel was cleaned and sent to a recycler. As a result, nearly all of the materials removed were thermally desorbed or recycled. Very little material, primarily wood debris and tree roots, was taken to the local landfill. The total cost of the project was $2 million. This cost includes preparing the thermal desorption site and installing utilities, excavating all the sites, hauling excavated material from Hampton, Charles City, and Independence to Waterloo, backfilling, and labor to place the fill; it also includes the thermal desorption services, with the cost of fuel. The average cost per ton of soil treated was calculated for the project and is shown in the table below.

Item	Average Cost per Ton* ($)
Excavation	4.83
Thermal Treatment	47.87
Transportation	12.53
Backfill	4.83
Miscellaneous*	8.62
Total	**78.62**

*This includes the cost of analytical and engineering services, air monitoring, etc.

Contacts

Sam Nelson, MidAmerican Energy Company, (712) 277-7851

Dan Klimek, MidAmerican Energy Company, (712) 277-7930

Johanshir Golchin , Iowa Department of Natural Resources**,** (515) 281-8925

Jim Colbert, USEPA Region VII**,** (913) 551-7489

Mason City, Iowa, Former MGP Site

Thermal desorption was used at a site in Mason City, Iowa, owned by Interstate Power Company. The property had been used for production of natural gas from coal in the late 1900s and had become contaminated with a variety of heavily weathered PAHs and cPAHs. From April to October 1996, approximately 22,000 tons of soil were thermally treated at temperatures of up to 1,200 °F. A process rate of 32 tons per hour was achieved.

The soil that was treated contained concentrations of PAHs in excess of 3,000 mg/kg, and in many areas, soft, agglomerated, heavy oil was present. Pretreatment of excavated soils included shredding, crushing, screening, and blending to avoid exceeding the process capacity of the thermal desorption system. Also, a significant amount of brick, concrete, wood, and steel pipe required specialized material handling and processing. The brick and concrete were crushed and blended with more heavily contaminated soil before thermal treatment; the steel and wood were separated and sent off for recycling.

Six test runs were performed during a comprehensive demonstration testing program. The average results of these test runs showed that concentrations of total and cPAHs in the treated soil were reduced from 804 mg/kg and 95 mg/kg, respectively, to less than 3.3 mg/kg and less than 1.22 mg/kg, respectively. A DRE of greater than 99.99 percent was demonstrated for all combined PAH compounds. Stack gas was sampled and analyzed for all combined PAH compounds. Sulfur dioxide, nitrogen oxide, carbon monoxide, and PAH emissions were in accordance with the USEPA and Iowa DNR protocol.

Contacts

Bruce Greer, Alliant Energy, (608) 252-3948

Johanshir Golchin, Iowa Department of Natural Resources, (515) 281-8925

Diane Engeman, USEPA Region VII, (913) 551-7746

5.2.2.2 In Situ Thermal Processes

In situ thermal processes are treatment processes designed to increase the mobilization of contaminants via volatilization and viscosity reduction. The addition of heat to the subsurface by radio frequency, electrical resistance, or steam increases the removal of organic compounds particularly in low permeability formations. Heat also increases volatility (and hence removal) of compounds that are not readily extractable using conventional SVE (e.g., heavy oils). Three in situ thermal processes are reviewed in this section: Dynamic Underground Stripping (DUS), In Situ Thermal Desorption (ISTD), and Contained Recovery of Oily Waste (CROW™).

5.2.2.2.1 Dynamic Underground Stripping (DUS)

Technology Description

Lawrence Livermore National Laboratory and the School of Engineering at the University of California, Berkeley (UC Berkeley), developed DUS in the early 1990s. The area to be cleaned using DUS is ringed with wells for injecting steam. Extraction wells in the central area are used to vacuum out vaporized contaminants. To ensure that thick layers of less permeable soils are heated sufficiently, electrode assemblies may be sunk into the ground and heated, which forces trapped liquids to vaporize and move to the steam zone for removal by vacuum extraction. These combined processes achieve a hot, dry, treatment zone surrounded by cool, damp, untreated areas. Steam injection and heating cycles are repeated as long as underground imaging shows that cool (untreated) areas remain (Newmark, 1998).

Operational Considerations

The capacity of DUS treatment systems is limited only by the size of the installation. DUS generally does not require material handling or pretreatment prior to application at a site. Electrical heating may be applied to less-permeable contaminated clay layers in situ to help release contaminants prior to steam injection. DUS requires both subsurface and aboveground equipment. Aboveground equipment includes a steam generation plant, electrical heating equipment, and treatment systems for recovering free product and contaminants from the separate liquid and vapor streams collected from the extraction wells. Because the aqueous and gaseous streams are in intimate contact with the free product, they will typically be saturated with dissolved or vaporized free product components following their passage through the oil / gas / water separators.

The DUS treatment system consumes significant quantities of electricity, water, and, for some applications, natural gas. Operation difficulties that may be encountered during DUS include biofouling (especially from microorganisms destroyed by steaming), scaling and deposits on sensors, clogging from fines brought to the surface, and difficulties in maintaining the cycling, pressure-varying, and high-temperature technology. Further refinement is also required for system design and operating and monitoring techniques.

The DUS technology is labor intensive, requiring significant field expertise to implement. It is best applied to sites with contaminants above and below the water table and complex sites that are difficult to clean up.

Applications and Cost

Although the initial capital outlay for DUS is higher than for pump-and-treat systems, DUS could save money in the long run because it is completed much more quickly. Most of the equipment, such as boilers for generating steam, can be rented. Initial expenditures include installing the heating wells and operating the system intensively for a short period of time. Because the technology is short term, long-term operation and maintenance costs are reduced or eliminated. In a 1993 field trial of DUS at Lawrence Livermore National Laboratory, the technology cost about $110 per cubic yard of soil treated (Newmark, 1998).

Benefits

- Will work in a wide range of soil types
- Works in both saturated and unsaturated conditions
- Treatment possible in areas where traditional excavation and removal are impossible
- Minimal disruption to nearby industrial operations or surrounding neighborhoods; no digging and hauling of contaminated materials eliminates exposure to toxic fumes and dust
- Will work close to or under existing structures, including buildings and roadways

Limitations

- Although DUS removes considerable mass and may improve groundwater quality, there is currently limited experience regarding the ability of DUS to achieve maximum contaminant levels (MCLs) and thus alleviate the need for pump-and-treat.

Case Study

Visalia Poleyard, California

The Southern California Edison Visalia Poleyard site was used for 80 years to treat utility poles with both creosote and pentachlorophenol (PCP). Creosote contains PAHs similar to those found in MGP wastes. This 4-acre site was one of the first to be listed on the National Priorities List. The sediments underlying the poleyard are alluvial fan deposits, and the site currently contains DNAPL contamination in three distinct water-bearing zones. There are several shallow aquifers from about 35 to 75 feet bgs, and an intermediate aquifer from about 75 to 100 feet bgs. The most sensitive groundwater resource is found in the deep aquifer below about 120 feet. The thermal remediation system was designed to remove contaminants from the intermediate and shallow aquifers without disturbing the deep aquifer.

DUS was selected for the Visalia poleyard. An array of 11 injection wells was installed encircling the contaminant source area. Although each injection point had two injection pipes, screened in either the shallow or the intermediate aquifer, only the 11 pipes completed in the lower unit were used for injection from 80 to 100 feet bgs. Three additional extraction wells were placed in the central area to supplement existing extraction wells. No supplemental electrical heating was performed; the entire site was heated using steam alone. Steam was generated utilizing commercially available oil field steam generators (Struthers type). Steam was injected at pressures up to 150 psi, routinely at pressures less than 100 psi. Vacuum pressures of approximately 0.5 atmospheres (atm) were applied in a steady mode.

Ancillary equipment included cooling equipment for the extracted water and vapor, two stages of free product separation (including dissolved air flotation), and final filtration of the pumped water by activated carbon. Approximately 16 percent of the contaminant was destroyed in place, yielding carbon dioxide. Both vapor and water streams were continuously monitored for hydrocarbon and carbon dioxide content.

In addition to thermocouples, an innovative geophysical technique was employed to monitor movement of steam and progress of heating. Electrical resistance tomography is an imaging method like CAT scanning that provides near-real-time images of underground processes between pairs of monitoring wells. Baseline measurements are used to characterize a site and predict steam pathways. Soil electric properties vary with temperature, soil type, and fluid saturation. During treatment at Visalia, daily resistivity readings provided a picture of the progress of the steam front and heated zones. Monitoring the progress of the heating fronts ensured that all soil was treated. Temperature measurements made in monitoring wells revealed details of the complex heating phenomena in individual soil layers.

As of August 1998, the DUS process recovered approximately 110,000 gallons of free product a rate of about 46,000 pounds per week. In addition, approximately 29,400 pounds of hydrocarbon were burned in the boilers; 17,500 pounds of dissolved hydrocarbon were collected in the activated carbon filtrator; and, based on removed carbon dioxide, an estimated 45,500 pounds were destroyed in situ.

Contaminant concentrations in recovered groundwater continue to decline. Southern California Edison will treat the liquid free product onsite and may use it as a lubricant. Current estimates are that the project will be completed in 1 to 2 years, with an additional 4 years of monitoring. This is in contrast to the 20 or more years expected for pump-and-treat remediation.

With DUS, contaminants are vaporized and recovered at the surface. Approximately 50 percent of the cost of cleanups is associated with treating recovered groundwater and disposing of contaminants. The addition of hydrous pyrolysis oxidation (HPO) to the basic DUS technology could save additional costs. HPO involves injection of steam and air to aerate a heated oxygenated zone. When injection is halted, the steam condenses and contaminated groundwater returns to the heated zone. The groundwater mixes with the condensed steam and oxygen, destroying dissolved contaminants. As noted above, HPO is estimated to be responsible for a portion of the contaminant treatment at the Visalia site. To evaluate the progress of in situ chemical destruction, field methods were developed to sample and analyze hot water for contaminants, oxygen, intermediate products, and reaction products.

Laboratory testing on the Visalia suite of contaminants showed that both PCP and the range of PAH compounds present are readily destroyed by HPO’s in situ oxidation process. Isotopic testing during remediation showed that the carbon dioxide being recovered in the vapor stream was coming from oxidation of creosote. This process is expected to aid in bringing groundwater concentrations to regulatory standards.

Contacts

Roger D. Aines, Lawrence Livermore National Laboratory, (925) 423-7184

Robin Newmark, Lawrence Livermore National Laboratory, (925) 423-7184

Kent Udell, UC Berkeley, (510) 642-2928

Craig Eaker, Southern California Edison, (626) 302-8531

5.2.2.2.2 In Situ Thermal Desorption (ISTD)

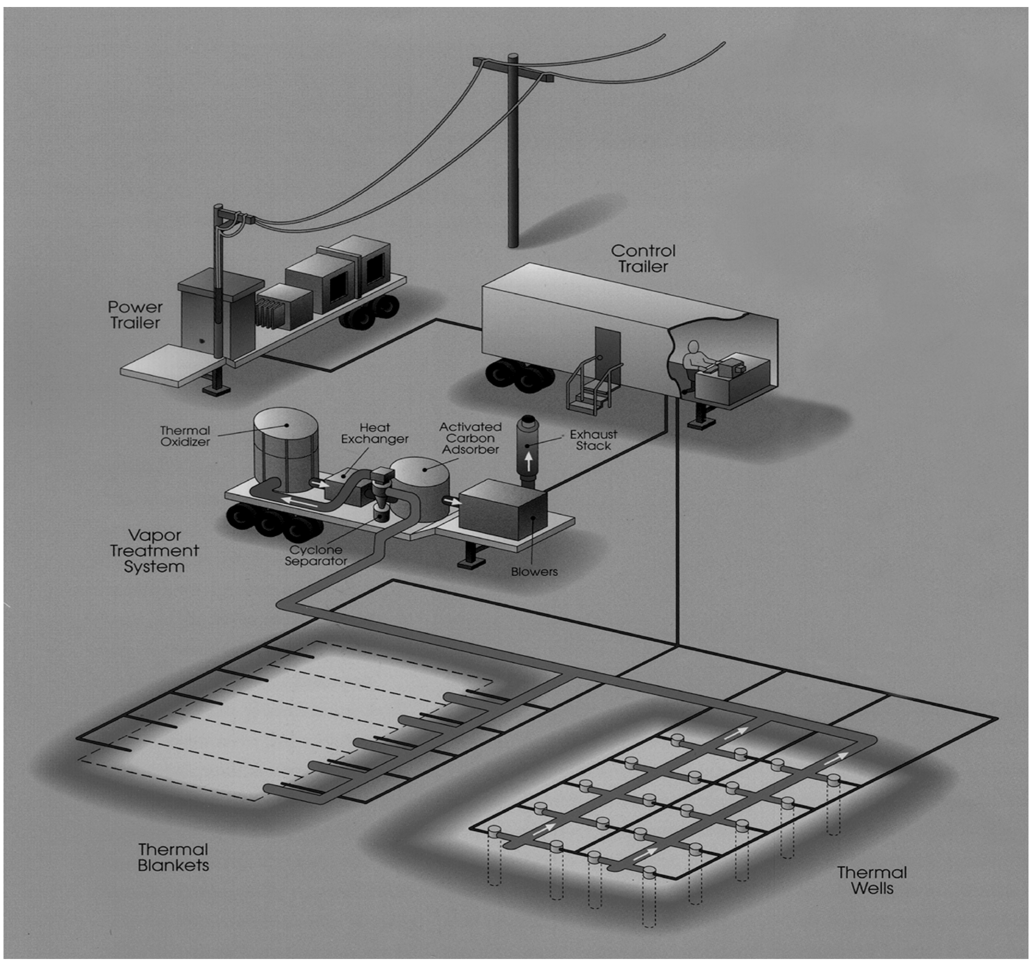
Technology Description

ISTD consists of a system or array of surface and / or in-well heaters or electrodes combined with vacuum wells to heat contaminated soils and extract the resulting vaporized / volatilized fluids and contaminants. Vapors produced through the soil heating process are treated in surface facilities to remove residual contaminants. According to the ISTD vendor, up to 99 percent of contaminants are destroyed.

ISTD involves the placement of Thermal Blankets (over areas of surface contamination to a depth of approximately 18 inches) or Thermal Wells (which can be drilled in areas of deep contamination) in the area to be treated. Both the blankets and the wells use electricity to heat soil to the boiling temperatures of contaminants. The contaminant vapors are then extracted and further processed through a flameless thermal oxidizer and activated charcoal filter. Water and carbon dioxide are released to the atmosphere during treatment.

Operational Considerations

A staging area near the contaminated site and accessibility to a local power grid are required for the placement of ISTD process and control trailers. Limitations of the ISTD process are primarily related to the amount of moisture in the soil. Too much water (e.g., groundwater recharge) requires either dewatering or installing of a barrier to halt groundwater recharge as the soil is heated. There is minimal impact to surrounding neighborhoods during ISTD treatment because the process is confined to the site, and there is no direct handling of contaminated soils. Minimal dust and noise are generated during treatment. A schematic ISTD setup is shown below.



A limited number of applications have been conducted to date; therefore, other operational considerations that may affect the application of this technology at former MGP sites are not known. Additional unknown factors include how the technology will handle tarry waste material and underground subsurface structures (e.g., former gas holders) at former MGP sites, and the depth of soil to which this technology can practicably be applied.

Applications and Cost

ISTD can be applied to shallow contamination (to a depth of 18 inches below grade) through the use of Thermal Blankets and to deeper contamination through the use of Thermal Wells. The technology is capable of treating a wide variety of volatile and semivolatile organic contaminants including PCBs, chlorinated solvents, pesticides, and petroleum wastes. The system is designed to control emissions through use of a flameless oxidizer and activated carbon absorber.

Soil treatment by TerraTherm Company's ISTD at the Missouri Electric Works (MEW) Superfund site in Cape Girardeau, Missouri, cost $120 to $200 per cubic yard of soil. Sites with special water-handling requirements, custom well or blanket configurations, or other size restrictions may cost up to $300 per cubic yard.

Benefits

- Will work in a wide range of soil types
- Treatment possible in areas where traditional excavation and removal are impossible
- Minimal disruption to nearby industrial operations or surrounding neighborhoods; no digging and hauling of contaminated materials eliminates exposure to toxic fumes and dust
- Will work close to or under existing structures, including buildings and roadways
- Demonstrated ability to recover PCBs with residual soil concentrations well below 2 ppm

Limitations

- ISTD has not been applied in full-scale at an MGP site to date, nor has it been applied to MGP wastes (e.g., PAHs, tars)
- Unclear whether sufficient contaminant mass can be recovered to alter groundwater quality
- Utility costs associated with heating may be high

Case Studies

Mare Island Naval Shipyard, California

A demonstration of ISTD was performed at the Mare Island Naval Shipyard in California from October through November 1997. Soil samples at Mare Island's former electrical shop site were contaminated with PCB Aroclors 1254 and 1260, with average pretreatment concentrations of 54 ppm and maximum concentrations of 2,300 ppm. The most stringent USEPA requirement for residual PCB concentrations is 2 ppm following treatment.

The Mare Island demonstration was conducted as a collaboration between the U.S. Navy, the Bay Area Defense Conversion Action Team, TerraTherm (a subsidiary of Shell Technology Ventures, Inc.), and RT Environmental Services, who acted as general contractor. Agencies participating included the USEPA, California EPA, and the Bay Area Air Quality Management District. A draft Toxic Substance Control Act (TSCA) permit was issued by USEPA. California EPA worked closely with TerraTherm to streamline the permit process and expedite approvals with the California DTSC and the Bay Area Air Quality Management District while still providing strong regulatory oversight.

The test site was chosen to demonstrate the effectiveness of ISTD near an existing large structure without damaging it. Both Thermal Blankets (two 8-foot by 20-foot units) and Thermal Wells (12 wells containing heating elements drilled to a depth of 14 feet) were used during the demonstration. The soil was heated to the boiling point of the PCBs (approximately 600 °F); heated vapors were extracted through a vacuum collection system utilizing a flameless ceramic oxidizer and an activated charcoal filter. Resulting vapor releases to the atmosphere contained primarily carbon dioxide and water. Both aspects of the demonstration were completed in a total of 44 days. All post-treatment samples exhibited nondetectable PCB concentrations (less than 0.033 ppm).

Contact

Rich G. Hansen, TerraTherm, (281) 544-2020

Cape Girardeau, Missouri

A field demonstration of ISTD was completed at the Missouri Electric Works Superfund site in Cape Girardeau, Missouri, from April 21 to June 1, 1997. This demonstration removed high-concentration PCB contamination from clay soils using 12 heater/vacuum wells installed in multiple triangular arrays with 5-foot well spacing to a depth of 12 feet. Surface heating pads were placed at the center of each triangle to assist in heating near-surface soils between the wells. A vacuum frame structure was constructed around the well area to insulate the surface and provide a seal. Steel sheets were fitted together and welded to the heater wells. A 16-inch-thick layer of vermiculite insulation was placed over the steel plates to reduce heat losses and insulate the surface-piping manifold embedded in the vermiculite (TerraTherm, 1997).

During remediation, electric resistance heating and vacuum were applied to the wells for 42 days. Approximately 500 watts per foot were initially injected into the clay soil at heater temperatures of 1,600 °F. Later in the process as the soil dried, about 350 watts per foot could be injected. The thermal wells were connected to a single manifold, which delivered the desorbed and partially treated vapors to a thermal oxidizer unit. Stack sampling was performed to monitor for by-products (e.g., hydrogen chloride) and to measure DRE of PCBs.

Soil temperatures were monitored throughout the experiment, and soil samples were taken with a split-spoon sampler fitted with 6-inch brass coring sleeves to verify the removal of contaminants. Temperatures above 1,000 °F were achieved in the interwell regions, and PCB concentrations in the treated area were reduced from a maximum of approximately 20,000 ppm to nondetect (< 33 ppb) after treatment by EPA Method 8080. The system DRE for PCBs was 99.98 percent (TerraTherm, 1997).

Contacts

Ms. Paulette France-Isetts, USEPA Region VII, 726 Minnesota Avenue, Kansas City, KS 66101, (913) 551-7701

Mr. Donald Van Dyke, Missouri Department of Natural Resources, P.O. Box 176, Jefferson City, MO 65102, (573) 751-3176

Mr. Rich G. Hansen, TerraTherm, (281) 544-2020

5.2.2.2.3 Contained Recovery of Oily Waste (CROW™)

Technology Description

The CROW™ process was developed by the Western Research Institute (WRI) in the 1970s as a hot-water flushing technology to aid in extraction of oil from sands and deep shale deposits. During the 1980s, the concept of hot water flushing was revisited as a remedial technology. Hot-water displacement is used to move accumulated oily wastes and water to production wells for aboveground treatment. Hot water is injected through wells and in groundwater to dislodge contaminants from the soil matrix. The mobilized wastes are then displaced toward pumping wells by the hot water.

With the CROW™ process, subsurface accumulations of oily wastes are reduced by reducing NAPL concentrations to residual saturation. Controlled heating of the subsurface reverses the downward penetration of NAPL. The buoyant oily wastes are displaced to production wells by sweeping the subsurface with hot water. NAPL flotation and vapor emissions are controlled by maintaining both temperature and concentration gradients in the injection water near the ground surface.

Operational Considerations

CROW™ requires both subsurface injection and extraction wells and an aboveground treatment train. No pretreatment of soils is required for CROW™ operation.

Applications and Cost

The CROW™ process has been demonstrated to treat PAHs, coal tars, pentachlorophenol, creosote, and petroleum by-products.

Benefits

- Will work in a wide range of soil types
- Applicable in both saturated and unsaturated conditions
- Treatment possible in areas where traditional excavation and removal are impossible
- Minimal disruption to nearby industrial operations or surrounding neighborhoods; no digging and hauling of contaminated materials eliminates exposure to toxic fumes and dust
- Will work close to or under existing structures, including buildings and roadways

Limitations

- Ability to control injected steam in the subsurface has been questioned
- Unclear whether sufficient contaminant mass can be recovered to alter groundwater quality

Case Study

Stroudsburg, Pennsylvania

The Brodhead Creek MGP Site is an NPL site located in Stroudsburg, Pennsylvania. The site occupies a flood plain area of approximately 12 acres at the confluence of Brodhead Creek and McMichael Creek. The enhanced recovery technology CROW™ was utilized to mobilize and extract free coal tar from the subsurface at the site. The ROD specified that 60 percent of the free coal tar be removed from the subsurface at the site. Because of sampling difficulties and the heterogeneity of the subsurface, the tar volume was not quantified although it was estimated to be several thousand gallons. Without a reliable starting figure, removal of 60 percent was impossible to document.

However, based on treatability results, the enhanced recovery process was expected to recover more than 80 percent of the free tar present. For this reason, EPA allowed a performance standard to be written that the enhanced recovery process would operated until the increase in cumulative recovery of coal tar dropped to 0.5 percent or less per pore volume of water flushed through the formation.

The affected soils at the site were 30 feet bgs, below the water table. The soils were a sand / gravel mixture residing above a silty sand confining layer. The sand and gravel soils did not allow for representative sampling of the subsurface to determine chemical characterization although free DNAPL was observed in wells in this portion of the site at depths from inches to several feet.

At the Brodhead Creek site, six injection wells were installed near the edges of the tar deposit. Two production wells were installed near the center of the tar deposit. Water and tar were pumped from the production wells at approximately 40 gallons per minute (gpm), which produced a drawdown within the wells and induced a gradient from the injection points to the production points. The induced gradient contained the heat within the target zone and prevented mobilized contaminants from being released into the surrounding aquifer. Once the tar / water mixture was pumped to the surface, tar and water were separated. The tar was then stored in the gravity settling tanks and an oil storage tank until being trucked off site for disposal. Approximately 33 gpm of separated water was recycled through the water heater and injected into the six injection wells. The remaining 7 gpm was pumped to a granular activated carbon fluidized bed reactor where the organic constituents were biologically degraded. The treated water was then pumped through four carbon adsorption units prior to discharge to Brodhead Creek.

Because of sampling difficulties in the gravelly matrix and because of heterogeneity of the subsurface soils, no pre- and post-remediation samples were obtained that were representative of the subsurface. CROW™ was operated at the site for one year. During that time, the CROW™ process swept approximately 5,000 to 6,000 cubic yards of soil in the subsurface to recover more than 1,500 gallons of DNAPL. Remediation at the site has been completed, and the equipment has been dismantled and removed. The final Remedial Action Report has been accepted by USEPA Region III.

Contacts

Mr. James F. Villaume, Pennsylvania Power & Light Company, (610) 774-5094

Dr. Thomas D. Hayes, Gas Research Institute, (773) 399-8325

Mr. John Banks, USEPA Region III, (215) 566-3214

5.2.3 Asphalt Batching

Asphalt batching is a widely demonstrated technology for reuse of petroleum-contaminated soils. During asphalt batching, contaminated soils are mixed with asphalt, aggregate, and other emulsions to create a product for use in paving and backfilling. Asphalt batching can be a cold-mix or hot-mix process; both are described below.

5.2.3.1 Cold-Mix Asphalt Batching

Technology Description

Cold-mix asphalt batching has been successfully used to immobilize and reuse MGP-contaminated soils and residues. Asphalt batching is essentially an ex situ stabilization process that binds contaminated soil and tarry residues into the matrix of an asphalt product. Residues are mixed with wet aggregate and asphalt emulsion at ambient temperature. The product is used as paving.

In the cold-mix asphalt batch process, wet aggregate material and an asphalt emulsion are mixed and left at ambient temperature. The cold-mix batch product is then cured or allowed to set undisturbed for a specific period that depends on its ingredients. This curing process can begin either before or after the pavement has been placed and compacted.

The asphalt batching process is generally performed in several steps:

- Excavation and stockpiling of materials
- Material preprocessing (typically screening and/or crushing material to the desired size)
- Stabilization with asphalt emulsion reagent
- Curing in a stockpile
- Using material for paving

The final product is a material that can be used as a sub-base for paving in areas of heavy vehicular traffic or possibly as surface paving in areas of light traffic. Additional grading and paving or excavation are often required around the treated material to accommodate its height.

Cold-mix asphalt batch products are typically produced either at a central plant location or are mixed in place. The choice between producing them at a central plant pavement or mixing in place must consider the intended use of the product and the logistics and economics of staging an onsite treatment versus transporting to an offsite facility (EPRI, 1997). A photograph of asphalt plant operations is shown below.

Operational Considerations

This technology requires a treatability study to test leachability and engineering properties of the treated material. The mix design is dependent on the performance requirements of the finished product and the nature of the soil being treated. Clayey soils are generally not appropriate for cold-mix asphalt batching because a high clay content will reduce the strength of asphalt concrete. However, soils with high clay or loam content can be mixed with high-grade aggregate to produce a material used in lower-performance applications such as parking lots or driveways. Similarly, the percentage of fine grains in contaminated soil should be less than 20 percent passing the No. 200 sieve because excessively fine-grained particles could lead to both an increase in the required asphalt content and performance problems such as cracking and instability.

Applications and Cost

Before processing soil for cold-mix asphalt batching, an asphalt batching contractor typically examines the physical and chemical characteristics of the soil to determine whether it can be incorporated into a usable-quality pavement. For offsite asphalt batching, the preacceptance criteria for using soil that contains tar are plant specific and designed to meet certain chemical and physical thresholds. None of the preacceptance criteria require that the chemistry of the MGP tar be examined to see how closely it resembles that of asphalt (EPRI, 1997). The analytical requirements of the batch plant may include EPA-certified analyses for VOCs and SVOCs, petroleum hydrocarbons, pesticides, herbicides, and metals.

Because there have been few full-scale applications of cold-mix asphalt batching, cost information is limited. In California, vendor quotations range from $40 to $50 per ton for onsite cold asphalt batching and $60 to $70 per ton for offsite batching (transportation included).

Benefits

- Material reused rather than disposed of offsite
- Effective in immobilizing PAHs

Limitations

- Curing times can be long, particularly in cold weather
- Limits on acceptable percentage of fine-grained material
- Few examples of long-term durability of the product

Case Studies

Monterey Former MGP Site

From 1900 to 1947, an MGP in Monterey, California, provided gas to canneries in the immediate area. This former MGP site was subsequently sold to the City of Monterey, which planned construction of a gymnasium and pool complex. Site investigations indicated that MGP wastes were present in the form of an oxidized mixture of crude oil and bunker fuel to depths of 20 feet below grade. Soil at the site consisted of sandy silt to clay material with a moisture content ranging from 6 to 22 percent.

Contaminated soil excavated from the former MGP site was blended into an asphalt product at a rate of 300 tons per hour using onsite portable mixing equipment. The treated material was then trucked to a second location, also owned by the city of Monterey. The treated material was used in place of ¾-inch Class II aggregate base in a new construction project. A 2-inch lift of dense hot mix was applied as a wearing surface over the treated material.

Contact

Robert Doss, Pacific Gas and Electric Company, (415) 973-7601

Salt Lake City Former MGP Site

From 1872 to 1908, the American Barrel NPL site in Salt Lake City, Utah, was used as a coal gas manufacturing plant with an oil gas plant for meeting peak demands. The plant had one holder, one tar well pump, six tar wells, and two coal tar stills. From approximately 1920 to 1950, creosote operations were conducted at the site. From 1955 to 1987, the site was leased to a barrel refurbisher, American Barrel, who stored approximately 50,000 barrels on the property. The surface soils contained high levels of PAHs, phenolic compounds, heavy metals and other organic residues associated with the barrel storage activities. Subsurface soils had high levels of PAHs and phenolic compounds.

USEPA and state agency regulatory managers felt that recycling the material was superior to landfilling or thermal desorption. Salt Lake City is a Clean Air Act nonattainment area; therefore at the time of the remediation, the air quality division of the state would not allow thermal desorption in the valley. Cold-mix asphalt batching was selected over hot-mix asphalt batching for the proposed remedial technology because the regulators felt that the hot mix was simply another form of thermal desorption. USEPA and the state required that the asphalt produced be used for roads and not for parks and schools.

Approximately 20,700 tons of soil and debris were removed from the site. About 12 tons of this material were determined to be hazardous (e.g., wood from the tar wells) and shipped to an incinerator. About 1,300 tons of the material were nonhazardous but were not acceptable for asphalt batching (e.g., contained metal and other debris). These were shipped to a landfill. The remaining 19,400 tons of material were incorporated into cold-mix asphalt, including bricks and concrete from the gas holder, tars from the holder and tar wells, and contaminated surface and subsurface soils. This produced 194,966 tons of cold-mix asphalt. The gravel pits in the Salt Lake City area are very low in fines, and the contaminated soil had a high percentage of fine-grained material, so the asphalt with the contaminated soil was of higher quality than could be produced with local gravel. The original estimates for blending the contaminated soil into asphalt were 10 percent contaminated soil, 7 percent oil, and 83 percent aggregate. The contaminated soil had enough tar and oils in it to replace 40 percent of the oil needed to produce the cold-mix product.

The first batch of asphalt produced with 7 percent oil was not of good quality and had to be removed and mixed with additional aggregate. The final batches of asphalt contained 4 percent oil, 10 percent contaminated soil, and 86 percent aggregate and were of very high quality. All the resulting asphalt product was donated to counties and cities. The county and city that ultimately used the product asked the contractor if the mix could be made as a regular product because of its superior performance in Utah's cycles of cold and hot weather.

Contact

Jeff Tucker, Pacific Corp, (801) 220-2989

1993 Harbor Point Study, Utica, New York

In August 1993, Niagara Mohawk Power Corporation (NMPC) and United Retek Corporation jointly performed a field demonstration of cold-mix asphalt batching of soils at the Harbor Point site located in Utica, New York. Four 100-ton pilot batches of soil were processed into pavements; three of the batches included MGP soils containing tar; the fourth was a control sample of aggregate that met the grading requirements of cold-batch pavements. The following evaluations were then conducted:

- Leachability and permeability testing to determine how well hazardous constituents were immobilized
- Marshall stability tests to determine the structural applicability of the finished product

- Road tests to evaluate how the fines content and constituents of the MGP soils affected the product's environmental acceptability
- Evaluation of the extent of contaminant migration from the installed product as measured by a stormwater runoff test
- Additional nondestructive deflection road tests to further evaluate structural performance

General conclusions of the testing indicated that the incorporation of MGP tar-containing soils in cold-batch asphalt pavements reduced the leachability of the tar constituents associated with these soils (EPRI, 1997). The data showed that the more water-soluble compounds, such as benzene and naphthalene, would continue to leach from these pavements after 21 days of curing. Further research to establish the curing time to decrease leaching needs to be conducted. During the study, unconsolidated material curing durations of the pavements was 2 weeks; however, depending on the site-specific tar composition, curing durations may need to be extended to ensure benzene and naphthalene concentrations in leachate are minimized.

MGP asphalt products appear to be slightly lower in strength than PCS asphalt while still meeting the minimum requirements specified by the Asphalt Institute. The durability of MGP asphalt was inferior to the control asphalt in the Harbor Point study, as evidenced by the development of some potholes in the test road sections (EPRI, 1997).

California Former MGP Site

A cold-mix asphalt batching study was performed for a California utility to assess the potential for treating tar-containing soils from MGPs in standard cold-batch pavements. Chemical data consisting of total and extractable PAHs were evaluated to determine how successful the batching was in immobilizing contaminants. Several structural parameters were also evaluated to determine the engineering properties of the pavement created by the batching process.

The results of the study indicated that some lighter-weight PAH compounds leached from the pavement. However, the study also concluded that, had additional leaching tests been conducted on the asphalt products after longer curing periods, improvement in chemical immobilization might have been observed. Further investigation into the relationship between curing times and chemical immobilization was recommended (EPRI, 1997). Engineering data also indicated that as the MGP soil percentage was increased, engineering properties deteriorated, most notably for durability parameters such as moisture loss. Nonetheless, the pavements generated through the cold-mix asphalt batching process were strong enough for general use (all batches exceeded the minimum Marshall stability value of 2,200 Newtons) even though their moisture content was higher than is generally accepted for cold-batch pavements (EPRI, 1997).

1995 to 1996 Harbor Point Study, Utica, New York

Niagara Mohawk Power Company conducted a joint hot- and cold-mix asphalt batching study in 1995 and 1996 at its Harbor Point facility. As part of this study, tar-containing soils from MGP sites were thermally desorbed before cold-mix batching. The desorption step was necessary because of acceptance criteria established by New York State Department of Environmental Conservation (NYSDEC). Approximately 100 tons of previously excavated MGP soils were mixed and designated for use in the project; these consisted of 30 percent coal tar soils, 30 percent water gas tar soils, 30 percent processed construction spoils, and 10 percent tar emulsion soils (EPRI, 1997).

Following thermal desorption, two cold-mix designs were used. The first cold-mix design was for a bituminous stabilized base course; the second was a dense graded mix. Desorbed material was supplemented with clean aggregate: 56 percent desorbed soil for cold-mix No. 1 and 40 percent desorbed soil for cold-mix No. 2. The cold-mix products were prepared offsite by combining the desorbed material and clean aggregate in a pugmill with a predetermined addition of asphalt emulsion.

Two areas were selected for test panels using the cold-mix asphalt. Panel A consisted of a composite design of a 3-inch-thick layer of bituminous stabilized base course overlain with a 3-inch-thick layer of hot-mix top course. Panel B consisted of adjoining 3-inch-thick sections of the two cold-mix products. After the panels were placed, they were subjected to qualitative and quantitative evaluations. Visual inspections were made over six months. The cold-mix products improved over that period, consistent with previous observations that cold-mix asphalt batch products require longer curing times. A quantitative analysis which consisted of in-place density and deflection testing was also conducted. Based on the results of these tests, the study concluded that the test panels performed satisfactorily for a variety of applications, especially for roads subjected to light and moderate traffic.

5.2.3.2 Hot-Mix Asphalt Batching

Technology Description

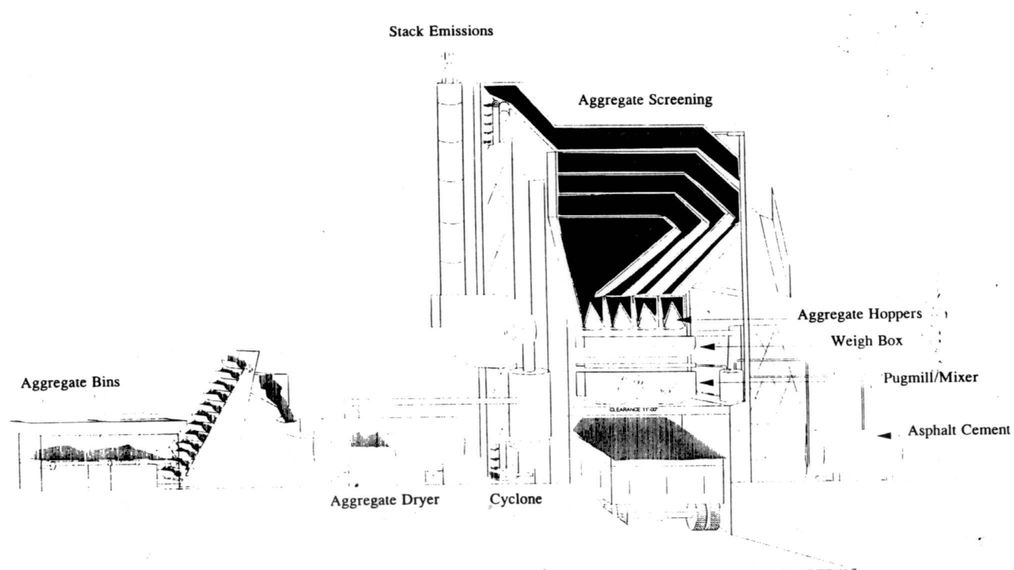
Pilot projects have used hot-mix asphalt batching to immobilize and reuse MGP-contaminated soils and residues. Hot-mix asphalt batching is an ex situ stabilization process that blends contaminated soil and tarry residues with aggregate and asphalt emulsion to create a hot asphalt product. The high processing temperatures of hot asphalt batching volatilize lighter weight compounds found in MGP wastes (e.g., benzene) and promote formation of a homogenous blend of aggregate and asphalt cement. Materials treated via hot-mix asphalt batch are used in paving surfaces.

The hot-mix asphalt batching process is generally performed onsite or offsite in several steps:

- Excavation and stockpiling of materials

- Material preprocessing (typically screening and / or crushing material to the desired size)
- Heating and drying aggregate material prior to mixing
- Stabilization of dried material with asphalt emulsion reagents
- Compacting the finished product at temperatures well above ambient
- Using treated material for paving

The final product is a material that can be used as a sub-base for paving in areas of heavy vehicular traffic.



Operational Considerations

Hot-mix asphalt batching requires a treatability study to test leachability and engineering properties of the treated materials. The mix design is dependent on Marshall and Hveem testing of the performance requirements of the finished product and on the nature of the material being treated. Clayey soils are generally not appropriate because a high clay content will reduce the strength of asphalt concrete. However, soils with high clay or loam content can be mixed with high-grade aggregate to produce a material used in lower-performance applications such as parking lots or driveways. Similarly, the percentage of fine grains in the contaminated soil should be less than 20 percent passing the No. 200 sieve because excessively fine-grained particles could lead to both an increase in the required asphalt content and performance problems such as cracking and instability.

Applications and Cost

Prior to processing soil for hot-mix asphalt batching, an asphalt batching contractor typically examines the soil's physical and chemical characteristics to determine whether it can be incorporated into a pavement of usable quality. For offsite asphalt batching, different plants have different preacceptance criteria regarding use of soil that contains tar; these criteria establish certain chemical and physical thresholds. None of the preacceptance criteria require that the chemistry of the MGP tar be examined to see how closely it resembles that of asphalt (EPRI, 1997). The analytical requirements of a plant may include EPA-certified analyses for VOCs, SVOCs, petroleum hydrocarbons, pesticides, herbicides, and metals.

Because there have been few full-scale applications of this technology, cost information is limited. In California, vendor quotations have ranged from $60 to $70 per ton for offsite asphalt batching (transportation included).

Benefits

- Material reused rather than disposed of offsite
- Effective in immobilizing PAHs and volatilizing VOCs
- One of the few viable technologies available for MGP tars

Limitations

- Potential for leaching of contaminant from the asphalt product
- Potential for release of volatile contaminants
- Potential for objectionable odors
- Excavation treatment primarily limited to gravelly soils and sands
- For offsite asphalt batching, possible difficulty in identifying a local facility technically prepared and permitted to process MGP waste
- Few examples of long-term durability of the product

Case Studies

Wisconsin Power & Light

EPRI, in cooperation with Wisconsin Power & Light, performed a limited study on the chemical and physical properties of hot-batched asphalt pavements that incorporate tar-containing soils from MGPs. The aggregate blend produced for hot batching consisted of 25 percent tar-containing soils, 20 percent clean sand, 40 percent bottom ash with $^{9}/_{16}$-inch diameter, and 15 percent bottom ash with $^{3}/_{32}$-inch diameter. The tar-containing soils used in this study had total PAH concentrations as high as 690 mg/kg. The only TCLP metal detected in a pretreatment extract was barium. This constituent actually increased in extract concentration after treatment. The average reduction in contaminants was 88 percent. TCLP extract concentrations were reduced to below the practical quantitation limit (PQL) for all of the metals and all VOCs except benzene, toluene, and naphthalene, which were reduced but still detected in the low parts per billion range (EPRI, 1997).

Harbor Point Study, Utica, New York

Niagara Mohawk Power Company conducted a joint hot- and cold-mix asphalt batching study in 1995 and 1996 at its Harbor Point facility. In this study, tar-containing soils from an MGP were thermally desorbed prior to hot-mix batching. The desorption step was necessary because of the acceptance criteria set by the state regulatory agency. Approximately 100 tons of previously excavated MGP soils were mixed and designated for use in the project; these consisted of 30 percent coal tar soils, 30 percent water gas tar soils, 30 percent processed construction spoils, and 10 percent tar emulsion soils (EPRI, 1997).

Following thermal desorption, two hot-mix designs were used. The first hot-mix design was for a top course, and the second hot-mix design was for a modified bituminous plant mix. Desorbed material was supplemented with clean aggregate: 30 percent desorbed soil for hot-mix No. 1, and 40 percent desorbed soil for hot-mix No. 2. The hot-mix products were prepared at an offsite batch mix plant, with hot asphalt and the desorbed material-aggregate blended in a pugmill. These products were then conveyed to the site in trucks. Temperature loss during transport of the hot mix was approximately 25°F, which was within acceptable limits.

Three areas were selected for test panels using the hot-mix asphalt. Panel A consisted of a composite design of a 3-inch layer of bituminous stabilized base course overlain with a 3-inch thick layer of hot-mix top course (hot-mix design No. 1). Panel C consisted of adjoining 3-inch sections of the two hot-mix products. After the panels were placed, they were subjected to qualitative and quantitative evaluations. Visual inspections were made over 6 months. A quantitative analysis was also conducted which consisted of in-place density and deflection testing. Based on the results of these tests, the study concluded that the test panels performed satisfactorily for a variety of applications, especially for roads subjected to light and moderate traffic.

5.2.4 Bioremediation/Chemically Enhanced Bioremediation

5.2.4.1 Ex Situ Bioremediation

Bioremediation generally refers to the breakdown of organic compounds (contaminants) by microorganisms. This degradation can occur in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic). Bioremediation techniques create a favorable environment for microorganisms to use contaminants as a food and energy source. Ex situ bioremediation processes treat soil above grade using conventional soil management practices to enhance degradation of contaminant. Generally, some combination of oxygen, nutrients, and moisture are provided and pH is controlled. Bioaugmentation may be used, in which microorganisms adapted for degradation of specific contaminants are applied (USEPA, 1998).

Although not all organic compounds are amenable to biodegradation, bioremediation techniques have been successfully used to remediate soils and sludges contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. The rate and extent to which microorganisms degrade these contaminants is influenced by the specific contaminants present, soil type, oxygen supply, moisture content, nutrient supply, pH, and temperature. Other factors that influence the rate and extent of degradation include the availability of contaminant(s) to the microorganisms, the concentration of the contaminants (e.g., high concentrations may be toxic to the microorganisms), and the presence of other substances toxic to the microorganisms, (e.g., mercury), or inhibitors to the metabolism of the contaminant (USEPA, 1998).

For MGP applications, biological treatment is generally most effective on BTEX and 2- and 3-ring PAH compounds, with treatment efficiency declining for 4-, 5-, and 6-ring PAH compounds because of their reduced solubility and availability to microorganisms.

A common observation with bioremediation is that eventually the degradation rate reaches a plateau and it is difficult to reduce concentrations further in a practical manner. Residual PAHs after bioremediation, though detectable and often above regulatory standards, may have little or no significant effect on the environment. The leaching potential from residual PAHs in soils and direct contact toxicity from these residuals are the subject of ongoing research.

The most commonly used ex situ biological technologies include landfarming, biopiles (composting), and slurry phase biological treatment. Each of these is described below.

5.2.4.1.1 Landfarming

Technology Description

Landfarming (also called land treatment) involves placing contaminated soil in lined beds and periodically turning it over or tilling it to aerate the waste. The soil is irrigated, and nutrients are added as needed to optimize growing conditions. Land farming requires excavation and placement of contaminated soils onto prepared beds or liners to control leaching of contaminants. Contaminated soil is then treated in lifts that are up to 18 inches thick. After the desired treatment is achieved, the lift is removed and a new lift is constructed. It is advantageous to remove only the top of the remediated lift and then to construct the new lift by adding more contaminated media to the remaining material and mixing. This strategy inoculates the freshly added material with an actively degrading microbial culture and can reduce treatment times (USEPA, 1998).

Operational Considerations

Soil conditions are controlled for ex situ bioremediation to optimize the rate of contaminant degradation. Conditions normally controlled include:

- Moisture content (for biopiles and landfarming; solids content for slurry treatment)
- Aeration

- pH
- Nutrients
- Other amendments (e.g., bulking agents)

Although a contaminant might have been shown to be biodegradable in the laboratory or at another site, its rate and extent of degradation in each particular location and specific soil condition depend on many factors. To determine whether bioremediation is an appropriate and effective remedial treatment for the contaminated soil at a particular site, it is necessary to characterize the contamination, soil, and site, and to evaluate the biodegradation potential of the contaminants. A preliminary treatability study for all ex situ bioremediation methods should identify:

- Amendment mixtures that best promote microbial activity
- Percent reduction and lowest achievable concentration limit of contaminant
- Potential degradation rate

Landfarming requires a large amount of space and is dependent on environmental conditions affecting biological degradation of contaminants (e.g., temperature and rainfall). VOC emissions and dust control are also important considerations, especially during tilling and other material handling operations. Waste constituents may be subject to “land-ban” regulation and thus may not be eligible for treatment by landfarming.

Applications and Cost

Ex situ bioremediation methods have been used to treat petroleum hydrocarbons, VOCs, and PAHs. As a rule of thumb, the higher the molecular weight (and the more rings a PAH has), the slower the degradation rate. Landfarming is very simple from a technology point of view.

Costs for treatment include approximately $75 per cubic yard for the prepared bed. Studies conducted prior to treatment can range from $25,000 to $50,000 for laboratory studies, and $100,000 to $500,000 for pilot tests or field demonstrations.

Benefits

- Ex situ’s main advantage is that it generally requires shorter time periods than in situ treatment, and there is more certainty about the uniformity of treatment because soil can be homogenized, screened, and continuously mixed
- Ex situ treatment is favored over in situ biological techniques for heterogeneous soils, low-permeability soils, areas where underlying groundwater would be difficult to capture, or when faster treatment times are required
- Bioremediation reduces the source of contamination

Limitations

- None of the ex situ biological treatment options can completely remove organic contaminants

- All ex situ treatment requires excavation of soils, with associated costs and engineering for equipment, permits, and material handling / worker exposure considerations

Case Study

Vandalia Road MGP Site

MidAmerican Energy has used the Institute of Gas Technologies (IGT) MGP-REM, a chemically enhanced bioremediation process, for a full-scale remediation of its MGP site near Des Moines, Iowa. This was the first full-scale use of the MGP-REM chemical / biological treatment process for coal-tar contaminated soils in a solid-phase application (landfarming). The process combines the two complementary remedial techniques of chemical oxidation and biological treatment. The MGP-REM process uses the addition of Fenton's reagent (H_2O_2 plus Fe^{2+}) to produce hydroxyl radicals that start a chain reaction with the organic contaminants. These contaminants, specifically PAHs, are transformed into products that are more readily degraded by microorganisms; the ultimate products of the process are carbon dioxide, water, and biomass (Srivastava, 1996).

The Vandalia Road site is a former landfill that contains residues from a former MGP related to the Capital Gas Light Company site located in Des Moines. This site operated from 1876 to 1957. The Vandalia Road MGP site was selected for a full-scale test of the MGP-REM technology because of a number of site attributes:

- The site is located on property that is currently owned by MidAmerican.
- The site is located in a rural area, even though it is within the city limits of the City of Pleasant Hill.
- The site is surrounded by company-owned farmland that could be used to construct an adjacent treatment facility (Kelley, 1997).

After laboratory treatability studies were completed at the IGT laboratory facilities in Des Plaines, Illinois, and the data indicated that the contaminated media at the Vandalia Road MGP site were amenable to the MGP-REM process, the full-scale treatment facility was constructed in the fall of 1996 and the spring of 1997. The soil treatment portion of the facility was 100 feet by 300 feet, bermed and lined with high-density polyethylene (HDPE). The two 12-inch lifts each had a capacity of 1,000 cubic yards. Overall capacity for a given treatment phase was 2,000 cubic yards. At the end of the first treatment phase, treated soil was removed from the facility and used for backfill in the former excavation. Adjacent facility structures included a water retention basin for runon and runoff control, an automatic sprinkler system, a decontamination / soil processing pad and a field laboratory. The total cost of the treatment facility and associated structures was approximately $360,000 (Kelley, 1997). Additional phases of treatment may be required to complete the site remediation.

In 1997, contaminated soil was excavated from the former landfill and placed in the treatment facility. All of the soil that was excavated from the former landfill was located below the groundwater level, so a dewatering area was constructed adjacent to the excavation to assist in reducing the water content of the excavated media prior to loading into the land treatment unit (LTU). Once sufficiently dewatered to allow handling, the material was hauled to the adjacent treatment facility and placed in the LTU (Kelley, 1997). A small bulldozer was used to spread the materials across the facility to a consistent depth of 12 inches. Originally, excavated material was to be processed through a screening plant to remove oversize debris; however, the material, even after dewatering, was too wet to pass through the screening plant. Because the landfill appeared to consist of coal tar materials placed there in liquid form, the debris typically found at an MGP site (brick, concrete, timbers, etc.) was not present, which reduced the need for screening.

The routine operations for the biological portion of the process consisted of aeration of the soil, addition of nutrients, and maintenance of the proper moisture content. All of the equipment used for operation of the treatment facility was standard agricultural equipment, such as field cultivators, rototillers, subsoilers, and a two-bottom plow. The two-bottom plow was necessary to turn over the entire lift of soil placed in the facility, for proper aeration. The plow was necessary because the lower 4 to 6 inches of soil were so compacted by loading in the LTU that the soil could not be turned over using a tiller or field cultivator. A critical parameter for biological degradation is the moisture content of the media treated; moisture content needs to be between 40 and 80 percent of field-holding capacity. An irrigation system was installed to automate the soil moisture adjustments. During the first year of operation, too much water, in the form of heavy rain, affected the facility's operations. This made aeration difficult and may have caused a lack of oxygen, which may have inhibited biological degradation.

Chemical enhancement was also used in this bioremediation treatment process. IGT's MGP-REM chemical treatment process consisted of three steps. First, the soil pH was adjusted to approximately 5.0. Next, ferrous sulfate was added to the soil and mixed by rototilling. Third, hydrogen peroxide was added to the process resulting in a combination of direct oxidation and hydroxylation of the 4-, 5-, and 6-ring PAH compounds. Both of these chemical reactions (oxidation and hydroxylation) generally increase the solubility of the PAH compounds and, as a result, improve their biological availability to the bacteria (Kelley, 1997). The chemicals were added to the plot using commercially available agricultural equipment modified for this project.

During the first year of operation of the biological treatment phase, total PAH reduction was 51 percent. Chemical treatment reduced total PAHs by an additional 20 percent. In addition, the reduction of 4- to 6-ring compounds was increased twofold. Overall, the MGP-REM process used at the Vandalia Road MGP site reduced total PAHs by 70 percent. Based upon current cost estimates for continued operation of the facility, MidAmerican expects to save approximately $1.2 million using this technology as compared to co-burning the soil in its power plant facility near Sioux City, Iowa (Kelley, 1997).

5.2.4.1.2 Biopiles

Technology Description

Biopile treatment is a variation of composting in which excavated soils are usually mixed with soil amendments and placed in piles on a treatment area. Biopiles often include leachate collection systems and some form of aeration. In most cases, indigenous microorganisms are used. Soil amendments may include nutrients, moisture, or bulking agents such as wood chips.

Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. The treatment area will generally be contained with an impermeable liner to minimize the risk of contaminants leaching into uncontaminated soil. Biopiles often have a buried distribution system that passes air through the soil either by vacuum or by positive pressure. As an alternative to forced aeration, biopiles may also be turned regularly. Biopiles can be covered with plastic to control runoff, evaporation, and volatilization (USEPA, 1998). Heat can be generated in the piles, potentially providing for higher degradation rates and winter operation.

Operational Considerations

Soil conditions are controlled for ex situ bioremediation to optimize the rate of contaminant degradation. Conditions normally controlled include:

- Moisture content (for biopiles and landfarming; solids content for slurry treatment)
- Aeration
- pH
- Nutrients
- Other amendments (e.g., bulking agents)

Although a contaminant might have been shown to be biodegradable in the laboratory or at another site, its rate and extent of degradation in each particular location and under specific soil conditions depend on many factors. To determine whether bioremediation via biopiles is an appropriate and effective remedial treatment for contaminated soil at a particular site, it is necessary to characterize the contamination, soil, and site, and to evaluate the biodegradation potential of the contaminants. A preliminary treatability study for all ex situ bioremediation methods should identify:

- Amendment mixtures that best promote microbial activity
- Percent reduction and lowest achievable concentration limit of contaminant
- Potential degradation rate

For biopiles, batches of the same size may require longer retention times than in slurry-phase processes. Static treatment processes may result in less uniform treatment than processes that involve periodic mixing, which is difficult for biopiles. Windrow composting is an alternative that overcomes that problem.

Applications and Cost

Ex situ bioremediation methods have been used to treat petroleum hydrocarbons, VOCs, and PAHs. As a rule of thumb, the higher the molecular weight (and the more rings a PAH has), the slower the degradation rate. Biopiles are a little more complex technologically than landfarming. The associated costs of this method reflect the increased complexity. Costs for biopiles may run $100 to $200 per cubic yard, exclusive of laboratory and pilot studies. Laboratory studies may cost between $25,000 and $50,000. Pilot tests or field demonstrations may cost $100,000 to $500,000.

Benefits

- Ex situ treatment's main advantage is that it generally requires shorter time periods than in situ treatment, and there is more certainty about the uniformity of treatment because soil can be homogenized, screened, and continuously mixed
- Ex situ treatment is favored over in situ biological techniques for heterogeneous soils, low-permeability soils, areas where underlying groundwater would be difficult to capture, or when faster treatment times are required
- Bioremediation reduces the source of contamination

Limitations

- None of the ex situ biological treatment options can completely remove organic contaminants
- All ex situ treatment requires excavation of soils, with associated costs and engineering for equipment, permits, and material handling / worker exposure considerations

Case Study

Navy National Test Site

A demonstration of biopile technology was performed to investigate and optimize methods of pretreatment, construction, operation, and performance monitoring. Soil contaminated with petroleum hydrocarbons was treated in 500-cubic-yard biopiles at Port Hueneme, California, following a treatability study that was conducted to predict biopile performance and to identify optimum nutrient rates. Two biopiles with the appropriate dimensions of 52 feet by 52 feet by 8 feet were constructed on a liner, with an aeration system consisting of slotted PVC piping and a positive displacement blower. An irrigation system was also included. The piles were covered with polyethylene, and a carbon emission control system was installed (Chaconas, 1997). The demonstration was conducted in two phases from 1994 to 1996. In the first phase, soils consisted of brown silty sand with a trace of clay (35 percent passing a No. 200 sieve), contaminated primarily with diesel fuel. The second phase of the test used soils that consisted of brown clayey silt (52 percent passing a No. 200 sieve), contaminated with a combination of diesel fuel and heavier fuel oils. In both phases, the petroleum hydrocarbons were found to be significantly weathered (degraded), as evidenced by the absence of normal alkanes. In the second phase of the test, contaminated soils were pulverized with the hammer mill prior to placement in the biopile; in the first phase soils were directly placed in the pile.

Moisture and temperature probes, field respirometry testing, and innovative laboratory techniques to track degradation of various hydrocarbon classes were employed to monitor performance. Nondestructive field measurements of biological respirometry (oxygen uptake), moisture content, and temperature proved successful in monitoring the operation of the biopiles (Chaconas, 1997).

During the first phase, the technology removed 88 percent (reduction from an average of 1,990 mg/kg to 232 mg/kg) of petroleum hydrocarbons in the diesel range during 51 weeks. During 47 weeks of operation, the second phase achieved an 88 percent reduction in the diesel range, from an average of 4,769 mg/kg to 592 mg/kg, and a 71 percent reduction in the motor oil range, from an average concentration of 5,638 mg/kg to 1,617 mg/kg (Chaconas, 1997). In each phase, the largest reductions occurred during the first 4 weeks of biopile operations, and TEPH degradation rates slowed dramatically after 6 to 8 weeks of operation. This “plateauing” of concentrations is consistent with result of other studies in the literature for this technology. The hammer mill step in the second phase appears to have been successful because comparable results were obtained although the pulverized soil contained more clay. Degradation rates calculated from respirometry testing data correlated well with TEPH degradation observed in laboratory analyses.

5.2.4.1.3 Bioreactors

Technology Description

Slurry-phase biological treatment involves controlled treatment of excavated soil in a bioreactor. Excavated soil is first physically processed to separate gravel, sand, and debris, and the soil is then mixed with water to a predetermined concentration dependent upon the concentration of the contaminants, the rate of biodegradation, and the physical nature of the soils. Typically, a slurry contains from 10 to 50 percent solids by weight.

The solids are maintained in suspension in a reactor vessel and mixed with nutrients and oxygen. Microorganisms may be added if a suitable population is not present. When biodegradation is complete, the soil slurry is dewatered using clarifiers, pressure filters, vacuum filters, sand drying beds, centrifuges or other dewatering devices.

Operational Considerations

Soil conditions are controlled for ex situ bioremediation to optimize the rate of contaminant degradation. Conditions normally controlled include:

- Solids content (for slurry treatment, moisture content for biopiles and landfarming)
- Aeration

- pH
- Nutrients
- Other amendments (e.g., bulking agents)

Although a contaminant might have been shown to be biodegradable in the laboratory or at another site, its rate and extent of degradation in each particular location and under specific soil conditions depend on many factors. To determine whether bioremediation is an appropriate and effective remedial treatment for the contaminated soil at a particular site, it is necessary to characterize the contamination, soil, and site, and to evaluate the biodegradation potential of the contaminants. A preliminary treatability study for all ex situ bioremediation methods should identify:

- Amendment mixtures that best promote microbial activity
- Percent reduction and lowest achievable concentration limit of contaminant
- Potential degradation rate

For bioreactors, sizing of materials prior to putting them into the reactor can be difficult and expensive. Nonhomogeneous and clayey soils can create serious materials handling problems. Dewatering of treated soil fines can be expensive, and finding an acceptable method for disposing of nonrecycled wastewaters is required.

Applications and Cost

Ex situ bioremediation methods have been used to treat petroleum hydrocarbons, VOCs, and PAHs. As a rule of thumb, the higher the molecular weight (and the more rings a PAH has), the slower the degradation rate. Bioreactors are the most complex of the ex situ processes. The associated costs of this method reflect its complexity. However, bioreactors provide the highest level of treatment attainable for ex situ bioremediation of soils because they provide optimal conditions (e.g., mixing, temperature, pH). Costs for bioreactors run approximately $216 per cubic yard, exclusive of laboratory and pilot studies. Laboratory studies may cost between $25,000 and $50,000. Pilot studies or field demonstrations may run between $100,000 and $500,000.

Benefits

- Ex situ treatment’s main advantage is that it generally requires shorter time periods than in situ treatment, and there is more certainty about the uniformity of treatment because soil can be homogenized, screened, and continuously mixed
- Ex situ treatment is favored over in situ biological techniques for heterogeneous soils, low-permeability soils, areas where underlying groundwater would be difficult to capture, or when faster treatment times are required
- Bioremediation reduces the source of contamination

Limitations

- None of the ex situ biological treatment options can completely remove organic contaminants
- All ex situ treatment requires excavation of soils, with associated costs and engineering for equipment, permits, and material handling / worker exposure considerations

Case Study

Niagara Mohawk Research

A field-scale pilot test of bioslurry treatment was performed in 1995 at the Niagara Mohawk Power Corporation (NMPC) Remediation Research Facility in Utica, New York. Sediment was dredged from Utica Harbor and placed in two 10,000-gallon capacity slurry bioreactors where it was mixed by single top-mounted mixers, aerated by blowers, and treated for 68 days.

Grain size analysis of the sediments dredged from the harbor indicated that the material was approximately 34 percent sand, 52 percent silt, and 14 percent clay. The target slurry density for the pilot test was 20 percent by weight, and a working slurry volume of 7,300 gallons was used in each tank. Prior to treatment, the sediments exhibited a hydrocarbon odor and sheen. Initial concentrations of BTEX and PAHs were 86 and 651 mg / kg, respectively. Oil and grease analysis showed a concentration of 1.4 percent (dry weight), and total organic carbon was measured at 5.8 percent (dry weight).

Following bioslurry treatment, the sediments did not exhibit the hydrocarbon odor or sheen that had been observed when the material was dredged. No detectable BTEX was present in the sediments, and the total PAH concentration was measured at 203 mg / kg. The overall DRE for PAHs was 69 percent, ranging from a DRE of 89 percent for 3-ring PAHs to a DRE of 0 percent for 6-ring PAHs. The majority of PAH degradation was achieved within the first 21 to 35 days of treatment. The oil and grease concentration was measured following treatment at 0.31 percent, a reduction of 78 percent.

The sediments were tested before and after treatment using a 14-day earthworm test. Prior to treatment, only 24 percent of the test organisms survived using undiluted dewatered sediment; after treatment, 94 percent of the organisms survived. Decanted wastewater post treatment was found to be toxic to fish, in part because of residual nutrient concentrations from the treatment process. These results indicate that management of residual nutrients in the wastewater effluent will be required as part of full-scale bioslurry treatment.

The potential for leaching BTEX and PAHs before and after bioslurry treatment was measured using the EPA synthetic precipitation leaching procedure test (SPLP). Following treatment, no BTEX or PAHs were found in the SPLP extract above the detection limit.

This remedial technology demonstration confirmed that bioslurry treatment of aquatic sediments can be performed at a field scale. Although bioreactor treatment of the sediments did not achieve the removal efficiency typical of more aggressive methods such as incineration or thermal desorption, this demonstration suggests that, after bioslurry treatment, sediments may be placed in aquatic or terrestrial environments. Using risk-based treatment criteria for such placement may be an environmentally acceptable option for biologically treated sediments.

Contacts

Jean-Pierre Moreau, Niagara Mohawk Power Corporation, 300 Erie Boulevard, West, Syracuse, NY 13322, (315) 428-6808

Dr. Thomas D. Hayes, Gas Research Institute, 8600 West Bryn Mawr Avenue, Chicago, IL 60631, (312) 399-8325

James B. Harrington, P.E., New York State Department of Environmental Conservation, 50 Wolf Road, Albany, NY, (518) 457-0337

5.2.4.2 In Situ Bioremediation/Bioventing

Technology Description

Bioremediation generally refers to the breakdown of organic compounds (contaminants) by microorganisms. This degradation can occur in the presence of oxygen (aerobic) or in the absence of oxygen (anaerobic). Bioremediation technologies stimulate the growth of microorganisms and their use of contaminants as a food and energy source. Biodegradation processes are enhanced by creating a favorable environment for microorganisms through the introduction of some combination of oxygen (aerobic), nutrients and moisture, and by controlling the temperature and pH of the soil or groundwater environment. Bioaugmentation is another bioremediation technology in which microorganisms adapted for the degradation of specific contaminants are added to enhance the biodegradation process (USEPA, 1998). Bioventing is a third bioremediation technology. It uses conventional soil vapor extraction (SVE) equipment to introduce oxygen to indigenous soil microorganisms.

Although not all organic compounds are amenable to biodegradation, bioremediation has been successfully used to clean up soils and sludges contaminated by petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. Aerobic biodegradation is the primary mechanism for in situ biotreatment of petroleum hydrocarbons and PAHs in soil. The rate at which microorganisms degrade contaminants is influenced by the concentrations of contaminants present, the degree of contact between the microorganisms and the contaminants, the oxygen supply, moisture, temperature, pH, and nutrient supply in the soil or water to be treated (USEPA, 1998). In situ biological treatment technologies are sensitive to certain soil parameters. For example, the presence of clay or humic materials in soil can cause variations in biological treatment process performance. For MGP sites, biological treatment of PAHs is generally most effective on BTEX and 2- and 3-ring PAH compounds; treatment efficiency declines for 4-, 5-, and 6-ring PAH compounds because of their reduced solubility and availability to microorganisms.

Of the available in situ biological treatment technologies, bioventing has been the most frequently demonstrated. As previously mentioned, this technology stimulates the in situ biodegradation of aerobically degradable compounds in soil by providing oxygen to existing indigenous soil microorganisms. Bioventing uses conventional SVE equipment to stimulate biodegradation by providing oxygen to indigenous soil microorganisms. However, bioventing uses low air-flow rates to provide just enough oxygen to sustain microbial activity while minimizing contaminant volatilization (GRI, 1996), which is the opposite of the high air-flow rates used in treatment by SVE. Bioventing systems may either use a vacuum approach to draw air and oxygen into the contaminated subsurface area or a positive pressure system to inject air into the contaminated subsurface through wells. Extraction wells may be used at the perimeter of the treatment zone to control vapors. Bioventing is a medium- to long-term technology applicable only to soils in the vadose zone, and cleanup times range from a few months to several years (USEPA, 1998).

Operational Considerations

Soil characteristics that affect microbial activity (and therefore biodegradation rates) include pH, moisture, presence of nutrients, (e.g., nitrogen and phosphorus), and temperature. The optimal pH range is 6 to 8 for microbial activity although microbial respiration has been observed at sites that have soils outside this range. Optimum soil moisture is very soil-specific. For bioventing, too much moisture can reduce the air permeability of the soil and decrease its oxygen transfer capability. Too little moisture inhibits microbial activity. A sufficient population of microorganisms needs to be present to attain reasonable degradation rates.

Applications and Cost

In situ bioremediation is typically useful for treating the portion of MGP residues containing lower molecular-weight hydrocarbons (e.g., volatile and semi-volatile portions of coal tar.) Bioventing and in situ bioremediation techniques have been successfully used to treat soils contaminated by petroleum hydrocarbons, nonchlorinated solvents, pesticides, wood preservatives, and other organic chemicals. For example, the U.S. Air Force Bioventing Initiative is demonstrating that this technology is effective under widely varying site conditions. As of 1996, data have been collected from 125 sites (Leesch and Hinchee, 1996). Regulatory acceptance of bioventing has been obtained in 35 states and in all 10 USEPA Regions (Leesch and Hinchee, 1996).

The time required to remediate a site using bioventing or in situ bioremediation is highly dependent upon the specific soil and chemical properties of the contaminated media. Costs for operating a bioventing system typically are $10 to $70 per cubic meter of soil ($10 to $60 per cubic yard; AFCEE, 1994). Factors that affect the cost of bioventing include contaminant type and concentration, soil permeability, injection well spacing and number, pumping rate, and off-gas treatment. Bioremediation costs vary considerably depending on the volume of soil to be treated, specific soil and chemical properties of the contaminated media, and site-specific requirements for bioremediation enhancements or nutrients. The technology does not have high capital or operation and maintenance costs because it does not require expensive equipment and relatively few personnel are involved in the operation and periodic maintenance of the bioventing system.

Benefits

- Cost savings achieved by avoiding excavation and transportation of soil
- Generally inexpensive
- Contaminants partially destroyed
- “Low tech” and relatively easy to implement.
- Minimal disruption of current operations at sites
- Bioventing demonstrated highly effective for treating lighter-weight petroleum hydrocarbons (e.g., gasoline)

Limitations

- Generally more time required than for ex situ processes
- Verification that contaminants have been destroyed sometimes difficult
- Treatment uniformity uncertain because of variability in soil characteristics and contaminant distribution
- Not demonstrated effective for higher-molecular-weight petroleum hydrocarbons or PAHs
- Bioventing performance reduced by shallow groundwater table, saturated soil lenses, or low-permeability soils; low soil moisture content may limit bioventing effectiveness.
- Monitoring of offgases at soil surface possibly required for bioventing; possible vapors buildup in basements within the radius of influence of air injection wells can be alleviated by extracting air near any facility of concern

Case Studies

Tar Site, St. Louis Park, Minnesota

A demonstration of bioventing was conducted at the Reilly Tar and Chemical Corporation site in St. Louis Park, Minnesota. This site formerly housed a coal tar refinery and wood-preserving facility at which creosote in mineral oil served as the primary preservative. The facility operated from 1917 until 1979. A pilot-scale bioventing demonstration began in November 1992 to determine whether the technology was effective for PAHs.

The pilot-scale bioventing system consisted of a single-vent well with 12 tri-level soil-gas monitoring points. The vent well was screened from 5 to 15 feet below grade and was placed in the center of a 50-foot by 50-foot treatment area that was selected based on depressed oxygen concentrations measured during an initial soil gas survey (Alleman, 1995). The soil-gas monitoring points were placed radially outward at 10, 20, and 30 feet from the vent well in four directions towards the corners of the plot. The probes were set at 4, 6, and 8 feet below grade. A control area was established approximately 150 feet to the northwest of the treatment area.

Soil samples were collected from both the treatment and control areas to quantify PAH concentrations prior to bioventing. Respiration measurements were made to estimate PAH biodegradation as a means of monitoring the progress of the bioventing. In situ respiration tests were conducted every 3 months to measure oxygen utilization rates and calculate biodegradation rates (Alleman, 1995).

Bioventing at the tar site achieved a greater than 10 percent reduction per year in total PAHs during the first two years of the study. Respiration measurements indicated that 13.4 percent and 17.3 percent degradation of total PAH content was possible during the first and second year, respectively. Although not all of the respiration can be attributed conclusively to PAH metabolism, strong correlations were found between the PAH concentration and biodegradation rates (Alleman, 1995).

Loring Air Force Base, Maine

Bioventing was selected to treat petroleum-contaminated soils at Loring AFB in Maine. Sixteen bioventing systems were installed and all continue to operate. These systems cover approximately 17.6 acres and are treating a combined total of more than 500,000 cubic yards of fuel-contaminated soil. The major contaminants being treated by bioventing are TPHs, benzene, toluene, and xylene. The cleanup goal for TPHs is 870 mg/kg, based on risk to human health. Cleanup criteria for benzene, toluene, and xylene are based on soil leaching potential.

Operational difficulties have been encountered because of soil heterogeneity, high or perched groundwater, and inability to collect soil-gas samples. Oxygen utilization rates from more than 40 respiration tests range from 0.01 to 7.5 percent per hour, with the site median being 0.63 percent per hour (Underhill, 1997).

5.2.5 Containment

Technology Description

Containment methods are used to prevent or significantly reduce migration of contaminants in soils or groundwater and to prevent human and animal exposure to contaminants. Containment is generally necessary whenever contaminated materials are to be buried or left in place at a site. In general, containment is chosen when extensive subsurface contamination at a site precludes excavation and removal of wastes because of potential health hazards, prohibitive costs, or lack of adequate treatment technologies (USEPA, 1998).

Containment or site capping can be implemented in various forms. The technology can be as simple as an asphalt or concrete cap or as elaborate as RCRA Subtitle C or Subtitle D engineered landfill cap. The goals of cap design are to prevent rainwater infiltration through impacted soils, prevent soil vapors from rising to the surface, and provide a barrier between animal and plant life and the underlying contaminated media. The final design of a cap depends on the structural and performance requirements of the particular area. The cap should be designed to facilitate water collection into drains and to minimize ponding. Cap maintenance consists of inspection for and repair of cracks.

Cap design is site-specific and depends on the intended or existing use of the former MGP site. The most effective single-layer caps are composed of concrete or bituminous asphalt. These materials are used to form a barrier between the waste and the surface environment. All covers should be designed to prevent the "bathtub" effect, which occurs when a more permeable cover is placed over a less permeable bottom liner or natural subsoil. When this occurs rainfall infiltrates the cover and ponds on the less permeable underlying material, thereby "filling up" the bathtub (USEPA, 1998).

Landfill caps are generally complex and can range from a one-layer system of vegetated soil to a complex multi-layer system of soils and geosynthetics. The most critical components of a landfill cap are the barrier layer and the drainage layer. The barrier layer can be low-permeability soil (clay) and/or geosynthetic clay liners (GCLs). The low-permeability material diverts water and prevents its passage into the underlying waste. The higher permeability materials placed atop the barrier layer carry away water to prevent percolation through the cap. Soils used as barrier materials are generally clays compacted to a hydraulic conductivity no greater than 1×10^{-6} cm/sec. Compacted soil barriers are generally installed in 6-inch minimum lifts to achieve a thickness of 2 feet or more (USEPA, 1998).

Operational Considerations

Aspects to be considered in cap design include the existing and future uses of the facility, the leaching potential of the waste materials, and the location of the waste relative to the groundwater table. Other considerations include the ease of relocating existing facility operations during construction activities.

Site capping mitigates migration, but does not lessen toxicity, mobility, or volume of hazardous wastes. Caps are most effective where most of the underlying waste is above the water table. A cap, by itself, can prevent only the vertical entry and migration of precipitation into and through waste, not the horizontal flow of groundwater through the waste. In many cases, caps are used in conjunction with vertical cutoff walls to minimize horizontal flow and migration. The effective life of the cap can be extended by long-term inspection and maintenance. Vegetation must be eliminated from the cap area because roots may penetrate deeply. Precautions must be taken to assure that the integrity of the cap is not compromised by surface activities.

Laboratory tests are needed to ensure that the materials being considered for cap components are suitable. Testing includes grain size analysis, Atterberg limits, and compaction characteristics (USEPA, 1998). The key engineering soil properties that must be defined are shear strength and hydraulic conductivity. Shear strength may be determined with the unconfined compression test, direct shear test, or triaxial compression test. Hydraulic conductivity of soils may be measured in the laboratory by the constant or falling head permeability test. Laboratory tests are also needed to ensure that geosynthetic materials will meet cap requirements (USEPA, 1998).

Quality assurance for cap construction is the most critical factor in containment; USEPA has generated a technical guidance document on this subject; this technical guidance should be consulted during design and construction.

Applications and Cost

Containment approaches vary from repaving existing blacktop to installing a single- or double-layer concrete cap to installing a full-blown RCRA landfill cap. In between these extremes are double-layer concrete caps and non-RCRA Subtitle D landfill caps.

A RCRA Subtitle C multi-layered landfill cap is a baseline design that is suggested for RCRA hazardous waste applications. This cap generally consists of an upper vegetative (topsoil) layer, a drainage layer, and a low-permeability layer made of a synthetic liner over 2 feet of compacted clay. Compacted clay liners are effective if they retain a certain moisture content and are susceptible to cracking if the clay material dries out. Therefore, other cap designs are usually considered for arid environments.

RCRA Subtitle D requirements are for nonhazardous municipal solid waste landfills. The design of a landfill cover for a RCRA Subtitle D facility is generally a function of the bottom liner system or natural subsoils present. The cover must meet the following specifications (USEPA, 1998):

- The material must have a permeability no greater than 1×10^{-5} cm/s or equivalent permeability of any bottom liner or natural subsoils present, whichever is less.
- Generally the infiltration layer must contain at least 45 cm of earthen material.
- The erosion control layer must be at least 15 cm of earthen material capable of sustaining native plant growth.
- Concrete is somewhat less susceptible to cracking and is more durable than asphalt (engineered or standard) as a capping material.

The costs of single-layer concrete and asphalt caps are dependent upon the cost of the material and local labor costs. Approximate per-acre construction costs for concrete caps are $140,000; for asphalt caps and multi-layer, $170,000; for soil caps, $45,000. Each type of cap involves some operations and maintenance costs. Costs per acre per year are estimated as follows: concrete caps, $2,000; asphalt caps, $4,000; multi-layer and soil caps, $20. Additional cost information can be found in the Hazardous, Toxic, and Radioactive Wastes Historical Cost Analysis System developed by Environmental Historical Cost Committee of Interagency Cost Estimation Group.

Benefits

- Requires only short installation times
- Unlike ex situ soil treatment, does not require excavation of soils and thus avoids some of the associated disadvantages (increased costs from engineering design of equipment, permits, waste handling)

- Generally less expensive than other technologies
- Minimizes potential worker exposure onsite at an operating facility
- Prevents vertical infiltration of water into wastes and subsequent vertical migration of contaminants
- Creates a land surface that can support vegetation and/or be used for other purposes

Limitations

- Generally contains wastes, does not address future liability at site
- Requires periodic inspections for settlement, ponding of liquids, erosion, and naturally occurring invasion by deep-rooted vegetation
- Usually requires groundwater monitoring for verification of containment
- Typically requires deed restrictions or other institutional controls
- Typically requires long-term operation and maintenance programs

Case Study

Jackson MGP Site, Jackson, Michigan

The Jackson, Michigan, site housed an MGP that operated from 1887 until 1947 and was demolished during the 1950s. The current land uses at the site include a residential apartment complex, city park, and elementary school playground. The remedy selected for a portion of the site was a cap consisting of an impermeable HDPE membrane covered with 3 feet of soil for frost protection. The cap was designed and constructed according to Michigan's requirements for an impermeable cap at a hazardous waste landfill.

The remedial goals for the cap were to: eliminate a potential direct human contact hazard posed by PAHs present in subsurface soils and fill materials at concentrations in excess of Michigan's residential criteria; and limit the leaching of PAHs to groundwater to less than Michigan's health-based drinking water criteria.

The matrix covered by the cap is a mixture of topsoil, sandy subsurface soils, and fill materials consisting of slag, wood, coal, and brick. A concrete slab foundation for a former gas holder is also present below ground. The area covered by the cap is approximately 2 acres. A cap was chosen because removal of the wastes would have resulted in greater human exposure.

Total PAH concentrations in the subsurface soils and fill materials range up to 9,000 mg/kg. The cap is not expected to affect the concentration of PAHs. However, the cap will control exposure by eliminating a direct human contact pathway at the site. The cap is also expected to serve as a source control by eliminating potential source of PAH loading to groundwater.

The volume of subsurface soils and fill materials impacted by PAHs and covered by the cap is estimated to be approximately 10,000 cubic yards. The Michigan Department of Environmental Quality approved the cap as an interim remedial action (pending completion of the remedial investigation on other portions of the site) in May 1995. Construction of the cap was completed in August 1995.

Contact

G.L. Kelterborn, (517) 788-2484, fax (517) 788-1064

5.2.6 Stabilization/Solidification (S/S)

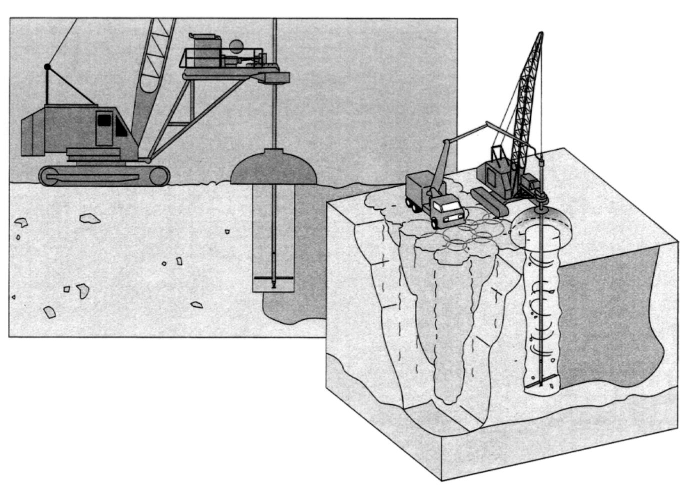
5.2.6.1 In Situ Stabilization/Solidification

Technology Description

In situ solidification / stabilization (S / S) is a remediation technology that can be used for MGP-related soil contamination. In-place cutoff walls are constructed, and soils and residues are treated in situ to depths of 30 feet or more. In situ S / S involves mixing soil with chemical binders such as cement, bentonite, additives, and proprietary chemicals that immobilize contaminants of concern (e.g., PAHs).

One method of in situ S / S uses a series of overlapping, large-diameter stabilized soil columns. A crane-mounted drill attachment turns a single-shaft, large-diameter auger head consisting of two or more cutting edges and mixing blades. As the auger head is advanced into the soil, grout is pumped through a hollow drill shaft and injected into the soil at the pilot bit. Cement, bentonite, additives, and proprietary chemicals may also be mixed into the grout. The cutting edges and mixing blades blend the soil and grout with a shearing motion. When the design depth is reached, the auger head is raised to expose the mixing blade at the surface and then advanced again to the bottom. Once the shaft is completed, another column is drilled using a specified pattern of overlapping columns; what is left behind is a series of interlinked columns.

The following is a schematic diagram showing the mixing augers.



A second method of in situ S/S requires the MGP wastes to be stabilized in shallow soil (approximately the upper 2 feet). In this scenario, admixtures containing Portland cement, bentonite, and other chemicals are placed directly on the ground surface. Tillers and sheepsfoot rollers are used to mix and compact the soil.

Operational Considerations

The success of S/S methods depends on soil type and properties, contaminant type and concentrations, moisture content, organic content, density, permeability, unconfined compressive strength, leachability, pH, and particle size. A treatability study is recommended for this technology to create a mix that minimizes leaching and has appropriate strength characteristics. The creation of concrete-like material in the subsurface may severely limit access to utilities, which may need to be permanently rerouted. The machinery used for in situ S/S via mixing augers is approximately the same size as a large drilling rig; low overhead lines may limit the use of this technology.

Applications and Cost

Inorganic constituents have traditionally been the target contaminant group for in situ S/S. The technology has limited effectiveness against SVOCs and no expected effectiveness against VOCs. It has been applied to MGP sites for PAH treatment. Costs for cement-based S/S techniques vary widely according to materials or reagents used and their availability, project size, and the chemical nature of the contaminants. In situ mixing/auger techniques average $40 to $60 per cubic yard in shallow applications.

Benefits

- Immobilizes contaminants
- Neutralizes soil
- Improves bearing capacity or shear strength of treated area
- Leaves treated area, if reinforced, able to withstand differential soil and hydrostatic loading

Limitations

- Possible leaching of volatile or mobile constituents
- Creation of concrete-like material in the subsurface (may severely limit access to utilities, which may need to be permanently rerouted)
- Possible significant increase in volume of mixture (up to double the original volume)
- Reagent delivery and effective mixing more difficult than in ex situ applications

Case Studies

Columbus, Georgia, Former MGP Site

A full-scale demonstration of in situ S/S for MGP contamination was performed in Columbus, Georgia, where an estimated 94,000 cubic yards of soil at a town gas site were stabilized (Geo-Con, 1993). The 4-acre site is located in the central business district of Columbus and is bounded to the west by the Chattahoochee River. Contaminated soils extended over a 15-foot interval beneath 10 to 20 feet of miscellaneous fill. Depth to groundwater was approximately 20 feet bgs, and the 10-foot saturated zone was underlain by bedrock.

In situ treatment was accomplished by mixing/drilling a Type I Portland Cement slurry with the soil to an approximate depth of 35 feet using an 8-foot-diameter auger. A containment wall was installed adjacent to the river; the remainder of the site was stabilized by advancing augers at approximately 1,800 overlapping locations.

Prior to treatment, contamination of the MGP-affected soils was as high as 300 mg/kg of VOCs, 2,400 mg/kg of PAHs, and 5,500 mg/kg of petroleum hydrocarbons. The performance criteria for the concrete mixtures were:

- Ultimate Compressive Strength (UCS) of 60 psi within 28 days
- Permeability of no more than $1x10^{-6}$ cm/s for the containment wall and no more than $1x10^{-5}$cm/s for the remainder of the site
- PAH concentration in TCLP leachate not to exceed 10 mg/L

UCS testing was conducted on all samples, and permeability and leach testing was performed on 10 percent of the samples obtained from approximately 300 randomly selected shafts of freshly stabilized soils. Any shafts that did not comply with the performance criteria had to be reprocessed. After the soils were stabilized, the area was covered with an HDPE liner and backfilled soil and then converted into a park and walkway.

Contacts

Darahyl Dennis, Georgia Power Company, Atlanta, GA 30302, (404) 526-7064

Harold F. Reheis, Georgia Department of Natural Resources, Atlanta, GA 30334, (404) 656-4713

Manitowoc, Wisconsin, Former MGP Site

The Wisconsin Fuel & Light site is a former MGP facility located along the Manitowoc River in Manitowoc, Wisconsin. The site had been filled with uncontrolled material, including debris and other material typically used behind sea walls. Portions of the foundations from the previous coal gasification structures also remained. The underlying soils at this site were contaminated with coal tars; these were stabilized using a reagent mixture of activated carbon, cement, fly ash, and organophilic clays.

The S/S treatment of impacted soil was accomplished by simultaneous injection and mixing of cement-based grout using 4- and 7-foot-diameter tools. This created a series of overlapping, vertically oriented columns of stabilized soil. The rotary and vertical movement of the boring/mixing tool was designed to assure effective mixing. In 1994 alone, a total volume of 6,859 cubic yards of soil was stabilized with 209 soil columns. Overall, approximately 15,000 cubic yards of soil were treated during a 2-year period to an average depth of 32 feet.

A minimum UCS of 120 psi and a permeability of 1.8×10^{-7} cm/s were achieved through the stabilization process, and the stabilized material also passed ASTM D559 and D560 durability tests. Verification soil samples were extracted using a modified Static Leaching Method. Of 16 extracts, only one contained a PAH (naphthalene at a concentration of 16 µg/L), and no other SVOCs were detected above the Minimum Detection Limit. Four extracts contained a VOC, methylene chloride, but because this compound also showed up in an apparatus blank and is not a normal constituent of coal tar, it is thought that this was a laboratory contaminant.

Contact

Ted Vallis, Wisconsin Fuel & Light, Manitowoc, Wisconsin, (414) 683-2538

5.2.6.2 Ex Situ Stabilization/Solidification (S/S)

Technology Description

Stabilization/solidification (S/S) uses physical and chemical means to reduce the mobility of hazardous substances and contaminants. Unlike other remedial technologies, S/S seeks to trap or immobilize contaminants, instead of removing them. The term S/S has been used synonymously with other terms, including immobilization, encapsulation, and fixation (GRI, 1996). Specific definitions have been assigned to each of these terms by USEPA and others to differentiate among them. For the purposes of this document, all of these technologies will be referred to as S/S.

Ex situ S/S was originally developed for inorganic wastes. Although this technology has limited applicability to organics and cyanides, it may be useful at MGP sites for management of purifier box wastes, gas-holder tank sludge, and soils contaminated with organic compounds (GRI, 1996). Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are introduced between the stabilizing agent and contaminants to reduce their mobility (stabilization).

Ex situ S/S is one method by which soil containing MGP wastes can be stabilized and replaced. The technology typically involves mixing the soil with chemical binders that solidify and/or immobilize the chemicals of concern. Pugmills are often used to perform mixing, although stockpiles may be mixed by mechanical means. Following S/S, treated materials may be replaced in their excavation, recompacted, and allowed to cure. Leachability testing is typically performed to verify contaminant immobilization.

There are many variations of the S/S technology using different processes and/or stabilizing agents such as Pozzolan/Portland cement, bitumen, and emulsified asphalt. The technology has been applied to soils, sludges, lagoons, and radioactive waste. The use of MGP soils in the production of asphalt is discussed in Section 5.2.3. The discussion in this section will focus on the use of Pozzolan / Portland Cement with MGP soils.

Pozzolan / Portland cement consists primarily of silicates from Pozzolanic-based materials like fly ash, kiln dust, pumice, or blast furnace slag as well as cement-based materials. These materials react chemically with water to form a solid matrix that improves the strength of the matrix in which waste is found and minimizes the likelihood of contaminant leaching. They also raise the pH of the water, which may help precipitate and immobilize some heavy metals. Pozzolanic and cement-based binding agents are typically appropriate for inorganic contaminants. The effectiveness of this binding agent with organic contaminants varies (USEPA, 1998).

Operational Considerations

A key design consideration is the identification of a stabilizing agent that is compatible with the waste at a site and that yields a treated product that contains no free liquids, meets a minimum compressive strength, and does not leach contaminants (GRI, 1996). Lab- and pilot-scale studies are required to identify the type and quantity of agent for each application. Physical and chemical characterization of the soil are also required to select suitable mixing materials.

The effectiveness of ex situ S / S depends primarily on effective mixing. If large materials (greater than 3 / 8 inch) are present, they must be excluded by screening. These materials can be used in the S / S process if they are crushed and screened. Mixing time should be sufficient to produce a homogeneous mix. This parameter has a great impact on project duration and treatment cost (GRI, 1996).

Soil parameters that must be determined for ex situ S / S include particle size, Atterberg limits, moisture content, metal concentrations, sulfate content, organic content, and density. Post-treatment parameters that require monitoring and testing include permeability, unconfined compressive strength, leachability, microstructure analysis, and physical and chemical durability (USEPA, 1998). Soil particle size is an important factor as fine particles may delay setting and curing times and can surround larger particles, causing weakened bonds in S / S processes (USEPA, 1998). Soil homogeneity and isotropy also affect S / S. Larger particles, such as coarse gravel or cobbles, may not be suitable for the S / S technology.

A consideration in the use of the technology at MGP sites is the presence of oil and grease. Oil and grease coat soil particles, which tends to weaken the bond between soil and cement in cement-based solidification (USEPA, 1998).

Applications and Cost

Ex situ S / S may be used to treat soils from MGP sites. It is a viable option when soil contaminants are primarily metals (as with purifier box wastes). Full-scale S / S of free-phase hydrocarbons and contaminated soils from MGP sites has been performed, but there is little documentation of the result of these demonstrations (GRI, 1996).

Cost of ex situ S / S depends on the costs of mobilization / demobilization of personnel and equipment, excavation, equipment, startup, supplies and consumables, labor, utilities, and analytical requirements. Ex situ S/S processes are among the most accepted remediation technologies. Comparing representative overall costs from more than a dozen vendors gives an approximate cost of under $110 per metric ton ($100 per ton), including excavation (USEPA, 1998).

Benefits

- Has been widely used to immobilize inorganic chemicals; several vendors claim that their proprietary additives can make organics amenable to stabilization

Limitations

- Performance of S/S process is dependent upon the chemical composition of the wastes
- Long-term immobilization of contaminants possibly affected by environmental conditions
- Certain wastes incompatible with certain S/S processes; treatability studies generally required
- VOCs are generally not immobilized by the stabilization process
- Long-term effectiveness not demonstrated for many contaminant/process combinations
- Volumetric increase in amount of material

Case Study

DuQuoin Former MGP Site

Remedial activities were conducted under the Illinois Site Remediation Program at an 8-acre former MGP site owned by Ameren CIPS in DuQuoin, Illinois. The remedial work, funded jointly by Ameren CIPS, Commonwealth Edison, and Nicor Gas, was conducted during the first half of 1997.

Tar and purifier waste was excavated from a lagoon approximately 59,650 square feet in area. A total of 4,290 tons of tar and tar-contaminated soil was generated during the excavation of impacted material at the site. This material was manifested as a hazardous waste and transported to a RCRA Subtitle C landfill.

The area identified as the lagoon excavation was stabilized by incorporating calciment bottom ash at a ratio of 7 parts ash to 10 parts soil into the bottom two feet of impacted clay subgrade. The stabilized clay was then placed back in 6-inch lifts and compacted with a D-6 bulldozer and sheepsfoot roller.

Soils from other areas of the site, identified as posing a risk greater that 10^{-6} to industrial workers (hot-spot soils), were excavated, stabilized with calciment bottom ash (at a one-to-ten ratio) and placed on top of the lagoon subgrade. The material was placed in 6-inch lifts and compacted with the use of the D-6 bulldozer and sheepsfoot roller. Approximately 4,611 cubic yards of stabilized material were used as backfill in the lagoon area. Confirmation sampling performed in the area of excavation and stabilization activities indicated that the remediation activities were successful.

Backfill obtained from an offsite commercial source was used to cover the stabilized material in the lagoon area. The backfill was compacted in place, graded to promote drainage of precipitation, and seeded with prairie grass.

The site is zoned commercial/industrial and will be used for these purposes in the future. Because stabilized impacted soils are present beneath the 1-foot surface cover, certain procedures and precautions will be followed to maintain this layer.

Contacts

Don Richardson, Ameren CIPS, (314) 554-4867

Peter McCauley, Com Ed, (312) 394-4470

Stan Komperta**,** Illinois Environmental Protection Agency**,** (217) 782-5504

5.2.7 Soil Washing

Technology Description

Soil washing is a physical/chemical process for scrubbing soils ex situ to remove contaminants.

The process removes contaminants from soils in one of two ways (USEPA, 1998): by dissolving or suspending them in the wash solution (which can be sustained by chemical manipulation of pH for a period of time); or by concentrating them into a smaller volume of soil through particle size separation, gravity separation, and attrition scrubbing (similar to techniques used in sand and gravel operations).

Soil washing is considered a media transfer technology because contamination is not destroyed but merely transferred from solid- to liquid-phase media. The contaminated water generated from soil washing is treated with the technologies suitable for the contaminants. Soil washing is potentially applicable to soils contaminated with a wide variety of heavy metals, radionuclides, and organic contaminants. Application of the process is not widespread in the United States. This technology has been more widely applied in Europe.

The concept of reducing soil contamination through the use of particle size separation is based on the finding that most organic and inorganic contaminants tend to bind, either chemically or physically, to clay, silt, and organic soil particles (USEPA, 1998). Silt and clay attach to sand and gravel particles by physical processes, primarily compaction and adhesion. Washing separates the fine (small) clay and silt particles from coarser sand and gravel soil particles thus concentrating contaminants into a smaller volume of soil that can then be managed (treated further or disposed of at a landfill). Gravity separation is effective for removing high- or low-specific-gravity particles such as heavy-metal-containing compounds. Attrition scrubbing removes adherent contaminant films from coarser particles. It can also increase the fines in soils. The clean soil can be returned to the site for reuse.

Complex mixtures of contaminants in soil (such as a mixture of metals, nonvolatile organics, and semivolatile organic compounds) and heterogeneous contaminant compositions throughout a soil mixture make it difficult to formulate a single washing solution that will consistently and reliably remove the different types of contaminants. Soil washing is typically not recommended for these types of sites.

Operational Considerations

Soil type is an important factor for soil washing. In general, coarse, unconsolidated materials, such as sands and fine gravels, are easiest to treat. Soil washing may not be effective where the soil is composed of large percentages of silt and clay because of the difficulty of separating the adsorbed contaminants from fine particles and from wash fluids (USEPA, 1998).

High soil moisture content may cause excavation, material handling, and material transport problems (USEPA, 1998).

The pH of the waste being treated may affect soil washing; high pH in soil normally lowers the mobility of inorganics in soil (USEPA, 1998).

High humic content will bind the soil, decreasing the mobility of organics and thus the threat to groundwater; however, high humic content can inhibit soil washing as a result of strong adsorption of the contaminant by the organic material (USEPA, 1998).

A complete bench-scale treatability study is typically required before using soil washing as a remedial solution. Like any ex situ soil treatment, this technology requires space for soil processing and materials handling.

Applications and Cost

This technology is suitable for treating soils and sediment contaminated with organics such as PCBs, creosote, fuel residues, and heavy petroleum; heavy metals sucah as cadmium, chromium, lead, arsenic, copper, cyanides, mercury, nickel, and zinc; and radionuclides. The technology can recover metals and can clean a wide range of organic and inorganic contaminants from coarse-grained soils.

At the present time, soil washing is used extensively in Europe but has had limited use in the United States. Between 1986 and 1989, the technology was one of the selected source control remedies at eight Superfund sites. The average cost for use of this technology, including excavation, is approximately $170 per ton, depending on site-specific conditions and the target waste quantity and concentration.

Benefits

- Offered by multiple vendors
- High degree of certainty regarding treatment performance

Limitations

- Material handling possibly expensive and time consuming, especially for large amounts

- Applicability and effectiveness of the process limited by:
  - Complex waste mixtures (e.g., metals with organics) which make formulating washing fluid difficult
  - High humic content in soil, which may require pretreatment
- Washwater requiring treatment at demobilization
- Additional treatment steps that may be required to address hazardous levels of washing solvent remaining in the treated residuals
- Difficultly removing organics adsorbed onto clay-size particles

Case Studies

Former Basford Gasworks, Nottingham, UK

A large-scale UK soil washing project is being conducted at the former Basford gasworks site in Nottingham. The 7.8-hectare (ha) site is owned by BG plc, the UK gas supply infrastructure group. The cleanup is valued at $7.5 million (Haznews, 1998).

Soil washing commenced in August 1997, and was scheduled to be completed in July 1998 after processing approximately 72,000 cubic meters of contaminated material. The soil washing was performed by Linatex/Heijmans, a joint-venture between UK and Dutch firms, using a plant with a nominal process rate of 50 tonnes per hour.

The Basford site is underlain by a drinking water aquifer, with no subsurface geological barrier to prevent off-site migration of contaminants. The soil conditions at the site made it a suitable candidate for evaluating the cost-effectiveness of soil washing; information which would be useful in evaluating this technology for other contaminated MGP sites. Basford began operating in 1854 and was the principal gas supply for the City of Nottingham. The site also provided by-products such as coke, sulphuric acid, and ammonium sulphate fertilizer until gas production stopped in 1972 (Haznews, 1998).

During the site characterization, 350 test pits were dug on a 10 meter grid, producing 2,500 samples for analytical testing. This detailed investigation allowed a more accurate identification of waste types, volume, and location. A model was subsequently developed to optimize the treatment technology and estimate the amount of materials that could be recycled. For example, 26,000 cubic meters of clean ash and clinker are being recovered for use in steel and building block production (Haznews, 1998).

Approximately 91,000 cubic meters of contaminated material was identified. Of this, about 15,000 cubic meters has been classified as untreatable (along with tar and asbestos wastes) and was sent to an off-site disposal location. The remainder of the wastes are being processed through the soil washing plant.

In the soil washing process, excavated material is crushed and screened to 100 mm and magnetically separated. The remaining material is wetted and then passed to a 2-mm vibrating screen where it is disaggregated with high-pressure water. The > 2 mm gravel fraction goes to a counter-current washer and is eventually drained and discharged for reuse as onsite fill. The gravel washwater and a smaller slurry fraction is split between two hydrocyclones which separates the material into a 63 µm to 2 mm sand fraction and a < 63 µm slurry (Haznews, 1998). The sand is processed in a dense medium separator from which clean sand is dewatered and then discharged to a collection bay. The fines fraction slurry is treated in a thickener tank where flocculants may be added to improve the treatment process. This tank produces sludge with 20 to 40 percent dry matter which is pumped to a continuous filter press. The resulting contaminated filter cake is sent to a landfill for disposal.

Light materials, such as coke, wood fragments, and plastics, are separated out during the washing process and also sent to the landfill with the contaminated fines (Haznews, 1998).

According to BG's property division, the use of soil washing has resulted in a remediation period that is 60 to 70 percent longer than the conventional clean-up approach of excavation of contaminated material and landfill disposal. However the advantages of soil washing include the reduced need for imported clean fill, and a large reduction in transportation during the site work. Overall, the cost of the project is comparable to a "dig and haul" approach (Haznews, 1998).

SITE Program Demonstration, Toronto, Ontario

Soil washing was accepted into the Superfund Innovative Technology Evaluation (SITE) Demonstration Program in the winter of 1991. It was demonstrated in Toronto, Ontario, Canada, in April 1992 as part of the Toronto Harbour Commission soil recycling process.

The soil washing process begins when an attrition soil wash plant removes relatively uncontaminated coarse soil fractions using mineral processing equipment; contaminants are concentrated in a fine slurry that is routed for further treatment. The wash process includes a trommel washer to remove clean gravel, hydrocyclones to separate the contaminated fines, an attrition scrubber to free fines from sand particles, and a density separator to remove coal and peat from the sand fraction. If only inorganic contaminants are present, the slurry is treated in an inorganic chelator unit. This process uses an acid leach to free inorganic contaminant from the fine slurry and then removes the metal using solid chelating-agent pellets in a patented countercurrent contactor. The metals are recovered by electrowinning from the chelation agent regenerating liquid. Organic removal is accomplished by first chemically pretreating the slurry from the wash plant or metal removal process. Next, biological treatment is applied in upflow slurry reactors using bacteria that have developed naturally in the soils. The treated soil is dewatered using hydrocyclones and returned to the site from which it was excavated.

The technology is designed to reduce organic and inorganic contaminants in soils. The process train approach is most useful when sites have been contaminated as a result of multiple uses over a period of time. Typical sites where the process train might be used include refinery and petroleum storage facilities, former metal processing and metal recycling sites, and manufactured gas and coal or coke processing and storage sites. The process is less suited to soils with high inorganic constituents that are inherent to the mineralogy.

Results of the demonstration described above have been published in the Demonstration Bulletin (EPA/520/MR-92/015), the Applications Analysis Report (EPA/540/AR-93/517), the Technology Evaluation Report (EPA/540/R-93/517), and the Technology Demonstration Summary (EPA/540/SR-93/517). These reports are available from USEPA.

The demonstration results showed that soil washing produced clean coarse soil fractions and concentrated the contaminants in the fine slurry. The chemical treatment process and biological slurry reactors, when operated on a batch basis with a nominal 35-day retention time, achieved at least a 90 percent reduction in simple PAH compounds such as naphthalene, but did not meet the approximately 75 percent reduction in benzo(a)pyrene required to achieve the cleanup criteria.

The biological process discharge did not meet the cleanup criteria for oil and grease; the washing process removed almost no oil and grease. The hydrocyclone dewatering device did not achieve significant dewatering. Final process slurries were returned to the excavation site in liquid form.

The metals removal process achieved a removal efficiency of approximately 70 percent for toxic heavy metals such as copper, lead, mercury, and nickel.

The metals removal process equipment and chelating agent were fouled by free oil and grease, forcing sampling to end prematurely. Biological treatment or physical separation of oil and grease will be required to avoid such fouling.

Contact

Teri Richardson, USEPA Project Manager, National Risk Management Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH 45268, (513) 569-7949, fax (513) 569-7105

SITE Program Demonstration, Saginaw, Michigan

A field demonstration of Bergmann, Inc.'s soil washing technology was conducted in May 1992 at the Saginaw Bay Confined Disposal Facility in Saginaw, Michigan. The Applications Analysis Report (EPA/540/AR-92/075) and the Demonstration Bulletin (EPA/540/MR-92/075) are available from USEPA.

Demonstration results indicate that the soil- and sediment-washing system can effectively isolate and concentrate PCB contamination into organic fractions and fines. Levels of metals contamination were also beneficially altered. The effectiveness of soil and sediment washing on inorganic compounds equaled or exceeded its performance for PCB contamination.

During a 5-day test in May 1992, the Bergmann soil and sediment washing system experienced no downtime, operating for 8 hours per day to treat dredged sediments from the Saginaw River.

The demonstration provided the following results:

- Approximately 71 percent of the particles smaller than 45 µm in the input sediment were apportioned to the enriched fines stream.
- Fewer than 20 percent of the particles smaller than 45 µm in the input sediment were apportioned to the coarse clean fraction of soil.

The distributions of the concentrations of PCBs in the input and output streams were as follows:

- Input sediment = 1.6 mg/kg
- Output coarse clean fraction = 0.20 mg/kg
- Output humic materials = 11 mg/kg
- Output enriched fines = 4.4 mg/kg

Heavy metals were concentrated in the same manner as the PCBs. The coarse clean sand consisted of approximately 82 percent of the input sediment.

Contacts

Mr. Jack Hubbard, USEPA Project Manager, National Risk Management Research Laboratory, 26 West Martin Luther King Drive, Cincinnati, OH 45268, (513) 569-7507, fax (513) 569-7620

Mr. George Jones, Bergmann, A Division of Linatex, Inc., 1550 Airport Road, Gallatin, TN, 37066-3739, (615) 230-2217, fax (615) 452-5525

SITE Program Demonstration, New Brighton, Minnesota

The BioTrol Soil Washing System is a patented, water-based volume reduction process used to treat excavated soil. The system may be applied to contaminants concentrated in the fine-sized soil fraction (silt, clay, and soil organic matter) or in the coarse soil fraction (sand and gravel).

In the first part of the process, debris is removed from the soil. The soil is then mixed with water and subjected to various unit operations common to the mineral processing industry. The equipment used in these operations can include mixing trommels, pugmills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering apparatus.

The core of the process is a multistage, countercurrent, intensive scrubbing circuit with interstage classification. The scrubbing action disintegrates soil aggregates, freeing contaminated fine particles from coarser material. In addition, surficial contamination is removed from the coarse fraction by the abrasive scouring action of the particles themselves. Contaminants may also be solubilized as dictated by solubility characteristics or partition coefficients.

Contaminated residual products can be treated by other methods. Process water is normally recycled after biological or physical treatment. Contaminated fines may be disposed of offsite, incinerated, stabilized, or biologically treated.

This system was developed initially to clean soils contaminated with wood preservative wastes, such as PAHs and PCP. The system may also apply to soils contaminated with petroleum hydrocarbons, pesticides, PCBs, various industrial chemicals, and metals.

The BioTrol Soil Washing System was accepted into the SITE Demonstration Program in 1989 and demonstrated between September and October 1989 at the MacGillis and Gibbs Superfund site in New Brighton, Minnesota. A pilot unit with a treatment capacity of 500 pounds per hour operated 24 hours per day during the demonstration. Feed for the first phase of the demonstration (2 days) consisted of soil contaminated with 130 ppm PCP and 247 ppm total PAHs; feed for the second phase (7 days) consisted of soil containing 680 ppm PCP and 404 ppm total PAHs. Contaminated process water was treated biologically in a fixed-film reactor and then recycled. A portion of the contaminated soil fines was treated biologically in a three-stage, pilot-scale EIMCO Biolift reactor system supplied by the EIMCO Process Equipment Company. The Applications Analysis Report (EPA/540/AR-91/003) and the Technology Evaluation Report Volume I (EPA/540/5-91/003a) and Volume II (EPA/540/5-91/003b and EPA/540/5-91/003c) are available from EPA.

Key findings from the BioTrol demonstration are summarized below:

- Feed soil (dry weight basis) was successfully separated into 83 percent washed soil, 10 percent woody residues, and 7 percent fines. The washed soil retained about 10 percent of the feed soil contamination; 90 percent of this contamination was contained in the woody residues, fines, and process wastes.
- The multistage scrubbing circuit removed up to 89 percent PCP and 88 percent total PAHs, based on the difference between concentration levels in the contaminated (wet) feed soil and the washed soil.
- The scrubbing circuit degraded up to 94 percent PCP in process water. PAH removal could not be determined because of low influent concentrations.

Contact

Dennis Chilcote, BioTrol, 10300 Valley View Road, Suite 107, Eden Prairie, MN 55344-3456, (612) 942-8032, fax (612) 942-8526

5.2.8 Soil Vapor Extraction (SVE)

SVE is mechanically similar to bioventing (Section 5.2.4.2), but is operated at a higher flow rate to achieve volatile compound removal in addition to oxygen replenishment**.** SVE uses an electric- or gasoline-powered blower system connected to wells via manifolds. Air treatment, whether through a separate system (such as activated carbon or catalytic oxidation) or as part of a gasoline-powered system, is usually the most expensive single component of an SVE project and may represent as much as 50 percent of the overall cost.

Performance of an SVE system is monitored using measurements at the blower system and at piezometers (small-diameter wells or soil gas sample points) installed in the zone being treated. Flow measurements at the blower or at individual wells can be used to help calculate removal rates. Vapor samples from piezometers, wells, or at the blower discharge can be analyzed in the field or by a laboratory, and the results can be used to estimate the rate of subsurface decontamination and the rate of volatile compound removal. Vapor samples from the discharge of the air treatment system are usually required to test system performance and to verify permit requirements. Final evaluation of SVE performance can be assessed by collecting soil vapor samples from piezometers and / or soil samples from the treated zone.

Operational Considerations

The suitability of SVE for MGP sites will depend on the site-specific requirements for volatile compound removal or prevention of volatile compound migration as a remediation objective. The site also needs to have a water table depth at least 10 feet and a subsurface profile that allows air to flow through the zone to be treated. This profile criterion is met if the soil is coarse- or fine-grained but not saturated and if the organic compound mass is infiltrated into the soil, rather than collected in a subsurface pool (which would be impermeable to air flow).

The design feasibility of SVE is typically proven through a field pilot test. The test typically consists of pumping a single well that is screened in the center of the zone to be treated. Piezometers are placed throughout and near the margins of the zone to be treated. The purposes of this test are to:

- Size the blower by assessing how much air can be pumped from a well.
- Size the air treatment system by determining what initial concentrations might be expected.
- Observe the subsurface flow pattern throughout the zone of treatment.

If the piezometers indicate the pilot test well did not produce an adequate subsurface flow pattern, the full-scale design could call for additional wells, a new well with a deeper screened interval, or sealing to eliminate surface leakage. Shallow sites may be more effectively treated using horizontal wells in trenches.

Most SVE systems operate for 1 to 3 years. During this time, the air treatment system requires periodic maintenance or changeout, a condensate tank requires emptying (especially in cold weather), and samples and measurements need to be collected and reported. At the site, the aboveground portion of the system usually takes up one or two parking spaces and almost always requires 115V or 220V electrical power. Natural gas is sometimes required (if catalytic oxidation is selected as the air treatment option). The blower itself may be a source of excessive noise if silencers (upstream and downstream) or soundproof containment are not provided or if the blower is undersized and working near its maximum output. The underground portion of the system is typically accessed through well vaults, and the manifold lines connecting the wells to the blower system are often buried in frequently accessed areas.

Sites with relatively shallow water tables or with wells screened near the water table can experience excessive water accumulation and blockage of air flow if too much vacuum is applied to the system. Most systems can be operated safely under these conditions by managing the applied vacuum (in feet of water column) to be less than one half the distance from the water table to the top of the well screen.

Granular activated carbon is often selected as the air treatment alternative because of its minimal power requirements, its availability, and its acceptability to regulators. It is often the least expensive, on a unit basis, for sites with relatively low vapor concentrations. Carbon operates at highest efficiency when temperatures are lower than 120°F; however, most SVE design manuals fail to provide guidance on temperature management of the blower discharge to the carbon vessels. Excessive heat may be a concern at sites with high ambient temperature, such as in the south or southwestern United States, and/or where relatively high vacuums are required because of fine-grained soil conditions. In these situations, carbon may still be cost effective if used in conjunction with a condenser or a heat exchanger.

Applications and Cost

SVE has been used as a remediation process of choice at thousands of underground storage tank leak sites. Applications at MGP sites are not as widespread; however, SVE can be used to treat soils at sites contaminated with some SVOCs (such as naphthalene).

SVE can be applied with little disturbance to existing facilities and operations. The technology can be used at sites where areas of contamination are large and deep or when the contamination is present beneath a building. The system may be modified depending on additional analytical and subsurface characterization data and/or changing site conditions (RIMS, 1998).

The components of SVE systems are commonly available off the shelf, and the necessary wells can be installed by any qualified local engineering firm. Aboveground installations typically include:

- Vacuum pumps and/or blowers and associated controls
- Pressure gauges and flow meters at wellheads and pumps
- Control valves to adjust air flow
- An air-liquid separator (for removing moisture from the extracted gases)
- Vapor treatment unit(s)

More complex SVE systems may incorporate trenches, horizontal wells, forced air injection wells, passive air inlet wells, low permeability or impermeable surface seals, or multiple level vapor extraction wells in single boreholes. In addition, sophisticated systems are available to monitor moisture, contaminant levels, and temperature (RIMS, 1998).

The efficiency of SVE can be enhanced through the use of formation fracturing, pulsed pumping, or horizontal extraction wells. These enhancements can increase the soil permeability or the efficiency of mass removal or allow access to previously inaccessible areas of contaminated soil (e.g., below the water table, in less permeable formations) (RIMS, 1998).

Treatment costs for sites using SVE depend on various conditions such as site size, extent of contamination, regulatory requirements for permits, other site-specific and chemical-specific conditions, and site cleanup criteria. Therefore, cost can only be estimated on a case-by-case basis. To provide an indication of the range in SVE project costs, the treatment of 185,000 cubic yards of soil at one site cost $2 per cubic yard while, at another site where 650 cubic yards required treatment, the cost was $450 per cubic yard. These values represent treating the soil rather than cost per pound of contaminant treated. The major part of the total process cost associated with SVE is usually the operating expenses for labor, maintenance, and monitoring (RIMS, 1998).

Benefits

- Treats in situ, volatile compounds in soil, including areas beneath structures, at lower cost than excavation
- Accomplishes both volatile compound removal and oxygen replenishment, and promotes in situ biodegradation for compounds that may not be removed
- Can be implemented with relatively little disruption to ongoing operations
- Focuses on volatile compounds, including benzene and naphthalene; therefore treats the most mobile of the organic compounds beneath an MGP site, which makes it an effective risk-reduction approach
- Has well-established design and feasibility evaluations

Limitations

- Not effective at sites where remediation goals include concentration reduction of low-volatility compounds (which are frequently important for MGP site restoration)
- Difficult to successfully implement where the water table is shallower than 5 to 10 feet below grade, or where the soil is fine-grained (clayey) and nearly saturated
- Limited effectiveness on volatile compounds trapped in a liquid mass or pool of subsurface organic compounds (air will not flow through liquids; volatile compounds trapped in liquids will only be removed through diffusion, which is too slow to be cost effective)

Case Study

Beale AFB, Marysville California

Numerous SVE systems were installed using granular activated carbon with no air temperature management. Upon start up, breakthrough of the carbon occurred within three days. Systems were retrofitted with a converted truck radiator installed downstream of the blower. Air was produced at ten degrees above ambient for carbon treatment; and carbon efficiency increased three-fold (CH2M HILL, 1998; Nelline Scheuer).

Contacts

Ms. Carol Goudette, 9 CES / CEVR, 6601 "B" Street, Beale AFB, CA 95903

Ms. Cori Condon, RWGCB, Assistant Engineering Geologist, 3443 Routies Road, Sacramento, CA 95827

Chapter 6

References

AFCEE, 1994. Bioventing Performance and Cost Summary, Draft. Brooks AFB, TX.

ASTM, 1995. Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites. Designation E-1739-95.

ASTM, 1996. Provisional Standard Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases. Designation PS 3-95.

Alleman et al., 1995. "Bioventing PAH Contamination at the Reilly Tar Site." In Situ Aeration: Air Sparging, Bioventing and Related Remediation Processes. Battelle Conference Proceeding.

Backhus, Debra A., Joseph N. Ryan, Daniel M. Groher, John K. MacFarlane, and Philip M. Gschwerd, 1993. "Sampling Colloids and Colloid-Associated Contaminants in Ground Water." *Ground Water*, May-June, Vol. 31, No. 3, pp. 466-479.

Barnett Alexander, Catherine, 1977. MGP Site Planning: New Community Development Opportunities. *American Gas*, November.

Barr Engineering Company, 1996. "Field Demonstrations of Thermal Desorption of Manufactured Gas Plant Soils." EPRI TR-105927. Electric Power Research Institute. Minneapolis, Minnesota. September.

Bay Area Air Quality Management District, 1996. BAAQMD CEQA Guidelines, Assessing the Air Quality Impacts of Projects and Plans. p. 66. April.

Biotreatment News, 1996. "BAC Meets." p. 10. November.

Bradley, L.J.N., B.H. Magee, and S.L. Allen, 1994. "Background Levels of Polycyclic Aromatic Hydrocarbons (PAH) and Selected Metals in New England Urban Soils." *Journal of Soil Contamination*. CRC Press, Inc.

Bevolo, A.J., B.H. Kjartanson, and J.P. Wonder, 1996. "Ames Expedited Site Characterization Demonstration at the Former Manufactured Gas Plant Site, Marshalltown, Iowa." Ames Laboratory. March.

Brown, S.M., D.R. Lincoln, and W.A. Wallace, 1988. "Application of Observational Method to Hazardous Waste Engineering." ASCE. *Journal of Management Engineering,* Vol. 6, No. 4, pp. 479-500.

Burton, Jacqueline C., 1994. "Expedited Site Characterization for Remedial Investigations at Federal Facilities." Argonne National Laboratory, FER III and WM II Conference & Exhibition. April 27-29.

Cambridge, Megan and Adam Palmer, 1998. "Expedited Remedial Action Program, Alhambra Manufactured Gas Plant Site." Department of Toxic Substances Control, California Environmental Protection Agency. April.

Chaconas, J. et al., 1997. "Bioremediation of Diesel-Contaminated Soils at Navy National Test Site." *In-Situ and Onsite Bioremediation, Volume 1*. Battelle Press, p. 497.

Commonwealth of Pennsylvania, Department of Environmental Protection, 1996a. Multi-Site Remediation Agreements.

Commonwealth of Pennsylvania, Department of Environmental Protection, 1996b. "News Release: DEP Signs Innovative Environmental Agreement with Utility Companies."

Covello, Vincent T. and Miley W. Merkhofer, 1993. *Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks*. Plenum Press, New York, NY.

D'Appolonia, E, 1990. "Monitored Decisions." *Journal of Geotechnical Engineering*, 116:4-34.

Daddario, David J, 1997. "Revitalizing Real Estate Having Contamination Constraints." Proceedings from Conference on Risk-Based Decision-Making Influencing Financial Transactions and Brownfields Redevelopments, RTM Communications, Inc., San Francisco, CA. November.

Department of Energy, Grand Junction Projects Office. Grand Junction, CO.

DíAngelo, Wm. Chip, and Anthony Chiesa, 1998. "Take it to the MART." *Soil & Groundwater Cleanup*, June.

DMLS™. http://www.margan.com.

Edwards, Nelson, T, 1983. "Polycyclic Aromatic Hydrocarbons (PAHs) in the Terrestrial Environment – A Review." *Journal of Environmental Quality*, Vol. 12, No. 4, p. 427. October-December.

Elsevier Sciences Inc, 1997. "Three Innovative Soil Gas Monitoring Technologies Evaluated." *The Hazardous Waste Consultant*. Vol. 15, Issue 6, p. 1.8-1.10. (no author credited).

EPRI. Undated. *Report Summary – Microscale Solvent Extraction Methods for the Analysis of Solids and Liquids, Vol. 1 and 2.* TR105317.

EPRI Journal, 1995. "In the Field." May/June.

EPRI, 1997. *Cold-Patch Asphalt*. Report No. TR-108597.

EPRI, 1997. *Review: Asphalt Batching of MGP Tar-Containing Soil*. Report No. TR-108597. December.

Finley, et al., 1994. "Recommended Distribution For Exposure Factors Frequently Used in Health Risk Assessment." *Risk Analysis*, Vol. 14, No. 4.

Gas Research Institute (GRI), 1996. *Management of Manufactured Gas Plant Sites, Volume 2.*

Geo-Con, Inc, 1993. *SSM Soil Stabilization, Case Study No. 2, Shallow Soil Mixing from Geo-Con, Inc.*. C-SSM-02-93.

Haimann, Richard, Kathleen Schoen, Houshang Nezafati, and Jim Hartley, 1996. "An Observational Approach to Removing LNAPL." Non-Aqueous Phase Liquids (NAPLs) in Subsurface Environment. Proceedings of the Conference of American Society of Civil Engineers. November 12-14.

Hasbrouck, J.C., O.A. Dickenson, T.T. Boyd, and W.P. Hasbrouck, 1996. *Baseline Seismic Technology Report, 3D/3C Seismic for Site Characterization.* U.S. Department of Energy. Grand Junction, CO. April.

Haznews, 1998. "Gasworks Clean-Up First Large-Scale Soil Washing in U.K." *Haznews*, No. 122, p. 1. May.

Human and Ecological Risk Assessment, Vol. 4, No. 2, 1998. Special Issue: Probabilistic Methods in Risk Assessment. CRC Press. April.

Kelley, R.L., K. Kayser, V.J. Srivastava, et al, 1997. "MGP-REM Process in Full-Scale Landfarming Application: Integrating Low-Cost, Innovative Technology with Risk-Based Cleanup." Presented at the IGT Gas, Oil and Environmental Biotechnology and Site Remediation Technologies, Orlando, Florida. December 8-10.

Leeson, A. and R.E. Hinchee, 1996. Battelle Memorial Institute. Principles and Practices of Bioventing. Volume 1: Bioventing Principles.

Nelson, G.L., Steven Shipley, Johanshir Golchin, Robert K. Kelly, Kevin Kayser, Vipul Srivastava and Don Richard. "Risk-Based Remediation of MGP Wastes Using an Innovative Process."

Newmark, Robin L., and Roger D. Aines, 1998. "They All Like It Hot: Faster Cleanup of Contaminated Soil and Groundwater." *Science & Technology Review*. May.

New York State Department of Environmental Conservation, 1992. "News Release: For Release: Immediate, Tuesday, December 8, 1992, Niagra Mohawk to Act on 22 Former Coal Gas Plants Statewide."

Nielsen, P.H., T. Christensen, H. Albrechsten, and R. Gillham, 1996. "Performance of the In-Situ Microcosm Technique for Measuring the Degradation of Organic Chemicals in Aquifers." *Ground Water Monitoring Review,* Winter: 130-140.

NJDEP / PSE&G, 1996. *Manufactured Gas Plant Site Remediation Streamlining Report*. January.

North American Realty, 1997. *CASE STUDY: Adaptive Reuse of Manufactured Gas Plant Site to Mixed-Use Redevelopment*. Racine, WI.

Onsite Environmental Laboratories Inc, 1998. (510) 490-8571 / (617) 472-8022. http://www.onsitelabs.com.

Peck, R. B, 1969. "Advantages and Limitations of the Observational Method in Applied Soil Mechanics." *Geotechnique,* Vol. 19, pp. 171-187.

PP&L, Resources, Inc, 1996. "News Release: PP&L to do Cleanup Work as Part of Lycoming College Redevelopment Project."

PSE&G, 1997. Generic Remedial Investigation Work Plan. November.

Precision Sampling, Inc, 1998. Technical literature from company.

Rader, Kermit L., and Martin H. Sakolow, Jr, 1997. "Multi-Site Remediation Agreements." *Environmental Law, A Supplement to the Legal Intelligencer, PA Law Weekly*. April.

RIMS, 1998. Online Remediation Technology Library. http://remedial.com.

Risk Analysis, Volume 14, Number 4, 1994. *Special Issue: Uncertainty Analysis*. Plenum Publishing Company. August.

Saar, R.A, 1997. "Filtration of Ground Water Samples: A Review of Industry Practice." *Ground Water Monitoring and Remediation*, Winter, Vol. XVII, No. 1, pp. 56-62.

Solinst Canada Ltd, 1998. Technical literature from company. 1-800-661-2023. http://www.solinst.com

Srivastava, Vipul J, 1996. "MGP Site Remediation Strategies and a Review of Available Technologies" and "IGT's Innovative Approaches" from Proceedings from the Ninth International IGT Symposium on Gas, Oil, and Environmental Biotechnology. December 9-11.

TerraTherm, 1997. Cost and Performance Report. Provided to USEPA Technology Innovation Office & Tetra Tech EM, Inc. October 7.

The Annals of the American Academy of Political and Social Science, Vol. 545, 1996. Challenges in Risk Assessment and Risk Management. May.

Underhill, 1997. Battelle Bioremediation Conference Proceedings.

USACE, 1995. *Engineering and Design Manual—Soil Vapor Extraction and Bioventing*. Publication No. EM 1110-1-4001. November.

USACE, 1998. *Engineering and Design Manual—Soil Vapor Extraction and Bioventing.* Publication No. 1110-1-4001. November 30.

USEPA, 1989. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A).*

USEPA, 1991. *Applications Analysis Report*. EPA/540/AR-91/003.

USEPA, 1991. *Technology Evaluation Report. Volume 1.* EPA/540/5-91/003a.

USEPA, 1991. *Technology Evaluation Report, Volume 2*. EPA/540/5-91/003b and EPA/540/5-91/003c.

USEPA, 1992. *Applications Analysis Report*. EPA/540/AR-92/075.

USEPA, 1992. *Demonstration Bulletin*. EPA/520/MR-92/015.

USEPA, 1993. *Applications Analysis Report*. EPA/540/AR-93/517.

USEPA, 1993. *Technology Demonstration Summary*. EPA/540/SR-93/517.

USEPA, 1993. *Technology Evaluation Report*. EPA/540/AR-93/517.

USEPA, 1997. *Analysis of Selected Enhancements for Soil Vapor Extraction.* EPA/542/R-97/007. September.

USEPA, 1997. *Guiding Principles for Monte Carlo Analysis*. Office of Research and Development, NCEA. EPA/630/R-97/001. http://www.epa.gov/ncea/monteabs.htm.

USEPA, 1997. "Policy for Use of Probabilistic Analysis in Risk Assessment at the U.S. Environmental Protection Agency." Office of the Administrator. Available at http://www.epa.gov/ORD/spc/probcovr.htm and http://www.epa.gov/ORD/spc/probpol.htm.

USEPA, 1998a. *Bangor Gas Works, Bangor, Maine. A Superfund Redevelopment Success.* Office of Emergency and Remedial Response. EPA/540/F-98/008. June.

USEPA, 1998. Region 9 Preliminary Remediation Goals (PRGs). May.

USEPA, 1998. *Remediation Technologies Screening Matrix and Reference Guide*. Downloaded from USEPA's Technology Innovation Office homepage @ http://clu-in.com.

Voorhees, John, Isaacson, Rosenbaum, Woods and Levy, 1997. "Managing Brownfields Risks Using the Systems Approach." Adapted from the *International Environmental Risk Management: ISO 14000 and the Systems Approach.*

Wilson, John T., Jong S. Cho, and Frank P. Beck, 1997. "Field Estimation of Hydraulic Conductivity for Assessments of Natural Attenuation." *In Situ and On-Site Bioremediation: Volume 2.* Presented in New Orleans, April 28 - May 1 and reprinted by Batelle Press.

Wilson, L.G., Larne G. Everett, and Stephen J. Cullen, 1995. *Handbook of Vadose Zone Characterization and Monitoring.*" p. 569.

Winsor, Eleanor W, 1996. "Multi-Site Agreements: A Smart Strategy." *Pennsylvania's Environment*. June.

Work Systems Associates, Inc, 1995. "The Chartering Process to Create High Performance Work Teams."

Chapter 7

Additional Sources of Information

American Gas Association. MGP Management Symposium Conference Proceedings.

Electronic Power Research Institute. 1991. Selected Technologies for MGP Site Remediation GS-7554. October.

Institute of Gas Technology. Gas, Oil and Environmental BIOTECHNOLOGY IX Conference Proceedings.

Edison Electric Institute. 1984. Handbook on Manufactured Gas Plant Sites. September.

Historical Overview of Manufactured Gas Processes Used in the United States. Remediation Technologies, Inc. as presented at the International Symposium and Trade Fair on the Clean-up of Manufactured Gas Plants. September. 1995.

Institute of Gas Technology, Environmental Biotechnologies and Site Remediation Technologies Conference Proceedings.

Institute of Gas Technology, Hazardous Waste and Environmental Management in Gas Industry Conference Proceedings.

Electric Power Research Institute and Gas Research Institute, Management of Manufactured Gas Plant Sites, Technology Transfer Seminar Conference Proceedings.

Management of Manufactured Gas Plant Sites, a Two-Volume Practical Reference Guide from Gas Research Institute. 1996.

Manufactured Gas Plant Overview. Arizona Public Service Company, October. 1992.

Recovery of MGP Cleanup Costs Conference Proceedings.

U.S. Production of Manufactured Gases: Assessment of Past Disposal Practices. U.S. Environmental Protection Agency, October. 1987.

Summary Report of the Town Gas Site Workgroup. California Environmental Protection Agency, Department of Toxic Substances Control, Site Mitigation Branch. August. 1991.