COMMITTEE ON
THE CHALLENGES OF
MODERN SOCIETY

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NATO/CCMS Pilot Study

Evaluation of Demonstrated and Emerging Technologies for the Treatment and Clean Up of Contaminated Land and Groundwater (Phase III)

2002
SPECIAL SESSION REPORT

Monitoring and Measurement

Number 256

NORTH ATLANTIC TREATY ORGANIZATION

NATO/CCMS Pilot Study

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Rome, Italy
May 5-10, 2002

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NOTICE

This Special Session Report was prepared under the auspices of the North Atlantic Treaty Organization's Committee on the Challenges of Modern Society (NATO/CCMS) as a service to the technical community by the United States Environmental Protection Agency (U.S. EPA). The report was funded by U.S. EPA's Technology Innovation Office. The report was produced by Environmental Management Support, Inc., of Silver Spring, Maryland, under U.S. EPA contract 68-W-00-084. Mention of trade names or specific applications does not imply endorsement or acceptance by U.S. EPA.

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INTRODUCTION

The Council of the North Atlantic Treaty Organization (NATO) established the Committee on the Challenges of Modern Society (CCMS) in 1969. CCMS was charged with developing meaningful programs to share information among countries on environmental and societal issues that complement other international endeavors and to provide leadership in solving specific problems of the human environment. A fundamental precept of CCMS involves the transfer of technological and scientific solutions among nations with similar environmental challenges.

The management of contaminated land and groundwater is a universal problem among industrialized countries, requiring the use of existing, emerging, innovative, and cost-effective technologies. This document reports on the fourth meeting of the Phase III Pilot Study on the Evaluation of Demonstrated and Emerging Technologies for the Treatment and Clean Up of Contaminated Land and Groundwater. The United States is the lead country for the Pilot Study, and Germany and The Netherlands are the Co-Pilot countries. The first phase was successfully concluded in 1991, and the results were published in three volumes. The second phase, which expanded to include newly emerging technologies, was concluded in 1997; final reports documenting 52 completed projects and the participation of 14 countries were published in June 1998. Through these pilot studies, critical technical information was made available to participating countries and the world community.

The Phase III study, which concluded in 2002, focused on the technologies for treating contaminated land and groundwater. The study addressed issues of sustainability, environmental merit, and cost-effectiveness, with continued emphasis on emerging remediation technologies. The objectives of the study were to critically evaluate technologies, promote the appropriate use of technologies, use information technology systems to disseminate the products, and to foster innovative thinking in the area of contaminated land. The Phase III Mission Statement is provided at the end of this report.

The Phase III pilot study meetings were hosted by several countries and at each meeting, a special session was held for the discussion of a specific technical topic. The meeting dates and locations were:

- February 23-27, 1998: Vienna, Austria
- May 9-14, 1999: Angers, France
- June 26-30, 2000: Wiesbaden, Germany
- September 9-14, 2001: Liège, Belgium
- May 5-10, 2002: Rome, Italy

The special session topics were:

- Treatment walls and permeable reactive barriers (Vienna)
- Monitored natural attenuation (Angers)
- Decision support tools (Wiesbaden)
- Performance validation of in situ remediation technologies (Liège)
- Monitoring and measurement (Rome)

This and many of the Pilot Study reports are available online at http://www.nato.int/ccms/ and http://www.clu-in.org/intup.htm. General information on the NATO/CCMS Pilot Study may be obtained from the country representatives listed at the end of the report. Further information on the presentations in this special session report should be obtained from the individual authors.

Stephen C. James
Walter W. Kovalick, Jr., Ph.D.
Co-Directors

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PRESENTATIONS AT THE SPECIAL SESSION

HOW TO APPROACH ENVIRONMENTAL PROBLEM-SOLVING

Eric Koglin[1]

1. INTRODUCTION

Environmental problems associated with the improper disposal of hazardous, industrial chemicals have existed for a long time in the United States; however, very little effort was spent on them until the creation of the U.S. Environmental Protection Agency in 1971. In the early 70's there was much emphasis placed on air and surface water pollution problems. Then, in the late 70's, a national concern for protecting human health and the environment arose as a result of the discovery of seriously contaminated land that was formerly used as a chemical landfill and was home to a portion of the Niagara Falls, New York community. This area, known as Love Canal, thrust the issue of environmental protection into the forefront and forced the Nation to develop and adopt new methods and approaches for solving environmental problems.

The public demanded action, especially in light of the fact that other communities were actively identifying additional contaminated lands. The Resource Conservation and Recovery Act (RCRA) was passed in 1978 to establish a means to regulate the disposal of industrial chemicals. But RCRA did not address the problem of cleaning up uncontrolled hazardous waste sites. The U.S. Congress responded by passing the Comprehensive Environmental Response, Compensation and Liability Act of 1980, more commonly known as Superfund. The passage of Superfund signaled a new awareness of the fragile nature of the environment and the potentially grave consequences to the public of prolonged exposure to industrial chemicals.

2. WHAT DID WE KNOW ABOUT "CLEANING UP" THE ENVIRONMENT?

Many people thought that the tools and approaches that had been developed in the course of implementing the mandates of the Clean Air Act and the Clean Water Act would prepare us for tackling the cleanup of contaminated soil and water and industrial wastes. Unfortunately, the parallels between the needs of Superfund and the air and water programs were few.

Of course it was naive to assume that it would be a simple problem to solve. It quickly became apparent that technologies had to be created to safely treat, store, and dispose of wastes, as well as measure their concentration and distribution. The number and diversity of contaminated sites was daunting. The most obvious sites represented the biggest concerns. Along with Love Canal, there were other sites that drew national attention such as Valley of the Drums in Kentucky, Stringfellow Waste Pits in California, and the PCB (polychlorinated biphenyls) contamination in the Hudson River. However, the list of sites rapidly grew into the thousands and included many small sites such as gas stations, dry cleaners, and wood preservers. The variety of sites brought along a myriad of contaminants, which included organic solvents, heavy metals, pesticides, and PCBs and dioxin.

For most sites there was a general lack of useful information and trustworthy data. This lack of data was further confounded by our fledgling scientific understanding of waste migration. In addition, there were some other basic ingredients missing for remediation that included:

- A lack of appropriately trained engineers and scientists. This involved two aspects: Limited training in applying geological and hydrological skills to environmental management; and the absence of project management skills
- A poor understanding of the toxicological and ecological effects of the 60,000+ known industrial chemicals

[1] U.S. Environmental Protection Agency, Las Vegas

- No suitable administrative processes or approaches for addressing problems
- Ill-defined and poorly understood legislative mandates

Another important shortcoming was the lack of suitable technologies for all aspects of environmental cleanup including technologies for:

- Assessing the problem
- Collecting and treating wastes and contaminated soil and water
- Disposing of treated and untreated materials
- Protecting the hazardous waste site workers from harm

3. INTRODUCING SITE CHARACTERIZATION AND MONITORING

This new demand for environmental protection gave rise to a new environmental industry that introduced the notions of “site characterization” and “monitoring,” among other things. Characterizing and remediating a contaminated site appeared to be relatively simple tasks. Initially the goals focused on determining whether a hazard existed; if one did exist, then there was a need to determine the risks to human health and the environment; and, finally, to gather the necessary information to select the appropriate remedy and to support long-term monitoring.

The early approach to site characterization focused on reviewing past records, drilling one upgradient and three downgradient wells (to assess ground-water quality), sending samples to an off-site chemical analytical laboratory, occasionally conducting a geophysical survey, and then waiting for results. Typically, a few months after the samples were collected the data would be pulled together only to discover that there remained significant data gaps resulting in another costly visit to the site to collect more samples. It was not uncommon for the field crews to be called back to sites three or more times to gather sufficient information about the nature and extent of contamination so as to be useful in the selection of a remedy. This approach constituted accepted practice for over 20 years. Our motives were good and there was a genuine desire to eliminate, or at least minimize, environmental harm and undesirable exposure. We approached every site the same way and were anxious to get the remedy in place as quickly as possible. The “one size fits all” approach did not provide the flexibility necessary to account for the oftentimes unique attributes of contaminates sites. The data collection efforts were slow and costly because the real cleanup goals were not well defined at the outset the project.

4. TAKING SITE CLEANUP TO THE NEXT LEVEL

Initially, we did not fully understand the complexities of site cleanup, how to plan a cleanup project, nor did we have the best tools to do the job. The task at hand appeared to be to simply restore the site to its original or nearly original condition. The goal was basically to clean the site by removing the hazards and eliminate the risk posed by the exposure to toxic chemicals. We were so consumed with bringing out the dust pan and the broom, that we often lost sight of the importance of sufficiently understanding the nature and extent of the problem to select the right size dust pan and a big enough broom. Our site investigative and cleanup tools were, by today’s standards, relatively primitive.

Early on, data quality was almost exclusively linked to the laboratory analytical methods. Therein lies an important misconception – that using regulator-approved methods to produce “definitive data” was suitable for decision making. A further misconception was that the quality assurance needs of the project would be satisfied by the quality assurance/quality control program used by the analytical laboratory during sample analysis.

It has taken years of trial and error to realize that the quality of data used for project decision-making is affected by more factors than just sample analysis. It seems obvious now, but perfect analytical chemistry combined with poorly collected and/or non-representative samples can only result in one thing - bad data. It took a while, but it is clear that analytical data quality has to be distinguished from overall data quality.

We have reconsidered our approach in light of our past trials and tribulations in site cleanup. We have redefined data quality to mean the data's ability to support site decisions. Clearly, the "representativeness" of the data is a function of the sampling *and* the analytical representativeness, so anything that compromises data representativeness compromises data quality (Crumbling, 2002). Further, the up front project or site-specific planning must match the scale of data generation with the scale of decision-making.

So where have these revelations lead us? Our field-based site characterization philosophy has changed dramatically due, in large part, to our better understanding of the data needs of decision makers. Crumbling (2001) pulls this new-found understanding together into a concept she coins as "effective data." She states that "This concept embodies the principle that the information value of data (i.e., data quality) depends heavily upon the interaction between sampling design, analytical design, and the intended use of the data."

Understanding and embracing this concept is key in building a strong scientific foundation for project decision-making that will result in achieving the true goals of environmental protection. We must abandon our previous notions concerning how we characterize contaminated lands because they cannot produce results that meet the needs of most characterization and cleanup projects. There has been a gradual transition to a field-based characterization approach that is intended to:

- streamline the site characterization and response action process
- minimize mobilizations to a site
- produce more data on a site at lower costs (relative to conventional approaches)
- produce data in near-real-time
- produce measurable data quality

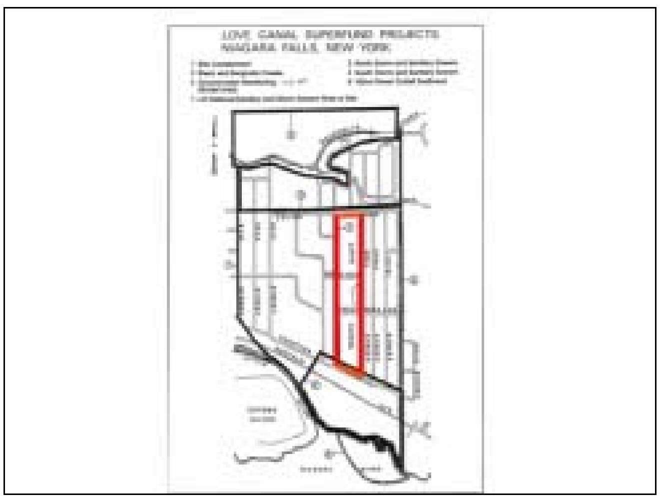
Later in this Special Session I will address a new approach to streamlining site investigations and cleanup decisions that incorporates three elements: (1) systematic planning, (2) dynamic work plans, and (3) the use of on-site analytical tools. This approach has been called the Triad Approach and will be discussed in much more detail over the next day and a half.

5. RESOURCES

1. Crumbling, D.M. 2002. *Getting to the Bottom Line: Decision Quality vs. Data Quality*. Presented at the 21st Annual National Conference on Managing Environmental Quality Systems, Phoenix, Arizona, April 8 - 11, 2002.

2. Crumbling, D.M. 2001. *Current Perspectives in Site Remediation and Monitoring: Applying the Concept of Effective Data to Environmental Analyses for Contaminated Sites*. EPA 542-R-01-013. October. Available at http://cluin.org/tiopersp

7. PRESENTATION VISUALS ~ *presented by Eric Koglin*



Evacuation at Love Canal

Oil pond at Bridgeport Rental and Oil Services site in New Jersey

Abandoned chemical warehouse in Elizabeth, New Jersey

Dawn of a New Era in Environmental Awareness and Protection

- Protecting the environment had become a national interest
- News stories about badly contaminated sites and chemical fires abounded
- Renewed concerns about health effects from hazardous materials
- New Federal legislation enacted to mitigate problems

What did we know about solving these problems?

Unfortunately, very little

Very little was known about exactly how to proceed in preventing the spread of these contaminants into the environment. Technologies had to be created to:

- Assess the problem
- Collect the wastes
- Treat the wastes so that the contaminants presented less of a threat
- Dispose of the wastes in ways that were safe from additional exposure
- Ensure the safety of the hazardous waste workers

The Basic Ingredients for Remediation

- *Engineers and Scientists* trained to deal with chemically contaminated sites – How do the chemicals behave in the environment?
- *Toxicologists and Ecologists* to help understand the potential health and environmental effects of the 60K + industrial chemicals
- *Administrative Processes* and approaches to address the problems
- *Technology* – remediation, characterization, and monitoring
- *Project Management Skills* – these projects are not your typical construction or engineering problems
- *Legislative Mandates* to force compliance and protection

A new environmental industry was born. "Site characterization" and "monitoring" became part of our vocabulary.

Site Characterization…

a seemingly simple concept

Fundamental Goals

- To determine whether a hazard exists
- If so, whether there are risks to human health and the environment, and
- To gather the necessary information to select the appropriate remedy and support long-term monitoring

From this…

The East Ditch, located at the south end of Bowers Landfill in Ohio, contained discarded tires and debris

The south end of Bowers Landfill is now a wetlands wildlife refuge

… to this.

But what about sites like these?

Or these?

In many cases, immediate action was necessary, but...

Cleanup at Bruin Lagoon site in Pennsylvania

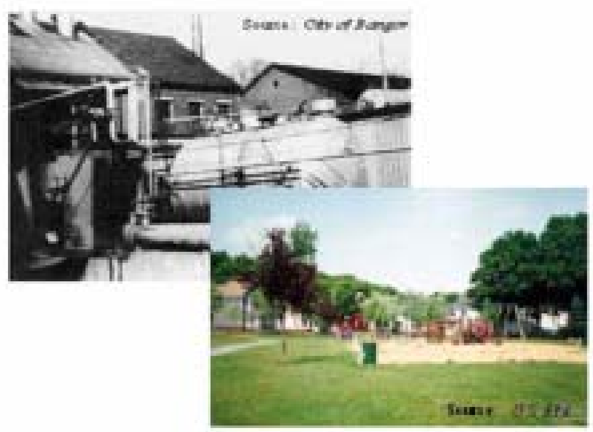
...longer term actions necessitated a more methodical and comprehensive approach

The number and diversity of contaminated sites was daunting

Site Types and Contaminants
Brownfields Sites

- Gas Stations – petroleum hydrocarbons
- Dry cleaners - solvents (PCE, CCl_4)
- Plating - cyanide, mercury, arsenic, cadmium, mercury, TCE, sulphuric acid
- Tanning - Lead, mercury, benzene, toluene, chromium
- Coal gas - wide variety of VOCs, SVOCs, PAHs, metals
- Wood preserving - creosote, arsenic, PCP
- Glass - lead, cadmium, arsenic, chromium
- Electronics/semi-conductors - VOCs, metal

Residential cleanup of hazardous waste



Site Types and Contaminants

- Chemical recyclers – organic solvents
- Lead-acid battery recyclers – heavy metals
- Chemical manufacturers – wide variety of chemicals
- Landfills – wide variety of chemicals
- Pesticide applicators – organophosphorous and organochlorine compounds
- Smelters – heavy metals
- Incinerators – dioxin, PCBs, heavy metals

Abandoned drums containing hazardous waste

Abandoned chemical warehouse in Elizabeth, New Jersey

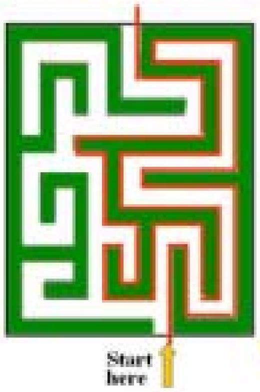
We Lacked the Basic Ingredients

- There was no guidance
- There were few experts
- Investigative and analytical techniques and capabilities were crude or under development
- The knowledge base was limited

70's & 80's Approach to Site Characterization

- Review past records
- Drill one upgradient and three downgradient wells
- Collect samples and send to an off-site laboratory
- Geophysical surveys occasionally completed
- Wait weeks or months for the results

The Historical Process – One size fits all!



- Identify the site and *rapidly* charge into the maze
- 1980s:
  - Work needed to be accomplished right away
  - Limited experience, knowledge
  - Few tools available for characterizing, monitoring, or cleanup

"If you don't know where you're going you'll end up somewhere else." --Yogi Berra

We've had 20+ years to improve upon the approach…

First Generation Data Quality Model
Assumptions

- "Data quality" depends on analytical methods
- Using regulator-approved methods ensures "definitive data"
- QC checks that use ideal matrices are representative of method performance for real-world samples
- Laboratory QA suffices for project QA
- One-size-fits-all methods eliminate the need for analytical chemistry expertise

Reality: Data used for Project Decision Making is Generated on <u>Samples</u>

Perfect Analytical Chemistry + **Non-Representative Sample**

"BAD" DATA

Distinguish:
Analytical Quality from Data Quality

Second Generation Data Quality Model
Scientific Foundation

- "Data quality" = data's ability to support decisions
- Anything that compromises data representativeness compromises data quality
- "Data" representativeness = sampling representativeness + analytical representativeness
- Project-specific planning: matches scale(s) of data generation with scale(s) of decision-making
- Technical expertise required to manage sampling and analytical uncertainties

Characterization & Cleanup Strategy: Where We Are Heading

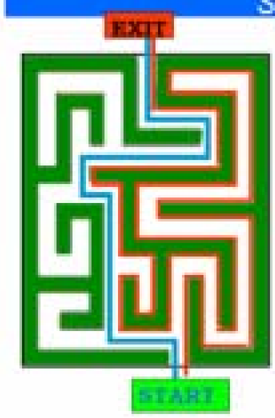
Field-Based Site Characterization Philosophy

- Streamline the site characterization and response action processes
- Minimize mobilizations to a site
- Produce more data on a site at lower costs relative to conventional approaches
- Produce data in near real time
- Produce measurable data quality

A Clearer and More Definitive Understanding of the…

- Importance of generating *effective* data
- Importance of defining the end goals of the project
- Application of emerging, field-based analytical and sampling technologies
- Roles of the stakeholders, consultants, and site owners

Today and Tomorrow: Toward a Better Strategy



- Proven Effective:
- Project planning (vs. process)
- Multidisciplinary team
- Stakeholders involved
- Create c… al-tim… ve ti…
- Real-time decisions need real-time data & uncertainty mgt
- Site-specific conceptual site model to plot resource-effective course

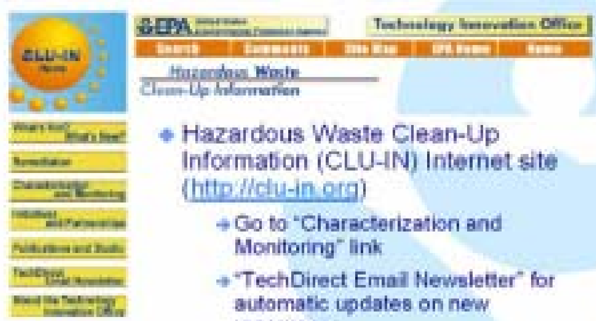
Triad Approach

Sources of Site Characterization Technology Information

Sources of Site Characterization Technology Information

- Federal agencies, organizations, programs, and partnerships
- Laboratories
- Internet information
- Software
- Publication clearinghouses
- Publications

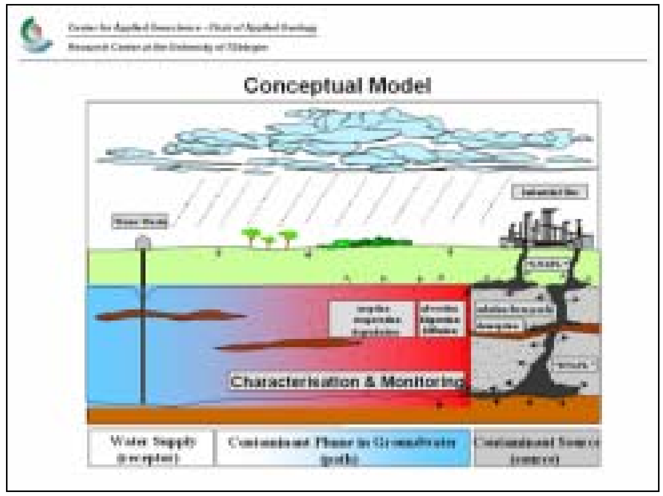
Resources: General

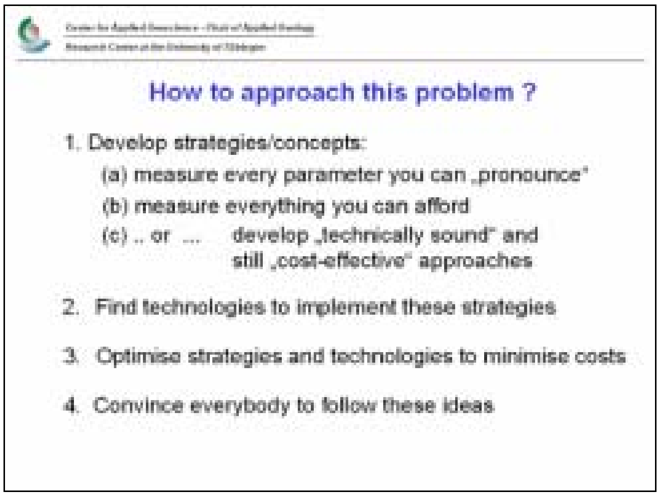


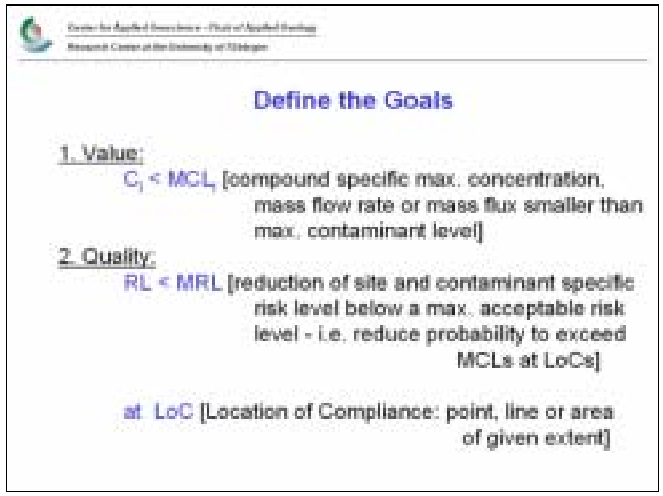
- Hazardous Waste Clean-Up Information (CLU-IN) Internet site (http://clu-in.org)
  - Go to "Characterization and Monitoring" link
  - "TechDirect Email Newsletter" for automatic updates on new resources

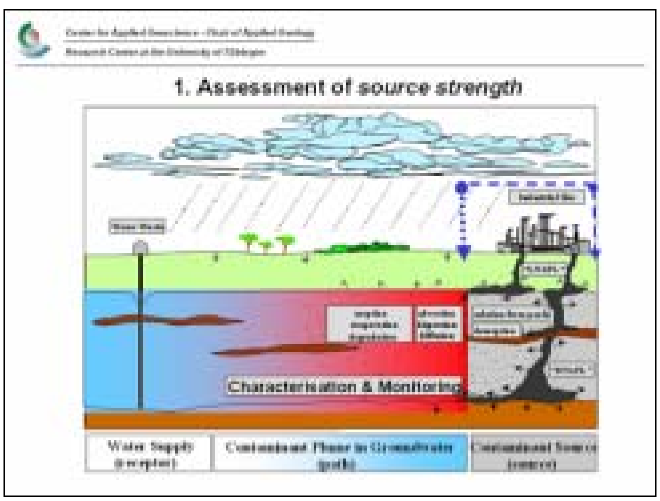

Resources - General
Brownfields Technology
Support Center
http://www.brownfieldstsc.org
Publications
Request site-specific support (Federal, state, local personnel)
Reports on past projects
Events

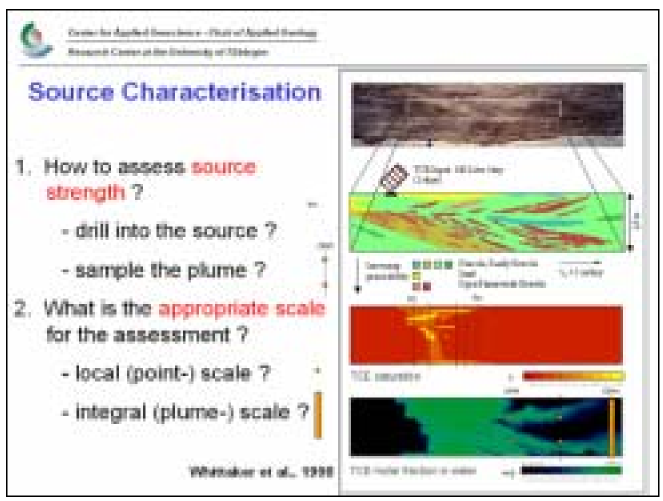
6. PRESENTATION VISUALS ~ *presented by Georg Teutsch*

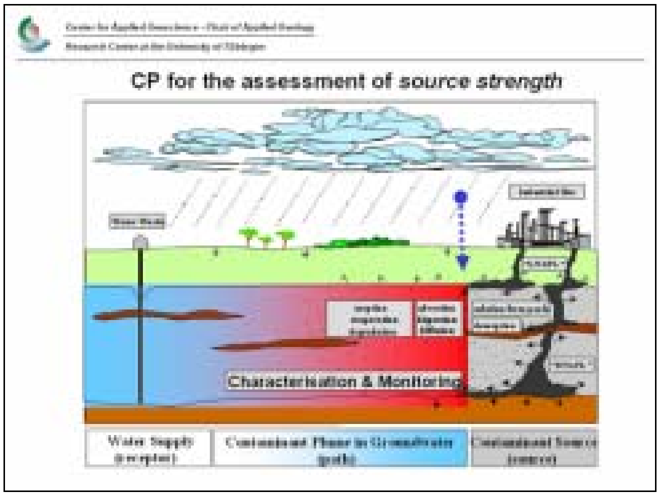


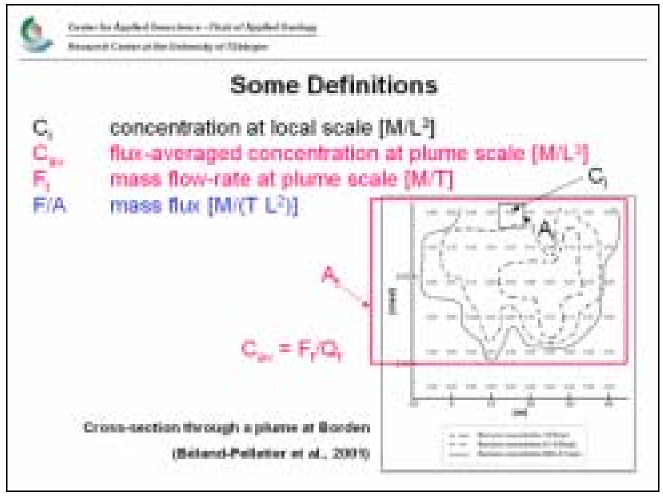


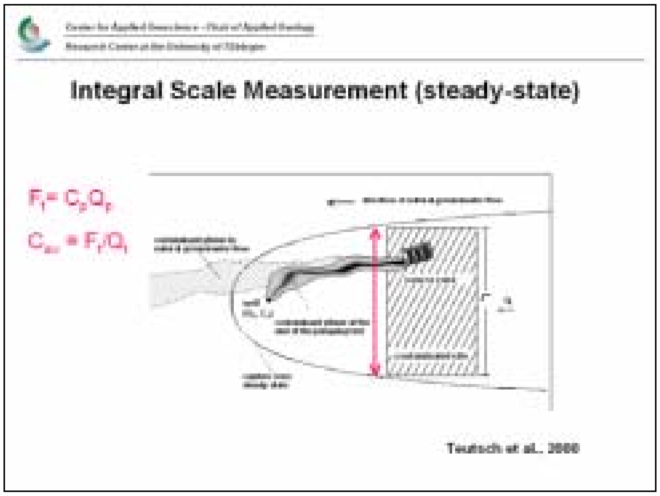


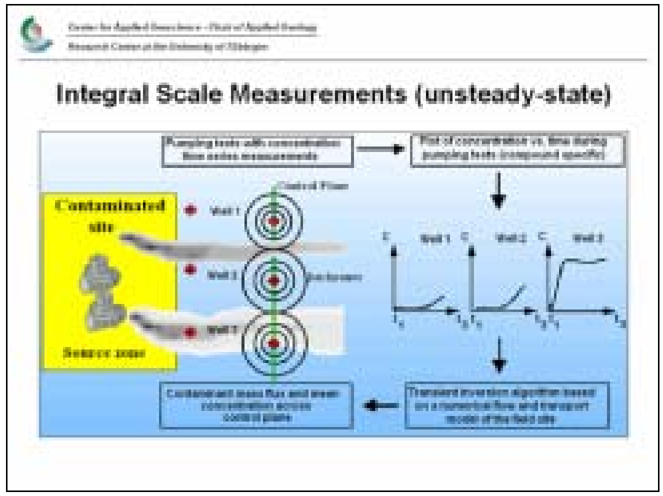


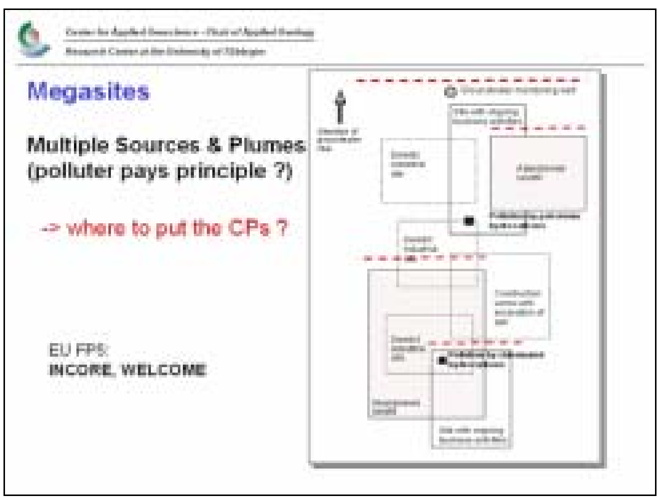


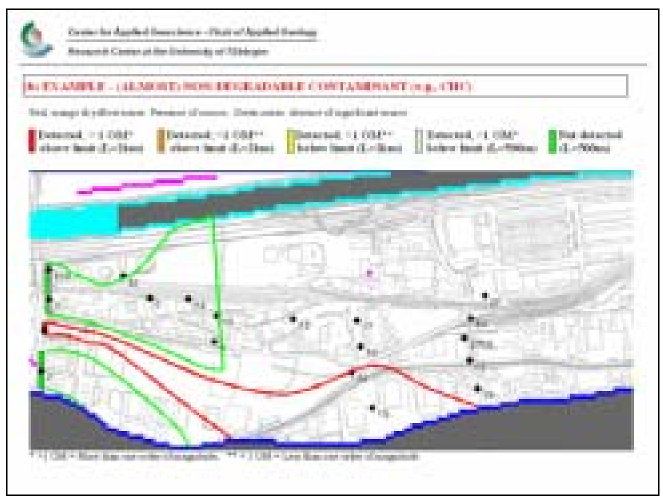

CP for the assessment of source strength
Characterisation & Monitoring
Water Supply (receptor)
Contaminant Plume in Groundwater (path)
Contaminant Source (source)

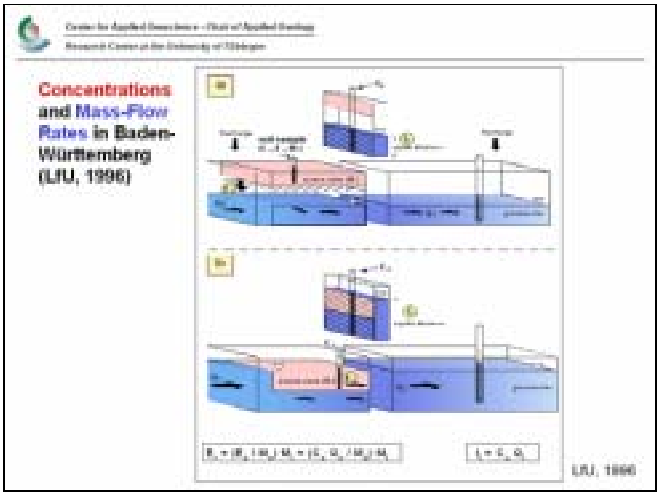

Some Definitions
C_l concentration at local scale [M/L³]
C_av flux-averaged concentration at plume scale [M/L³]
F_l mass flow-rate at plume scale [M/T]
F/A mass flux [M/(T L²)]
C_av = F_l/Q_l
Cross-section through a plume at Borden
(Béland-Pelletier et al., 2001)


Integral Scale Measurement (steady-state)
F_l = C_p Q_p
C_av = F_l/Q_l
Teutsch et al., 2000


Integral Scale Measurements (unsteady-state)
Contaminated site
Source zone


Megasites
Multiple Sources & Plumes
(polluter pays principle ?)
-> where to put the CPs ?
EU FP5:
INCORE, WELCOME



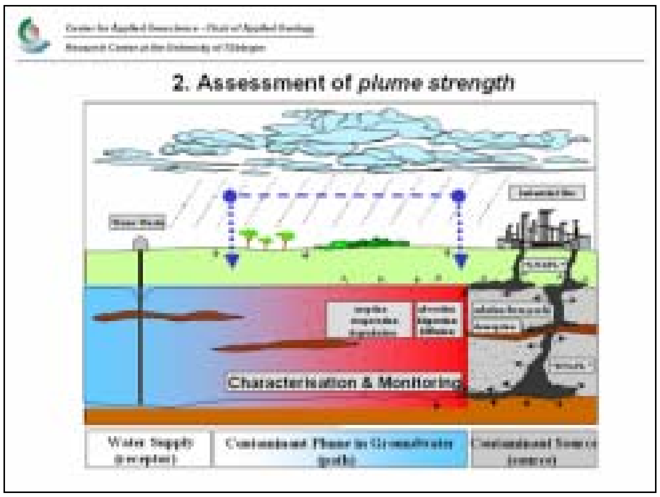


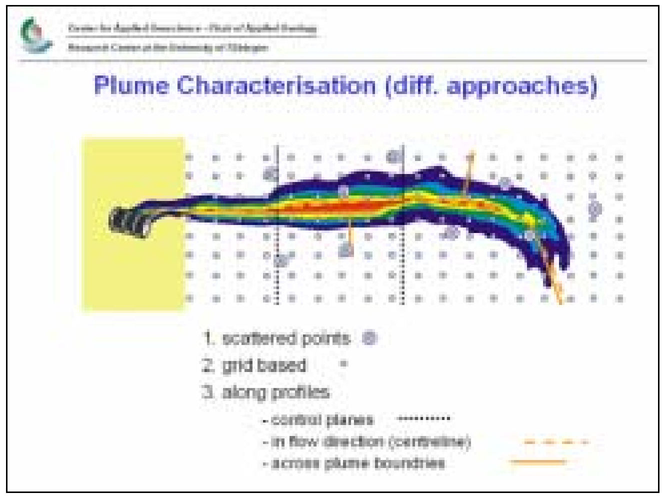
Why to combine concentr. & mass flow-rates in decision making ?

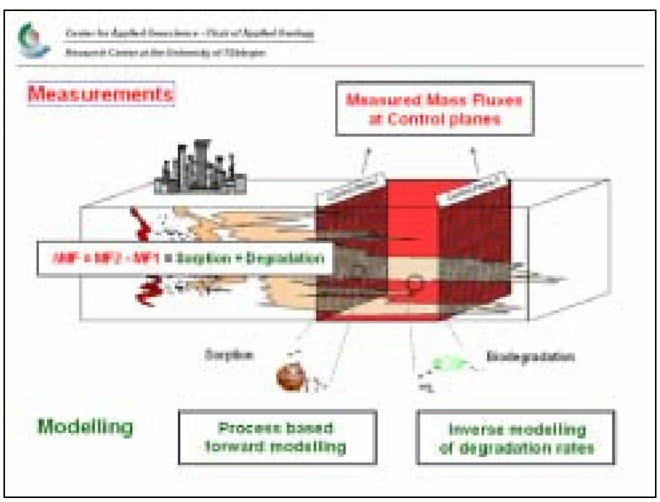
Total mass flow-rate F_t (e.g. at site scale) might be a valuable additional decision variable:

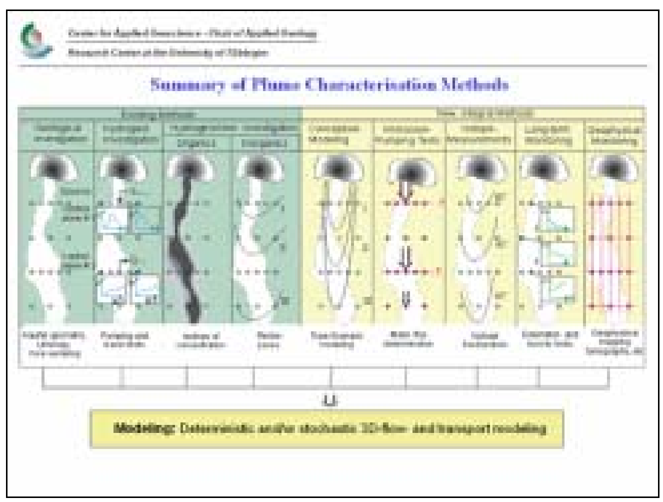
a) low conductivity, high concentration (e.g. source located in aquitard formation)
→ resulting mass flow rate $F_t = C * Q$ [M/T] will be low → **NO ACTION REQUIRED**

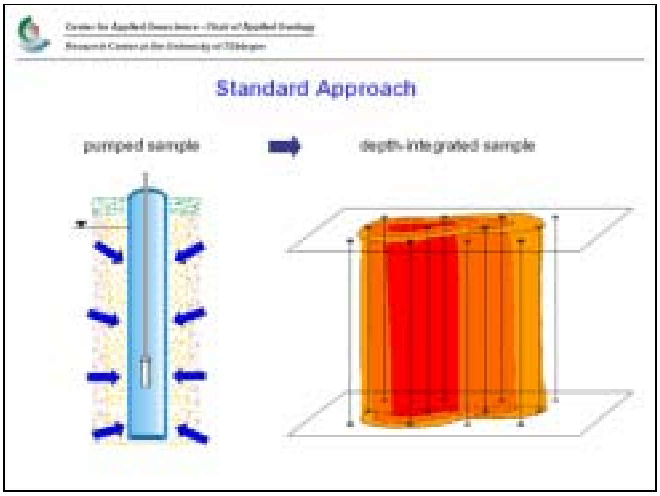
b) high conductivity, low concentration (e.g. source feeding into major aquifer system)
→ resulting mass flow rate $F_t = C * Q$ [M/T] will be high → **ACTION REQUIRED**

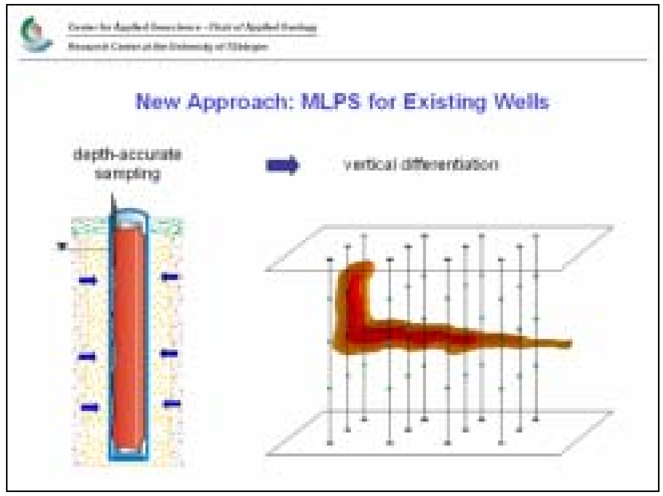




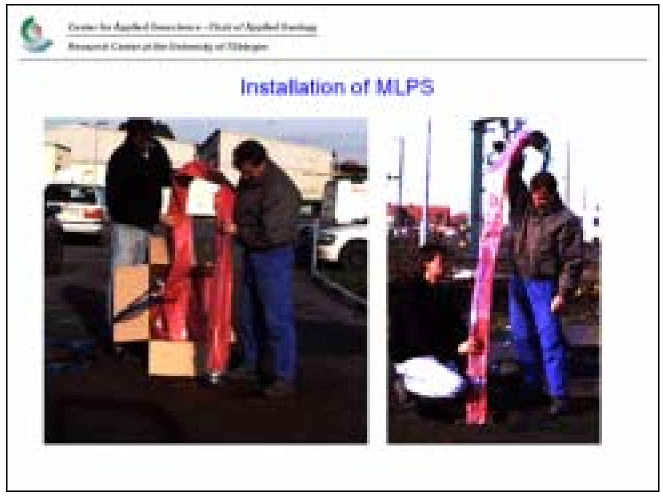


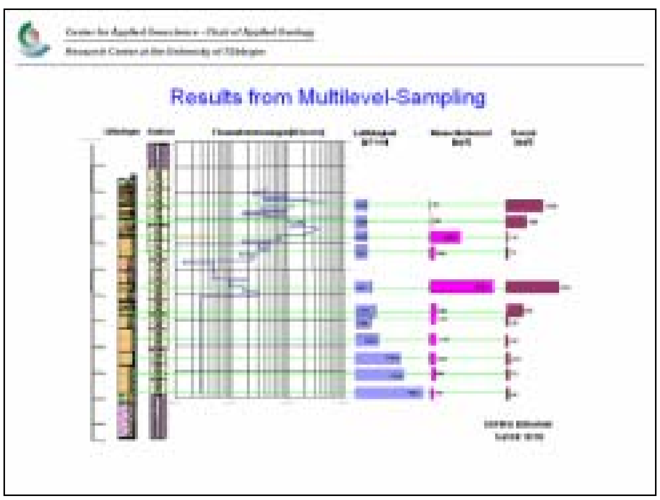


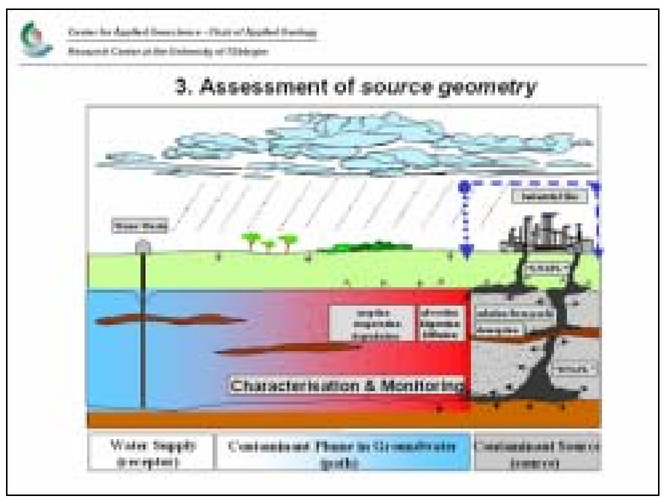

Standard Approach
pumped sample
depth-integrated sample

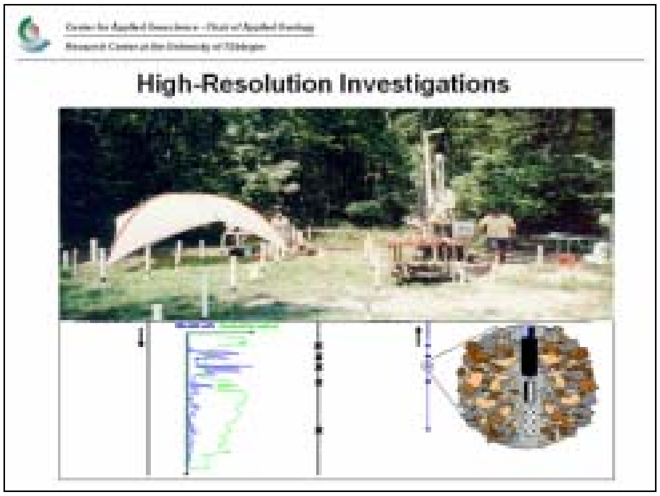

New Approach: MLPS for Existing Wells
depth-accurate sampling
vertical differentiation


Elements of Multilevel-Packer-System (MLPS)


Installation of MLPS

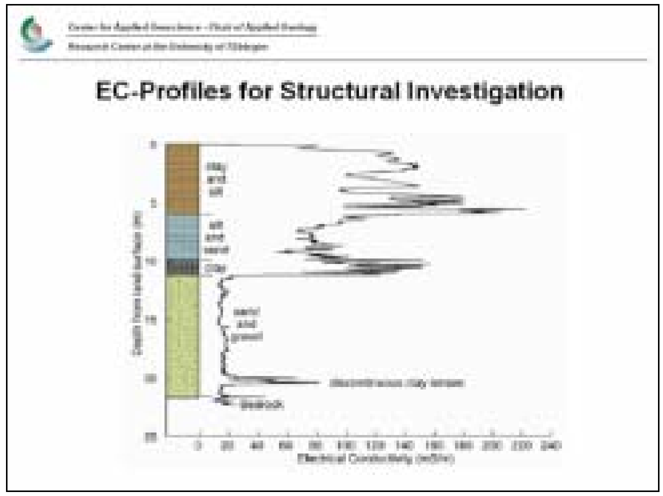

Results from Multilevel-Sampling

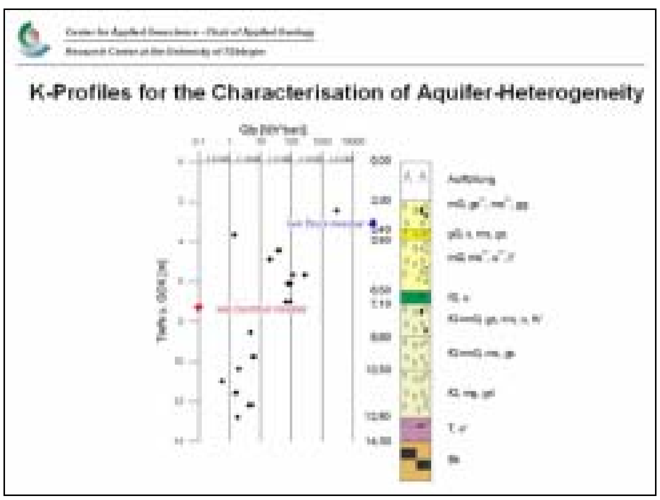

3. Assessment of source geometry
Characterisation & Monitoring
Water Supply (receptor)
Contaminant Phase in Groundwater (path)
Contaminant Source (source)

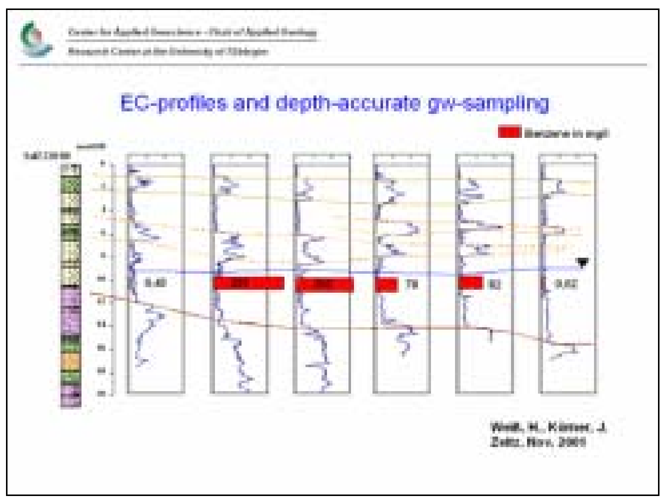

High-Resolution Investigations

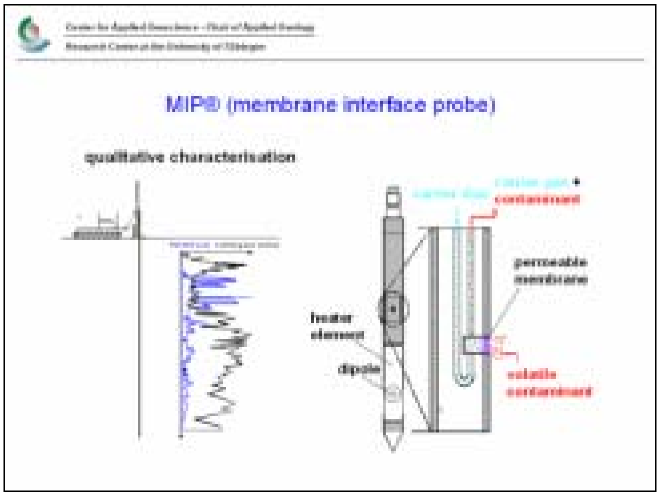

Geoprobe® 66DT
hammering & continous push
Standard-Tools:
- EC-Log
- Profiler
- MIP


continous-push


EC-Profiles for Structural Investigation
clay and silt
silt and sand
clay
sand and gravel
discontinuous clay lenses
bedrock
Electrical Conductivity (mS/m)

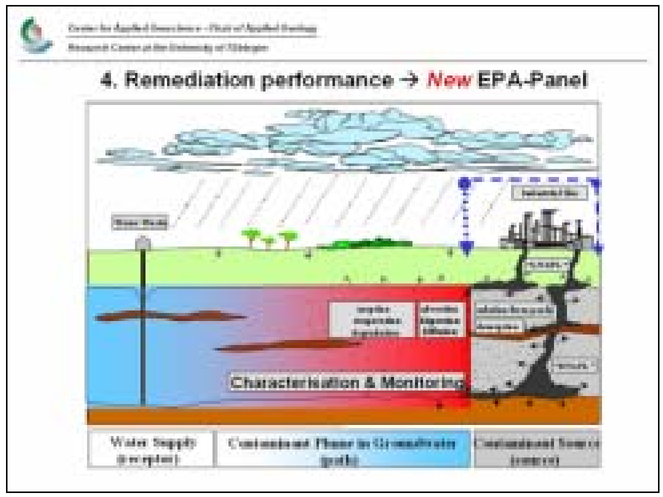

K-Profiles for the Characterisation of Aquifer-Heterogeneity
Auffüllung

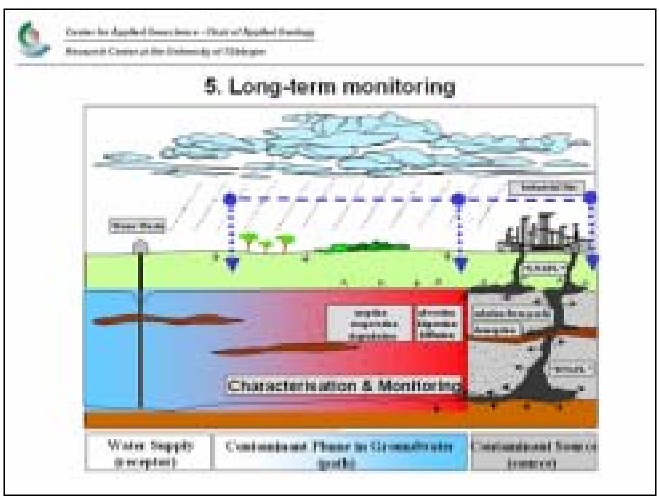

EC-profiles and depth-accurate gw-sampling
Benzene in mg/l

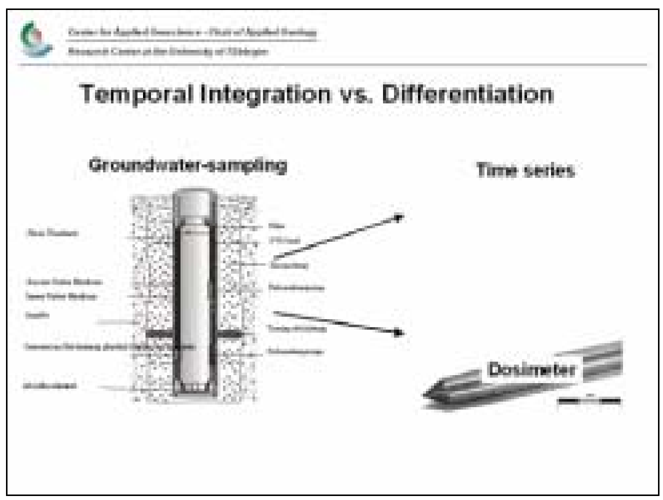

MIP® (membrane interface probe)
qualitative characterisation
contaminant
permeable membrane
heater element
dipole
volatile contaminant

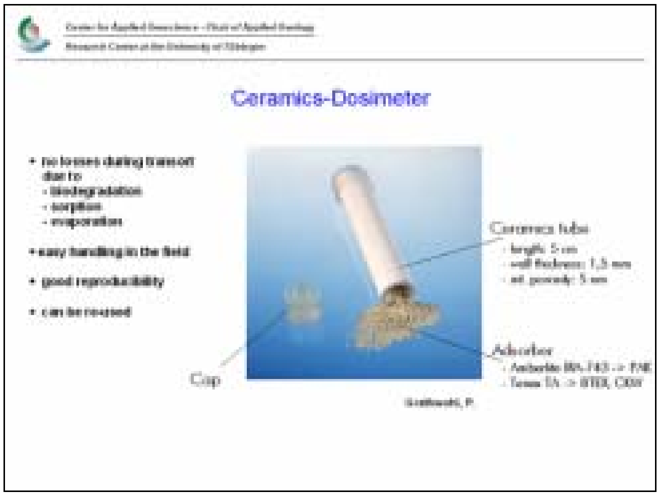

New Developments: Mini-Pressure-Pumps (MDP)


New Development: GW-Monitoring Drive Points

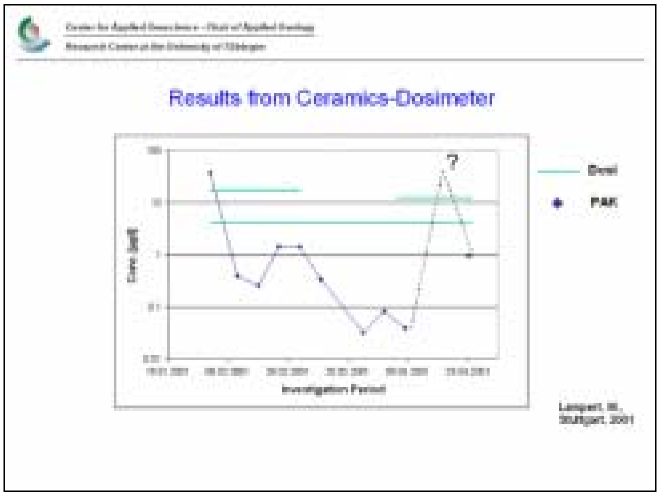

4. Remediation performance → New EPA-Panel
Characterisation & Monitoring
Water Supply (receptor)
Contaminant Plume in Groundwater (path)
Contaminant Source (source)

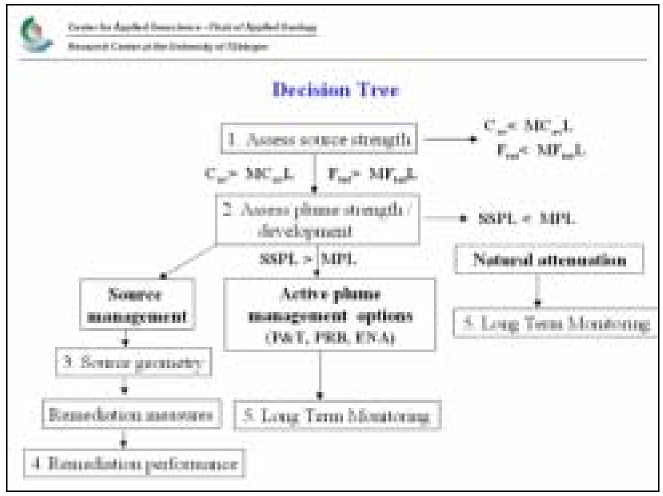

5. Long-term monitoring
Characterisation & Monitoring
Water Supply (receptor)
Contaminant Plume in Groundwater (path)
Contaminant Source (source)

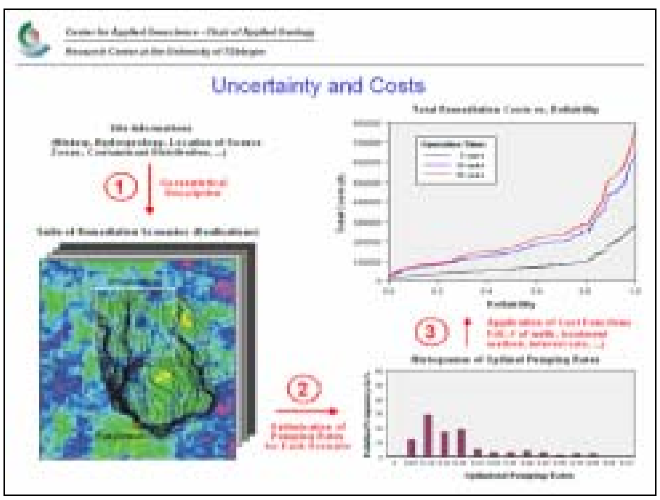

Temporal Integration vs. Differentiation
Groundwater-sampling
Time series
Dosimeter

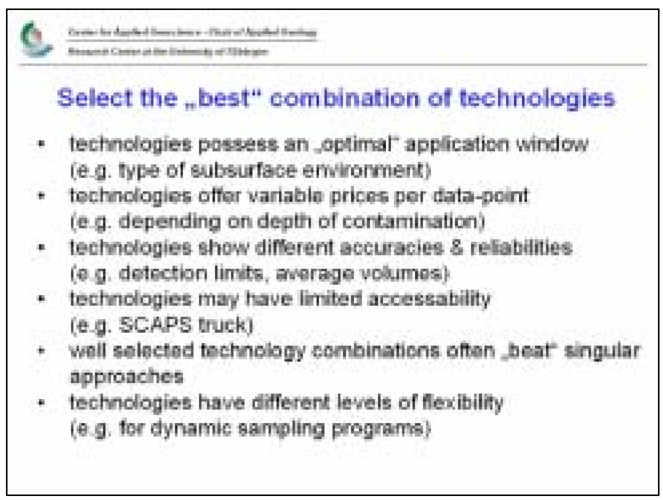

Ceramics-Dosimeter
• no losses during transport due to
- biodegradation
- sorption
- evaporation
• easy handling in the field
• good reproducibility
• can be re-used
Ceramics tube
Adsorber
Cap

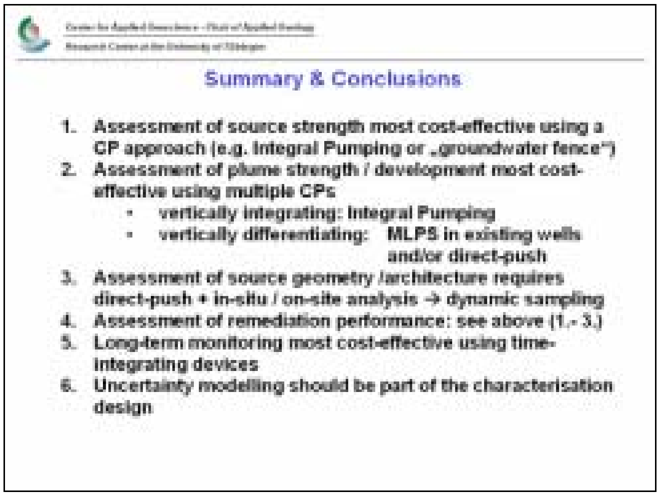

Application of Ceramics-Dosimeter
→ depth-oriented sampling

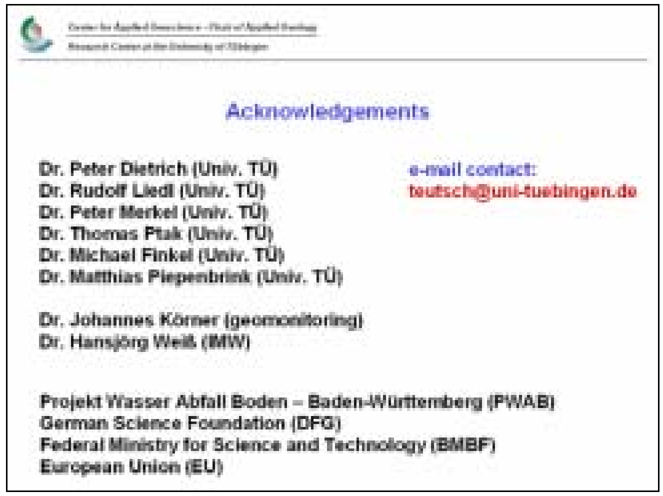

Results from Ceramics-Dosimeter
?
Investigation Period
Bmi
PAK


Decision Tree
1. Assess source strength
2. Assess plume strength / development
SSPL < MPL
SSPL > MPL
Natural attenuation
Source management
Active plume management options (P&T, PRB, ENA)
5. Long Term Monitoring
3. Source geometry
Remediation measures
5. Long Term Monitoring
4. Remediation performance


Uncertainty and Costs
1
2
3


Select the „best" combination of technologies
• technologies possess an „optimal" application window (e.g. type of subsurface environment)
• technologies offer variable prices per data-point (e.g. depending on depth of contamination)
• technologies show different accuracies & reliabilities (e.g. detection limits, average volumes)
• technologies may have limited accessability (e.g. SCAPS truck)
• well selected technology combinations often „beat" singular approaches
• technologies have different levels of flexibility (e.g. for dynamic sampling programs)


Summary & Conclusions
1. Assessment of source strength most cost-effective using a CP approach (e.g. Integral Pumping or „groundwater fence")
2. Assessment of plume strength / development most cost-effective using multiple CPs
• vertically integrating: Integral Pumping
• vertically differentiating: MLPS in existing wells and/or direct-push
3. Assessment of source geometry /architecture requires direct-push + in-situ / on-site analysis → dynamic sampling
4. Assessment of remediation performance: see above (1.- 3.)
5. Long-term monitoring most cost-effective using time-integrating devices
6. Uncertainty modelling should be part of the characterisation design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German Science Foundation (DFG)
Federal Ministry for Science and Technology (BMBF)
European Union (EU)


The End

PREDICTING NAPL SOURCE ZONES IN FRACTURED ROCK

Gary P. Wealthall[1], David N. Lerner[2] and Steven F. Thornton[3]

1. ABSTRACT

Two case studies are presented that describe integrated site characterisation methods for defining NAPL source zones in fractured rock aquifers. The first case study illustrates the use of stochastic modeling to examine the effect of fracture network heterogeneity in the prediction of DNAPL penetration depths. The second case study redefines the established conceptual model for LNAPL behaviour in fractured rocks. Adoption of the proposed methodologies incurs higher up-front costs, but is likely to provide improved confidence in the prediction of NAPL source zones.

2. INTRODUCTION

Fractured bedrock aquifers are a valuable source of groundwater in Europe. These aquifers provide capacity to store large volumes of water in the porous matrix and to deliver groundwater to wells though a high transmissivity network of fractures. However, these aquifer properties leave them vulnerable to pollution from a range of industrial and agricultural activities. A major threat to groundwater results from a group of pollutants termed non-aqueous phase liquids (NAPLs). NAPLs include light non-aqueous phase liquids (LNAPLs), which are often assumed to float on the groundwater surface, and dense non-aqueous phase liquids (DNAPLs), which penetrate below the water table. When released to the subsurface NAPLs form a discrete pollutant source that may exist for decades to centuries (Pankow and Cherry, 1996). Furthermore, dissolution of the NAPL source results in dissolved plumes with contaminant concentrations that can exceed relevant drinking water limits by several orders of magnitude.

Characterising NAPL source zones in fractured bedrock aquifers is a significant challenge to scientists and engineers involved in the assessment and remediation of groundwater pollution (Cherry et al., 1996). This is largely due to the uncertain distribution of NAPL within a source zone (Sale and McWhorter, 2001). NAPL movement is highly susceptible to the physical properties of the rock mass and is controlled by both large- and small-scale features in the subsurface. NAPLs will preferentially migrate along pathways which represent the lowest capillary resistance to flow - in fractured bedrock aquifers this is typically the fracture network (Kueper and McWhorter, 1991). However, the distributions of fractures in the subsurface are generally poorly known. This results from a number of factors including physical constraints due to the limited 3-D exposure of fractures, and economic constraints resulting in restrictive SI budgets. The uncertainty in our understanding of the distribution of fracture networks, and hence NAPL migration pathways, affects our ability to predict NAPL source zones.

The objective of this paper is to evaluate methods for predicting NAPL source zones in fractured bedrock aquifers based on the availability of site-specific data. We illustrate this using two case studies. The first reports a method to estimate the penetration depth of DNAPLs in a fractured sandstone aquifer, and focuses on the effect of uncertainty on the range of predicted values. The second case study describes the behaviour of LNAPL in a fractured dual porosity aquifer. It challenges the conventional conceptual model for LNAPL behaviour in the subsurface. The implications of the findings are discussed.

3. CASE STUDY 1. DNAPLs in Fractured Sandstone

This case study details a methodology for estimating DNAPL penetration depth in fractured sandstone aquifer. The approach has three elements - field data acquisition, constructing geometric fracture models, and invasion percolation modeling. The novelty of this work is the application of stochastic methods to

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study the propagation of uncertainty in measuring fracture network properties to the prediction of DNAPL behaviour.

A. Methods

Fieldwork at a research site in southwest Scotland, UK, involved multi-scale fracture characterisation. Outcrop mapping identified fracture type, intensity, orientation, dip and dip direction. These data were compared to fracture logs from rock core samples and borehole televiewer logs at a nearby industrial site. Packered pumping tests were used to determine vertical profiles of aquifer transmissivity and calculate hydraulic aperture (Wealthall and Lerner, 2000).

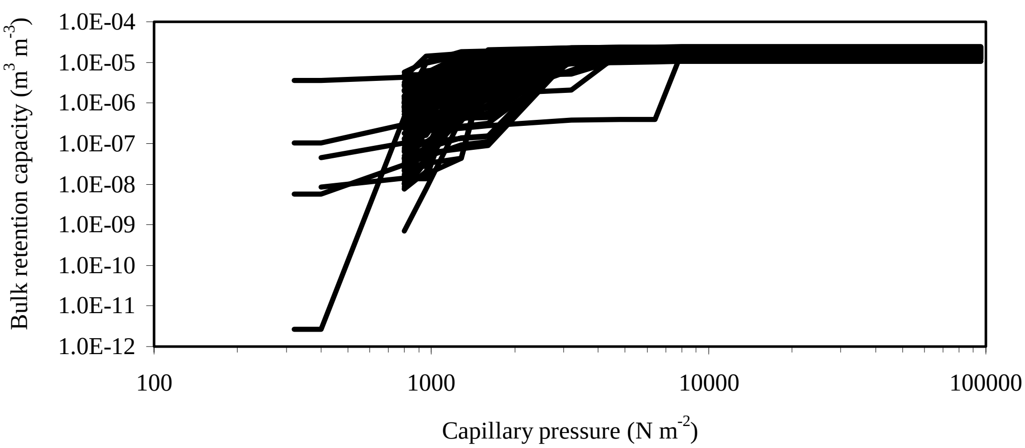
The fracture network spatial geometry was reconstructed using a 3-D stochastic discrete fracture network model (Dershowitz et al., 1988). Multiple fracture network realisations were generated. The fracture network in each realisation becomes the conductive elements for simulating fluid flow.

A 3-D invasion-percolation model (Wealthall et al., 2002) simulates the macroscopic invasion of a DNAPL in a fractured rock aquifer. Invasion proceeds as a succession of equilibrium capillary pressure steps, but does not account for flow resistance due to viscous forces (Keller et al., 2000; Kueper and McWhorter, 1992; Pruess and Tsang, 1990). Bulk retention capacity is determined for each capillary pressure step. The profiles of bulk retention capacity are qualitatively similar to the capillary pressure saturation curves measured in fractured rocks (Reitsma and Kueper, 1994) or derived using numerical simulation of DNAPLs in naturally fractured media (Keller et al., 2000); (Zhou, 2001). The plot of capillary-pressure versus bulk retention capacity is used with hypothetical spill volumes and inferred aquifer geometries to estimate the depth of penetration of the DNAPL.

B. Results and Discussion

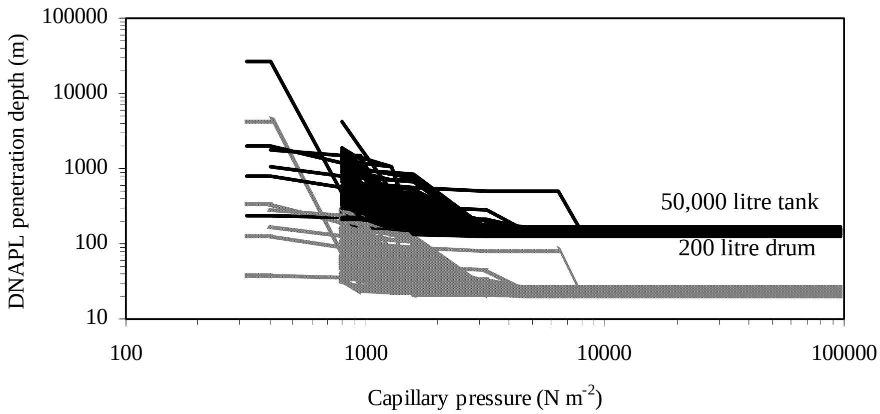
Ninety-nine models were generated with 340 fractures per realisation and, depending on individual model geometry, up to 1500 fracture intersections. Bulk retention capacity is positively correlated with capillary pressure (Figure 1). At low capillary pressure values the bulk retention capacity is low, as only a limited number of low entry pressure fractures are accessible by the invading fluid. The break in slope at approximately 3000 N m^{-2} is the maximum value where all connected fractures in the fracture network have been invaded, the lowest fracture aperture has been encountered, and increasing the capillary pressure does not change the bulk retention capacity.

Figure 1. Bulk retention capacity for 99 model realisations



Hypothetical spill volumes were applied to the bulk retention capacity curves to define the DNAPL penetration depth (Figure 2).

Figure 2. DNAPL penetration depth for 99 model realisations



In the absence of detailed information on the geometry of the aquifer, a cubic block geometry was used to estimate potential DNAPL penetration depth. DNAPL penetration depth is inversely proportional to capillary pressure. This reflects the low storage capacity at low capillary pressures and indicates that a given volume of DNAPL will travel much further in a low storage capacity rock mass than in a high storage capacity system. The modeling results define an envelope of values that represent the most likely range of PCE DNAPL storage capacity and penetration depths in this type of formation. These values (reported in SI units) are summarised in a look-up table (Table 1) for the given hypothetical spill volumes of PCE DNAPL. Outlier values are not included in this reference table.

Table 1. Bulk retention capacity and DNAPL penetration depth ranges

	Low capillary pressure release	High capillary pressure release
Capillary pressure ($N\ m^{-1}$)	799	3197
Equivalent PCE DNAPL pool height (m)	5	20
Bulk retention capacity ($m^3\ m^{-3}$)	$8x10^{-9}$	$2x10^{-5}$
PCE DNAPL storage capacity ($ml\ m^{-3}$)	0.008	20
200 l spill: DNAPL penetration depth (m)	325	23
50000 l spill: DNAPL penetration depth (m)	2050	146

4. CASE STUDY 2. LNAPLs in the Chalk Aquifer

This case study describes an integrated methodology for the investigation of contaminant fate in dual porosity aquifer to understand dissolved contaminant migration and the NAPL source zone characteristics. The approach includes the analysis of geological, hydrogeological and hydrochemical characteristics using rock core, geophysical (down-hole) fracture logging, vertical hydraulic profiling and multilevel sampling (MLS) of vertical solute profiles. The monitoring borehole network was constrained by restricted access and difficulty of installing monitoring boreholes at optimum locations in an urban setting - the site is adjacent to a busy main highway and surrounded by industrial and residential buildings.

A. Methods

A network of long-screen monitoring boreholes was installed at the site prior to the initiation of this study. Groundwater samples from these boreholes show dissolved phase contamination between 20-30 m depth, with a mixed oxygenate/BTEX plume close to the site and oxygenate-only plume further downgradient. Additional site investigation was undertaken, which included the drilling of cored boreholes, hydraulic testing and installation of MLS upstream of the site, in the oxygenate/BTEX plume, 30 m from the site, and in the oxygenate-only plume, 115 m from the site.

The spatial distribution and properties of the fracture network (type, aperture, intensity and orientation) were measured using undisturbed rock core and downhole geophysical logging of monitoring boreholes prior to well completion. Packered pumping tests were used to characterise the aquifer hydraulic properties (transmissivity, storativity, hydraulic gradient), with a test-zone (inter-packer) spacing of 1-2 m. Vertical profiles of solute distribution were obtained from the MLS installation. Monitoring intervals on the MLS were determined using profiles of VOCs (from rock core and pumping tests), relative transmissivity (from pumping test flow rate and relative drawdown), lithology and fracture intensity (from rock core and geophysical logs). The MLS were installed up to a depth of 55 m and the boreholes were completed using sand packs and bentonite seals.

B. Results and Discussion

The fracture network characterisation identified bedding-parallel fractures with a dominant ENE-WSW strike and dip of 2-29∀to the SSE. A subordinate bedding-parallel fracture set with E-W strike and N dip of 10-30∀is also present. High angled fractures include sets with a ENE-WSW or E-W trend and NNW dip of 30 to 80∀, and sets with a NW-SE trend and NE dip of 35-75∀. The mean fracture spacing for combined bedding-parallel and high-angled fractures is 0.23 m.

Fractures form preferential pathways for the migration of LNAPL and dissolved phase contaminants in the Chalk aquifer. The main controls on the subsurface geometry of the LNAPL source term are transverse spreading of the LNAPL, penetration to below the water table, and redistribution within the vadose zone due to water table fluctuations (smearing). The high concentrations of dissolved phase contaminants (Figure 3) to ca. 40 m depth and negligible vertical hydraulic gradient at this depth (figure 4) imply penetration of LNAPL below the water table along vertical fractures.

Figure 3. Organic contaminant profiles for MLS boreholes 30m from site (a) and 115m from site (b)

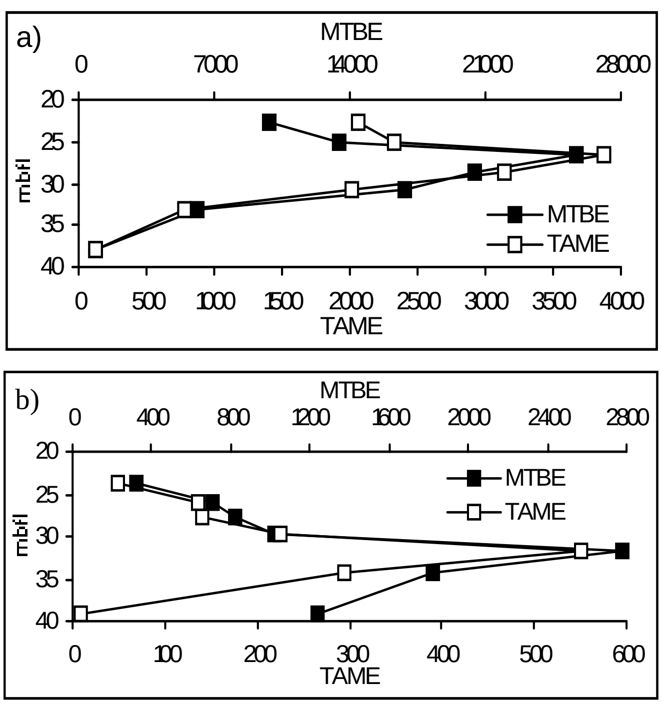
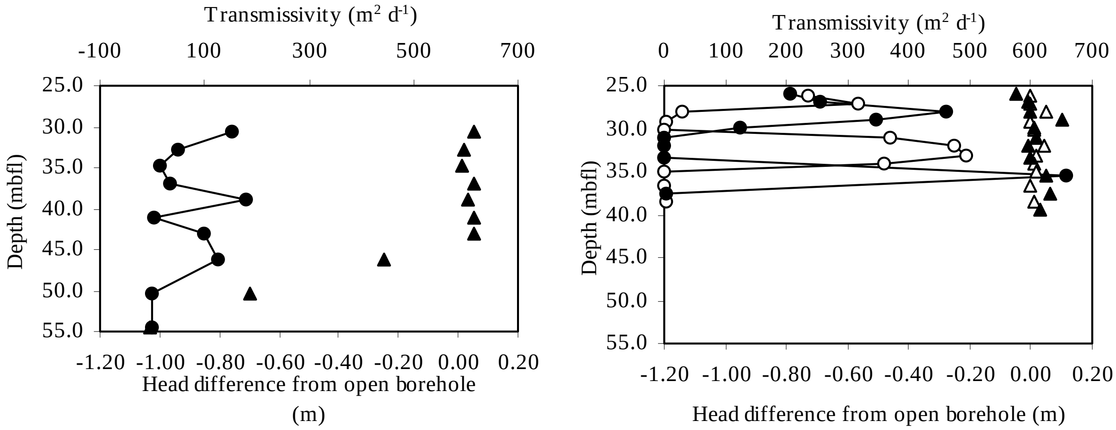
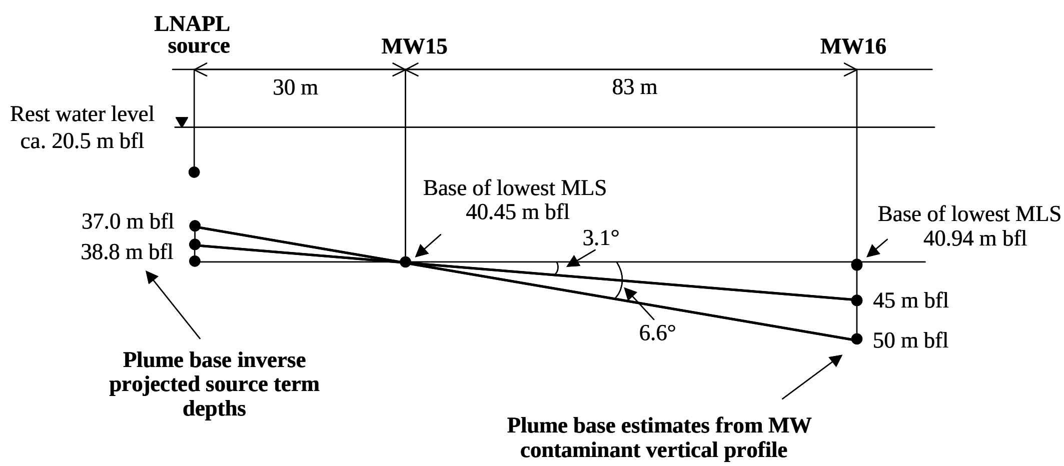


Figure 4. a) Transmissivity (closed circle) and hydraulic head (closed triangle) in the upstream MLS borehole and b) Transmissivity (closed circle) and hydraulic head (closed triangle) in the MLS 30 along the plume flowpath plus transmissivity (open circle) and hydraulic head (open triangle) in the MLS borehole 115 m along the plume flowpath.



An 'indirect' estimate of the depth of LNAPL penetration, using an inverse-projection of the plume base (**Figure 5**) indicates that the base of the source term may be 37.0 to 38.8 mbfl, equivalent to16.5-18.3 m depth below the water table. The base of the plume defines dip values (3.1 to 6.6º) which are in the range of the bedding-plane fracture structural dips determined from the televiewer logs. Adopting a simple 1-D force balance model (Hardisty et al., 1998), fuel density of 750 kg m^{-3} and negligible capillary forces (due to large fracture apertures, ca. 1 mm), indicates that a 5.5 to 6.3 m height of LNAPL above the water table is required to produce the inferred penetration.

Figure 5. Estimation of LNAPL source term depth using an inverse-projection of the plume base



The dominant NE-SW to E-W trending high angled fractures suggests that LNAPL may be distributed transverse to the plume orientation, producing a more widely dispersed source zone. This is also implied by inverse projection of the plume envelope, based on changes in flow direction, which suggests a source zone width of 40-60 m.

Limited direct information is available on the geometry and mass distribution of the source term, as observed in many SIs. However, the fracture porosity is ca. 1% of the bulk rock volume and it is clear that even small volumes of LNAPL may pervade the fracture network. Direct evidence is not, however, available to define the true source width. Buoyancy forces may also redistribute LNAPL, particularly in the higher angled fractures and, when present below the water table, lead to capillary trapping of LNAPL. Water table fluctuation may also act as a mechanism for pumping LNAPL both vertically and laterally. The depth of aquifer contamination is controlled by LNAPL penetration below the water table. This vertical migration of product will form a deeper source zone for dissolved phase contaminants in addition to residual product present in the vadose zone.

5. CONCLUSIONS

Integrated site characterisation approaches which combine appropriate, and often novel, techniques are required to develop the lines-of-evidence from which we can predict NAPL source zones with greater confidence. Adoption of the methodologies described in the two case studies incurs higher “up-front” costs in site investigation. However, this provides a higher-quality dataset, improved confidence in the interpretation of contaminant fate, reduced uncertainty in risk assessment and assists in realistic cost-benefit analysis of the treatment of groundwater polluted by NAPLs.

6. ACKNOWLEDGEMENTS

Case Study 1: Funding was provided by the UK Engineering and Physical Sciences Research Council. DuPont (UK) Ltd is thanked for access at their Dumfries site. The support of the Environment Agency and ICI Chemical and Polymers Ltd is acknowledged. FracMan was used under an Academic licence agreement with Golder Associates Inc.

Case Study 2: TotalFinaElf is thanked for funding the work described in Case Study 2. The support of the Environment Agency and CL:AIRE is acknowledged. Gary P. Wealthall publishes with the permission of the Director of the British Geological Survey.

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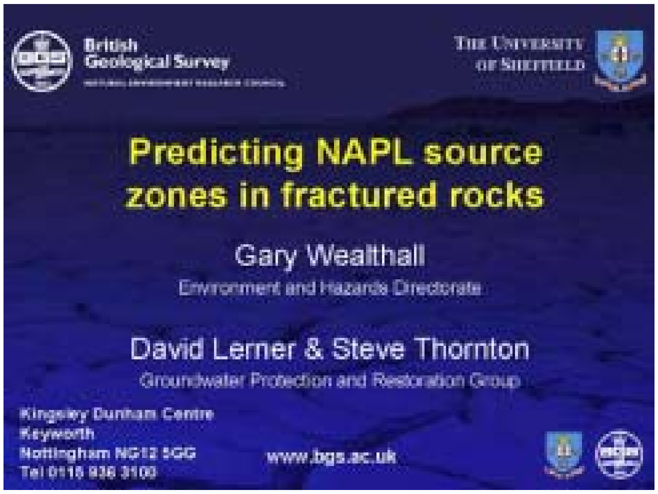
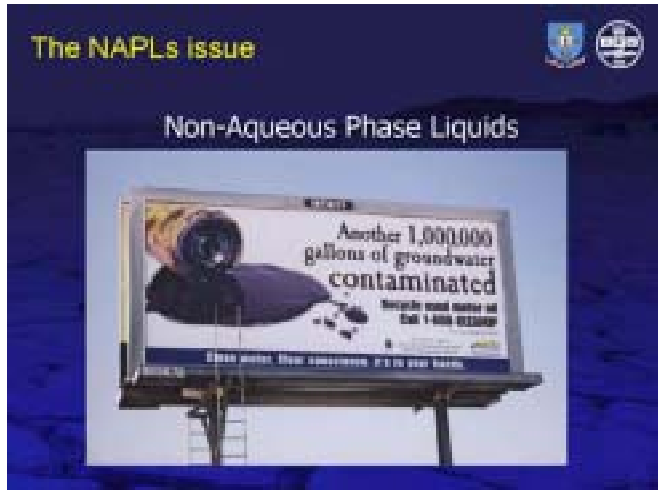
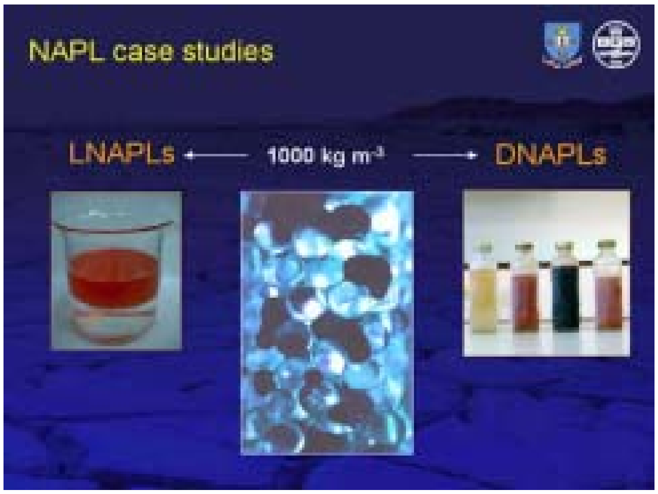
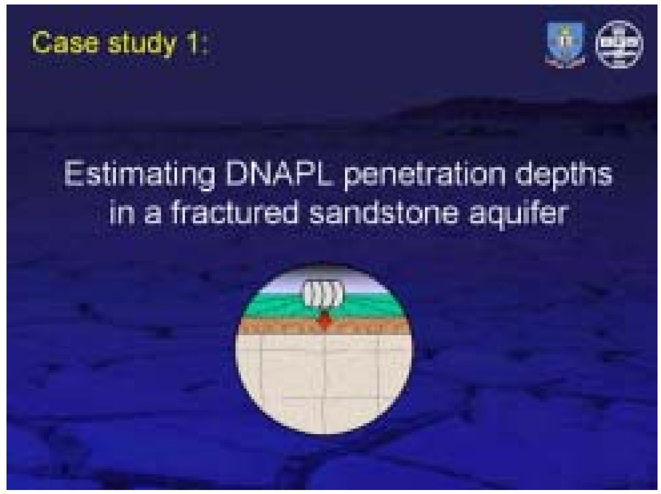
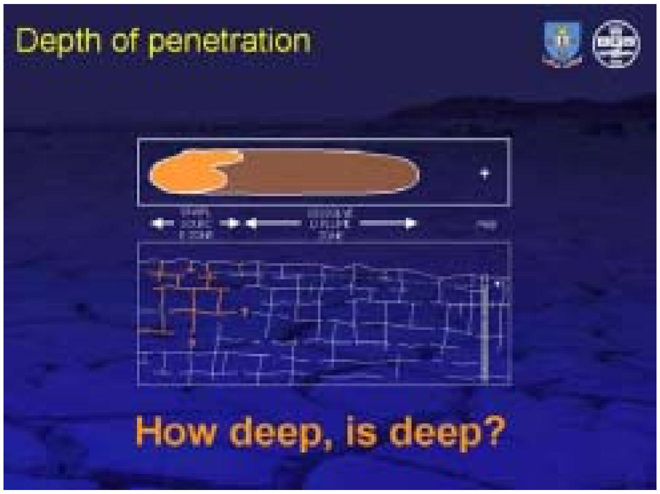
8. PRESENTATION VISUALS ~ *presented by Gary P. Wealthall, David N. Lerner and Steven F. Thornton*

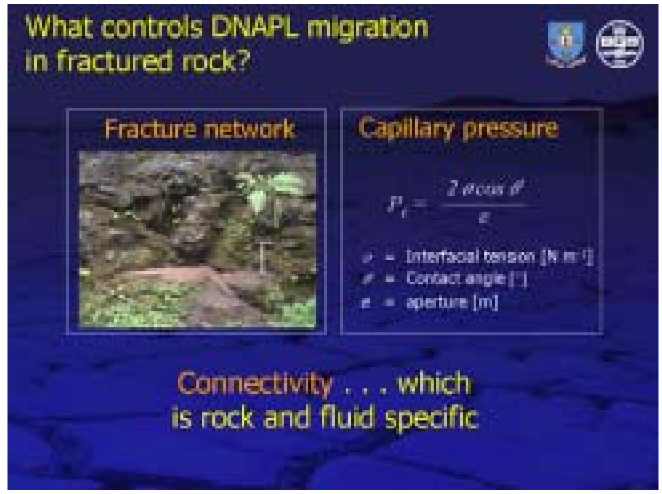


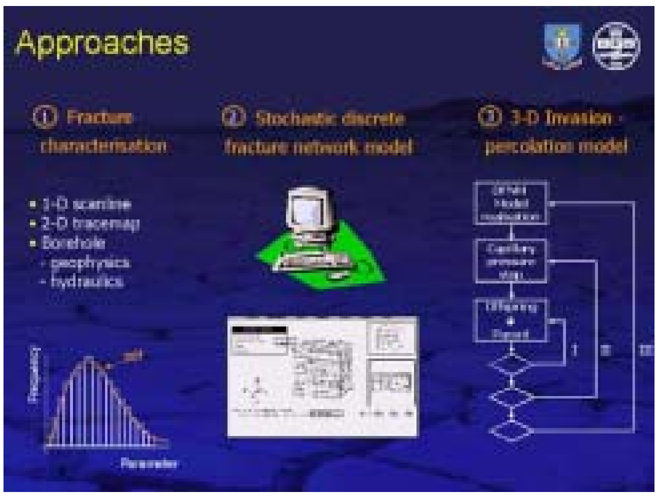


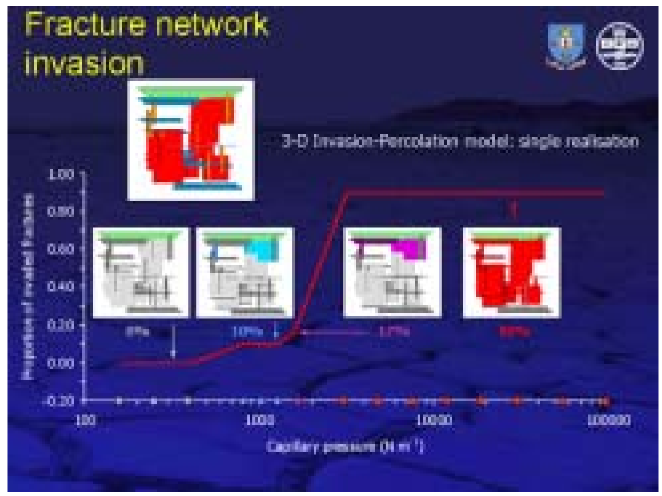


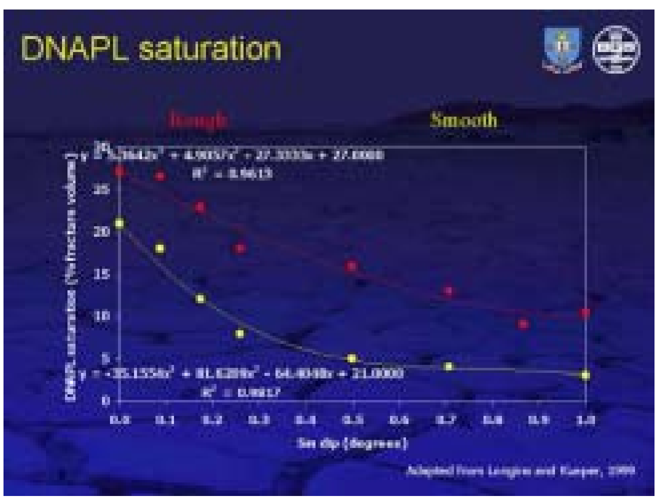


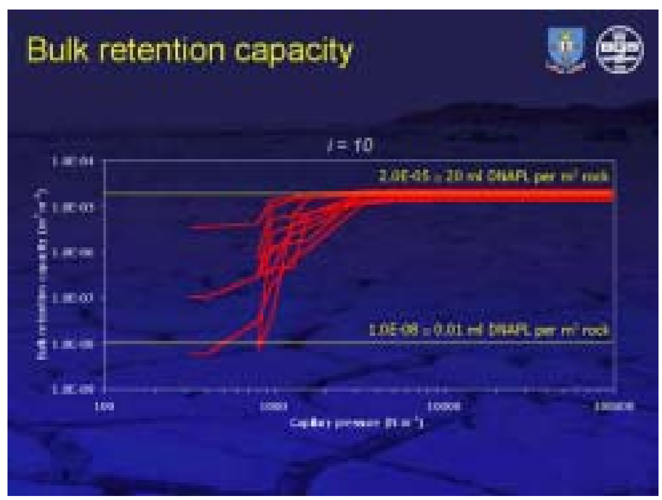

Depth of penetration
How deep, is deep?

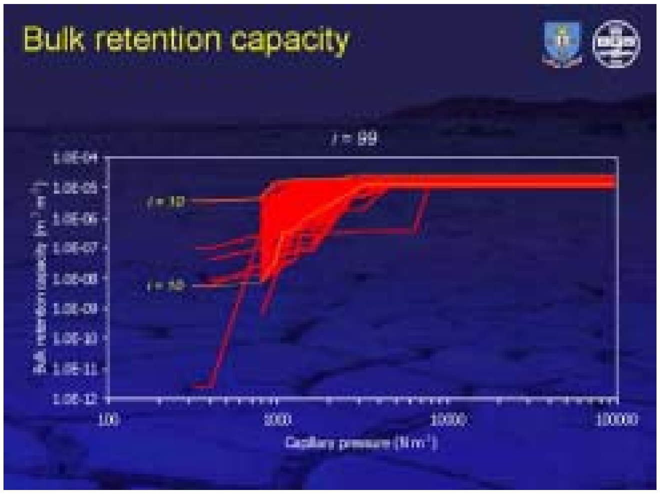

What controls DNAPL migration in fractured rock?
Fracture network
Capillary pressure
Interfacial tension [N m⁻¹]
Contact angle [°]
aperture [m]
Connectivity . . . which is rock and fluid specific

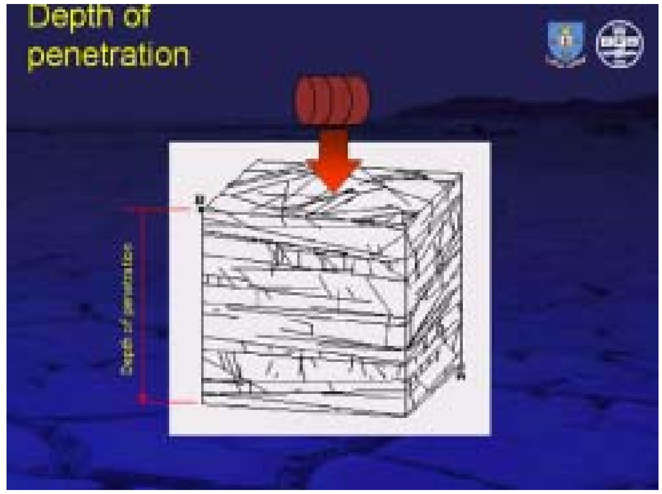

Approaches
① Fracture characterisation
② Stochastic discrete fracture network model
③ 3-D Invasion - percolation model
• 1-D scanline
• 2-D tracemap
• Borehole
- geophysics
- hydraulics
Frequency
Parameter

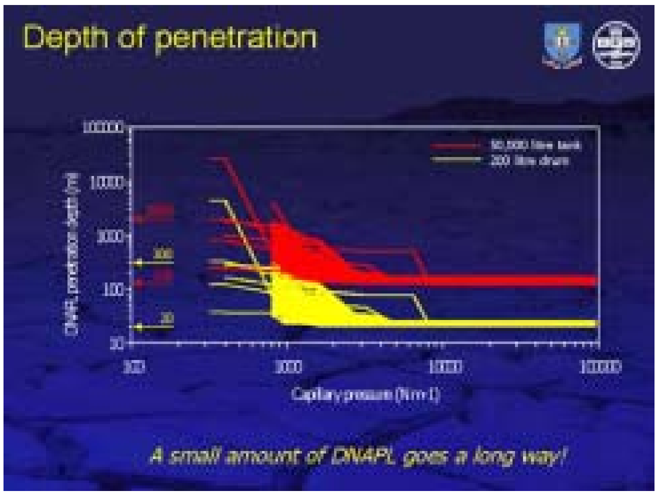

Fracture network invasion
3-D Invasion-Percolation model: single realisation
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
100
1000
10000
100000
Capillary pressure (N m⁻¹)

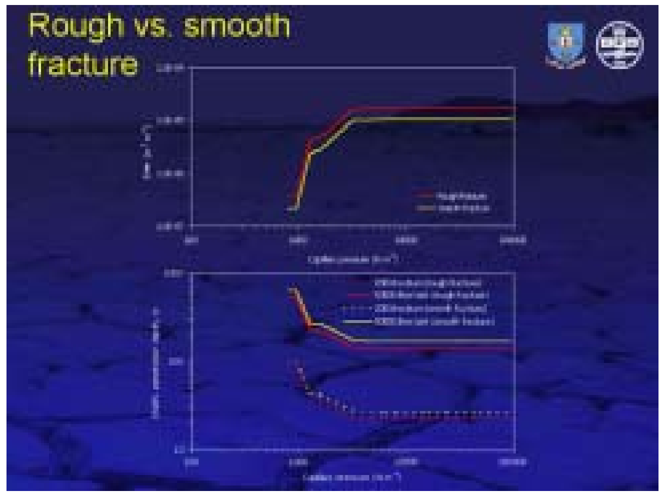

DNAPL saturation
Rough
Smooth
DNAPL saturation (% fracture volume)
Sin dip (degrees)
Adapted from Longino and Kueper, 1999

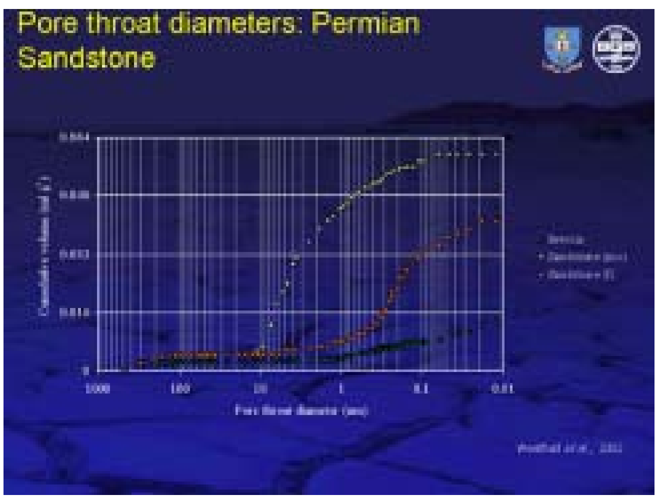

Bulk retention capacity
2.0E-05 = 20 ml DNAPL per m³ rock
1.0E-08 = 0.01 ml DNAPL per m³ rock

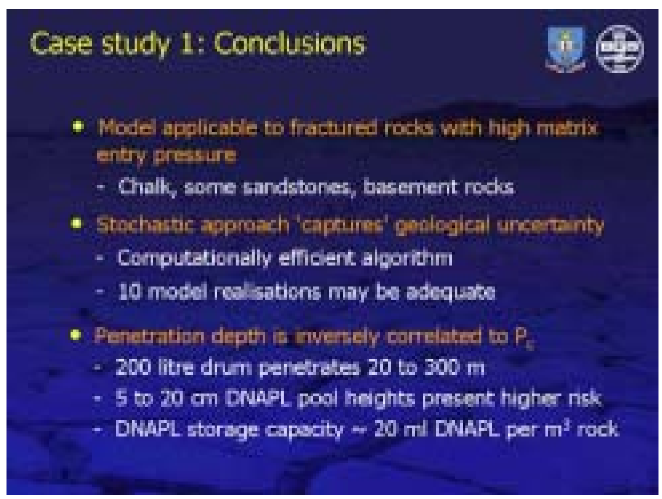

Bulk retention capacity
i = 99
i = 10
i = 50
Bulk retention capacity (m³ m⁻³)
Capillary pressure (N m⁻²)
100
1000
10000
100000

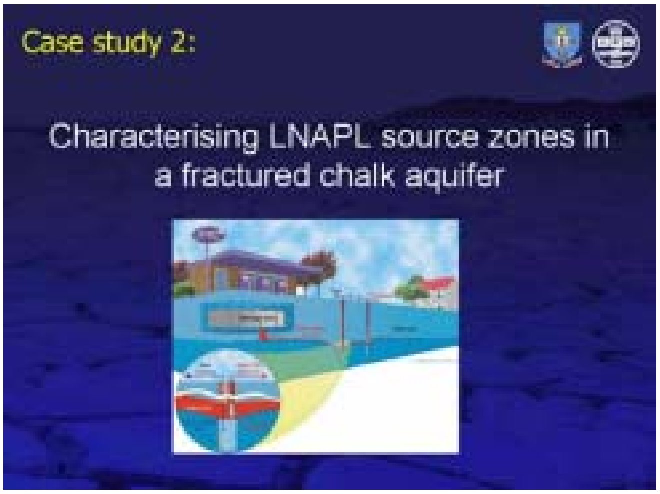

Depth of penetration
Depth of penetration


Depth of penetration
50,000 litre tank
200 litre drum
DNAPL penetration depth (m)
Capillary pressure (N m-1)
A small amount of DNAPL goes a long way!


Rough vs. smooth fracture


Pore throat diameters: Permian Sandstone
Pore throat diameter (µm)


Case study 1: Conclusions
Model applicable to fractured rocks with high matrix entry pressure
- Chalk, some sandstones, basement rocks
Stochastic approach 'captures' geological uncertainty
- Computationally efficient algorithm
- 10 model realisations may be adequate
Penetration depth is inversely correlated to P_c
- 200 litre drum penetrates 20 to 300 m
- 5 to 20 cm DNAPL pool heights present higher risk
- DNAPL storage capacity ~ 20 ml DNAPL per m³ rock


Case study 2:
Characterising LNAPL source zones in a fractured chalk aquifer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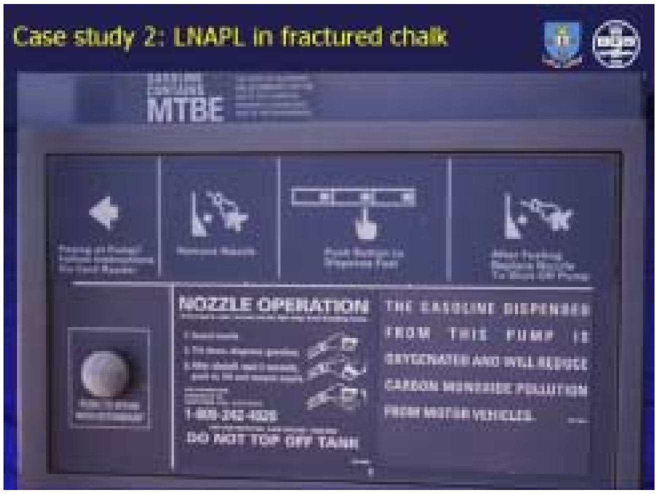
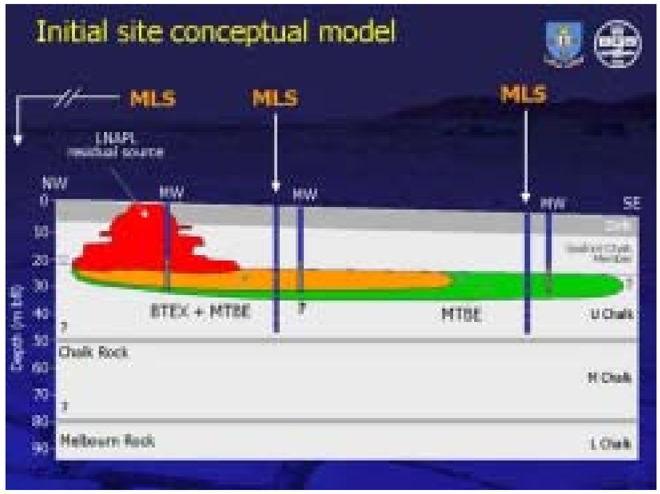
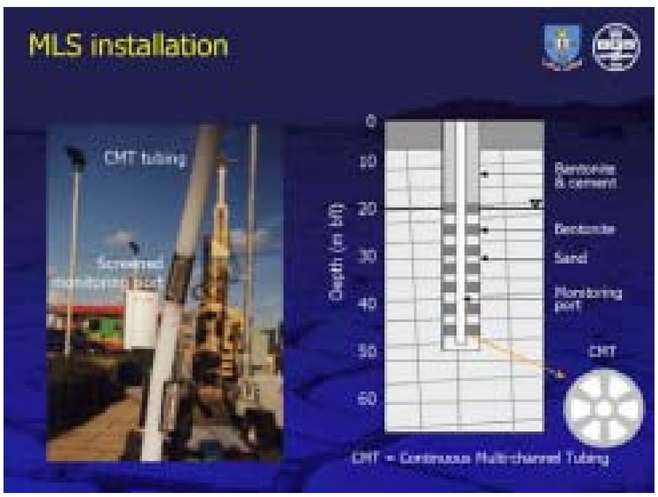
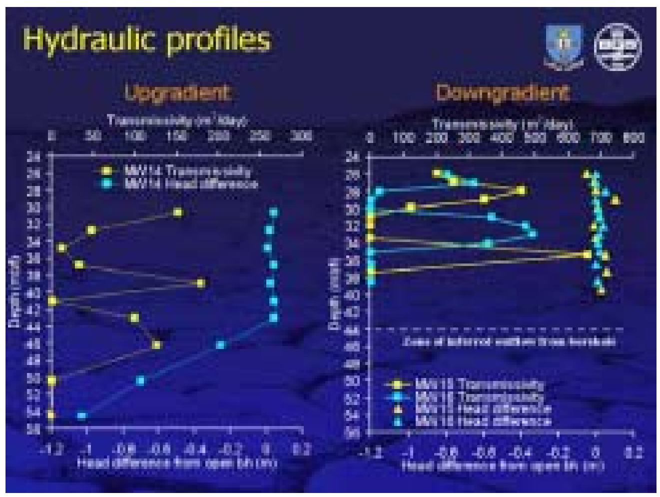
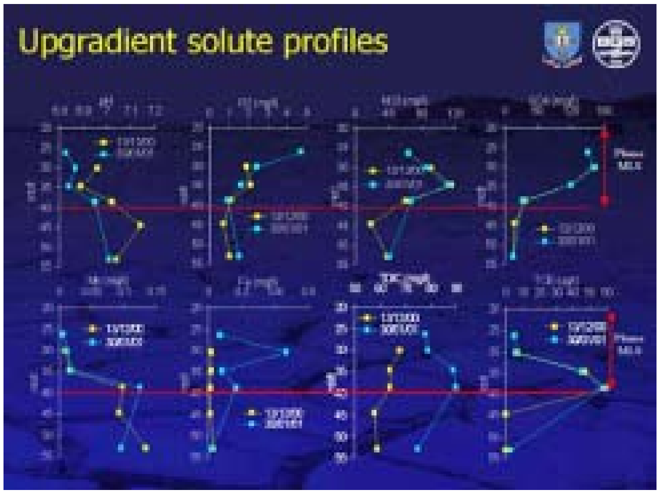
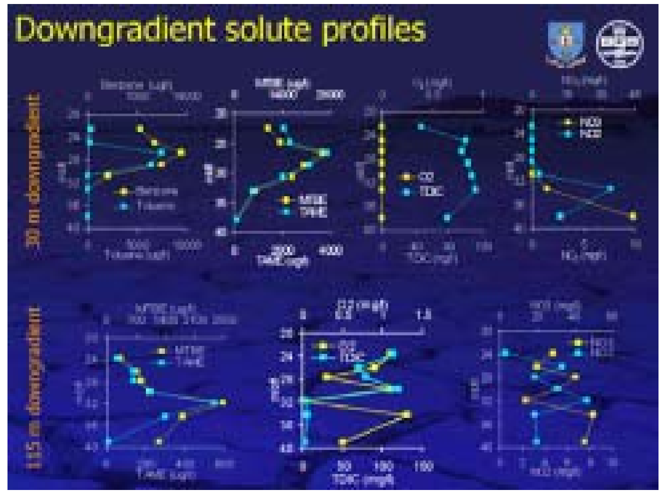

Case study 2: LNAPL in fractured chalk
MTBE
NOZZLE OPERATION
THE GASOLINE DISPENSED FROM THIS PUMP IS OXYGENATED AND WILL REDUCE CARBON MONOXIDE POLLUTION FROM MOTOR VEHICLES.
DO NOT TOP OFF TANK

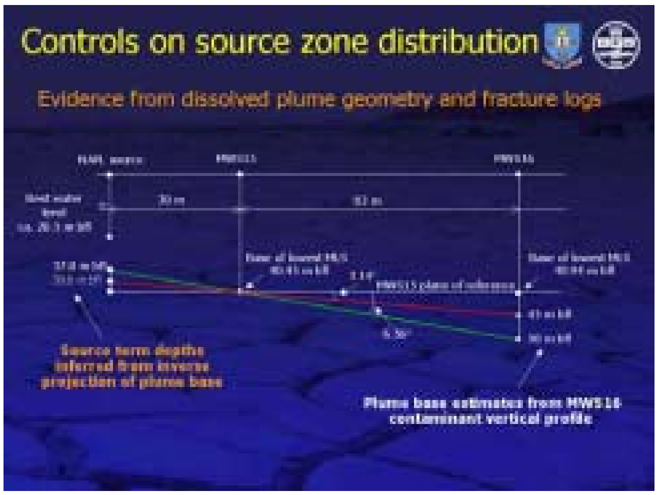

Initial site conceptual model
MLS
MLS
MLS
LNAPL residual source
NW
SE
MW
MW
MW
BTEX + MTBE
MTBE
Depth (m bfl)
Chalk Rock
Melbourn Rock
U Chalk
M Chalk
L Chalk

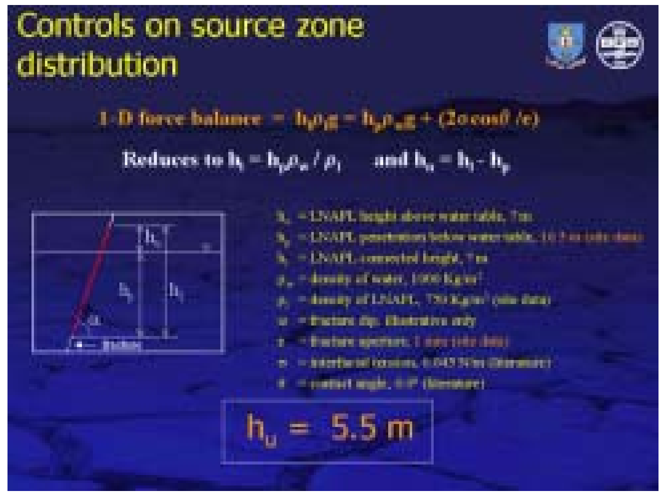

MLS installation
CMT tubing
Screened monitoring port
Depth (m bfl)
Bentonite & cement
Bentonite
Sand
Monitoring port
CMT
CMT = Continuous Multi-channel Tubing

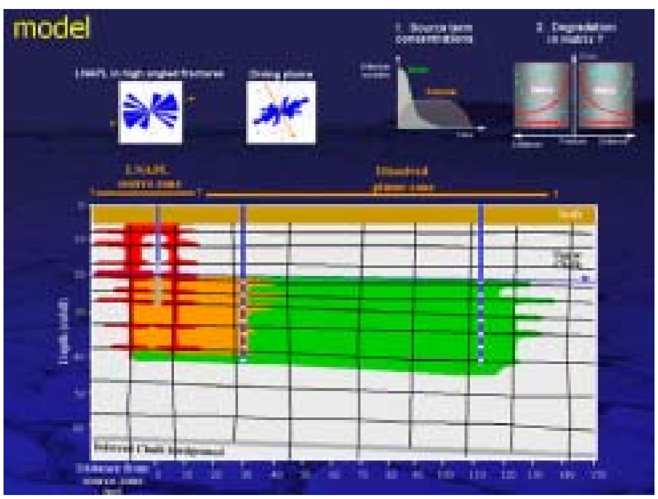

Hydraulic profiles
Upgradient
Downgradient
Transmissivity (m² /day)
MW14 Transmissivity
MW14 Head difference
Zone of inferred outflow from borehole
MW15 Transmissivity
MW16 Transmissivity
MW15 Head difference
MW16 Head difference
Depth (mbfl)
Head difference from open bh (m)

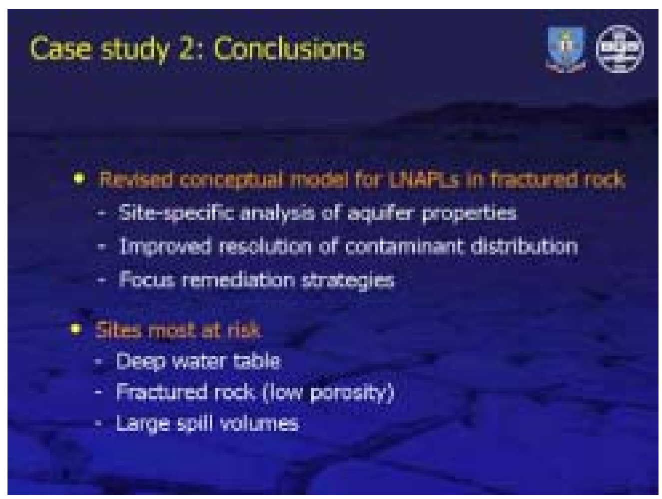

Upgradient solute profiles
Plume MLS

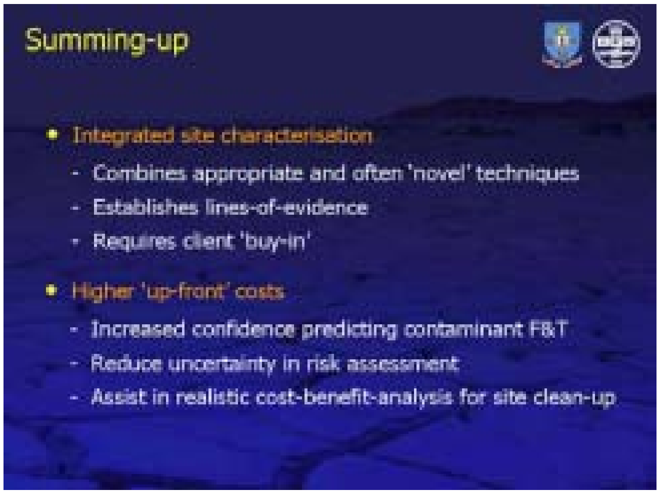

Downgradient solute profiles
30 m downgradient
135 m downgradient


Controls on source zone distribution
Evidence from dissolved plume geometry and fracture logs
Source term depths inferred from inverse projection of plume base
Plume base estimates from MWS16 contaminant vertical profile


Controls on source zone distribution
1-D force balance
$h_u = 5.5$ m


model


Case study 2: Conclusions
• Revised conceptual model for LNAPLs in fractured rock
- Site-specific analysis of aquifer properties
- Improved resolution of contaminant distribution
- Focus remediation strategies
• Sites most at risk
- Deep water table
- Fractured rock (low porosity)
- Large spill volumes


Summing-up
Integrated site characterisation
- Combines appropriate and often 'novel' techniques
- Establishes lines-of-evidence
- Requires client 'buy-in'
Higher 'up-front' costs
- Increased confidence predicting contaminant F&T
- Reduce uncertainty in risk assessment
- Assist in realistic cost-benefit-analysis for site clean-up

NON-DESTRUCTIVE TECHNIQUES IN ENVIRONMENTAL SURVEYING IT'S FINE... BUT WHAT DO WE SEE?

Dr. Jurjen K. van Deen[1]

1. INTRODUCTION

In this paper we will consider the term 'non destructive' in a liberal sense. A surgeon who applies a needle to look into one's knee or abdomen is performing an intrusive measurement but is certainly not supposed to do anything destructive. It is good to understand that penetrating the subsoil with push-in instrumentation and measuring in situ is quite comparable, apart from the scale of the operation. Even drilling and sampling would be called in medical terms 'taking a biopt', and even that is not supposed to be a destructive or even disruptive activity. All these techniques are non-destructive in the sense that they leave the process at study largely undisturbed.

Push away techniques are much better known than surface techniques and will therefore be given less attention in this paper. It is however good to realise that the question 'what do we see?' applies as well to the push away techniques (and, by the way, to drilling and sampling as well). What we 'see' is an accurate number at an accurate location, but that is strength and weakness in one: it is also *only* on that location and *only* that number.

Geophysical or surface techniques determine physical properties of the subsoil, measuring from the surface. There is a large gap between this type of information and the answers that are wanted on specific questions in environmental or civil engineering projects. In environmental issues the questions vary from 'where are the borders of this landfill' (or even: 'where are the landfills'), 'are there any drums in this landfill (and are they leaking)' to 'what is the concentration of pollutant X at this location'. To bridge the gap generally a lot of interpretation is needed, making the results less objective and prone to 'errors'. This can easily lead to disappointment for both the principal and the geophysical contractor.

It is the purpose of this paper to argue that the strengths of geophysics in environmental surveying can be employed twofold. In the first place geophysics should always be applied as an element of an integrated survey strategy and should focus on the delineation of geometrical features more than trying to detect 'pollution' directly. In the second place geophysics is important for monitoring purposes as it interferes little in the processes at hand.

The focus of the paper will be on basic understanding more than on casuistry. Survey results are so dependent on the site circumstances that relying on cases may easily lead to misunderstanding. Heterogeneity, type of soil (or rock) and groundwater level are primary determinants of the applicability.

The paper is organized in six parts. After the introduction follows a very short sketch of push away techniques concluding in some general statements on the possibilities of push away techniques. After that a rough overview of shallow geophysical methods is given, with typical application areas. In the next section a number of typical environmental problems will be indicated and analyzed which contribution the abovementioned methods may have. The fourth and fifth section will discuss and conclude on why, when and where to apply geophysical methods.

2. PUSH AWAY TECHNIQUES

The mother of all push away techniques is the standard cone penetration test (CPT), which measures the forces on the tip and the friction jacket of a 36 mm diameter cone and thereby generates valuable information about mechanical properties and layering of the subsoil. Especially when combined with measurement of the pore water pressure, the method is very informative of the type of soil and can discriminate sands, silts, clay, and peat soils into considerable detail (Cheng-hou and Greeuw, 1990).

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However, virtually every conceivable measurement method can be converted to a push away version; a (little bit outdated by 2002) overview is given by Stienstra and Van Deen (1994). Five examples suffice in this context.

A first step from the traditional well sampling is taking ground water samples with a push away probe. By the multilevel ground water sampling probe a number of samples can be taken along one vertical line in one push away operation. Evaporation of volatile compounds is avoided by using a pressure pump 'down under' instead of a suction pump at the surface. Cross contamination between different levels is effectively prevented by flushing the filter and drying with nitrogen before pushing through to the next level. The measurement is fast since there is no such thing as a well volume, which has to be filled or flushed.

The next step is obviously to transfer the measurement also downwards: the chemoprobe measures chemical macroparameters like pH and EC 'at location' by sucking a minute amount of ground water into the probe and performing the measurement, again at multiple levels and avoiding cross contamination by flushing and drying.

An example of a third type of measurement is the monopole permeability probe. This probe is a stimulus/response-type of instrument: a known discharge of water is introduced (pumped) into the subsoil, and the resulting pressure gradient a few centimeters below is registered by a differential pressure transducer. This device measures the local hydraulic conductivity at that specific location, and, if necessary, along the complete vertical profile.

The fourth and quite recent development in this family is the camera probe. This is the real counterpart of the surgeon's needle with fibre optics to peep into one's knee. The soil and the pore volume is visually observed as it flows along the push away probe. Grain sizes can be estimated, the interface between clay and soft underlying chalkstone is easily seen and colored substances like creosote oil in the soil are recognized immediately. The strength of the camera probe is the richness of the really visual 'picture' one obtains.

A final and very recently developed probe to be mentioned here is the MIP-probe which is opening possibilities of direct in situ detection and measuring low concentrations (ppm level) of VOC. The system consists of a hydrophobic membrane mounted at the side of a probe, which is heated in order to promote diffusion of volatile compounds through the membrane. The volatile molecules are transported by a gas flow to the detection apparatus at the surface.

These examples suffice to show that where it concerns the type of measurement there are virtually no restrictions. On the other hand the local circumstances are restrictive. Push away techniques can be applied very well in (soft) soils. However their use has to be discouraged when there are pebbles in the soil – or worse. Fortunately, large parts of densely populated areas (North Western Europe, Mississippi, Japan) are situated on really thick deposits of soft soils. One should realise that also stiff sands and soft chalks can often be considered as 'soft soil'.

All the push away techniques of course also have the restriction that they measure only at that specific location. However, in any type of soil investigation one always has to start from a conceptual subsoil model. Sound engineering judgment on what can be expected from an environmental point of view is an indispensable tool in this respect, as is a thorough knowledge on the geology of the site. Consultation of a geologist with local expertise always pays off!

3. OVERVIEW OF GEOPHYSICAL METHODS

Geophysical methods can be divided in several ways. In the first place we discriminate between passive and active methods, the former utilizing natural phenomena like the earth's magnetic field or its thermal radiation. The active methods can be divided once more in volume methods and imaging methods. Separately we will pay attention to tomographic techniques.

Gravimetry and magnetometry are typical examples of passive methods. Gravimetry measures the local strength of the earth's gravity field. Differences in density in the subsoil cause (generally minuscule) differences in gravity. The method is sensitive to (large) holes like Karst phenomena, but also abandoned mine workings. The presentation is a contour map of gravity. Ambiguity is a problem in the interpretation, different origins may cause comparable effects. Recent development is an increased sensitivity of the instruments, however, not solving the ambiguity problem.

Magnetometry measures the local strength of the earth's magnetic field. As this field is influenced strongly by ferromagnetic objects (iron and steel) the method is employed frequently for detection of steel drums and unexploded bombs. Here ambiguity is also a problem: a bomb is indiscernible from a transformer as are an empty steel drum and an oil leaking drum. Although one might wish to have less false-positive results, the correct-positive results can reduce risks greatly. Recent developments in data processing have increased the effectiveness of large-scale bomb tracing greatly.

Remote sensing surely belongs to the geophysical methods. Aerial photography and infrared sensing can contribute to the large scale detection of features. On the one hand visual images are relatively easy to interpret because a human interpreter can understand what he sees, on the other hand the penetration in the soil is virtually nil and subsoil features remain undisclosed. Infrared pictures sketch a thermal image that may be influenced by features at some depth, either because heat is generated or because the heat balance is locally disturbed.

A. Volume Methods

Electromagnetic and geoelectric measurements both determine the bulk electrical specific resistivity (often in terms of its reciprocal: the conductivity) of a volume of soil. Typical dimensions of the volume are meters to tens of meters (and in mineral exploration work even larger). Geoelectric measurements use electrodes physically implanted at the surface of the ground. The electromagnetic (EM) method uses coils to induce currents in the subsoil; this does not need physical contact with the ground. In the first place these methods are sensitive to differences in soil composition because most soils have characteristic and different conductivities. Also the groundwater and the chemical content of the groundwater determine the conductivity. This leads to information on e.g. leachate plumes, but it will be clear that ambiguity often exists in the interpretation.

The effective penetration depth of the measurement can be controlled by varying the distance between the electrodes resp. the EM-coils and by using several distances a more or less accurate depth profile can be generated. Besides the ambiguity in interpretation a second problem of resistivity methods is the equivalence problem: a thin highly conductive layer gives nearly the same response as a thicker, less conductive layer.

The resolution of the methods decreases rapidly with depth. The presentation of EM and geoelectric methods can be in maps or vertical sections where regions of different conductivities are outlined. In vertical sections it is often not clearly indicated how large the inaccuracy is in the isoconductivity-lines, and often one is not even aware of a problem. Although the use of iso-lines can suggest a high accuracy (in the few- %-range), in practice the depth accuracy is not better than 30-50% of the depth due to the ambiguity mentioned above.

Developments in these methods are the multi-electrode methods which have become popular after computer controlled measurements on large number of electrodes became possible, also in combination with sets of electrodes in boreholes and applying tomographic techniques. This has improved the lateral continuity of the measurement results considerably. Also different variants of the resistivity methods (spontaneous and induced polarization) using natural electric fields and the time dependence of induced fields have been applied to characterize the subsoil.

B. Imaging Methods

The third and final group of geophysical methods consists of the imaging methods. In principle these methods can give the most accurate picture of the subsoil with a resolution, which deteriorates only slightly with depth. The methods are so called pulse-echo methods; they are based on the measurement of the travel time (and sometimes also the amplitude) of a reflection from a transmitted pulse. The reflections observed at a large number of locations are combined numerically to a synthetic image of the subsoil.

The basic difference between volume methods and imaging methods is that volume methods determine primarily an average value of soil properties between the surface and some effective penetration depth. Depth information is gained by subtracting values from different penetrations. On the other hand the pulse-echo methods generate echoes from interfaces between layers or other heterogeneities. In principle this is a depth-independent process and the deterioration of results with depth is caused by signal attenuation which decreases the signal to noise ratio.

The imaging methods have an acoustic and an electromagnetic variant, reflection seismics and ground probing radar (GPR). Reflection seismics has been developed to a great extent in oil and gas exploration since the penetration in the soil is many kilometers. Downscaling the method to ground water exploration depths (100 m) has been performed successfully. However, application to shallower depths is limited because of instrument related problems, which have not yet been solved. Recent developments are focused on better controlled sources (vibration units) for compressional and shear waves.

The information that is acquired by seismics is related to mechanical properties. Reflections arise from acoustic discontinuities. Depth to bedrock, or in case of marine seismic surveys depth to bottom, is an easy target. Soil interfaces are sometimes discernable but it appears often difficult to relate seismic ‘horizons’ as they are called, to hard information from borings or CPTs. Pollution is generally invisible for seismic methods. A severe disadvantage on land is that the method is time consuming because one needs physical contact with the soil to generate the acoustic pulse or wave and to detect the reflections. In practice this means pushing a large number of geophones into the ground.
The hardest restriction from the point of view of environmental applications is the depth range which in fact just starts at 30 - 50 m, which is too deep for most problems. The second restriction is that pollution hardly influences the acoustic parameters; the information obtained is therefore of a general, geologic nature more than the distribution of pollution.

The electromagnetic counterpart of seismics is ground penetrating radar (GPR). The first difference with seismics is that the pulse is an electromagnetic wave instead of acoustic. The reflections originate therefore from electromagnetic contrasts instead of acoustic. The second difference is an operational one: the lack of need of tight physical contact. In GPR it is possible to drag the transmit and receive antenna over the surface; this makes the measurement less time consuming. As with seismics, data processing is essential to generate an image. The most important development in the last years is the introduction of 3D techniques where echo data from several parallel tracks is combined. This has led to a significant improvement in resolution and reliability.

GPR echoes are generated primarily by changes in the dielectric permittivity, a parameter that is largely determined by the water content and the composition of the soil. This means that the primary information is on layering and heterogeneity of soil strata. In principle the presence of organic contaminants (DNAPL as well as LNAPL) will change the water content or influence the shape and thickness of the vadose zone. Therefore the presence of these substances may be (and has claimed to be) visible in the echograms. The second electric parameter that influences GPR is the electrical conductivity. It is generally this parameter that limits the application of the method because of the signal attenuation. As clay has a high conductivity, the penetration through clay and clayey soils is rather limited. On the other hand conductive polluting substances in ground water may give themselves away by the attenuation they generate in GPR signals.

Pulse-echo methods are usually presented in the form of vertical sections below the survey tracks. One should be aware, however, that echo's from 'aside' the track are indiscernible from echoes down under, although the presentation suggests otherwise. This makes interpretation often cumbersome. Introduction of 3D data acquisition has proven to be an essential step forward, but of course increases the amount of work and therefore the cost of a survey considerably. On the other hand it may be worthwhile when it is important to have a 3D image of the location's subsoil.

C. Borehole Techniques/ Tomography

Many of the abovementioned techniques can, with or without adaptations, be applied from boreholes or between boreholes. In the first place, the soil geometry as well as the pollution are viewed from a different angle when working in a borehole. Especially for deeper locations this may be an advantage without compromising the resolution. Moreover, working between two boreholes and applying tomographic techniques opens new possibilities: for GPR, where attenuation is generally a problem, the penetration increases greatly since one measures in transmission, not reflection. However, the great advances that have been made in medical tomography cannot be expected to occur in geophysics as the number of measurement positions remains too small for a satisfactory coverage. Therefore in many cases the resolution remains the bottleneck in application of tomography in geotechnology.

The above overview is largely based on an inventory (CUR, 1996), containing 22 four-page fact sheets on the different techniques (in Dutch). A similar fact sheet collection was made a few years earlier by BRGM (1992) (in French). The CUR report also has a special section on tomography.

4. TYPICAL ENVIRONMENTAL PROBLEMS

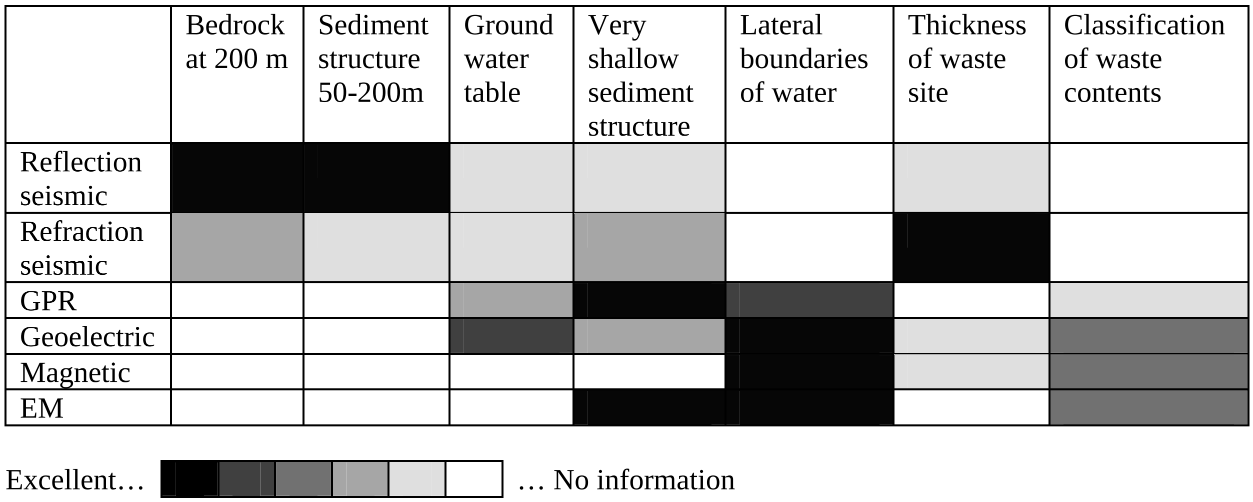
In order to estimate the significance of geophysics in environmental engineering, a number of typical application areas were defined in a brainstorm session in 1999 in the context of the NOBIS program, NOBIS being the predecessor of the current SKB-program (CUR/NOBIS, 1999). This list may serve as well to illustrate the possibilities and limitations of the several methods. The typical problem areas are:

1- mapping the preferential air channels during sparging in sandy soil
2 - detection of physical objects (cables, UXO)
3 - monitoring of processes in a contaminant plume near a landfill
4 - detection of hot spots DNAPL in the subsoil
5 - detection of oil contamination in industrial area.

For these five problems a check was done on the performance of the geophysical techniques. The result is summarized below.

Area	Geophysical Applications
1	**GPR** can image heterogeneity at 10 cm scale, application from surface or borehole multi electrode **geoelectric** (preferably from borehole or push away system) cheaper but less detailed aspect 'monitoring' (changes from the time zero situation) is helpful
2	GPR: in sand adequate, in clayey soils of limited use, 'all' type objects (also synthetics). EM for conductive objects (metal) magnetometer (for iron/steel objects)
3	extent of plume (if conductive) by **GPR, EM, geoelectric** processes *in* the plume: little options available
4	**GPR:** detection of first non-permeable layer and irregularities therein. If within depth range: perhaps direct detection of DNAPLs **reflection seismics**: 'deep' (20m+) heterogeneity
5	**GPR**: some claims that direct detection is possible.

A recent study on the feasibility of geophysical investigations of small landfills was published by the geophysics group of ETH Zurich (Green, 1999). The main result of that study is summarized in the figure below. Refraction seismic, which is a specific application (interpretation) of seismics, is mentioned separately in this study. This reflects that site specific circumstances (Switzerland overburden on bedrock - vs. Netherlands only soft soil) influence the feasibility of techniques heavily.



Comparison of information content of different geophysical data sets (taken from Green, 1999).

An important conclusion from Green (1999) is that integration of the datasets is crucial in order to obtain a consistent picture of the landfill and the surrounding sediments. No single dataset was capable of providing all of the necessary information.

5. DISCUSSION

The optimism in the beginning of the 1990's for specific application of geophysics on environmental problems has disappeared gradually. A typical example is the extended study on the Borden site in Canada, where a controlled spill of DNAPL was monitored by all possible techniques, geophysical as well as traditional. Numerous publications show that is very well possible to follow the process. The real problems become manifest when we try to survey an unknown site without a clean, time-zero reference. Geophysical results are generally ambiguous with respect to natural heterogeneity and pollution, so it is difficult to state the extent of the pollution, not to speak of concentrations. The number of 'pollution detection' papers in the SAGEEP conferences which have been and are the primary channel for this type of results, has decreased over the years. Incidentally one finds claims of separate companies that success has been achieved.

The basic contribution of geophysics is in delineating the geometry of a site: layering, the ground water table, heterogeneity e.g. fissures in hard rock and either sandy or clayey beds and lenses in soft soil, and the location of objects as (possibly leaking) drums. Because of the overview one gets by the geophysical methods they are useful in an early stage of a site investigation also in order to guide the more traditional sampling and in situ measurements. Moreover traditional techniques are always necessary to check and specifically to depth calibrate the geophysical results. It is important that the investigators think in terms of a conceptual subsoil model and try to 'colour' that model with help of all pieces of information available, including a rough or a detailed process model of the subsoil and the pollution: the geometry of the sources of pollution, groundwater flow, dissolution, adsorption and desorption are the key factors. A suitable strategy is outlined in the ETH paper mentioned earlier (Green, 1999). An important advantage of geophysics in environmental engineering is the non-intrusive character, lessening the risk of cross contamination along the vertical direction.

In the near future the most important contribution of environmental geophysics can be expected in monitoring applications: measurement and process control of rehabilitation projects. In the world of oil exploration the development of monitoring techniques and strategies is under way and can be found in the literature under key words like ‘4D-techniques’ (time being the 4th dimension) or ’time lapse measurements’ (Tura, 2001). In the oil world it becomes more and more important to deplete existing reservoirs more fully and therefore to monitor the depletion process. It can be expected that the R&D results will gradually disperse through the open literature and can so be transferred to the civil and environmental engineering business where R&D budgets are always orders of magnitude behind those of oil exploration.

6. CONCLUDING REMARKS

R&D papers and case histories are prone to stress successes and underrate failures. Success stories are in 9 out of 10 cases controlled situations or monitor cases. Within that context they are successful and valuable; they can however not be extrapolated to reconnaissance tasks at ‘new’ sites. Monitoring is surely the field where environmental geophysics in the next years will contribute most.

An important aspect of environmental measurements in general and environmental geophysics in particular is the validation of the measurements. Of course there is never a ‘golden standard’ to which the results can be calibrated. It is therefore crucial to think from a subsoil model perspective and try to fit the results within that model, understanding that individual results sometimes can be faulty or inaccurate. What is needed is a best guess of the overall situation, based on the best available evidence. Unfortunately it is not clear beforehand which method will deliver which part of the information.

It will be clear that geophysical methods are not a panacea for every problem. It should be understood, however, that this is the case for sampling and in-situ methods as well. On the other hand, oil and mineral exploration is inconceivable without geophysical surveys, although only a fraction of the locations indicated by geophysics really leads to actual exploitation. It would be a good thing when this was kept in mind in environmental and civil engineering applications as well.

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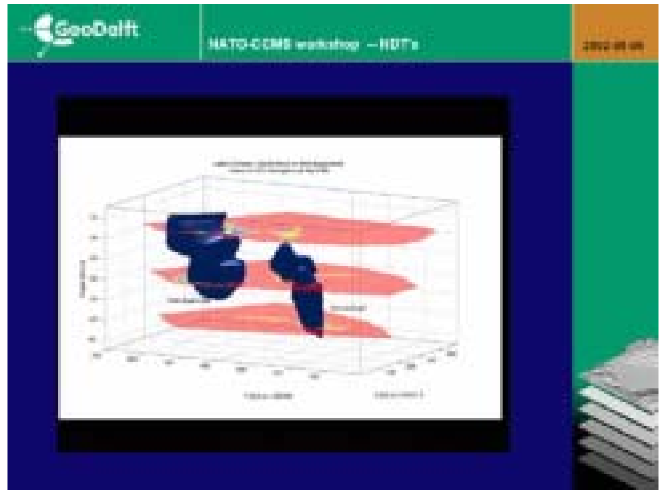
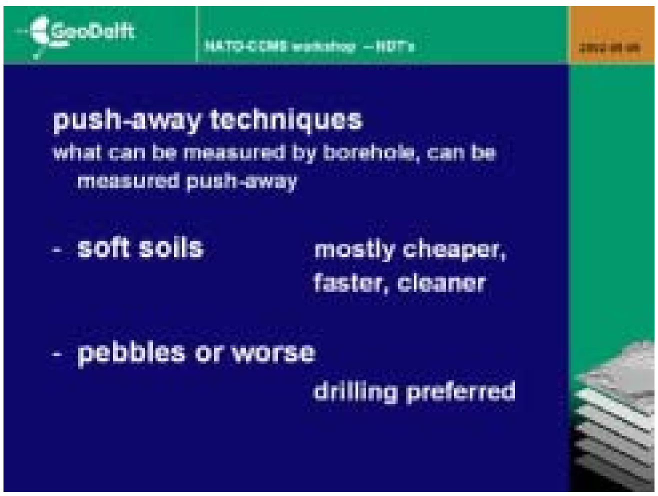
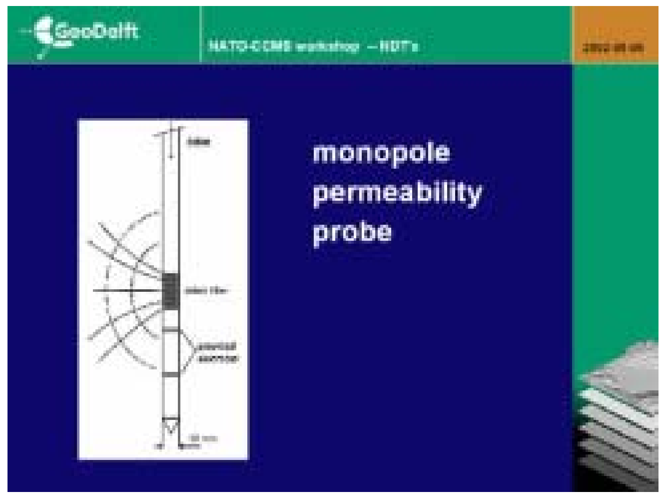
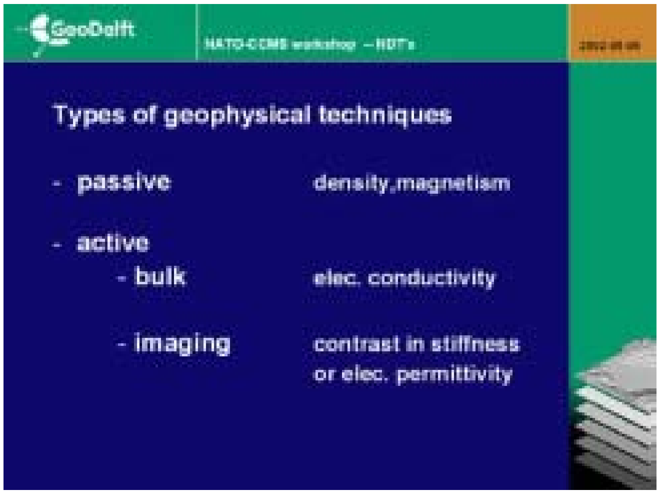
8. PRESENTATION VISUALS ~ *presented by Dr. Jurjen K. van Deen*



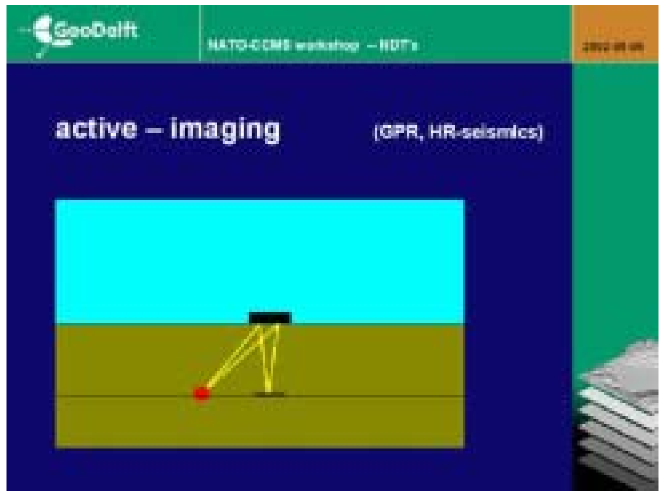





GeoDelft
NATO-CCMS workshop – NDT's
Types of geophysical techniques
- passive
density,magnetism
- active
- bulk
elec. conductivity
- imaging
contrast in stiffness
or elec. permittivity


GeoDelft
NATO-CCMS workshop – NDT's
passive
(magneto)


GeoDelft
NATO-CCMS workshop – NDT's
active – bulk
(geo-electric, EM)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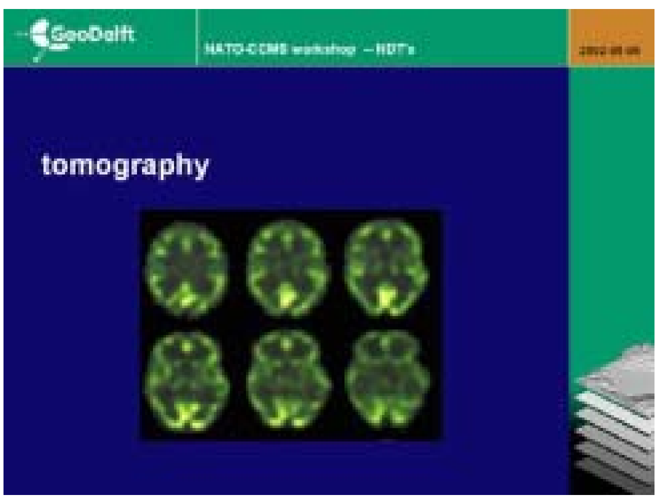
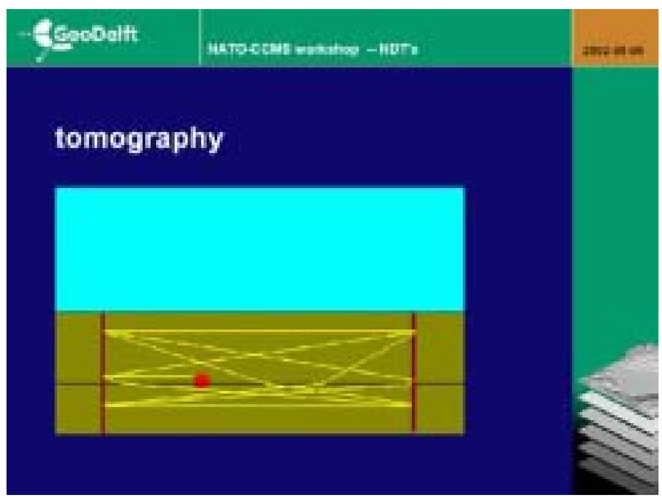
NATO-CCMS workshop – NDT's
active – imaging
(GPR, HR-seismics)


GeoDelft
NATO-CCMS workshop – NDT's
tomography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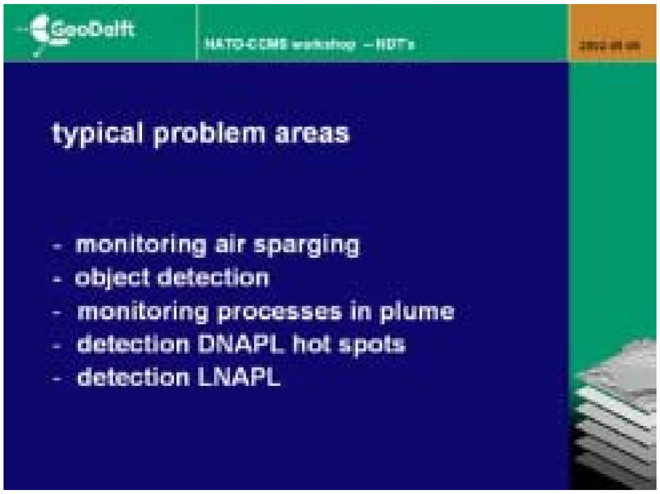
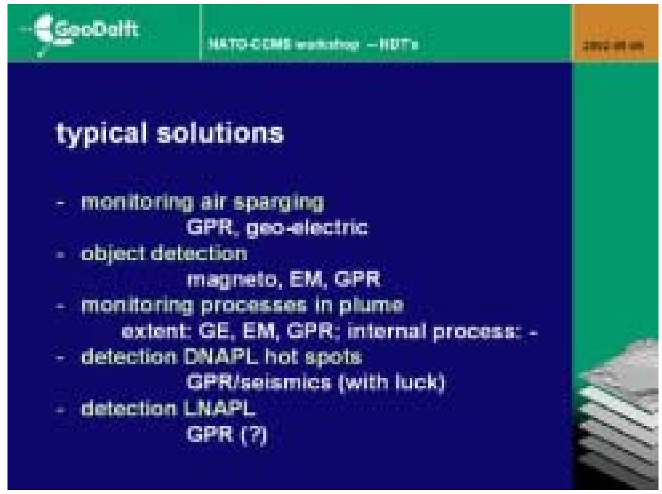
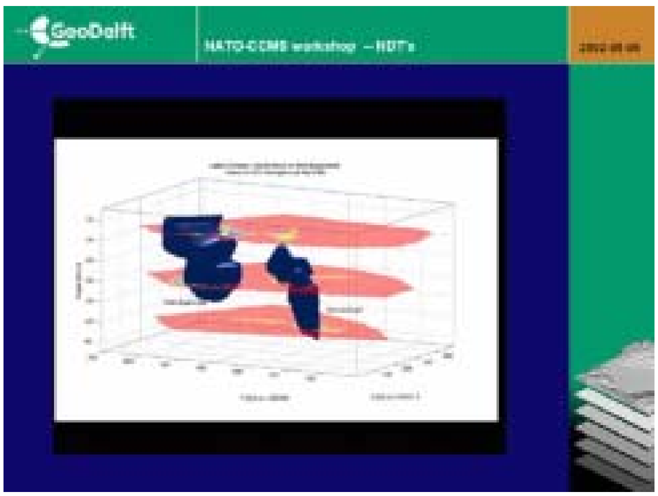
NATO-CCMS workshop – NDT's
tomography


GeoDelft
NATO-CCMS workshop – NDT's
typical problem areas
- monitoring air sparging
- object detection
- monitoring processes in plume
- detection DNAPL hot spots
- detection LNAPL


GeoDelft
NATO-CCMS workshop – NDT's
typical solutions
- monitoring air sparging
GPR, geo-electric
- object detection
magneto, EM, GPR
- monitoring processes in plume
extent: GE, EM, GPR; internal process: -
- detection DNAPL hot spots
GPR/seismics (with luck)
- detection LNAPL
GPR (?)


GeoDelft
NATO-CCMS workshop – NDT's

SAMPLING TECHNOLOGIES FOR SITE CHARACTERIZATION AND LONG-TERM MONITORING

Robert L. Siegrist[1]

1. OVERVIEW

Contamination of soil and groundwater by toxic chemicals is a widespread problem at industrial and military sites around the world. Effective site characterization and long-term monitoring that manage uncertainty are fundamental to remediation practices that protect public health and environmental quality with cost-effective expenditures of limited resources (Crumbling *et al.* 2001). For example, when a site is first discovered or alleged to be contaminated, site characterization activities must accurately delineate the current nature and extent of contamination in the subsurface and provide appropriate and adequate data to enable site cleanup goals to be established. Once cleanup goals are defined for a contaminated site, remediation technologies may be implemented and process monitoring is commonly critical to ensure proper operations. Following cleanup to a given end-state, longer term monitoring may be required to ensure no change in risk evolves during periods of years to decades.

Site characterization and monitoring involves several components and specific activities. Environmental sampling is one of the most critical components that can provide data to:

- Characterize contamination, if any, at a site following its initial discovery,
- Enable risk assessments to determine the need for cleanup and set cleanup goals,
- Enable control of technology function during cleanup operations,
- Help verify achievement of cleanup goals and termination of active cleanup, and
- Ensure that short-term cleanup performance is sustained over the long-term.

Sampling involves the definition of a problem domain and the observable members or population units within that domain (Figure 1). In specifying observable units within the domain requires consideration of the representative elemental volume (REV). This is a volume of environmental media that embodies all relevant features so that sampling and analyses of a single REV unit can be used for inferences about a site or a subpart thereof. The problem domain is normally comprised of multiple replicates of REV's that represent that domain. The size of a REV can vary from micro- (e.g., mm to cm) to macro-scales (e.g., m to km) and the number representing a site is highly dependent on the properties of the site and the contaminant release and distribution properties within that site. Sampling then involves specifying a position in space and time (known as a space-time framework) often followed by the physical acquisition and removal of a specimen upon which a measurement can be made either onsite or at a remote location. The samples so collected can include different media and be in the form of discrete samples (independent single points in space and time) or composite samples (combined multiple points in space and time), or subsamples of either of these. Sampling may also involve direct sensing or observation of a property of interest without physically acquiring or removing a "sample" per se from the environment. For example, volatile organic compounds (VOCs) can be measured using a probe that is inserted into groundwater within a monitoring well.

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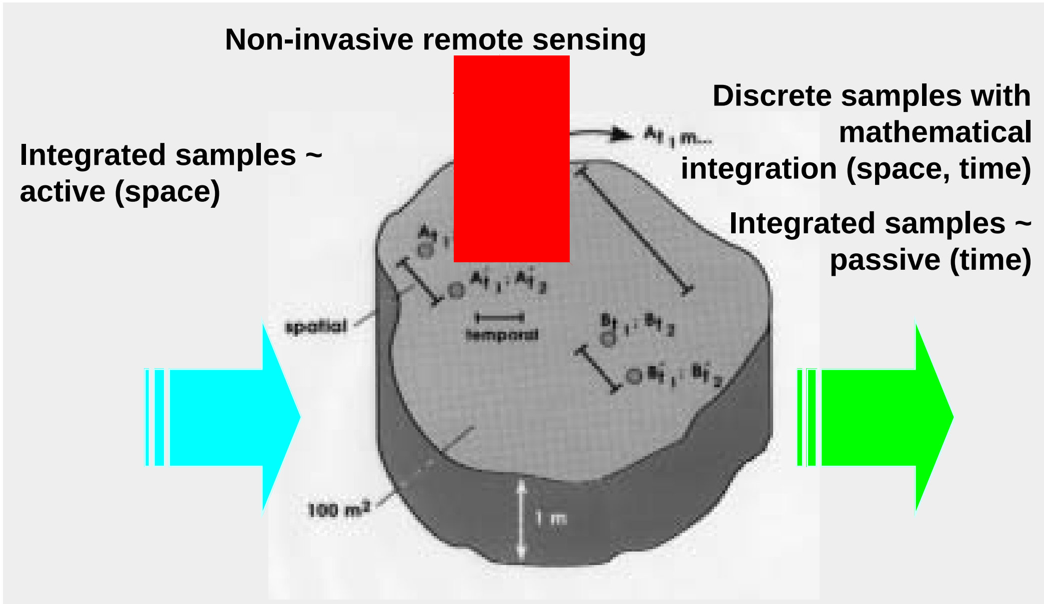
Figure 1. Features of a space-time framework for sampling at contaminated sites.



The toolbox for sampling technologies is large and still growing (e.g., USEPA 2002). It includes a wide array of devices and systems, many of which are designed for shallow subsurface sampling, drilling for sample acquisition, and direct-push insertion for sampling. Factors affecting which technologies and methods to are most suitable include (1) site location and access, (2) media to be sampled, (3) properties to be measured in the sampled media, (4) size and geometry of the domain to be sampled, and (5) duration and frequency of sampling required. Effective technologies enable acquisition of samples that are representative, meaning (1) the attribute of interest does not change as a result of sample acquisition and pre-analyses handling and (2) the attribute measured in a sample can be used to infer an attribute for the larger domain from which it was taken. Sampling technologies should minimize the cost of acquisition to maximize the number of space-time locations that can be observed, should be compatible with the property to be measured, and should enable measurements to be made in situ or onsite.

Effective sampling for characterization and monitoring at contaminated sites becomes more challenging under the following circumstances:

- Absence of information about the characteristics of the origin of contamination,
- Increasing size of the domain of interest in space and time,
- Increasing spatial and temporal heterogeneity of the environmental media and contaminant distribution,
- Contaminants are unstable and/or extremely costly to quantify (e.g., VOCs, redox-sensitive metals, and dense nonaqueous phase liquids (DNAPLs)), and
- Sampling is required to support critical and costly decisions that must necessarily be based on detailed and highly certain results.

Field investigations and laboratory research have demonstrated the importance of sampling to achieve accuracy and certainty when quantifying subsurface contamination (e.g., Siegrist and van Ee 1994, Crumbling *et al.* 2001). Examples of research involving sampling effects on quantifying VOCs and DNAPLs in soils are given in this presentation, including: (1) sampling and spatial modeling of trichloroethene (TCE) and 1,1,1-trichloroethane (TCA) in silty clay soil at a field site in Ohio (West *et al.* 1995), (2) sampling and analyses of TCE in sandy vadose zone soil during a laboratory study (Sheldon *et al.* 2000), and (3) sampling effects on quantifying DNAPLs in sand from a site in Florida. Some implications of these and related studies include the following. In subsurface samples containing VOCs like TCE, to avoid serious negative bias in quantifying concentrations, sampling must be done such that it minimizes media disruption and atmospheric exposure and samples must be immediately immersed directly into the analysis solvent (e.g., methanol). At DNAPL sites, under some conditions sampling effects (e.g., bias) can cause overestimates of the mass depletion of the DNAPL source that is actually achieved. In unsaturated soils, quantification errors may be more serious due to volatilization effects exacerbating negative bias. These and other results affirm the need for great care in sampling practices and also support the need for onsite and *in situ* measurements.

Sampling is a major component of site remediation and is critical to characterization and monitoring. Sampling includes issues and activities related to sample quantification (whether it involves physical acquisition or direct sensing) and also estimation of properties at un-observed locations in space and time. The toolbox for sampling technologies is large and growing. In general, technologies must minimize sampling-induced changes in the environmental media or properties of interest. As a result, direct-push sampling is equivalent to or better than conventional drilling and sampling methods and *in situ* and integrating approaches are needed. Careful application of multiple tools is critical to cost-effective characterization and long-term monitoring.

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3. PRESENTATION VISUALS ~ *presented by Robert L. Siegrist*

Sampling Technologies
~
Site Characterization and Long-Term Monitoring

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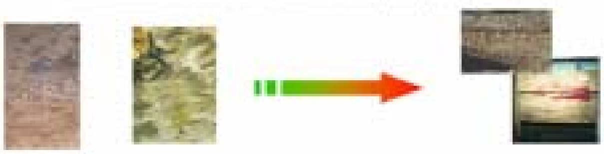
NATO/CCMS Country Representatives Meeting
Rome, Italy
5-10 May 2002

Sampling Framework

Contaminated Sites & Media

Sampling Framework

- Representative elemental volume (REV)
  - Volume of media that embodies all relevant features so that sampling and analyses of a single REV unit can be used for inferences
  - Domain of interest is comprised of multiple replicates of REV's representing that domain
  - REV's depend on heterogeneity and can vary from cm- to m- to km-scales depending on subsurface properties and contaminant release and distribution properties



Sampling Framework

- Why do we sample... ?
  - Provide a knowledge base from which inferences can be made regarding the entire population and domain of interest
  - Sampling is required for:
    - Characterizing the nature and extent of contamination
    - Risk assessments to determine the need for cleanup
    - Monitoring of process function during cleanup
    - Monitoring to verify achievement of cleanup goals
    - Long-term monitoring to verify performance

Sampling Framework

- What do we mean by "Sampling" ?
  - Environmental sampling consists of activities related to the definition of a problem domain and the observable members or population units within that domain
  - For most environmental studies, sampling involves specifying a position in either space or time, or both
  - This can be referred to as the "space-time framework" for environmental observation

Sampling Framework

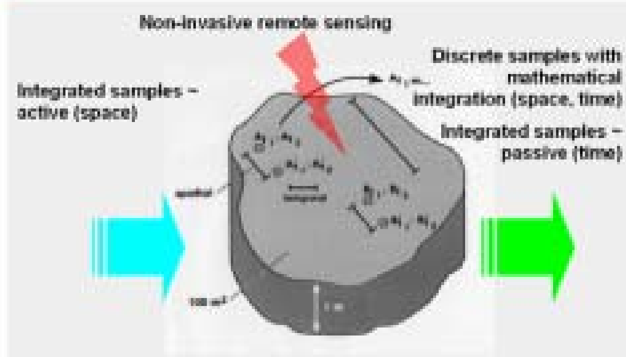
- Sampling can consist of the physical acquisition and removal of a specimen upon which a measurement is made either onsite or at a remote location
  - For example, a 1-L sample of water from a groundwater well can be taken and TCE then measured in it
- The samples collected and then analyzed can include different media and be in the form of:
  - Discrete samples
  - Composite samples, or
  - Subsamples of either of the above

Sampling Framework

- Sampling may also involve the direct sensing or observation of a property of interest without physically acquiring or removing a "sample" per se from the environment
  - For example, VOCs can be measured using a probe which is inserted into a groundwater well

Sampling Framework

- Features of a typical sampling domain

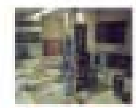


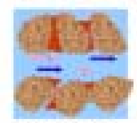
Sampling Technologies

- The "toolbox" for sampling technologies is quite large with a wide array of devices and systems
- Effective technologies enable acquisition of samples that are "representative"
  - Attribute of interest does not change as a result of sample acquisition and pre-analyses handling
  - Attribute measured in a sample can be used to infer an attribute of the larger domain from which it was taken
- Sampling technologies should
  - Minimize cost of acquisition to maximize number of locations
  - Be compatible with the property to be measured
  - Enable measurements to be made in situ or onsite

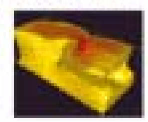
Sampling Technologies

- Factors affecting technologies and methodologies used
  - Site location and access
  - Media to be sampled (solids, water, air,...)
  - Properties to be measured in the sampled media
  - Size and geometry of the domain to be sampled
  - Duration and frequency of sampling required
  - Other....???





pH, TOC, VOCs, metals



Sampling Technologies

- Shallow subsurface sampling
  - Soil probes for gas sampling
  - Hand auguring for soil solids and gas diffusion wells
  - Backhoe test pits for profile analysis and sampling
  - Small drilling and probing equipment

Sampling Technologies

- Drilling for sample acquisition
  - Disturbed soil samples from flight augur cuttings
  - Intact soil cores by thin-tube or split-spoon samplers
  - Soil solution sampler emplacement (porous cups)
  - Groundwater well installation with screens and filter packs
  - Multi-level sampler installation (depth discriminating)
  - Side-wall sampler emplacement (depth discriminating)

Sampling Technologies

- Direct-push for sampling
  - Soil gas sampling
  - Intact soil cores
  - Ground water samplers
  - In situ measurements
    - Imaging, chemical probes,...

Sampling Challenges

- Effective sampling for characterization and monitoring becomes more challenging with:
  - Absence of information about the origin of contamination
  - Increasing size of the domain of interest in space and time
  - Increasing spatial and temporal heterogeneity of the environmental media and contaminant distribution
  - Sampling to quantify unstable contaminants, such as:
    - Volatile organic compounds (PCE, TCE, BTEX,...)
    - Redox-sensitive metals (Cr, As,...)
    - Nonaqueous phase liquids (DNAPLs)
  - Sampling to support decisions that require detailed and highly certain results and firm conclusions

Sampling is Critical

- Field investigations and laboratory research have demonstrated the importance of sampling to achieve accuracy and certainty when quantifying subsurface contamination
- Example experiences with VOCs and DNAPLs
  - Sampling and spatial modeling of TCE and TCA in silty clay soil at a field site in Ohio
  - Sampling and analysis of TCE in sandy vadose zones
  - Sampling effects on quantifying DNAPLs in sand from a site in Florida

Sampling Effects on VOCs

- Purpose and Approach
  - Determine the effect of sample acquisition and handling on quantifying TCE in silty clay soil at the Portsmouth X-231B site, Ohio
  - Abandoned land treatment site contaminated by VOCs (TCE, TCA,...)
  - Direct-push sampling (Geoprobe)
    - Micro-core subsampling, infield immersion in hexane, onsite GC analysis
    - Normal jar containerization plus offsite subsampling and GC analysis
  - Comparisons between methods plus spatial modeling

Sampling Effects on VOCs

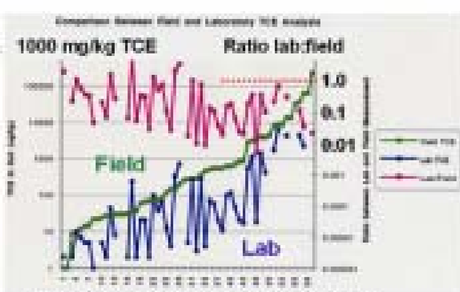
Direct-push sampling with micro-core subsampling

Field GC analyses

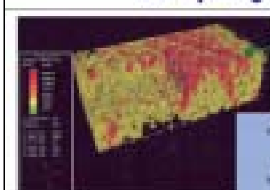
versus

Offsite lab GC analyses

TCE results from field analyses were 10 to 100x higher than lab analyses

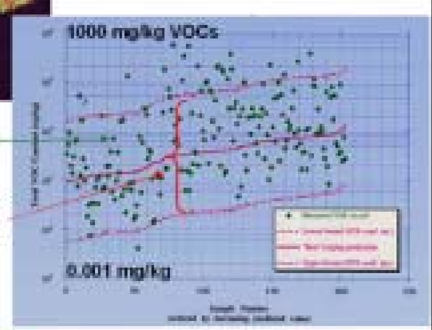


Sampling Effects on VOCs



Kriging geostatistical realization of VOCs based on soil sampling

200 samples in ~10,000 m² (1:50 m²)



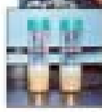
Measured VOCs in soil samples

Kriging predicted VOCs at discrete locations in soil +/- 95% C.I.

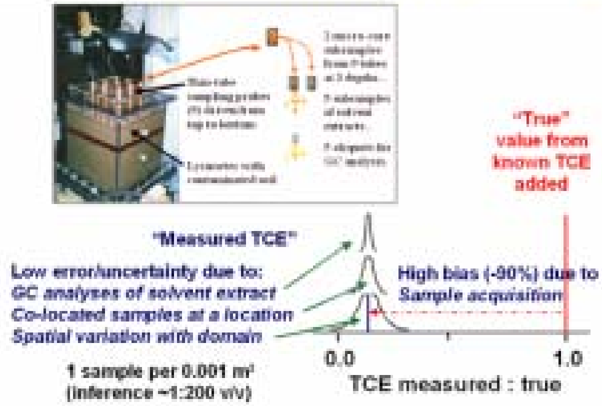
Need large nos. of samples to define VOCs in the domain

Sampling Effects on VOCs

- Purpose and Approach
  - Determine the effect of sample acquisition and handling on quantifying TCE in homogeneous, unsaturated sands
  - Controlled lab contamination of a sand tank by up-flow saturation with TCE in water followed by drainage
  - TCE mass present = TCE mass added - TCE mass in drainage
  - Sampling by direct-push, thin-tube methods with micro-core subsampling, direct immersion in hexane, and GC analysis
  - Comparisons of TCE measured at different locations, and to known TCE mass added

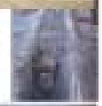


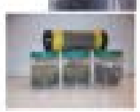
Sampling Effects on VOCs



Sampling Effects on DNAPLs

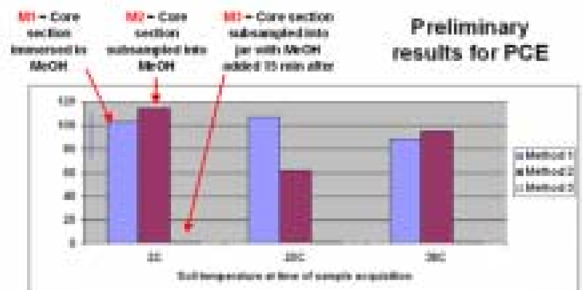
- Purpose and Approach
  - Determine the effect of sample acquisition and handling on quantifying TCE and PCE DNAPLs in sand from the Cape Canaveral LC-34 site
  - Contamination at 0.3x and 3x DNAPL saturation
  - Temperatures of 2, 18, and 38C
  - Four sample acquisition methods:
    - Core section immersed in MeOH
    - Core section subsampled into MeOH
    - Core section subsampled into jar then MeOH
  - Gas chromatography analyses
  - Comparisons between methods plus known mass added and whole core extraction in MeOH





Sampling Effects on DNAPLs

- Findings summary (preliminary)
  - Sample disruption and exposure can dramatically affect PCE and TCE levels measured and magnitude of negative bias
  - Temperature effects were modest for conditions observed



Sampling Effects

- Some implications of sampling effects...
  - In subsurface samples containing PCE and TCE, to avoid serious bias in quantifying concentrations,
    - minimize media disruption and atmospheric exposure
    - immediately immerse into the analysis solvent (methanol)
  - At DNAPL sites, sampling effects can cause over-estimates of the source mass depletion actually achieved (e.g., estimate 95% when substantially less is achieved)
  - In unsaturated soils, quantification error may be more serious due to volatilization effects
  - Results affirms need for great care in sampling practices and also the need for in situ measurements
  - R&D is needed to support improved standard practices

Closing Remarks

- Sampling is a major component of site remediation and is critical to characterization and monitoring
- Sampling issues: (1) sample quantitation plus (2) estimation at un-observed locations in space and time
- Toolbox of sampling technologies is large and growing
- Sampling technologies should minimize changes in media or properties of interest as a result of sampling
- Direct-push sampling is equivalent or better than conventional drilling and sampling methods
- *In situ* and integrating approaches are needed
- Careful application of multiple tools is critical to cost-effective characterization and long-term monitoring

THE SELECTION AND USE OF FIELD ANALYTICAL TECHNOLOGIES FOR TECHNICALLY SOUND DECISIONS AT CONTAMINATED SITES AN ANNOTED OUTLINE

Wayne Einfeld[1]

The following outline discusses some critical issues in a question and answer format that should be considered prior to the deployment and use of field analytical technologies for contaminated site characterization or monitoring. A summary overview of the various field portable analytical technologies is also included.

1. WHAT ARE THE KEY COMPONENTS IN THE DATA QUALITY OBJECTIVE PROCESS?

Application of the data quality objective (DQO) process is fundamental to the successful use of field analytical methods. The DQO process is a methodical approach used to facilitate technically sound project decisions and the ultimate achievement of an acceptable project end point. The key element in the DQO process is the development of a decision rule, which is essentially a quantitative statement of the project objective. Other key components in the process that support the development and use of the decision rule are given below:

∉ Qualitatively define the decision that needs to be made
∉ Further define the decision in quantitative terms using a decision rule
∉ Define the limits on the error associated with the decision rule
∉ Identify the measurement data necessary to support the decision rule

2. WHAT DECISION NEEDS TO BE MADE USING THE DATE FROM ON-SITE MEASURMENTS?

The data quality objective process (DQO) can help in the transition from a qualitative problem statement to a quantitative framework through the use of decision rules and their associated margins of error. This quantitative problem statement or decision rule helps sets the stage for selection and use of field analytical methods.

∉ Example qualitative decision rule: If TCE levels increase in the down-gradient monitoring wells, remedial action may be required
∉ Example quantitative decision rule: If the average concentration of TCE at any down-gradient well is greater than 50 σg/L then remedial action is required. A 5% chance of designating a well sample "clean" when in fact it is "dirty" is acceptable. Similarly, a 15% chance of designating a "clean" sample "dirty" is also acceptable.

The development of such a decision rule will help in the selection of measurement technologies and in the determination of the sample size necessary to generate the data needed to make the decision. Field analytical methods may be an appropriate choice to generate the data that are used to make these critical decisions. Some typical applications are listed below:

∉ Identify a "clean" or "dirty" site
∉ Identify or map a subsurface contaminant plume
∉ Conduct a real-time, on-site determination of the adequacy of an ongoing treatment process for contaminant removal

[1] Sandia National Laboratories

- Generate data that will support a decision as to whether contaminant cleanup levels have been reached and formal site closure can occur.
- Conduct periodic long-term monitoring for assessment of contaminant stability at a closed site

3. WHAT LEVEL OF UNCERTAINTY IS TOLERABLE AT THE DECISION POINT?

All measurements have associated uncertainty and these may translate into decision errors. For example, declaring a site clean when in fact it is dirty (false negative) or, declaring a site dirty when in fact it is clean (false positive) are both decision errors influenced by sampling and analytical uncertainty. The acceptable errors, set during the DQO process will influence both the choice of the sampling and analytical method and the number of samples needed from the site. Important concepts and considerations related to overall uncertainty include:

- Confidence interval about a mean measurement value
- Tolerance for false positives (declaring dirty when in fact clean)
- Tolerance for false negatives (declaring clean when in fact dirty)
- Tolerable error levels may be specified in regulations or may require good judgment (e.g. statistical best practice)
- Performance measures of candidate analytical methods, such as accuracy and precision, are necessary in order to best apply the DQO process.
- The combination of sampling error and analytical error will strongly influence the overall uncertainty in a measurement
- Often the sampling error is large in comparison to the analytical error
- The combined accuracy and precision of the candidate sampling and analytical methods should be known in order to best apply the DQO process.

4. WHAT ARE THE VARIOUS CONSTRAINTS ASSOCIATED WITH THE USE OF FIELD ANALYTICAL METHODS?

Site characterization, monitoring, and cleanup projects that may utilize field analytical instrumentation will necessarily have a number of associated constraints. They will likely include the some or all of following:

- Budget
- Schedule
- Regulatory requirements for a specific method
- Availability of field analytical measurement equipment
- Cost of rental or procurement of field analytical equipment
- Requirement to interface with other scheduled events at the site
- Contractual obligations (e.g. lab services may be designated in the overall site cleanup contract)
- Regulatory acceptance of innovative or alternative methods
- Availability of performance attributes (e.g. accuracy and precision) of the candidate field analytical methods

5. WHAT IS KNOWN ABOUT THE CONTAMINANTS AT THE SITE?

Prior to the initiation of work at a site, it is important to ascertain as much as possible about the site prior to any measurement campaigns. This information can be used to build a conceptual site model and assist in the development of a technically sound overall project strategy. Sources of information may include the following:

- Legal records
- Other archived corporate site historical data

- Previous environmental measurements
- Experience from similar site operations at other locations
- Other sources of information (e.g. personal interviews)

6. WHAT GENERAL MEASUREMENT APPROACHES ARE AVAILABLE FOR USE?

In the development of a site measurement plan, careful consideration should be given to all of the available options for measurement options. The optimum solution might include a blend of various approaches. Cost tradeoffs between the various options may not be clearly obvious. In many cases the use of the field analytical methods may be nearly equivalent to the off-site laboratory approach in terms of direct costs. Cost savings through field analytical approaches are often seen in indirect ways such as: a reduced overall deployment time on site; a reduction in the need for multiple deployments of sampling crews at a site; or expedited site characterization/remediation by virtue of near real-time measurements onsite combined with a dynamic workplan. The general measurement approaches that can be applied are listed below:

- Fixed off-site laboratory
- On-site mobile laboratory
- Field-portable instrumentation with *ex-situ* samples
- Field-portable instrumentation with *in-situ* samples
- Conventional sampling (e.g. drilling)
- Innovative sampling and analysis (e.g. direct push + *in-situ* probes)

7. WHAT ARE THE ADVANTAGES AND LIMITATIONS OF FIELD PORTABLE METHODS?

The selection of a field analytical approach brings with it both advantages and disadvantages. In most instances, the advantages outweigh and disadvantages such that the overall field analytical approach is desirable and will expedite site characterization and project completion. Important advantages and limitations are listed below:

Advantages

- Quick-turnaround, timely information
- Detection limits generally below risk-based action levels
- Sample preservation and shipping issues can be minimized
- Compatible with the dynamic planning process (e.g. the ability to change the overall investigation plan based on new, timely information)
- Lower per sample cost and analysis speed may enable a higher sample density at the site thereby resulting in a more thorough site characterization
- Technology can be targeted at specific analytes for increased speed
- May be able to operate field analytical methods with existing field crews thereby avoiding the need for a separate analysis crew

Disadvantages

- Potential for additional training of field crews
- Field-portable systems may not be readily accessible
- Regulator distrust or outright rejection of innovative field analytical methods may occur
- Some field analytical methods may have reduced precision and accuracy when compared to conventional laboratory methods
- Some level of confirmatory off-site laboratory analysis may be advisable

- Unknown contaminants may be encountered which are outside the analytical scope of the field analytical method
- Performance attributes (e.g. precision and accuracy) of some of the newer field analytical technologies may not be known

8. WHAT ARE SOME OF THE FIELD-PORTABLE TECHNOLOGIES AVAILABLE FOR USE (SORTED BY CHEMICAL CLASS)?

Geophysical Technologies

- Ground Penetrating Radar
- Electromagnetometry Survey
- Magnetometer Survey
- Seismic Survey
- Borehole Geophysical Survey

Metals

- Field portable x-ray fluorescence
- Field-portable electrochemical methods (Anodic stripping voltametry, ion specific electrodes)
- Hand-held mercury analyzers
- Colorimetric tests

Inorganics (nitrate, sulfates, etc.)

- Electrochemical *in-situ* analyzers for water applications
- Colorimetric test kits

Semi-volatile Organics

- Fluorescence analyzers for BTEX or other aromatic hydrocarbons in soil
- Immunoassay kits for PCBs, pesticides, and explosive residues
- Field-portable reagent kits
- Field portable GC and GC/MS (with temperature programming)
- CPT with LIF for aromatic hydrocarbons

Volatile Organics

- Photoacoustic spectrometers
- Handheld photoionization and flame ionization detectors
- Field portable GC and GC/MS
- Field-portable reagent kits
- Field portable FTIR spectrometers
- Direct push sampling and analysis with MIP

9. WHERE CAN I FIND MORE INFORMATION ON FIELD ANALYTICAL METHODS?

- US EPA Technology Innovation Office
  www.epa.gov/tio

- US EPA Superfund Field Analytical Technologies
  www.epa.gov/superfund/programs/dfa/fldmeth.htm

- US EPA, Field Analytical Technologies Encyclopedia
  http://fate.clu-in.org/

- US EPA REACHIT Technologies and Applications Database
  http://www.epareachit.org/index.html

- The Triad approach to Site Characterization and Remediation:
  http://www.epa.gov/swertio1/pubichar.htm

- Case Studies Involving Field Analytical Methods
  http://www.epa.gov/tio/chartext_edu.htm#case

- US EPA Environmental Technology Verification Program (ETV)
  www.epa.gov/etv

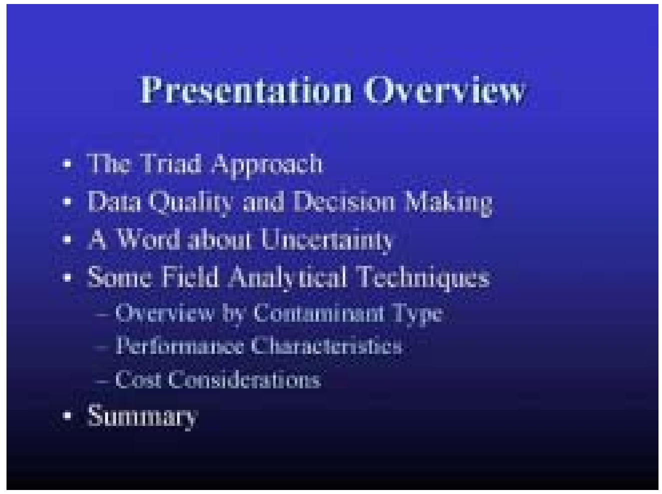
- U.S. Department of Defense Environmental Science Technology Certification Program (ESTCP)
  http://www.estcp.org/index.cfm

For More Information Contact:

Wayne Einfeld, Sandia National Laboratories
Phone: 505/845-8314 E-mail: weinfel@sandia.gov

Eric Koglin, US EPA Office of Research and Development
Phone: 702/798-2432 E-mail: koglin.eric@epamail.epa.gov

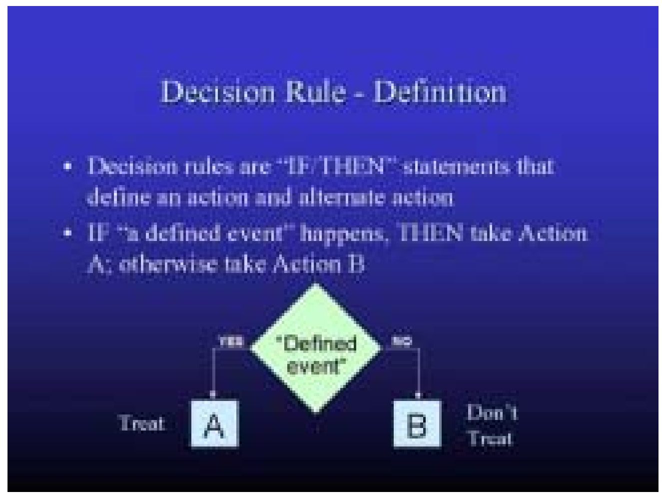
10. PRESENTATION VISUALS ~ *presented by Wayne Einfeld*

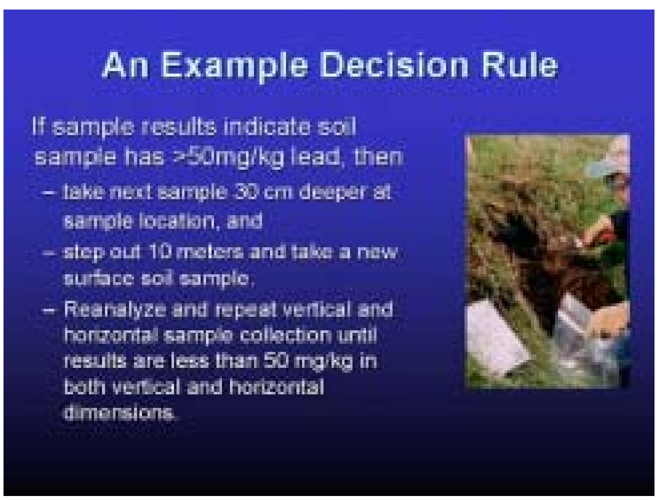


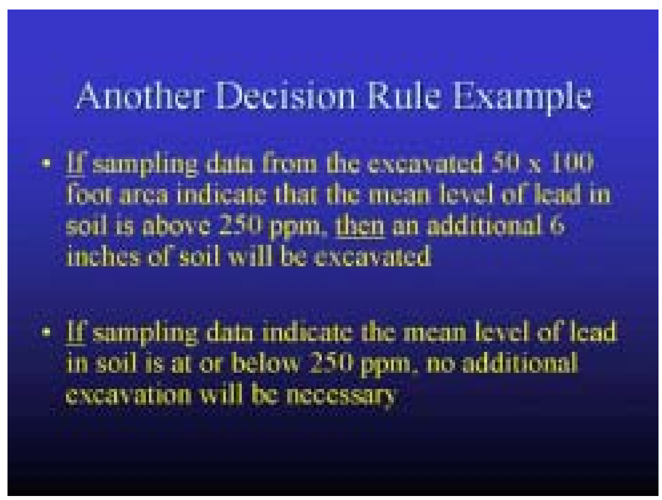

Data QualityTerminology
• Data Quality Objectives (DQO) Process - A systematic, iterative, and flexible planning process conceptually identical to the scientific method
• Data Quality Objectives - Qualitative and quantitative statements that translate non-technical project goals into technical project-specific decision goals


The DQO Process
Project Planning/SAP Development
Project Decisions
DQOs
MQOs
QC Protocol
Data
Data Interpretation/Project Completion
All data generation activities are derived from the
Project Decisions
so that data interpretation will lead to and directly support the
Project Decisions

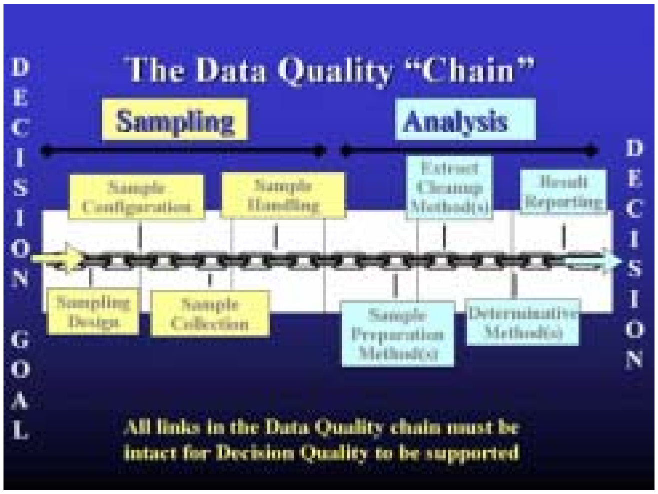

Seven Stages of DQO Planning
Step 1: State the Problem to Be Addressed
Step 2: Identify the Decision(s) to Be Made
Step 3: Identify All the Inputs to the Decision(s)
Step 4: Narrow the Boundaries of the Study
Step 5: Develop Decision Rule(s)
Step 6: Develop Uncertainty Constraints
Step 7: Optimize the Design for Obtaining Data

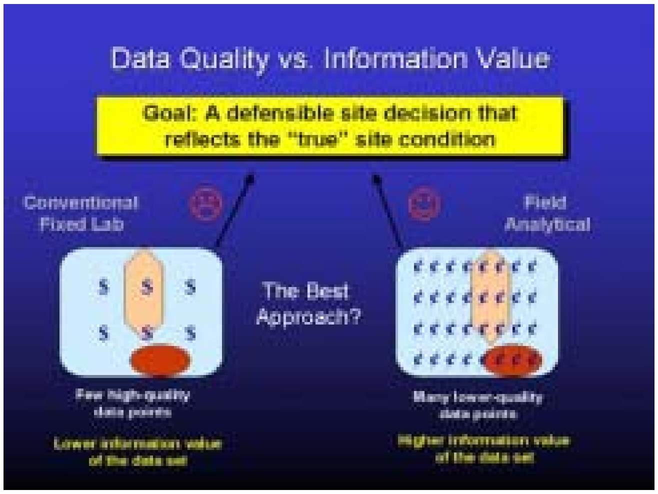

Decision Rule - Definition
• Decision rules are "IF/THEN" statements that define an action and alternate action
• IF "a defined event" happens, THEN take Action A; otherwise take Action B
YES
"Defined event"
NO
Treat
A
B
Don't Treat

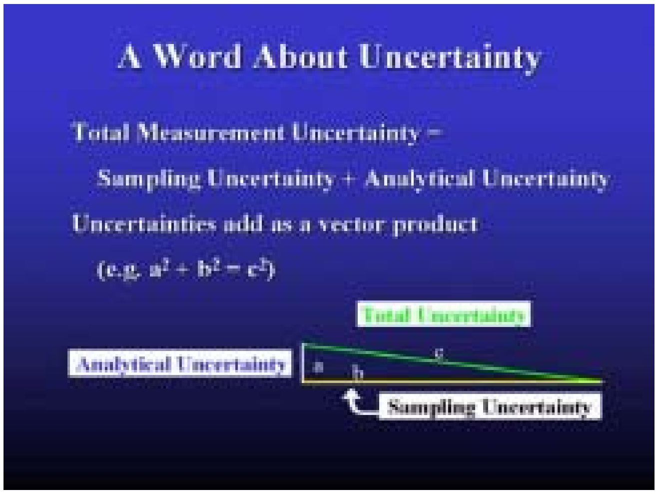

An Example Decision Rule
If sample results indicate soil sample has >50mg/kg lead, then
– take next sample 30 cm deeper at sample location, and
– step out 10 meters and take a new surface soil sample.
– Reanalyze and repeat vertical and horizontal sample collection until results are less than 50 mg/kg in both vertical and horizontal dimensions.

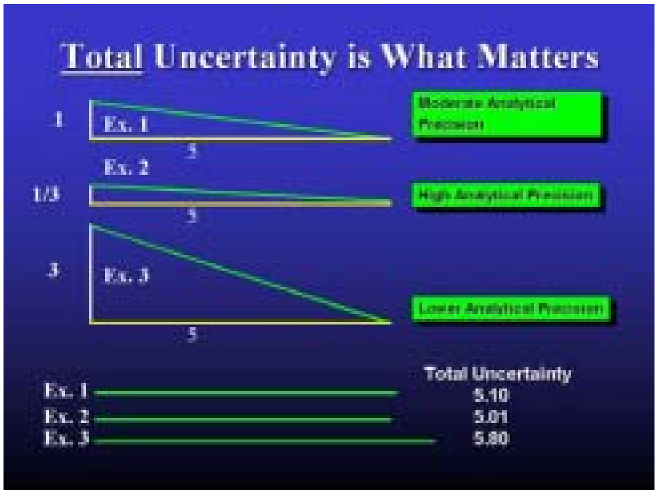

Another Decision Rule Example
• If sampling data from the excavated 50 x 100 foot area indicate that the mean level of lead in soil is above 250 ppm, then an additional 6 inches of soil will be excavated
• If sampling data indicate the mean level of lead in soil is at or below 250 ppm, no additional excavation will be necessary

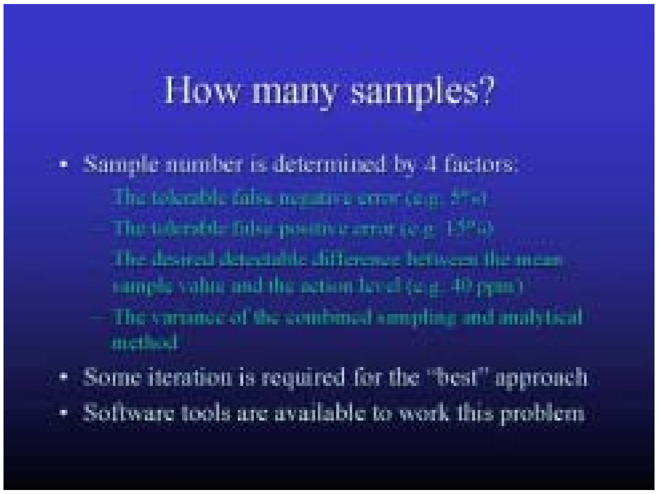

How Good is Your Data?
Perfect Analytical Chemistry
+
Non-Representative Sample
"BAD" DATA
Must Distinguish Analytical Data Quality from Overall Data Quality


The Data Quality "Chain"
DECISION GOAL
Sampling
Analysis
Sample Configuration
Sample Handling
Extract Cleanup Method(s)
Result Reporting
Sampling Design
Sample Collection
Sample Preparation Method(s)
Determinative Method(s)
DECISION
All links in the Data Quality chain must be intact for Decision Quality to be supported


Data Quality vs. Information Value
Goal: A defensible site decision that reflects the "true" site condition
Conventional Fixed Lab
Field Analytical
The Best Approach?
Few high-quality data points
Lower information value of the data set
Many lower-quality data points
Higher information value of the data set

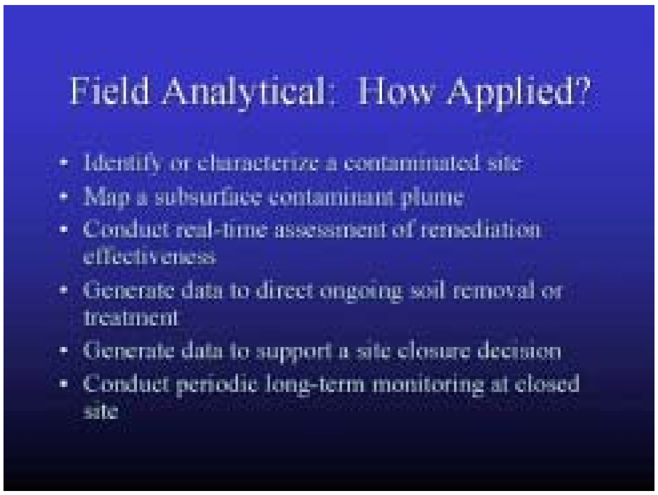

A Word About Uncertainty
Total Measurement Uncertainty =
Sampling Uncertainty + Analytical Uncertainty
Uncertainties add as a vector product
(e.g. a² + b² = c²)
Total Uncertainty
Analytical Uncertainty
a
b
c
Sampling Uncertainty


Total Uncertainty is What Matters
1
Ex. 1
5
Moderate Analytical Precision
Ex. 2
1/3
5
High Analytical Precision
3
Ex. 3
5
Lower Analytical Precision
Total Uncertainty
Ex. 1 5.10
Ex. 2 5.01
Ex. 3 5.80


How many samples?
Sample number is determined by 4 factors:
The tolerable false negative error (e.g. 5%)
The tolerable false positive error (e.g. 15%)
The desired detectable difference between the mean sample value and the action level (e.g. 40 ppm)
The variance of the combined sampling and analytical method
Some iteration is required for the "best" approach
Software tools are available to work this problem


Why Field Analytical?
• Advantages
– Quick-turnaround, timely information
– Generally adequate detection limits
– Generally adequate precision
– Avoid sample preservation and shipping
– Compatible with dynamic planning process
– Lower per sample cost => higher sample density
– Use same sampling and analysis crew


Why Field Analytical?
• Limitations
– Field analytical systems readily available?
– Additional cost of procurement or rental
– Regulatory distrust or outright rejection
– Documented and adequate accuracy and precision?
– Some confirmatory analysis may be required
– Additional crew training may be necessary

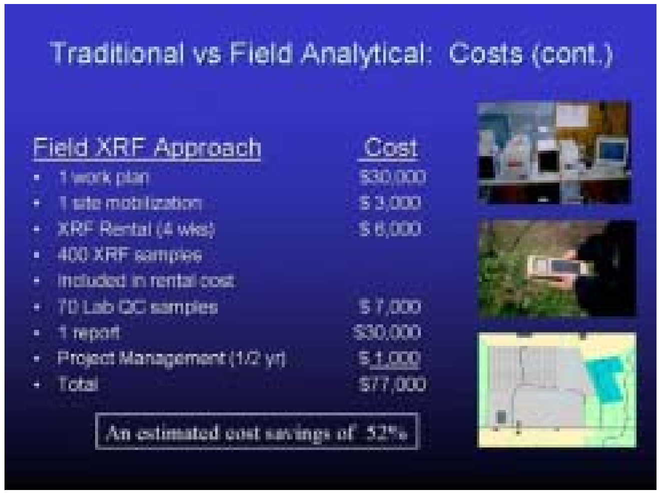

Field Analytical: How Applied?
• Identify or characterize a contaminated site
• Map a subsurface contaminant plume
• Conduct real-time assessment of remediation effectiveness
• Generate data to direct ongoing soil removal or treatment
• Generate data to support a site closure decision
• Conduct periodic long-term monitoring at closed site

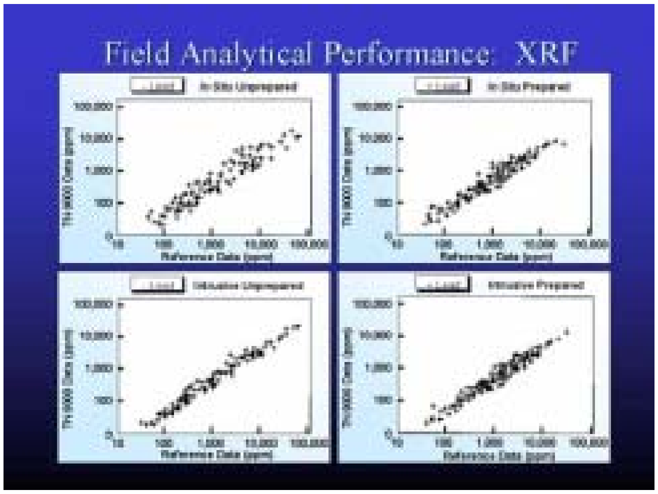

Field Analytical: What's Available
Metals
– X-ray fluorescence
– Anodic stripping voltammetry
– Hand-held mercury analyzers
– Colorimetric test kits

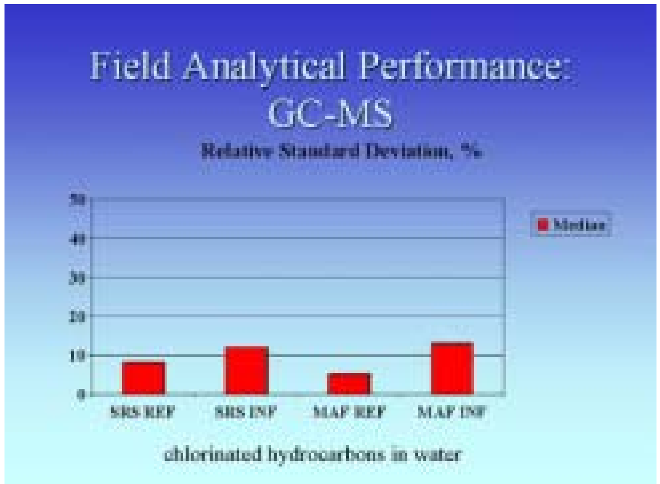

Field Analytical: What's Available?
Volatile Organics
– Photo-acoustic spectrometers
– GC and GC-MS
– Photo-ionization detectors
– Reagent test kits

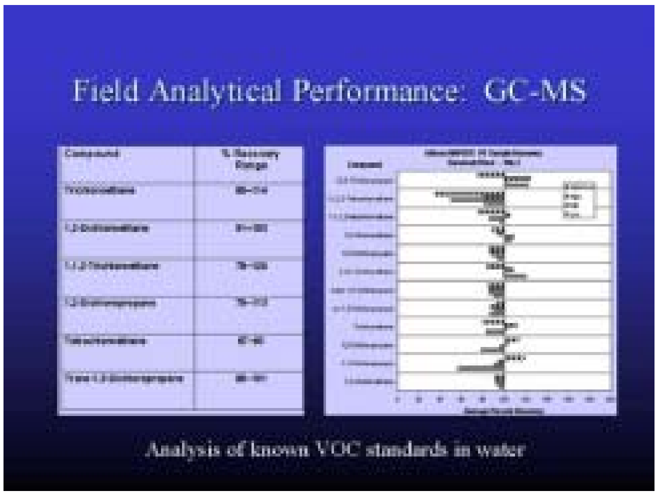

Field Analytical: What's Available?
Semi-volatile Organics
– Fluorescence analyzers
– Immunoassay kits
– Reagent kits
– GC-IMS
– CPT-LIF

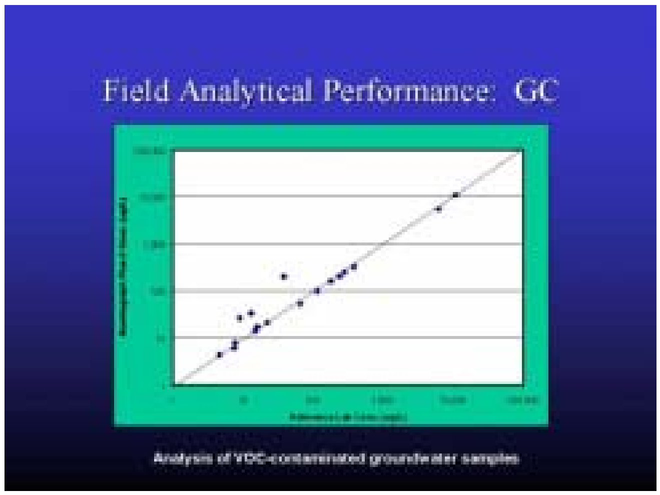

Traditional vs Field Analytical: Costs
Problem: Perform full characterization of 8 historic firing ranges for heavy metals at the Presidio of San Francisco.
Traditional Approach
Cost
1 work plan, 2 addenda
$54,000
3 site mobilizations
$ 9,000
400 samples
$40,000
1 report, 2 addenda
$54,000
~ 11/2 year project management
$ 5,000
Total
$162,000


Traditional vs Field Analytical: Costs (cont.)
Field XRF Approach
Cost
1 work plan
$30,000
1 site mobilization
$ 3,000
XRF Rental (4 wks)
$ 6,000
400 XRF samples
Included in rental cost
70 Lab QC samples
$ 7,000
1 report
$30,000
Project Management (1/2 yr)
$ 1,000
Total
$77,000
An estimated cost savings of 52%

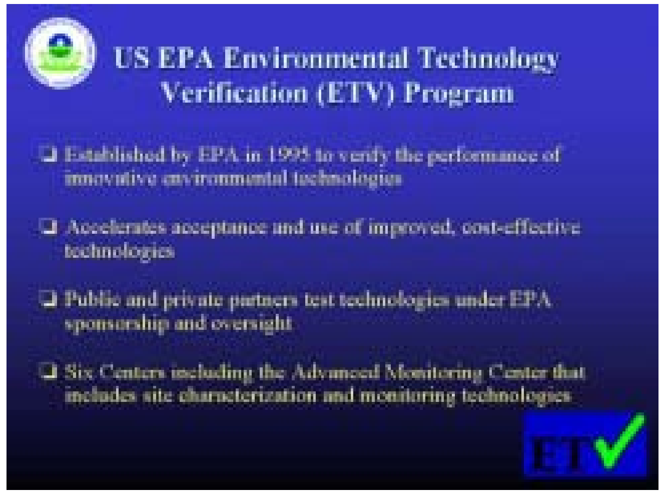

Field Analytical Performance: XRF
In-Situ Unprepared
In-Situ Prepared
Intrusive Unprepared
Intrusive Prepared
Reference Data (ppm)


Field Analytical Performance: GC-MS
Relative Standard Deviation, %
Median
SRS REF
SRS INF
MAF REF
MAF INF
chlorinated hydrocarbons in water

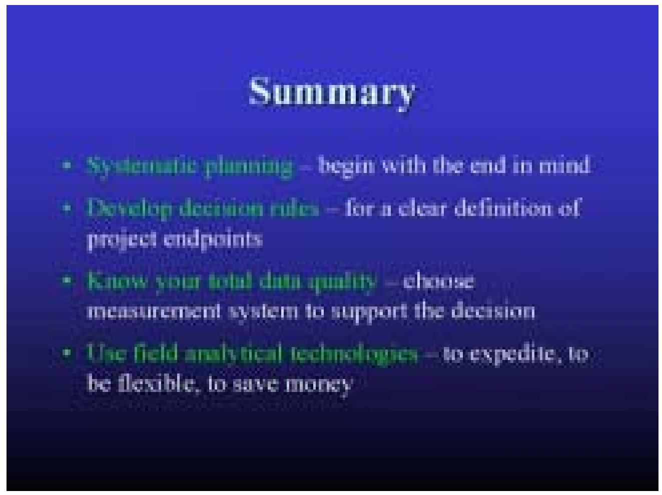

Field Analytical Performance: GC-MS
Analysis of known VOC standards in water


Field Analytical Performance: GC
Analysis of VOC-contaminated groundwater samples


Field Analytical Performance Parameters
Should be known for project planning and DQO development
– Estimate
– Self-test
– Consult user community
– US EPA Environmental Technology Verification Program and other technology demonstration programs


US EPA Environmental Technology Verification (ETV) Program
Established by EPA in 1995 to verify the performance of innovative environmental technologies
Accelerates acceptance and use of improved, cost-effective technologies
Public and private partners test technologies under EPA sponsorship and oversight
Six Centers including the Advanced Monitoring Center that includes site characterization and monitoring technologies
ETV


For more information on ETV...
ETV Site Characterization and Monitoring Technologies Center information is at the US EPA web site
www.epa.gov/etv
The web site contains:
Technology categories
Test schedules
Test plans
Report summaries
Complete reports
Center news


Summary
Systematic planning – begin with the end in mind
Develop decision rules – for a clear definition of project endpoints
Know your total data quality – choose measurement system to support the decision
Use field analytical technologies – to expedite, to be flexible, to save money

CURRENT PERSPECTIVES IN SITE REMEDIATION AND MONITORING: USING THE TRIAD APPROACH TO IMPROVE THE COST-EFFECTIVENESS OF HAZARDOUS WASTE SITE CLEANUPS

Deana M. Crumbling[1]

1. EXECUTIVE SUMMARY

U.S. EPA's Office of Solid Waste and Emergency Response is promoting more effective strategies for characterizing, monitoring, and cleaning up hazardous waste sites. In particular, the adoption of a new paradigm holds the promise for better decision-making at waste sites. This paradigm is based on using an integrated triad of systematic planning, dynamic work plans, and real-time measurement technologies to plan and implement data collection and technical decision-making at hazardous waste sites. A central theme of the triad approach is a clear focus on overall decision quality as the overarching goal of project quality assurance, requiring careful identification and management of potential causes for errors in decision-making (i.e., sources of uncertainty).

2. PERSPECTIVE

EPA's Office of Solid Waste and Emergency Response (OSWER) manages the Superfund, RCRA Corrective Action, Federal Facilities, Underground Storage Tank, and Brownfields programs. "Smarter solutions" for the technical evaluation and cleanup of such contaminated sites can take two major forms. One is through the adoption of new technologies and tools; the other is to modernize the strategy by which tools are deployed. Both are connected in a feedback loop, since strategy shifts are both fueled by and fuel the evolution of innovative technology. In the area of hazardous waste site monitoring and measurement, new technologies have become available with documented performance showing them capable of substantially improving the cost-effectiveness of site characterization.

The current traditional phased engineering approach to site investigation (mobilize staff and equipment to a site, take samples to send off to a lab, wait for results to come back and be interpreted, then re-mobilize to collect additional samples, and repeat one or more times) can be incrementally improved by the occasional use of on-site analysis to screen samples so that expensive off-site analysis is reserved for more critical samples. Yet, as discussed elsewhere, integration of new tools into site cleanup practices faces an array of obstacles [1]. If the cost savings promised by new technologies is to be realized, a fundamental change in thinking is needed. Faster acceptance of cost-effective characterization and monitoring tools among practitioners is even more important now that Brownfields and Voluntary Cleanup Programs are gaining in importance. For these programs that focus on site redevelopment and reuse, factors such as time, cost, and quality are of prime concern. Modernization of the fundamental precepts underlying characterization and cleanup practices offers cost savings of about 50% while simultaneously improving the quality of site decision-making.

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

- it would be driven by achieving performance, rather than by complying with checklists that do not add value;
- it would use transparent, logical reasoning to articulate project goals, state assumptions, plan site activities, derive conclusions, and make defensible decisions;
- it would value the need for a team of technical experts in the scientific, mathematical, and engineering disciplines required to competently manage the complex issues of hazardous waste sites;
- it would require regular continuing education of its practitioners, especially in rapidly evolving areas of practice;

[1] U.S. Environmental Protection Agency, Technology Innovation Office, Washington, DC

- ∉ its practitioners would be able to logically evaluate the appropriateness of an innovative technology with respect to project-specific conditions and prior technology performance, with residual areas of uncertainty being identified and addressed; and
- ∉ it would reward responsible risk-taking by practitioners who would not fear to ask, "why don't we look into...?" or "what if we tried...?"

What form might such an idealized model take? A major step toward this goal would involve institutionalizing the triad of systematic planning, dynamic work plans, and real-time analysis as the foundation upon which cost-effective, defensible site decisions and actions are built. None of the concepts in the triad are new, but the boost given by computerization to technology advancement in recent years is now providing strategy options that did not exist before. Pockets of forward-thinking practitioners are already successfully using this triad; the concept is proven.

3. THE TRIAD'S FIRST COMPONENT: SYSTEMATIC PLANNING

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

Systematic planning is the scaffold around which defensible site decisions are constructed. The essence of systematic planning is asking the right questions and coming up with a strategy to best to answer them. It requires that for every planned action the responsible individual can clearly answer the question, "Why am I doing this?" First and foremost, planning requires that key decision-makers collaborate with stakeholders to resolve clear goals for a project. A team of *multi-disciplinary, experienced technical staff* then works to translate those goals into realistic technical objectives. The need for appropriately educated, knowledgeable practitioners from *all* disciplines relevant to the site's needs is vital to cost-effective project success.

A. Multi-disciplinary Technical Team

During the planning phase, the most resource-effective characterization tools for collecting data are identified by technically qualified staff that is familiar with both the established and innovative technology tools of their discipline. For example, the hydrogeologist will be conversant not only with the performance and cost issues of well drilling techniques, but also with the more innovative and (generally) less costly direct push technologies entering common use. The sampling design expert will understand how uncertainties due to sampling considerations (where, when, and how samples are collected) impact the representativeness of data generated from those samples, and thus the ability of those samples to provide accurate site information [4]. The team's analytical chemist will not only know the relative merits of various traditional sample preservation, preparation, and analysis methods, but also the strengths and limitations of innovative techniques, including on-site analytical options. The chemist's responsibilities include designing the quality control (QC) protocols that reconcile project-specific data needs with the abilities of the selected analytical tools. When risk assessment is part of a project, involvement of the risk assessor at the beginning of project planning is vital to ensure that a meaningful data will be available for risk assessment purposes. Other technical experts might include (depending on the nature of the project) regulatory experts, soil scientists, geochemists, statisticians, wildlife biologists, ecologists, and others. When project planners wish to express the desired decision confidence objectively and rigorously in terms of a statistical certainty level, statistical expertise is required to translate that overall decision goal into data generation strategies. Demonstrating overall statistical confidence in decisions based on environmental data sets will require the cost-effective blending of the:

- number of samples,
- expected variability in the matrix (i.e., matrix heterogeneity),
- analytical data quality (e.g., precision, quantitation limits, and other attributes of analytical quality) [5],
- expected contaminant concentrations (i.e., how close are they expected to be to regulatory limits),
- sampling strategy (e.g., grab samples vs. composites; a random sampling design vs. a systematic design), and
- costs.

Since sampling design and analytical strategy interact to influence the statistical confidence in final decisions, collaboration between an analytical chemist, a sampling expert, and a statistician is key to selecting a final strategy that can achieve project goals accurately, yet cost-effectively. Software tools are also available now to assist technical experts to develop sampling and analysis designs. Although they can be powerful tools, neither statistics nor software programs can be used as "black boxes." A knowledgeable user must be able to verify that key assumptions hold true in order to draw sound conclusions from statistical analyses and software outputs.

The statistician is concerned with controlling the overall (or summed) variability (i.e., uncertainty) in the final data set, and with the interpretability of that final data set with respect to the decisions to be made. The statistician does this during project planning by addressing issues related to "sample support" (a concept that involves ensuring that the physical dimensions of samples are representative of the original matrix in the context of the investigation), by selecting a statistically valid sampling design, and by estimating how analytical variability could impact the overall variability. The field sampling expert is responsible for implementing the sampling design while controlling contributions to the sampling variability as actual sample locations are selected and as specimens are actually collected, preserved, and transported to the analyst. The analytical chemist is responsible for controlling components of variability and uncertainty that stem from the analytical side (such as analyte extraction, concentration, and instrumental determinative analysis), but also for overseeing aspects of sample preservation, storage, homogenization, and possibly subsampling (if done by the analyst). The analytical chemist should select analytical methods that can meet the analytical variability (precision) limits estimated by the statistician. The chemist must be able to evaluate the relative merits of methods for their detection capacity (detection or quantitation limits), specificity (freedom from interferences), and selectivity (uniqueness of the analytes detected), and match those properties to the data type and quality needed by all the data users involved with the project. Finally, the chemist is responsible for designing an analytical QC program that will establish that the analytical data sets are of known and documented quality.

Controlling the various sources of analytical and sampling uncertainties (assuming no clerical or data management errors) ensures that data of known overall quality are generated. Since the single largest source of uncertainty in contaminated site decisions generally stems from matrix heterogeneity, increasing the sampling density is critical to improving decision confidence.

B. Managing Uncertainty as a Central Theme

Project planning documents should be organized around the theme of managing the overall decision uncertainty. The purpose of systematic planning, such as EPA's Data Quality Objectives (DQO) process used for the systematic planning of environmental data collection, is to first articulate clear goals for the anticipated project, and then to devise cost-effective strategies that can achieve those goals. Project planning documents [such as work management plans, quality assurance project plans (QAPPs), sampling and analysis plans (SAPs), etc.] should be written so that the reader can explicitly identify what those decisions are and what sources of uncertainty could potentially cause those decisions to be made in error. The balance of project planning documents should discuss the rationale and procedures for managing each major source of uncertainty to the degree necessary to achieve the overall decision quality (i.e., decision confidence and defensibility) desired by project managers and stakeholders.

After completion of the project, summary reports should clearly discuss the project goals that were actually achieved, the decisions that were made, the uncertainties that actually impacted project decision-making, the strategies used to manage these uncertainties, and the overall confidence in the project outcome (which is a function of what uncertainties remain).

C. Conceptual Site Model

Using all available information, the technical team develops a conceptual site model (CSM) that crystallizes what is already known about the site and identifies what more must be known in order to achieve the project's goals. A single project may have more than one CSM. Different CSM formulations are used to depict exposure pathways for risk assessment, the site's geology or hydrogeology, contaminant concentrations in surface or subsurface soils, or other conceptual models of contaminant deposition, transport, and fate. Depending on the specifics of the project, CSMs may take the form of graphical representations, cross-sectional maps, plan-view maps, complex representations of contaminant source terms, migration pathways, and receptors, or simple diagrams or verbal descriptions. The team uses the CSM(s) to direct field work that gathers the necessary information to close the information gaps that stand in the way of making site decisions. Data not needed to inform site decisions will not be collected. (Although this sounds elementary, the one-size-fits-all approach used by many practitioners routinely leads to the collection of costly data which are ultimately irrelevant to the project's outcome.) The CSM will evolve as site work progresses and data gaps are filled. The CSM thus serves several purposes: as a planning and organizing instrument, as a modeling and data interpretation tool, and as a communication device among the team, the decision-makers, the stakeholders, and the field personnel.

Systematic planning provides the structure through which foresight and multi-disciplinary technical expertise improves the scientific quality of the work and avoids blunders that sacrifice time, money, and the public trust. It guides careful, precise communication among participants and compels them to move beyond the ambiguities of vague, error-prone generalizations [5]. Systematic planning requires unspoken assumptions to be openly acknowledged and tested in the context of site-specific constraints and goals, anticipating problems and preparing contingencies. It should be required for all projects requiring the generation or use of environmental data [6].

4. THE SECOND COMPONENT OF THE TRIAD: DYNAMIC WORK PLANS

When experienced practitioners use systematic planning combined with informed understanding about the likely fate of pollutants in the subsurface and advanced technology, an extremely powerful strategy emerges for the effective execution of field activities. Terms associated with this strategy include expedited, accelerated, rapid, adaptive, or streamlined site characterization. Its cornerstone is the use of dynamic work plans. Formulated as a decision tree during the planning phase, the dynamic work plan adapts site activities to track the maturing conceptual site model, usually on a daily basis. Contingency plans are developed to accommodate eventualities that are considered reasonably likely to occur during the course of site work, such as equipment malfunction, the unanticipated (but possible) discovery of additional contamination, etc. Dynamic work plans have been championed and successfully demonstrated for over 10 years by a number of parties [7, 8]. Success hinges on the presence of experienced practitioners in the field to "call the shots" based on the decision logic developed during the planning stage and to cope with any unanticipated issues. For small uncomplicated sites, or for discrete tasks within complex sites, project management can be streamlined so smoothly that characterization activities blend seamlessly into cleanup activities.

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

5. THE THIRD COMPONENT: REAL-TIME ANALYSIS

Real-time decision-making requires real-time information. There are a variety of ways real-time data can be generated, ranging from very short turnaround from a conventional laboratory (off-site analysis) to on-site mobile laboratories using conventional analytical instrumentation to "hand-held" instrumentation set up in the back of a van or under a tent in the field. For many projects, on-site analysis in some manner will be the most cost-effective option, although this will always depend on many factors, including the target analyte list and the nature of the decisions to be made at a particular project. On-site analysis can be performed within the standard phased engineering approach; however, it does not achieve its full potential for cost- and time-savings except in the context of dynamic work plans. *All* sampling and analysis designs should be designed with thoughtful technical input from systematic planning, but the nature of field analytical methods and the critical role they play in the context of dynamic work plans makes systematic planning vital so that the most appropriate sampling and measurement tools are selected and suitably operated.

Data collection is not an end in itself: its purpose is to supply information. There has been a counter-productive tendency to fixate solely upon the quality of data points, without asking whether the information quality and representativeness of the data set was either sufficient or matched to the planned uses of the data. On-site analysis can never eliminate the need for traditional laboratory services; but the judicious blending of intelligent sampling design, dynamic work plans, and on-site analysis, supplemented by traditional laboratory testing as necessary, can assemble information-rich data sets much more effectively than total reliance on fixed lab analyses. The lower costs and real-time information value of field analysis permits much greater confidence in the representativeness of data sets due to greater sampling density and the ability to delineate a hot spot or "chase a plume" in real-time [4]. When the gathering of reliable information to guide defensible site decisions is a clear priority, field analytical technologies offer a much more valuable contribution than is implied when the concept is downplayed as "field screening." The cost advantages of on-site analysis extend well beyond possible "per sample" savings, since the use of the integrated triad approach maximizes the chances that the project will be done right the first time over the shortest possible time frame.

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

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

Environmental chemists are not alone in recognizing the potential of field analysis. Even the pharmaceutical industry is taking their analytical methods to the field to screen for new drugs in marine and terrestrial ecosystems. “Who would have thought we could do this much *in situ* now? When we first started, people said we were crazy,” marveled a University of Illinois chemistry professor. While acknowledging that “on-site analysis may seem the stuff of science fiction,” he predicted that the pace of technological advances will make it commonplace for the pharmaceutical industry within five years [9]. Will the same be true for the environmental remediation industry?

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

6. EXPERIENCE WITH THE TRIAD APPROACH

In the early 1990s, the Department of Energy (DOE) articulated the concepts of the triad approach as Expedited Site Characterization (ESC) [10]. In addition, DOE linked dynamic work plans with systematic planning with the intent of speeding up Superfund site investigations and feasibility studies at DOE sites in an approach called SAFER (Streamlined Approach for Environmental Restoration). Showing the acceptance of this paradigm among remediation experts, ASTM has issued three guides describing various applications of expedited or accelerated approaches [11, 12, 13].

In 1996-1997, EPA Region 1 and Tufts University coordinated with the U.S Air Force to conduct a demonstration of a dynamic site investigation using real-time results generated by a mobile laboratory to delineate residual soil contamination at Hanscom Air Force Base. The project showed that innovative technologies combined with an adaptive sampling and analysis program could drastically reduce the time and cost, while increasing the confidence, of site decisions [14].

Argonne National Laboratory’s Environmental Assessment Division (EAD) uses Adaptive Sampling and Analysis Programs (ASAP) to expedite data collection in support of hazardous waste site characterization and remediation. ASAPs rely on "real-time" data collection and field-based decision-making, using dynamic work plans to specify the way sampling decisions are to be made, instead of determining the exact number and location of samples before field work begins. EAD focuses on the decision support aspects of ASAP data collection, including the management and visualization of data to answer questions such as: What's the current extent of contamination? What's the uncertainty associated with this extent? Where should sampling take place next? When can sampling stop? A variety of software tools are used to facilitate real-time data collection and interpretation, including commercial databases, standard geographical information system (GIS) packages, customized data visualization and decision support software based on Bayesian statistics, and Internet applications to foster real-time communication and data dissemination. The EAD is documenting that ASAP-style programs consistently yield cost savings of more than 50% as compared to more traditional sampling programs [15].

The U.S. Army Corps of Engineers (USACE) began institutionalizing an integrated approach to systematic planning under the name “Technical Project Planning (TPP) Process.” Although it does not address dynamic work plans and on-site analysis directly, the TPP engineering manual stresses the importance of a multi-disciplinary team that performs “comprehensive and systematic planning that will accelerate progress to site closeout within all project constraints" [16]. A 1997 review of 11 initial projects performed under the TPP approach demonstrated the following successes:

∉ Met all schedules (and "train-wreck" and "break-neck" milestones);
∉ Improved project focus and communications;
∉ Improved defensibility and implementability of technical plans;
∉ Eliminated "excessive" data needs and identified "basic" data needs;
∉ Increased satisfaction of USACE's Customers;
∉ Improved relations and communication with regulators; and
∉ Documented cost savings of at least $4,430,000 (total savings for all 11 projects) [17].

In addition, a well-documented USACE project using the triad approach in combination with Performance-Based Measurement System (PBMS) principles (for both the field analytical and fixed laboratory methods) achieved site closure while demonstrated an overall project savings of 50% ($589K actual project cost vs. $1.2M projected cost) [18].

The Florida Department of Environmental Protection created the Drycleaning Solvent Cleanup Program (DSCP) to address contamination from small dry cleaner shops. Under the DSCP, rapid site characterizations are performed using on-site mobile laboratories and direct push technologies to characterize soil and ground water contamination, assess cleanup options, and install permanent monitoring wells, all in an average of 10 days per site. Site characterization costs have been lowered by an estimated 30 to 50 percent when compared to conventional assessments [19].

Whether the focus of a site investigation is ground water, surface water, sediment, soil, or waste characterization, or a combination thereof, the triad approach has been shown to achieve site closeout faster and cheaper than traditional phased approaches. The question becomes: What are the barriers that hinder wider utilization of this approach? Past reasons no doubt included the limited selection of rapid turnaround field analytical and software tools so vital for implementing dynamic work plans efficiently. As described earlier however, recent years have seen a growing array of analytical options able to meet many types of data quality needs. Technology advancement would be even more brisk if a paradigm of logical evaluation, acceptance, and use by practitioners and regulators were the norm. To benefit from the tools we currently have and boost our available options, we must modernize habits that were established during the infancy of the environmental remediation industry. Other papers in this series address the limitations of prescriptive requirements for analytical methods and analytical data quality [4, 20].

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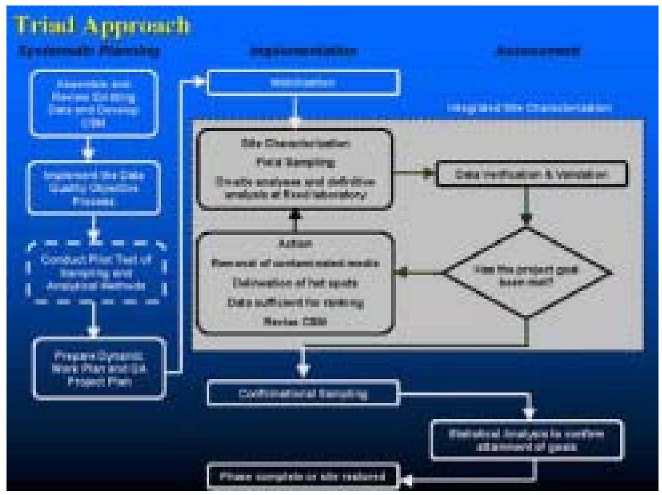
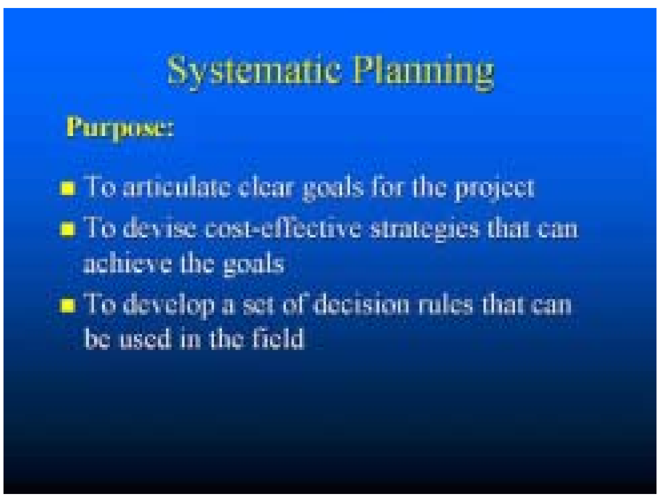
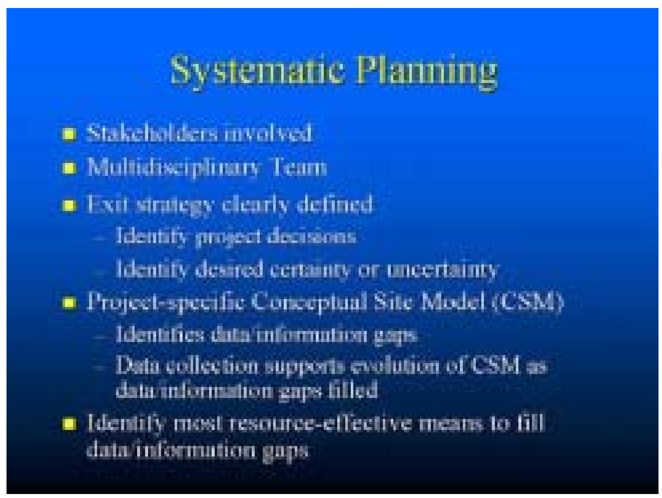
8. PRESENTATION VISUALS ~ *presented by Eric Koglin and Deana M. Crumbling*



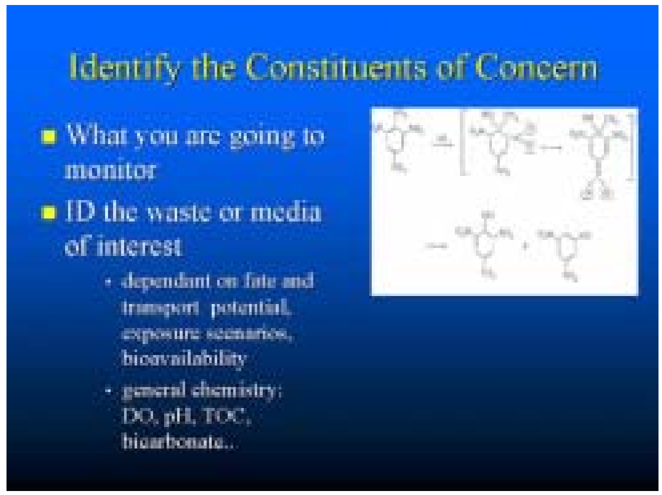


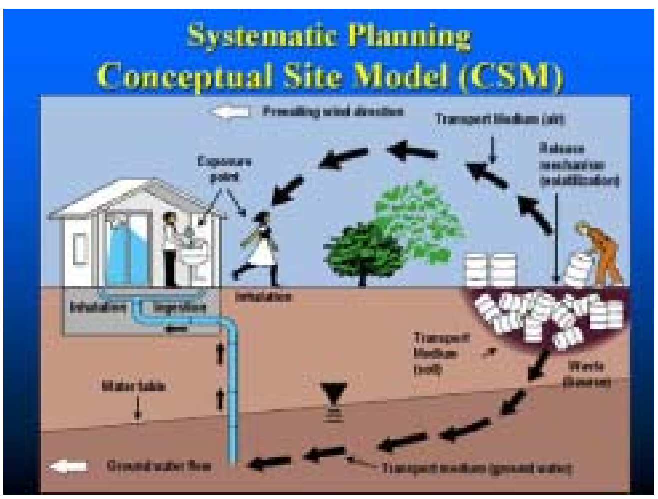



Systematic Planning
Technical Project Team
Assemble the project team by getting the right people involved
May include: statistician, chemist, hydrologist, legal or regulatory advisor, biologist, geologist, etc.


Review Existing Data and Build Conceptual Site Model


Sift and Sort Data Needs
Group Similar Data Needs
Identify Data Need Overlaps
– Balancing Sensitivity Requirements
– Meeting Process Requirements
Risk
Compliance
Remedy
Responsibility
GW Data Needs
SW Data Needs


Identify the Constituents of Concern
What you are going to monitor
ID the waste or media of interest
• dependant on fate and transport potential, exposure scenarios, bioavailability
• general chemistry: DO, pH, TOC, bicarbonate..


Systematic Planning
Conceptual Site Model (CSM)
Prevailing wind direction
Transport Medium (air)
Release mechanism (volatilization)
Exposure point
Inhalation
Ingestion
Inhalation
Transport Medium (soil)
Waste (Source)
Water table
Ground water flow
Transport medium (ground water)


Implement the DQO Process

Seven Steps of DQO Planning

- Step 1: State the Problem to Be Addressed
- Step 2: Identify the Decision(s) to Be Made
- Step 3: Identify All the Inputs to the Decision(s)
- Step 4: Narrow the Boundaries of the Study
- Step 5: Develop Decision Rule(s)
- Step 6: Develop Uncertainty Constraints
- Step 7: Optimize the Design for Obtaining Data

Determining Process End Goals

- Define the decisions that must be made
- Develop decision rules
- Identify the data necessary to support decision making
- Determine limits on decision errors

Establish Cleanup Goals/Action Levels

- Define regulatory requirements
- Establish background and/or anthropogenic levels for inorganic/organic parameters
- Determine preliminary risk-based cleanup goals
- Evaluate practicability to meet cleanup goals
- Establish clean-up goals with regulator concurrence

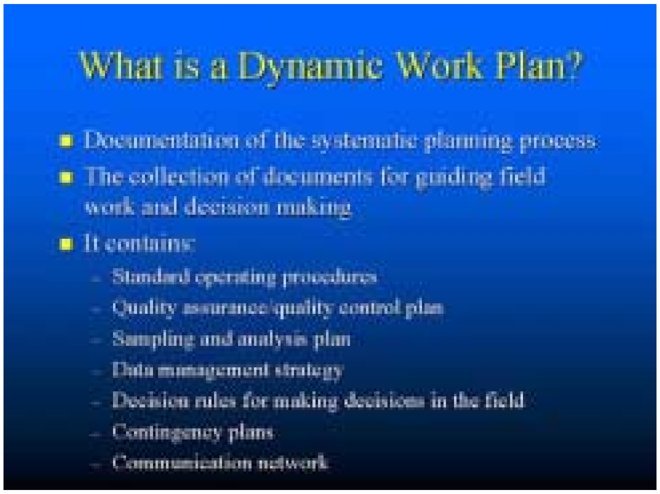
Evaluating Resources and Constraints

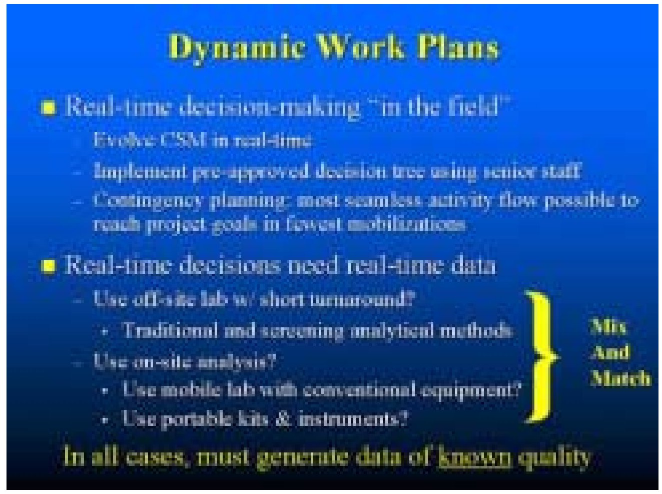
- Assessing team dynamics, expertise, and other constraints
- Evaluating in-house options
- Identification of and resources to mitigate contingencies
- Determining the budget
- Establishing the schedule

Generating Real-time Data Using Field Methods

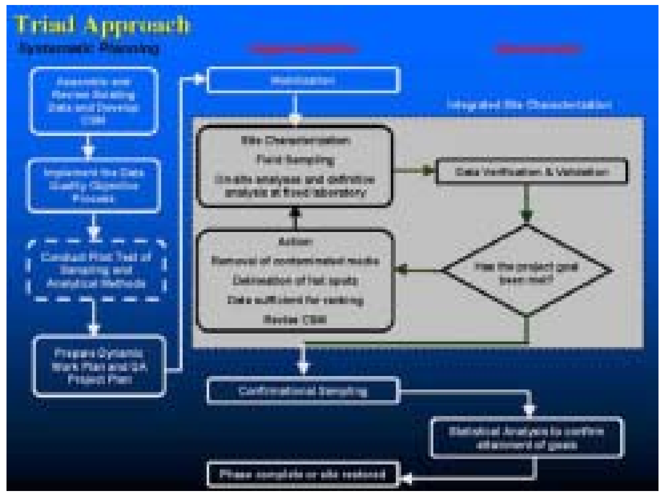
- Need clearly defined data uses—tie to project goals
- Understand dynamic work plan—branch points & work flow
- Project-specific QA/QC protocols matched to intended data use
- Select field analytical technologies to
  - Support the dynamic work plan (greatest source of $$ savings)
  - Manage sampling uncertainty (improves decision quality)
- Select fixed lab methods (as needed) to
  - Manage uncertainties in field data (as ONE aspect of QC)
  - Supply analyte-specific data and/or lower quantitation limits (as needed for regulatory compliance, risk assessment, etc.)

Dynamic Work Plans

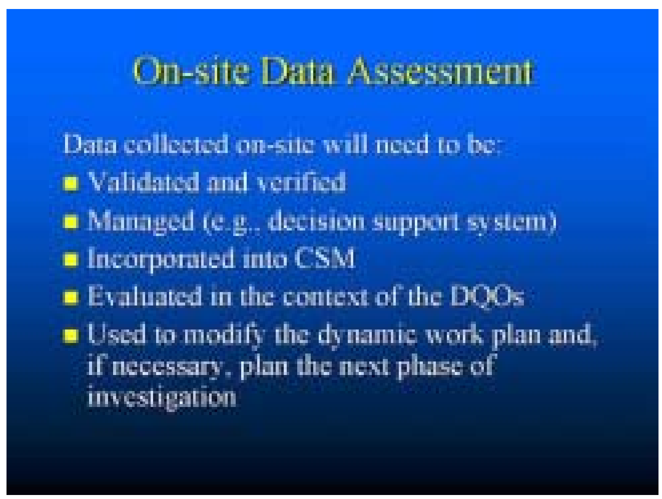

What is a Dynamic Work Plan?
Documentation of the systematic planning process
The collection of documents for guiding field work and decision making
It contains:
Standard operating procedures
Quality assurance/quality control plan
Sampling and analysis plan
Data management strategy
Decision rules for making decisions in the field
Contingency plans
Communication network

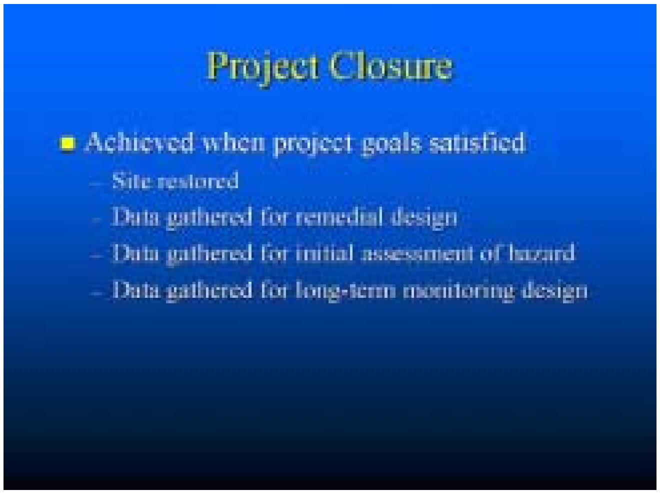

Dynamic Work Plans
Real-time decision-making "in the field"
Evolve CSM in real-time
Implement pre-approved decision tree using senior staff
Contingency planning: most seamless activity flow possible to reach project goals in fewest mobilizations
Real-time decisions need real-time data
Use off-site lab w/ short turnaround?
Traditional and screening analytical methods
Use on-site analysis?
Use mobile lab with conventional equipment?
Use portable kits & instruments?
Mix And Match
In all cases, must generate data of known quality


Implementation


Triad Approach
Systematic Planning
Mobilization
Site Characterization
Field Sampling
Data Verification & Validation
Action
Removal of contaminated media
Delineation of hot spots
Revise CSM
Has the project goal been met?
Conduct Pilot Test of Sampling and Analytical Methods
Prepare Dynamic Work Plan and QA Project Plan
Confirmational Sampling
Phase complete or site restored

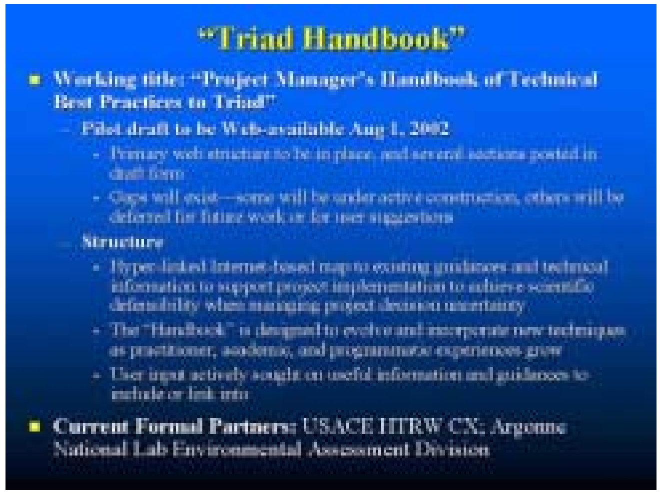

Attacking the Problem
Mobilize equipment
Coordinate field team:
Project leader
Field crew
Technical specialists
Begin initial phase of data collection

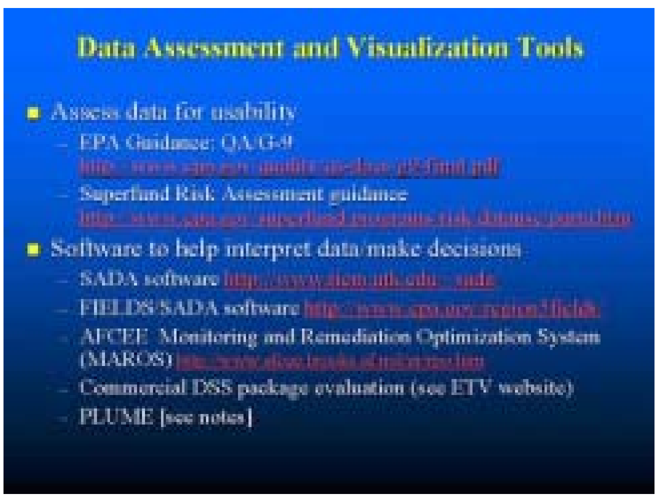

On-site Data Assessment
Data collected on-site will need to be:
Validated and verified
Managed (e.g., decision support system)
Incorporated into CSM
Evaluated in the context of the DQOs
Used to modify the dynamic work plan and, if necessary, plan the next phase of investigation


Project Closure
Achieved when project goals satisfied
Site restored
Data gathered for remedial design
Data gathered for initial assessment of hazard
Data gathered for long-term monitoring design


Field-Based Site Characterization Philosophy
Streamline the site characterization and response action processes
Minimize mobilizations to a site
Produce more data on a site at lower costs relative to conventional approaches
Produce data in near real time
Produce measurable data quality

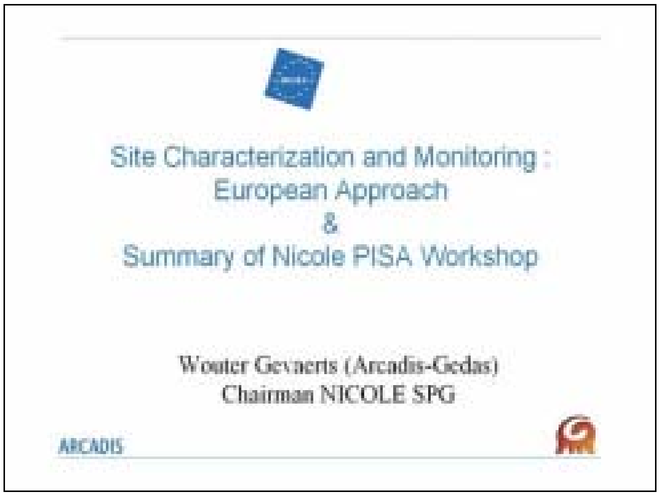

Summary
The components of Triad have been around for years
The collective approach is novel as compared to the traditional staged approach
The use of near real time data on site has been rarely done

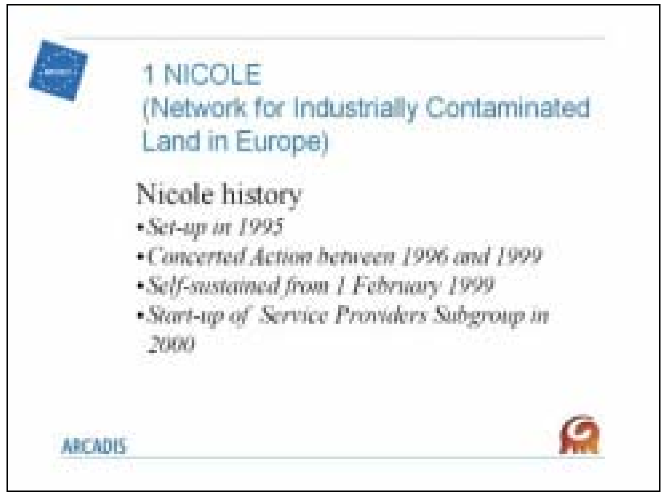

"Triad Handbook"
Working title: "Project Manager's Handbook of Technical Best Practices to Triad"
Pilot draft to be Web-available Aug 1, 2002
Primary web structure to be in place, and several sections posted in draft form
Gaps will exist—some will be under active construction, others will be deferred for future work or for user suggestions
Structure
Hyper-linked Internet-based map to existing guidances and technical information to support project implementation to achieve scientific defensibility when managing project decision uncertainty
The "Handbook" is designed to evolve and incorporate new techniques as practitioner, academic, and programmatic experiences grow
User input actively sought on useful information and guidances to include or link into
Current Formal Partners: USACE HTRW CX; Argonne National Lab Environmental Assessment Division

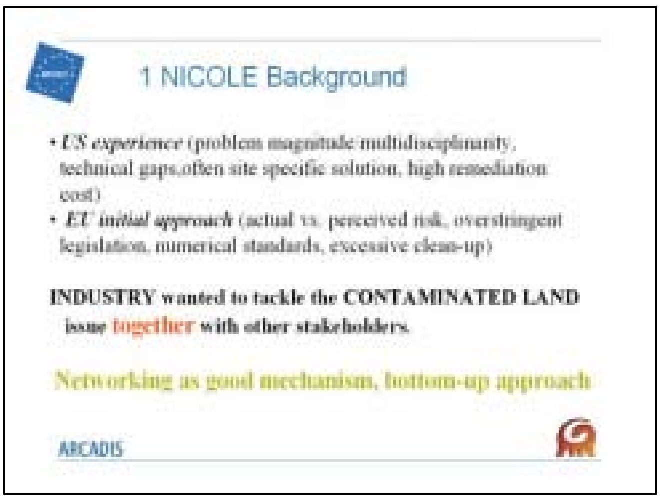

Data Assessment and Visualization Tools
Assess data for usability
EPA Guidance: QA/G-9
Superfund Risk Assessment guidance
Software to help interpret data/make decisions
SADA software
FIELDS/SADA software
AFCEE Monitoring and Remediation Optimization System (MAROS)
Commercial DSS package evaluation (see ETV website)
PLUME [see notes]

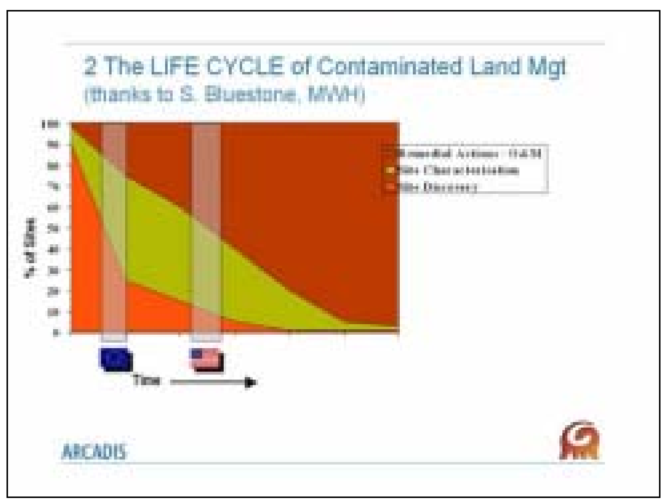
SITE CHARACTERIZATION AND MONITORING: EUROPEAN APPROACH & SUMMARY OF NICOLE PISA WORKSHOP

Wouter Gevaerts[1]

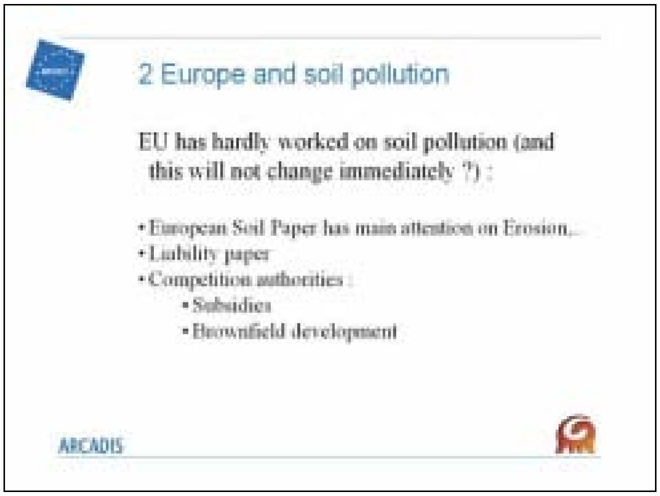


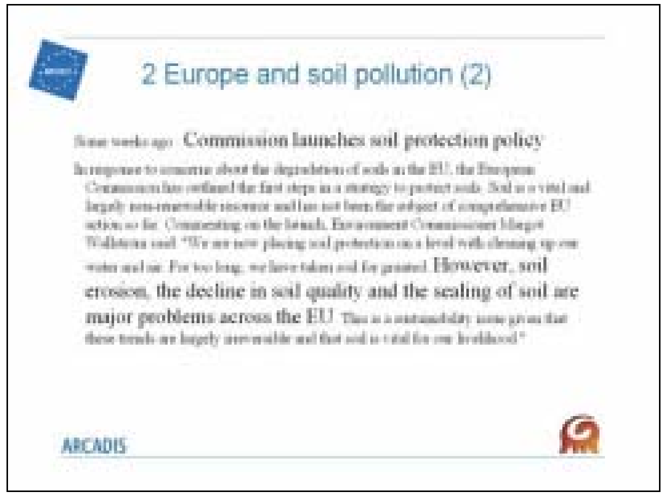






[1] Archadis-Gadas, Chairman NICOLE SPG, Belgium; email: info@gedas.be


2 Europe and soil pollution
EU has hardly worked on soil pollution (and this will not change immediately ?) :
• European Soil Paper has main attention on Erosion,..
• Liability paper
• Competition authorities :
• Subsidies
• Brownfield development
ARCADIS


2 Europe and soil pollution (2)
Commission launches soil protection policy
However, soil erosion, the decline in soil quality and the sealing of soil are major problems across the EU
ARCADIS


2 European Environmental Agency
ARCADIS


2 European countries and soil pollution
• A lot of legislation
• North to south
• West to east
• A lot of different practices (technical, subsidies,...)
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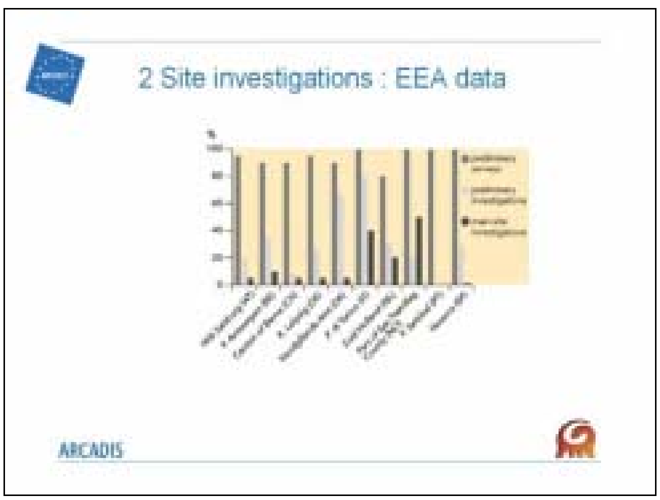
2 Site investigations : EEA data
ARCADIS


2 Site remediation : EEA data
EUR per capita per year
40
35
30
25
20
15
10
5
0
ARCADIS

2 European networks

Countries stakeholders nevertheless try to develop some cross-boundary exchange

- General soil networks :
  - Nicole
  - Common Forum
- Technical soil networks
  - Clarinet
  - Cabernet
  - Incore
  - Welcome
  - ...

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4 Common Forum

Goals :

- exchange of information and experience in development and implementation of policies
- opportunity for informal debate
- initiate transnational projects
- dialogue on EU policy development
- dialogue with and feedback from networks
- expectations from EU-institutes

Next meeting is in Paris (June)

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2 NICOLE Network Meeting on 18-19 April 2002

COST-EFFECTIVE SITE CHARACTERISATION

Dealing with uncertainties, innovation, legislation constraints

Focus on :

- site characterisation strategies
- geostatistics
- non destructive new proven technologies
- destructive new proven technologies
- non proven technology

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3 Soil investigation strategies

- Tiered approach :
  1. Preliminary investigation
  2. Descriptive investigation
  3. Remediation plan
- Risk assessment and fit for use are getting accepted
- Sustainable land management and source removal/plume management are in discussion

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3 Site investigations : 2 small examples

- For the Nicole Pisa workshop : Nicole SPG asked Fugro to develop two theoretical cases; Fugro asked the Nicole SPG members to make an "offer" for a soil investigation
  - Industrial site
  - Gasoil station

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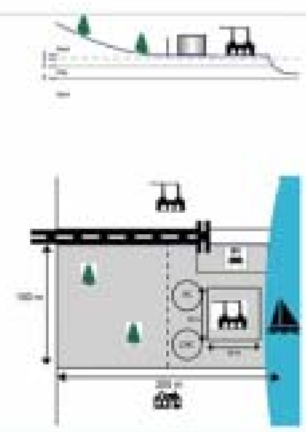

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Results Questionnaire 2 hectares industry site

country	meters (drills)	cost				time (wks)
		field	lab	desk	total	
Belgium min		3062	313	1028	3777	6
Belgium max	100	3840	2160	2100	8100	
Italy min	40				50000	
Italy max		17000	15000	22500	54500	6
Germany min		11500	3500	2500	17500	
Germany max		25250	5220	3750	34220	7
Netherlands min	100	3500	6120	6150	15770	10
Netherlands max	200	15000	7000	15000	32000	15

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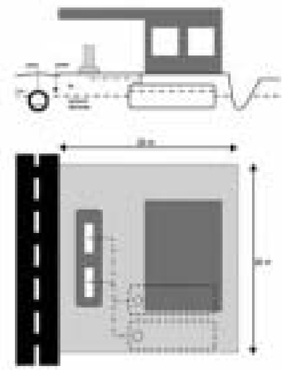

ARCADIS

Results Questionnaire retail station

country	number of phases	cost				time (wks)
		field	lab	desk	total	
Belgium		1882	529	1011	2482	6
Italy		5700	1150	1650	8500	3
Germany		500	800	800	2100	2.5
NL min		400	150	800	1350	6
NL max		2500	1300	2900	6700	8

ARCADIS

3 Site investigation examples : conclusions

- Although quite simple and clear descriptions :
  - A lot of differences between countries
  - Gasoil station is more standard : answers are more coherent
  - The longer a country is active in soil investigation, the cheaper it is.

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4 Current technology

- Mechanical drilling (auger,...) or manual drilling (hand auger); no geoprobe direct push;
- Soil gas sampling much more popular in G than in Nl or B;
- Off site chemical analyses on specific parameters
- Off site interpretation

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5 Almost proven but almost not used/accepted

- Technology Geoprobe MIP
- Geophysics
- On site analyses
- Geostatistics
- Fluxes ≠ concentrations

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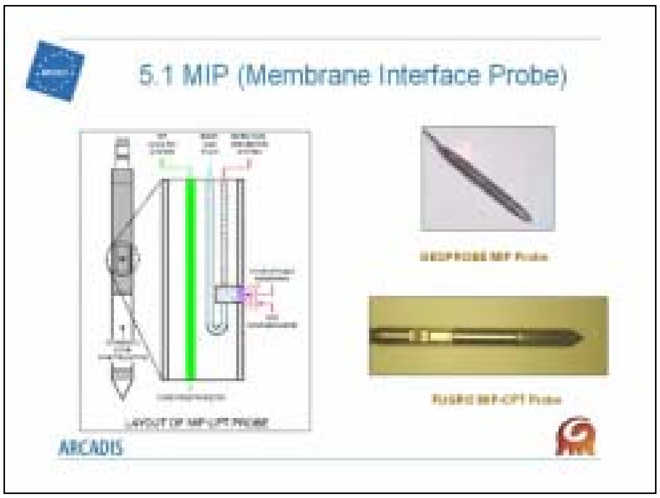
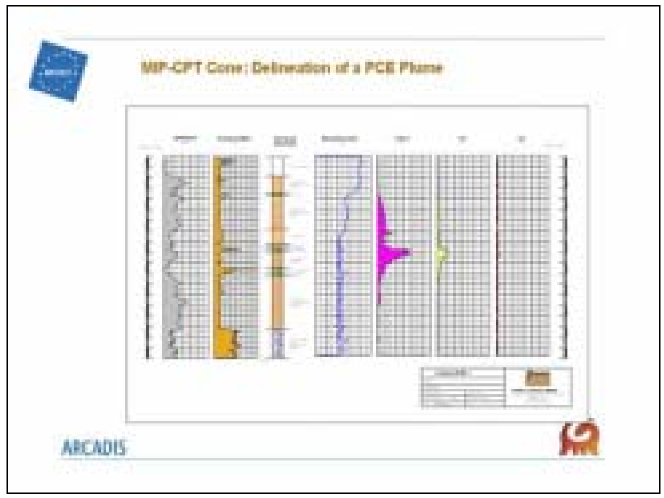
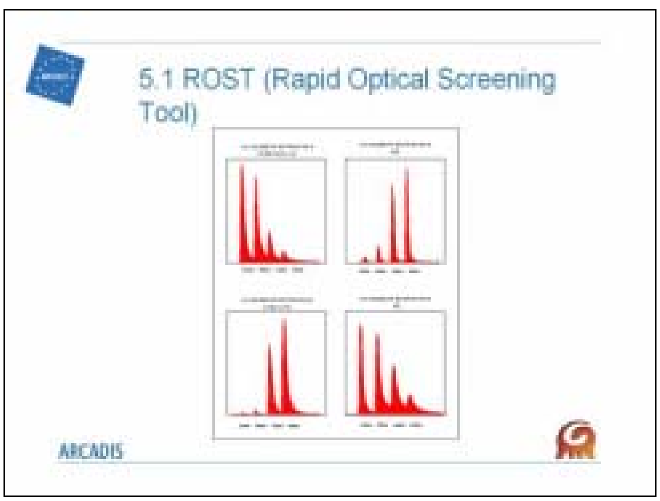
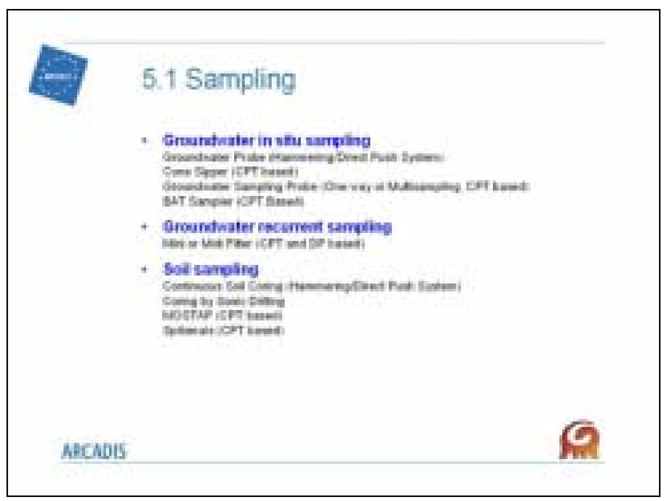
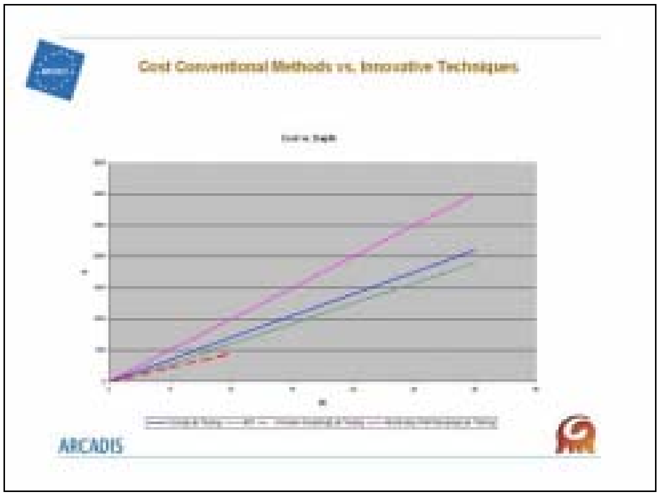
5.1 Existing technology
(thanks to Mr. Neuhaus, Fugro)
MIP (Membrane Interface Probe)
VOC, CHC, BTEX (+NAPL)
ROST™ (Rapid Optical Screening Tool)
TPH, Fuel, Mineral Oil, Creosote, Tar (+NAPL)
Conductivity Cone
Landfill Leachate, Salinity
Piezo-Cone
Dynamic Pore Water Pressure, Fine Stratigraphy
Camera Cone
Soil Strata, Color, NAPL
ARCADIS

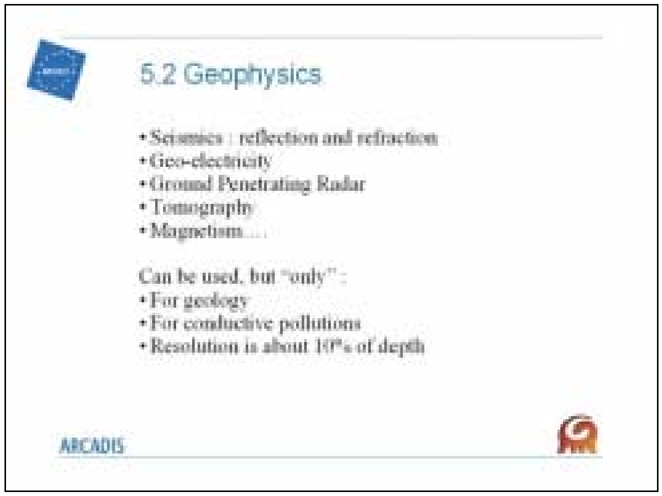

5.1 MIP (Membrane Interface Probe)
GEOPROBE MIP Probe
FUGRO MIP-CPT Probe
LAYOUT OF MIP-CPT PROBE
ARCADIS

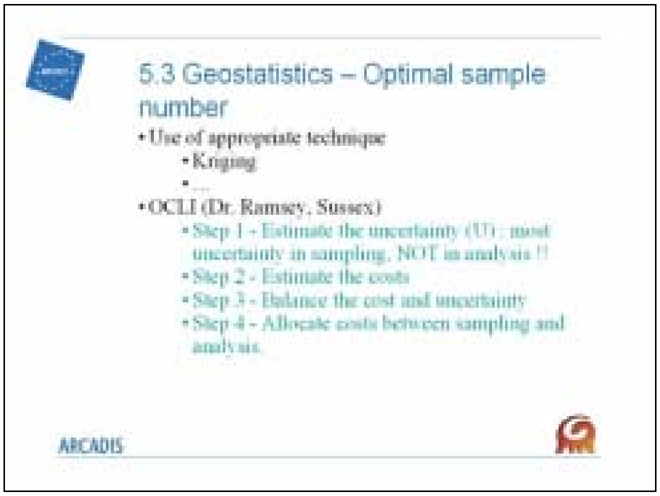

MIP-CPT Cone: Delineation of a PCE Plume
ARCADIS

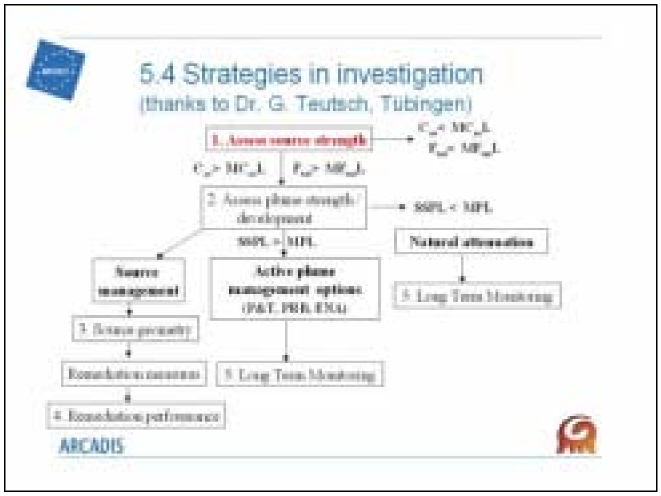

5.1 ROST (Rapid Optical Screening Tool)
ARCADIS

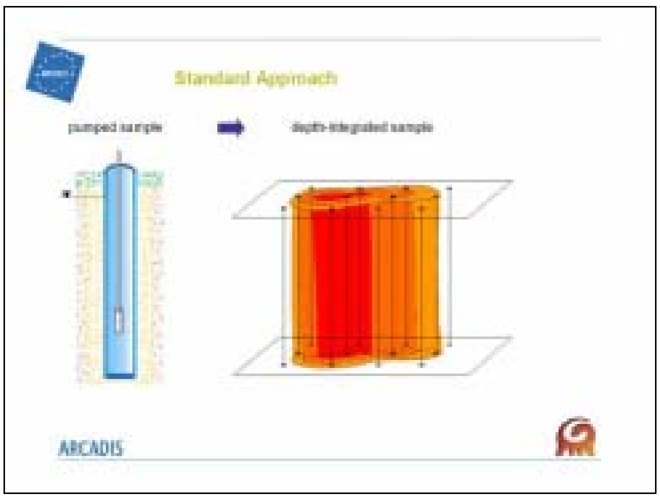

5.1 Sampling
Groundwater in situ sampling
Groundwater Probe (Hammering/Direct Push System)
Cone Sipper (CPT based)
Groundwater Sampling Probe (One-way or Multisampling, CPT based)
BAT Sampler (CPT Based)
Groundwater recurrent sampling
Mini or Midi Filter (CPT and DP based)
Soil sampling
Continuous Soil Coring (Hammering/Direct Push System)
Coring by Sonic Drilling
MOSTAP (CPT based)
ARCADIS

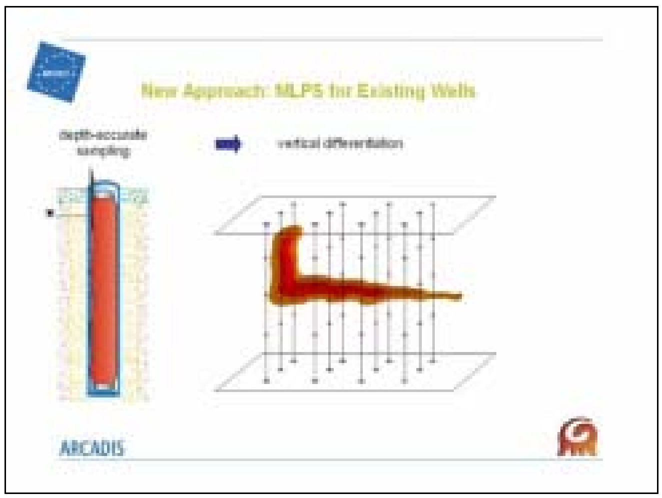

Cost Conventional Methods vs. Innovative Techniques
ARCADIS


5.2 Geophysics
• Seismics : reflection and refraction
• Geo-electricity
• Ground Penetrating Radar
• Tomography
• Magnetism….
Can be used, but "only" :
• For geology
• For conductive pollutions
• Resolution is about 10% of depth
ARCADIS

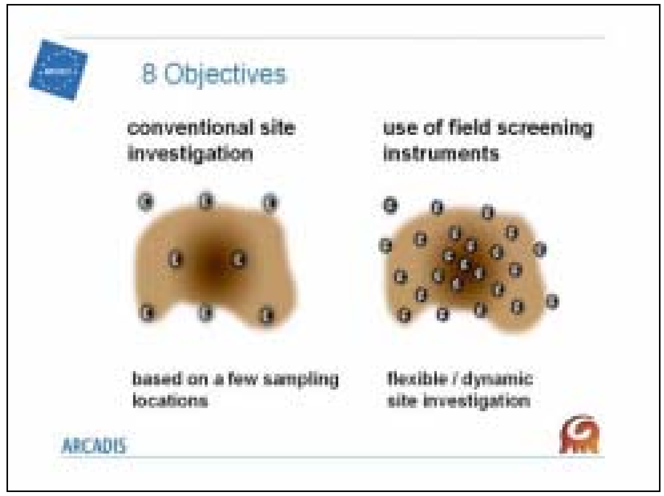

5.3 Geostatistics – Optimal sample number
• Use of appropriate technique
• Kriging
• ….
• OCLI (Dr. Ramsey, Sussex)
• Step 1 - Estimate the uncertainty (U) : most uncertainty in sampling, NOT in analysis !!
• Step 2 - Estimate the costs
• Step 3 - Balance the cost and uncertainty
• Step 4 - Allocate costs between sampling and analysis
ARCADIS

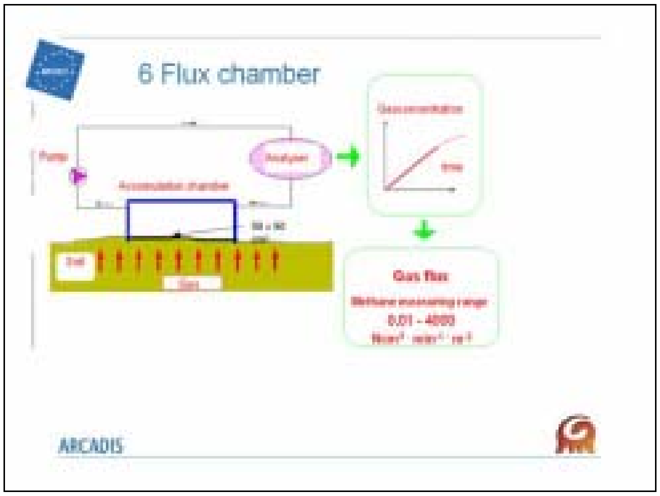

5.4 Strategies in investigation
(thanks to Dr. G. Teutsch, Tübingen)
Natural attenuation
ARCADIS


Standard Approach
pumped sample
depth-integrated sample
ARCADIS

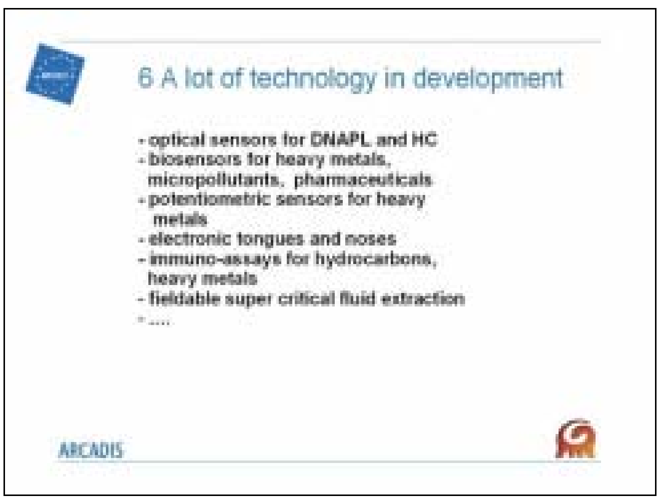

New Approach: MLPS for Existing Wells
depth-accurate sampling
vertical differentiation
ARCADIS

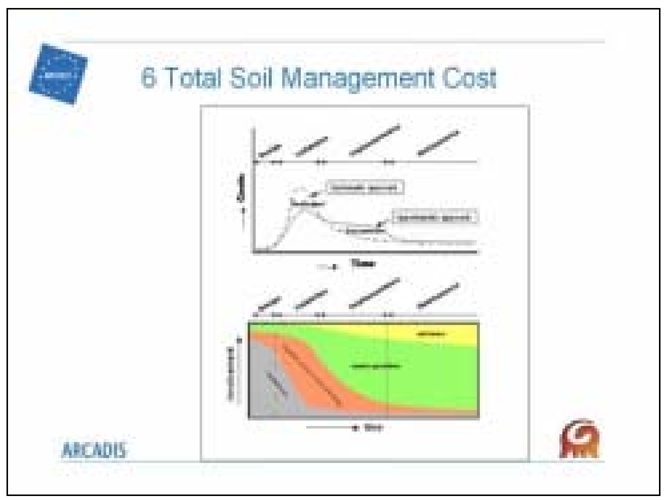

6 Non proven technology
(thanks to D. Van Ree, Geodelft)
. Continuing interest in site characterisation, high expectations
. Lots of exciting sensors, technologies
. May be 1% makes it to the field on a more or less regular basis
ARCADIS

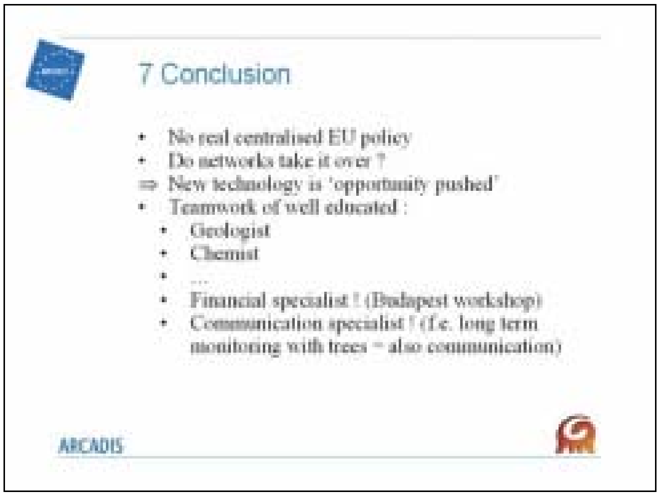

8 Objectives
conventional site investigation
use of field screening instruments
based on a few sampling locations
flexible / dynamic site investigation
ARCADIS


6 Flux chamber
Pump
Analyser
Accumulation chamber
Soil
Gas flux
Methane measuring range
0,01 - 4000
ARCADIS


6 MACROSENSE
ARCADIS


6 A lot of technology in development
- optical sensors for DNAPL and HC
- biosensors for heavy metals, micropollutants, pharmaceuticals
- potentiometric sensors for heavy metals
- electronic tongues and noses
- immuno-assays for hydrocarbons, heavy metals
- fieldable super critical fluid extraction
- ....
ARCADIS


6 Total Soil Management Cost
Time
ARCADIS


7 Conclusion
• No real centralised EU policy
• Do networks take it over ?
⇒ New technology is 'opportunity pushed'
• Teamwork of well educated :
• Geologist
• Chemist
• ...
• Financial specialist ! (Budapest workshop)
• Communication specialist ! (f.e. long term monitoring with trees = also communication)
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7 Conclusion : Future ? Hopefully !
(thanks to Simon Bluestone, MWH)
Geostatistics
Risk Assessment and Toxicology
Environmental Chemistry
Fate and Transport Modelling
Geophysics
Risk Communication
Decision Analysis
Environmental Management Systems
Data Management
Remediation Technology
Geochemistry
Design
Project Management
Construction
Hydrogeology
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APPENDIX A

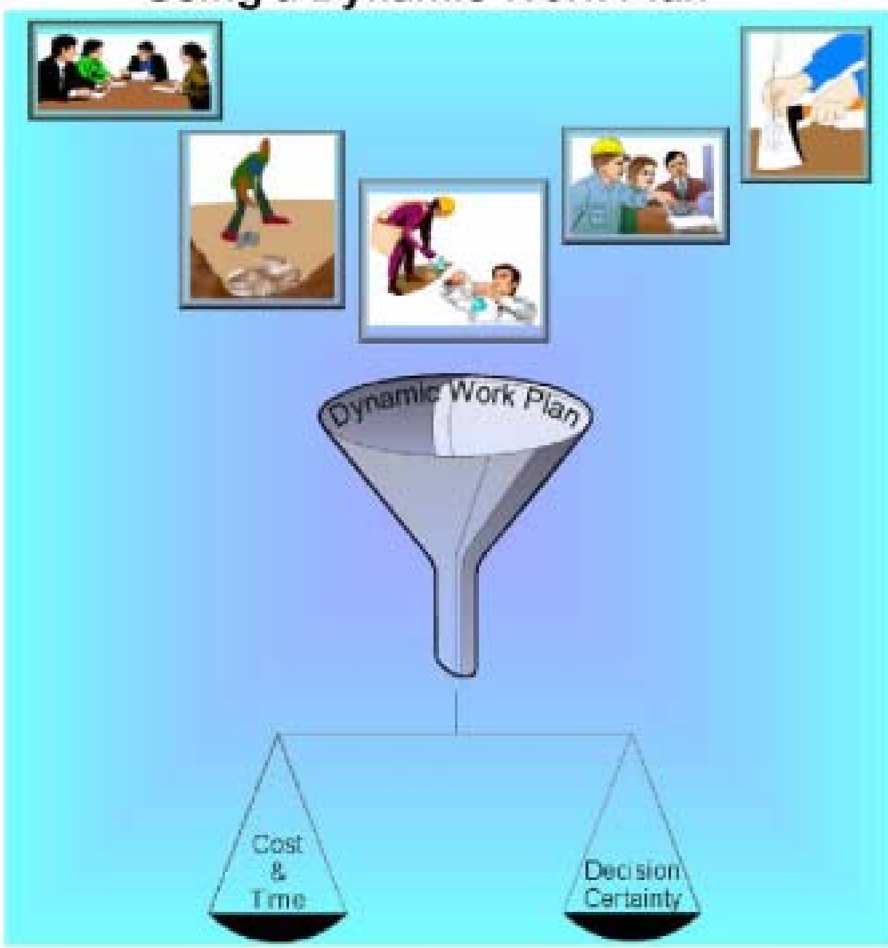
United States Environmental Protection Agency

Solid Waste and Emergency Response (5102G)

EPA-542-R-00-009
August 2000
www.epa.gov/tio
cluin.org

Innovations in Site Characterization

Case Study: Site Cleanup of the Wenatchee Tree Fruit Test Plot Site Using a Dynamic Work Plan



EPA-542-R-00-009
August 2000

Innovations in Site Characterization
Case Study: Site Cleanup of the Wenatchee Tree Fruit Test Plot Site Using a Dynamic Work Plan

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

Notice

This material has been funded wholly by the United States Environmental Protection Agency under Contract Number 68-W6-0068. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Copies of this report are available free of charge from the National Service Center for Environmental Publications (NSCEP), P.O. Box 42419, Cincinnati, OH 45242-2419; telephone (800) 490-9198 or (513) 489-8190 (voice) or (513) 489-8695 (facsimile). Refer to document EPA-542-R-00-009, *Innovations in Site Characterization Case Study: Site Cleanup of the Wenatchee Tree Fruit Test Plot Site Using a Dynamic Work Plan*. This document can also be obtained electronically through EPA's Clean Up Information (CLU-IN) System on the World Wide Web at *http://cluin.org* or by modem at (301) 589-8366. For assistance, call (301) 589-8368.

Comments or questions about this report may be directed to the United States Environmental Protection Agency, Technology Innovation Office (5102G), 401 M Street, SW, Washington, DC 20460; telephone (703) 603-9910.

Foreword

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

Acknowledgments

This document was prepared by Science Applications International Corporation (SAIC) for the United States Environmental Protection Agency's (EPA) Technology Innovation Office under EPA Contract No. 68-W6-0068. Special acknowledgment is given to the U.S. Army Corps of Engineers, Seattle District, and Garry Struthers Associates, Inc. for their thoughtful suggestions and support in preparing this case study.

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List of Tables

CASE STUDY ABSTRACT

Wenatchee Tree Fruit Research and Extension Center (WTFREC) Test Plot Wenatchee, Washington

Site Name and Location: Wenatchee Tree Fruit Research and Extension Center (WTFREC) Test Plot Wenatchee, Washington	**Sampling & Analytical Technologies:** 1. Systematic planning process 2. Dynamic workplan 3. Direct push soil sampling 4. Field measurement immunoassay analysis (IA) technologies combined with limited fixed laboratory analyses	**CERCLIS #:** None
Period of Operation: 1966-early 1980s **Operable Unit:** A 2,100-square foot test plot area used for pesticide disposal testing		**Current Site Activities:** Washington State University test and laboratory facilities; local residential development.
Point of Contact: Greg Gervais Quality Assurance Representative U.S. Army Corps of Engineers-Seattle District 4735 East Marginal Way South Seattle, WA 98134	**Media and Contaminants:** Soil contaminated with organochlorine pesticides, organophosphorus pesticides, carbamate pesticides, and paraquat	**Technology Demonstrator:** Garry Struthers Associates, Inc. 3150 Richards Road, Suite 100 Bellevue, WA 98005-4446 (425) 519-0300

Number of Samples Analyzed during Investigation:

A total of 271 samples were analyzed for the focused removal, characterization, final confirmation, waste profile, and wastewater analysis phases of this project. Roughly two-thirds of analyses were performed in the field by IA kits. Field and laboratory QC samples were also analyzed during this project.

Cost Savings:

The site characterization and cleanup approach used in this project resulted in savings of about 50% (over $500,000) over traditional site characterization and remediation methods, which rely on fixed-base laboratory analysis with multiple rounds of mobilization/demobilization to accomplish site cleanup.

Results:

Project was completed successfully and cost-effectively. The WTFREC test plot area was remediated, and shown to a high degree of certainty that regulatory cleanup standards were achieved. The regulator, the client, and local stakeholders were very satisfied with the project's outcome.

Description:

This case study describes an approach to site cleanup that includes the use of systematic planning, on-site measurement technologies combined with limited fixed laboratory analyses, and rapid decision-making (using a dynamic work plan) to facilitate quick cleanup. Site characterization information, obtained in the field through the use of IA kits, was used to guide removal activities by means of an adaptive sampling strategy. This approach permitted a cost-effective cleanup of the contaminated site.

TECHNOLOGY QUICK REFERENCE SHEET
EnviroGard® DDT Immunoassay Test Kit

Case Study: Site Cleanup of the Wenatchee Tree Fruit Test Plot Site Using a Dynamic Work Plan

Technology Name EnviroGard® DDT Immunoassay Test Kit			
Summary of Case Study's Performance Information			
Project Role: Supporting in-field decisions regarding further characterization, removal, waste segregation, and disposal of soils contaminated with DDT and other pesticides.	**Analytical Information Provided:** Semiquantitative concentration data for DDT and other organochlorine pesticides in soil with sensitivity down to 0.2 mg/kg (ppm). The results are reported as the concentration of DDT, but represent the sum of the responses from the 2,4'- and 4,4'-isomers of DDT, DDD, and DDE. During the case study, the test kit results were compared to fixed laboratory analyses for individual pesticide compounds and site-specific action levels were developed for the various decisions to be made (e.g., characterization, removal, waste segregation, and disposal) using the test kit results.		
Total Contract Cost: $13,036 for 230 samples (includes project samples, PE samples, and blind field duplicates)		**Total Cost Per Sample:** approx. $57 per sample (includes QC costs)	
Project Cost Breakdown			
Spectrometer Cost: $2000 for purchase, or rentals available at $175/day to $800/month	**Consumables Cost:** $515 for a 20-test kit	**Labor Cost:** approx. $20 per sample (includes QC costs)	**Waste Disposal Cost:** Methanol extract waste: $470 per lab pack (bulk) disposal
Site-Specific Accuracy/Precision Achieved: The test kit is intentionally biased 100% high by the manufacturer in order to reduce the occurrence of false negative results. Based on a pilot study of the test kits and fixed laboratory data for the individual organochlorine pesticides in soil samples from the site, the project team determined that a DDT test kit result of 5 mg/kg (ppm) could indicate that the site-specific cleanup level for an individual compound (e.g., DDT, DDE, or DDD) had been exceeded. An important aspect of this project was that this initial determination was reviewed and revised as needed during the latter phases of the project. For example, in the deeper soils from the area of the site where bags of concentrated pesticides were buried, the action level for DDT test kit results was raised to 10 mg/kg. The precision achieved by the test kit was assessed by the analysis of a pair of duplicate samples with each of 16 batches of field samples. The relative percent difference of the duplicates ranged from 0% to 113% for these 16 batches, with a mean RPD value of 38% and a median RPD of 28%.			**Throughput Achieved:** A batch of 12 field samples could be extracted and analyzed in a half day by one person.

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TECHNOLOGY QUICK REFERENCE SHEET
EnviroGard® DDT Immunoassay Test Kit (continued)

General Commercial Information (Information valid as of August 2000)

Vendor Contact:	**Vendor Information:**	**Limitations on Performance:**
Not available	Strategic Diagnostics, Inc. 111 Pencader Drive Newark, DE 19702 1-800-544-8881 www.sdix.com	This test kit is not specific for just DDT. It also responds to the DDT daughter products DDE and DDD, as well as some other organochlorine pesticides.

Principle of Analytical Operation:

This test is based on a competitive enzyme-linked immunosorbent assay (ELISA) reaction between DDT and related compounds extracted from the sample with methanol and an antibody coated on a test tube containing the extract.

The antibodies bound to the target analytes cannot bind to an enzyme conjugate added to the tube. When a color-developing reagent is added, the enzyme conjugate forms a colored product. The color density is read with a spectrometer and is proportional to the amount of conjugate reagent present. Darker color means less of the target analyte is present. The DDT results are determined by comparison to 3-point calibration.

Availability/Rates:

Test kits are commercially available as off-the-shelf products. Associated test equipment, including hand-held spectrometer, is available for purchase or rental from manufacturer.

Power Requirements:

110 or 220 volt power is needed to charge the hand-held spectrometer, which may then be used in the field without additional power.

Instrument Weight and/or Footprint:

Approximately 5 square feet of space is required for sample processing and analysis.

General Performance Information

Known or Potential Interferences: Other organochlorine pesticides can react with the antibodies to varying degrees. The manufacturer provides cross-reactivity data with the test kit.

Applicable Media/Matrices:	**Analytes Measurable with Expected Detection Limits:**	**Other General Accuracy/Precision Information:**
Soil and Water		See SW-846 Method 4042
Wastes Generated Requiring Special Disposal: Small volumes of methanol used for sample extraction, plus the used sample volume.	DDT 0.2 mg/kg DDD 0.05 mg/ kg DDE 0.6 mg/kg	**Rate of Throughput:** Up to 17 samples can be assayed at one time, with results available in 30 minutes.

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TECHNOLOGY QUICK REFERENCE SHEET
RaPID Assay® Cyclodienes Immunoassay Test Kit

Case Study: Site Cleanup of the Wenatchee Tree Fruit Test Plot Site Using a Dynamic Work Plan

<table>
<tr><td colspan="4">Technology Name RaPID Assay® Cyclodienes Immunoassay Test Kit</td></tr>
<tr><td colspan="4">Summary of Case Study's Performance Information</td></tr>
<tr><td>Project Role:

Supporting in-field decisions regarding further characterization, removal, waste segregation, and disposal of soils contaminated with cyclodiene pesticides.</td><td colspan="3">Analytical Information Provided:

Semiquantitative concentration data for cyclodiene pesticides in soil with sensitivity down to 0.15 mg/kg (ppm). Greater sensitivity was achieved in this project through method modifications. The results are reported as the concentration of dieldrin, but other cyclodiene pesticides can be used to calibrate the assay as well.

During the case study, the test kit results were compared to fixed laboratory analyses for individual pesticide compounds and site-specific action levels were developed for the various decisions to be made (e.g., characterization, removal, waste segregation, and disposal) using the test kit results.</td></tr>
<tr><td colspan="2">Total Contract Cost: $13,036 for 230 samples (includes project samples, PE samples, and blind field duplicates)</td><td colspan="2">Total Cost Per Sample: approx. $57 per sample (includes QC costs)</td></tr>
<tr><td colspan="4">Project Cost Breakdown</td></tr>
<tr><td>Spectrometer Cost:
$2000 for purchase, or rentals available at $175/day to $800/month</td><td>Consumables Cost:
$540 for a 20-test kit</td><td>Labor Cost:
approx. $20 per sample (includes QC costs)</td><td>Waste Disposal Cost:
Methanol extract waste: $470 per lab pack (bulk) disposal</td></tr>
<tr><td colspan="3">Site-Specific Accuracy/Precision Achieved:

The test kit is intentionally biased 100% high by the manufacturer in order to reduce the occurrence of false negative results. Based on a pilot study of the test kits and fixed laboratory data for the individual organochlorine pesticides in soil samples from the site, the project team determined that a cyclodienes test kit result of 0.086 mg/kg (ppm) could indicate that the site-specific cleanup level for an individual compound (e.g.,dieldrin or endrin) had been exceeded. An important aspect of this project was that this initial determination was reviewed and revised as needed during the latter phases of the project.

The precision achieved by the test kit was assessed by the analysis of a pair of duplicate samples with each of 14 batches of field samples. The relative percent difference of the duplicates ranged from 0% to 110% for these 14 batches, with a mean RPD value of 35% and a median RPD of 7%.</td><td>Throughput Achieved:

A batch of 12 field samples could be extracted and analyzed in a half day by one person.</td></tr>
</table>

TECHNOLOGY QUICK REFERENCE SHEET
RaPID Assay® Cyclodienes Immunoassay Test Kit (continued)

General Commercial Information (Information valid as of August 2000)

Vendor Contact:

Not available

Vendor Information:

Strategic Diagnostics, Inc.
111 Pencader Drive
Newark, DE 19702
1-800-544-8881
www.sdix.com

Limitations on Performance:

This test kit is not specific for just a single cyclodiene pesticide. It responds to: dieldrin, aldrin, endrin, heptachlor, heptachlor epoxide, chlordane, endosulfan (I and II), α-BHC, γ-BHC (lindane), δ-BHC, and several other organochlorine pesticides.

Principle of Analytical Operation:

This test is based on a competitive enzyme-linked immunosorbent assay (ELISA) reaction between cyclodiene compounds extracted from the sample with methanol and an antibody bound to a magnetic particle and added to a tube containing the extract.

The antibodies bound to the target analytes are separated from the extract using by retaining the magnetic particles with a magnetic field and decanting off the extract. When a color-developing reagent is added, the enzyme conjugate forms a colored product. The color density is read with a spectrometer and is proportional to the amount of conjugate reagent present. Darker color means less of the target analyte is present. The cyclodiene results are determined by comparison to 3-point calibration.

Availability/Rates:

Test kits are commercially available as a special order products. Associated test equipment, including hand-held spectrometer, is available for purchase or rental from manufacturer.

Power Requirements:

110 or 220 volt power is needed to charge the hand-held spectrometer, which may then be used in the field without additional power.

Instrument Weight and/or Footprint:

Approximately 5 square feet of space is required for sample processing and analysis.

General Performance Information

Known or Potential Interferences: Other organochlorine pesticides can react with the antibodies to varying degrees. The manufacturer provides cross-reactivity data with the test kit.

Applicable Media/Matrices:

Soil and Water

Wastes Generated Requiring Special Disposal:

Small volumes of methanol used for sample extraction, plus the used sample volume.

Analytes Measurable with Expected Detection Limits:

From manufacturer:
Cyclodienes, as dieldrin:
0.15 mg/kg in soil and
0.6 µg/kg in water

As employed for the case study:
18 µg/kg (ppb) in soil.

Other General Accuracy/Precision Information:

See SW-846 Method 4041

Rate of Throughput:

Up to 50 samples can be assayed at one time, with results available in 60 minutes.

Wenatchee Tree Fruit Test Plot

EXECUTIVE SUMMARY

This case study describes an approach to site cleanup that includes systematic planning, on-site measurement technologies combined with limited fixed laboratory analyses, and rapid decision-making using a dynamic work plan to facilitate quick cleanup. The integration of site characterization, on-site measurements, on-site remedial decision-making, and remedial action resulted in the expedited and cost-effective cleanup of a site contaminated with pesticides.

The test plot area of the Wenatchee Tree Fruit Research and Extension Center (WTFREC) contained soils contaminated with organochlorine pesticides, organophosphorus pesticides, and other pesticides due to agriculture-related research activities conducted from 1966 until the mid-1980s. In 1997, the U.S. Army Corps of Engineers (USACE) implemented an integrated site characterization and remediation project at the site. This approach permitted characterization, excavation, and segregation of soil based on the results of rapid on-site analyses employing commercially-available immunoassay testing products.

Key to the project's success was a pilot test that assessed the suitability of the on-site analytical methods. Site-specific contaminated soil was analyzed by both immunoassay (IA) methods and by traditional fixed laboratory methods. The results of the pilot test demonstrated the applicability of the DDT and cyclodiene pesticide IA methods and provided comparability data that the project team used to develop site-specific action levels that would guide on-site decision-making using the IA results. The IA action levels were refined during the course of project implementation as additional comparability data sets (composed of matched IA and fixed laboratory results) became available.

A soil excavation profile was developed in the field using the analytical results according to a decision matrix developed by the USACE. Several phases of field activities were conducted under a dynamic work plan framework using an adaptive sampling strategy. Characterization and cleanup were accomplished within a single 4-month field mobilization, and the entire project cost was about half the cost estimated according to a more traditional site characterization and remediation scenario relying on multiple rounds of field mobilization, sampling, sample shipment, laboratory analysis, and data assessment. The costs of waste disposal were significantly reduced by using field analyses to characterize and segregate wastes that required costly incineration from other wastes that were suitable for less expensive disposal methods. The "surgical" removal of contaminated materials ensured that closure testing would demonstrate regulatory compliance to a high degree of certainty, while making field activities such as sample collection, sample analysis, soil removal, soil segregation, and final disposal of soil and wastewater highly efficient and effective.

The key features of the project that contributed to its success included:

- Systematic planning accomplished by a team representing the USACE, EPA, the site owners, and state regulators with the appropriate mix of skills and decision-making authority.
- A conceptual site model based on a review of historical records from the site.
- A dynamic work plan that permitted the field team to make real-time decisions on the basis of data generated in the field.
- The pilot study that demonstrated the utility of the field analyses and provided data that were used to establish site-specific action levels.
- An adaptive sampling and remediation strategy that relied on the combination of the field analyses and fixed laboratory data.

SITE INFORMATION

Identifying Information

Site Name:	Wenatchee Tree Fruit Research and Extension Center (WTFREC) Test Plot
Location:	Wenatchee, Washington
Technology:	Site Cleanup Using a Dynamic Work Plan and Immunoassay Field Kits
Operable Unit:	None
CERCLIS #:	None
ROD Date:	None

Background

Physical Description: The Wenatchee Tree Fruit Research and Extension Center (WTFREC), an agricultural research facility, is located in southeast Wenatchee, Washington (see Figure 1).

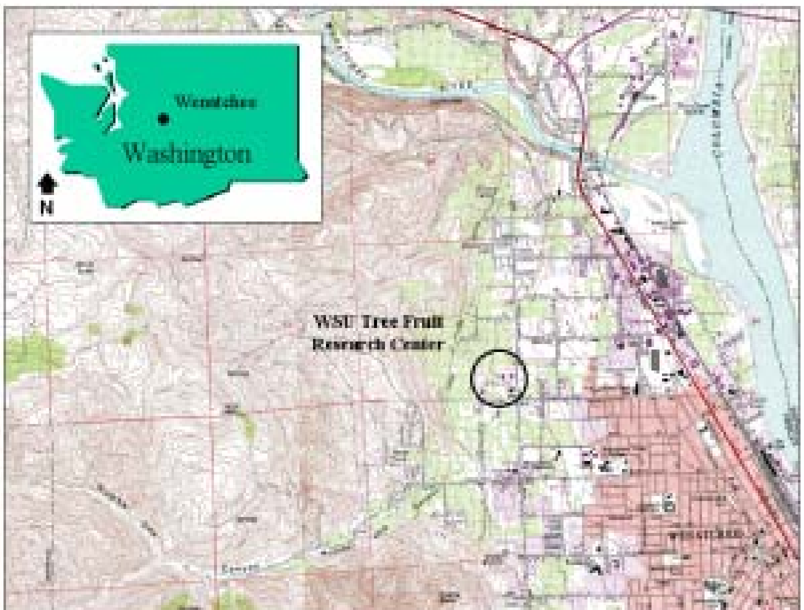

Figure 1. Topographic map showing the location of the WTFREC relative to the town of Wenatchee and the State of Washington

SITE INFORMATION continued

In the past, the U.S. Public Health Service (PHS), and the U.S. Environmental Protection Agency (EPA) used a 2,100 square-foot test plot area located in the northeast corner as a pesticide disposal research area. During the initial stage of the site remediation study, the location and dimensions of that test plot were determined based on the location of existing barbed wire fencing. Based on the fence location, the approximate dimensions of the test plot were 70 feet by 30 feet, and the area was located approximately 23 feet south of the WTFREC facility's northern property line. However, after evaluation of sampling results from investigations conducted by Washington State University (WSU) and EPA, the U.S. Army Corps of Engineers (USACE) concluded that lateral contamination extended beyond the previously identified edge of the test plot area. The new dimensions of the contaminated area were then determined to be 85 feet by 33 feet. The test plot is adjacent to a graduate student mobile home, an unpaved access road, and a nearby manufactured home development (see Figure 2).

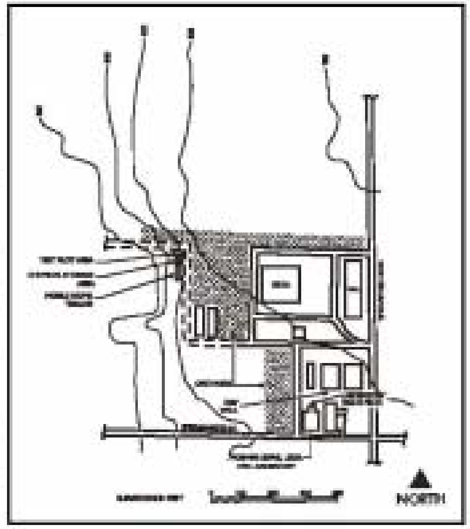

Figure 2. Site Plan for the WTFREC Test Plot

Site Use: The WTFREC was historically used as an agricultural research facility. The test plot area was initially used by the PHS, and later by the EPA, as a test facility to determine the effectiveness of various land disposal methods for pesticides.

Pesticide disposal testing reportedly began in 1966 and continued until the early 1980s. The disposal experiments focused on organochlorine (OC) and organophosphorus (OP) pesticides, but could possibly have included the testing of other pesticides. Pesticide burial was conducted at the site using the following three methods:

(1) Pesticides were diluted with solvent and poured through the openings of cinder blocks (see Figure 3);

(2) Pesticides were diluted with solvent and poured directly onto the ground surface; and

3) Pesticides were mixed with lime, lye, or Purex®, placed in paper bags and buried two to three feet below the ground surface (see Figure 4).

Figure 3. Disposal on the ground.

Figure 4. Burial of concentrated pesticide products

SITE INFORMATION continued

In the mid-1980s, the property was transferred from EPA to the Washington State University (WSU). WSU currently operates test and laboratory facilities at the WTFREC and uses the orchards shown in Figure 2 as their primary research areas. Nearby residential development is changing the land use pattern, increasing the concern that the test plot be remediated.

Release/Investigation History: Between 1985 and 1987, WSU performed limited sampling and analysis of soil in and near the test plot in response to concerns about pesticide contamination. After this initial sampling, WSU contacted EPA and asked for assistance in characterizing and remediating the test plot site. EPA and its contractors performed site investigations, which included sampling and analysis, in 1990, 1991, and 1994. Sampling activities included the collection of four background samples from an area approximately 1,200 feet west of the test plot.

EPA's Office of Research and Development (ORD) obtained assistance from the USACE for the purpose of remediating the test plot site. USACE used sample results from the WSU and EPA sampling events to determine the primary areas of OC and OP pesticide contamination at the site. Prior to writing specifications for the test plot remediation, the USACE reviewed records and publications from the research facility and contacted several WTFREC researchers for additional information regarding experiments at the site. Based on this research, the USACE identified the three reported methods of pesticide disposal used during pesticide research activities at the WTFREC.

Given the history of pesticide disposal at the site, there were significant concerns regarding the vertical migration of pesticides in the test plot area. Research articles written by EPA researchers in the 1970s indicated that no significant pesticide contamination was expected at depths greater than 8 inches below any of the initial disposal depths in the test plot area. Sampling performed by WSU and EPA in the 1980s and 1990s at the test plot area confirmed this expectation. USACE used the article findings and sampling data from EPA's and WSU's investigations to develop initial plans for characterization and excavation at the test plot area.

Regulatory Context: The Wenatchee Tree Fruit Test Plot cleanup was performed under the regulatory oversight of the State of Washington Department of Ecology's Voluntary Cleanup Program.

SITE INFORMATION continued

Site Logistics/Contacts

"Customer" or Responsible Party:
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MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Soil

Site Geology/Stratigraphy

The WTFREC is situated at approximately 800 feet above sea level and 194 feet above the normal elevation of the Columbia River. The WTFREC is located approximately two miles east of the Columbia River. The eastern foothills of the Cascade Mountains, which begin approximately one-half mile to the west of WTFREC, rise to about 2,000 feet above sea level. The site lies on an alluvial fan deposited along a steep drainage that flows eastward from the Cascade Mountains to the Columbia River. The alluvial soils are composed of poorly sorted boulder gravel and gravelly sand with some clay layers. The surface gradient in the area is approximately 200 feet per mile. The gradient portion becomes less steep as the alluvial fan merges with the Columbia River flood plan.

Contaminant Characterization

Primary Contaminant Group: Table 1 contains a list of the established contaminants of concern and action (cleanup) levels used for the WTFREC Test Plot remediation. The primary contaminant groups include organochlorine pesticides, organophosphorus pesticides, carbamate pesticides, and paraquat. The action levels in Table 1 were based on the specifications of the Washington State Model Toxics Control Act (MTCA) and range over five orders of magnitude. See the "Site Characterization and Remediation Process" section for more information on establishing cleanup levels during this study.

The on-site and fixed laboratory analyses performed for this project focused on two groups of organochlorine pesticides: the cyclodienes and the DDT series. The cyclodiene group is characterized by a six-membered ring with an endomethylene bridge structure (a double bond between two carbons at one end of the ring). The specific cyclodienes of interest at the WTFREC site included: aldrin, chlordane, dieldrin, endrin, endrin aldehyde, endrin ketone, endosulfan I and II, endosulfan sulfate, heptachlor, heptachlor epoxide, and toxaphene.

The DDT series consists of the various isomers (2,4'- and 4,4'-) of DDT, as well as the isomers of the related compounds DDE and DDD. The compounds of greatest toxicological concern are the 4,4'-isomers, which are also typically the most prevalent compounds contained in commercial DDT formulations. The toxicological data for the 2,4'-isomers are more limited, and 2,4'-DDT was generally present in lesser amounts in commercial formulations than 4,4'-DDT (often a 20/80 percent mixture of the 2,4'- and 4,4'- isomers), although the exact ratio varies with formulation and manufacturer. As a result of the scarcity of toxicity data for the 2,4'-isomers alone and the desire to have protective action levels, the action levels used for the WTFREC test plot remediation were based on the sum of both isomers (2,4'- and 4,4'-) for all three compounds in the DDT series.

On-site analyses for DDT and cyclodienes were used to guide the decisions of the dynamic work plan. Fixed laboratory analyses for the primary contaminant group in Table 1 were used to establish a closure confirmation data set for regulatory compliance.

MEDIA AND CONTAMINANTS continued

Table 1. Established Contaminants of Concern for the WTFREC Test Plot Remediation

Suspected Contaminant	MTCA Method B* Cleanup Level (mg/kg)	Suspected Contaminant	MTCA Method B* Cleanup Level (mg/kg)
Organochlorine Pesticides		**Organophosphorus Pesticides**	
Dieldrin	0.0625	Di-Syston (disulfoton)	3.20
Endrin	24	Guthion (azinphosmethyl)**	3.20
Endrin aldehyde**	24	Parathion	480
Endrin ketone**	24	Methyl parathion	20
Endosulfan I	480	Aminomethyl parathion**	20
Endosulfan II	480	Malathion	1600
Endosulfan sulfate**	480	Ethion	40
DDT***	2.94	DDVP (dichlorvos)	3.44
DDE***	2.94	Diazinon	72
DDD***	4.17	Dimethoate	16
gamma-BHC (lindane)	0.769	Paraoxon-ethyl**	480
Methoxychlor	40	Paraoxon-methyl**	20
Aldrin	0.0588	**Carbamate Pesticides**	
alpha-BHC	15.9	Carbaryl	8000
beta-BHC	0.556	Furadan (carbofuran)	400
delta-BHC	0.556	**Miscellaneous Pesticide**	
Chlordane	0.769	Paraquat	360
Heptachlor	0.222		
Heptachlor epoxide	0.110		
Toxaphene	0.909		

* The Washington State Model Toxics Control Act (MTCA) specifies three methods for establishing cleanup levels, Methods A, B, and C. Method B is the standard method for cleanup of soil and was used at the WTFREC Test Plot remediation. See the "Site Characterization and Remediation Process" section for more information on the use of MTCA Method B cleanup levels during this study.

** The action level is based on the parent compound's action level.

*** The action levels used for the site were based on the sum of the concentrations of the 2,4'-isomers and the 4,4'-isomers of each compound (e.g., the sum of *o,p'*-DDT and *p,p'*-DDT).

MEDIA AND CONTAMINANTS continued

Site Characteristics Affecting Characterization Cost or Performance

The design of the study and the implementation of field and laboratory activities were influenced by several site-specific characteristics. These included:

- Above-ground objects and vegetation that required removal prior to field sampling
- The presence of concentrated pesticide products buried at the site
- The need to segregate the excavated materials for cost-effective disposal

Removal of Above-Ground Objects and Vegetation: A number of objects that were in and immediately adjacent to the test plot at the commencement of the work were removed and disposed of according to the Remedial Action Management Plan (RAMP). These included the barbed wire fence and fence posts, the chemical storage shed, and the trash cans. Additionally, all of the vegetation within the boundaries of the test plot was cleared to a level of approximately two-inches above the ground surface or less (GSA, Inc. 1998, p. 15).

Excavation and Removal of Concentrated Pesticide Products: Concentrated pesticide products had been buried at two locations on the site. Prior to characterizing the entire site, these buried products were removed during "focused removal" activities. These activities consisted of excavation of materials based upon visual indicators, followed by closure confirmation sampling of the areas to ensure that all of the contaminated materials had been removed.

Figure 5 is a site plan showing the orientation of the rows and columns established for the cleanup activities as well as the locations of the various types of samples that were collected. The rows in Figure 5 were established based on historical data from the site regarding the pesticide disposal experiments that were conducted there. As noted earlier, in addition to burying bags of concentrated pesticide products mixed with lime, lye, or other chemicals on the site to monitor their breakdown, pesticides were diluted with solvents and poured through concrete blocks on the site, and mixed with soil and placed directly onto the surface. Each row includes areas used for similar disposal experiments. For example, during the site characterization phase, samples collected from columns 1 and 9 were only analyzed for OC pesticides, and samples collected from columns 2 through 8 were analyzed for both OP and OC pesticides. The columns were drawn perpendicular to the rows to provide a grid spacing that was statistically determined to allow detection of a hypothetical 5 foot by 10 foot elliptical hot spot.

The two focused removal areas were each approximately 10 feet wide (east-west direction) by approximately 24 feet long. One area was identified as Focused Removal Area 2/3 (FR2/3) because it spanned adjacent portions of columns 2 and 3 on the site; while the other area was identified as Focused Removal Area 4/5 (FR 4/5), because it spanned portions of columns 4 and 5 (see Figure 5). Based upon the USACE review of the research records, the materials removed from FR2/3 were expected to contain elevated levels of OP pesticides and the FR4/5 materials were expected to contain elevated levels of OC pesticides.

Bags of concentrated pesticide materials were encountered within each of the two areas, at approximately 18" below ground surface (bgs). Excavation continued downwards until approximately 6" of soil was removed below the last visually-observed bag remnant. Final excavation depths were approximately 27" bgs for FR2/3 and approximately 33" bgs for FR4/5. Excavated materials were segregated according to expected contaminant and concentration during excavation and placed directly into designated roll-off bins. A total of 45.74 tons of material was excavated during the focused removal activity, 22.32 tons from FR2/3 and 23.42 tons from FR4/5.

MEDIA AND CONTAMINANTS continued

Segregation of Excavated Materials for Disposal: With over 45 tons of material excavated from the focuses removal activities, the potential costs to dispose of those materials were significant. Of the contaminants of concern shown in Table 1, endrin and lindane were significant disposal concerns because of their presence on the list of constituents for the RCRA hazardous waste toxicity characteristic. All wastes generated during the remediation activities were to be recycled, salvaged, incinerated, or disposed of in a RCRA Subtitle C permitted landfill. The following three different "disposal" classifications were anticipated, based on RCRA and the Washington State waste regulations:

- Dangerous waste
- Non-dangerous waste
- All other solid waste (including demolition debris, personal protective equipment, etc.)

The "dangerous waste" included soil containing pesticides and contaminated with endrin and lindane at levels in excess of the RCRA toxicity characteristic limits. The "non-dangerous waste," a State of Washington designation, consisted of soils that passed the toxicity characteristic, but contained contaminants in excess of the State of Washington limits.

The IA testing product for the cyclodienes responds more strongly to endrin than to any other cyclodiene other than chlordane. Therefore, after correlating the IA results with gas chromatographic analyses conducted off-site during the pilot study, the on-site IA results for the cyclodienes were used to identify those excavated materials that were high in endrin and therefore designated for the most costly disposal option, incineration. The IA testing product for DDT responded to DDT, DDE, and DDD, and the on-site results were similarly correlated with gas chromatographic analyses conducted off-site during the pilot study.

The wastes in the roll-off bins were profiled in this fashion, based upon analytical data and generator knowledge. In addition, TCLP leaching was conducted off-site, based on the IA results, and used for final classification of the endrin-containing wastes.

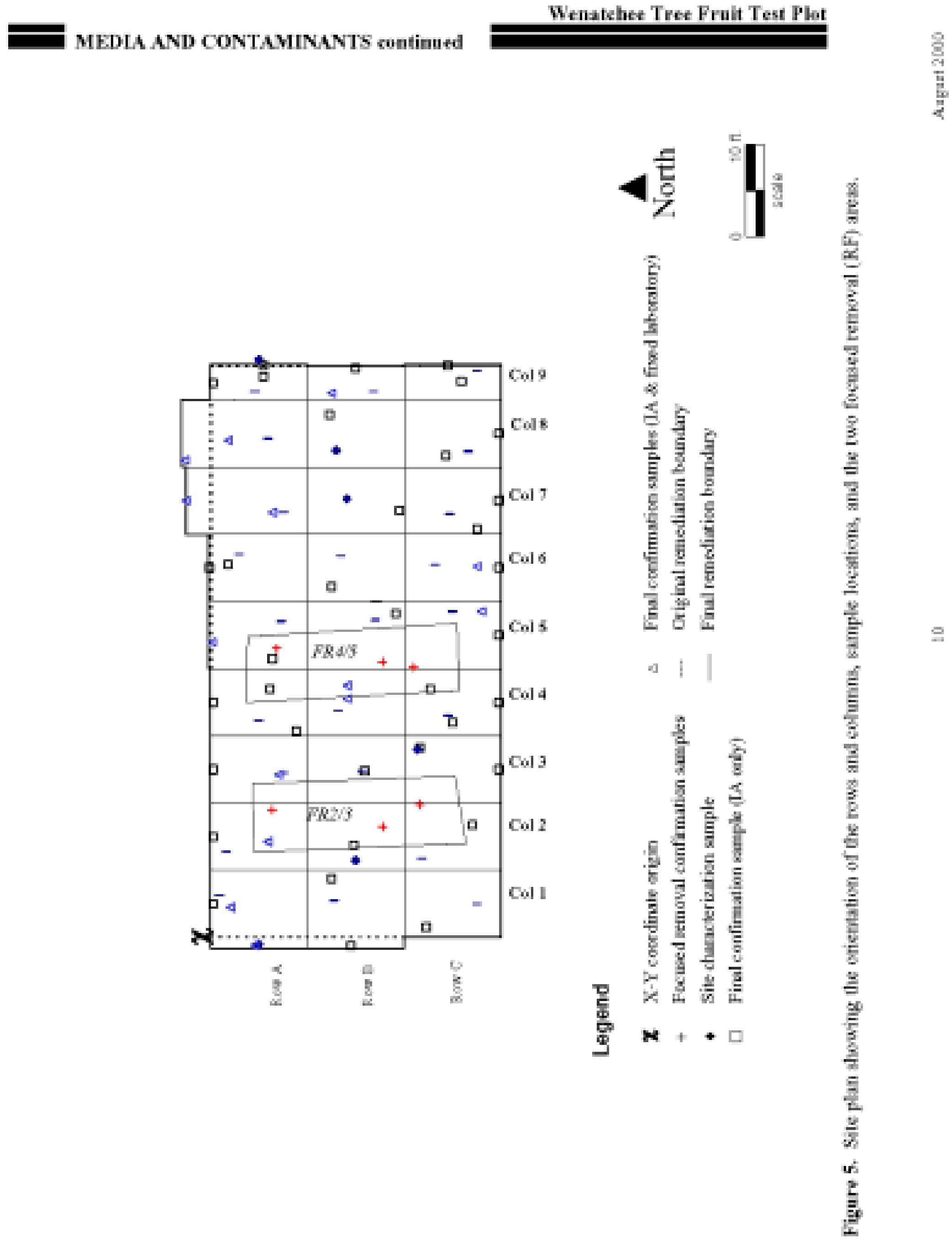

Figure 5. Site plan showing the orientation of the rows and columns, sample locations, and the two focused removal (RF) areas.

SITE CHARACTERIZATION AND REMEDIATION PROCESS

Systematic Planning and Sampling Work Plan

Prior to implementing the remedial action at the WTFREC Test Plot, the USACE and their contractor (GSA, Inc.) planned the project by preparing narrative and quantitative acceptance and performance criteria for data collection, a field sampling plan (FSP), and a quality assurance project plan (QAPP). Project planning was based on the specifications set forth in the Remedial Action Management Plan (RAMP). Current EPA guidance suggests that acceptance and performance criteria be developed for data collection, evaluation, using the Data Quality Objectives (DQO) process. The DQO process is part of an overall systematic data collection planning process and ensures that the right type, quality, and quantity of data are collected to support overall project-level decision making (e.g., see *Data Quality Objectives for Superfund: Interim Final Guidance* (USEPA 1993) and other guidances for the Data Quality Objectives Process (USEPA 1994, 1999, and 2000). The use of systematic planning, and subsequently, the use of a dynamic work plan, optimizes all site activities (not just data collection) and achieves the most effective results.

Planning and Field Teams: Planning and field teams were created to include the appropriate mix of skills and regulatory authorities needed to plan and implement cleanup of the WTFREC test plot. In particular, the regulatory authority (Washington State Department of Ecology) was involved in the planning process and approved the use of the dynamic work plan and the decision logic to be used during the cleanup.

The Planning Team was comprised of representatives from EPA ORD (as the USACE's customer), the regulator (Washington State Department of Ecology), stakeholders (Washington State University, as property owner, represented by the Environmental Manager, the Facility Manager, and an Environmental Scientist in charge of cleanup issues), the USACE Project Manager/Team Leader, and the USACE Project Chemist/Scientist, Project Engineer, Health & Safety Industrial Hygienist, and a Construction Engineer.

The Field Team was comprised of representatives from the USACE (Project Manager/Team Leader, Project Chemist/Scientist, Construction/Project Engineer, Field Quality Assurance Officer, and Health & Safety); the prime contractor (Project Manager, Field Engineer, Project Chemist/QC Officer); and subcontractors to perform excavation, IA, operate the Geoprobe, and manage soil disposal activities.

Conceptual Site Model: The initial conceptual site model (CSM) was developed by the USACE after review of records and publications available at the research facility and based on contacts with WTFREC researchers. The information indicated that vertical migration of pesticides to a depth greater than eight inches below the disposal point was not expected at the test plot area. In addition, the information indicated that there would be negligible horizontal migration of pesticides at the site.

The initial remediation boundary of the investigation was established based on the location of an existing barbed wire fence around the site. The approximate dimensions of the test plot were determined to be 70 feet by 30 feet. For additional information on delineation of the test plot area, see the discussion below in DQO process Step 4, "Define the Boundaries."

Dynamic Work Plan: Based on a pilot study, the USACE determined that site decisions could be made in the field, aided by the use of semiquantitative data (i.e., data used to make a decision about whether concentrations were above or below a certain action level) generated using on-site measurement technologies. The use of data generated on-site would allow relatively quick decision-making regarding subsequent steps. This approach would efficiently guide the characterization and removal efforts by means of an adaptive dynamic sampling strategy. Using adaptive sampling and analysis strategies, field-generated results were used to update the CSM and to better direct the analyses of the next batch of samples (see Figure 6).

This study approach permitted rapid location and definition of "hot" areas, guided the removal of contaminated soil, and quickly identified when enough information had been collected to address the remedial decisions. With this approach, the project team minimized the collection and analysis of uninformative samples, avoided unnecessary removal of soil, avoided multiple rounds of mobilization/demobilization of equipment and personnel, and efficiently identified when the project was "done," thus saving time and money.

Figure 6 shows the overall flow of work, including the systematic planning and the implementation of the dynamic work plan. The use of the field analytical methods allowed for integration of the site characterization with site remediation. In particular, site characterization information was used in the field to make soil removal decisions. In Figure 6, the field sampling, field analysis, and decision-making are shown in an iterative and dynamic "loop."

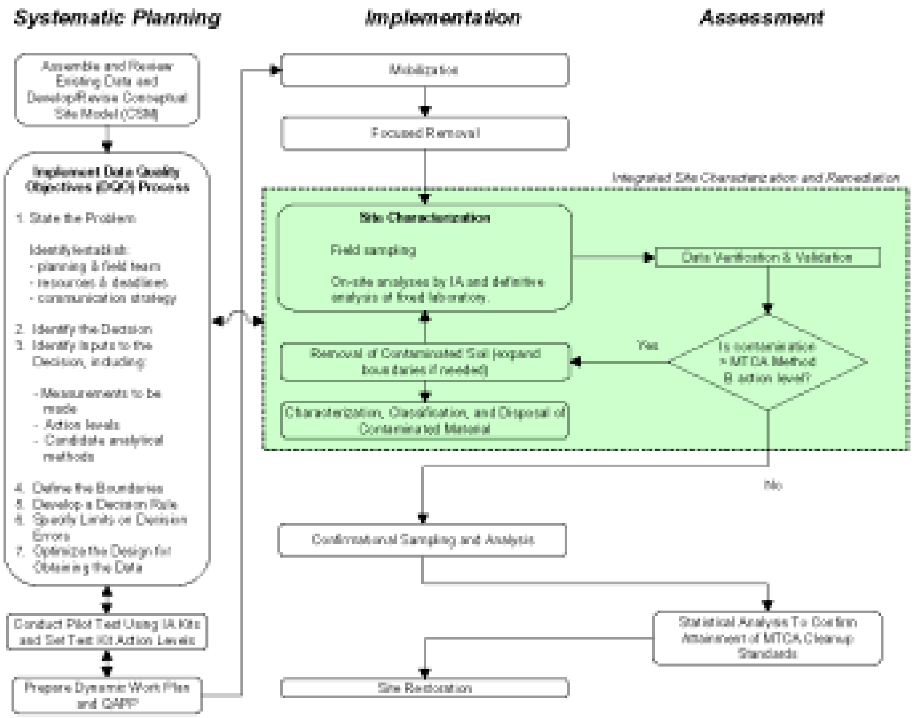

Figure 6. Flow chart showing the integration of site characterization and remediation and use of the dynamic work plan.

SITE CHARACTERIZATION AND REMEDIATION PROCESS continued

Application of the Data Quality Objectives Process: The initial planning steps, stated in terms of EPA's DQO process, are described below:

Step 1: State the Problem – In this step of the DQO process, it is necessary to define the problem, identify the planning team, and establish a budget and schedule. For the purpose of the remedial action, the problem was to identify those soils and wastes which were contaminated.

The specific goals of the WTFREC Test Plot Remediation included:

- Focused removal of concentrated pesticide product
- Gross removal of pesticide-contaminated soil
- Restoration of the site to achieve the MTCA Method B Cleanup Levels
- Characterization, classification, and disposal of contaminated materials.

As described previously, planning and field teams were assembled with the appropriate mix of skills needed to plan and implement the cleanup project. The planning team specified an expedited schedule for completion of the remedial action.

Step 2: Identify the Decision – Three decisions were identified during this step of the DQO process. The first decision was to determine whether the soil within each "exposure unit" (described below) was contaminated above the action levels established under the MTCA for each contaminant of concern (COC). Any soils contaminated above the action levels had to be removed. Any soil that was not contaminated at or above those levels could remain in place.

After removal, a second decision was required to determine if the remaining soil attained the cleanup standard.

Once they were removed from their original locations, soil and other wastes required appropriate disposal, based upon RCRA and the Washington State Dangerous Waste Regulations (WAC 173-303). Therefore, the third decision was to determine the appropriate classification of the remediation waste for disposal purposes. Three different waste classifications were used: dangerous waste, non-dangerous waste, and solid waste (including demolition debris, personal protective equipment, etc.). Each classification involves different disposal methods, including incineration for the dangerous wastes, the most costly approach. Therefore, it was critical that wastes from the site be segregated on the basis of their waste classification in order to control disposal costs.

Step 3: Identify Inputs to the Decision – This step of the DQO process required a list of the information inputs needed to resolve all parts of the decision statement. For example, to make remedial decisions (i.e., to remove or not remove the soil), the necessary inputs included, at a minimum, a list of contaminants of concern and action (cleanup) levels (see Table 1), the units of measure (e.g., mg/kg or mg/L), target quantitation limits, candidate analytical methods capable of achieving the quantitation limits, and measurement performance criteria.

A list of constituents of concern were identified based on previous investigations conducted by WSU and the USEPA. The Washington State Model Toxics Control Act (MTCA) establishes three basic methods for establishing cleanup levels: Methods A, B, and C. The MTCA Method B is the standard method for determining cleanup levels for ground water, surface water, soil, and air. Cleanup levels are established using applicable state and federal laws or by using the risk equations and criteria specified in the MTCA regulations. The planning team determined that the Method B was an appropriate method for setting the cleanup levels for those COCs with calculated MTCA Method B levels.

For COCs that do not have calculated MTCA Method B levels, the USACE, EPA, Washington State Department of Ecology, and WSU agreed to use the MTCA Method B cleanup levels for their parent compounds (e.g., endrin ketone and endrin aldehyde had the action level of endrin and endosulfan sulfate had the action level of endosulfan I).

Table 1 contains the list of the contaminants of concern and the MTCA Method B cleanup levels established for this project. The quantitation limits for the field and fixed laboratory analyses were established as described in Step 7.

It was determined that commercially-available immunoassay field test kits could measure two of the most important classes of pesticides, DDT and two cyclodienes, dieldrin and endrin. The availability of the test kits proved to be a critical element in optimizing the study design (see DQO Step 7), implementing a dynamic work plan, and using real-time decision-making to streamline the cleanup process.

Step 4: Define the Boundaries – In this step, the planning team developed a detailed description of the spatial and temporal boundaries of the cleanup problem.

Initially, the surface location and dimensions of the test plot area were established based upon the location of the barbed wire fencing. The barbed wire fencing secured a rectangular area with approximate dimensions of 69 feet-9 inches (from east to west) by 29 feet-9 inches (north to south). From the previous investigations, however, the USACE concluded the horizontal extent of contamination, as defined by the MTCA Method B action levels, was not necessarily confined to the fenced test plot. For the initial conceptual site model (CSM), the USACE decided to extend the boundary of the area of potential contamination as follows:

- Another three feet beyond the northern edge of the test plot
- An additional 5.5 feet beyond the eastern edge of the test plot
- Another 10 feet beyond the western edge of the test plot.

Other locations within and near the test plot were identified by the USACE as having minimal to no data indicating the presence of contaminants. However, during the site characterization, as the CSM matured, the boundaries were extended slightly beyond the original boundary established for the remedial action (see Figure 5). Samples collected by EPA from the non-orchard area indicated that the background pesticide levels in the area did not exceed the MTCA Method B cleanup levels (GSA, Inc. 1998).

The test plot was divided into nine columns (1 through 9) and three rows (A, B, and C), making 9 removal columns and 27 sampling grids. Each column was a separate "exposure unit" and was established by the USACE to correspond with a discrete potential removal location, based on historic data on disposal locations, as well as past sampling and analysis actions. The final determination of attainment of the cleanup standards was made based upon evaluation of the entire footprint of the test plot site (i.e., all nine columns).

Depth of contamination was another spatial boundary of concern for site remediation. Within the site boundary, two areas or were identified within which bags of concentrated pesticide product were buried. Based on historical information, it was determined that pesticide product may have been buried to depths up to 4 feet (48 inches) below ground surface (bgs). Historical data and research indicated that migration of pesticide contamination beyond this depth was expected to be minimal (i.e., an additional 8 to 12 inches). These two areas were designated as FR2/3 and FR3/4 and were excavated as part of the focused removal excavation (see previous discussion of "Excavation and Removal of Concentrated Pesticide Product" on page 8) followed by closure confirmation sampling of the areas.

SITE CHARACTERIZATION AND REMEDIATION PROCESS continued

The temporal boundary (i.e., time frame for project completion) was established based on the desire to complete on-site activities prior to the onset of winter. The winter climate at Wenatchee often includes cold temperatures and snow. Therefore, completion of the site activities before winter was important to ensure worker safety and to avoid weather-related delays of excavation and sampling. In addition, EPA requested an expedited cleanup schedule in order to show good faith to the stakeholders.

Step 5: Develop a Decision Rule – In this step, the planning team specified the parameters of interest, action levels, and developed a decision rule.

As noted previously in "Media and Contaminants" (see page 6), the DDT series consists of the various isomers (2,4'- and 4,4'-) of DDT, as well as the isomers of the related compounds DDE and DDD. As a result of the scarcity of toxicity data for the 2,4'-isomers alone and the desire to have protective action levels, the USACE, EPA, Washington State Department of Ecology, and WSU agreed that it was appropriate to add up the soil concentrations of the 4,4'- and 2,4'-isomers of DDT and to compare this value with an action level based on the sum of both isomers (2,4'- and 4,4'-) for all three compounds in the DDT series.

A soil removal decision matrix was established for both the "shallow burial columns" and the "deep burial columns" to guide the field sampling and establish a basis for removal and confirmation sampling, or no further action. For example, if the immunoassay field kits found contamination in the interval 0 to 12" bgs at concentrations exceeding the action level established for the kit, then additional analyses were performed on samples representing the interval 12" to 24" bgs. If no contamination was found above the action level, then the 0 to 12" interval was removed and the removed soil was subjected to confirmation sampling and analysis.

Based on the IA results and the decision matrix, more samples were actually collected than were analyzed. This type of decision rule was applied to depths no greater than 72" bgs. Sampling was limited to depths of 72 inches because the USACE believe that all pesticide contamination would effectively be found within that depth interval. This was based on the assumption that no pesticide product was disposed below 4 feet (48 inches) bgs and that migration of pesticides would be minimal (less that one foot) beyond that depth.

Finally, for the closure confirmation data to demonstrate attainment of the cleanup standards, the data must pass three statistical tests. These tests are:

- The analyte concentration for no more than 10 percent of the samples can exceed the cleanup standard for that analyte;
- No sample concentration can exceed a level more than two times the cleanup standard for any particular analyte; and
- The upper confidence limit (UCL) of the data for each analyte must be statistically shown to be less than the cleanup criteria for that analyte.

The procedure to be used to calculate UCLs depends on the distributional assumptions that are made about the data (e.g., normal, log normal, or other distribution) and the size of the sample population. For the WTFREC test plot cleanup, UCLs were calculated using guidance published by the State of Washington Department of Ecology (see Ecology 1992 and 1995). For most of the data sets, an assumption of a log normal distribution was appropriate, and in these cases the UCL was calculated using Land's method as described in the Washington State Department of Ecology guidance. For data sets that contained a large percentage (>50%) of nondetects, the largest value in the data set was used as the UCL in accordance with the Washington State Department of Ecology guidance.

Step 6: Specify Limits on Decision Errors – A decision error occurs when sampling data mislead the decision maker into choosing a course of action that is different from or less desirable than the course of action that would have been chosen with perfect information (i.e., with no constraints on sample size and no measurement error). Data obtained from sampling and analysis are never perfectly representative and accurate, and the costs of trying to achieve near-perfect results can outweigh the benefits. Uncertainty in data must be tolerated to some degree. The DQO process controls the degree to which uncertainty in data affects the outcomes of decisions that are based on those data. This step of the DQO process allows the decision maker to set limits on the probabilities of making an incorrect decision.

When the data lead you to decide that the baseline condition (or "null hypothesis") is false when in fact it is true, a "false rejection" decision error occurs (i.e., the null hypothesis is falsely rejected – also known as a false positive decision error or Type I error). In the reverse case, a "false acceptance" decision occurs when the data lead you to decide that the baseline condition is true when it is really false (i.e., the null hypothesis is falsely accepted – also known as a false negative decision error or Type II error).

For the final calculation of upper confidence limits on the mean using the closure confirmation sampling data, the Type I error rate (α) was set at 0.05 as specified by the requirements of the MTCA. Setting the error rate at this level ensures there is only a 5% chance of falsely rejecting the null hypothesis. In other words, when the MTCA standard has not truly been met, the chances are only 1 in 20 that the statistical test will erroneously conclude it has been met.

Step 7: Optimize the Design for Obtaining the Data – The objective of this step is to use the outputs of the first six steps of the DQO process to develop a sampling and analysis plan that obtains the requisite information from the samples for the lowest cost and still satisfies the project objectives.

For this project, the overall DQOs were as follows:

- Provide field analytical results for DDT and cyclodienes (especially dieldrin and endrin) with quantitation limits that are less than the field/operational action levels in order to guide the removal of contaminated soil from each defined "column" of soil at the site such that final cleanup goals will be met within a single field mobilization.

- Ensure that the turnaround time for the field-generated data supports the real-time decision-making needs of the dynamic work plan.

- Collect sufficient soil data to confirm that the soil left in place meets the MTCA cleanup standards such that:

  - no more than 10 percent of samples exceed the cleanup standard,
  - no sample can exceed two times the cleanup standard, and
  - the true mean concentration must be below the cleanup standard as measured by a 95% upper confidence limit on the mean.

- Provide analytical results that can be used to segregate and classify excavated soil and other remediation wastes for management as solid, hazardous, or dangerous waste according to RCRA and the Washington State Dangerous Waste Regulations.

Pilot Test

In an effort to develop the analytical plan and identify a cost-effective analytical strategy, a pilot test of the IA methods was conducted using contaminated surface soil from the site. The pilot study was critical to the success of this project in that it allowed the investigators to demonstrate the usefulness of the IA methods for on-site analysis of soils for DDT and cyclodiene at their respective soil cleanup levels, thereby providing an important tool for on-site decision making and implementation of the dynamic work plan approach.

By their nature, the commercially-available IA testing products relevant to this study are not specific to a single target compound. Rather, the antibodies used in the kits bind to a variety of structurally-similar contaminants. Therefore, although the test kit may be calibrated using one specific pesticide, the response generated during the test is due to all of the potential reactants present in the sample, each of which elicits a response to a different degree. Since the cleanup levels for this and most other projects are based on specific contaminants, the IA test results cannot be used to make cleanup decisions without considering the site-specific nature of this limitation.

The pilot study was designed to evaluate the utility of the IA test kits by comparing their results to a more traditional fixed-laboratory, contaminant-specific analytical approach. Samples of soil from the test plot were collected and split into two portions, one for IA analysis and one for the traditional approach. The results of both types of analyses were evaluated by the project team to determine the utility of the IA results for site-specific decision making.

Analytical Method Selection

Analytical methods for the pilot study were selected that could achieve the method performance requirements established by the project team and documented in the QAPP (GSA, Inc. 1997b). A list of the analytical methods is presented in Table 2.

Table 2. Analytical Methods

Analyte	Method
Cyclodiene IA field test	SW-846 4041
DDT IA field test	SW-846 4042
Organophosphorus pesticides	SW-846 8141, modified*
Organochlorine pesticides	SW-846 8081
Carbamates	SW-846 8141, modified*
Paraquat	RM-8-10**

* GC/MS was used in Method 8141 for the OP pesticides. The carbamate analyses used GC/NPD.

** This is a spectrophotometric method based on procedures developed by Chevron Oil

Modification of Methods under PBMS

As noted in Table 2, some of the reference methods were modified to accommodate the specific contaminants of concern at the site. These modifications were designed by the project team that included an analytical chemist and were conducted in accordance with the performance-based measurement system (PBMS) approach adopted by EPA in recent years. The modifications are described in greater detail in "Analytical Technologies and Method Modifications." In addition to the modifications to the fixed laboratory reference methods, the IA methods were modified in order to allow a single sample extract to be analyzed using both the DDT and cyclodienes test kits.

Establishing Site-Specific Action Levels for the Field Test Kits

The pilot study results confirmed that the IA test kits are intentionally biased 100% high by the manufacturer in order to reduce the occurrence of false negative results. Combined with the fact that the test kits respond to more than one of the contaminants of concern at the site, the project team determined that a DDT test kit result of 5 mg/kg (ppm) could indicate that the site-specific cleanup level for an individual compound (e.g., DDT, DDE, or DDD) had been exceeded. Similarly, they determined that a cyclodienes test kit result of 0.086 mg/kg (ppm) could indicate that the site-specific cleanup level for an individual compound (e.g., dieldrin or endrin) had been exceeded. These values (5 ppm and 0.086 ppm) became the site-specific field action levels associated with the DDT IA test kit and the cyclodiene IA test kit, respectively, at the start of field work.

Final Method Selection

The analytical methods used for cleanup phases of the project were based on the methods modified for the pilot study (see Table 2). The sensitivities of the analytical methods selected for the field IA testing and fixed laboratory confirmation analyses were evaluated relative to the MTCA Method B cleanup levels established for this project. The goal was to employ a method that was sensitive enough to make measurements at no more than one-half the MTCA Method B cleanup level. Table 3 illustrates the sensitivities for the major contaminants of concern relative to the MTCA Method B cleanup levels.

Table 3. Sensitivities of Field and Fixed Laboratory Methods Relative to Cleanup Levels

Contaminant	MTCA Method B Cleanup Level (mg/kg)	Field Method Sensitivity* (mg/kg)	Fixed Laboratory Method Sensitivity** (mg/kg)
Dieldrin	0.0625	0.018	0.00007
Endrin	24	--	0.00012
4,4'-DDT	2.94	0.8	0.0013
4,4'-DDE	2.94	--	0.0036
4,4'-DDD	4.17	--	0.00017

*The IA test kit sensitivities were established by the concentration of the lowest of the calibrator solutions analyzed using the test kit. The cyclodiene kit used for dieldrin and endrin was calibrated using chlordane and the DDT test kit was calibrated using DDT. Thus, the values above represent quantitation limits for the specific compounds used for calibration.

**The fixed laboratory method sensitivities were based on the method detection limit (MDL) values reported by the laboratory. Thus, the values above represent detection limits, and not quantitation limits, but they are specific to the individual analytes listed. The MDL values were reported by the laboratory in units of µg/kg, and have been converted to mg/kg in this table for ease on comparison with the cleanup levels.

Field Analytical Quality Control

Following the pilot test, the chemist and the project team designed a field analytical quality control (QC) program that was used to monitor and ensure the quality of the field results. That program included the use of such traditional QC operations such as calibrations and laboratory control samples, as well as continuing to submit some split samples for fixed laboratory analyses in order to detect potential interferences and to monitor the comparability of the field and fixed laboratory results over time and across different areas of the site.

Monitoring and Refining the Action Levels

As a result of the continued generation of fixed laboratory results for a subset of all the samples collected for field kit analyses, the field kit action levels were further refined after the characterization phase. Comparison of the IA and fixed laboratory data sets generated during the characterization phase determined that the 5 ppm field action level being used for the DDT IA kit was overly conservative. With the approval of the regulator, the DDT IA field action level was raised to 10 ppm for the removal phase of the project.

Site Cleanup Phases

Using information from previous site investigations and the results of the pilot study, the cleanup project was designed to take place in seven phases.

Phase 1: Mobilization

Phase 2: Focused removal of pesticide product

This phase employed field test kit IA analyses with fixed laboratory confirmation of a subset of those results.

Phase 3: Characterization of the remediation area

This phase employed field test kit analyses for DDT and cyclodienes, fixed laboratory analyses for the organophosphorus and carbamates pesticides and Paraquat, as well as fixed laboratory confirmation of a subset of the field test kit results, leading to the revision of the action levels for the test kits in some areas of the site.

Phase 4: Gross removal of contaminated soil

This phase employed field test kit IA analyses

Phase 5: Final confirmation sampling for site closure

This phase employed fixed laboratory analyses.

Phase 6: Backfilling, grading, and restoration

Phase 7: Characterization and disposal of contaminated materials.

The final phase employed fixed laboratory analyses of soil samples as well as the production and analysis of TCLP leachates to characterize RCRA-regulated wastes.

SITE CHARACTERIZATION AND REMEDIATION PROCESS continued

Optimizing the Sampling and Remediation Program

The optimization strategy focused on Phases 3, 4, 5, and 7 of the site cleanup. One of the key elements of the optimization of the sampling and remediation program was the use of field methods to make remedial decisions in the field (primarily during Phases 3 and 4).

In Phases 2 and 3, the sampling strategy for the site characterization was optimized by the use of a "focused" sampling design in which sampling was conducted in areas where potential or suspected soil contamination could reliably be expected to be found. Another example of the optimization was the use of direct push soil sampling technology (i.e., Geoprobe) in lieu of traditional and more costly drill rig and split-barrel samplers. Using homogenization and sample splitting techniques, the team was able to provide sample volumes for IA analysis, fixed laboratory analysis (if needed), and archiving from a single collection event (see additional discussion under "Sampling Design and Methodology" on page 21 of this report).

In addition, the team employed field analyses using IA and supported by limited fixed laboratory analyses to increase the density of sample locations compared to that possible under traditional sampling and analysis programs. This facilitated the “surgical” removal of contaminated materials and ensured that closure confirmation testing would demonstrate compliance to a high degree of certainty. The combined benefits of the optimized approach produced both time savings and significant reductions in the overall project costs by making field activities such as sample collection, sample analysis, soil removal, soil segregation, and final disposal of soil and wastewater highly efficient.

On-site activities in all phases were facilitated by the use of a mobile office trailer and a mobile laboratory trailer. The cost of trailer rental was more than offset by savings realized from the on-site analyses (see also "Cost Comparison" in this report).

Note that the advantages of using field methods include the ability to match the rate of sample processing with the rate of sample collection providing efficient sample handling (e.g., minimal sample tracking, transport, and storage) and rapid turnaround time of field results in relation to the desired on-site decision-making abilities.

Sampling Design and Methodology

Sampling was performed at the site during various stages of the investigation including the following:

- After **focused removal** of pesticide products
- During the **site characterization** (using a direct push sampling method combined with IA analyses) prior to excavation
- After gross soil removal to evaluate attainment of the cleanup standards (**closure confirmation sampling**) and to guide further soil removal activities, and
- Sampling of waste soil and decontamination water prior to **waste characterization** for waste classification and disposal.

The text to follow discusses the sampling design and methodology for each of these sampling events.

Focused Removal Sampling Design: Focused Removal Area 2/3 (FR 2/3) and Focused Removal Area 4/5 (FR 4/5) (see Figure 5) were excavated until all visible evidence of pesticide disposal was removed. Upon completion of excavation activities, confirmatory samples were collected. The sampling grids for this effort were established by the row divisions of the test plot across the excavated areas. This resulted in six sampling areas or grids. A single random sample was then taken from within each sampling grid, except for one grid in which the sample location was biased towards a location with a piece of white particulate matter. The particulate matter may have come from one of the bags of concentrated pesticide products buried at the site.

Site Characterization Sampling Design: Site characterization sampling was initiated following completion of the focused removal activities. The site characterization included collection of soil samples throughout the test plot area. The samples were collected for the purpose of characterizing the site so that an excavation plan and preliminary waste disposal plan could be developed. Samples were collected using direct-push sampling equipment.

The sample collection approach was described as "focused sampling." Focused sampling is defined as the selective sampling of areas where potential or suspected soil contamination can reliably be expected to be found if present. One sample was collected from within each grid. The number and size of each grid were determined in advance using a statistical analysis of the site and an estimate of potential hot spot size. For sampling within each grid, biased locations were selected in the field based on visual observations of surface conditions. If there was not sufficient information to select a biased location, then a random sample was obtained instead.

At each sample location, a soil core was taken from the ground surface down to 72 inches. Samples were taken from each core to represent each one-foot interval within the bore hole. Each sample representing each one-foot interval was then homogenized and split into three subsamples – one for field analysis, one for possible fixed laboratory analysis, and one to be archived for possible future analysis.

Gross soil removal was aided by the use of a decision matrix to guide the analysis of samples, develop a removal profile, and select samples for fixed lab analysis. This approach was part of the adaptation of the sampling design under the dynamic work plan. Table 4 is an example of the decision matrix used at the WTFREC site for shallow soils. For example, if the field kits found contamination in the interval 0 to 12" bgs at concentrations exceeding the action level established for the kit, then the next interval (12" to 24" bgs) was analyzed by the field kits. If no contamination was found above the action level, then the 0 to 12" interval would be slated for removal, and a split of the 12" to 24" interval was sent for fixed laboratory analysis. (The fixed laboratory data helped ensure the accuracy of the removal profile, as well as add to the data set establishing the comparability of the field results to fixed laboratory analyses with respect to the action level.) This type of decision rule was applied to depths no greater than 72" bgs. Sampling was limited to depths of 72" because the USACE believed that all pesticide contamination would effectively be found within that interval. This was based on the assumption that no pesticide product was disposed below 4 feet (48 inches) bgs and that migration of pesticides would be minimal (less that one foot) beyond that depth.

Confirmation Sampling Design: At the conclusion of the gross removal excavation, closure confirmation sampling was conducted of the bottom and side walls of all 27 grids using IA analyses. Each grid to be sampled was laid out into nine equal sub-grids, a random selection of the sub-grid to be sampled was made, and the sampling point was marked with a wooden stake. Shallow soil samples were collected from within a 12-inch diameter area around the sampling point, placed directly into the sampling jar, and analyzed using the field IA method. Concentrations found above the IA action levels resulted in further excavation. The modified action level of 10 ppm for the DDT test was used to direct this excavation. The comparability data set had established that DDT IA results below 10 ppm correlated well with the mix of individual DDT, DDE, and DDD concentrations that did not exceed their respective MTCA standards.

When IA analyses indicated that no further excavation was needed, closure confirmation sampling for fixed laboratory analysis was performed. This sampling consisted of ten samples, one for each column, plus a sample for the second elevation in column 4. To ensure conservatism, the grid with the highest IA result in a given column was the grid sampled for the fixed laboratory analysis. The ten final closure confirmation samples for fixed laboratory analysis were discrete surface samples taken from the same location as the previous IA sample (refer to Figure 5 on page 10 where the triangle symbol represents this IA/fixed laboratory sampling location). The final closure confirmation samples submitted to the fixed laboratory were analyzed for the OP and OC pesticides, paraquat, and carbamate pesticides listed in Table 1.

Waste Characterization Sampling Design: Upon removal of the material from the ground, it becomes a waste governed by the Washington State Dangerous Waste Regulations (WAC 173-303) and not by the MTCA action levels. The waste was segregated into roll-off bins. See "Segregation of Excavated Materials for Disposal" in the "Media and Contaminants" section of this report (page 9) for more information on waste segregation. Waste stream characterization sampling was conducted at the conclusion of the focused removal excavation and again as significant segments of the initial gross removal excavation were completed.

During the focused removal, samples were collected from each of the segregated waste streams. Each sample was collected as a composite sample from at least five different locations within either a single roll-off bin or a grouping of roll-off bins. The proportion of sample collected from within any roll-off bin was representative of the proportion of waste soil within the bin as compared to the collective grouping of bins.

Some of the roll-off bins were not specifically sampled, particularly towards the end of the gross removal activities. Based upon the information known about the contents of these bins, the judgement was made that the relative contaminant concentrations within these bins were either at or lower than other bins, which were already known to be in the non-Resource Conservation and Recovery Act (RCRA) regulated waste category. All waste characterization samples were analyzed by fixed laboratory methods.

Table 4. Example Removal Decision Matrix for Shallow Disposal
(Contamination above MTCA Method B/Field Kit Action Level at depth)

Scenario#	0 to 12"	12 to 24"	24 to 36"	36 to 48"	48 to 60"	60 to 72"	Action
1	No	n/a	n/a	n/a	n/a	n/a	Confirmation Sampling
2	Yes	No	n/a	n/a	n/a	n/a	Find contamination in 0-12 sample, field sample 12-24" Find no contamination in 12-24" sample above MTCA: 0-12" of soil. Confirmation Sampling. No Further Action.
3	Yes	Yes	No	n/a	n/a	n/a	Find contamination in 0-12" sample, field sample 12-24" Find contamination in 12-24" sample, field sample 24-36" Find no contamination in 24-36" sample above MTCA: 0-24" of soil. Confirmation Sampling. No Further Action.
4	Yes	Yes	Yes	No	n/a	n/a	Find contamination in 0-12" sample, field sample 12-24" Find contamination in 12-24" sample, field sample 24-36" Find contamination in 24-36"sample, field sample 36-48" Find no contamination in 36-48" sample above MTCA: 0-36" of soil. Confirmation Sampling. No Further Action.
5	Yes	Yes	Yes	Yes	No	n/a	Find contamination in 0-12" sample, field sample 12-24" Find contamination in 12-24" sample, field sample 24-36" Find contamination in 24-36" sample, field sample 36-48" Find contamination in 36-48" above MTCA, field sample 48- Find no contamination in 48-60" sample above MTCA: 0-48" of soil. Confirmation Sampling. No Further Action.
6	Yes	Yes	Yes	Yes	Yes	No	Find contamination in 0-12" sample, field sample 12-24" Find contamination in 12-24" sample, field sample 24-36" Find contamination in 24-36" sample, field sample 36-48" Find contamination in 36-48 above MTCA, field sample 48- Find contamination in 48-60 sample, field sample 60-72" soil Find no contamination in 60-72" sample above MTCA: 0-60" of soil. Confirmation Sampling. No Further Action.

n/a = not applicable, i.e, the depth interval above the one specified was found to have no contamination above the MTCA Method B action level.

Analytical Technologies and Method Modifications

The project team used a selective mix of on-site analyses and fixed laboratory analyses to evaluate the contaminants of concern. For the focused removal, site characterization, soil gross removal and final confirmation sampling phases of this project, immunoassay field analysis (IA) kits were used at the site for organochlorine pesticides, and results were supplemented by limited data from fixed laboratory analyses. Waste characterization samples were analyzed for OP and OC pesticides, TCLP OC pesticides, and TCLP metals at a fixed laboratory. The text to follow discusses the performance of these analyses and related QC issues. The anticipation of such issues and related corrective actions was part of the project planning process. Analytical chemists were involved in developing plans for using both IA and fixed laboratory analyses.

Immunoassay Field Analysis: For on-site soil sampling and analysis during the focused removal and site characterization phases, two on-site immunochemical analyses, one for DDT and one for cyclodienes, were performed by GSA. The performance criteria for the immunoassay tests are outlined in Table 5.

Table 5. Immunoassay Test Kit Performance Criteria

Compound	Matrix Type	Correlation with Definitive Analysis (RPD and r^2)	Accuracy (LCS Recovery, %)	Precision (Duplicate % RPD)
DDT - Method 4042	Soil	≤50 > 0.90	60-140*	≤50
Cyclodienes - Method 4041	Soil	≤ 50 > 0.90	60-140*	≤50

*Verification of analytical accuracy was based on a mixed pesticide standard and a computed value based on the sensitivities for the reactivity groups given above. If the mean LCS recovery was not near 100%, further evaluation was performed to assess the accuracy.

The immunoassay tests were performed in batches of approximately 12 samples, at a rate of approximately one batch per test kit per day. Each batch consisted of a set of project samples and quality control (QC) samples; such as, calibration samples, field duplicates, lab duplicates and laboratory control samples. Some of the calibration samples were conducted in duplicate. The calibration data were fit into a straight line with linear regression and the resulting calibration line was used to compute the project sample concentrations.

During the course of the field analysis, project chemists investigated quality control problems and implemented corrective actions prior to releasing data for use. Most of the laboratory control sample (LCS) results fell within an accuracy window from 100 to 300 percent, with a mean near 200 percent. This was consistent with the known 100 percent calibration bias designed into the kits by the manufacturer. However, for the first five sample batches, the concentration of the laboratory control sample (LCS) was above the calibration range of the tests and the LCS recovery was high. This problem was overcome by diluting the LCS solution starting with Batch 6. After dilution of the LCS into the range of calibration, the mean LCS recovery was closer to the expected 200 percent. Other cases of LCS recovery exceeding the accuracy goals were determined to be caused by dilution errors. These cases were evaluated on a case-by-case basis and did not result in data rejection. The data in these instances were still deemed usable for the intended purpose.

In some batches, other LCS non-conformances were identified that indicated calibration deficiencies. In these cases, the LCS did not meet the acceptance criteria for LCS recovery. Such calibration deficiencies resulted in these batches being rejected and rerun.

Despite the sample homogenization process used, the homogeneity of a sample was questionable in a few cases. However, the overall conclusion was that sample inhomogeneity had not significantly affected the site decisions.

Fixed Laboratory Analysis: A documented industry-developed method (Chevron, 1978) and SW-846 methods were used for all definitive confirmation sampling and waste characterization. Soxhlet extraction (Method 3540 or 3541) and appropriate cleanup methods, as required by the interferences encountered, were used for all soil samples to be analyzed for organochlorine pesticides and organophosphorus pesticides. All pesticides listed on the quantitation limit tables for the IA kits were reported by the laboratory. Modifications and equivalency of methods are described below.

Method Modifications: Some aspects of the fixed laboratory methods were modified for the purpose of achieving the analytical performance required to support project goals. These modifications to reference methods were evaluated and documented through the QC procedures, in order to provide data quality indicators (e.g., precision and bias) appropriate to the intended data use. A list of the method modifications applied to the EPA reference methods along with justification for these modifications is presented in Table 6.

For the analysis of OP pesticides by Method 8141, gas chromatography/mass spectroscopy (GC/MS) instrumentation was used instead of the gas chromatograph with nitrogen phosphorus detector (NPD) specified in the method. As a result, improved selectivity and low quantitation limits were achieved. For the analysis of OC pesticides by Method 8081, a GC with an electron capture detector (ECD) was used to allow the analysis of both the primary compounds of interest and multi-component pesticides (technical cyclodiene, reported as dieldrin and endrin, and toxaphene). The carbamates were analyzed by Method 8141 instead of Method 8321. The use of the less sensitive but more selective GC/NPD instead of the high performance liquid chromatography (HPLC) technique usually recommended for these compounds was possible due to the moderate project detection limit requirements and restricted analyte list. As a result, improved performance was achieved due to reduction of interferences.

The IA tests were also modified slightly to make a single soil extraction serve for both the cyclodiene and DDT field test kits. The immunoassay was calibrated to report the cyclodienes as dieldrin and endrin.

The overall goal of the method modifications was to improve sensitivity and selectivity for specific analytes. Method modifications for the purpose of improving performance is consistent with the performance-based measurement system (PBMS) approach being implemented by EPA. EPA defines PBMS as a set of processes wherein the data quality needs, mandates or limitations of a program or project are specified and are used as criteria for selecting methods that meet those needs in a cost-effective manner. Under the PBMS approach, the regulated community has the option to select an appropriate method other than those found, for example, in SW-846 or make method modifications that are capable of measuring the analytes of concern, in the matrices of concern, at the regulatory levels of concern, and at the confidence level of concern. The goal is to make compliance with EPA's regulations easier and more cost effective by allowing more flexibility in method selection and use. For more information on PBMS, go to http://www.epa.gov/SW-846/pbms.htm.

In addition to the specific methods referenced, various sections of SW-846 contain specifications that apply to the methods for this project. General gas chromatography method requirements are outlined in

Method 8000. Chapters Three and Four of SW-846 describe specific sample handling requirements for metals and organics, respectively.

Table 6. Modifications to Reference Methods

Parameter	Method	Modification/Justification
Cyclodiene IA test	4041	Extraction fluids were pure methanol rather than water/methanol mix. This made the test compatible with the DDT test, allowing for a single sample extraction for both tests. The extraction volume was doubled to 20 mL to better bracket the action levels for these tests based on the pilot study cross-sensitivity results.
DDT IA test	4042	The extraction volume was doubled to 20 mL to better bracket the action levels for these tests based on the pilot study cross-sensitivity results.
OP pesticides	8141	GC/MS rather than GC/NPD was used. The surrogates and calibration requirements appropriate for this method were utilized from the source method (8141). The modification improved selectivity and maintained low enough quantitation limits to meet the project DQOs.
Carbamates by GC	8141, modified	GC/NPD was used as directed in EPA Method 632, modified for a soil matrix according to the SW-846 methods. The moderate project detection limit requirements and restricted analyte list allowed the less sensitive but more selective GC/NPD technique to be used instead of HPLC (EPA Method 8321). The benefits were primarily in improved performance due to reduction of interference. The surrogate selected was bolstar. This pesticide was chosen as a surrogate since the compound is rarely used for agricultural applications in this geographical area.
Paraquat	RM-8-10	This spectrophotometric method accommodates paraquat in a soil matrix according to procedures developed by Chevron Oil (Chevron, 1978).

Correlation of Immunoassay Tests with Fixed Laboratory Results: During the pilot study and prior to the development of the RAMP, the USACE tested the IA kits against fixed laboratory results with surface soils from the site. For the compound distributions found in these soils, it was apparent from the pilot study that a DDT kit result of 5 ppm or a cyclodiene kit result of 0.1 ppm might indicate that a clean-up standard for an individual compound was exceeded. The IA tests are most accurate at the midpoint concentration level; therefore, the sample preparation procedures were customized to the decision-making needs of the project by setting the calibration midpoint concentration at 5 ppm and 0.086 ppm for DDT and cyclodienes, respectively.

The particular test kits used for this project were intentionally biased high by the manufacturer by 100 percent in order to reduce the occurrence of false negative decision error. Thus, when quantitatively comparing the IA results against the fixed-laboratory data and QC samples, the IA results are expected to be twice as high (i.e. a 200 percent recovery on QC samples). DDT and dieldrin were thought to respectively contribute the most to the response for the DDT and cyclodiene immunoassay kits. However, because the project samples all contained a mixture of compounds, the immunoassay results were expected to correlate better with the sum of the compounds (after taking into account their respective reactivities toward the immunoassay test) than with any single component.

As expected, a plot of the correlation between the field and fixed laboratory results during the focused removal and characterization phase of the remediation was not quantitatively consistent. A number of IA results were higher than predicted by the regression line, particularly for the cyclodiene test. In some cases, cross-reacting pesticides or other compounds were present to cause additional response. Most of the samples were either well above or well below the IA action limit, so at few locations was the proposed excavation profile uncertain based on the IA results alone.

For the most part, the proposed excavation profile based on IA results alone was confirmed to be correct when compared to the excavation profile based on the fixed laboratory results. The excavation decisions that were based on IA results below the action level (i.e., results indicating a "no further action required" decision for that sampling location) were entirely confirmed by the fixed laboratory results. Therefore, the IA tests produced no false negative decision errors with respect to the action level. Due to the presence of cross-reacting compounds (i.e., interferences), a few cases of false positive decision errors with respect to the action level were encountered. In particular, endosulfan compounds present in the analyzed soils were found to respond strongly in the cyclodiene test, yet these compounds have a relatively high clean-up standard. When endosulfans were present, even a high IA result (e.g., 2 ppm cyclodienes, reported as dieldrin and endrin) did not necessarily indicate that a clean-up standard was exceeded.

During the characterization phase (Phase 3), ongoing comparison between the IA results and fixed lab results revealed that IA results below 10 ppm correlated well with the mix of individual DDT, DDE and DDD concentrations that did not exceed their respective MTCA standards. As a result, the action level for DDT was further refined to 10 ppm (i.e., raised from the 5 ppm field action level used at the start of the project). The modified DDT action level was used during the gross soil removal phase (Phase 4) to determine the need for further excavation.

Quality Assurance/Quality Control (QA/QC) Measures

A number of different QA/QC measures were implemented during sample collection and field and fixed laboratory analyses. Table 7 provides a summary of field QC samples prepared and analyzed. The table also provides the total number of field samples associated with the analyses. In addition, laboratory control samples and blanks were analyzed for each parameter at a frequency of 1 per batch (up to 20 samples) for all analyses, both field and fixed laboratory analyses. Matrix spike and matrix spike duplicates were also analyzed at a frequency of 1 per batch (up to 20 samples) for all parameters, with the exception of cyclodienes, DDT and TSS. For those analyses, matrix spikes were not used and matrix duplicates were analyzed at a frequency of 1 duplicate per batch. In addition, four performance evaluation (PE) samples were analyzed by the fixed laboratory during the various sampling and analysis phases of the project. The various QA/QC measures are described below.

CHARACTERIZATION TECHNOLOGIES continued

Field Quality Control Samples: Field quality control samples were collected during field work to monitor the performance of sample collection and measure the effects of sampling bias or variability. Field QC samples included the following:

Equipment (rinsate) blank: An equipment blank is a rinse sample of the decontaminated sampling equipment to evaluate the effectiveness of equipment decontamination or to detect cross contamination. Equipment blanks were prepared during the focused removal, site characterization, and final confirmation study phases. Equipment blanks were not prepared for analysis by IA.

Field duplicate: Field duplicates are taken to evaluate the reproducibility of field sampling procedures. Field duplicates were prepared during all phases of the cleanup project including focused removal, site characterization, final confirmation, waste profiling, and wastewater characterization. Field duplicates were collected for IA field analysis and fixed laboratory analysis.

Field Analysis (IA) QA/QC Measures: Quality control checks employed during field analysis included the following:

Calibration samples: High-purity materials provided by the kit manufacturer were used as calibration samples to determine kit range, detection or quantitation limits, precision, and instrument drift. For the IA tests, a set of three calibration standards were used. Calibration verification was performed with each batch of 12 samples.

Negative control: An unspiked blank was used along with calibration samples during kit calibration.

Matrix duplicates: An intralaboratory split sample was used to document the precision of the method in a given sample matrix.

Laboratory control samples: A laboratory control sample was prepared from a solid matrix performance evaluation (PE) sample containing known concentrations of target analytes.

Fixed Laboratory QA/QC Measures: In addition to periodic five-point calibrations, the following laboratory internal analytical quality control measures were employed by the fixed laboratory to ensure the quality of the analytical data:

Continuing calibration verification (CCV) compounds: CCV compounds were used daily to verify calibration.

Internal standards: Internal standards were used for GC/MS analysis to monitor the consistency of response factors, relative retention times, injection efficiency, instrument drift, etc., for many organic analysis.

Surrogates: Surrogates are compounds which are similar to the target analytes in chemical composition and behavior in the analytical process, but are not normally found in real-world samples. They are added to each sample, blank and matrix spike prior to extraction or processing. They were used to monitor the performance of the extraction, cleanup (when used), and analytical system.

CHARACTERIZATION TECHNOLOGIES continued

Method blank: A method blank is used to assess contamination levels in the laboratory. It is prepared from clean reference matrix and carried through the complete sample preparation and analytical procedure.

Matrix spike: A matrix spike is an aliquot of the sample spiked with known concentration of target analytes. It is used to document the bias of the method.

Matrix spike duplicate (MSD): MSDs were used to document the precision and bias of the method; the MSDs are intralaboratory split samples spiked with identical concentrations of target analytes.

Laboratory control sample: Laboratory control samples were used by the fixed laboratory in conjunction with the matrix spike results to differentiate matrix-related problems from laboratory performance issues.

Performance evaluation (PE) samples: PE samples can be used to provide information on the baseline performance of a laboratory. A total of four PE samples were submitted as blind QC samples to the fixed laboratory during the various sampling and analysis phases of the project.

Table 7. Summary of Field Duplicate and Equipment Blank QC Samples

Analytical Parameter	Technique	Sample Type	No. Field Samples	No. Field Duplicates	No. Equip. Blanks
Focused Removal					
OC and OP Pesticides	GC/MS and GC	Soil	6	1	1 / day
Characterization					
Cyclodienes and DDT	IA	Soil	162	16	0
OC and OP Pesticides	GC/MS and GC	Soil	36	4	1 / day
Final Confirmation					
Cyclodienes and DDT	IA	Soil	27	3	0
OC and OP Pesticides, Carbamate pesticides	GC/MS and GC	Soil	9	1	1 / day
Paraquat	Spectrometric	Soil	9	1	1 / day
Waste Profile					
Prelim OC, OP	GC and GC/MS	Soil	6	1	0
Final OC, OP	GC and GC/MS	Soil	3	0	0
Carbamate Pesticides	GC	Soil	1	1	0
Paraquat	Spectrometric	Soil	1	1	0
OC Pesticides	GC	TCLP extract	3	1	0
Metals	3010/6010	TCLP extract	3	1	0
Equipment Decontamination Rinse Water					
OC and OP Pesticides	GC/MS and GC	Water	1	1	0
Metals	ICP/MS and GFAA	Water	1	1	0
Total Suspended Solids (TSS)	Gravimetric	Water	1	1	0

PERFORMANCE EVALUATION

Performance Objectives

The goal of the project was to identify, characterize, remove, and dispose of all pesticide-contaminated soil and debris from the test plot area of the WTFREC. Action levels for soil removal on the project were determined to be the MTCA Method B Cleanup Levels (see Table 1).

The final determination of whether the remedial action attained the cleanup standards was based on a statistical analysis of the sample data representative of the final conditions at the entire footprint of the site at the maximum extent of excavation. The statistical requirements to demonstrate cleanup were:

1. The analyte concentration for no more than 10 percent of the samples can exceed the cleanup standard for that analyte;

2. No sample concentration can exceed a level more than two times the cleanup standard for any particular analyte; and

3. The upper confidence limit of the data for each analyte must be statistically shown to be less than the cleanup criteria for that analyte.

Approximately 230 soil samples were analyzed by IA to support focused removal, site characterization, closure confirmation, waste characterization, and QA (including field and laboratory duplicates) activities. Approximately 100 soil samples were analyzed in a fixed laboratory to support focused removal, site characterization, closure confirmation, waste characterization (including wastewater analysis, TCLP organics and inorganics, PCBs, total metals and total pesticides in preparation for waste disposal) and QA (including equipment blanks and performance evaluation samples) activities.

Strategy and Technologies Used to Attain the Performance Goals

The strategy and technologies used to attained the project goals included:

- Systematic planning
- Use of an adaptive (dynamic) sampling plan
- On-site analysis and "immediate" availability of results using immunoassay analysis (IA) technologies combined with limited fixed laboratory analyses, and
- Rapid on-site decision-making guided by a decision matrix (a dynamic work plan) that used field analytical results to characterize, excavate, and segregate pesticide-contaminated soil.

Performance of the dynamic work plan approach was highly superior to a traditional scenario, had that occurred at this site. Because of the ability to sample and test the sides of the excavated areas, it was discovered that pesticide contamination exceeding the regulatory standard existed outside of the original boundaries of the site (as determined from historical information). Since this was discovered immediately, it was simple and convenient to continue excavating until compliant soil was reached. This resulted in the removal of an additional 60 tons of soil by extending the sides of the original boundaries (see Figure 5).

Under a traditional scenario, however, this discovery would not have been made until fixed laboratory results for samples collected for cleanup attainment confirmation were received. Likely those sample analysis results would not have been available until after the excavation team had left the site. Closure would have been delayed and additional expenses would have been incurred to prepare a second work plan and sampling and analysis plan, remobilize to the site to characterize the boundaries of the remaining contamination, wait for the results to come back from the fixed lab, and then return to the site to excavate yet again and perform additional closure testing. The use of on-site analyses and a dynamic work plan avoided that unpleasant and inefficient chain-of-events.

The USACE's contractors completed the project work in conjunction with the USACE, and the project was successful. The Test Plot no longer contains soils exceeding the site action levels. The cleanup was accomplished in a shorter time frame and at a lower cost than the traditional site characterization and remediation approach in which multiple rounds of field mobilization, sampling, sample shipment, laboratory analysis, and data assessment are required.

The time frame for various activities at the Wenatchee Tree Fruit Test Plot is presented in Table 8. Once mobilization to the site occurred, all phases of site work were completed within 4 months.

Table 8. Time Frame for Activities

Date	Activity
1985-1987	WSU performs sampling and analysis at WTFREC
1990, 1991, 1994	EPA performs 3 sampling and analysis events at WTFREC
April 1996	USACE begins project planning process to accommodate EPA ORD request to remediate the WTFREC site
June 1996	Pilot study performed with site-specific soils to assess IA and Geoprobe performance
August 1997	USACE contracts with GSA to perform site work
Sept. 15-22, 1997	Mobilization of construction support items to site
Sept. 22-24, 1997	Focused Removal activities started/completed (45.74 tons excavated)
Oct. 13, 23& 24, 1997	Gross Removal activities started/completed (271 tons excavated); initial closure confirmation samples obtained and additional contamination discovered
Oct 23; Nov. 3, 4, 17 and Dec. 10, 1997	Additional excavation of sidewalls and floor performed; final closure confirmation sampling completed (60 tons excavated)
Dec. 12, 1997	Closure confirmation activities completed
January 1998	463 tons of material used to backfill; site restoration completed

COST COMPARISON

The approach to site cleanup employed in the WTFREC Test Plot resulted in considerable savings compared to traditional site characterization and remediation approaches. The use of systematic planning, a dynamic workplan, and on-site measurement technologies combined with limited fixed laboratory analyses allowed for the cost-effective cleanup of the contaminated site with savings of roughly 50% over traditional methods. Although it is extremely difficult to project a likely cost scenario if a project were to be performed using a different work strategy, extrapolations are sometimes possible if enough cost detail is available from the actual project. The USACE made detailed unit and activity costs available for preparing this case study. A cost comparison is projected based on the following information and assumptions:

Assume that a more traditional approach would also use direct push sampling to produce a similar site characterization profile in order to roughly delineate the boundaries of contaminated soil requiring removal. Then a similar number of samples sent for traditional fixed laboratory analysis might be assumed. Based on knowledge obtained during the actual cleanup, remediation of this area without the use of a dynamic work plan could have possibly produced at least 391 tons of contaminated soil (see Notes 4 and 7 of Table 9) requiring incineration, since segregation of less contaminated materials from more contaminated materials during excavation would have been difficult without the immediate feedback of real-time results. The excavation, transportation, and disposal cost alone for this volume of contaminated soil would have exceeded $560,000 (see Table 9). The use of fixed laboratory methods and/or more rapid turn-around times for fixed lab results would have resulted in a substantial increase in analytical costs.

Furthermore, the dynamic work plan allowed the site team to discover immediately that unexpected contamination existed outside of the original project boundaries and then to seamlessly extend sampling and excavation until clean soil was reached. Under a traditional scenario, this discovery would likely not have occurred until after the fixed lab results for anticipated closure confirmation had been returned, examined, and reported to project decision-makers. In all likelihood, the discovery that the initial removal did not attain regulatory cleanup standards would have incurred additional costs to prepare new planning documents, remobilize to the size, and conduct yet another round of characterization sampling and analysis, excavation, and closure confirmation sampling. In all, the estimated cost of cleanup without the use of a dynamic work plan and field analytical methods may be projected as totaling nearly $1.2 million. A simple analysis of cost repercussions also does not factor in the frustration of regulators, clients, and stakeholders when “surprises” delay site closeout.

In contrast, the actual total cost for site characterization, remediation and closeout at WTFREC was approximately $589,000. Of this total, $100,000 were expended by the USACE for planning, design, contracting and project management. (The cost for project oversight was assumed to be the same under a traditional scenario.) A moderately detailed breakdown of actual and projected costs and assumptions is shown in Table 9.

In addition, the USACE had prepared a different cost comparison estimate for remediating the site that assumed excavating and incinerating the entire 70-foot long by 30-foot wide by 7-foot deep original plot (estimated as 708 tons of soil) without performing any site characterization. The estimate for this was $1,122,049. Although this estimate included closure testing, it did not include the cost of remobilization to extend the excavation after sidewall contamination was discovered. It is notable that the cost of traditional site characterization could have been approximately equivalent to the cost of the most conservative treatment option for this site.

COST COMPARISON continued

Table 9. Cost Comparison

Item	Estimated Cost Without Use of Dynamic Work Plan and Field Analysis (i. e., a "traditional" approach)	Actual Cost Using Dynamic Work Plan and Field Analysis
Design	$36,000	$36,000
Procurement	$9,000	$9,000
Oversight/Contract Management	$45,000	$45,000
Technical Review	$10,000	$10,000
General, Mobilization, Construction, Data Analysis, Demobilization	$128,846 (See Note 1)	$129,446
Contaminated Material Excavation	$35,959 (see Note 2)	$46,052 (see Note 3)
Soil Analysis	$235,942 (see Note 4)	$79,412
Backfilling, Grading, and Revegetation of Test Plot	$11,486	$11,486
Waste Transport and Disposal	$353,358 (see Note 5)	$112,622
Environmental Planning and Reporting	$15,304	$15,304
Additional Characterization (including revised planning documents and remobilization)	$29,563	Not applicable.
Additional Sample Analysis	$101,356 (see Note 6)	$28,364
Additional Soil Excavation	$9,773 (see Note 7)	$10,615
Additional Backfilling of Test Plot	$3,046	$2,031
Additional Waste Transport and Disposal	$168,193	$49,627
Data Validation	$4,053	$4,053
TOTAL PROJECT COST	**$1,196,880**	**$589,012**

Notes:

1. Mobilization would not require rental of a trailer for the field laboratory, therefore, mobilization costs are slightly less than that required for the dynamic work plan with field laboratory.
2. Cost estimates assumes 271 tons of soil excavated with no on-site temporary storage.
3. Cost includes on-site temporary storage.
4. Cost assumes 230 field and QC samples analyzed by fixed lab for OC pesticides, OP pesticides, carbamates, and paraquat to delineate the 271 tons of soil to be removed.
5. Cost assumes that all excavated soil would be managed as dangerous waste (i.e., incinerated).
6. Cost assumes 80 samples analyzed at fixed lab for OC pesticides, OP pesticides, carbamates, and paraquat.
7. Cost estimates for additional soil excavation, backfilling, transport, and disposal assume that 120 additional tons of soil would be removed to avoid another remobilization. Note that the actual quantity of additional soil removed was approximately 60 tons.

OBSERVATIONS AND LESSONS LEARNED

The involvement of the regulator and stakeholders during project planning allowed the team to develop a decision-making strategy that all parties would follow during the removal action. This reduced the amount of risk and cost associated with clean closure disagreements that can cause schedule delays, especially during contractor mobilization on site. However, it relied on a planning team with the appropriate mix of both skills and regulatory authorities.

The conceptual model of the site was based on a thorough review of historical records of site activities. However, the project team still encountered contaminants in areas that were not originally anticipated. Without the ability to generate analytical data on site and in near real time, the costs to remediate the test plot and the time required would have increased greatly.

Substantial cost-savings were realized through the use of IA and an adaptive sampling plan. Cost savings were realized through reduced analytical costs (compared to traditional fixed based laboratory analysis) and reduced mobilization/demobilization costs that would be incurred if multiple mobilizations were required.

The on-site analysis was designed to support in-field decisions regarding further characterization, removal, waste segregation, and waste disposal. By conducting the pilot study and using additional fixed-laboratory results to correlate with the immunoassay results, the action levels for the field analyses were continually updated and adapted to changing site conditions. This approach reserved resources (both time and dollars) that could then be applied to the relatively expensive fixed-laboratory analyses, or used to increase the number of samples that were collected and analyzed by immunoassay.

The ability to increase the number and density of samples that were collected also helped to minimize the amount of soil that was removed, as well as reducing the amount of soil sent for incineration, the most expensive possible disposal option.

The length of the project from mobilization to site restoration of the site was relatively quick compared to traditional methods.

The adaptive sampling strategy allowed several different sampling strategies to be employed throughout the cleanup, based on the intended use of the data and the need to optimize the overall design. For example, during the focused removal phase, random sampling was conducted within grid blocks, except where there was a need to bias a sample location towards an observed stain in the soil. During site characterization, soil cores were purposefully located near visual indicators of contamination within grid blocks. In the absence of visual indicators of contamination, sample locations were randomly selected. Finally, samples collected for confirmation of cleanup were discrete samples randomly located within grid blocks. The assumptions of random samples is required for application of the statistical tests to determine attainment of the cleanup standards.

The combined benefits of this optimized approach facilitated the "surgical" removal of contaminated materials and ensured that closure confirmation testing would demonstrate compliance to a high degree of certainty. Significant time and cost savings over the life of the project were possible by making field activities such as sample collection, sample analysis, soil removal, soil segregation, and final disposal of soil and wastewater as efficient and effective as possible.

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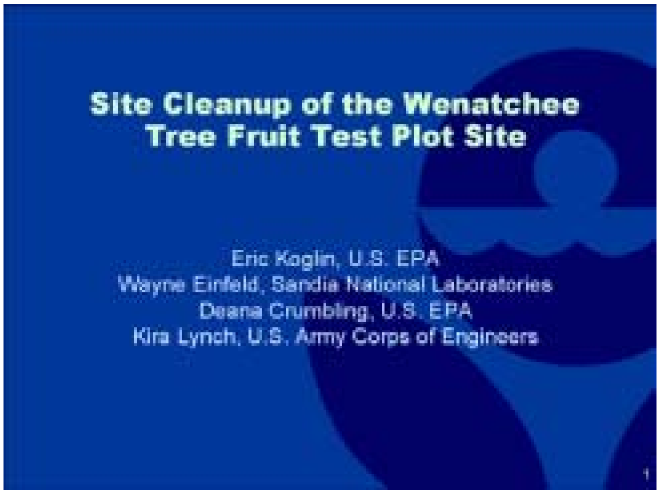
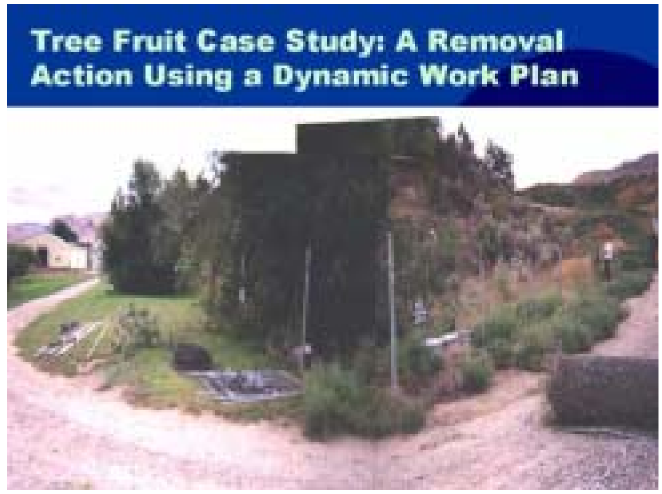
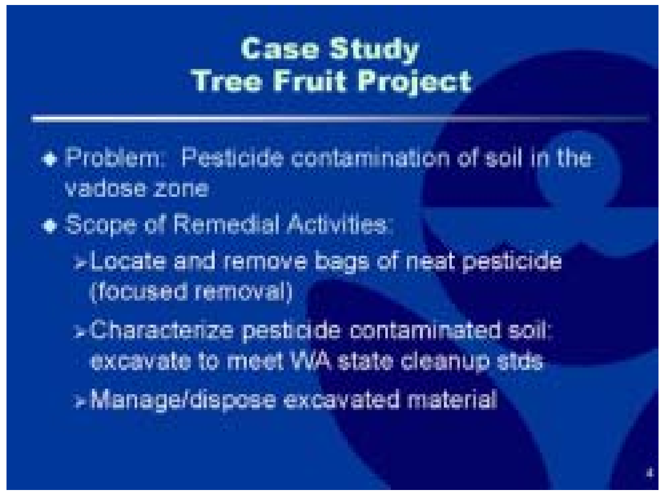
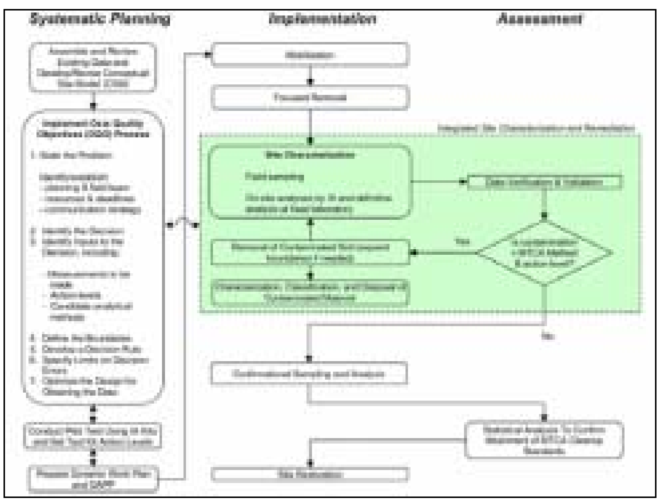
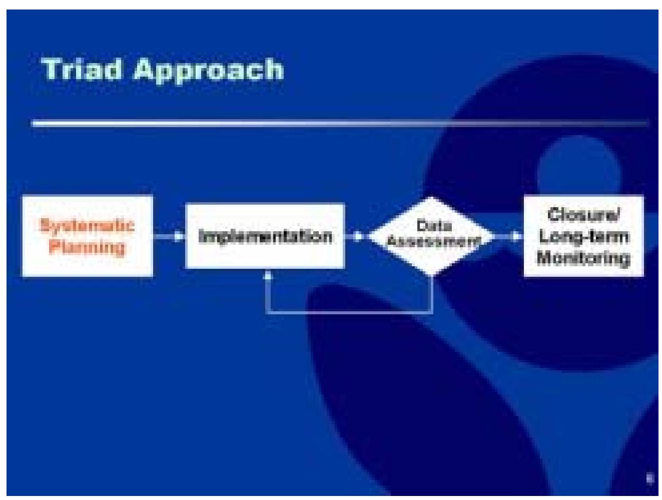
PRESENTATION VISUALS ~ *presented by Eric Koglin, Wayne Einfeld, Deana Crumbling, and Kira Lynch*











Systematic Planning
Coordinate/Assemble Teams

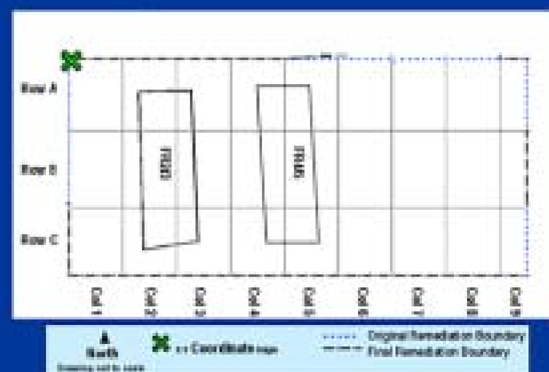
- Who's Who?: Coordinate with client, regulators and stakeholders
- Planning Team: client, State, stakeholder, and USACE staff
- Technical/Field Team: USACE staff, prime contractor staff, and subcontractor staff
- Community outreach found little additional interest

Systematic Planning
Review Existing Information/CSM

- Evaluate site history
- Interview informants
- Review historical information
- Develop Initial CSM
  - See following diagrams
  - Begin to develop list of potential contaminants

Systematic Planning
Project's Initial Conceptual Site Model

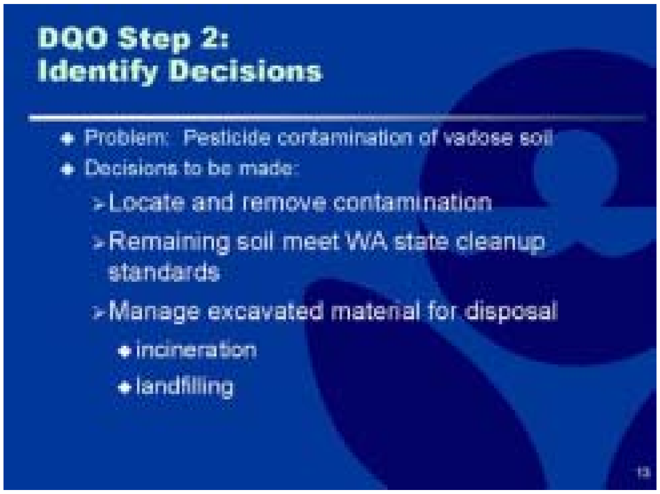
Site Grid with Probable Locations of Buried Bags

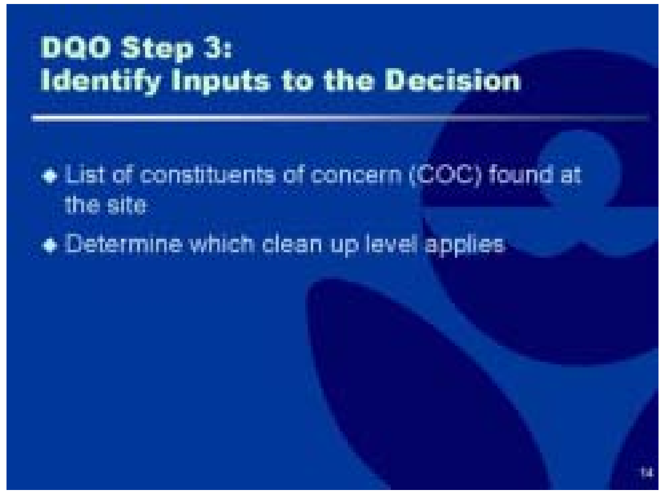


Working Through the DQO Process

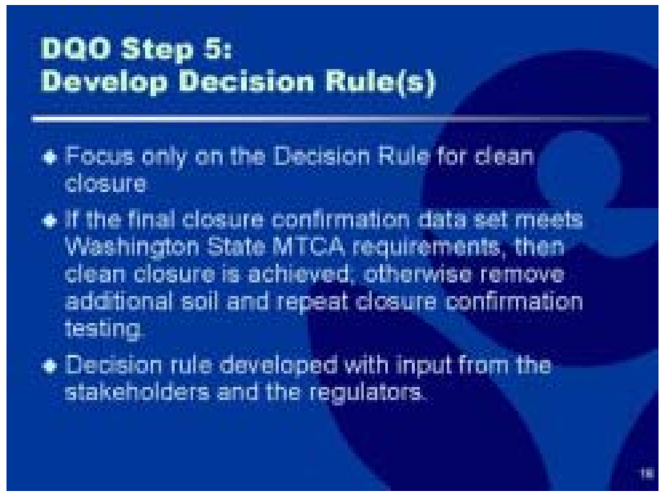
DQO Step 1:
State the Problem

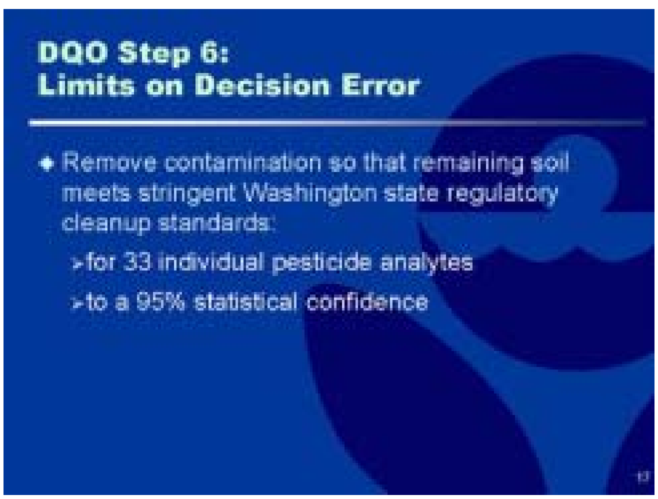
- Hazardous materials must be located and removed.
- Contaminated soils must be addressed to meet cleanup standards
- Waste materials must be disposed of properly

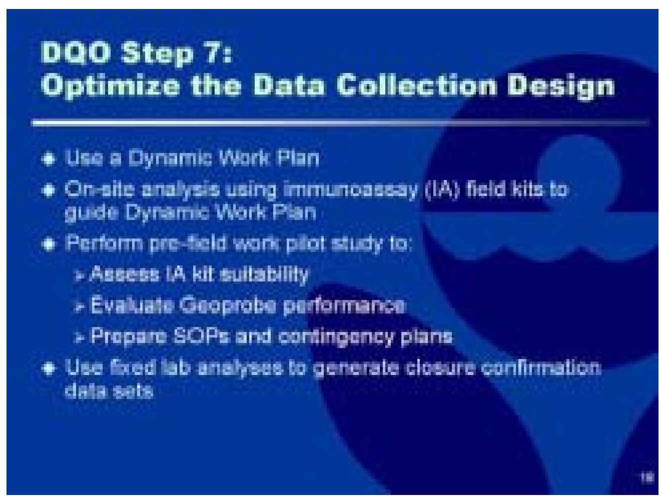

DQO Step 2:
Identify Decisions
◆ Problem: Pesticide contamination of vadose soil
◆ Decisions to be made:
➢ Locate and remove contamination
➢ Remaining soil meet WA state cleanup standards
➢ Manage excavated material for disposal
◆ incineration
◆ landfilling

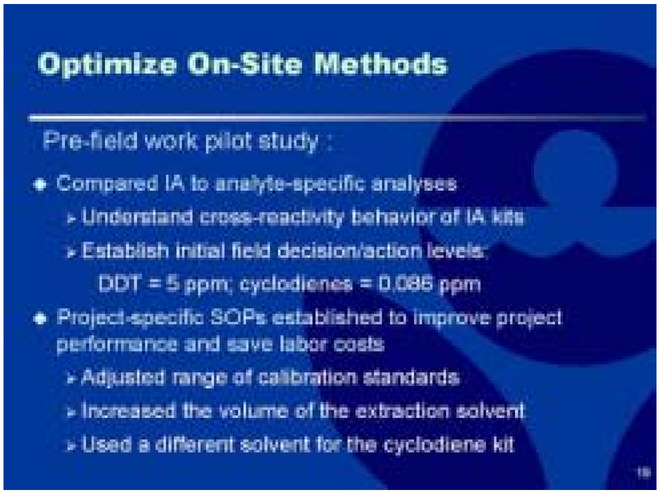

DQO Step 3:
Identify Inputs to the Decision
◆ List of constituents of concern (COC) found at the site
◆ Determine which clean up level applies


DQO Step 4:
Define Boundaries/Constraints
Determine
◆ Spatial boundaries
◆ Time boundaries
◆ Cost constraints

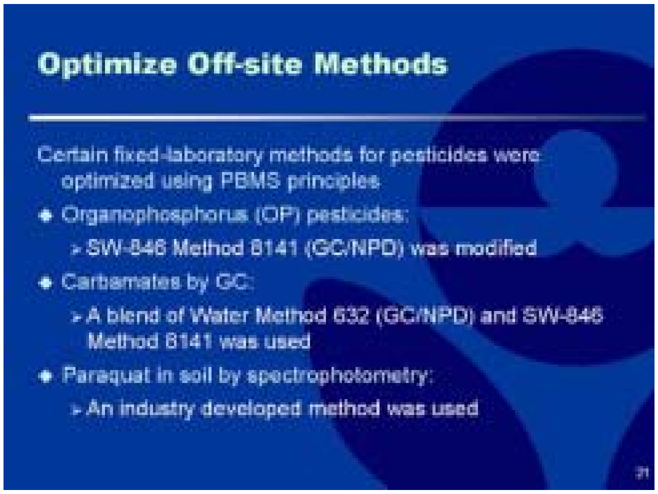

DQO Step 5:
Develop Decision Rule(s)
◆ Focus only on the Decision Rule for clean closure
◆ If the final closure confirmation data set meets Washington State MTCA requirements, then clean closure is achieved; otherwise remove additional soil and repeat closure confirmation testing.
◆ Decision rule developed with input from the stakeholders and the regulators.

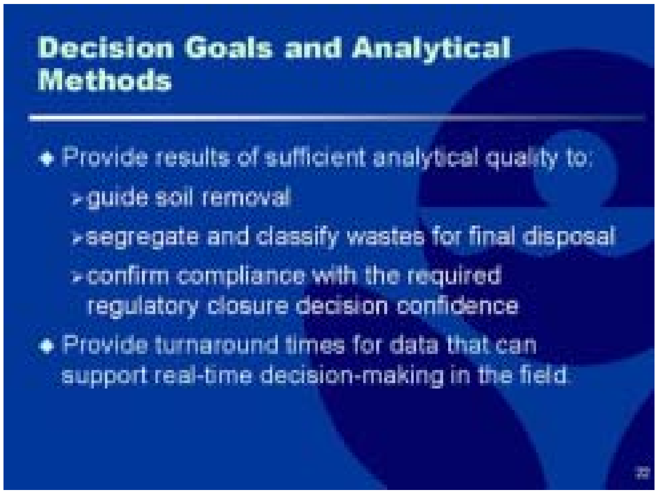

DQO Step 6:
Limits on Decision Error
◆ Remove contamination so that remaining soil meets stringent Washington state regulatory cleanup standards:
➢ for 33 individual pesticide analytes
➢ to a 95% statistical confidence

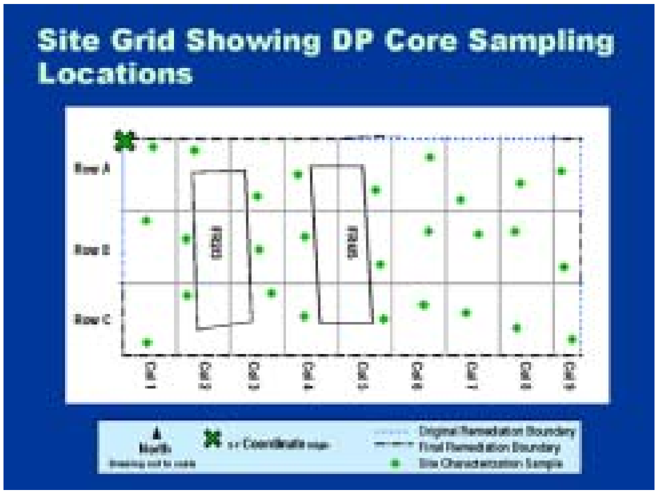

DQO Step 7:
Optimize the Data Collection Design
◆ Use a Dynamic Work Plan
◆ On-site analysis using immunoassay (IA) field kits to guide Dynamic Work Plan
◆ Perform pre-field work pilot study to:
➢ Assess IA kit suitability
➢ Evaluate Geoprobe performance
➢ Prepare SOPs and contingency plans
◆ Use fixed lab analyses to generate closure confirmation data sets

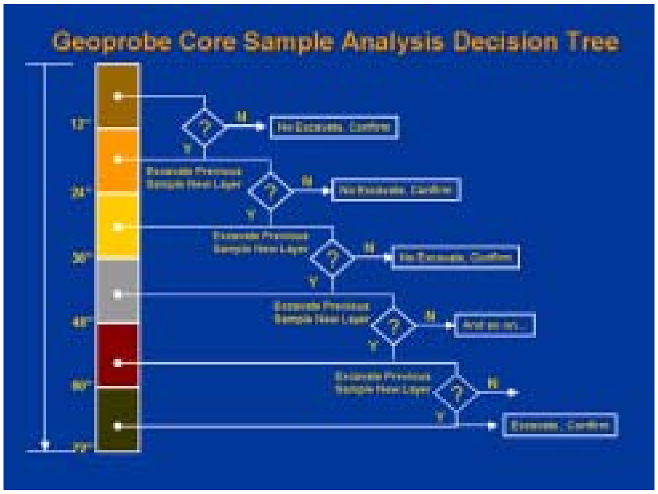

Optimize On-Site Methods
Pre-field work pilot study :
◆ Compared IA to analyte-specific analyses
➢ Understand cross-reactivity behavior of IA kits
➢ Establish initial field decision/action levels:
DDT = 5 ppm; cyclodienes = 0.086 ppm
◆ Project-specific SOPs established to improve project performance and save labor costs
➢ Adjusted range of calibration standards
➢ Increased the volume of the extraction solvent
➢ Used a different solvent for the cyclodiene kit

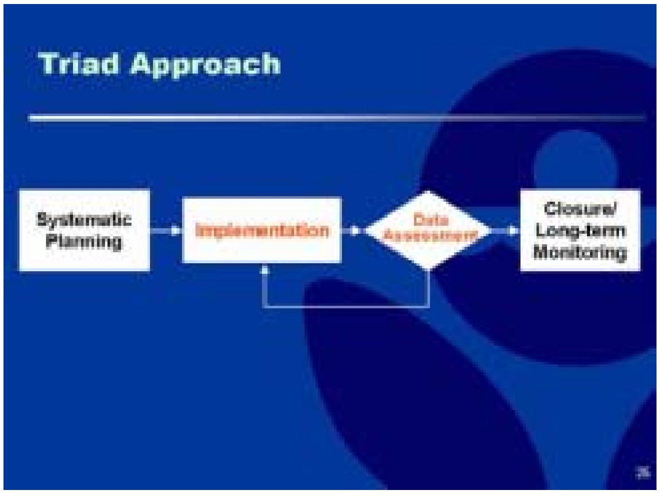

Immunoassay Kit
One kit for Cyclodiene Family
One kit for DDT Family

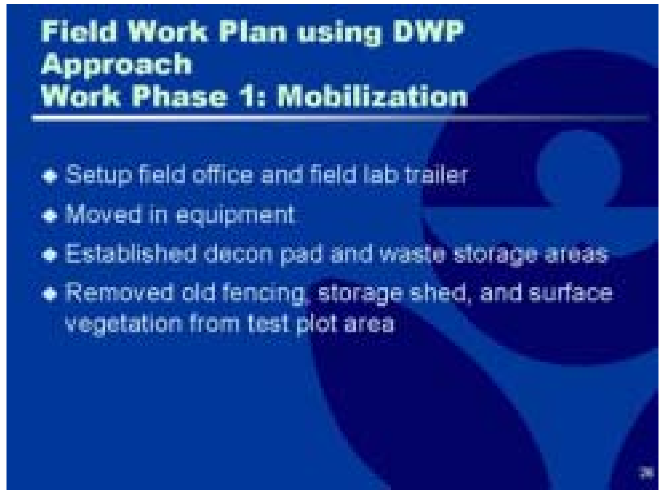

Optimize Off-site Methods
Certain fixed-laboratory methods for pesticides were optimized using PBMS principles
◆ Organophosphorus (OP) pesticides:
➢ SW-846 Method 8141 (GC/NPD) was modified
◆ Carbamates by GC:
➢ A blend of Water Method 632 (GC/NPD) and SW-846 Method 8141 was used
◆ Paraquat in soil by spectrophotometry:
➢ An industry developed method was used
21

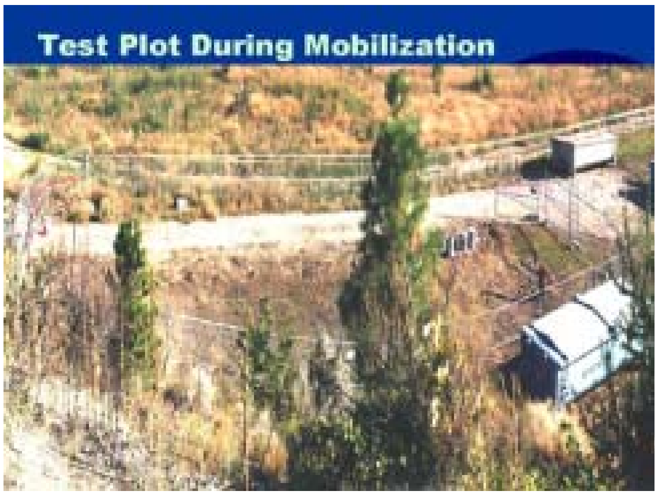

Decision Goals and Analytical Methods
◆ Provide results of sufficient analytical quality to:
➢ guide soil removal
➢ segregate and classify wastes for final disposal
➢ confirm compliance with the required regulatory closure decision confidence
◆ Provide turnaround times for data that can support real-time decision-making in the field
22

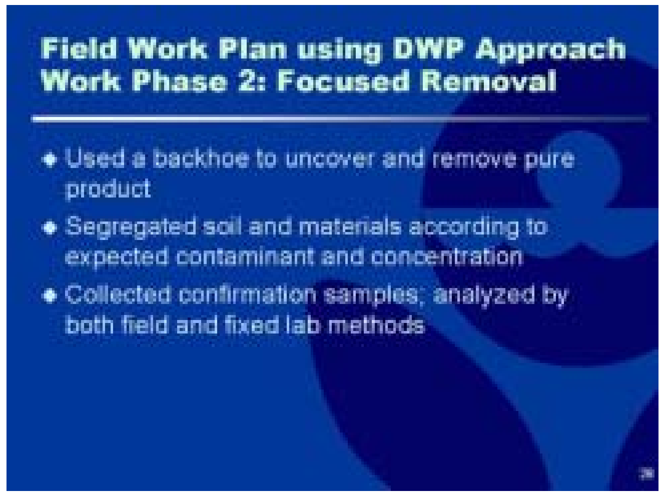

Site Grid Showing DP Core Sampling Locations
Row A
Row B
Row C
North
Original Remediation Boundary
Final Remediation Boundary
Site Characterization Sample


Geoprobe Core Sample Analysis Decision Tree
N
Y
No Excavate, Confirm
Excavate Previous
Sample Next Layer
And so on...
Excavate, Confirm


Triad Approach
Systematic Planning
Implementation
Data Assessment
Closure/ Long-term Monitoring

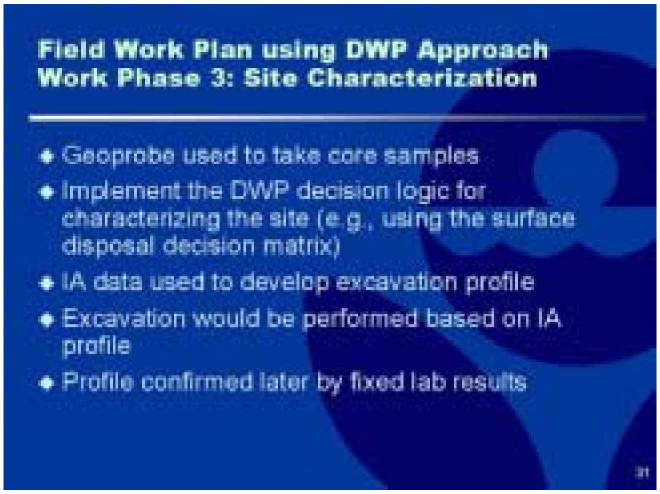

Field Work Plan using DWP Approach
Work Phase 1: Mobilization
◆ Setup field office and field lab trailer
◆ Moved in equipment
◆ Established decon pad and waste storage areas
◆ Removed old fencing, storage shed, and surface vegetation from test plot area


Test Plot During Mobilization


Field Work Plan using DWP Approach
Work Phase 2: Focused Removal
◆ Used a backhoe to uncover and remove pure product
◆ Segregated soil and materials according to expected contaminant and concentration
◆ Collected confirmation samples; analyzed by both field and fixed lab methods


Focused Removal Activities
Removal of Buried Bags

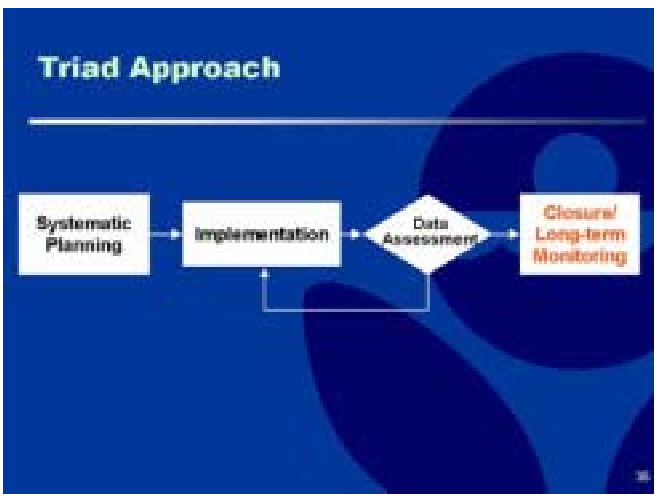

Focused Removal Depth

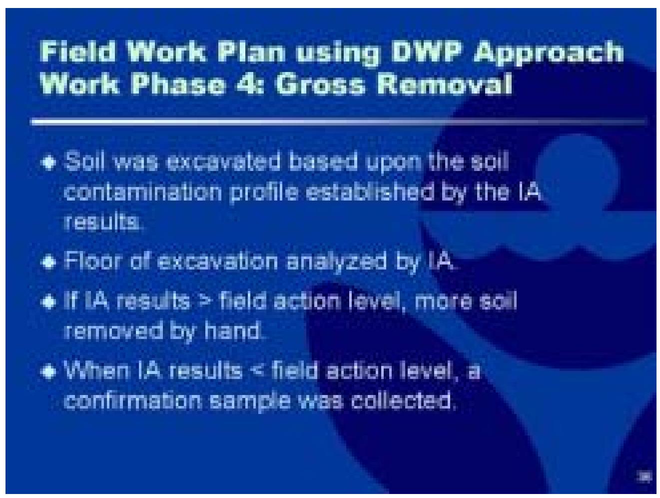

Field Work Plan using DWP Approach
Work Phase 3: Site Characterization
◆ Geoprobe used to take core samples
◆ Implement the DWP decision logic for characterizing the site (e.g., using the surface disposal decision matrix)
◆ IA data used to develop excavation profile
◆ Excavation would be performed based on IA profile
◆ Profile confirmed later by fixed lab results


Site Characterization Sampling with Geoprobe

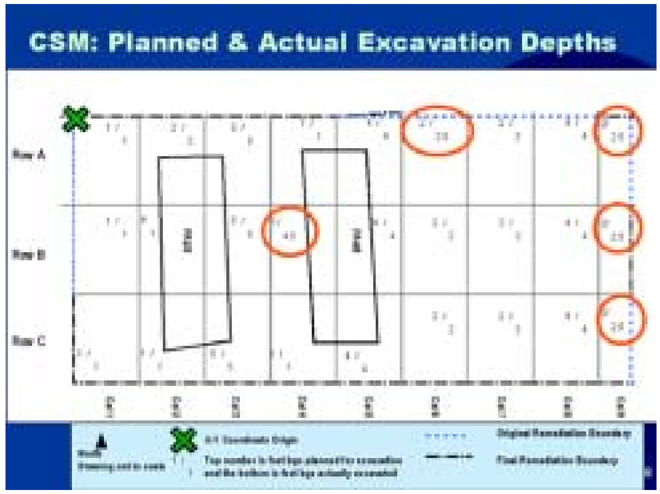

Dividing Direct Push Core into 1-ft Interval Samples

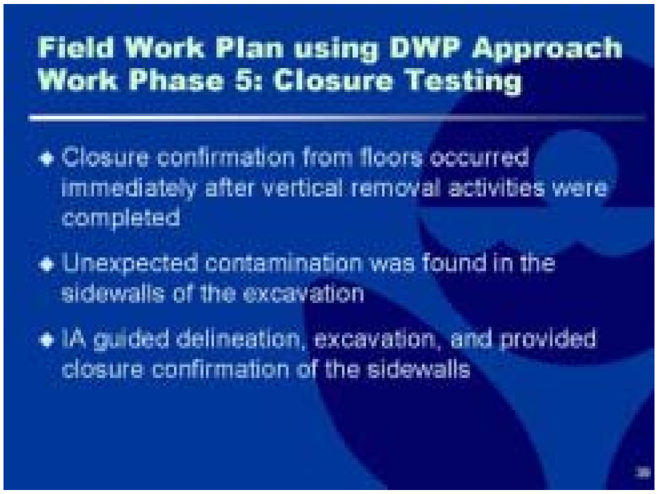

Homogenization of Samples

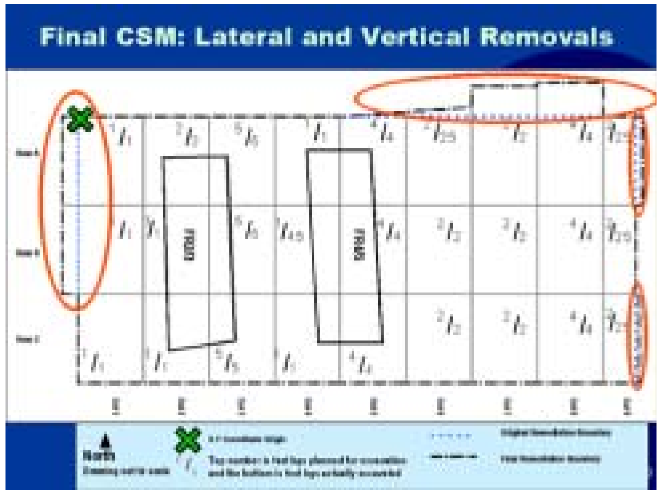

Triad Approach
Systematic Planning
Implementation
Data Assessment
Closure/ Long-term Monitoring


Field Work Plan using DWP Approach
Work Phase 4: Gross Removal
◆ Soil was excavated based upon the soil contamination profile established by the IA results.
◆ Floor of excavation analyzed by IA.
◆ If IA results > field action level, more soil removed by hand.
◆ When IA results < field action level, a confirmation sample was collected.


Placing Gross Removal Soil into a Roll-off Bin


CSM: Planned & Actual Excavation Depths
Row A
Row B
Row C


Field Work Plan using DWP Approach
Work Phase 5: Closure Testing
◆ Closure confirmation from floors occurred immediately after vertical removal activities were completed
◆ Unexpected contamination was found in the sidewalls of the excavation
◆ IA guided delineation, excavation, and provided closure confirmation of the sidewalls


Final CSM: Lateral and Vertical Removals
North


Collecting Final Confirmation Sample


Field Work Plan using DWP Approach
Work Phase 6: Site Restoration
◆ Site was backfilled with 463 tons of material
◆ Topsoil was placed and hydroseeded

Field Work Plan using DWP Approach Work Phase 7: Waste Disposal

- Compositing was used to representatively sample wastes
- Wastes were analyzed by fixed laboratory analysis to characterize waste to meet disposal requirements.
  - Definitive OP and OC analyses
  - TCLP OC pesticides
  - TCLP metals

Cost Comparison (per USACE)

	Traditional	DWP
1. Review Existing Data	$7,150	$11,000
2. Design Site Characterization	$0	$17,640
3. Implement Site Characterization	$0	$84,134
4. Review Char. data	$0	$10,000
5. Design Remedy	$16,500	$26,460
6. Implement Remedy (- Disposal)	$168,094	$271,116
7. Waste Disposal	$910,000	$153,570
8. Closure report	$20,305	$20,305
TOTAL	**$1,122,049**	**$594,225**

This traditional cost estimate assumes no characterization, only removal and incineration of the entire plot volume

Wenatchee Tree Fruit Project: Successes and Lessons Learned

- Cost: Site was remediated/closed out for < $600k
- Time: About two years from time of request; < 4 months of field work using a DWP approach.
- On-going regulator/stakeholder input critical to resolve problems that could have derailed project.
- Systematic planning focused efforts on end-use of data.
- A regulatory focus on project outcome/performance permitted flexibility to maximize innovation and cost savings.

Wenatchee Tree Fruit Project: Successes and Lessons Learned (cont.)

- Onsite analysis (IAs) increased the number and density of samples.
- The CSM was refined in the field; specific sampling strategies selected to match the specific decision
- A pilot study helped determine
  - appropriate field sampling & measurement tools
  - project-specific field action levels for decisions
  - project-specific SOPs and QC for field analysis

Summary: Applications of Field-Based Analytical Technologies

- Not limited to characterization alone
- Many different types of sampling and analysis efforts can be accompanied with field-based technologies
  - Conducting site inspections and expanded site inspections
  - Monitoring treatment processes
  - Monitoring long-term compliance
  - Confirming cleanup
  - Managing response operations

Resources

- USACE Cost and Performance Report: www.frtr.gov/cost/pdf/Wenatchee.pdf
- EPA Case Study: http://cluin.org/chartext_edu.htm#case
- TPP Manual downloadable from: http://www.usace.army.mil/inet/usace-docs/eng-manuals/em.htm
- "A Guideline for Dynamic Workplans and Field Analytics" video (http://cluin.org/video/hanscom.htm)

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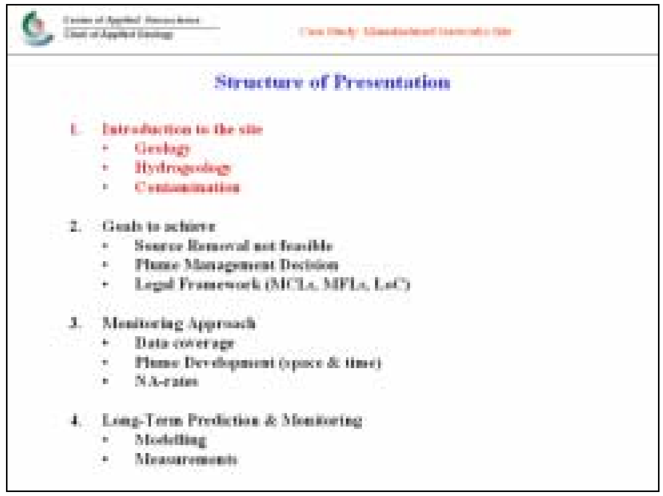
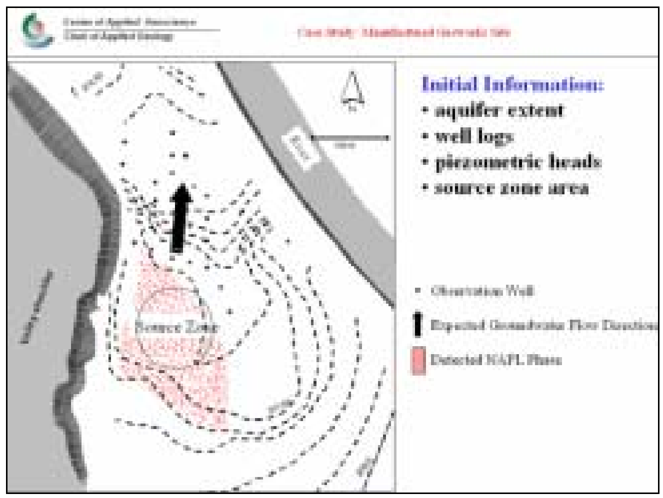
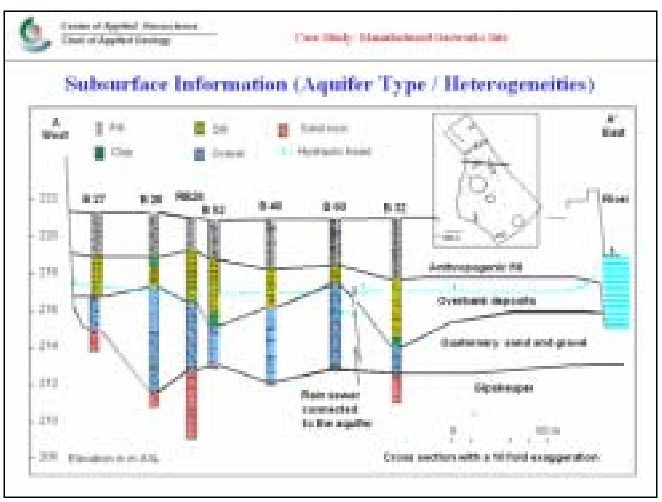
APPENDIX B

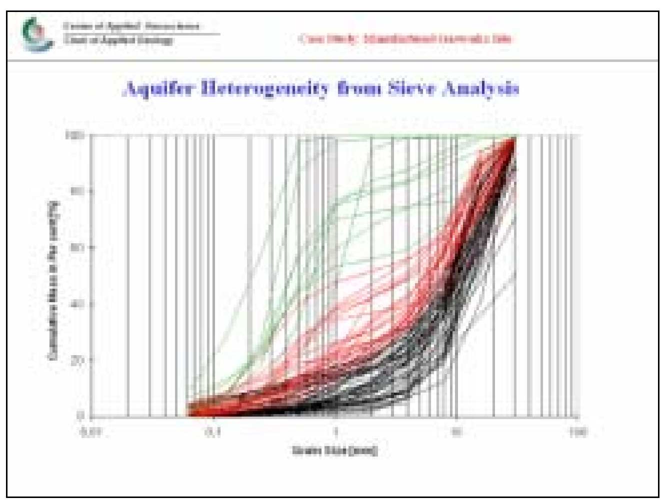
CASE STUDY 2 – GROUNDWATER RISK ASSESSMENT AT A GASWORKS SITE IN A HIGHLY HETEROGENEOUS SAND & GRAVEL AQUIFER ENVIRONMENT

George Teutsch[1] and Peter Merkel[2]





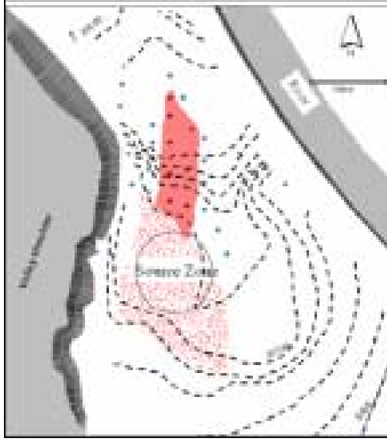




[1] Center for Applied Geoscience (ZAG), University of Tubingen, Germany
[2] Center for Applied Geoscience (ZAG), University of Tubingen, Germany

Hydraulic Conductivity Statistics

	sieve analysis		Flowmeter		Pumping Test Drawdown Data	
Data Type	ln K	(K) [m/s]	ln K	(K) [m/s]	ln(T/M)	(T/M) [m/s]
Number	50		172		25	
Minimum	–10,18	(0,000038)	–11,71	(0,0000082)	–7,82	(0,00040)
Maximum	–1,02	(0,36)	–3,64	(0,026)	–4,96	(0,0070)
Median	–6,75	(0,0012)	–6,63	(0,0013)	–6,0	(0,0025)
Variance	4,67		2,13		0,28	



Monitoring Data:

- Chemical analysis
- Extent of plume

Structure of Presentation

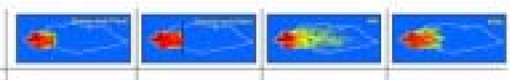
1. Introduction to the site
   - Geology
   - Hydrogeology
   - Contamination
2. Goals to achieve
   - Source Removal not feasible
   - Plume Management Decision
   - Legal Framework (MCLs, MFLs, LoC)
3. Monitoring Approach
   - Data coverage
   - Plume Development (space & time)
   - NA-rates
4. Long-Term Prediction & Monitoring
   - Modelling
   - Measurements

Plume Management Options

Contaminated Site

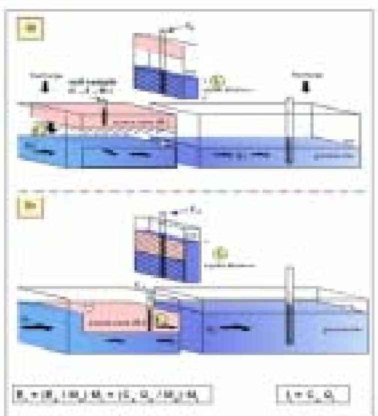
Future Situation

Options



Technical Complexity	moderate	high	low	high
Investment Costs	low	high	low	moderate
O & M Costs	high	low	low	moderate
Land Use	low	low	high	moderate

Concentrations and **Mass-Flow Rates** in Baden-Württemberg (LfU, 1996)

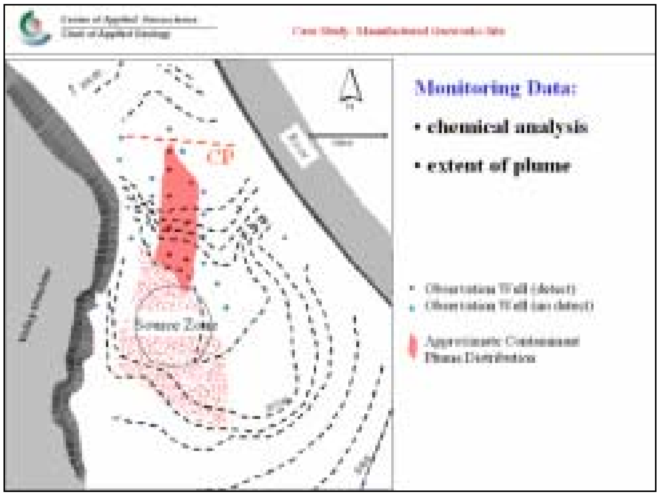


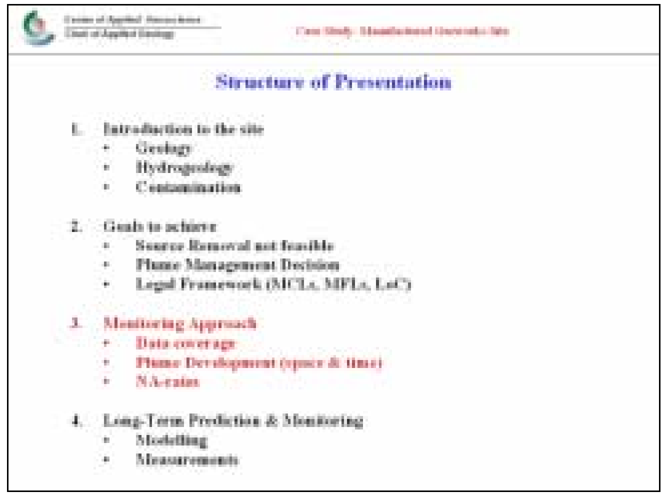
LfU, 1996

Define the Goals

1. Value:
   C_i < MCL$_i$ [compound specific max. concentration, mass flow rate or mass flux smaller than max. contaminant level]
2. Quality:
   RL < MRL [reduction of site and contaminant specific risk level below a max. acceptable risk level - i.e. reduce probability to exceed MCLs at LoCs]

   at LoC [Location of Compliance: point, line or area of given extent]


Monitoring Data:
• chemical analysis
• extent of plume
CP
Source Zone


Structure of Presentation
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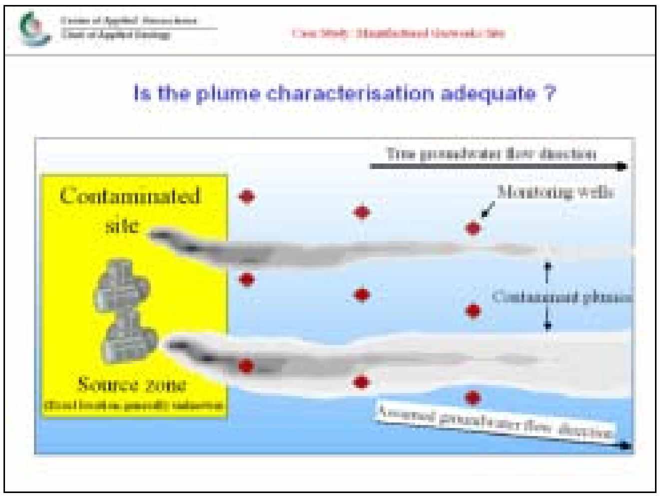
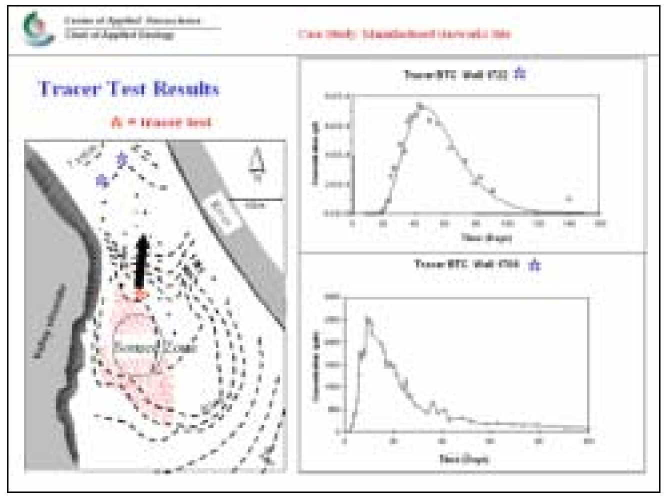
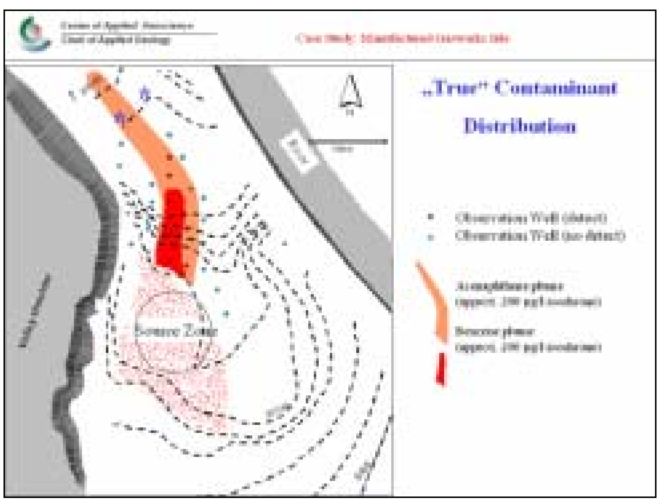
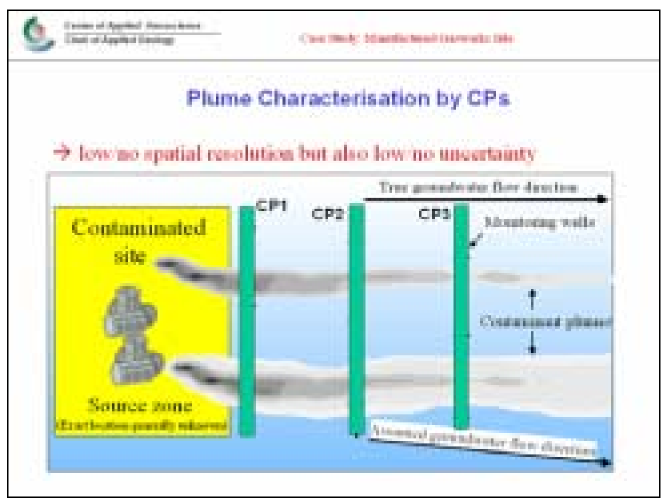
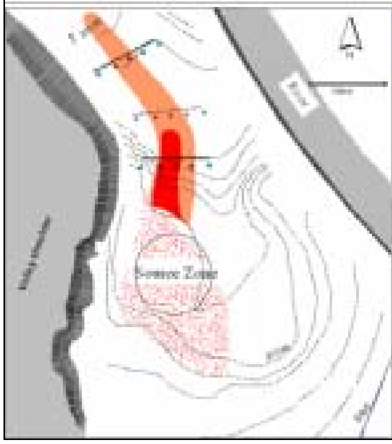
• Measurements


Is the plume characterisation adequate ?
True groundwater flow direction
Contaminated site
Monitoring wells
Contaminant plumes
Source zone
Assumed groundwater flow direction


Tracer Test Results
Source Zone


„True" Contaminant Distribution
Source Zone

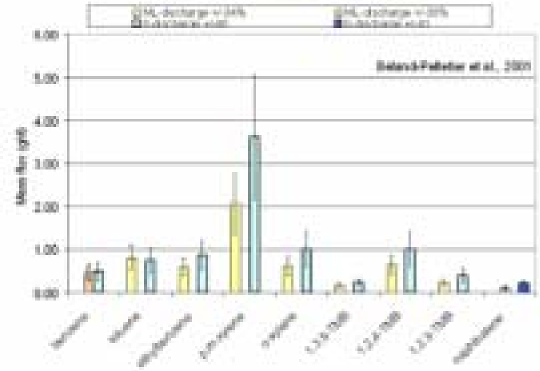

Plume Characterisation by CPs
→ low/no spatial resolution but also low/no uncertainty
True groundwater flow direction
CP1
CP2
CP3
Contaminated site
Monitoring wells
Contaminant plumes
Source zone
Assumed groundwater flow direction



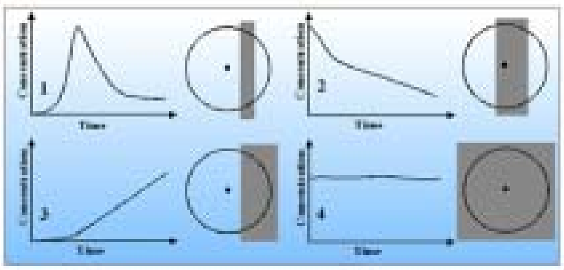
Plume Detection Methods based on transects /CPs

- Observation Well (detect)
- Observation Well (no detect)
- Direct Push Technology
- Well transects (integral pumping)

Mass Flow-Rate Comparison



Integral Scale Measurements (unsteady-state)



→ what do local-scale concentration measurements mean ?

Integral Pumping Test Data

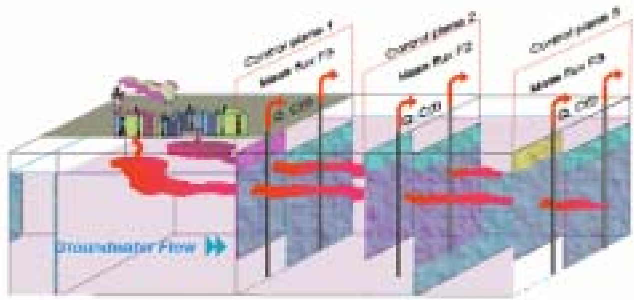
Well	Saturated thickness	Transmissivity	Hydraulic Gradient	Q	t	r
B42	4.0	7.0E-03	0.002	4.00E-03	144	33.6
P2	3.4	3.2E-03	0.0032	1.60E-03	96	18.7
B41	3.06	3.1E-03	0.0035	4.50E-03	96	32.1
P1	3.25	3.0E-03	0.0033	4.00E-03	96	32.6

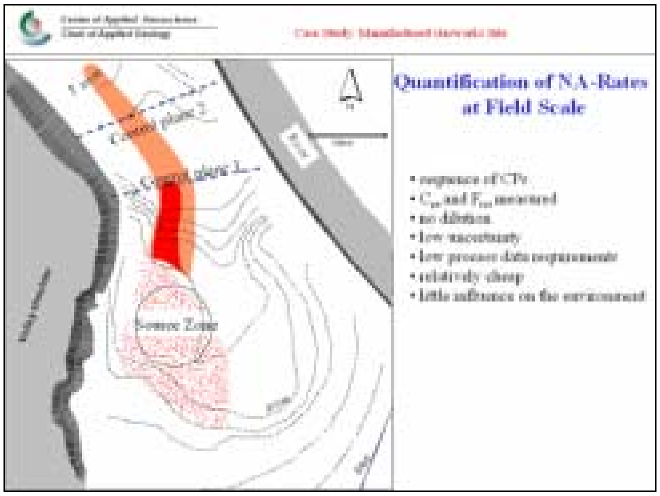
Mixed Contamination (VOCs + PAHs)

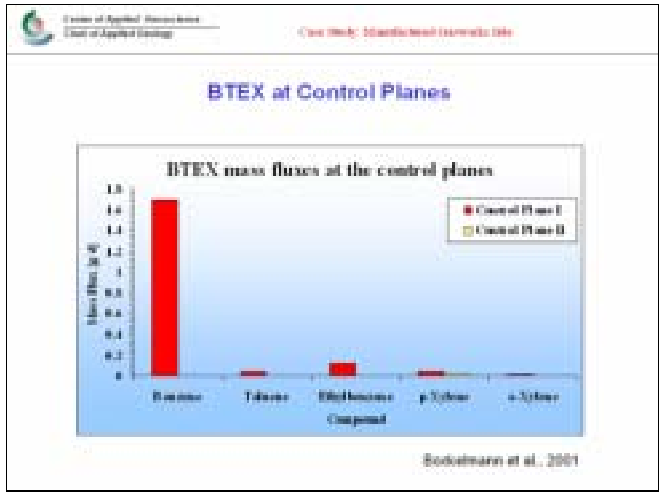
(250 m width, sand & gravel aquifer – 60 ha)

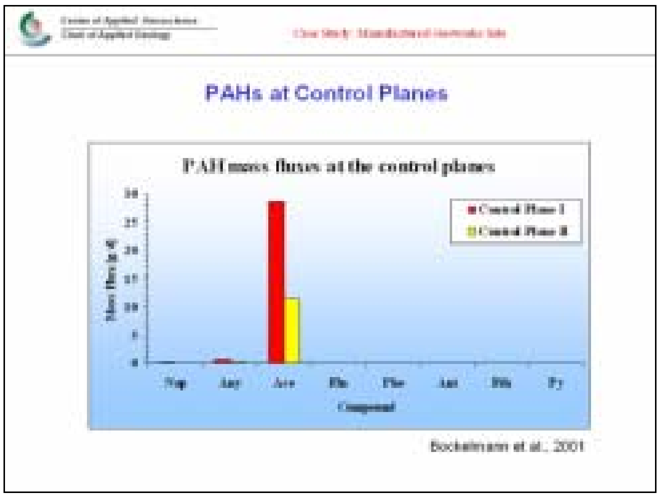
4 pumping wells 20 m depth (6", incl. Multilevel-Samplers)	30,000 €
4 Integral Pumping Tests (15L/sec)	15,000 €
Chemical Analysis (gesamt)	10,000 €
Planning, Interpretation and Reporting	10,000 €
Total Costs (incl. wells)	65.000 €

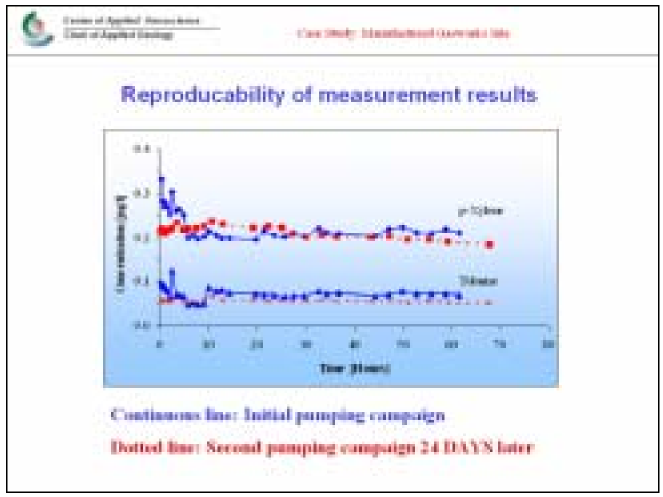
Multiple Control Planes for NA-Quantification

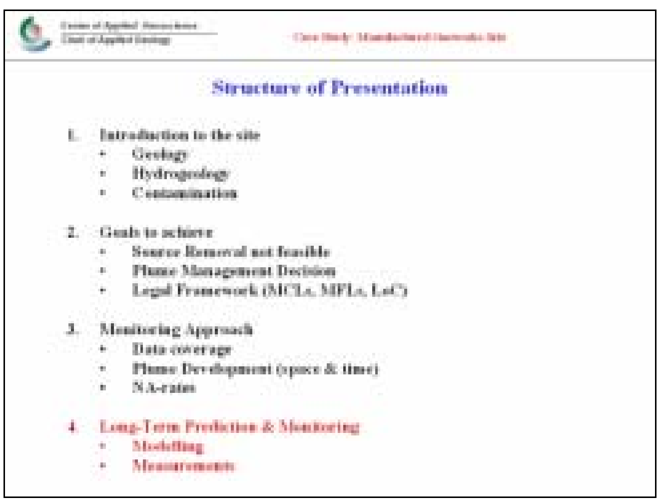



Quantification of NA-Rates at Field Scale
Control plane 2
Control plane 1
Source Zone
• sequence of CPs
• no dilution
• low uncertainty
• low process data requirements
• relatively cheap
• little influence on the environment


BTEX at Control Planes
BTEX mass fluxes at the control planes
Control Plane I
Control Plane II
Benzene
Toluene
Ethylbenzene
p-Xylene
o-Xylene
Compound
Bockelmann et al., 2001


PAHs at Control Planes
PAH mass fluxes at the control planes
Control Plane I
Control Plane II
Nap
Any
Ace
Flu
Phe
Ant
Fth
Py
Compound
Bockelmann et al., 2001


Reproducability of measurement results
p-Xylene
Toluene
Time [Hours]
Continuous line: Initial pumping campaign
Dotted line: Second pumping campaign 24 DAYS later


Structure of Presentation
1. Introduction to the site
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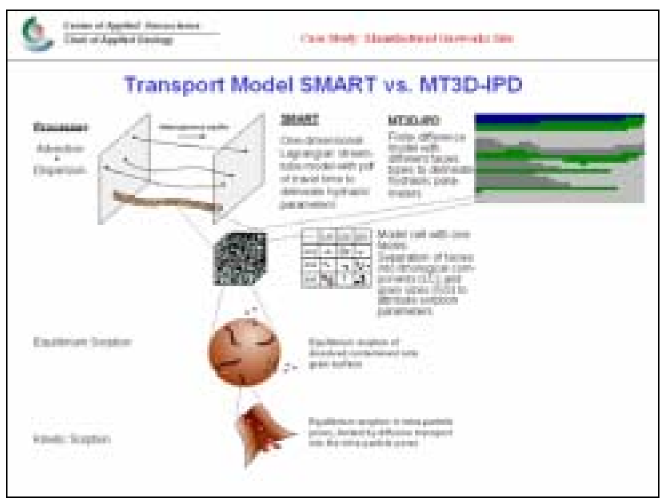
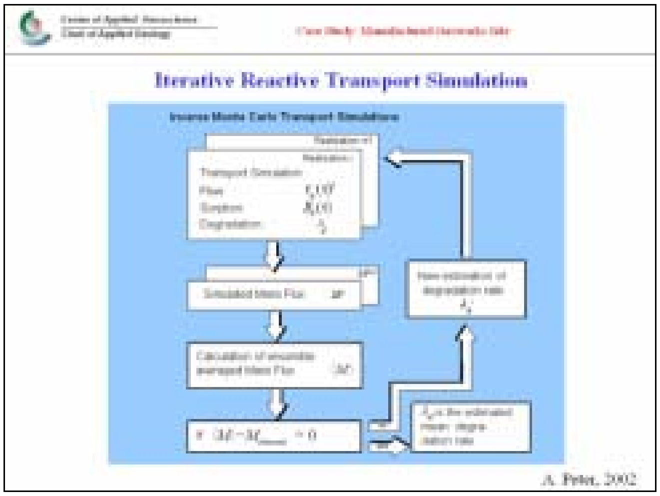
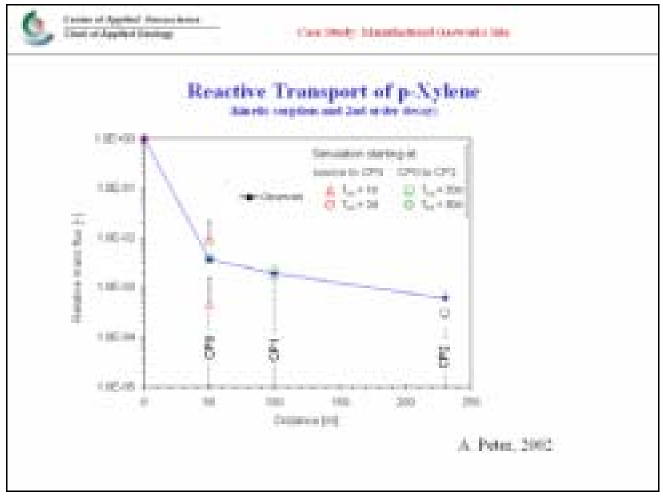
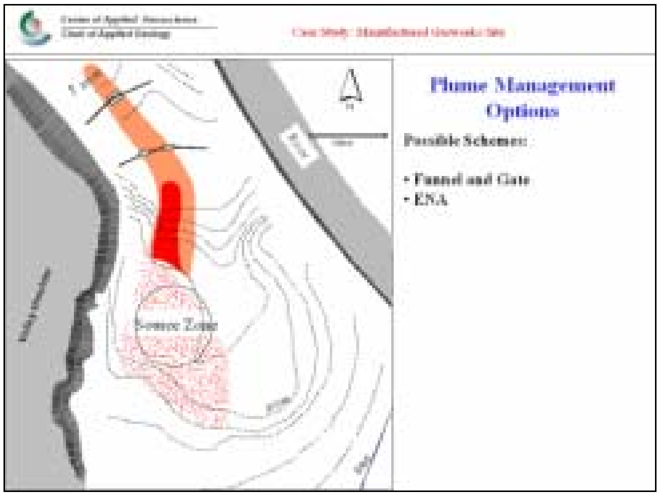
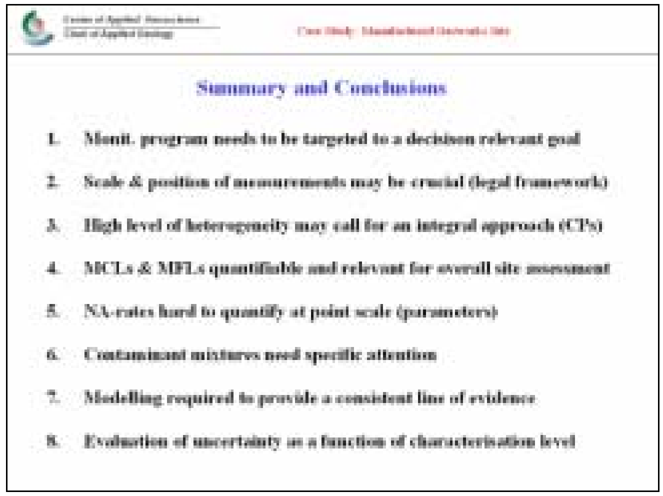

Transport Model SMART vs. MT3D-IPD
SMART
MT3D-IPD


Iterative Reactive Transport Simulation
Transport Simulation
Flow
Sorption
Degradation
Simulated Mass Flux
Calculation of ensemble averaged Mass Flux
New estimation of degradation rate
A. Peter, 2002


Reactive Transport of p-Xylene
Simulation starting at
Distance [m]
A. Peter, 2002


Source Zone
Plume Management Options
Possible Schemes:
• Funnel and Gate
• ENA


Summary and Conclusions
1. Monit. program needs to be targeted to a decision relevant goal
2. Scale & position of measurements may be crucial (legal framework)
3. High level of heterogeneity may call for an integral approach (CPs)
4. MCLs & MFLs quantifiable and relevant for overall site assessment
5. NA-rates hard to quantify at point scale (parameters)
6. Contaminant mixtures need specific attention
7. Modelling required to provide a consistent line of evidence
8. Evaluation of uncertainty as a function of characterisation level

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PILOT STUDY MISSION
October 1997
PHASE III C Continuation of NATO/CCMS Pilot Study:
Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land and Groundwater

1. BACKGROUND TO PROPOSED STUDY

The problems of contamination resulting from inappropriate handling of wastes, including accidental releases, are faced to some extent by all countries. The need for cost-effective technologies to apply to these problems has resulted in the application of new/innovative technologies and/or new applications of existing technologies. In many countries, there is increasingly a need to justify specific projects and explain their broad benefits given the priorities for limited environmental budgets. Thus, the environmental merit and associated cost-effectiveness of the proposed solution will be important in the technology selection decision.

Building a knowledge base so that innovative and emerging technologies are identified is the impetus for the NATO/CCMS Pilot Study on "Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land and Groundwater (Phase II)." Under this current study, new technologies being developed, demonstrated, and evaluated in the field are discussed. This allows each of the participating countries to have access to an inventory of applications of individual technologies, which allows each country to target scarce internal resources at unmet needs for technology development. The technologies include biological, chemical, physical, containment, solidification/stabilization, and thermal technologies for both soil and groundwater. This current (Phase II) pilot study draws from an extremely broad representation and the follow up would work to expand this.

The current study has examined over fifty environmental projects. There were nine fellowships awarded to the study. A team of pilot study country representatives and fellows is currently preparing an extensive report of the pilot study activities. Numerous presentations and publications reported about the pilot study activities over the five-year period. In addition to participation from NATO countries, NACC and other European and Asian-Pacific countries participated. This diverse group promoted an excellent atmosphere for technology exchange. An extension of the pilot study will provide a platform for continued discussions in this environmentally challenging arena.

2. PURPOSE AND OBJECTIVES

The United States proposes a follow-up (Phase III) study to the existing NATO/CCMS study titled "Evaluation of Demonstrated and Emerging Technologies for the Treatment of Contaminated Land and Groundwater." The focus of Phase III would be the technical approaches for addressing the treatment of contaminated land and groundwater. This phase would draw on the information presented under the prior studies and the expertise of the participants from all countries. The output would be summary documents addressing cleanup problems and the array of currently available and newly emerging technical solutions. The Phase III study would be technologically orientated and would continue to address technologies. Issues of sustainability, environmental merit, and cost-effectiveness would be enthusiastically addressed. Principles of sustainability address the use of our natural resources. Site remediation addresses the management of our land and water resources. Sustainable development addresses the re-use of contaminated land instead of the utilization of new land. This appeals to a wide range of interests because it combines economic development and environmental protection into a single system. The objectives of the study are to critically evaluate technologies, promote the appropriate use of technologies, use information technology systems to disseminate the products, and to foster innovative thinking in the area of contaminated land. International technology verification is another issue that will enable technology users to be assured of minimal technology performance. This is another important issue concerning use of innovative technologies. This Phase III study would have the following goals:

a) In-depth discussions about specific types of contaminated land problems (successes and failures) and the suggested technical solutions from each country=s perspective,

b) Examination of selection criteria for treatment and cleanup technologies for individual projects,

c) Expand mechanisms and channels for technology information transfer, such as the NATO/CCMS Environmental Clearinghouse System,

d) Examination/identification of innovative technologies,

e) Examining the sustainable use of remedial technologiesClooking at the broad environmental significance of the project, thus the environmental merit and appropriateness of the individual project.

3. ESTIMATED DURATION

November 1997 to November 2002 for meetings.
Completion of final report: June 2003.

4. SCOPE OF WORK

First, the Phase III study would enable participating countries to continue to present and exchange technical information on demonstrated technologies for the cleanup of contaminated land and groundwater. During the Phase II study, these technical information exchanges benefited both the countries themselves and technology developers from various countries. This technology information exchange and assistance to technology developers would therefore continue. Emphasis would be on making the pilot study information available. Use of existing environmental data systems such as the NATO/CCMS Environmental Clearinghouse System will be pursued. The study would also pursue the development of linkages to other international initiatives on contaminated land remediation.

As in the Phase II study, projects would be presented for consideration and, if accepted by other countries, they would be discussed at the meetings and later documented. Currently, various countries support development of hazardous waste treatment/cleanup technologies by governmental assistance and private funds. This part of the study would report on and exchange information of ongoing work in the development of new technologies in this area. As with the current study, projects would be presented for consideration and if accepted, fully discussed at the meetings. Individual countries can bring experts to report on projects that they are conducting. A final report would be prepared on each project or category of projects (such as thermal, biological, containment, etc.) and compiled as the final study report.

Third, the Phase III study would identify specific contaminated land problems and examine these problems in depth. The pilot study members would put forth specific problems, which would be addressed in depth by the pilot study members at the meetings. Thus, a country could present a specific problem such as contamination at an electronics manufacturing facility, agricultural production, organic chemical facility, manufactured gas plant, etc. Solutions and technology selection criteria to address these problems would be developed based on the collaboration of international experts. These discussions would be extremely beneficial for the newly industrializing countries facing cleanup issues related to privatization as well as developing countries. Discussions should also focus on the implementation of incorrect solutions for specific projects. The documentation of these failures and the technical understanding of why the project failed will be beneficial for those with similar problems. Sustainability, environmental merit, and cost-benefit aspects would equally be addressed.

Finally, specific area themes for each meeting could be developed. These topics could be addressed in one-day workshops as part of the CCMS meeting. These topic areas would be selected and developed by the pilot study participants prior to the meetings. These areas would be excellent venues for expert speakers and would encourage excellent interchange of ideas.

5. NON-NATO PARTICIPATION

It is proposed that non-NATO countries be invited to participate or be observers at this NATO/CCMS Pilot Study. Proposed countries may be Brazil, Japan, and those from Central and Eastern Europe. It is proposed that the non-NATO countries (Austria, Australia, Sweden, Switzerland, New Zealand, Hungary, Slovenia, Russian Federation, *etc.*) participating in Phase II be extended for participation in Phase III of the pilot study. Continued involvement of Cooperation Partner countries will be pursued.

6. REQUEST FOR PILOT STUDY ESTABLISHMENT

It is requested of the Committee on the Challenges of Modern Society that they approve the establishment of the Phase III Continuation of the Pilot Study on the Demonstration of Remedial Action Technologies for Contaminated Land and Groundwater.

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Lead Organization: U.S. Environmental Protection Agency

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Co-Partner Countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Japan, New Zealand, Norway, Poland, Portugal, Slovenia, Sweden, Switzerland, The Netherlands, Turkey, United Kingdom, United States

Addenda

Phase III Meetings Held: February 23-27, 1998, in Vienna, Austria
May 9-14, 1999, in Angers, France
June 26-30, 2000, in Wiesbaden, Germany
September 9-14, 2001, in Liège, Belgium
May 5-10, 2002, Rome, Italy