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Emergency Response
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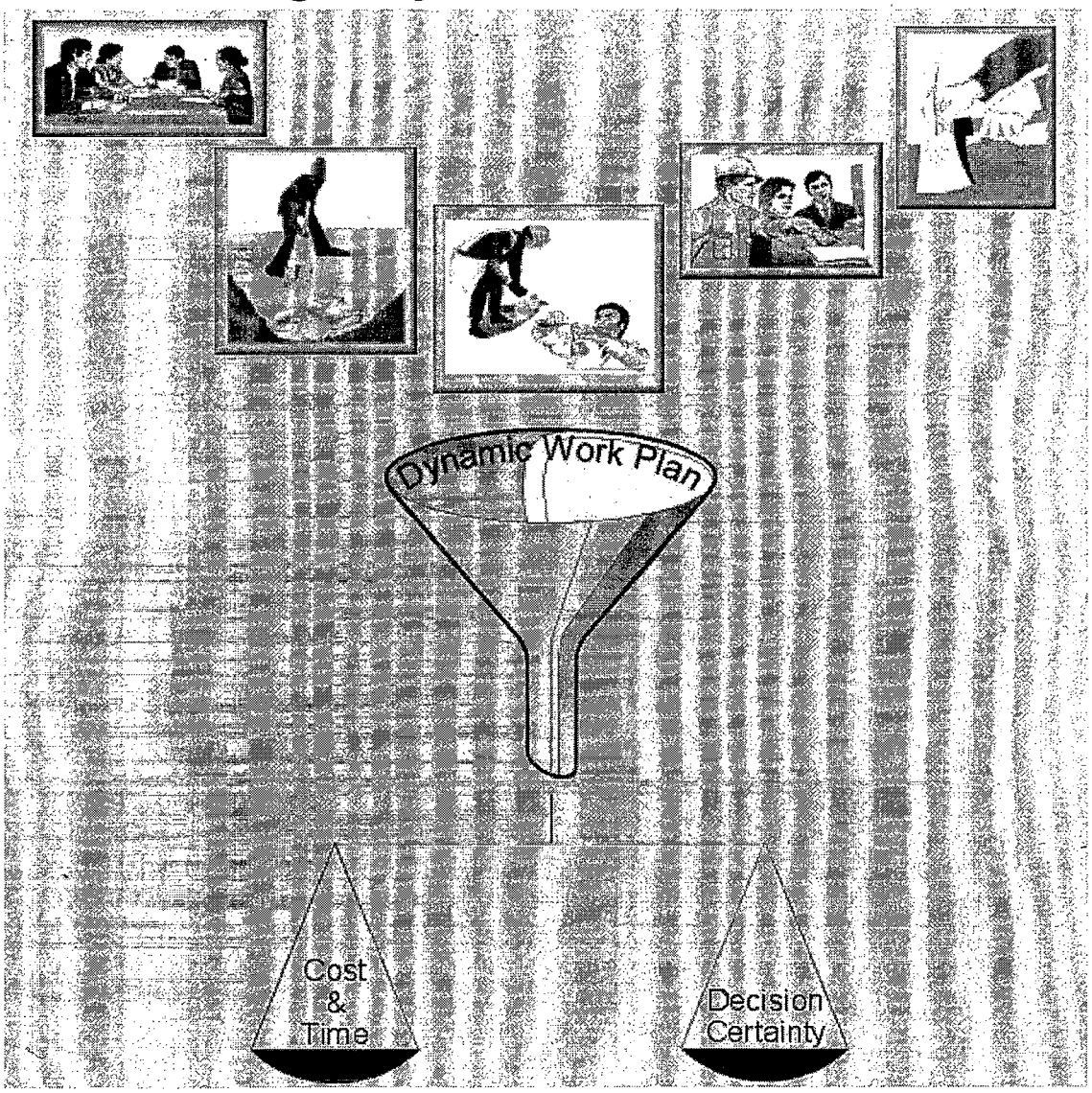
Innovations in Site Characterization

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



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

Notice

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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

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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.

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TECHNOLOGY QUICK REFERENCE SHEET
EnviroGard® DDT Immunoassay Test Kit

Case Study: 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.

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.

TECHNOLOGY QUICK REFERENCE SHEET
RaPID Assay® Cyclodienes Immunoassay Test Kit

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

Technology Name RaPID Assay® Cyclodienes 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 cyclodiene pesticides.	**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.		
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:** $540 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 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%.			**Throughput Achieved:** A batch of 12 field samples could be extracted and analyzed in a half day by one person.

TECHNOLOGY QUICK REFERENCE SHEET
RaPID Assay® Cyclodienes 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 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:	Analytes Measurable with Expected Detection Limits:	Other General Accuracy/Precision Information:
Soil and Water		See SW-846 Method 4041
Wastes Generated Requiring Special Disposal: Small volumes of methanol used for sample extraction, plus the used sample volume.	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.	**Rate of Throughput:** Up to 50 samples can be assayed at one time, with results available in 60 minutes.

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).

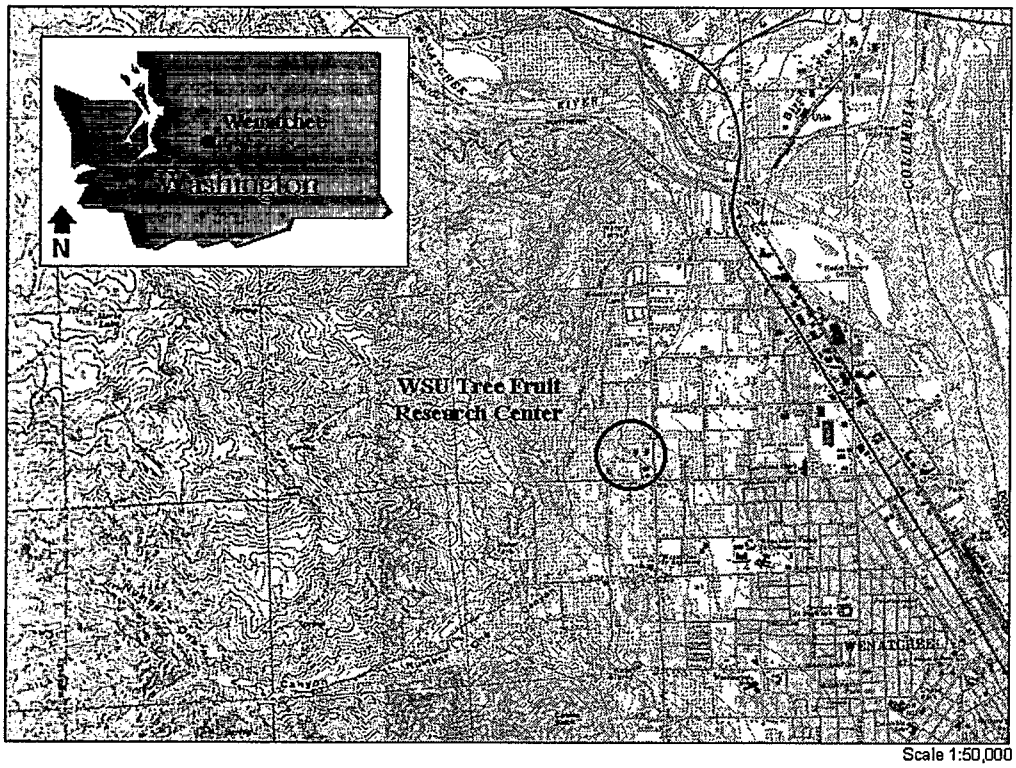

Figure 1. Topographic map showing the location of the WTFREC relative to the town of Wenatchee and the State of Washington

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).

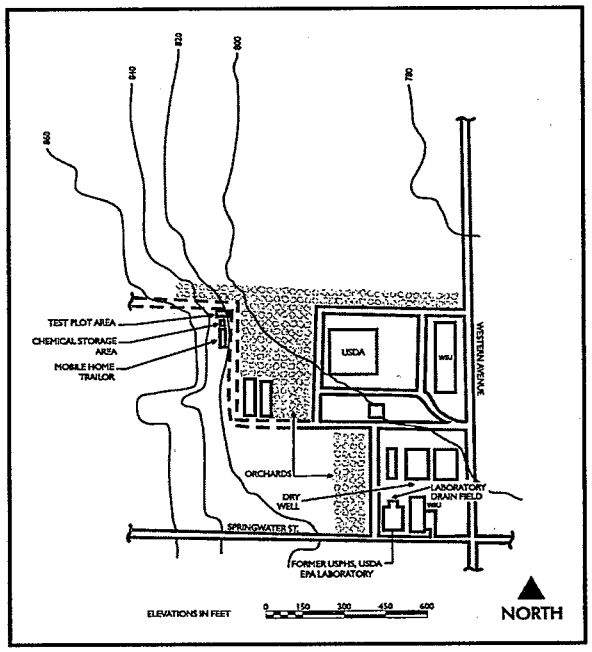

Figure 2. Site Plan for the WTFREC Test Plot

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

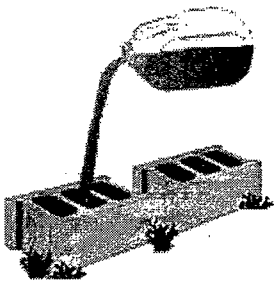

Figure 3. Disposal on the ground.

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).

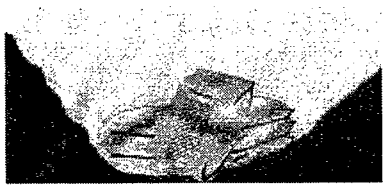

Figure 4. Burial of concentrated pesticide products

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:
Howard Wilson
U.S. Environmental Protection Agency (USEPA)
Office of Research and Development (ORD)
USEPA Headquarters/Ariel Rios Building
1200 Pennsylvania Avenue, NW
Washington, DC 20460
(202) 564-1646

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Bellevue, WA 98005-4446
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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.

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).

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.

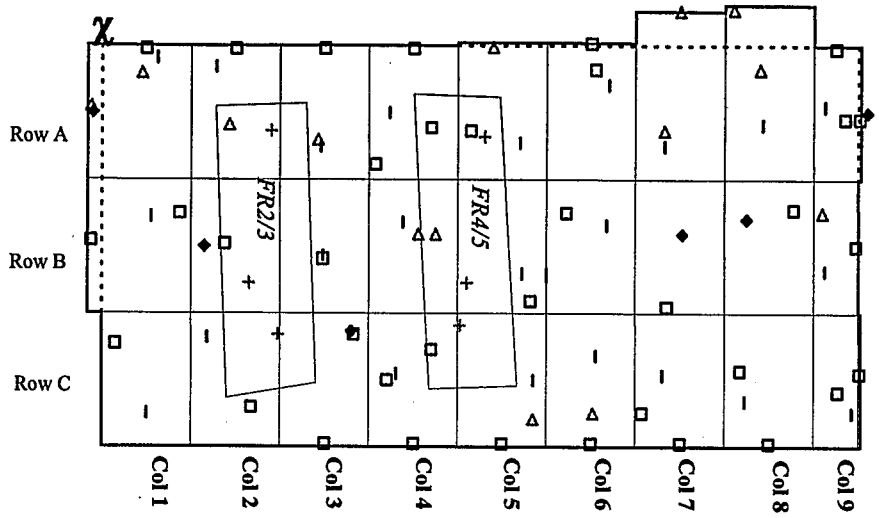
Segregation of Excavated Materials for Disposal: With over 45 tons of material excavated from the focuses removal activities, the potential costs to dispose of those materials were significant. Of the contaminants of concern shown in Table 1, endrin and lindane were significant disposal concerns because 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.



Legend

- χ X-Y coordinate origin
- + Focused removal confirmation samples
- ♦ Site characterization sample
- □ Final confirmation sample (IA only)
- △ Final confirmation samples (IA & fixed laboratory)
- --- Original remediation boundary
- —— Final remediation boundary

North

0 10 ft.
scale

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

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."

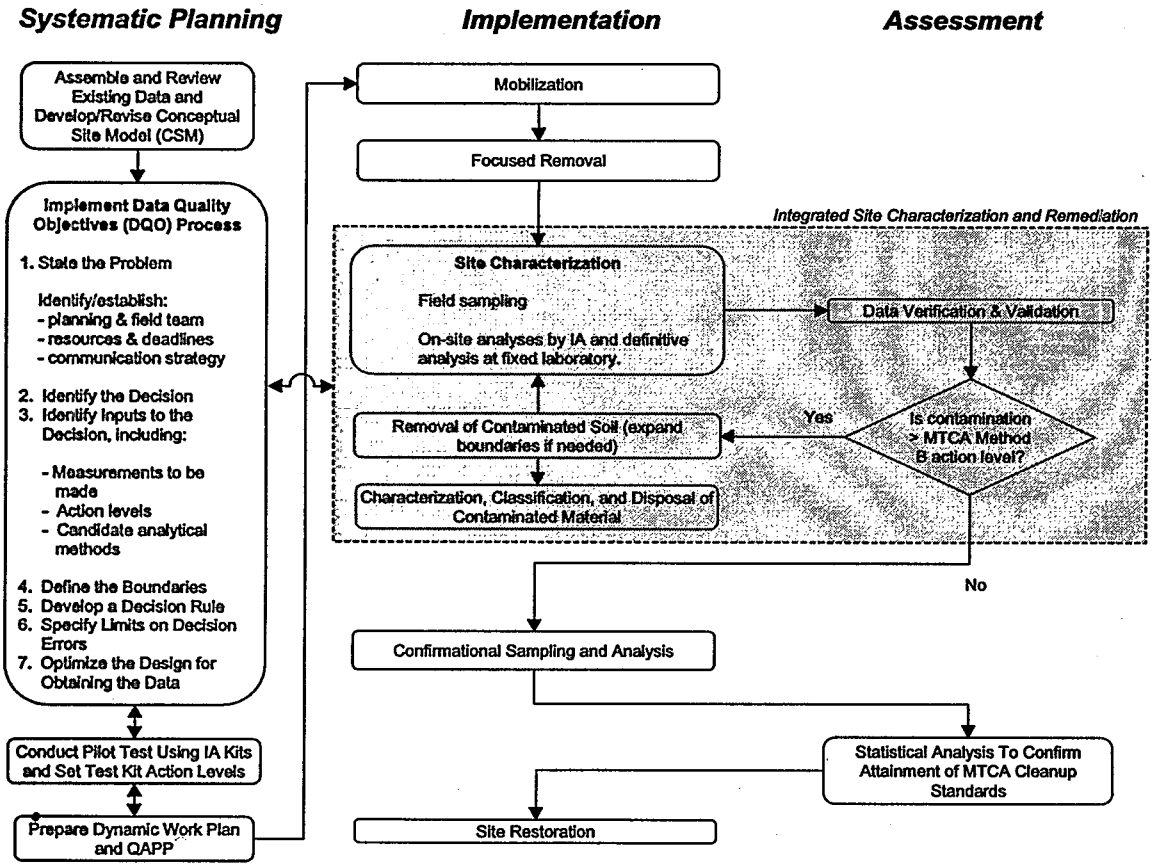


Figure 6. Flow chart showing the integration of site characterization and remediation and use of the dynamic work plan.

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.

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.

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.

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.

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	5	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.

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.

REFERENCES

1. GSA, Inc. (Gary Struthers Associates, Inc.). 1998. Final Report, Wenatchee TFREC Test Plot Remediation, Wenatchee, Washington. DACA67-95-G-0001-38. Prepared for USACE Seattle District, Seattle, WA. August.

2. GSA, Inc. 1997a. *Sampling and Analysis Plan Field Sampling Plan, Part B-Wenatchee TFREC Test Plot Remediation*. August.

3. GSA, Inc. 1997b. *Quality Assurance Project Plan Sampling and Analysis Plan, Part C-Wenatchee TFREC Test Plot Remediation*. August.

4. USACE (U.S. Army Corp of Engineers). 1997. Wenatchee Tree Fruit Research Center (TFRC) Test Plot Removal Action. Basic Ordering Agreement 1013-95-510711/DACA67-95-G-0001. August.

5. USACE. 2000. *Cost and Performance Report - Expedited Characterization and Soil Remediation at the Test Plot Area, Wenatchee Tree Fruit Research Center, Wenatchee, Washington*. May. http://www.frtr.gov/cost/pdf/Wenatchee.pdf

6. USEPA. 1993b. *Data Quality Objectives Process for Superfund.* Interim Final Guidance. EPA/540.G-93/071. Office of Solid Waste and Emergency Response. Washington, DC.

7. USEPA. 1994. *Guidance for the Data Quality Objectives Process, EPA QA/G-4.* http://es.epa.gov/ncerqa/qa/qa_docs.html#G-4. EPA/600/R-96/055. Office of Research and Development. Washington, DC.

8. USEPA 1999. *Guidance for the Data Quality Objectives Process, EPA QA/G-4, Peer Review Draft.* http://www.epa.gov/quality1/qs-docs/g4-prd.pdf. Office of Environmental Information. Washington, DC.

9. Washington State Department of Ecology (Ecology). 1992. *Statistical Guidance for Ecology Site Managers*. August 1992.

10. Washington State Department of Ecology (Ecology). 1995. *Guidance on Sampling and Data Analysis Methods*. Publication No. 94-49. January 1995.

11. Chevron Chemical Company. April 1978. Method RM-8-10: Analysis of Paraquat Residues. Ortho Research & Development Department. Richmond, CA. (Paraquat analyses performed by North Coast Laboratories, Arcata, CA.)

12. USEPA. 2000. *Data Quality Objectives Process for Hazardous Waste Site Investigations, EPA QA/G-4HW, Final.* http://www.epa.gov/quality1/qs-docs/g4hw-final.pdf. EPA/600/R-00/007. Office of Environmental Information. Washington, DC.