

# **Electrochemical Remediation Technologies (ECRTs) - In situ Remediation of Contaminated Marine Sediments**

## **Innovative Technology Evaluation Report**

National Risk Management Research Laboratory  
Office of Research and Development  
U.S. Environmental Protection Agency  
Cincinnati, Ohio 45268

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## **Notice**

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## Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

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Sally Guiterrez, Director  
National Risk Management Research Laboratory

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## Abstract

This Innovative Technology Evaluation Report summarizes the results of the evaluation of the Electrochemical Remediation Technologies (ECRTs) process, developed by P2-Soil Remediation, Inc. (in partnership with Weiss Associates and Electro-Petroleum, Inc.). This evaluation was conducted between August 2002 and March 2003 in cooperation with the Washington State Department of Ecology (Ecology). The ECRTs demonstration consisted of an evaluation of ECRTs' process to utilize a DC/AC current passed between an electrode pair (anode and cathode) in sediment in order to mineralize organic contaminants through an ElectroChemicalGeoOxidation (ECGO) process, or complex, mobilize, and remove metal contaminants deposited at the electrodes through the Induced Complexation (IC) process. The demonstration of the ECRTs process was conducted at the Georgia Pacific, Inc. (G-P) Log Pond located along the Whatcom Waterway in Bellingham Bay, Bellingham, Washington. This demonstration was designed to assess and evaluate the ability of the ECRTs process to reduce concentrations of mercury, PAHs, and phenolic compounds.

For the demonstration project, Weiss Associates, (Emeryville, CA) installed, operated, and removed the ECRTs pilot test equipment from the Log Pond site. Faulk Doering, electrochemical processes (ECP; Stuttgart, Germany) provided oversight and consultation for the system installation and operation. Installation of pilot study infrastructure involved placing 9 anode (steel plates) and 9 cathode (graphite plates) electrodes, in two parallel rows, into the sediments.

The G-P Log Pond is a marine embayment that served as a former log storage and handling area and receiving water for facility effluent and stormwater runoff. The ECRTs project area was designated as an approximately 50-foot (ft) by 50-ft area within a pre-characterized area of the G-P Log Pond known to contain elevated concentrations of mercury, phenolics, and PAHs. However, based on results from a preliminary survey, mercury was identified as the most ubiquitous and consistently elevated contaminant relative to Washington State Sediment Management Standards (SMS) Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL) which are used in Puget Sound to determine impacted sediments that require remediation under State law.

The primary technical objective of the demonstration was to determine whether there was a significant trend in the reduction of sediment mercury concentrations over the period of the demonstration. Reference area samples were collected for comparison to determine whether treatment differed from natural attenuation. The experimental design was based

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upon significant mercury reduction from baseline to a post-treatment sampling event. The primary objective is not associated with a percent reduction but instead the primary objective is to determine a statistically significant negative trend over time. Samples of the cap material and the underlying native material were used to evaluate potential migration of all contaminants, including mercury (primary objective), PAHs, and phenolics.

An assessment of the sediment chemistry results indicated a less than anticipated performance due in part to system operational problems encountered during the course of the demonstration. Electrical readings collected by the technology's sponsor indicated a steady degradation of system performance throughout the duration of the demonstration, resulting in an early shutdown of the system prior to completion of the planned test period. In addition, when the electrodes were removed from the test plot, it was evident that the connections between the electrical supply and anode electrode plates had completely corroded to the point that a viable contact had not been maintained.

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## Abbreviations and Acronyms

AQCR	Air Quality Control Regions
AQMD	Air Quality Management District
ARARs	Applicable or Relevant and Appropriate Requirements
BL	Baseline
CAA	Clean Air Act
CERI	Center for Environmental Research Information
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSL	Cleanup screening level
CV	Coefficient of variance
DC/AC	Direct Current/Alternating Current
DGPS	Differential global positioning system
ECGO	ElectroChemicalGeoOxidation
Ecology	Washington State Department of Ecology
ECRTs	Electrochemical Remediation Technologies
ft <sup>2</sup>	Square feet / square foot
GC/MS	Gas chromatography/mass spectroscopy
G-P	Georgia-Pacific Corporation
G&A	General and administrative
HPAHs	High molecular weight polycyclic aromatic hydrocarbons
HSWA	Hazardous and Solid Waste Amendments
ICP	Inductively coupled plasma spectroscopy
ITER	Innovative Technology Evaluation Report
Int	Intermediate
JARPA	Joint Aquatic Resources Permit Application
LCS	Laboratory control sample
LPAHs	Low molecular weight polycyclic aromatic hydrocarbons
LOS	Level of significance
LCL	Lower confidence limit
MSS	Marine Sampling Systems
MS/MSD	Matrix spike/matrix spike duplicate
MDL	Method detection limit
mg/kg	Milligrams per kilogram
MLLW	Mean lower low water
MTCA	Model Toxics Control Act
NAAQS	National Ambient Air Quality Standards

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## Abbreviations and Acronyms (Cont'd)

NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NRMRL	National Risk Management Research Laboratory (EPA)
NSCEP	National Service Center for Environmental Publications
ND	Non-detectable, not detected, less than detection limit
OSHA	Occupational Safety and Health Administration
ORD	Office of Research and Development (EPA)
OSC	On-scene coordinator
O&M	Operation and maintenance
OC	Organic carbon
PAHs	Polynuclear aromatic hydrocarbons
PCB	Polychlorinated biphenyl
PPE	Personal protective equipment
PO	Primary objective
PQL	Practical quantitation limit
PQA	Pre-Quality Assurance Plan Project Agreement
PVC	Polyvinyl chloride
POTW	Publicly owned treatment works
QAPP	Quality assurance project plan
QA/QC	Quality assurance/Quality control
RPD	Relative percent difference
RFP	Request for proposal
RPM	Remedial project manager
RCRA	Resource Conservation and Recovery Act
R&D	Research and development
RSD	Relative standard deviation
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act
SMS	Washington State Sediment Management Standards
SQS	Sediment quality standards
SVOCs	Semi-Volatile Organic Compounds
SOP	Standard operating procedure
SW-846	Test methods for evaluating solid waste, physical/chemical methods
SWDA	Solid Waste Disposal Act
SITE	Superfund Innovative Technology Evaluation
TER	Technology Evaluation Report
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
TRPH	Total recoverable petroleum hydrocarbons
TSCA	Toxic Substances Control Act
TSD	Treatment, storage, and disposal
UCL	Upper confidence (or control) limit
USEPA	United States Environmental Protection Agency
VOC	Volatile organic compound
WAC	Washington Administrative Code
yd <sup>3</sup>	Cubic yards

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## **Acknowledgments**

This report was prepared under the direction of Mr. Randy Parker, the EPA Technical Project Manager for this SITE demonstration at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio. Dr. Scott Beckman of Science Applications International Corporation (SAIC), Hackensack, NJ, served as the SITE work assignment manager for the demonstration project. Mr. Tim Hammermeister (SAIC, Bothell, WA) provided project oversight for evaluation study design, field survey implementation, and data reporting. Mr. Joe Evans (SAIC) provided QA oversight in conjunction with Mr. Hammermeister for evaluation study design and data reporting.

The demonstration project required the services of individuals from several companies and agencies including Georgia-Pacific (G-P), Marine Sampling Systems (MSS), Washington State Department of Ecology (Ecology), and Weiss Associates. Chip Hilardes, Field Services Manager for G-P (Bellingham, WA), provided site access, logistical support, and use of G-P facilities for sample processing and equipment storage. Bill Jaworski of MSS (Purdy, WA) provided and operated the sampling vessel for collecting sediment cores and conducting voltage probe measurements. Brad Helland of Ecology (Bellevue, WA), provided technical oversight of the technology developers. Joe Iovenitti, Don Hill, and Bill McIlvride of Weiss Associates (Emeryville, CA) served as logistical and technical contacts for the developer Dr. Faulk Doering, of P2-Soil Remediation, Inc. (Stuttgart, Germany).

This report was prepared by Scott Beckman, Joe Evans, Tim Hammermeister, Maureen Goff, and Joseph Tillman of SAIC. Ms. Rita Schmon-Stasik served as the SAIC QA coordinator for data review and validation. Tim Hammermeister, John Nakayama, Chris Hunt, Pete Heltzel, Mike Johnson, Ruth Otteman and Maureen Goff, all of SAIC, conducted field sampling and data acquisition efforts.

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## Executive Summary

This report summarizes the results of the evaluation of the Electrochemical Remediation Technologies (ECRTs) process, developed by P2-Soil Remediation, Inc. (in partnership with Weiss Associates and Electro-Petroleum, Inc.). The Superfund Innovative Technology Evaluation (SITE) demonstration of the ECRTs process was conducted at the Georgia Pacific, Inc. (G-P) Log Pond located along the Whatcom Waterway in Bellingham Bay, Bellingham, Washington. The demonstration was designed to assess and evaluate the ability of the ECRTs process to reduce concentrations of mercury, PAHs, and phenolic compounds.

### Overview of Site Demonstration

The ECRTs Demonstration project consisted of an evaluation of ECRTs' process to utilize DA/AC current passed between an electrode pair (anode and cathode) in sediment in order to mineralize organic c o n t a m i n a n t s t h r o u g h a n ElectroChemicalGeoOxidation (ECGO) process, or complex, mobilize, and remove metal contaminants deposited at the electrodes through the Induced Complexation (IC) process. Installation of a pilot study infrastructure involved placing 9 anode (steel plates) and 9 cathode (graphite plates) electrodes, in two parallel rows, into the sediments. Each electrode row was approximately 30 feet long. The distance between the anode and cathode sheet electrode rows was approximately 30 feet. Electricity was supplied, in parallel, to each individual electrode plate.

The G-P Log Pond is a marine embayment that served as a former log storage and handling area and receiving water for facility effluent and stormwater runoff. The ECRTs project area was designated as

an approximately 50-feet (ft) by 50-ft area within a pre-characterized area of the G-P Log Pond known to contain elevated concentrations of mercury, phenolics, and PAHs. However, based on results from a preliminary survey, mercury was identified as the most ubiquitous and consistently elevated contaminant relative to Washington State Sediment Management Standards (SMS) Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL) which are used in Puget Sound to determine impacted sediments that require remediation under State law,

The actual treatment area used to evaluate the technology's effectiveness was a 20-ft by 30-ft zone located between the electrode arrays. With the exception of the Port of Bellingham's Shipping Terminal dock on the Whatcom Waterway adjacent to the test plot, there were no structures within the project area. The mudline elevations within the test plot ranged from approximately -4 to -8 feet Mean Lower Low Water (MLLW). Log Pond sediments with elevated chemical concentrations and woody debris measured approximately 5 to 6 ft thick between underlying native material and a cap of clean sand from regional maintenance dredging projects. The area was capped in late 2000 and early 2001 with clean capping material as part of a Model Toxics Control Act (MTCA) interim cleanup action. Cap thickness within the sediment treatment demonstration area ranged from 0.5 to 1 foot in thickness. The formal SITE demonstration of the ECRTs system was conducted from August 2002 (Baseline Survey prior to installation) until March 2003 (Post-Demonstration Survey). The performance of the ECRTs process was evaluated by collecting sediment cores from within and adjacent to the electrode array and from 'reference' stations

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located within the log pond but beyond the influence of the ECRTs electrical field. Intermediate monitoring events were conducted in November 2002 and December 2002 during the active ECRTs demonstration period. A third monitoring event scheduled for February 2003 was canceled due to system operational concerns.

The primary technical objective of the demonstration was to determine whether there was a significant trend in the reduction of sediment mercury concentrations over the period of the demonstration. Reference area samples were collected for comparison to determine whether treatment differed from natural attenuation. The experimental design was based upon significant mercury reduction from baseline to a post-treatment sampling event. The primary objective is not associated with a percent reduction but instead the primary objective is to determine a statistically significant negative trend over time. Samples of the cap material and the underlying native material were used to evaluate potential migration of contaminants. Samples were submitted for analysis of mercury, PAHs, and phenolic compounds. In addition purse seining and infauna inumeration studies were conducted to determine the effect of the process on the native fish and wildlife. There was some concern that the ECRTs system would have a negative effect on electrosensitive marine life.

### **Conclusions from this SITE Demonstration**

Formal statistical analyses were used to evaluate the critical mercury data. The overall conclusions reached from these statistical analyses are as follows:

- An inferential statistical evaluation was performed to determine if there was any decreasing trend in contaminant mercury concentrations over time. The statistical analysis showed that there was no significant decreasing trend over time. Concentrations of mercury remained relatively heterogeneous but unchanging in the test plot during the duration of the demonstration. Therefore remediation results of the technology were not readily apparent from mercury concentration determinations obtained from

the test plot and the primary objective regarding mercury reduction was not achieved.

- Spatial and temporal plots of mercury from the contaminated sediment horizon in the test plot support the inferential statistical analysis. No significant changes in mercury concentration (from a remedial perspective) can be discerned from the spatial distribution over time.
- Operational problems with the ECRTs process may be responsible for the lack of a significant reduction in mercury levels in the test plot. Electrical readings collected by the technology's sponsor indicated a steady degradation of system performance throughout the duration of the demonstration. In addition, the connections between the electrical supply and anode plates had completely corroded to the point that a viable contact had not been made. Therefore, it is uncertain exactly how long (and to what extent) the ECRTs process was fully functional and operational.

Additional conclusions may be drawn from the evaluation of the ECRTs process, based on extensive analytical data supplemented by field observations. These include:

- Plots were generated for naphthalene, 2-methylnaphthalene, acenaphthalene, flourene, flouranthene, and 4-methylphenol. All other SW-846 method 8270 compounds were at concentrations too low to be able to observe any possible decrease due to technology remediation. The compounds noted above show no apparent decrease in concentration. The ECRTs technology demonstration was therefore unsuccessful at reducing organic compounds through mineralization. Overall it is believed that because of problems encountered by the developer for this demonstration that there was no significant effect on hazardous compound concentrations. The collected data suggest that there were no significant decreases in any of the compounds analyzed

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at the G-P log pond site.

- Vertical migration of contaminants (e.g. induced complexation and mobilization of mercury) was important to assess because possible decreases in concentration in any of the different horizons (sediment, cap, or native material) could be due to vertical migration of contaminants rather than actual remediation. There was, however, no significant decrease or increase in contamination for any of the contaminants of concern within the test plot for the contaminated horizon, the cap material, and the native material, confirming that the technology had no effect on contaminant migration.
- In order to determine the extent of the zone of influence of the ECRTs process, spatial measurement of electric potential and also changes in compound concentrations outside the immediate area of influence, designated as the treatment plot were monitored. Collected data indicated that there was no significant decrease in contaminant concentrations outside the immediate treatment plot.
- Benthic infauna effects and behavioral effects on electro-sensitive fish were monitored as part of the demonstration. There was no outward evidence that the ECRTs system was having an adverse impact on the local benthic community (i.e. sterile substrate).
- It appears that some mercury did adhere to the cathode surfaces during the demonstration. However, based on the analytical results and visual assessments of the electrodes, the relative quantity of mercury plated to the cathodes was limited, not readily recoverable (from a remedial perspective), and may be an artifact of the sediment in direct contact with the electrode plates. It also does not appear that mercury was mobilized to the extent that enriched sediments near the electrodes.
- Based upon review of data quality indicators, it appears the critical data generated during the final sampling and analysis post-treatment event for the demonstration met QAPP-specified criteria. These data are therefore considered suitable without qualification for use in evaluating the project objectives.
- The estimated cost to implement an approximate 2,500 ft<sup>2</sup> ECRTs treatment system, extending to a five foot depth to treat mercury-contaminated sediments over a six month period is approximately \$385,500, including a 5% technology fee assessed by P2 Soil Remediation.

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## Section 1.0 Introduction

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER), and describes the Electrochemical Remediation Technologies (ECRTs) process. Key contacts are listed at the end of this section for inquiries regarding additional information about the SITE Program, this technology, and the demonstration site.

### 1.1 Background

The Electrochemical Remediation Technologies (ECRTs) process was developed by P2-Soil Remediation Inc. P2-Soil Remediation Inc. formed a partnership with Weiss Associates and ElectroPetroleum, Incorporated to apply the technology to contaminated sites. The ECRTS process was evaluated for the treatment of marine sediments contaminated with mercury, polycyclic aromatic hydrocarbons (PAHs), and phenolic compounds. The demonstration of the ECRTs was conducted at the Georgia Pacific, Inc. (G-P) Log Pond in Bellingham Bay, Washington. The G-P Log Pond pilot project consisted of a demonstration of ECRTs, which utilizes an DC/AC current passed between an electrode pair (anode and cathode) in sediment. Remediation of the sediment was to be accomplished by either the mineralization of organic contaminants through the ElectroChemicalGeoOxidation (ECGO) process, or by use of the Induced Complexation (IC) process to complex, mobilize, and remove metal contaminants plated to the electrodes, as described in Section 1.5. The pilot study was designed to evaluate the ability of the ECRTs process to reduce concentrations of mercury, PAHs, and phenolic compounds.

The G-P Log Pond is a marine embayment located adjacent to the Whatcom Waterway navigation channel in Bellingham Bay, a well-established heavy industrial land

use area with a Maritime shoreline designation (Figure 1-1). The ECRTs project area was an approximately 50-feet (ft) by 50-ft area within the G-P Log Pond in Bellingham Bay. The actual treatment area used to evaluate the system's effectiveness was a 20-ft by 30-ft zone within the test area as described in section 4. With the exception of the Port of Bellingham's Shipping Terminal dock on the Whatcom Waterway next to the site, there are no structures in the project area. The test plot location has existing mudline elevations ranging from approximately -4 to -8 feet Mean Lower Low Water (MLLW). Log Pond sediments measure approximately 5 to 6 ft thick, and are contaminated with various contaminants including mercury, phenols, PAHs, PCBs and wood debris. The area was capped in late 2000 and early 2001 with an average of seven feet of clean capping material as part of a Model Toxics Control Act (MTCA) interim cleanup action. Cap thickness within the proposed *in situ* sediment treatment demonstration area is reported by Anchor Environmental, L.L.C. in the project JARPA Permit as approximately 0.5 feet. The integrated remediation and habitat restoration project was performed as an interim Remedial Action as part of an Agreed Order between G-P and the Washington State Department of Ecology (Ecology) in compliance with the State Model Toxics Control Act (MTCA; Chapter 173-340 WAC; RCW 70.105D). Approximately 43,000 yd<sup>3</sup> of clean cap/restoration material from regional maintenance dredging projects were placed within the Log Pond. The total placed thickness ranged from approximately 0.5 feet along the site perimeter to 1.0 feet within the interior of the project area. The restoration project produced 2.7 acres of shallow subtidal and 2.9 acres of low intertidal habitat, all of which had previously exceeded the Sediment Management Standards cleanup criteria (Anchor 2001b).





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Two prospective candidate sites within the Log Pond, designated A and B, were originally considered for project implementation. Data from these two areas indicated that the contaminant concentration ranges found in samples from Site A made this location better suited to conducting the ECRTs pilot study. In comparing sediment chemistry data from Sites A and B, average mercury concentrations in Site A exceeded those of Site B by a factor of 63. Average low molecular weight polycyclic aromatic hydrocarbons (LPAHs) and high molecular weight PAHs (HPAHs) in Site A exceed those of Site B by a factor of 112 and 17, respectively. However, based on results from a preliminary survey, mercury was identified as the most ubiquitous and consistently elevated contaminant relative to Washington State Sediment Management Standards (SMS) Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL) which are used in Puget Sound to determine impacted sediments that require remediation under State law. A debris survey indicated that buried logs/pilings were not likely to be encountered within Site A, with the exception of sporadic riprap located at the base of the bulkhead along the west edge of the site. In addition, Site A was a subtidal location (-4 to -8 MLLW) that was accessible by small boat, whereas Site B was an intertidal location with access limited by variable tidal stages.

## 1.2 Brief Description of the SITE Program

The SITE Program was created in order to develop, demonstrate, and establish the commercial potential of innovative technologies for treating wastes found at Superfund and other hazardous waste sites across the country. Through SITE Demonstrations, USEPA acquires the performance and cost data necessary to properly consider innovative technologies in the remedial action decision-making process. If tested successfully, these technologies become alternatives to less attractive, more costly forms of remedial action.

The SITE Program is a formal program established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act (SARA). The SITE Program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users can assess the technology's site-specific applicability. Technologies evaluated are either available commercially or close to being available for full-scale remediation of Superfund sites. SITE demonstrations usually are conducted at hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of the information collected. Data collected are used to assess:

1. the performance of the technology;
2. the potential need for pre- and post-treatment of wastes;
3. potential operating problems; and
4. the approximate costs.

The demonstration also provides opportunities to evaluate the long-term risks and limitations of a technology.

Existing and new technologies and test procedures that improve field monitoring and site characterizations are explored in the CSCT Program. New monitoring technologies, or analytical methods that provide faster, more cost effective contamination and site assessment data, are supported by this program. The CSCT Program also formulates the protocols and standard operating procedures (SOPs) for demonstration methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration and CSCT Programs through various activities. These activities increase awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer is to develop interactive communication among individuals requiring up-to-date technical information.

The U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program was established by EPA's Office of Solid Waste and Emergency Response and the Office of Research and Development (ORD) in response to the 1986 Superfund Amendments and Reauthorization Act, which recognized a need for an "Alternative or Innovative Treatment

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Technology Research and Demonstration Program." The SITE Program is administered by ORD National Risk Management Research Laboratory in the Land Remediation and Pollution Control Division (LRPCD), headquartered in Cincinnati, Ohio. The SITE Demonstration Program encourages the development and implementation of: 1) Innovative treatment technologies for hazardous waste site remediation, and 2) Monitoring and measurement.

In the SITE Demonstration Program, the technology is field-tested on hazardous waste materials. Engineering and cost data are gathered on the innovative technology so that potential users can assess the technology's applicability to a particular site. Data collected during the field demonstration are used to assess the performance of the technology, the potential need for pre- and post-processing of the waste, applicable types of wastes and waste matrices, potential operating problems, and approximate capital and operating costs.

### **1.3 The SITE Demonstration Program and Reports**

In the past technologies have been selected for the SITE Demonstration Program through annual requests for proposal (RFP). EPA reviewed proposals to determine the technologies with promise for use at hazardous waste sites. Several technologies also entered the program from current Superfund projects, in which innovative techniques of broad interest were identified for evaluation under the program. Once the EPA has accepted a proposal, cooperative arrangements are established among EPA, the developer, and the stakeholders. Developers are responsible for implementing and operating and/or maintaining their innovative systems at a selected site, and are expected to pay the costs to transport equipment to the site, operate and/or maintain any equipment on-site during the demonstration, and remove the equipment from the site. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, and disseminating information.

Usually, results of Demonstration Programs are published in three documents: the SITE Demonstration Bulletin, the Technology Capsule, and the ITER. The Bulletin describes the technology and provides preliminary results of the field demonstration. The Technology Capsule provides more detailed information about the technology, and emphasizes key results of the field demonstration. The ITER provides

detailed information on the technology investigated, a categorical cost estimate, and all pertinent results of the field demonstration. An additional report, the Technology Evaluation Report (TER), is available by request only. The TER contains a comprehensive presentation of the data collected during the demonstration and provides a detailed quality assurance review of the data.

For the ECRTs G-P Log Pond Demonstration, there is a SITE Technology Bulletin, Capsule, and ITER; all of which are intended for use by remedial managers for making a detailed evaluation of the technology for a specific site and waste. A TER is submitted as verification documentation.

### **1.4 Purpose of the Innovative Technology Evaluation Report (ITER)**

This ITER provides information on the ECRTs process for treatment of marine sediments contaminated with mercury, PAHs, and phenolics. This report includes a comprehensive description of this demonstration and its results. This ITER includes a comprehensive description of this demonstration and its results and is intended for use by EPA remedial project managers, EPA on-scene coordinators (OSCs), contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in evaluating specific technologies for further consideration as applicable options in a particular cleanup operation.

To encourage the general use of demonstrated technologies, the EPA provides information regarding the technology applicability to specific sites and wastes. The ITER includes information on cost and desirable site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste matrix. The characteristics of other wastes and other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that its applicability at other sites. Field demonstration data may require extrapolation for estimating operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

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## 1.5 Technology Description

The ECRTs Demonstration project consisted of a demonstration of ECRTs' process to utilize an DC/AC current passed between an electrode pair (anode and cathode) in sediment to attempt to either mineralize organic contaminants through an ElectroChemicalGeoOxidation (ECGO) process, or complex, mobilize, and remove metal contaminants deposited at the electrodes through the Induced Complexation (IC) process as described below.

**ElectroChemicalGeoOxidation:** According to the developer, by using a low voltage, low amperage proprietary coupled DC/AC current, an induced polarization field is created within the sediment. The sediment acts as a capacitor, discharging and charging electricity resulting in redox reactions, which cause desorption of the contaminants from the sediments and mineralization of the organics in the matrix. Empirical evidence indicates that reaction rates are inversely proportional to grain size, such that ECRTs remediate faster in finer-grained materials typically found at contaminated sediment sites. The sediment-pore water system can be considered an electrochemical cell. In an electrochemical cell, reactions only occur at the electrodes and comprise anodic oxidation or cathodic reduction. However, in sediment, in addition to the local electrode reactions, redox reactions occur simultaneously at any and all interfaces within the sediment-water-contaminant system at the pore scale. The reaction partners for oxidations and reductions are simultaneously generated by water hydrolysis.

Empirical ECRTs field remediation data of rapid mineralization of organic contaminants including phenolic compounds and PAHs (and enhanced mobilization rates for metals) suggest that the secondary current released via sediment electrical discharges provides the activation and dissociation energy for the ensuing redox reactions. Additionally, it is suspected that trace metals in the sediment may act as catalysts, reducing the activation energy required for the redox reactions. The quantification of these energy releases remains to be completed. Since the redox reactions are occurring at the pore scale, the ECRTs system pH is stabilized in the neutral range.

**Induced Complexation:** According to the developer, metals remediation may be achieved when redox reactions, created by the same low voltage/amperage current described above, desorb the contaminants from the sediment and create ionic metal complexes that are

significantly more mobile. These more mobile ions move readily to the electrodes, are electrically contained by the induced direct current, and are migrated to the electrodes where they are chemically deposited. Following treatment, the electrodes are removed and disposed, or the deposited metals are recycled.

For the demonstration project, Weiss Associates, (Emeryville, CA) installed, operated, and removed the ECRTs pilot test equipment from the Log Pond site. Faulk Doering, electrochemical processes (ECP; Stuttgart, Germany) provided oversight and consultation for the system installation and operation. Installation of pilot study infrastructure involved placing 9 anode (steel plates) and 9 cathode (graphite plates) electrodes, in two parallel rows, into the sediments. Each electrode row was approximately 30 feet long. The distance between the anode and cathode sheet electrode rows was approximately 30 feet. Electricity was supplied, in parallel, to each individual electrode plate.

## 1.6 Key Contacts

Additional information regarding the ECRTs process and the SITE program are available from the following Sources:

### EPA Project Manager

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U.S. EPA National Risk Management Research Laboratory  
26 W. Martin Luther King Jr. Dr.  
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### Technology Developer Contacts

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Wayne, PA 19087  
(610) 687-9070  
E-mail: [kwittle@electropetroleum.com](mailto:kwittle@electropetroleum.com)

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Information on the SITE Program is available through the following on-line information clearinghouses:

- The SITE Home page ([www.epa.gov/ORD/SITE](http://www.epa.gov/ORD/SITE)) provides general program information, current project status, technology documents, and access to other remediation home pages.
- The OSWER CLU-In electronic bulletin board (<http://www.clu-in.org>) provides information on innovative treatment and site characterization technologies while acting as a forum for all waste remediation stakeholders.

Technical reports may also be obtained by writing to USEPA/NSCEP, P.O. Box 42419, Cincinnati, OH 45242-2419, or by calling (800) 490-9198.

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## Section 2.0 Technology Applications Analysis

This section addresses the general applicability of the Electrochemical Remediation Treatment (ECRTs) process, developed by P2-Soil Remediation, Inc. (in partnership with Weiss Associates and Electro-Petroleum, Inc.) to sites having sediments contaminated with organic compounds, metals, or both. The analysis is based on results from, and observations made during, the SITE Program Demonstration, and from additional information received from Weiss Associate (the technology lessee that was responsible for installing, operating, and maintaining the ECRTs pilot test equipment at the Bellingham Bay G-P Log Pond site). The results of this SITE Demonstration are presented in Section 4.0 of this report. Weiss Associates had the opportunity to discuss the applicability, other studies, and performance of the technology in Appendix A.

### 2.1 Key Features of the Electrochemical Remediation Treatment Process

There are three key features comprising the ECRTs process. These include the following:

- ◆ Electrodes
- ◆ DC/AC Converters
- ◆ Auxiliary Equipment

Each of these components is discussed in the following paragraphs.

#### Electrodes

The electrodes are typically installed as two parallel lines of electrodes that are installed outside of the contaminated area to be treated. The electrodes can consist of either horizontal plates or pipes, or vertical pile sheets or pipes. (the raw materials are shipped to the site, and then modified). The electrode array installed at the G-P Log Pond site consisted of steel and graphite sheets that were

electrically continuous. Each electrode row was approximately 30 feet long and about 30 feet apart from one another. Figures 2-1a and 2-1b illustrate the design specifications for the anode (graphite) sheets and cathode (steel) sheets, respectively. Weiss Associates estimated weights for the steel and graphite electrodes used for the Demonstration as 240 lbs each and 120 lbs each, respectively.

The most important aspect of the ECRTs technology is the design of the electrode array network (i.e., the number, depth, and row length of electrodes) required for optimum treatment. The depth of installation is dictated by the thickness of the contaminant zone. For the Demonstration performed at the G-P log pond, metal and graphite vertical pile sheets were used as electrodes. The electrode array installed for the Demonstration consisted of two 30 foot long parallel rows of electrodes placed about 30 feet apart. The depth of treatment extended from the top of a clean cap (0.5 - 1 ft thick) to the bottom of a 5-6 ft thick contaminated zone. The maximum sediment volume treated was therefore approximately 30 ft x 30 ft x 5 ft = 4,500 ft<sup>3</sup> (167 yd<sup>3</sup>). Using a standard conversion of 1.3 tons/yd<sup>3</sup> of sediment, roughly 220 tons of contaminated sediment was targeted for treatment during the Demonstration.

#### DC/AC Converters

P2 Soil Remediation owns the proprietary DC/AC converters used to power the ECRTs system, and leases the use of the converters. At least one of these DC/AC converters, which are 480 Volt and 3 phase, are required to power the ECRTs system. For the Demonstration at the G-P Log Pond, a total of three DC/AC converters were used. Each of the three power supplies powered three anode sheets and three cathode sheets.

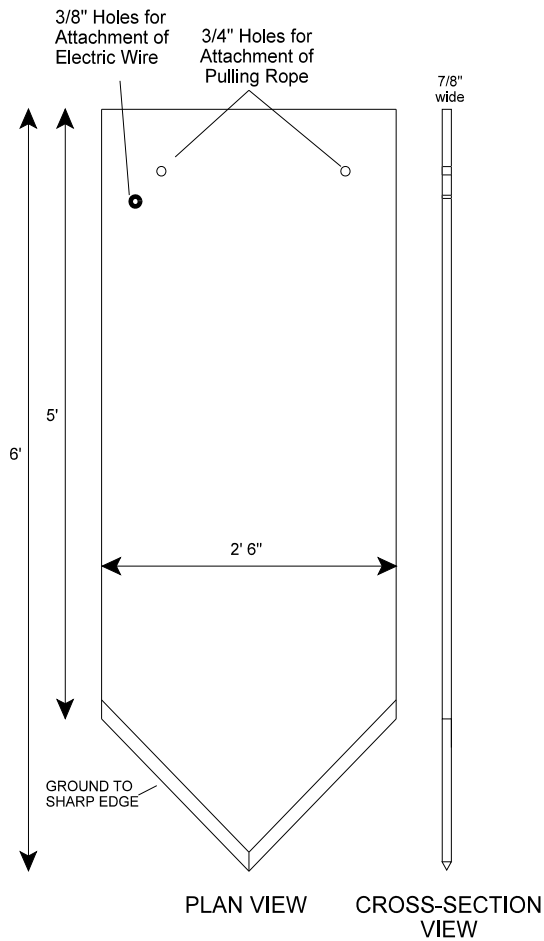


Figure 2-1a. Schematic of CS Grade Graphite Electrode.

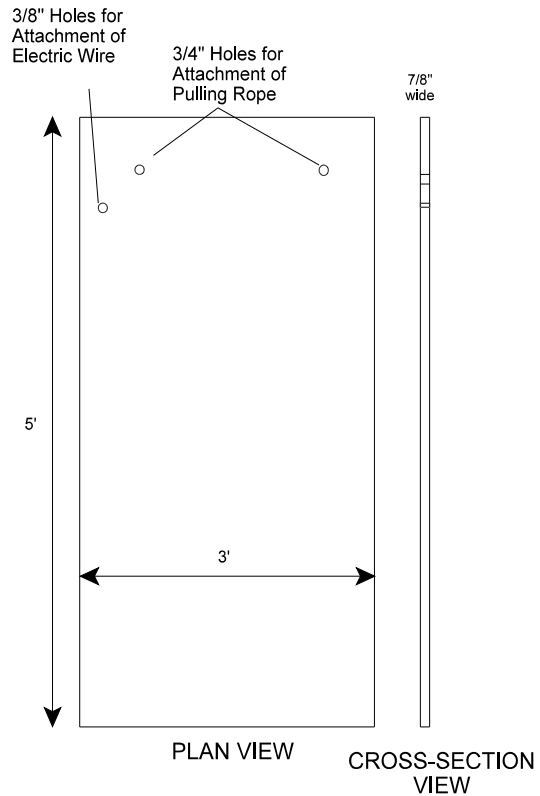


Figure 2-1b. Schematic of Mild Carbon Steel Plate Electrode.

### Auxiliary Equipment

Auxiliary equipment for marine application of the ECRTs technology may consist of a variety of electrical-related equipment and supplies. For the Demonstration at the G-P Log Pond, the following auxiliary equipment included the following:

- ▶ Marine gauge (10-12 awg) stranded wires that were double insulated as underwater pump cable

- ▶ A resistor of about  $3.5 \Omega$  was required to drive the minimum voltage.
- ▶ Epoxy sealant
- ▶ Electrical meter
- ▶ Shut-off-switch

It should be noted that the standard field array in soil consists of standardized  $16 \text{ mm}^2$  copper cables.

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## 2.2 Operability of the Technology

The ECRTs technology can be applied to soil and sediments both *in situ* and *ex situ*. *Ex situ* application would include treatment in a soil heap, which was reported done at a site in Enns, Austria (HazTECH News, 2001).

In many cases both organic and inorganic compounds are targeted by the ECRTs technology. When two different types of contaminants are encountered (i.e., metals and organics), the ECRTs system must be operated in two different voltage and amperage domains. One domain induces IC for mobilizing metals and a second domain induces ECGO for mineralizing organic contaminants to inorganic components.

For sediment application of the ECRTs, there are two surveys that should be conducted before installing and operating the ECRTs system. The first is a debris survey for determining the suitability of the site for installing the ECRTs system components. During the Demonstration, this survey involved advancing a pointed pole into the sediment until refusal to determine whether any large objects (e.g., sunken logs, pilings, etc.) were submerged in the sediment. This type of survey requires the services of a pontoon boat.

The second survey typically required is a cathodic protection survey, since there are typically structures in the vicinity of contaminated sediments. For the Demonstration, the Port of Bellingham required cathodic protection for structures in the vicinity of the demonstration site to ensure that those structures would not be susceptible to corrosion during operation of the ECRTs. Weiss Associates provided oversight of a contractor (Norton Corrosion Inc.), who conducted the survey.

Initially P2 Soil Remediation is involved in system startup by activating the DC/AC converters and adjusting and optimizing the operating parameters.

There are specific operations and maintenance O&M activities associated with the ECRTs system. These include:

1. Assuring DC/AC Converter Working Status - This is performed by looking at the meter indicating the availability of three phase power, reading the amp meter to determine availability of the required amperage, and the voltmeter as to the availability of the required voltage.
2. Making Oscilloscope Readings - performed weekly for two channels: voltage and amperage.

3. Conducting Trouble Shooting - performed when the Ground Fault Interrupter Switch (GFIS) has tripped and it requires resetting, and when other fuses have tripped requiring replacement
4. Restarting the DC/AC converter.

Generally speaking, no regulated waste streams are produced.

## 2.3 Applicable Wastes

The technologies (ECGO and IC) have been reported by the developer as effective in unsaturated and saturated zones in sediments for metals and organics, including free-phase organics, except that separate groundwater treatment is generally necessary for dissolved organics.

ECRTs' are reported as suitable for all soil types, especially clay or silt. Specific contaminant types mentioned in case study examples for ECGO have included TPH, BTEX, PCE, TCE, VC, PAHs, phenols, and PCBs. For IC, the metals arsenic, chromium, copper, lead, nickel, and zinc have been specified. The developer has also inferred ECRTs to be effective on radionuclides.

## 2.4 Availability and Transportability of Equipment

The ECRTs process can theoretically be implemented anywhere that an electrode array can be installed, which would include any location that can be accessed by equipment needed to install the electrode sheets (e.g., a crane).

Because the ECRTs uses proprietary DC/AC converters, they are available for lease from P2 Soil Remediation only. The availability of the DC/AC converters could therefore be an issue if the numbers are limited and units are being used elsewhere. In the specific case of the Demonstration, three DC/AC converters were used, one of which was shipped from Europe.

In knowing that the electrode sheets used for the Demonstration would have to penetrate a stiff sediment cap, graphite material suitable for driving with a vibrohammer was required for the Demonstration. Weiss Associates conducted research into the material specifications most suitable for constructing the graphite electrode sheets. Due to a discrepancy between the type of graphite available in Europe versus the type of graphite available domestically a graphite plate test was conducted on Union Carbide CS-grade graphite produced in West Virginia. The test involved using a vibrohammer to



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determine the driving capability of the domestically-produced graphite prior to procuring and installing graphite sheets at the demonstration site. Thus, for marine applications, the suitability of the electrode sheets (especially graphite) may require investigation.

## 2.5 Materials Handling Requirements

During the Demonstration, the electrode plates were placed in position by a mobile heavy lift crane with extended beam and a vibrohammer that was operated from the adjacent pier. The pier was evaluated for bearing load capacity to determine if the crane could be supported. Therefore, contaminated areas that are offshore may have to employ a barge to mobilize a crane.

Each electrode row (e.g., anode sheet electrode line) was approximately 30 feet long. The distance between the anode and cathode sheet electrode lines was approximately 30 feet. The total time of system installation was three days. Buoys were attached to each electrode for locating them from the surface once installed. An underwater camera was used to confirm proper placement into the sediment at the time of installation.

A forklift was also used during the Demonstration to move components from the shipping truck to the pier and crane.

## 2.6 Site Support Requirements

Site facilities are required to store and secure various components of the ECRTs system prior to and during treatment. Site facilities at the Demonstration site consisted of a shed and rented fencing to secure the area around the shed. The Port of Bellingham's Shipping Terminal Dock, having a load bearing capacity for supporting a crane with an extended beam, was an advantage for installing the electrode plates during the Demonstration. Thus, such a pier may be a site support requirement in certain marine applications.

Prospective sites must also be suitable for arranging for fixed or portable electrical power. Electricity is essential, as it is used to power the ECRTs treatment process. The developer has reported that typical current consumed when using their Direct Current technology to treat soil by ECGO ranges from 0.2 kWh to 3 kWh per ton of soil. Power consumption for metals remediation by IC is slightly higher (Doering, et. al.,).

It should also be noted that electrical power is also required for operating rental equipment and supplying power to an on-site trailer. At remote sites, a generator could be used

to power the ECRTs system. Generator size would depend on the size of the project, however 5 to 10 kW is the minimum size requirement.

A water source may be necessary for certain ECRTs applications. For one particular application of the ECRTs technology at a heaped soil pile an irrigation system was installed to humidify the soil (HazTech News, September 13 & 27, 2001). A water source may also be needed for occasional decontamination activities.

## 2.7 Limitations of the Technology

The soil particle surface area and the soil to water ratio are key parameters in determining the technologies' effectiveness. Therefore, the soil or sediment grain size is a potential limitation of the technology. Reaction rates are reported to be inversely proportional to grain size, such that ECRTs systems remediate faster in clays and silts than in sands and gravels (Doering, et. al., 2000).

Depth and placement is limited only by the installation technology.

According to the developer, the precipitation of metals onto the electrodes is non-selective. If different metals compete for precipitation, then the rate of precipitation of prospective metals is governed by the relationship between their different equivalent weights. The more metals competing for precipitation results in greater decrease in precipitation rate (*F. Doering writeup, p. 33, no date*). Therefore, sites containing many metals may be more difficult or take longer to remediate.

Use of the technology in marine environments can present additional challenges. During the Demonstration several system perturbations occurred which eventually lead to stopping the project. One of the most substantial problems was corrosion of the electrode leads. Although the electrical wire leads were within a double insulation, the insulation material was cracked due to movement of the sea near the shoreline. Electrical readings collected by the technology's sponsor indicated a steady degradation of system performance throughout the duration of the Demonstration, resulting in an early shutdown of the system prior to completion of the planned test period. In addition, when the electrodes were removed from the test plot, it was evident that the connections between the electrical supply and anode electrode plates had completely corroded to the point that a viable contact had not been maintained.

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## 2.8 ARARS for the Electrochemical Remediation Treatment Process

This subsection discusses specific federal environmental regulations pertinent to the operation of the ECRTs process, including the transport, treatment, storage, and disposal of wastes and treatment residuals. These regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); (2) the Resource Conservation and Recovery Act (RCRA); (3) the Clean Air Act (CAA); (4) the Clean Water Act (CWA); (5) the Safe Drinking Water Act (SDWA), and (6) the Occupational Safety and Health Administration (OSHA) regulations. These six general ARARs, and state requirements for the G-P Log Pond site, are discussed in the following subsections. Specific ARARs that may be applicable to the ECRTs process are identified in Table 2-1.

### 2.8.1 CERCLA

The CERCLA of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment; as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment.

As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 CFR Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination. SARA states a strong statutory preference for remedies that are highly reliable and provide long-term protection. It directs EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or the mobility of hazardous substances, pollutants, or contaminants;
- select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the

maximum extent possible; and

- avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121(b)].

In general, two types of responses are possible under CERCLA: removal and remedial actions. Superfund removal actions are conducted in response to an immediate threat caused by a release of a hazardous substance. Many removals involve small quantities of waste of immediate threat requiring quick action to alleviate the hazard. Remedial actions are governed by the SARA amendments to CERCLA. As previously stated, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances or pollutants.

The ECRTs process could possibly be part of a CERCLA remedial action since the volume and mobility of the contaminants of concern are intended to be reduced. Remedial actions are governed by the SARA amendments to CERCLA.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund remedial project manager (RPM) for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

### 2.8.2 RCRA

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities. It was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities.

**Table 2-1. Federal and State ARARs for the ECRTs Process.**

<b>Process Activity</b>	<b>ARAR</b>	<b>Regulation Description</b>	<b>General Applicability</b>	<b>Specific Applicability to ECRTs Process</b>
<b>Waste Characterization</b>	RCRA: 40 CFR Part 261 (or the state equivalent)	Standards apply to the identification and characterization of wastes.	Chemical and physical properties of waste determine its suitability for treatment by attenuated anaerobic dechlorination (i.e., the types of organic and metals contaminants present and the grain size of the soil/sediment determine suitability).	Chemical and physical analyses must be performed to determine if waste/contaminants are suitable for the ECRTs.
<b>Waste Processing</b>	RCRA: 40 CFR Part 264 (or the state equivalent)	Standards apply to treatment of wastes in a treatment facility.	Standards apply to treatment of wastes at a treatment facility (i.e., there are requirements for operations, record keeping, and contingency planning)	Not likely applicable to the ECRTs, since the process not normally conducted at treatment facilities.
	CAA: 40 CFR Part 50 (or the state equivalent)	Regulations govern toxic pollutants, visible emissions and particulates.	Any off-gas venting (i.e., from buildup of VOCs, etc.) must not exceed limits set for the air district of site. (Not likely to occur since the) target contaminants are either semi-volatile or non volatile).	Only applies to staged treatment. When treating SVOCs and metals, particulate emissions may contain regulated substances. In such a case, standards for monitoring and record keeping apply.
<b>Storage of auxiliary wastes</b>	RCRA: 40 CFR Part 264 Subpart J (or the state equivalent)	Regulation governs the standards for tanks at treatment facilities.	Storage tanks for liquid wastes (e.g., decontamination waste) must be placarded appropriately, have secondary containment and be inspected daily.	If storing non-RCRA wastes, RCRA requirements may still be relevant and appropriate.
	RCRA: 40 CFR Part 264 Subpart I (or the state equivalent)	Regulation covers the storage of waste materials generated.	Potential hazardous wastes remaining after treatment (i.e., contaminated electrodes) must be labeled as hazardous waste and stored in containers in good condition. Containers should be stored in a designated storage area and storage should not exceed 90 days unless a storage permit is obtained.	Applicable for RCRA wastes; relevant and appropriate for non-RCRA wastes.
<b>Determination of cleanup standards</b>	Local	Standards apply for treatment of sediments.	Remedial actions for sediments are required to meet local requirements (e.g., the State of Washington sediment quality standard for mercury is 0.41 mg/Kg).	In the case of the G-P Log Pond the primary cleanup objective was based on the Washington State Sediment Management Standards.
<b>Waste disposal</b>	RCRA: 40 CFR Part 262	Standards that pertain to generators of hazardous waste.	Potential hazardous waste generated by attenuated anaerobic dechlorination is limited to drill cuttings, well purge water, PPE, and decontamination wastes.	Generators must dispose of wastes at facilities permitted to handle the waste. Generators must obtain an EPA ID number prior to disposal.
	CWA: 40 CFR Parts 403 and/or 122 and 125	Standards for discharge of wastewater to a POTW or to a navigable waterway.	Applicable and appropriate for any decontamination wastewater generated from process. Discharge of wastewater to a POTW must meet pre-treatment standards; discharges to a navigable waterway must be permitted under NPDES.	No specific applicability to the ECRTs unless groundwater treatment specified as part of cleanup criteria. Standards may apply to wastewater generated from decontaminating sediment cores and electrode sheets that are removed at the end of treatment.
	RCRA: 40 CFR Part 268	Standards regarding land disposal of hazardous wastes	Applicable for off-site disposal of auxiliary waste (e.g., excess sediment sample).	Hazardous wastes must meet specific treatment standards prior to land disposal, or be treated using specific technologies.

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The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA. RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the attenuated anaerobic dechlorination process if RCRA defined hazardous wastes are present. Hazardous wastes that may be present include contaminated soil cuttings and purge water generated during well installation and development, and the residual wastes generated from any groundwater sampling activities (e.g., PPE and purge water). If wastes are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), essentially all RCRA requirements regarding the management and disposal of this hazardous waste will need to be addressed by the remedial managers.

Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. RCRA regulations do not apply to sites where RCRA-defined wastes are not present.

Unless they are specifically delisted through delisting procedures, hazardous wastes listed in 40 CFR Part 261 Subpart D currently remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that even after remediation, treated wastes are still classified as hazardous wastes because the pre-treatment material was a listed waste.

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported off-site), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F and Subpart S. These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which

particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

### **2.8.3 CAA**

The CAA establishes national primary and secondary air quality standards for sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. It also limits the emission of 189 listed hazardous pollutants such as vinyl chloride, arsenic, asbestos and benzene. States are responsible for enforcing the CAA. To assist in this, Air Quality Control Regions (AQCR) were established. Allowable emission limits are determined by the AQCR, or its sub-unit, the Air Quality Management District (AQMD). These emission limits are based on whether or not the region is currently within attainment for National Ambient Air Quality Standards (NAAQS).

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. The most likely air emissions that would be anticipated with Harding ESE's technology would be VOC emissions generated during drilling activities. These potential emissions would typically be very low concentrations and are easily monitored.

### **2.8.4 CWA**

The objective of the CWA is to restore and maintain the chemical, physical and biological integrity of the nation's waters by establishing federal, state, and local discharge standards. If treated water is discharged to surface water bodies or Publicly Owned Treatment Works (POTW), CWA regulations will apply. A facility desiring to discharge water to a navigable waterway must apply for a permit under the National Pollutant Discharge Elimination System (NPDES). When a NPDES permit is issued, it includes waste discharge requirements. Discharges to POTWs also must comply with general pretreatment regulations outlined in 40 CFR Part 403, as well as other applicable state and local requirements.

Since Harding ESE's attenuated anaerobic dechlorination process is *in situ* and purge water generated during the demonstration was discharged back to the aquifer material (in accordance with MaDEP site procedures), CWA criteria did not apply for this demonstration.

### **2.8.5 SDWA**

The SDWA of 1974, as most recently amended by the Safe

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Drinking Water Amendments of 1986, requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

### **2.8.6 OSHA**

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

If working at a hazardous waste site, all personnel involved with the installation and implementation of a treatment process are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. Workers on hazardous waste sites must also be enrolled in a medical monitoring program. The elements of any acceptable program must include: (1) a health history, (2) an initial exam before hazardous waste work starts to establish fitness for duty and as a medical baseline, (3) periodic examinations (usually annual) to determine whether changes due to exposure may have occurred and to ensure continued fitness for the job, (4) appropriate medical examinations after a suspected or known overexposure, and (5) an examination at termination.

For most sites, minimum personal protective equipment (PPE) for workers will include gloves, hard hats, steel-toe boots, and Tyvek® coveralls. Depending on contaminant types and concentrations, additional PPE may be required, including the use of air purifying respirators or supplied air. For an *in situ* dechlorination process, noise levels would potentially be high only during drilling activities involving the operation of a drill rig or Geoprobe®. During these activities, noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, workers will be required to wear hearing protection. The levels of noise

anticipated are not expected to adversely affect the community, but this will depend on proximity to the treatment site.

### **2.8.7 State and Local Requirements**

State and local regulatory agencies may require permits prior to implementing an *in situ* technology and/or for specifically treating sediments. Most federal permits will be issued by the authorized state agency. Since the ECRTs technology was implemented on marine sediments *in situ*, appropriate permits were required. For example, a Joint Aquatic Resource Permits Application (JARPA) was required by the U.S. Army Corps of Engineers (COE) for conducting construction work in or near the water. JARPA can be used to apply for Hydraulic Project Approvals (HPAs), Shoreline Management Permits, Water Quality Certifications, and COE Section 404 and Section 10 permits. For the Demonstration project, the JARPA application was completed prior to the SITE Program's involvement. SITE Program personnel were additionally required to obtain a scientific collection permit for conducting fish community samples.

It should be noted that permitting fees are commonly waived for government-conducted research type projects, such as SITE demonstrations. However, For construction projects (including remediation) the JARPA is mandatory.

If remediation is conducted at a Superfund site, federal agencies, primarily the USEPA, will provide regulatory oversight. If off-site disposal of contaminated waste is required, the waste must be taken to the disposal facility by a licensed transporter. With respect to the Demonstration, both steel and graphite sheets were wrapped in plastic drum liners, placed in shipping crates, and sent to a disposal/recycling facility in Wisconsin.

For the Demonstration, the primary cleanup objective was based on the Washington State Sediment Management Standards (SMS). Based on results from a preliminary survey, mercury was identified as the most ubiquitous and consistently elevated contaminant relative to Washington State SMS, Sediment Quality Standards (SQS) and Cleanup Screening Levels (CSL) which are used in Puget Sound to determine impacted sediments that require remediation under State law. For mercury, the SQS and CSL are 0.41 mg/Kg and 0.59 mg/Kg, respectively.

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## Section 3.0 Economic Analysis

### 3.1 Introduction

The purpose of this economic analysis is to estimate costs for commercial treatment of marine sediments contaminated with mercury and SVOCs utilizing an *in situ* Electrochemical Remediation Treatment (ECRTs) process, developed by P2-Soil Remediation, Inc. Weiss Associates of Emeryville, CA installed, operated, and maintained the ECRTs pilot test equipment at the Georgia Pacific, Inc. (G-P) Log Pond located along the Whatcom Waterway in Bellingham Bay, Bellingham, Washington. The G-P Log Pond is a marine embayment that served as a former log storage and handling areas well as a receiving water basin for facility effluent and stormwater runoff.

The Demonstration at the G-P Log Pond was conducted between October 2002 and January 2003. The treatment area of the G-P Log Pond was known to contain elevated concentrations of mercury, phenolics, and PAHs. Of these contaminants, mercury was determined as the most adversely contaminant affecting the sediments per State of Washington sediment management standards. Treatment of mercury was by Induced Complexation (IC), which according to the developer, enhances mobilization of metals in soils and sediments. Treatment of organic compounds in sediments was by ElectroChemicalGeoOxidation (ECGO), which according to the developer, mineralizes organic contaminants to their inorganic components.

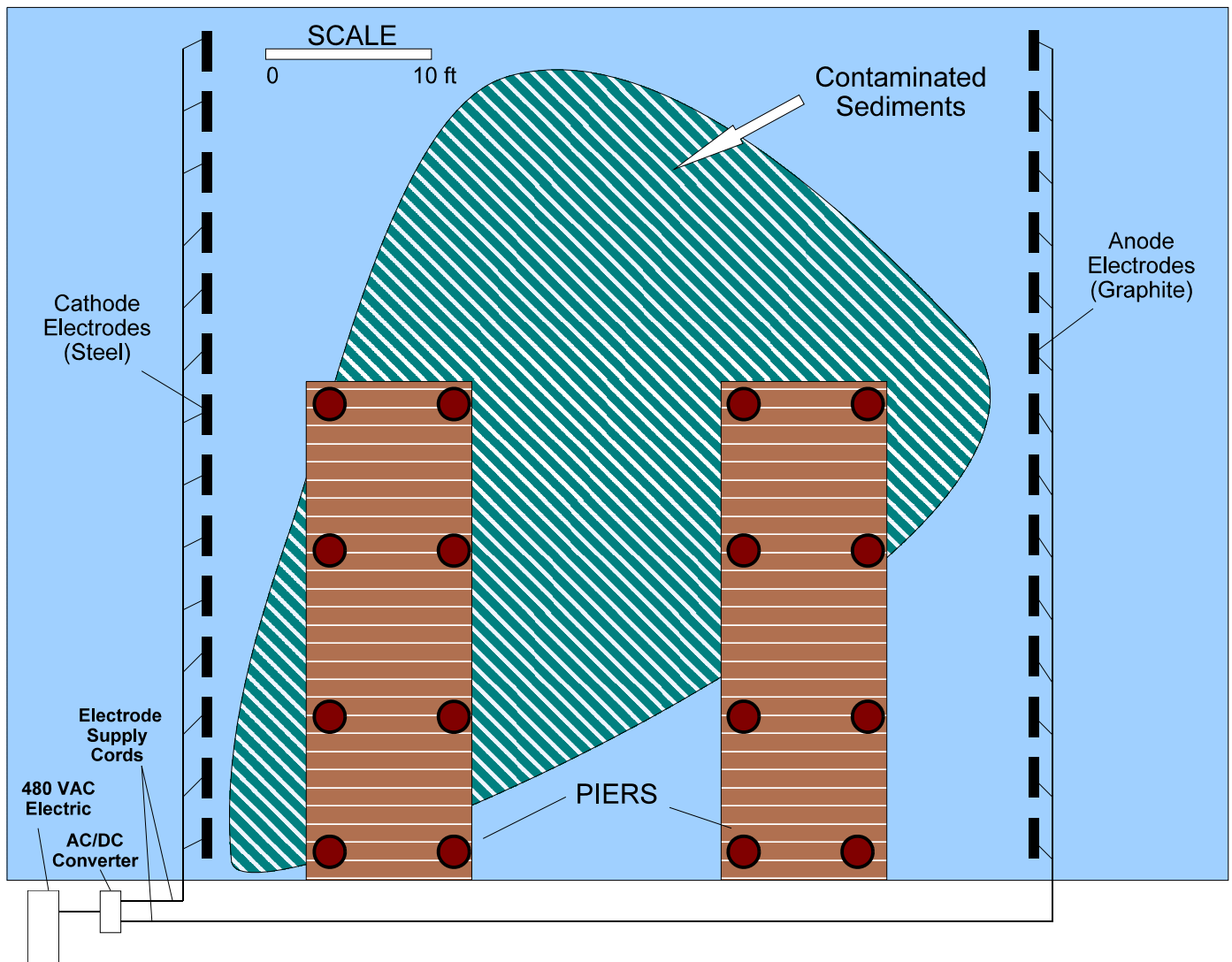
The electrode array installed for the Demonstration consisted of two 30 ft long parallel rows of electrodes placed about 30 feet apart. The depth of treatment extended from the top of a clean cap (0.5 - 1 ft thick) to the bottom of a 5-6 ft thick contaminated zone. The maximum sediment volume treated was therefore approximately 30 ft x 30 ft x 5 ft = 4,500 ft<sup>3</sup> (167 yd<sup>3</sup>). Using a standard conversion of 1.3 tons/yd<sup>3</sup> of sediment, roughly 220 tons of contaminated sediment was targeted for treatment during

the Demonstration. This volume and mass is considered a pilot-scale sized application of the ECRTs technology.

For this economic analysis, a hypothetical site having characteristics similar to the G-P log pond site was used to estimate full-scale costs (Figure 3-1). As shown in this figure, there is a fairly large zone of contaminated sediments that are partially obstructed by two piers comprising a boat slip. These structures would inhibit dredging of sediment, even if permitted. Therefore an *in situ* remedy, such as the ECRTs process, maybe appropriate for such a scenario. The two electrode lines (anode and cathode) could be installed outside of the piers to treat an approximate 50 ft x 50 ft area. Based on an electrode spacing similar to that used for the Demonstration, the electrode array at the hypothetical site is shown to consist of 14 anode sheets and 14 cathode sheets. Assuming the sediment contamination extends to five feet below the sediment surface, approximately 12,500 ft<sup>3</sup> (~ 460 yd<sup>3</sup>) of sediment would need to be treated. This correlates to about 600 tons of sediment affected by the ECRTs process, nearly three times that amount targeted during the Demonstration.

Costs associated with implementing the ECRTs technology at this hypothetical site have been broken down into 12 cost categories that reflect typical cleanup activities at Superfund sites. They include:

- (1) Site Preparation
- (2) Permitting and Regulatory Activities
- (3) Capital Equipment
- (4) Start-up and Fixed
- (5) Labor
- (6) Consumables and Supplies
- (7) Utilities
- (8) Effluent Treatment and Disposal
- (9) Residuals Shipping, & Disposal
- (10) Analytical Services
- (11) Maintenance and Modifications
- (12) Demobilization/Site Restoration



**Figure 3-1.** Hypothetical Site Diagram.

Table 3-1 presents a categorical breakdown of the estimated costs for implementing the ECRTs technology at this hypothetical site over the duration of six months. As with all cost estimates, there are associated factors, issues, and assumptions that caveat specific cost values. The major factors that can affect estimated costs are discussed in subsection 3.3. The issues and assumptions made regarding site characteristics are incorporated into the cost estimate. They are discussed in subsection 3.4.

The basis for costing each of the individual 12 categories in Table 3-1 is discussed in detail in subsection 3.5. Much of the information presented in that subsection has been

derived from observations made and experiences gained from the SITE demonstration. Other cost information has been acquired through records obtained from the State of Washington Department of Ecology and Department of Natural Resources (both of which contracted Weiss Associates), information gathered from the Weiss Associates web site ([www.weiss.com](http://www.weiss.com)), and subsequent discussions with Weiss Associates.

It should be emphasized that the cost figures provided for economic analyses are typically “order-of-magnitude” estimates, generally + 50% / -30%.

**Table 3-1. Cost Estimates for Full-Scale Application of the ECRTs Technology.<sup>1</sup>**

<u>Cost Category</u>	<u>Quantity</u>	<u>Units</u>	<u>Unit Cost</u>	<u>Extended Cost</u>	<u>\$/Category<sup>2</sup></u>	<u>% of Total</u>
<b>1. Site Preparation</b>					<b>\$39,760</b>	10.8
Baseline Survey (debris)	1	Each	\$4,360	\$4,360		
Cathodic Protection Survey	1	Each	\$5,200	\$5,200		
Site Facilities (Shed and Fencing)	1	Each	\$1,200	\$1,200		
Shipment of System Components <sup>3</sup>	1	NA	\$2,100	\$2,100		
Utility hookup	1	Each	\$26,900	\$26,900		
<b>2. Permitting &amp; Regulatory Activities</b>					<b>\$0</b>	
Permits	0	Each	\$0	\$0		
Studies and Reports	0	Each	\$0	\$0		
<b>3. Capital Equipment</b>					<b>\$10,1112</b>	2.7
Graphite Plates	14	Each	\$552	\$7,728		
Steel Plates	14	Each	\$106	\$1,484		
Digital Storage Oscilloscope	1	Each	\$900	\$900		
<b>4. Startup &amp; Fixed</b>					<b>\$87,620</b>	23.8
Treatability Study	1	Fixed	\$50,000	\$50,000		
Graphite Plate Testing	1	Fixed	\$4,080	\$4,080		
System Installation	1	Fixed	\$17,300	\$17,300		
Leasing of Proprietary Converters	1	Fixed	\$4,500	\$4,500		
System Operation Services	1	Fixed	\$11,700	\$11,740		
P2 Soil Remediation Technology Fee	5% of total project cost (see totals below)					
<b>5. Labor</b>					<b>\$129,400</b>	35.1
Weiss Associates <sup>4</sup>	950	Hours	\$100	\$95,000		
Sediment Sampling (4 events)	160	Hours	\$60	\$9,600		
Electrode Sampling (1 event)	20	Hours	\$60	\$1,200		
Boat Operator/Coring Tubes	4	Event	\$5900	\$23,600		
<b>6. Consumables and Supplies</b>					<b>\$3,150</b>	0.9
Electrode components <sup>5</sup>			\$3,150	\$3,150		
<b>7. Utilities (Electricity)<sup>6</sup></b>	31,700	kW-hr	\$0.10	\$3,170	<b>\$3,170</b>	0.9
<b>8. Effluent Treatment &amp; Disposal</b>	NA	NA	NA		<b>\$0</b>	
<b>9. Residuals &amp; Disposal</b>					<b>\$10,100</b>	2.9
Spent Electrodes <sup>7</sup>	NA	NA	\$10,100	\$10,100		
Contaminated Solids	NA	Drums	\$0	\$0		
<b>10. Analytical Services</b>					<b>\$17,070</b>	4.6
Mercury in Sediment (SW846 7471A)	48	Each	\$35	\$1,680		
Mercury in Electrodes (SW846 7471A)	28	Each	\$35	\$980		
SVOCs in Sediment	48	Each	\$260	\$12,480		
Total Solids	40	Each	\$7.00	\$280		
Metals in Sediment	10	Each	\$85	\$850		
Sample Shipments	8	Each	\$100	\$800		
<b>11. Maintenance &amp; Modifications<sup>8</sup></b>	4	Event	\$12,880	\$51,500	<b>\$51,520</b>	14
<b>12. Demobilization/Site Restoration</b>					<b>\$16,600</b>	4.5
Removal of Electrodes <sup>9</sup>	1	Fixed	\$15,000	\$15,000		
Shipment of Proprietary Converters	1	Fixed	\$1,600	\$1,600		
<b>Total Estimated Project Cost</b>					<b>\$368,182</b>	100
P2 Soil Remediation Technology Fee (5% of total project cost)					\$18,500	
<b>Total Estimated Cost</b>					<b>\$388,500</b>	

<sup>1</sup> Based on treatment of an approximate 12,500 ft<sup>3</sup> of sediment (~ 460 yd<sup>3</sup>).<sup>2</sup> Cost value totals in column are rounded to three significant digits.<sup>3</sup> Includes shipment of proprietary converters from Europe.<sup>4</sup> Weiss Associates labor costs listed in Table 3-2.<sup>5</sup> Includes items listed in Table 3-3.<sup>6</sup> Electrical cost based on rate of \$0.10/kW-hr.<sup>7</sup> Based on disposal cost estimates presented in Table 3-4.<sup>8</sup> Costs consist mainly of specialized services required for sampling marine sediments and are detailed in Table 3-6.<sup>9</sup> Costs consist mainly of subcontractor fees for a crane and divers to remove electrodes from sediments



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## 3.2 Conclusions

- (1) The estimated cost to implement an approximate 50 ft<sup>2</sup> ECRTs treatment system, extending to a five foot depth to treat mercury-contaminated sediments over a six month period is approximately \$388,500, including a 5% technology fee assessed by P2 Soil Remediation.
- (2) The largest cost components for the six-month application of the ECRTs technology at a site having characteristics similar to the G-P Log Pond site are 1) Labor (35.1 %) and 2) Startup & Fixed (23.8 %), together accounting for approximately 59% of the total cost. The other major costs, as estimated, include Maintenance & Modifications (14 %), Site Preparation (10.8%).
- (3) The cost of implementing the ECRTs technology may be less or more expensive than the estimate provided in this economic analysis depending on several factors. Such factors may include the depth and areal extent of the contaminated sediment, the contaminant concentration levels, the length of treatment the level of site preparation required, the number and size of electrodes needed to be installed, and the level of process monitoring required by a regulatory agency.

## 3.3 Factors Affecting Estimated Cost

There are a number of factors that could affect the cost of treatment of mercury-contaminated sediments using the Weiss ECRTs technology. The contaminant distribution pattern will also affect the design of the electrode array required to attain a sufficient area of ECRTs technology coverage to treat the contaminants to acceptable levels. It is apparent that the number of cathodes (steel plates) and anodes (graphite plates) required for the electrode array, and the number of samples required for characterizing sediments have very significant impacts on treatment costs.

## 3.4 Issues and Assumptions

This section summarizes the major issues and assumptions used to estimate the cost of implementing the ECRTs technology at full-scale. In general, the assumptions are based primarily on billing records and other information provided by the Washington Department of Ecology and Department of Natural Resources, and observations made during the Demonstration.

### 3.4.1 Site Characteristics

Site characteristics are an important consideration for deciding whether the ECRTs technology is an appropriate remedy for treating contaminated sediments at a particular

site. First and foremost, application of the technology relies on passing a low voltage electrical current through a zone of contaminated soil or sediment. For this reason, the contaminated area at the site must be well defined. In addition, the area to be treated must be surveyed for debris or other obstacles that could hinder installation of the electrodes (the electrodes are driven into the sediment).

The first general assumption for the economic analysis is that the prospective site has already been characterized as to the extent of contamination. Thus, site characterization costs are not included. The site characteristics used for the prospective site are assumed similar to the demonstration site with respect to contaminant type and geology. The water depth, however, is set at ten feet for the entire area treated.

The following specific assumptions have been made regarding the site characteristics of the hypothetical site.

1. The site is located close to shore in a sheltered bay; and thus easily accessible by a small boat.
2. Contaminated sediment occurs at about 10 feet below mean sea level (msl) and extends from the water/sediment interface to five feet below. This well defined area enables the proper placement of the ECRTs electrode array.
3. Contamination at the site consists primarily of mercury, ranging in concentration from 1.0 to 500 mg/kg dry weight (similar to concentrations detected at the demonstration site). The mercury contaminated sediment is situated primarily in the 0 to 5 foot zone below the sediment surface.
4. Debris is minimal, as confirmed by a preliminary survey. As a result, installation of the electrode array will not be adversely affected.
5. Sediment is composed primarily of silt, therefore the fine grain size is conducive to fairly rapid treatment by the ECRTs process.
6. Unlike the Demonstration, research-oriented data collection (e.g., benthic and fish community samples to monitor for negative environmental affects) is not required and thus not costed.

### 3.4.2 Design and Performance Factors

Basic ECRTs components include the following:

- ▶ Power Supply: DC/AC converters: 480 Volt, 3 phase; (Two were used for the Demonstration)
- ▶ Power Lines: Standardized 16 mm<sup>2</sup> copper cables, if required; and,

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- ▶ Electrodes: either horizontal plates or pipes, or vertical pile sheets or pipes (the raw materials are shipped to the site, and then modified).

The most important aspect of the ECRTs technology is the design of the electrode array network (i.e., the number, depth, and row length of electrodes) required for optimum treatment. The depth of installation is dictated by the thickness of the contaminant zone. For the Demonstration performed at the G-P log pond, metal and graphite vertical pile sheets were used as electrodes.

The following assumptions are made regarding the electrode array installed at the hypothetical site.

1. Due to the larger area treated, the electrode array will consist of 14 anodes (graphite sheets) and 14 cathodes (steel sheets), as opposed to the nine anodes and nine cathodes installed at the G-P Log Pond. However, both anode and cathode sheets will be the same dimensions as those used during the Demonstration (the anode graphite plates were measured to be 72 inches long, 31 inches wide and  $\frac{3}{4}$  to 1 inches thick; the cathode steel plates were measured to be 60 inches long, 36 inches wide and  $\frac{3}{8}$  inches thick).
2. The steel and graphite sheets are installed to the bottom of the contaminated sediment layer, 20 feet below msl and five feet into the sediment. As was the case during the Demonstration, a vibrating head hung from a crane is used for installation.
3. All sheets will be spaced about 1½ ft apart. The distance between anode and cathode rows will be approximately 45 ft.
4. The treatment duration is assumed to be six months, which is similar to the originally planned treatment duration for the Demonstration of approximately 6½ months.

### 3.4.3 Financial Assumptions

All costs are presented in Year 2002 U.S. dollars (unless otherwise noted) without accounting for interest rates, inflation, or the time value of money. Insurance and taxes are assumed to be fixed costs lumped into the specific costs under the "Startup and Fixed" category.

## 3.5 Basis for Economic Analysis

In this section, each of the 12 cost categories that reflect typical clean-up activities encountered at Superfund sites, are defined and discussed. Combined, these 12 cost categories form the basis for the detailed estimated costs presented in Table 3-1. The labor costs are grouped into a single labor category (subsection 3.5.5).

### 3.5.1 Site Preparation

Site preparation includes activities necessary for preparing the site for installing the ECRTs treatment system components. Included in this setup phase is the non-labor costs for conducting preliminary surveys and testing for determining the suitability of electrode installation, setting up a temporary trailer, shipping the system components from the vendor storage facility to the site, and conducting electrical setup and connections. Each of these site setup cost components is discussed in the following paragraphs.

#### 3.5.1.1 Baseline Surveying of Debris

A survey was conducted by a consultant, prior to the site program demonstration project, to determine the extent of large woody debris (i.e., sunken logs, pilings, etc). This survey involved advancing a pointed pole into the sediment until refusal to determine whether any large objects were submerged in the sediment. This preliminary survey should be conducted to determine suitability of the site for installing the ECRTs system components.

Weiss Associates utilized a local contractor, Anchor Environmental, to conduct the wood log debris survey. The actual cost of this survey was reported to be approximately \$4,360 (Weiss Associates, July 2001). This total cost included labor and materials, including the cost of renting a pontoon boat.

Prior to the demonstration, it was necessary for SITE Program personnel to mark (spray paint) the locations of sampling transects on the adjacent bulkhead, pier, and pilings. The level of effort was negligible, and not included as part of this cost estimate, but necessary for proper placement of the electrodes. Weiss Associates installed two sections of PVC pipe vertically into the log pond (visible from the surface) to provide additional visual reference points for placing the electrodes in parallel.

#### 3.5.1.2 Cathodic Protection Survey

The Port of Bellingham required cathodic protection for structures in the vicinity of the demonstration site to ensure that those structures would not be susceptible to corrosion during operation of the ECRTs. Weiss Associates provided oversight of a contractor (Norton Corrosion Inc.), who conducted the survey. The cost provided by Weiss Associates for this service was approximately \$5,200.

#### 3.5.1.3 Site Facilities

Site facilities are required to store and secure various components of the ECRTs system prior to and during treatment. Site facilities at the Demonstration site consisted of a shed and rented fencing to secure the area around the shed. Weiss associates costed the shed at \$953 and 100 feet of fencing at \$225. Therefore, for this

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cost estimate, total cost for site facilities is estimated at about \$1,200.

#### 3.5.1.4 Shipment of System Components

After the preliminary survey has cleared the way for installing the ECRTs treatment system, the components of that system must be shipped to the site. One of the major system components of the ECRTs process are the proprietary converters (i.e., transformers). For the Demonstration, Weiss Associates used three converters for operational flexibility. Two of the converters were shipped from Europe and one was shipped from a domestic site. For a pilot-scale system installed for the Demonstration, Weiss has indicated that one converter would normally suffice, but for larger sites two or more converters would be necessary.

For this cost estimate, an assumption will be made that two proprietary converters will be required for the full-scale ECRTs system at the hypothetical site. The cost to ship the two converters one way, including customs fees, was approximately \$1,600.

Besides the proprietary converters, other ECRTs system components are also shipped to a site (e.g., the raw materials used for constructing the electrodes). Materials and components such as these were delivered to the site by truck. Per review of Weiss Associates invoices to the State of Washington DNR, approximately \$500 was spent on shipping supplies to the site. For this cost estimate this same cost will be used for shipping components, with the assumption that the additional electrodes and materials required for the hypothetical site will not add any substantial shipping costs. Thus, the total shipment costs would total to an estimated \$2,100.

#### 3.5.1.5 Utility Hookup

The primary utility service typically required for implementing the ECRTs technology is electricity. Electricity is essential, as it is used to power the ECRTs treatment process, and also is needed for specific site activities. At the demonstration site, Weiss Associates procured the services of an electrical contractor for providing the 480V power supply, and for running extra DC cable lengths required by relocation of the ECRTs' converters 300 feet from the original planned location. The cost for these system hookup services, up to and including system installation, was approximately \$26,900.

It should be noted that electrical power is also required for operating rental equipment and supplying power to an on-site trailer. At remote sites, a generator could be used to power the ECRTs system. Generator size would depend on the size of the project, however 5 to 10 kW is the minimum size requirement.

### 3.5.2 Permitting and Regulatory Requirements

#### 3.5.2.1 Permitting Requirements

Several types of permits may be required for implementing a full-scale remediation. The types of permits required will be dependent on the type and concentration of the contamination and the regulations covering the specific location.

Since the ECRTs technology was implemented on marine sediments *in situ*, appropriate permits were required. For example, a Joint Aquatic Resource Permits Application (JARPA) was required by the U.S. Army Corps of Engineers (ACOE) for conducting construction work in or near the water. JARPA can be used to apply for Hydraulic Project Approvals, Shoreline Management Permits, Water Quality Certifications, and ACOE Section 404 and Section 10 permits. For the Demonstration project, the JARPA application was completed prior to SITE Program involvement.

In addition to the Hydraulic Project Approval (HPA) acquired via JARPA, SITE Program personnel were required to obtain a scientific collection permit for conducting fish community samples. This permit cost \$15 plus one hour of labor.

It should be noted that permitting fees are commonly waived for government-conducted research projects, such as SITE demonstrations. For construction projects (including remediation), however, the JARPA is mandatory. The JARPA application process helps define which permits are required. No permits are currently required for sediment sampling.

The total cost of acquiring licenses and permits for installing the ECRTs system for the Demonstration was listed by Weiss Associates at about \$270. Due to this insignificant amount, permitting related costs for this cost estimate are considered negligible.

#### 3.5.2.2 Other Regulatory Requirements

The costs incurred for ultimately receiving approval from the regulatory agency to install the treatment system would include the preparation of site characterization reports, the design feasibility study for the treatment system, and meetings with regulators for discussing comments and supplying related documentation for acquiring approval for installing and implementing the treatment technology.

Depending upon the classification of the site, certain RCRA requirements may also have to be satisfied as well. If the site is an active Superfund site, it is possible that the technology could be implemented under the umbrella of existing permits and plans held by the site owner or other

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responsible party. Certain regions or states have more rigorous environmental policies that may result in higher costs for permits and verification of cleanup. Added costs may result from investigating all of the regulations and policies relating to the location of the site; and for conducting a historical background check for fully understanding the scope of the contamination.

Due to the very site-specific nature of these costs, an assumption will be made that sufficient pre-existing site information exists. As a result, no further costs regarding site characterization will be included in this economic analysis.

### **3.5.3 Capital Equipment**

Because the ECRTs technology utilizes leased proprietary converters and the components comprising the electrode array are mostly consumable items, there is essentially little capital equipment associated with the technology. However, capital equipment for this cost estimate are the steel and graphite electrode sheets that are custom made for this application and an oscilloscope that was needed during the Demonstration to monitor the ECRTs system.

Graphite plates were purchased at \$552 each and steel plates were purchased at \$106 each. Therefore 14 graphite plates and 14 steel plates would cost \$7,728 and \$1,484, respectively. An oscilloscope (60 MHz Digital Storage) was purchased for \$900. Total estimated cost of capital equipment is therefore approximately \$10,112.

### **3.5.4 Startup and Fixed Costs**

Startup and fixed costs typically include service-oriented costs that are typically incurred before the actual treatment process is initiated, and are a one time non-recurring costs throughout the treatment duration. Based on information provided by Weiss Associates and the State of Washington DOE and DNR, startup costs for full scale application of the ECRTs technology would include: 1) initial treatability testing; 2) graphite plate testing; 3) installation of the ECRTs electrode array; 4) rental of a proprietary power system; 5) System Operation services; and 6) Licensing fees assessed by P2 Soil Remediation.

#### **3.5.4.1 Treatability Testing**

It should be noted that Weiss Associates typically does not conduct either bench- or pilot-scale treatability studies. Pilot-scale studies may be conducted as requested by the client or to assess the ECRTs system's performance when unusual site conditions occur. The cost of these studies can range from \$30,000 to \$300,000, depending on the goals of the pilot-scale study and site complexity.

For the full-scale application of the ECRTs system at the hypothetical site, an assumption will be made that some form of initial treatability testing will be conducted in order to justify proceeding with a 6-month treatment. The cost will be estimated at \$50,000, which is near the lower cost range provided by Weiss Associates.

#### **3.5.4.2 Graphite Plate Testing**

Weiss Associates conducted research into the material specifications most suitable for constructing the graphite electrode sheets. Due to a discrepancy between the type of graphite available in Europe versus the type of graphite available domestically a graphite plate test was conducted on Union Carbide CS-grade graphite produced in West Virginia. The test involved using a vibrohammer to determine the driving capability of the domestically-produced graphite prior to procuring and installing graphite sheets at the demonstration site. The actual cost of this graphite plate test was reported to be approximately \$4,080 (Weiss Associates, July 2001). This cost included purchasing and shipping a test electrode to Weiss Associates, purchasing miscellaneous equipment/materials, preparing the sheet for testing, shipping the prepared sheet for testing at a construction yard, and interpreting/reporting the results.

#### **3.5.4.3 System Installation**

Installation of the ECRTs electrode array included the use of subcontractors to provide a crane and vibrohammer. Buoys were attached to each electrode for locating them appropriately from the surface, once installed. An underwater camera was used to confirm proper placement into the sediment at the time of installation.

Each electrode row (e.g., anode sheet electrode line) was approximately 30 feet long. The distance between the anode and cathode sheet electrode lines was approximately 30 feet. The total time of system installation was three days. Weiss Associates has indicated the cost for installing the ECRTs system at the Demonstration site to be approximately \$17,300.

#### **3.5.4.4 Proprietary Power Rental**

P2 Soil Remediation owns the proprietary converters used to power the ECRTs system, and leases the use of the converters. The approximate cost for this lease during the Demonstration was \$4,500.

#### **3.5.4.5 System Operation Services**

During the Demonstration, there was basically two types of services utilized by Weiss directly related to the operation of the ECRTs system. Initially P2 Soil Remediation is involved in system startup by activating the AC/DC converters and adjusting and optimizing the operating

parameters. The cost for this optimization service for the Demonstration was approximately \$4,060. In addition, Weiss Associates acquired the services of two local electrical contractors for assisting with the operation of the ECRTs system. These itemized costs were approximately \$5,650 and \$2,030, respectively. Therefore, the total cost of system operation services is estimated at approximately \$11,740.

### 3.5.4.6 P2 Soil Remediation Technology Fee

For using the ECRTs proprietary process P2 Soil Remediation assesses a technology fee on the licensee. Weiss Associates has indicated that this fee typically costs 5-10% of the total project cost. For this cost estimate, an assumption will be made that the licensee fee will be a fixed cost of 5% of the total project cost, or \$18,500 as noted in Table 3-1.

Based on the aforementioned tasks, the total startup and fixed costs for the hypothetical full-scale ECRTs is estimated to be approximately \$87,620 plus the \$18,500. It should be noted that the P2 Soil Remediation technology fee was waived for the Demonstration.

### 3.5.5 Labor

Included in this subsection are the core labor costs that are directly associated with the ECRTs technology. Labor costs for the Demonstration were substantial, comprising well over half of the total cost incurred. It should be noted up-front that the labor costs provided in the section have been calculated using "loaded" hourly rates. Loaded hourly rates typically include base salary, benefits, overhead, and general and administrative (G&A) expenses.

Travel, per diem, and standard vehicle rental have not been included in this section, nor are they incorporated into any labor values.

Much of the labor for the Demonstration was provided by Weiss Associates personnel. Other labor that was used for the Demonstration, or would be used for a full-scale remediation, was subcontracted. Therefore, this section has been subdivided into two subsections. The first subsection addresses the cost of labor as provided by Weiss Associates and the second subsection provides other labor costs that would not typically be provided by Weiss Associates.

#### 3.5.5.1 Weiss Associates Labor Costs

Weiss Associates used a variety of professional disciplines, and management and technical support for conducting the pilot-scale Demonstration. The specific labor categories used by Weiss Associates included the following:

- ◆ Principle II

- ◆ Principle Geologist
- ◆ Senior Associate
- ◆ Senior Project Hydrogeologist
- ◆ Field Operations Manager
- ◆ Geological Technician II
- ◆ Technical Assistant
- ◆ Contracts Manager
- ◆ Clerical Support

Weiss Associates broke their labor costs incurred during the demonstration into the eight task categories, which are shown in Table 3-2 along with the approximate labor costs for each of the categories.

<b>Task Category</b>	<b>Cost <sup>1</sup></b>
1. Procurement and Electrode Preparation	\$15,000
2. Kickoff Meeting / Pre-Remediation Monitoring	\$5,600
3. System Installation	\$16,000
4. System Startup	\$3,700
5. Management of Pilot Test and Reporting	\$18,000
6. Review Monitoring Data to Optimize System Performance	\$12,000
7. Project Shutdown	\$5,900
8. System Demobilization	\$19,000
<b>Total</b>	<b>\$95,000</b>

<sup>1</sup> Values rounded to two significant digits.

According to Weiss Associates, these costs are not representative of a typical remediation project. Pilot project labor costs are higher due to more intensive monitoring and analysis of the system. Full-scale remediation operational costs could be much lower or higher than \$95K for 6 months, depending on project size and complexity. Weiss Associates do not break these costs out separately for full-scale projects, which are performed on a fixed-fee basis.

Taking into account that the ECRTs system was operated for approximately three months and that the aforementioned cost values are the best estimates available, these Demonstration labor costs will be considered as suitable estimates for of a full-scale system that would operate for six months.

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### 3.5.5.2 Other Labor Costs

In addition, there are also labor costs that would be incurred by other entities, besides Weiss Associates. Examples include the labor incurred during baseline surveys (debris and cathodic protection), installation of the ECRTs treatment system, and periodic sediment sampling activities. With respect to the surveys and system installation activities, subcontractor labor costs were included in a lump sum subcontractor fixed cost (see Site Preparation and Startup and Fixed Costs).

As a result, the only labor costs that can be adequately estimated, other than the Weiss Associates labor costs, are those incurred for sediment sampling. Sampling of marine sediments during the Demonstration was conducted by SAIC, the EPA SITE Program contractor.

As previously discussed, an assumption has been made that the contamination at the hypothetical site has been fully characterized prior to installation of the ECRTs system. During the Demonstration pilot study, sediment samples were collected from ten locations within the test plot; five from the extended zone of influence (adjacent to the test plot), and five remote reference locations. Samples were collected on four occasions including a baseline survey prior to the Demonstration, two intermediate monitoring events, and the final post-demonstration event.

For a full-scale application at the hypothetical site, a sampling scheme for collecting treatment verification samples, similar to the one used during the Demonstration, can be employed. Because sediments can commonly be re-worked, there would still be the need to collect baseline samples just prior to installation of an ECRTs electrode array. After establishing a true pretreatment baseline, two intermediate sampling events would be conducted (i.e., after a month of treatment and after 3 months of treatment), followed by a post-treatment event just prior to removal of the ECRTs system (i.e., 6 months or more after system startup). Thus, there would be a total of four sampling events. These four events are summarized as follows.

1. Pre-Treatment (Baseline)
2. 1<sup>st</sup> Intermediate - 1 month
3. 2<sup>nd</sup> Intermediate - 3 months
4. Post-Treatment - 6 months

It should be noted that during the Demonstration six samples were collected within each individual core. This was done because there were different sediment horizons at the Bellingham Bay site. As a result, each sample collected for the Demonstration represented a separate sediment horizon. Since an assumption has been made that there is only one sampling horizon at the hypothetical site, sub-sampling of each 10 foot long core would not be

required. Because the sediment contaminants consist of mercury and SVOCs, each core would be homogenized and represent a single sample point.

For this cost analysis, it will be assumed that a four-person sampling team can mobilize to the site, setup, sample the 10 locations, ship the samples to an outside laboratory, and demobilize in two 12-hour days. Therefore, each of the four sampling events would incur 112 hours of labor (i.e., 2 days x 4 people x 12 hours + 16 hours mob/demob = 112 hours). At \$60/hr, a labor cost of \$6,720 would be incurred for sediment sampling each event; thus the total labor cost of sediment sampling over the entire four-event treatment period is estimated at \$26,880.

A boat operator, coring equipment, core tubes, and DGPS will also be required for sediment sample collection. The cost for the sampling vessel equipped with sediment coring and DGPS navigational equipment would cost approximately \$2200/day. The cost for pre-cleaned core tubes is estimated at \$150/tube, which are not considered re-usable as they are destroyed during processing. Therefore, an additional cost of \$5,900 per sampling event is estimated for the sampling platform and related equipment; thus the total cost for the entire four-event treatment period is estimated to be \$23,600, not including boat transit time to and from the site.

In addition to sampling sediments, during the Demonstration, the actual electrodes were sampled and analyzed for mercury. This was conducted to estimate and compare the mass of mercury collected on the electrodes to sediment measurements for calculation of total mercury remediation. The metal sheets were sampled by scraping with a stainless steel chisel, and collecting the scraped powder in sample jars. For the graphite sheets, a ½ inch diameter plug was drilled and used as a sample. The electrode samples were treated as a soil sample and digested via the same method (SW-846 method 7471).

For a full-scale remediation, this type of sampling is assumed necessary to verify that mercury did indeed accumulate onto the electrodes. This would be a one time occurrence. For this cost, an assumption will be made that two people could sample all 28 electrodes in one 10-hour day. Thus, at the same \$60/hr rate, the estimated labor cost would be \$1,200 for this task.

### 3.5.6 Consumables & Supplies

The electrode array is primarily constructed of locally-purchased components. The majority of these components can be considered consumable items, as they are purchased as dedicated equipment that is typically customized for the specific site application. Weiss Associates provided a cost for the pilot-scale electrical

system components that were itemized in their cost estimate. These costs are provided in Table 3-3.

It should be noted that the \$3,150 cost value for the electrode array supplies may be low for a full scale system, since the electrode supply cords will need to be longer for reaching 14 anodes and 14 cathodes of equal spacing. However, the difference is assumed minor for this cost estimate. It should also be mentioned that other miscellaneous supplies typically would be needed for such a project (e.g., sample core tubes), however due to their direct association with other cost aspects, these supply costs are included within the labor cost category.

<b>Table 3-3. Electrical System Components Costs.</b>			
ITEM	QTY	UNIT COST	ITEM COST
Wire, 12 awg <sup>1</sup>	250 ft	\$1.00/ft	\$250
Wire, 8 awg <sup>1</sup>	300 ft	\$3.00/ft	\$900
125 A Cable	1 roll	\$100/Ea	\$100
Cord, 8 awg	60 ft	\$0.23/ft	\$13.80
Misc. Electrical	1	\$500	\$500
Epoxy Sealant	1	\$200	\$200
Meter, kW Hr	1	\$200	\$200
Shut-off-Switch	1	\$100	\$100
Insulation Mat.	1	\$240	\$240
Safety Supplies <sup>2</sup>	1	\$250	\$250
Thermal Printer	1	\$400	\$400
<b>Total</b>			<b>\$3,150 <sup>3</sup></b>

<sup>1</sup> Wire is marine grade

<sup>2</sup> Includes signs, PPE, etc.

<sup>3</sup> Total rounded to three significant digits.

### 3.5.7 Utilities

The main utility required for the ECRTs treatment system is electricity. At the Bellingham Bay site the electrical hookup and service were provided by G-P. The electricity provided the AC/DC current that passed between the electrode pair (anode and cathode). The developer has reported that typical current consumed when using their Direct Current technology to treat soil and by ECGO ranges from 0.2 kWh to 3 kWh per ton of soil. Power consumption for metals remediation by IC is slightly higher (Doering, et. al.,).

Although, actual records for electrical usage were not obtainable for the shortened 8-week operational period during the Demonstration, Weiss Associates did provide an electrical usage cost estimate of \$3,170 in their cost proposal. This estimate was based on a rate of \$0.10/kW-hr and assumed that the ECRTs system would be operational for six months.

It should be noted that electricity cost can vary greatly depending on geographical location.

Other utilities that may add nominal costs to a remediation project are communications and lavatory facilities. During the Demonstration, Weiss Associates passed on certain utility type costs to the Department of Ecology. These included pager, cell phone, and photocopier usage costs and rental of a laptop. These costs are not included in this cost estimate.

### 3.5.8 Effluent Treatment and Disposal

For this technology there is no effluent. Therefore, it is assumed that there will be no effluent treatment and disposal expense. Disposal of small amounts of decontamination wastewater generated from cleaning sampling equipment is considered negligible and not included in this cost estimate.

### 3.5.9 Residuals Shipping and Disposal

During the Demonstration, the primary residual generated by the ECRTs process was the spent electrodes. Due to the nature of the process, mercury is deposited on the electrodes. As a result the electrodes must either be processed following treatment to remove hazardous mercury or disposed of as hazardous waste. Although Weiss Associates has indicated that the mercury plated on the sheets could potentially be recovered and recycled (thus rendering the sheets reusable), this was not done for the Demonstration. This was likely due to the poor condition of the electrodes upon removal.

SITE demonstration personnel used a stainless steel chisel to scrape off material accreted to the surface of the steel plates and used a hole-cutting drill bit to collect solid plugs from the graphite plates as samples. Following this processing of electrodes, both steel and graphite sheets were wrapped in plastic drum liners and given back to Weiss Associates. G-P incurred the cost of disposing of the electrodes. Weiss Associates costed the disposal of their electrodes in their SOW, based on an estimated weight of the electrodes (Table 3-4).

ITEM	QTY	UNIT COST	ITEM COST
Electrodes <sup>1</sup>	2.9 tons	\$2,500/ton	\$7,250
Shipping <sup>2</sup>	1	\$1,300/trip	\$1,300
DOT-approved shipping crates	5	\$300/Ea	\$1,500
<b>Total</b>			<b>~\$10,100</b>

<sup>1</sup> Include steel and graphite plates, and plated mercury.

<sup>2</sup> From Seattle, WA to Union Grove, WI.

Weiss has provided the approximate weights for the steel and graphite electrodes as 240 lbs each and 120 lbs each, respectively. However, in their SOW, they estimated that the 18 electrodes with plated mercury would weigh about 1.88 tons. Since the hypothetical site utilizes a total 14 steel and 14 graphite electrodes, proportionately the total weight of these 28 electrodes and plated mercury would correlate to about 2.9 tons. The disposal cost was quoted at \$2,500/ton, thus the estimated disposal cost is \$7,250. Assuming that this tonnage could still be shipped in one trip in 5 DOT-approved shipping crates, the total disposal cost of the electrodes is approximately \$10,100.

Other than the electrodes, the other waste stream was excess sediment samples. G-P took responsibility for properly disposing of excess sediment. The cost of sediment disposal is not included in this cost estimate.

### 3.5.10 Analytical Services

Although the demonstration site contained both organic and inorganic contaminants, mercury was of prime interest since its concentrations were consistently above quantitation limits and were found to be less variable within the test location. During the pilot-scale Demonstration of the ECRTs treatment system, the SITE Program performed four separate sediment sampling events between August 2002 and March 2003. Six samples were collected from each sediment core including three separate vertical composite samples from the contaminated horizon (i.e., top, mid, and bottom third of material between the cap and native material); one composite over the length of the contaminated horizon (i.e., equivalent to compositing the three vertical samples together); one cap sample; and one native material sample. Select samples were either submitted for analysis of mercury, PAHs, phenolic, and sediment conventional analyses (organic carbon, total solids, and grain size distribution), or archived (frozen).

The level of testing required to substantiate successful treatment at full-scale site (i.e., at the hypothetical site) is

assumed to be significantly scaled down from the SITE Demonstration sampling plan. The ECRTs technology at the demonstration site was planned to attain the treatment goals within 6½ months but was discontinued after eight weeks. For this cost analysis, a treatment period of six months is assumed and the four-event sampling schedule discussed previously (see 3.5.5.4) will be considered of adequate frequency to monitor the treatment effectiveness.

Although the site owner or the site owner's contractor would likely collect these samples, the state or local regulatory agency may require independent analysis of the samples by an outside laboratory (especially for final post-treatment samples). It will also be assumed that for the four-event monitoring schedule there will be four analytical parameters. These parameters include mercury, PAHs, total solids (which is a requirement of the Puget Sound Estuary Program), and metals. These parameters are either deemed essential or are believed to provide the most useful information regarding the technology effectiveness.

Table 3-5 provides an estimate for the cost of analytical samples using the four-event sampling scenario. This estimate assumes that the only analyses requiring MS/MSD QA analyses are mercury and SVOCs, the primary contaminants.

Analysis	Mercury	SVOCs	Total Solids	Metals
Samples per event	12*	12*	10	10
# of Events	4	4	4	1
Total Sediment Samples	48	48	40	10
Electrode Samples	28	---	---	---
Cost/Sample	\$35	\$260	\$7	\$85
<b>Total Cost</b>	<b>\$2,660</b>	<b>\$12,480</b>	<b>\$280</b>	<b>\$850</b>

\* Includes one MS and one MSD analysis.

Typical mercury analysis cost, along with percent-moisture for dry-weight calculation is approximately \$35. The resulting total of 76 sediment/electrode samples, analyzed for total mercury at an estimated \$35 per sample, would cost \$2,660. The resulting total of 48 PAH analyses (using the method used during the demonstration) would cost an estimated \$260 per sample and total approximately \$12,480. The 40 Total Solids analyses estimated at \$7 each, would total \$280. Total Metals analyses estimated



at \$85 each, would total \$850. Thus, total analytical costs are estimated at approximately \$16,270.

Assuming that one laboratory would conduct all four analyses, two overnight sample shipments are estimated for each sampling event (i.e., one per sampling day). Conservatively assuming the eight shipments would cost \$100 each, total sample shipping costs would total \$800. Total analytical services costs (including shipping costs) for the 6-month treatment scenario is thus estimated at \$17,070.

### 3.5.11 Maintenance and Modifications

According to Weiss Associates general maintenance activities associated with the ECRTs system includes checking and recording electrical parameters, adjusting equipment operation, and tracking chemical data analysis.

With respect to the operational performance of the ECRTs system, oscilloscope readings are routinely performed weekly for two channels: voltage and amperage. If the system ground fault interrupter switch (GFIS) trips, it requires resetting. Tripped fuses require replacing. If either maintenance or modification of the actual ECRTs electrode array system is required, the system is powered down using a sequential protocol by an ECRTs-trained technician.

The tracking of chemical data was conducted by the SITE Program for the Demonstration, but for a full-scale remediation the cost would typically be incurred by the site owner. Sampling activities for monitoring sediment contaminant concentrations can thus be categorized as maintenance and would constitute the largest cost component of this category. As previously mentioned, due to the research-oriented nature of SITE project evaluations, monitoring costs are relatively high (i.e., there were a total of six sampling events planned for the Demonstration at Bellingham Bay). For the hypothetical site discussed in this economic analysis, four sampling events are assumed and would occur over a 6-month treatment period.

The labor cost incurred for tracking chemical data (i.e., sampling activities) has been discussed in subsection 3.5.5., however, more significant costs include the specialized services required to collect marine sediments.

Table 3-6 presents the actual costs for monitoring sediments during the Demonstration for each sampling event. These costs are assumed to be similar to the hypothetical site scenario with the exception that the number of sampling days per event for the hypothetical site has been halved from four to two in order to account for the decreased number of discrete samples collected.

Cost Item	Cost/Unit	No. Of Units	Extended Cost
Mob/Demob. <sup>1</sup>	\$4,250 (fixed)	NA	\$4,250
Coring Services <sup>2</sup>	\$2,075/Day	2	\$4,150
DGPS Positioning <sup>3</sup>	\$200/Day	2	\$400
Core Tubes <sup>4</sup>	\$145/tube	24	\$3,480
Crew Per Diem <sup>5</sup>	\$200/Day	3	\$600
<b>Total Cost Per Event</b>			<b>\$12,880</b>
<b>Total Cost for Four Events</b>			<b>\$51,500</b>

<sup>1</sup> For the Demonstration, a boat was trucked from near Tacoma, WA to Bellingham Bay. Similar costs are assumed for the hypothetical site.  
<sup>2</sup> Includes daily use of boat, deck hands, and coring equipment.  
<sup>3</sup> DGPS = Differential Global Positioning System.  
<sup>4</sup> Includes both materials and labor to decontaminate core tubes.  
<sup>5</sup> Per Diem cost includes two crew members..

As shown in Table 3-6, the specialized services required for conducting marine sediment sampling is estimate to cost \$12,880 per event and total to an estimated \$51,500 for all four events.

In addition to tracking chemical data, the SITE Program also conducted voltage probe measurements during the Demonstration to determine the spatial extent of the zone of influence of the ECRTs (a secondary objective of the Demonstration). This monitoring involved probing the sediment bottom with a custom designed 3" diameter pole with a con-shaped tip, charged with a current. The treatment area was probed for changes in voltage. This type of monitoring was more research oriented and would not typically be conducted for a remediation project. Thus, costs for this specialized monitoring are not considered.

### 3.5.12 Demobilization/Site Restoration

Demobilization and Site restoration are performed at the conclusion of the treatment project. Although site restoration can be an ongoing activity related to certain remediation technologies, for the ECRTs technology it is assumed that site restoration will consist primarily of removing the electrodes from the sediment bottom and either shipping the used components back to a storage facility for maintenance or properly disposing them.

Weiss Associates subcontracted a crane for removing the electrodes from the sediment via the pier, and has indicated that the cost of this operation to be \$15,000. The majority of these costs consisted of subcontractor fees for a crane and divers to remove the electrodes from the sediments (the divers were on standby to aid with electrode

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removal, but were not needed). After they were removed, photographs were taken of the electrodes and each was identified and labeled.

In addition to the electrode removal cost, an assumption will be made that the proprietary converters will be shipped back for the same cost as they were delivered, which was \$1,600. Thus, the total cost Demobilization/Site Restoration is estimated at \$16,600.

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## Section 4.0 Demonstration Results

### 4.1 Introduction

This section summarizes information on the performance and effectiveness of the ECRTs process, as evaluated by the SITE Program. The SITE Program was created in order to develop, demonstrate, and establish the commercial potential of innovative technologies for treating wastes found at Superfund and other hazardous waste sites across the country. Through SITE Demonstrations, USEPA acquires the data necessary to properly consider innovative technologies in the remedial action decision-making process. If tested successfully, these technologies become alternatives to less attractive, more costly forms of remedial action. The general study design and basis for the data collection efforts are detailed in the Quality Assurance Project Plan for the ECRTs Puget Sound Site Demonstration (SAIC 2002a) and the technical memoranda dated March 7, 2003, "*Sampling and analysis of electrodes upon removal following the ECRTs Demonstration Project at the G-P Log Pond, Bellingham, WA,*" (SAIC 2003).

#### 4.1.1 Project Background

The Electrochemical Remediation Technology (ECRTs) process, developed by P2-Soil Remediation, Inc. for the treatment of marine sediments contaminated with mercury, PAHs, and phenolic compounds was tested during this demonstration. The demonstration of the ECRTs process took place at the Georgia Pacific, Inc. (G-P) Log Pond located adjacent to the Whatcom Waterway navigational channel in Bellingham Bay, Washington. The ECRTs process utilizes a DC/AC current passed between an electrode pair (anode and cathode) in sediment. According to the developer, remediation of the sediment is accomplished by either the mineralization of organic contaminants through the ElectroChemicalGeoOxidation (ECGO) process, or by use of the Induced Complexation

(IC) process to complex, mobilize, and remove metal contaminants plated to the electrodes. The pilot study was designed to assess and evaluate the ability of the ECRTs process to reduce concentrations of PAHs, phenolic compounds, and mercury.

Pre-demonstration data were collected to determine the relative concentrations and variability of the contaminants noted above. A test plot area was established as a potential location for the ECRTs treatment. A reference area was established to determine natural attenuation of the contaminants of concern over the course of the treatment period. Results of this sampling effort for both the test plot and reference area locations are presented in a separate report (SAIC 2002b) and discussed in Section 4.2.1. In summary, elevated concentrations for contaminants of concern were detected in both the test plot and reference area locations. Mercury and phenolic compounds were detected in comparable concentrations at both the test and reference area locations. PAH concentrations were higher in the test plot than the reference location. In addition, concentrations for most of the contaminants of concern, with the exception of mercury, were highly variable and often below method detection and/or quantitation limits. Mercury concentrations were consistently above quantitation limits and were found to be less variable within the test location, however, overall mercury concentrations were still considered to be heterogeneous. Therefore, while the demonstration included testing for all contaminants of concern, as noted above, mercury was the only contaminant considered critical for purposes of the demonstration and for purposes of preparing a statistical experimental design in relation to the project primary objective. PAH concentrations below method detection and/or detection limits and higher PAH concentrations in the test plot (test and reference plots are not comparable) precluded an inferential test of treatment effectiveness.

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Primary and secondary objectives associated with all parameters are presented in section 4.1.2.

The ECRTs designated project area was approximately a 50-foot (ft) by 50-ft plot within the G-P Log Pond. Installation of ECRTs infrastructure involved placing 9 anode (steel plates) and 9 cathode (graphite plates) electrodes, in two parallel rows, into the sediments. Each electrode row was approximately 30 feet long. The distance between the anode and cathode sheet electrode rows was approximately 30 feet. Electricity was supplied, in parallel, to each individual electrode plate. The actual area for sample collection was a 20-ft by 30-ft zone located within the treatment plot, to allow a 5-foot buffer zone between sampling locations and the installed electrodes.

#### 4.1.2 Project Objectives

The primary goal of the SITE Program is to develop reliable performance and cost data on innovative, field-ready technologies. A SITE Demonstration must provide detailed and reliable data so that potential technology users have adequate information to make sound judgements regarding an innovative technology's applicability to a specific site, and to be able to compare the technology to other conventional technologies. This section presents the goals and objectives for the ECRTs demonstration.

*In accordance with QAPP Requirements for Applied Research Projects* (EPA,1998), the technical project objectives for the Demonstration were categorized as primary and secondary. Primary objectives are those goals that support the developer's specific claims for the technology demonstrated. These objectives are usually evaluated using both descriptive and inferential statistical analyses. Secondary objectives are also in support of developer claims, however, the data analysis associated with these objectives are considered less rigorous. Critical data support primary objectives, and non-critical data support secondary objectives. Primary objectives required the use of quantitative results to draw conclusions regarding technology performance. Secondary objectives pertain to information that is useful, and did not necessarily require the use of quantitative results to draw conclusions regarding technology performance.

##### 4.1.2.1 Primary Technical Objective

The primary technical objective was to determine whether there was a significant trend in the reduction of mercury over the period of the demonstration. A reduction percentage of 50% with a confidence level of being able to statistically determine this reduction set at 90% was used to better determine the number of samples needed from

each sampling event. The primary objective was not associated with a percent reduction, but instead, the primary objective was to determine a statistically significant negative trend over time.

##### 4.1.2.2 Secondary Objectives

Several additional project objectives were associated with the evaluation of the ECRTs process at the G-P Log Pond. These secondary objectives were defined as having an important role in determining the potential applicability and suitability of the technology for marine sediments. Ancillary data collected to achieve these goals are described below:

- *Determine the rate of organic compound mineralization* (i.e. reduction) by the collection and analysis of test plot samples for PAHs/SVOCs during multiple sampling events;
- *Assess potential vertical migration of contaminants* through the evaluation of data from samples collected over discrete depth intervals and analyzed for PAHs/SVOCs and mercury;
- *Determine the extent of the zone of influence of the ECRTs process* through the spatial measurement of electric potential and collection of contaminated samples outside the immediate area of the test plot;
- *Track natural attenuation changes in contaminant concentrations* by sampling/analysis of a reference area located outside the ECRTs's zone of influence;
- *Evaluate possible environmental effects of ECRTs* including benthic infauna effects and possible behavioral effects on sensitive fish by a series of measurements (e.g., benthic infaunal sampling, purse seining, and underwater video);
- *Evaluate potential contaminant flux across the water-sediment interface* by the evaluation of cap chemistry;
- *Evaluate migration of mercury towards electrodes* by determining the mass of mercury collected on electrodes at the end of the demonstration;
- *Determine field scale costs to implement the in-situ sediment technology in marine sediments* (results are presented in Section 3).

##### 4.1.2.3 Data Types

Several different data types were identified to meet the primary technical objective and secondary objectives described above. Data needs included sediment

chemistry, biological data, and other data such as electrical field measurements, cost information, and calculation of the mercury mass adhered to the electrodes at the end of the demonstration. These data were then classified as being critical (data needed to meet primary objective) or non-critical (data needed to meet secondary objectives). Table 4-1 summarizes the evaluation method for the critical primary objective and the non-critical secondary objectives.

#### 4.1.2.4 Project Schedule

The ECRTs demonstration was originally scheduled to operate for a six-month period; from September 2002 until February 2003. The demonstration period was scheduled based upon ecological constraints of being able to operate the process within the WDFW "fish window", designated for the protection of migrating salmonids. The demonstration period for the ECRTs project actually ran from September 19, 2002 to March 17, 2003, however the effective operating phase of the ECRTs electrodes was significantly less due to operational problems associated with maintaining electrical connections to the system. The demonstration period was to incorporate several data collection efforts to monitor and assess the ECRTs performance including a baseline, final, and three intermediate sampling events. The third intermediate sampling event was canceled due to operational difficulties with the ECRTs system. The dates of the data collection efforts and major project milestones were as follows:

Field Event	Date(s) of Event
Pre-demo. sampling	May 29-31, 2002 <sup>1</sup>
Baseline sampling	August 19-22, 2002 <sup>2</sup>
ECRTs installation	Sep. 17-18, 2002
ECRTs process initiation	Sep. 19, 2002
1 <sup>st</sup> Intermediate sampling	November 1-5, 2002 <sup>3</sup>
2 <sup>nd</sup> Intermediate sampling	Dec. 9-13, 2002
Process termination	March 17, 2003
3 <sup>rd</sup> Intermediate sampling	Cancelled <sup>4</sup>
ECRTs removal	April 1, 2003
Post-demo. sampling	March 18-21/April 1-2, 2003 <sup>5</sup>

<sup>1</sup> Pre-demonstration sampling conducted to verify contaminant concentrations at the demonstration site and provide data to develop the study design. Potential reference locations were also investigated, but data was not included for the ECRTs evaluation.

<sup>2</sup> Baseline sampling was conducted prior to the installation of the ECRTs system largely due to schedule and logistical constraints.

<sup>3</sup> The first intermediate sampling event was originally scheduled to commence two weeks following the installation and initiation of the ECRTs process. Equipment issues related to the power supply delayed the initiation of the demonstration project.

<sup>4</sup> This sampling effort was canceled due to the termination of the ECRTs process.

<sup>5</sup> The post-demonstration sediment sampling effort was conducted in March prior to the removal of the electrodes. The electrodes were sampled subsequent to their removal in April.

## 4.2 Field Activities

This section describes the various data collection efforts that were conducted prior to, during, and following the ECRTs demonstration project. The results of the Pre-demonstration activities are discussed relative to their implication on the study design developed for evaluating the ECRTs process. The results for all other data collection efforts are discussed in Section 4.3. Detailed descriptions of the sampling methods are provided in the project QAPP (SAIC 2002a).

### 4.2.1 Pre-Demonstration Activities

In May 2002, pre-demonstration characterization sampling and analysis was conducted. The pre-demonstration sampling and analysis was designed to accomplish two main objectives: 1) to delineate and characterize the contaminant levels, including the vertical distribution of contaminants, in the area designated as the test plot; and 2) to determine the location of a reference (no-treatment) area to be monitored during the demonstration.

**Table 4-1. Summary of Demonstration Objectives & Methods of Evaluation.**

Objective	Description	Method of Evaluation
<b>Primary Objective (Critical)</b>		
Objective 1	Determine whether or not there is a decreasing trend in mercury concentration over duration of the demonstration.	The rate parameter will be estimated and a 90% confidence interval around the rate parameter will be constructed. The confidence interval will be used to determine if there is a statistically significant decreasing trend.
<b>Secondary Objectives (Non-Critical)</b>		
Objective 2	Determine the rate of organic compound mineralization.	Collection and analysis of test plot samples for PAHs/SVOCs.
Objective 3	Assess potential vertical migration of contaminants	Evaluation of data from samples collected over discrete depth intervals including the cap and native material and analyzed for PAHs/SVOCs and mercury.
Objective 4	Determine the extent of the zone of influence of the ECRTs.	Spatial measurement of electric potential.
Objective 5	Assess the zone of influence for the demonstration.	Taking core samples outside the immediate area of the test plot.
Objective 6	Track natural attenuation changes in contaminant concentrations.	Sampling and analysis of a reference area (control plot) outside the ECRTs zone of influence.
Objective 7	Evaluate possible environmental effects of ECRTs including benthic infauna effects and possible behavioral effects on sensitive fish.	Biological monitoring including benthic infaunal sampling and purse seining
Objective 8	Evaluate potential contaminant flux across the water-sediment interface.	Evaluation of cap chemistry.
Objective 9	Evaluate migration of mercury towards electrodes.	Determining the mass of mercury collected on electrodes at the end of the demonstration.
Objective 10	Determine field scale costs to implement the in-situ sediment technology in marine sediments.	Details are provided in the economic analysis (Section 3.0).

Core samples were collected from six locations within the test plot area and were analyzed as composites of the material below the cap and above the native material (i.e. the contaminated sediment horizon). Additionally several cores were analyzed by collecting separate samples from up to three distinct intervals determined by dividing the contaminated sediment horizon evenly into thirds (top, middle and bottom). Results for detected parameters, concentration ranges and applicable SMS CSL limits are presented in the demonstration QA Project Plan (SAIC 2002a).

The sediment conventional parameters analyzed included total solids, total organic carbon (TOC), total sulfides, and grain size distribution. Total sulfide concentrations ranged from 2.8 mg/kg in native material to a high of 1870 mg/kg

within the contaminated horizon. The percentage of TOC was consistently lower in the cap and native material horizons (0.12 to 0.43%) than in the contaminated horizon (4.75 to 19.2%). The grain size distribution of the cap and native material samples consisted mostly of medium to coarse sand, whereas the contaminated horizon consisted primarily of fines (silt and clay). The visible difference in grain size composition, as well as texture, consistency, and color were the distinguishing factor for discerning the horizons during core processing. The analytical results for conventional and chemical parameters verified that visual observations were adequate for distinguishing the sediment cap, contaminated sediment horizon, and native material.

The SMS metals analyzed included arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc. Mercury

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is the primary contaminant of concern for metals at the G-P Log Pond Site. Mercury was detected at concentrations ranging from 1.02 to 456 mg/kg dry wt., exceeding the Cleanup Screening Level (CSL) of 0.59 (mg/kg dry wt.) in all samples from the contaminated horizon. In general, mercury concentrations were higher in the upper sediment horizons.

Numerous semi-volatile organic compounds (SVOCs) (e.g. 4-methylphenol, acenaphthalene, fluorene) were detected at concentrations exceeding SMS criteria in the contaminated horizon. SVOCs, however, were not found in the cap or native material samples at concentrations exceeding SMS criteria. In general, SVOCs below method detection and/or detection limits and higher SVOCs in the test plot (test and reference plots are not comparable) precluded an inferential test of treatment effectiveness, therefore, SVOCs were considered non-critical for purposes of the demonstration.

Multiple locations were evaluated to ascertain the location of a suitable area for the reference plot for the pilot study. Core samples were obtained from areas of similar cap thickness relative to the test plot, and visible comparisons were made to cores collected from the test plot. Those having geophysical characteristics similar to cores from the test plot were composited and sent for analysis, along with samples analyzed to assess vertical heterogeneity.

Concentrations of mercury in the chosen reference areas were more variable than in the test plot but were still considered to be relatively similar. The average mercury concentration in composited cores over the entire depth strata was around 5 mg/kg dry wt. but concentration in one vertical horizon was as high as 456 mg/kg dry wt., suggesting that this area also had high concentrations of mercury, comparable to those in the test plot. As with the test plot, PAH and phenolic concentrations were highly variable and at much lower concentrations. Additional sampling during the demonstration provided more definitive concentrations of contaminants, however, the preliminary pre-demonstration data suggested that reference area locations would provide insight as to the potential for natural attenuation compared to active remediation via the ECRTs process.

#### **4.2.2 Sample Collection and Analysis**

The collection of representative samples during the Demonstration was vitally important to the achievement of project objectives. Environmental samples were collected to examine the following relative to the ECRTs process: changes in contaminant concentrations and potential mobility, benthic infaunal community changes, effects on the fish community structure, the size and relative strength

of the electric field, and to monitor for possible behavioral effects on electro-sensitive fish.

Sediment sampling activities were conducted during the baseline, intermediate and final events for chemical analyses. Non-critical data types including sediment grabs for benthic infauna analyses, purse seining for fish community identification and enumeration. Electrical field measurements were collected during the baseline and intermediate events, but several measurements were discontinued due to operational limitations of the ECRTs process and cost-saving measures.

Underwater video transect for observing fish behavior was originally proposed as a monitoring technique, but was discontinued as not feasible because of the limited visibility within the Log Pond. The underwater video was used to examine the installation of the electrodes, to ensure the electrodes were all placed below the sediment surface.

A voltage probe to determine the extent of the electric field generated by the ECRTs was originally part of the demonstration field-monitoring plan but was not executed as part of the evaluation at the request of the Developer because of the proprietary nature of the voltage measurements. Due to cost implications relative to overall project objectives; the benthic flux (contaminant mobility at the sediment-water interface) evaluation was removed from the project scope prior to the baseline data collection effort. Therefore, no samples were collected specifically for determining potential benthic flux.

##### **4.2.2.1 Sampling Platform and Positioning**

Field sampling efforts involving sediment core collection and electric field measurements were conducted using the R/V Nancy Anne, owned and operated by Marine Sampling Systems of Burly, WA. The R/V Nancy Anne is specially designed and equipped for collecting sediment cores including a power winch, a bow-mounted A-frame, custom vibracorer, vertical core storage, and a core-cutting stand. Biological monitoring (purse seining, underwater video, and benthic grabs) was conducted using a small open vessel equipped with an outboard motor operated by SAIC personnel. The small sampling vessel is equipped with a processing table for handling seining nets and a power davit for deploying the benthic grab sampler.

Navigation and positioning was accomplished using Differential Global Positioning System (DGPS), which provided accurate positions ( $\pm 2$  meters in real-time) with a rapid positional update (e.g., every 3 seconds or less). The DGPS employs a receiver which tracks and times signals emitted by satellites orbiting the earth, a Coast Guard reference beacon located in the vicinity of the survey area, and a shipboard receiver. The receiver deployed at the

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Coast Guard reference beacon (horizontal control point) was used to correct for Selective Availability (SA) (satellites emit an encrypted signal designed to degrade the accuracy for non-military users by dithering the time code embedded in the signal). This receiver calculates position based on the satellite signals and compares the calculated position to the known position at the horizontal control point. A positional offset of correction factor is calculated and transmitted to the shipboard GPS receiver, which applies the correction factor to calculate the corrected vessel position. All station coordinates were recorded by latitude and longitude to the decimal minute.

To ensure the accuracy of the system, several survey control points were used from previously surveyed locations including a pier face, dock, and piling, of which all were accessible by the sampling vessel. A DGPS reading was taken twice daily, before and after sampling activities, at the control point, and compared to the surveyed coordinates. The position reading and surveyed coordinates were within a plus or minus two-meter accuracy.

Additionally, sampling locations within the test plot, "reference marks" were painted on the pier and bulkhead located adjacent to the test plot. Markings were made during baseline sampling in order to provide a visual reference point for subsequent sampling events. These were compared with real-time GPS readings and plotted target sampling locations, graphically displayed on the shipboard navigation computer. While not exact, this provided sufficient accuracy for returning to the same location for all subsequent sampling events and for placement of the electrode array. It should be noted that GPS positioning at sea is less accurate than continuous readings collected from a stable land-based location, due to the inherent difficulties of maneuvering and positioning a floating sampling platform to a precise location or maintaining a stationary position on a water surface influenced by wind, wave action, currents, and tide. Three taglines, connecting the vessel to the bulkhead and pier were used to maintain the boats position while sampling. The use of traditional anchors or spuds was not practical due to the resultant damage to the sediment cap and potential disruption to sampling locations.

Vertical positioning was determined using the depth sounder on the sampling vessel. A lead-line (weighted measuring tape) was used to measure from the water surface to the mudline to confirm the depth sounder reading and to provide a correction factor (if needed). Adjustments to the recorded depth due to tidal stage was made using tidal prediction software loaded onto the navigational system. Adjustment factors used based on

tidal prediction software was corroborated during post-processing using the actual tidal elevation observations recorded by the National Ocean Services (NOS) Cherry Point tide gauge.

#### 4.2.2.2 Sediment Sampling

Sediment samples included composites, as well as samples collected from distinct intervals in order to assess vertical distribution of contaminants. Based upon visual inspection, three distinct intervals (i.e. top, middle, and bottom) were subdivided and sampled over the length of the contaminated sediment layer. Samples of the overlying cap and underlying native material were collected and analyzed as well. The QA Project Plan provided details on the protocols for both critical and non-critical sampling, frequency of collection for all parameters, sample processing procedures and sample custody and handling procedures (SAIC 2002a).

Sediment samples were collected from within the test plot in support of the primary objectives, and from outside the test plot (extended zone of influence) and from within the reference plot in support of secondary objectives. All sediment samples were collected using a vibracoring system capable of obtaining cores to one foot below the proposed dredging prism. The vibracorer consists of a core barrel attached to a power head. Aluminum core tubes equipped with a stainless steel "eggshell" core catcher inserted in the core barrel were used to retain material. The vibracore was lowered into position on the bottom and advanced to the appropriate sampling depth. Once sampling was complete, the vibracore was retrieved and the core liner removed from the core barrel. The core sample was examined at each end to verify that sufficient sediment was retained for the particular sample. The condition, and quantity of material within the core was then inspected to determine acceptability.

To verify whether an acceptable core sample was collected the following criteria had to be met:

- ▶ target penetration depth (i.e., into native material) was achieved;
- ▶ sediment recovery of at least 65% of the penetration depth was achieved; and
- ▶ sample appeared undisturbed and intact without any evidence of obstruction or blocking within the core tube or core catcher.

The percent sediment recovery was determined by dividing the length of material recovered by the depth of core penetration below mudline. If the sample was deemed acceptable, overlying water was siphoned from the top of the core tube, and each end of the tube was capped and



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sealed with duct tape.

All cores were processed on board the sampling vessel (initial sectioning to ease handling) and at a shore-based processing facility (extrusion, documentation, and sample collection for analysis). Sediment cores were processed in the same order as collected in order to minimize storage time. Each section comprising a core sample was carefully cut into two sections using a depth-calibrated circular saw (only the aluminum tube is cut). Care was taken to preserve the integrity of the core section stratum by processing sections in order from top (e.g., mudline) to bottom (native material). Once the core was split open, a mark was made to delineate cap, the sediment horizon (the target zone), and underlying native sediment sections.

Sediment samples were collected from the test plot, the reference plot and the extended zone of influence during the baseline, each of two intermediate events, and the final, post-treatment event. Six samples were collected from each sediment core for mercury analysis, total solids, and total organic carbon (TOC). These included one composite collected over the length of the contaminated horizon from between the native material and the cap; three vertical composite samples collected from three discrete intervals (top, middle, bottom) over the length of the contaminated horizon; one cap sample; and one native material sample. Six samples were collected for SVOCs as noted above for mercury analysis, with the three discrete intervals initially placed in archive. Subsequent funding, provided by Ecology, allowed for the archived samples to be analyzed in May 2003.

Representative aliquots of sediment were sub-sampled over the entire length of a respective horizon, using decontaminated stainless steel spoons, in order to generate a composite sample for chemical and conventional analysis. Sediment was collected from the center of the core that had not been smeared by, or in contact with the core tube. The sediment sub-samples were placed in a decontaminated stainless steel bowl, and mixed until homogenous in texture and color (approximately two minutes). After all sediment for a composite sample was collected and homogenized, representative aliquots were placed in the appropriate pre-cleaned sample containers for analysis. Samples of the cap material and the underlying native material were collected in a similar manner.

The vertical distribution of contaminants was used to evaluate deposition patterns of chemical concentrations (baseline), and potential vertical migration of contaminants due to the ECRTs process (post-baseline sampling events). Based upon visual inspection, three distinct, equivalent intervals were subdivided and sampled over the

length of the objective sediment layer (top, bottom, and middle). Distinct layers of cap, contaminated sediment horizon, and native material were easily recognizable within each core.

#### 4.2.2.3 Benthic Infauna Sampling

Two biological parameters, the benthic invertebrate and fish communities, were proposed for monitoring to determine whether the operation of the ECRTs system would have any adverse effects on nearby biota. The monitoring of both of these parameters was considered discretionary in terms of the success of the ECRTs process. The primary goal of monitoring benthic invertebrates and fish was to provide qualitative observations as to potential impacts to biota. The monitoring approach was designed to provide a minimal line of evidence of biotic conditions, with a scope that could be expanded if warranted.

The benthic infauna sampling methods were consistent with the methods used for monitoring the Log Pond Cap and Puget Sound Estuary Program (PSEP) protocols (PSEP 1987). Conventional parameters (sediment grain size and TOC) were analyzed at each location in conjunction with benthic infauna analysis. The TOC and grain size data were collected from three cores in the test plot, and the zone of influence; however the TOC and grain size data were collected separately for the benthic grab co-located with the OMMP benthic station.

Benthos samples were collected before sediment chemistry samples in order to attain undisturbed site conditions. Three replicate benthos samples were collected at each proposed station using a 0.1 m<sup>2</sup> van Veen grab sampler for a total of 15 benthic infaunal samples per sampling event. To verify that a sample was not disturbed during retrieval, the van Veen grab sampler was inspected according to the following PSEP criteria:

- Sampler is not overfilled,
- Overlying water is present (e.g., no leakage),
- Sediment surface is relatively flat (e.g., no evidence of disturbance or winnowing), and
- The following minimum penetration depths are achieved:
  - ▶ 4-5 cm for medium-coarse sand
  - ▶ 6-7 cm for fine sand
  - ▶ ≥ 10 cm for silts and clays

Once a sample was deemed acceptable, a description of the collected material was recorded in logbooks by the project scientist, including such information as penetration depth, color, texture, odor, and biological structures or any

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other notable features. Overlying water was carefully siphoned off and poured through a 1.0 mm sieve to retain any organisms siphoned from the sample. The material collected on the screens were transferred into plastic sample jars and preserved in 10% formalin. Samples were later preserved with a 70% ethanol, 5% glycerine, and 25% water solution for long-term storage.

Benthic infauna samples were collected from five locations within the log pond: three locations within the demonstration site, one location near the boundary of the anticipated area of influence, and one location outside the area of influence. The far-field sampling location was selected to coincide with a sampling location used as part of the OMMP monitoring. Three replicate samples were collected at each location. Samples were collected on two occasions including a baseline (August 19, 2002) and a mid-demonstration (January 10, 2003) sampling event. Because the mid-demonstration sampling event took place (January 10, 2003) about the same time that the ECRTs process was terminated, a post-demonstration sampling event was deemed unnecessary.

Formal benthic community analysis—identification and enumeration of organisms to the species level—was not performed. Laboratory analysis of benthic samples was not warranted for the ECRTs demonstration, and the preserved samples remain in archive. Following completion of the Demonstration, archived benthos samples were transferred to the U.S. EPA.

#### 4.2.2.4 Fish Community Monitoring

Three monitoring methodologies were originally proposed to monitor the fish community: seining, underwater video, and acoustical tracking. The underwater video and acoustical tracking methods were dropped from further consideration due to cost-saving measures. Underwater video was also hindered by low water clarity at the site for observing such highly mobile organisms as fish. The fish community was monitored to assess whether the operation of the ECRTs results in: 1) changes in community structure; 2) changes in fish behavior; and 3) serves as an "attractive nuisance" for electro-sensitive fish.

The Log Pond fish community was monitored on three separate occasions using a 15' x 150' purse seine. Three locations were seined twice each during each sampling event. Seining was conducted for the baseline and two intermediate sampling events. The third intermediate sampling event was canceled due to the inoperable condition of the ECRTs system. Fish monitoring was not conducted during the post-demonstration sampling event due to cost-saving measures and the fact that the second intermediate event was close to the time period that the

ECRTs became totally inoperable (late January).

The qualitative fish surveys were conducted using purse seines to ascertain the general community structure (based on species presence and relative abundance) of fish populations in proximity to the ECRTs test site. Particular attention was paid to evaluate whether the ECRTs served as an "attractive nuisance" based on the relative presence and abundance of potentially electro-sensitive fish (e.g., spiny dogfish). Three locations within the G-P Log Pond were selected for fish community monitoring, one in the vicinity of the demonstration site, and two outside the influence of the ECRTs. Each location was seined twice, during both the low and high tidal cycles for each sampling event.

The 150 foot long by 15 foot deep purse seine was fitted with 1/4-inch mesh, floats, leadline, rings, and purseline. The seine was deployed from the bow of the boat, with one end of the seine firmly anchored while the boat moved quickly in reverse in a tight circle. The ends of the net were joined together and then the lead line is "pursed" creating a closed bag. The net was then lifted onto the boat and fish were removed for processing.

At the completion of each purse seine, fish were removed and transferred into a live tank for processing. The demersal fish were identified and measured; measurements were from the tip of the nose to the end of the tail. Once 30 fish of one species were measured from the set, all remaining fish of that species were counted but not measured. Fish were also examined for any signs of external lesions or parasites. Great care was taken to avoid excessive mortality by minimizing fish handling, processing each catch as quickly as possible, and carefully returning each specimen to the water. Demersal invertebrates were identified to species, counted, measured where appropriate to indicate carapace length, and sex determined on appropriate species (e.g., crabs).

#### 4.2.2.5 Benthic Flux Monitoring

One concern of conducting an *in situ* remediation pilot project was the potential to impair overlying water quality through the mobilization of contaminants. Potential contaminant flux across the sediment-water interface was therefore identified as a secondary objective for the ECRTs demonstration project. This transport mechanism is of interest due to potential compromising of the existing cap, exposure of ecological receptors to contaminants, and loss (reduction) of contaminants by a mechanism different to those claimed by the ECRTs proponents. Three types of contaminant flux monitoring were considered: 1) In situ benthic flux monitoring using the Benthic Flux Sampling Device (BFSD); 2) Sequential Batch Leachate Testing

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(SBLT); and 3) sediment cap monitoring of bulk concentrations. Each method provides a varying degree of direct measurement of the relative mobility of contamination through the cap material and into overlying water. In each case a different matrix is evaluated, therefore preventing a direct comparison between data types and their subsequent interpretation. Quantitative methods (e.g. benthic flux chambers, and sequential batch leachate testing) to determine the potential contaminant flux across the water-sediment interface, however, were deemed beyond the scope of the demonstration project. Sediment cap monitoring was therefore chosen due to the fact that it was already included as part of the cost of the demonstration. As part of the current study design, the cap material was analyzed for contaminants of concern at each location. Increases in contaminant concentrations at the test site, in lieu of similar increases at the reference location, would indicate that the ECRTs demonstration resulted in the upward migration of contaminants.

#### 4.2.2.6 Electrical Field Monitoring

The areal extent of influence of the ECRTs system on site sediments was to be determined by measuring the in situ voltage at the site. The voltage measurements were to be collected using a custom-built voltage probe which was designed, built, and operated by Marine Sampling Systems (MSS). The voltage probe design and operation was approved by Weiss Associates as a sufficient methodology for measuring the in-situ electrical field. However, subsequent concerns by Weiss Associates regarding the proprietary nature of the electrical field resulted in cancelling collection of this data.

#### 4.2.2.7 Electrode Sampling - Mercury Mass Calculation

Upon completion of the demonstration, material was sampled from the electrodes at the time of their removal. The objective of the data collection effort was to provide supplemental evidence that mercury present in the test plot sediments was mobilized and plated to the electrodes via ionization and mobilization during the ECRTs demonstration. Samples were collected directly from the electrode plates prior to installation (time zero) and following the demonstration to evaluate whether mercury had migrated towards *the in situ* electrodes. In addition, sediment samples were collected from any material found clinging to the surface of the electrode at the time of removal.

All power supplies were disconnected from the system prior to commencing any removal activities. Electrodes were removed from the sediment using a truck-mounted construction crane parked on the Port of Bellingham dock, west of the test plot. A pontoon boat, operated by Wilder

Environmental, facilitated the electrodes removal from the Log Pond surface. Buoy lines attached through two holes drilled in the top of the electrodes were used to locate and remove each respective electrode. Once the buoy lines were suitably rigged to the crane's hook block, the electrodes were hoisted from the sediment using a slow, constant force to minimize strain on the buoy lines and prevent sloughing of material from the electrode's surface.

Once the electrode cleared the water's surface and had been adequately secured to prevent excessive movement (i.e. swinging or spinning), the electrode was marked to indicate which surface faced the test plot (interior surface) and which surface faced away from the test plot (exterior surface). The electrode was then checked for mercury vapor and bagged with heavy-duty polyethylene drum liners to minimize the potential for loss of material. Once secure on the dock, samples of any material loosely adhered to the electrodes surface were collected by SAIC staff. Each electrode was identified by its respective array (A = anode or C= cathode) and numbered sequentially (1,2,3...9) from south to north (e.g. A-1 and C-1 were the electrodes closest to the catwalk/electrical junction boxes). Once the sediment samples had been collected, the electrodes were transported to the processing facility for further examination and sample collection. The remaining electrodes did not have sufficient quantity of sediment adhering to their respective surfaces to constitute a viable sample.

Each electrode was photographed and visually examined at the processing facility. Observations and measurements were recorded and the general condition of the electrical connection was carefully examined and recorded in the field notebook.

### 4.3 Performance and Data Evaluation

This subsection presents a summary of the performance data obtained during the demonstration sampling and monitoring over a period of several months. A good portion of the results are presented in tabular or graphical form. These were computer-generated graphs from demonstration data in order to provide easier data interpretation. Evaluation of these data are included in the narrative and complete data, including a discussion of Quality Assurance measures, are available in the Technical Evaluation Report (TER), which is unpublished but available upon request from EPA.

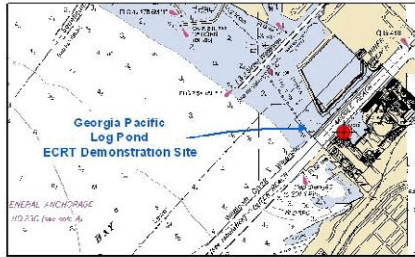
#### 4.3.1 Primary Objective

As previously stated, the primary technical objective was to determine whether there was a significant trend in the

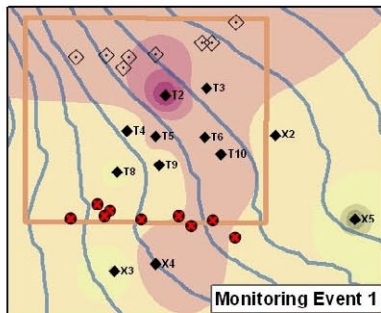
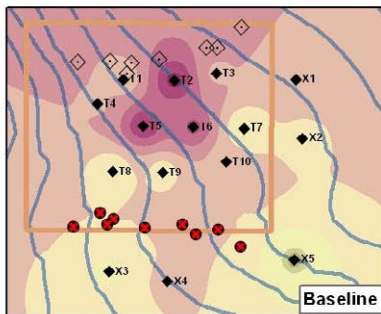
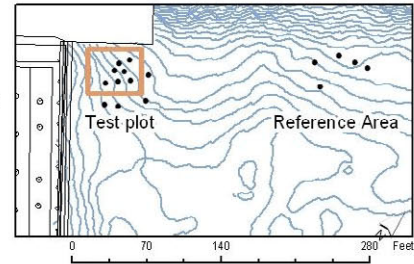
reduction of mercury in the test plot over the period of the demonstration that is attributable to the ECRTs process. For assessing this objective, composite samples from the contaminated sediment horizon were collected from the test plot during several sampling events, including a baseline event before operation of the ECRTs process. Figure 4-1 (Mercury Concentrations by Event: Test Plot - Sediment Horizon) presents a spatial representation of mercury concentrations in the test plot sediment horizon over the course of the Demonstration. In addition, the figure depicts the study plots, sampling locations, and electrode placement. Figure 4-2 is a graphical plot of the average mercury concentrations in the contaminated sediment horizon from the test plots. Table 4-2 is also included and shows the data used to plot Figure 4-1 and Figure 4-2. The sediment horizon was the contaminated portion of the test plot, treated as part of this demonstration. As previously mentioned, on top of this contaminated sediment horizon was a "cap material" which was used as a partial treatment of the G-P Log Pond. (A temporary fix or interim measure taken until a more permanent solution could be found.) Below the sediment horizon is the "native material". Samples were taken at ten different locations within the sediment horizon, the cap material, and the native material. Samples in the sediment horizon were obtained at three different vertical strata and additionally composite cores of the entire depth were also acquired. Composite cores of the sediment horizon were obtained to determine the primary objective associated with mercury concentration reductions. These same samples were used to determine SVOC concentration reductions. Samples were taken at three different vertical strata and above and below the sediment horizon in order to account for possible contaminant migration. Data for these samples will be discussed in subsequent paragraphs, included in this section. Mercury composite cores in the sediment horizon were considered critical as they were used to evaluate the primary project objective. Samples were taken over a period of approximately 6 months.

Technology operation was not constant over this time period, as explained previously, but sampling sessions were timed to anticipate optimum operational periods.

Grid Number	SAMPLING EVENT			
	Baseline	1 <sup>st</sup> Int.	2 <sup>nd</sup> Int.	Final
T1	116	---	---	33.9
T2	319	304	80.2	154
T3	141	115	146	125
T4	145	49.9	63.4	164
T5	304	113	172	64.0
T6	262	121	121	93.7
T7	31.6	---	135	149
T8	48.1	32.9	47.4	41.9
T9	71.6	82.3	60.8	98.1
T10	126	116	168	111
<b>Avg.</b>	<b>156</b>	<b>117</b>	<b>110</b>	<b>103</b>
SD	104	82.6	48	46
CV	0.66	0.71	0.44	0.45
90% UCL	205	207	163	116
90% LCL	108	27	58	90



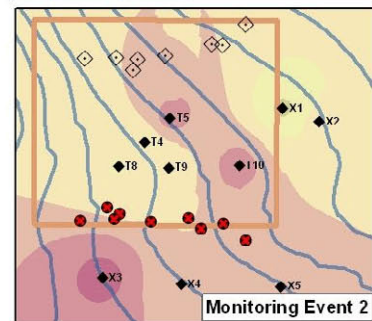
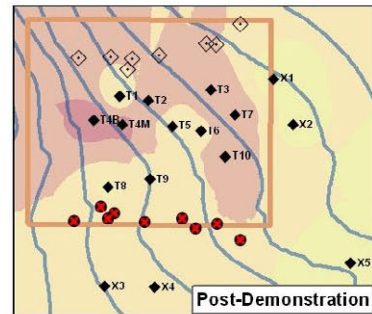
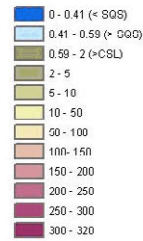
**Georgia Pacific Log Pond  
ECRT Demonstration Test Plot  
Mercury per Sampling Event  
Inverse-Distance Weighting Predicted Values  
SH - Composite**



0 5 10 20 30 40 50 Feet

- Negative Electrodes
- Positive Electrodes
- 1 Meter Bathymetric Contours

IDW predicted  
Mercury Concentration  
mg/kg



IDW Interpolations created using Spatial Analyst with default parameters.  
Grid values are for graphic presentation only and should not be used for map calculations.  
Data projected to UTM NAD 1983, Zone 10 and rotated to 313 degrees.

2004\_composite\_hq.mxd

**Figure 4-1. Spatial and Temporal Distribution of Mercury in Test Plot Sediment Horizon**

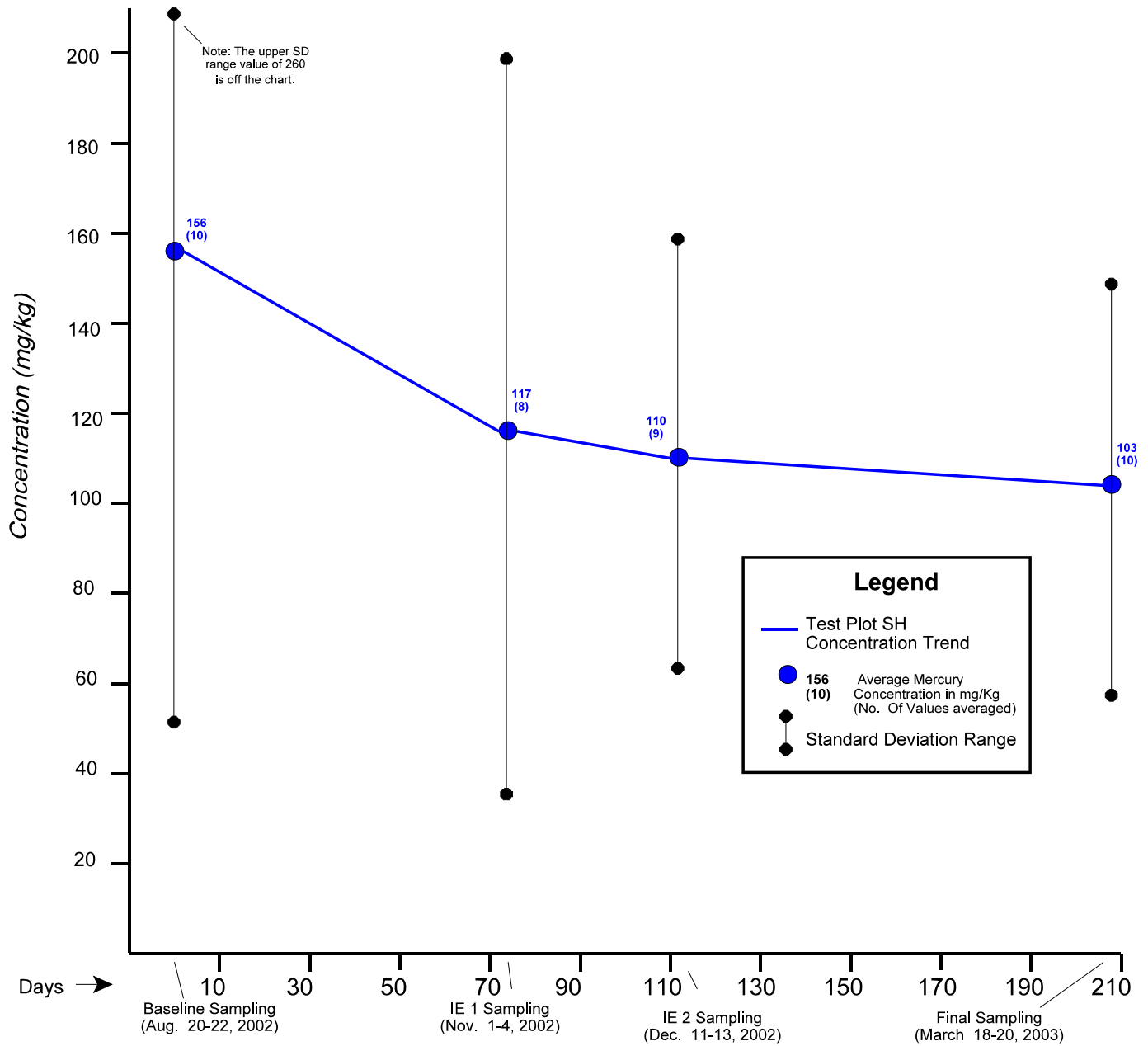


Figure 4-2. Average mercury concentrations in test plot sediment horizon.

Upon initial observation of Figure 4-2 it might appear that the mercury trend was decreasing over the 6 month operational period if, only average concentrations were considered. This same figure, however, shows the standard deviation bars around the average and as noted from these bars, concentrations from 10 sampling points within the 20 by 30 foot test area were very heterogeneous. Therefore, even though at first glance there may appear to be a decreasing trend, this trend should not be considered significant when standard deviations around the average concentrations are also included. An inferential statistical evaluation was therefore performed to determine whether or not there was a significant decreasing trend in mercury concentration in the test plot. This is explained in the subsequent paragraphs, which provide the detailed equations and resulting conclusions.

Statistical Model

Mercury concentration data were generated through assays of soil specimens taken from 10 test plot locations. The test plot locations were sampled on 4 separate occasions as follows:

Sampling Event	Date
Baseline	August 21, 2002
Event 1	November 5, 2002
Event 2	December 13, 2002
Final	March 19, 2003

These dates were used as single point estimates based upon actual sampling events that occurred over a period of a few days. This sampling approach specified a total of 40 mercury concentration measurements. A total of 37 measurements, however, were realized because 3 values were not obtained: the single measurement for Event 1 for test plot T7 and both measurements for Events 1 and 2 for test plot T1.

The first order decay rate model was assumed for the change in Hg concentrations within a test plot. Written symbolically, that model is:

$$Hg_t = C \cdot e^{-\lambda \cdot t}$$

with C being the initial concentration, λ being the decay rate, t being the elapsed time and Hg<sub>t</sub> being the Hg concentration at time.

With taking natural logarithms, we write the statistical model for the Puget Sound Demonstration test plot as:

$$Y_{ij} = \mu + \tau_i + \beta \cdot t_{ij} + \varepsilon_{ij}$$

where Y<sub>ij</sub> is the natural logarithm of the Hg concentration in mg/kg, μ is the mean intercept, τ<sub>i</sub> is the effect (or intercept effect) of the i<sup>th</sup> test plot for i = 1,2,...,10, β is the slope, t<sub>ij</sub> is the elapsed time in days for the i<sup>th</sup> test plot and j<sup>th</sup> sampling event for j = 1,2,3,4, and ε<sub>ij</sub> is the normally distributed error term with zero mean and variance σ<sup>2</sup>. Do note that:

- t<sub>i1</sub> = 0 days for Baseline monitoring
- t<sub>i2</sub> = 76 days for Event 1 monitoring ,
- t<sub>i3</sub> = 114 days for Event 2 monitoring ,
- t<sub>i4</sub> = 210 days for Final monitoring .

This model as constructed recognizes that the concentrations can vary across test plots, but the model does require that the single slope or decay rate is common to all test plots. Also observe that the decay rate is given by λ = -β and that the concentration half-life is given by:

$$\ln(2) / \lambda = -\ln(2) / \beta$$

The null hypothesis of no effect or of no removal is written as:

$$H_0 : \beta = 0$$

The slope coefficient β was estimated using maximum likelihood. The estimate was -0.00129 with a standard error of 0.001023 with 26 degrees of freedom. This point estimate of the slope β is equivalent to an estimate of the concentration half-life of 1.47 years. The estimates of β and standard error, nonetheless, yield a 2-tailed critical value of 0.219. Because the critical value is greater than 0.10, we reject the null hypothesis, at the 90% level.

This statistical analysis shows the decreasing trend in mercury concentration over time was not significant. Concentrations of mercury remained relatively heterogeneous but unchanging in the test plot during the duration of the demonstration. Based on the statistical analysis, the ECRTs process was not effective in reducing mercury concentrations over time in the test plot. Therefore, the primary objective regarding mercury reduction was not achieved.

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The statistical analysis of the ECRTs process performance is also supported by an examination of the spatial and temporal changes in mercury concentration from the contaminated sediment horizon of the test plot (see Figure 4-1). The figure depicts the spatial distribution of mercury from the contaminated sediment horizon within the test plot, as well from an extended zone outside of the effects of the ECRTs electrical field. All four sampling events are presented. The plots depict some changes in the spatial distribution of mercury. However, from a remedial and performance perspective, these differences are insignificant. It is important to note that no location during any of the post-baseline sampling events came close to the site's mercury cleanup screening level (CSL) of 0.59 mg/kg dry wt.

Operational problems with the ECRTs process may be responsible for the lack of a significant reduction in mercury levels in the test plot. Electrical readings collected by the technology's sponsor (Weiss) indicated a steady degradation of system performance throughout the duration of the demonstration, resulting in an early shutdown of the system prior to completion of the planned test period. In addition, when the electrodes were removed from the test plot, it was evident that the connections between the electrical supply and anode plates had completely corroded to the point that a viable contact had not been made. Therefore, it is uncertain exactly how long (and to what extent) the ECRTs process was fully functional and operational. Since the performance of the system is totally dependant on the effectiveness of the electrical connections and resultant electrical field, the ECRTs process should have a monitoring protocol to identify and quickly rectify any problems associated with electrical current distribution and field propagation.

#### **4.3.2 Secondary Objectives**

*Objective 2* for the demonstration was to determine the rate of organic compound mineralization (PAHs and phenols). This was evaluated by analyzing for SVOCs from ten sample locations collected within the test plot. Both

discrete intervals and composite test plot cores, which included the entire depth of the test plot, were collected. This was a secondary objective because SVOC concentrations were not considered to be significantly high enough, and exhibited high variability, in baseline samples to statistically determine a quantitative rate parameter for a potential decrease. SVOC concentrations for the compounds that were at high enough concentrations to plot the data over the course of the demonstration are presented in Figures 4-3 through 4-14. Data are presented for both the test plot and the extended zone of influence.

These plots include concentrations over the period of the demonstration for naphthalene, 2-methylnaphthalene, acenaphthalene, flourene, flouranthene, and 4-methylphenol. All other SW-846 method 8270 compounds were at concentrations too low to be able to observe any possible decrease.

As noted some of these graphs are similar to the mercury graphs, which show a potential decrease in average concentrations, however, because of the heterogeneity of compound concentrations in the test plot, these decreases are not considered significant when standard deviations are also included in the evaluation. (Standard deviation bars are included as part of the graphs.) These compounds show no apparent decrease in concentration. This would confirm previous conclusions about the process and its inability during this demonstration to significantly reduce concentrations of inorganic compounds through ionization and mobilization due to operational problems.

The ECRTs technology demonstration was also unsuccessful at reducing organic compounds through mineralization. Overall it is believed that because of problems encountered by the developer for this demonstration that there was no significant effect on hazardous compound concentrations. The data suggest that there were no significant decreases in any of the compounds analyzed at the G-P log pond site.



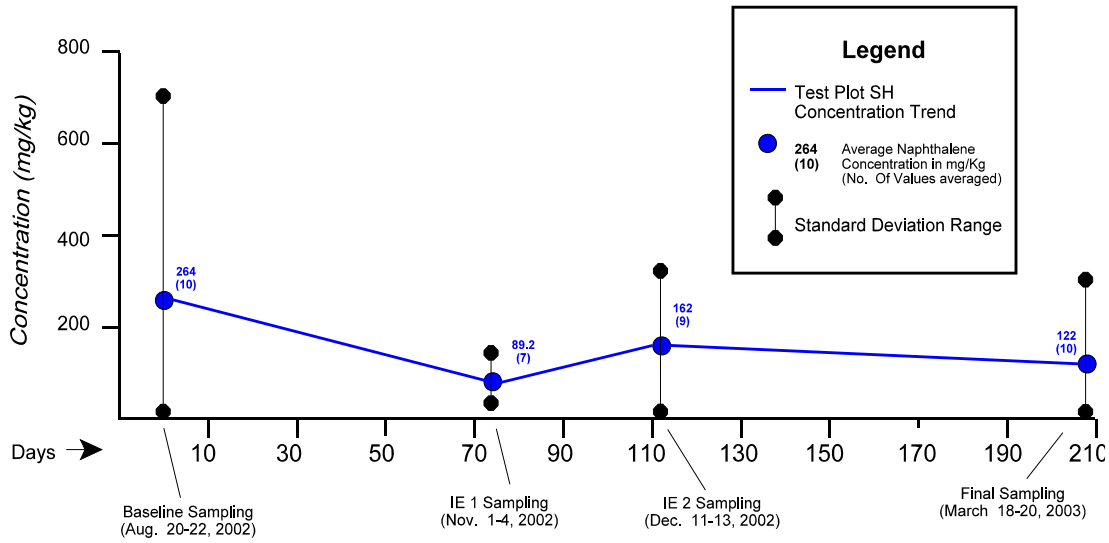


Figure 4-3. Average naphthalene concentrations in test plot sediment horizon.

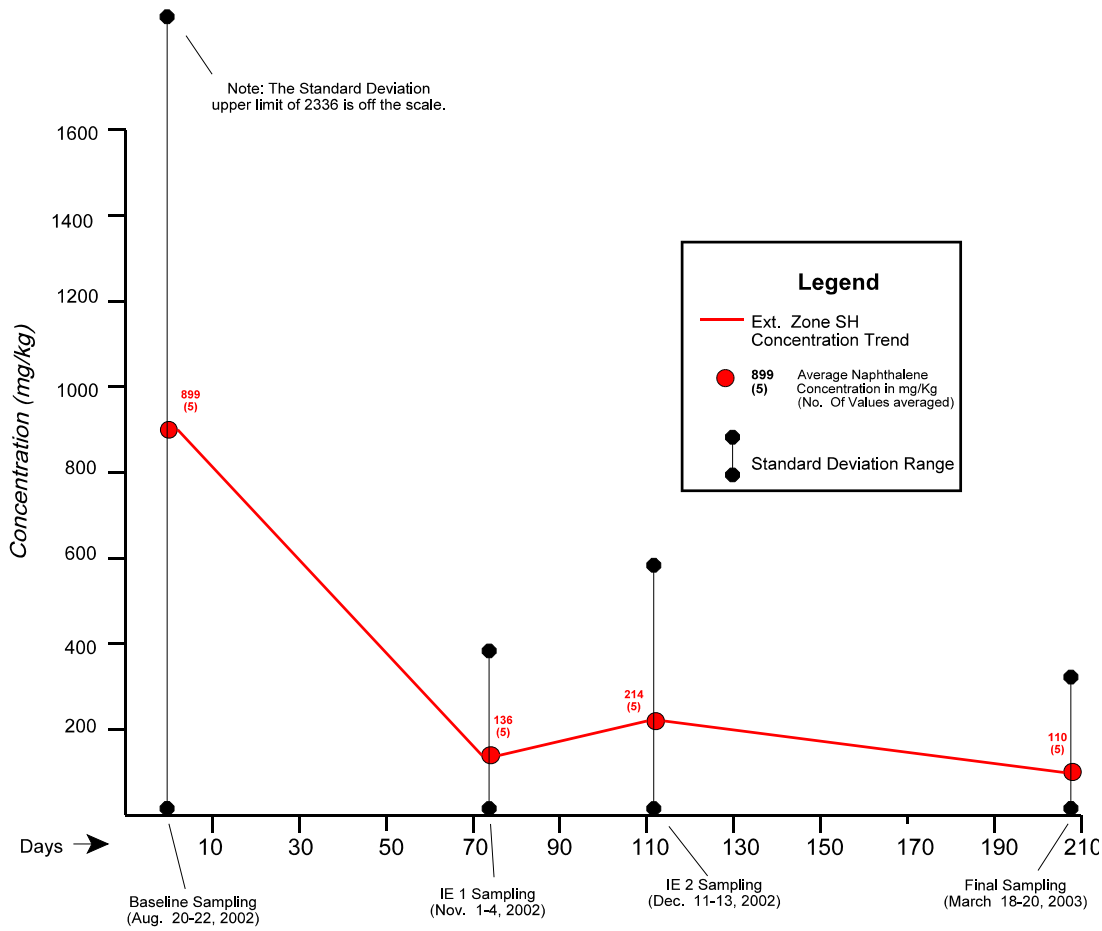


Figure 4-4. Average naphthalene concentrations in extended zone sediment horizon.

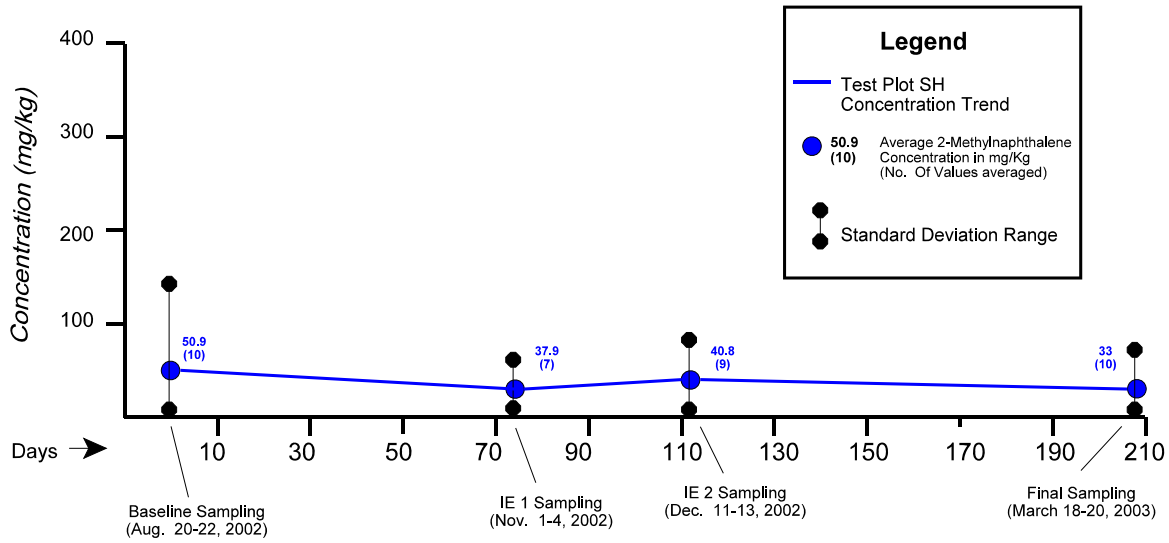


Figure 4-5. Average 2-methylnaphthalene concentrations in test plot sediment horizon.

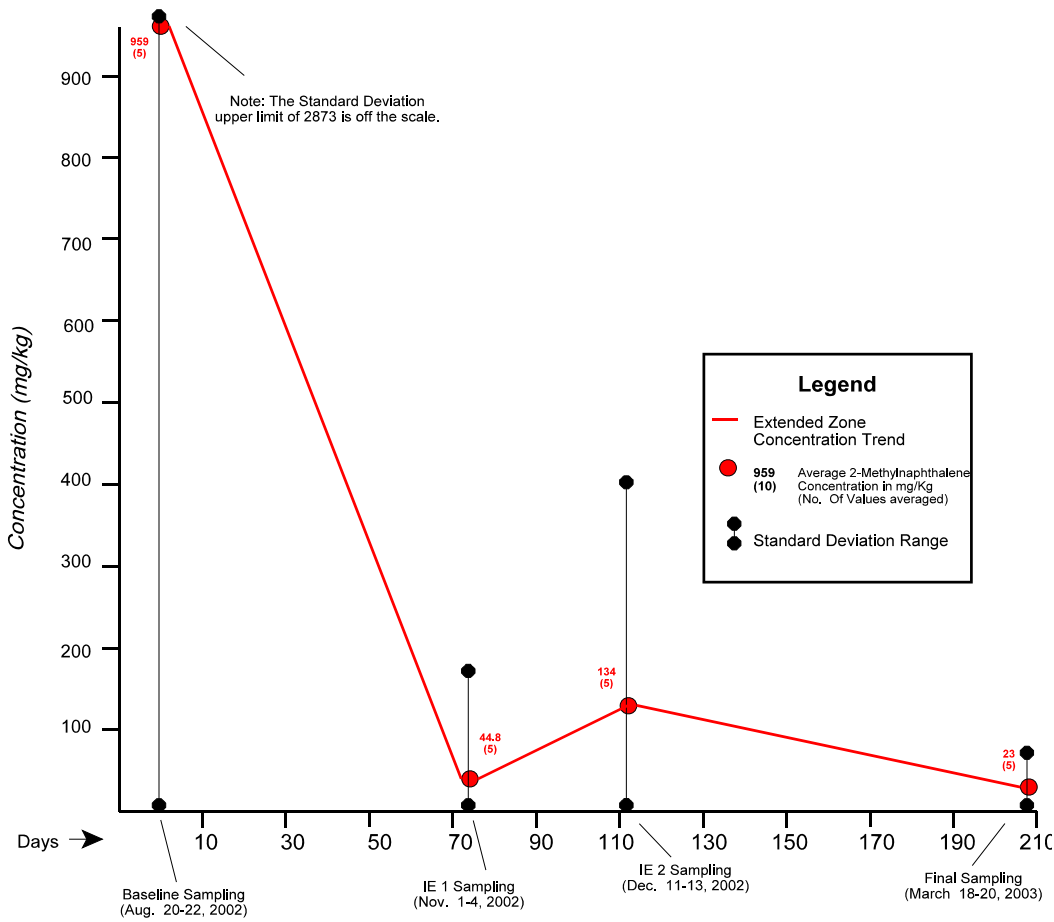


Figure 4-6. 2-methylnaphthalene concentrations in extended zone sediment horizon.

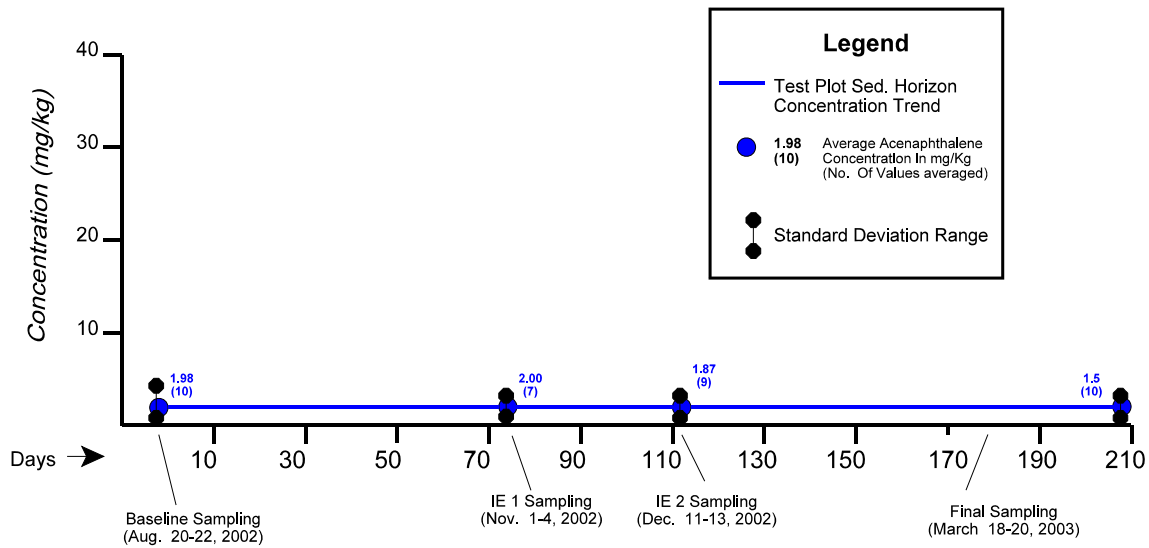


Figure 4-7. Average acenaphthalene concentrations in test plot sediment horizon.

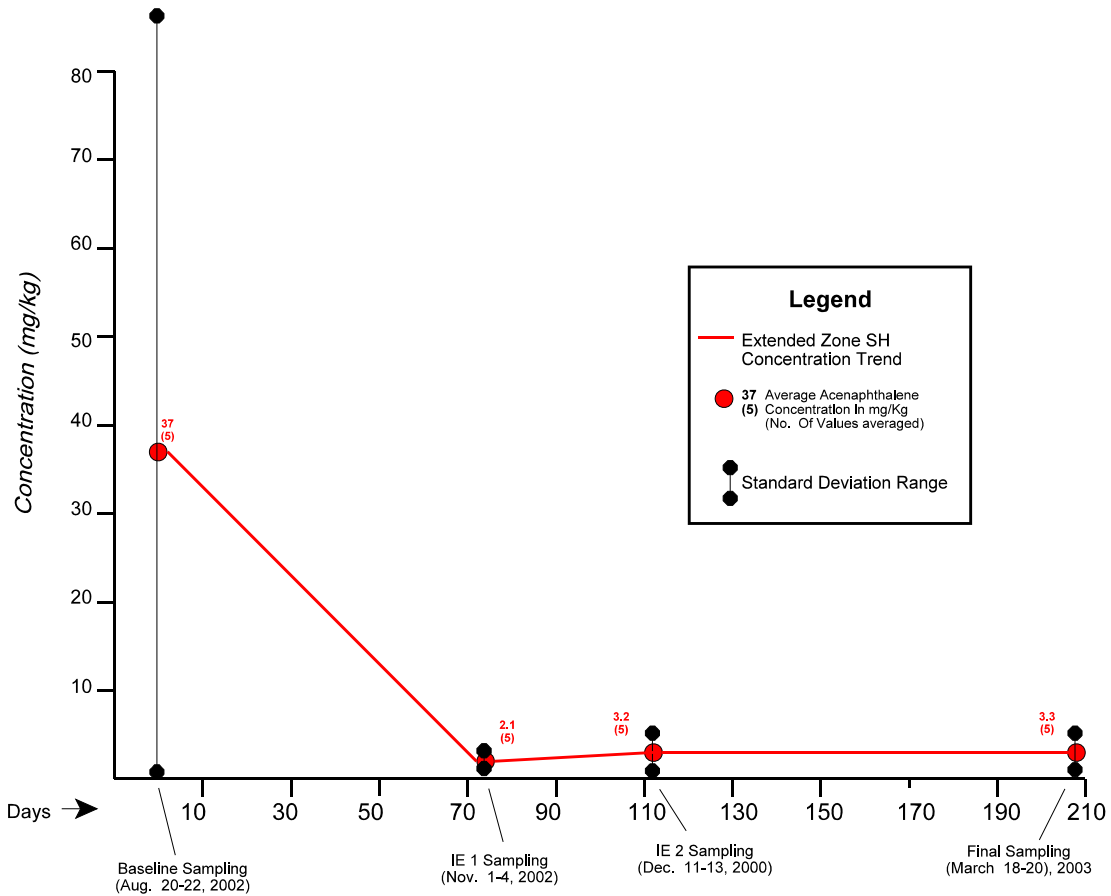


Figure 4-8. Average acenaphthalene concentrations in extended zone sediment horizon.

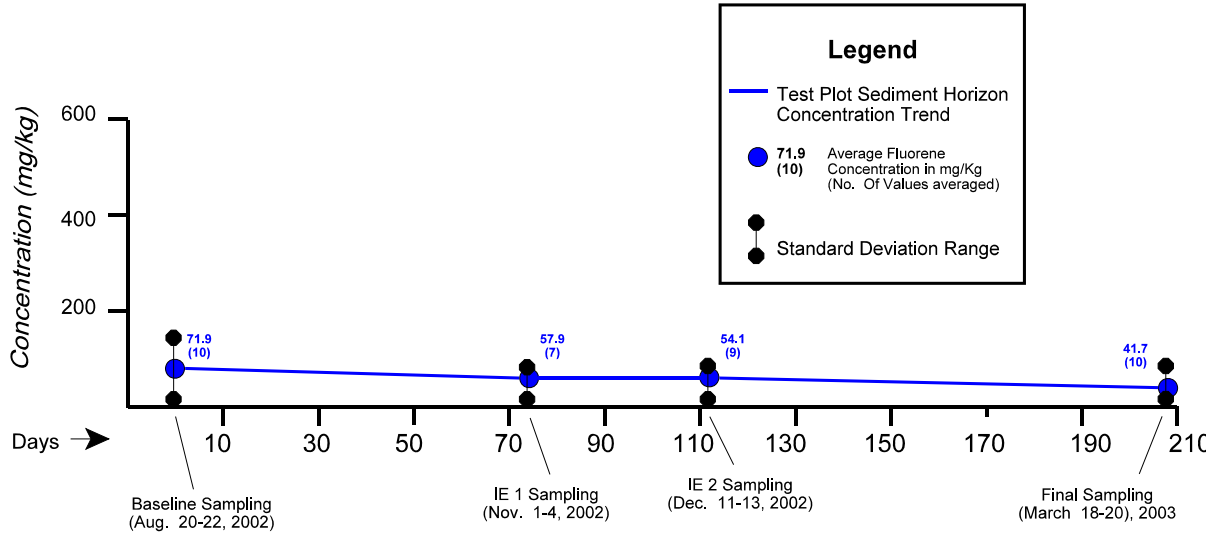


Figure 4-9. Average fluorene concentrations in test plot sediment horizon.

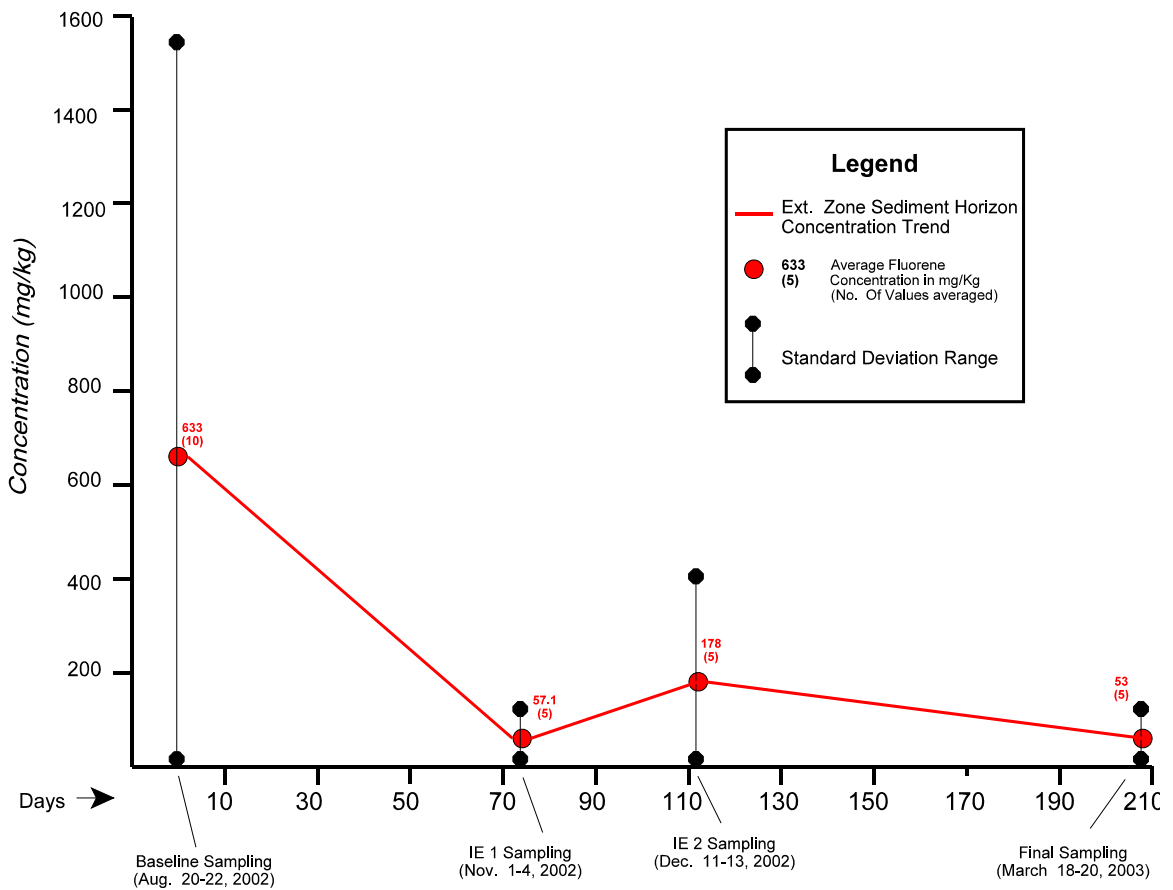


Figure 4-10. Average fluorene concentrations in extended zone sediment horizon.

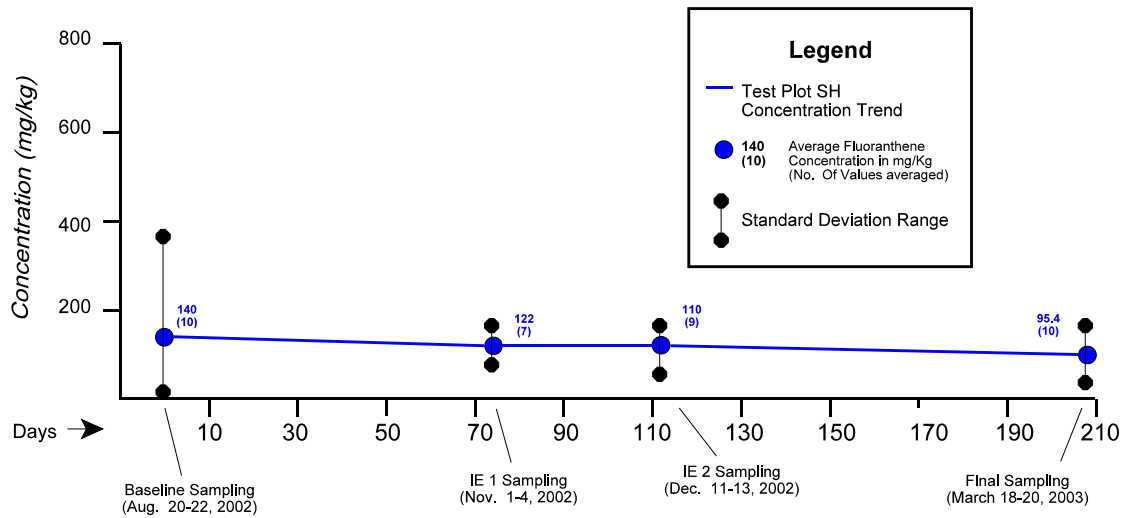


Figure 4-11. Average fluoranthene concentrations in test plot sediment horizon.

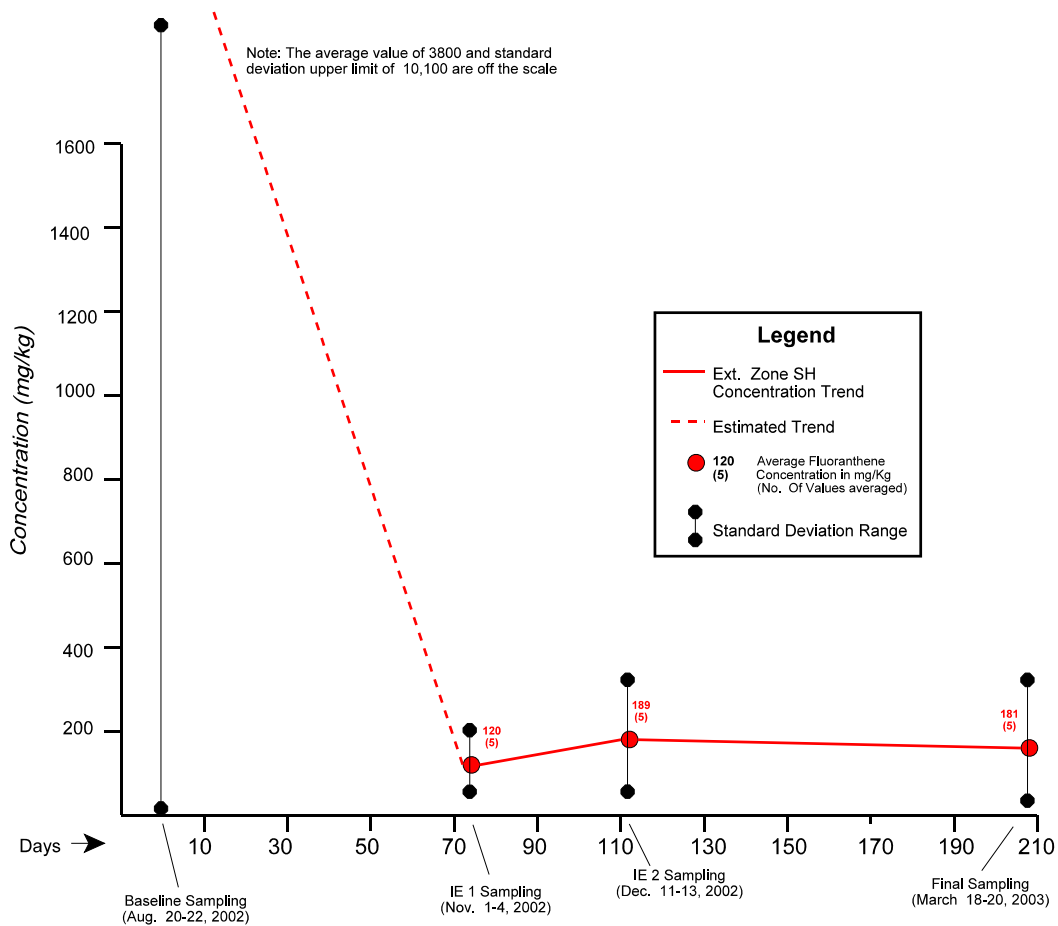


Figure 4-12. Average fluoranthene concentrations in extended zone sediment horizon.

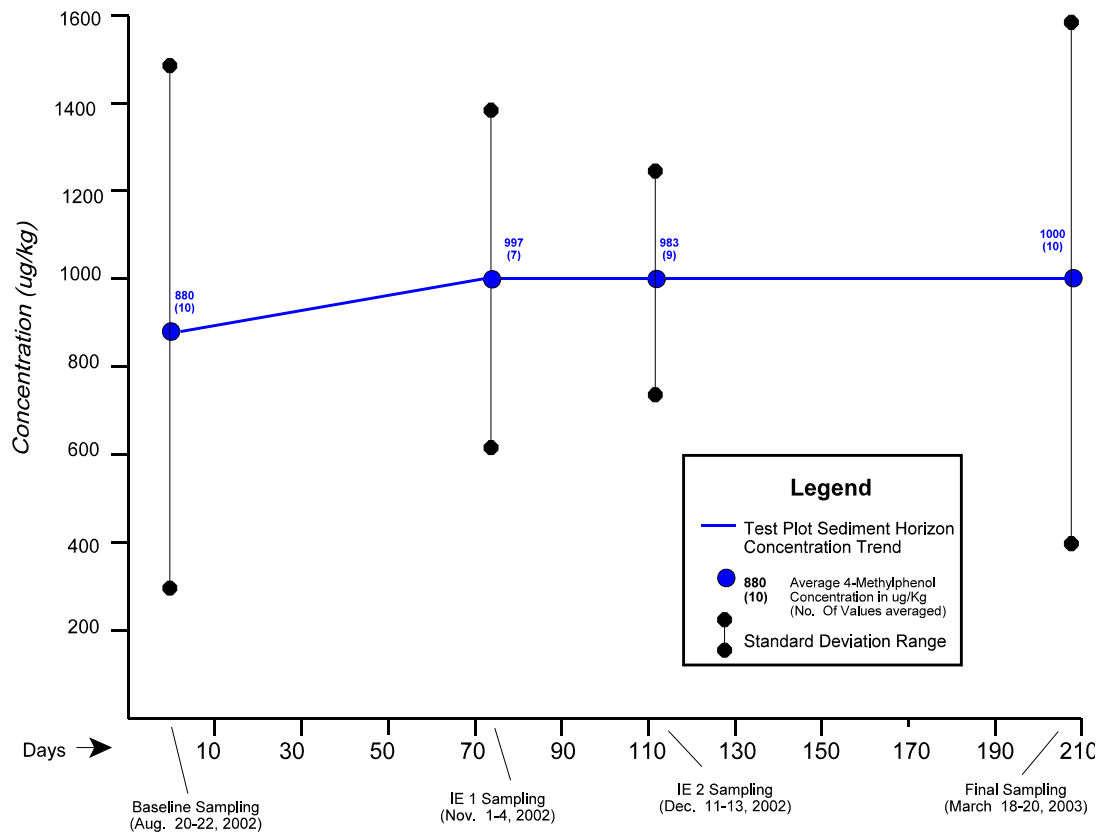


Figure 4-13. Average 4-methylphenol concentrations in test plot sediment horizon.

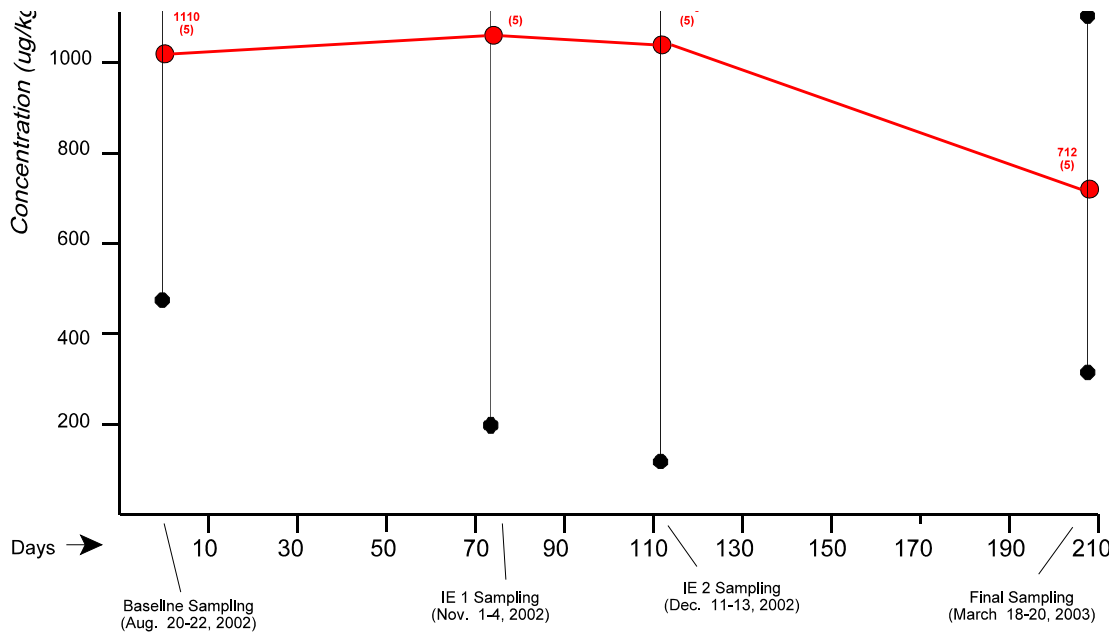


Figure 4-14. Average 4-methylphenol concentrations in extended zone sediment horizon.

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*Objective 3* was evaluated in order to assess vertical migration of contaminants (e.g. induced complexation and mobilization of mercury). This was proposed since possible decreases in concentration in any of the different horizons (sediment, cap, or native material) could be due to vertical migration of contaminants rather than actual remediation. There was, however, no significant decrease in contamination for any of the contaminants of concern within the test plot for the contaminated horizon, as noted previously. Nonetheless, vertical migration was shown by plotting concentrations of mercury in each of the separate horizons including the cap material and native material. Figures 4-2, 4-15 and 4-16 show no significant changes in concentration of mercury within the three previously defined vertical horizons; not only confirming that the technology had no effect on mercury migration but also showing that contaminants did not appear to significantly move within the specified horizons. This is not unexpected since the lack of a significant electrical field would have not significantly mobilized mercury. These plots were not generated for the SVOCs as there appeared to be no significant information that could be gained from plotting these additional data.

*Objectives 4 and 5* were evaluated to determine the extent of the zone of influence of the ECRTs through spatial measurement of electric potential and also track changes in compound concentrations outside the immediate area of influence, designated as the extended zone. The extended zone (area immediately outside the designated test plot) was considered as an area of influence that may also show treatment effects of the demonstration. Figure 4-17 presents summary data for mercury concentrations from the Extended Zone. Based upon this figure, there appears to be no significant decrease in mercury concentration due to the ECRTs treatment technology. A decrease in the extended zone would not be expected, however, because of a lack of an effective electrical field even in the test plot. In addition, data from the extended zone of influence for the previously noted SVOCs are included in figures 4-3 through 4-14. These also show no evidence of significant decrease for any of the noted compounds.

Voltage probe measurements were taken during the early phase of the Demonstration as a method for evaluating the spatial extent of the zone of influence of the ECRTs system. The voltage measurement data were not evaluated

as part of this report due to their proprietary nature and as such no conclusions concerning these data are presented in this report. These data, however, were evaluated and discussed between Weiss Associates, Ecology, and USEPA at the time of their collection.

*Objective 6* was intended to track natural attenuation changes (if any) in contaminant concentrations by sampling and analysis of a reference area located outside the ECRTs' zone of influence. Figure 4-18 shows collected mercury data over the period of the demonstration for the reference plot. This figure shows no significant change in mercury concentration over the period of the demonstration. The reason for obtaining data from the reference plot was to show that if there was a decrease in concentration of mercury in the test plot, then it would be necessary to show that this decrease was not due to natural attenuation. Since there was no significant decrease in mercury concentration in the test plot over the period of the demonstration, there was no decrease expected in the reference plot. This is shown to be true by graphing the data over the duration of the demonstration in a similar fashion as the graph for the test plot data. No similar graphs are constructed for the SVOC data because there was no concentration decrease in the test plot for the analyzed compounds and therefore no natural attenuation was anticipated.

*Objective 7* evaluated possible environmental effects of ECRTs including benthic infauna effects and possible behavioral effects on sensitive fish. Qualitative observations made at the time the samples were being sieved, indicated the clean sediment cap had been readily colonized by numerous polychaetes, amphipods, and mollusks. Samples collected during the active demonstration appeared to have the same relative abundance and composition, based solely on a visual assessment, as samples collected during the baseline sampling event. There was no outward evidence that the ECRTs system was having an adverse impact on the local benthic community (i.e. sterile substrate). Since the ECRTs process was not properly functioning, it cannot be concluded that the process, if properly operating, would have no adverse impact on the benthic infauna and sensitive fish.

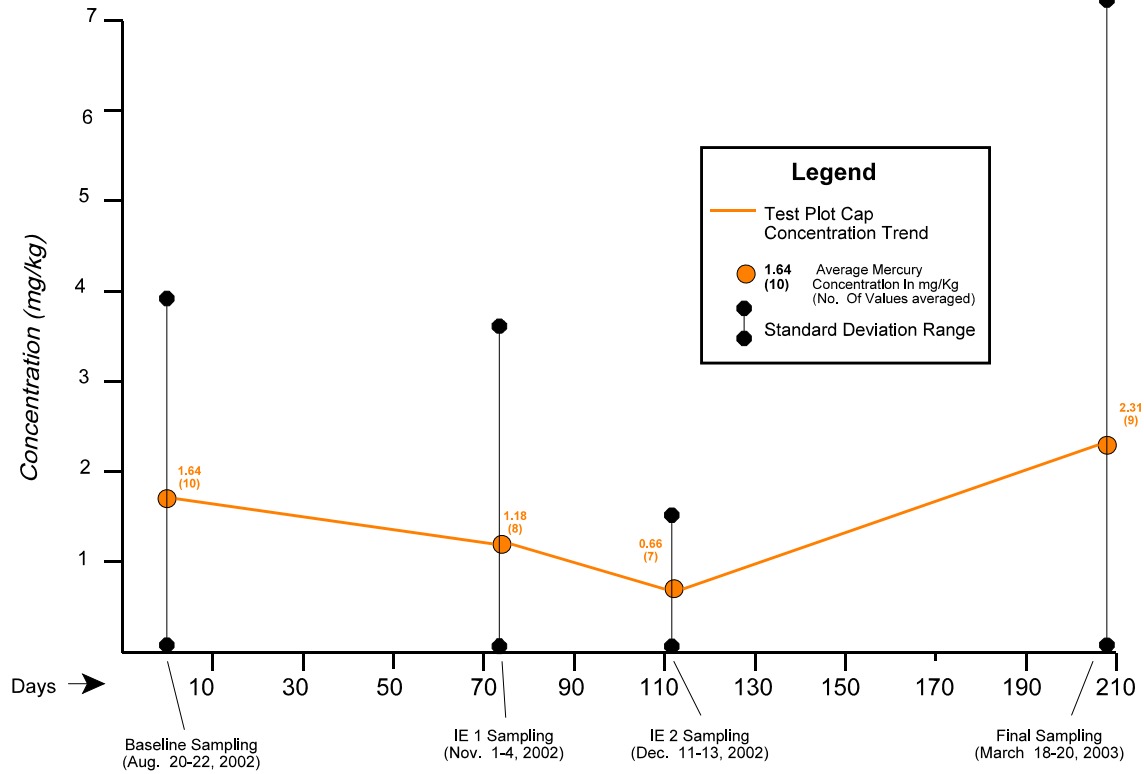


Figure 4-15. Average mercury concentrations in test plot cap.

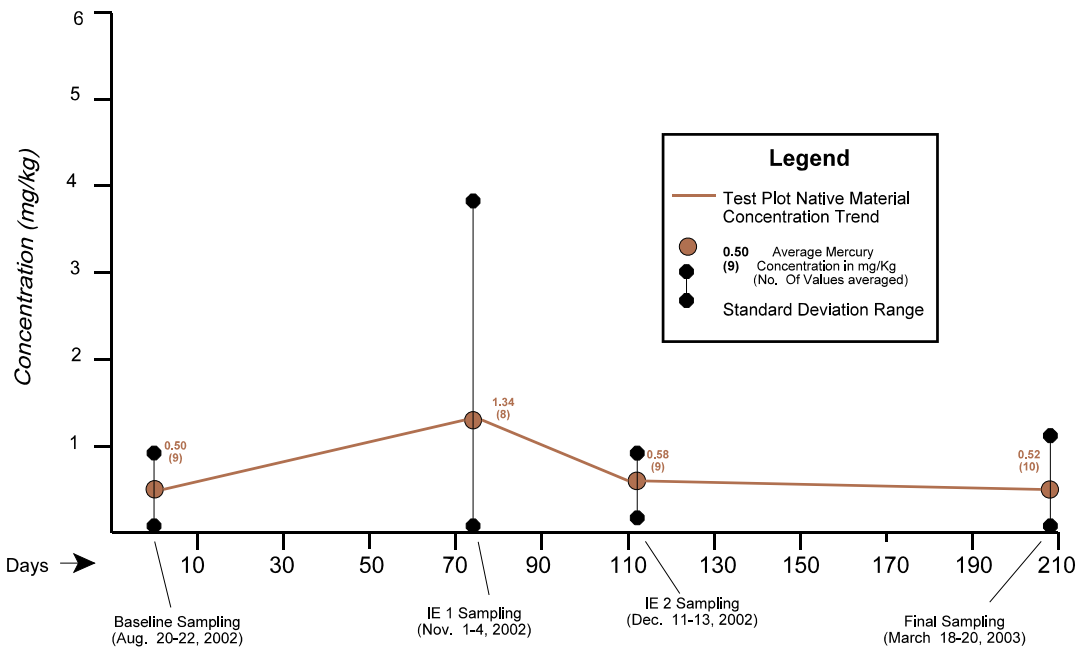


Figure 4-16. Average mercury concentrations in test plot native material.



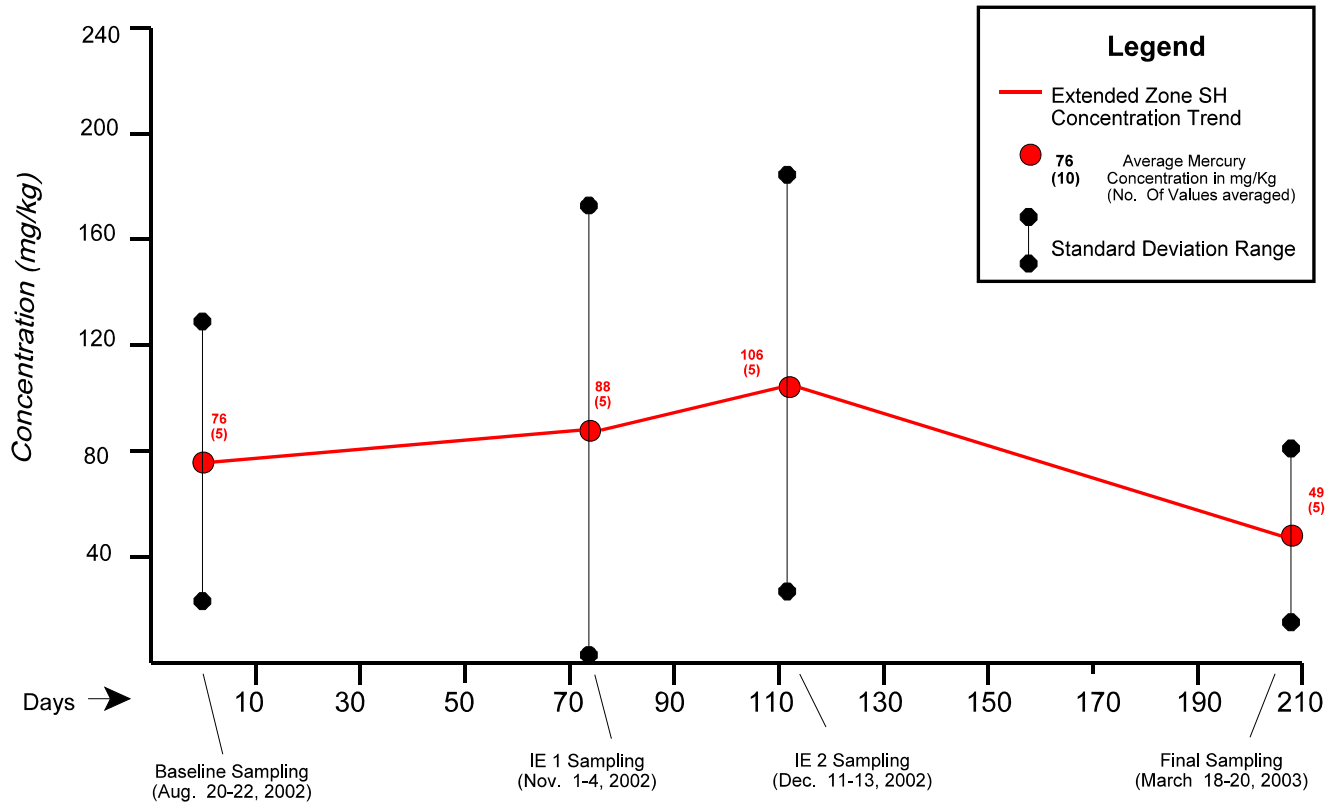


Figure 4-17. Average mercury concentrations in extended zone sediment horizon.

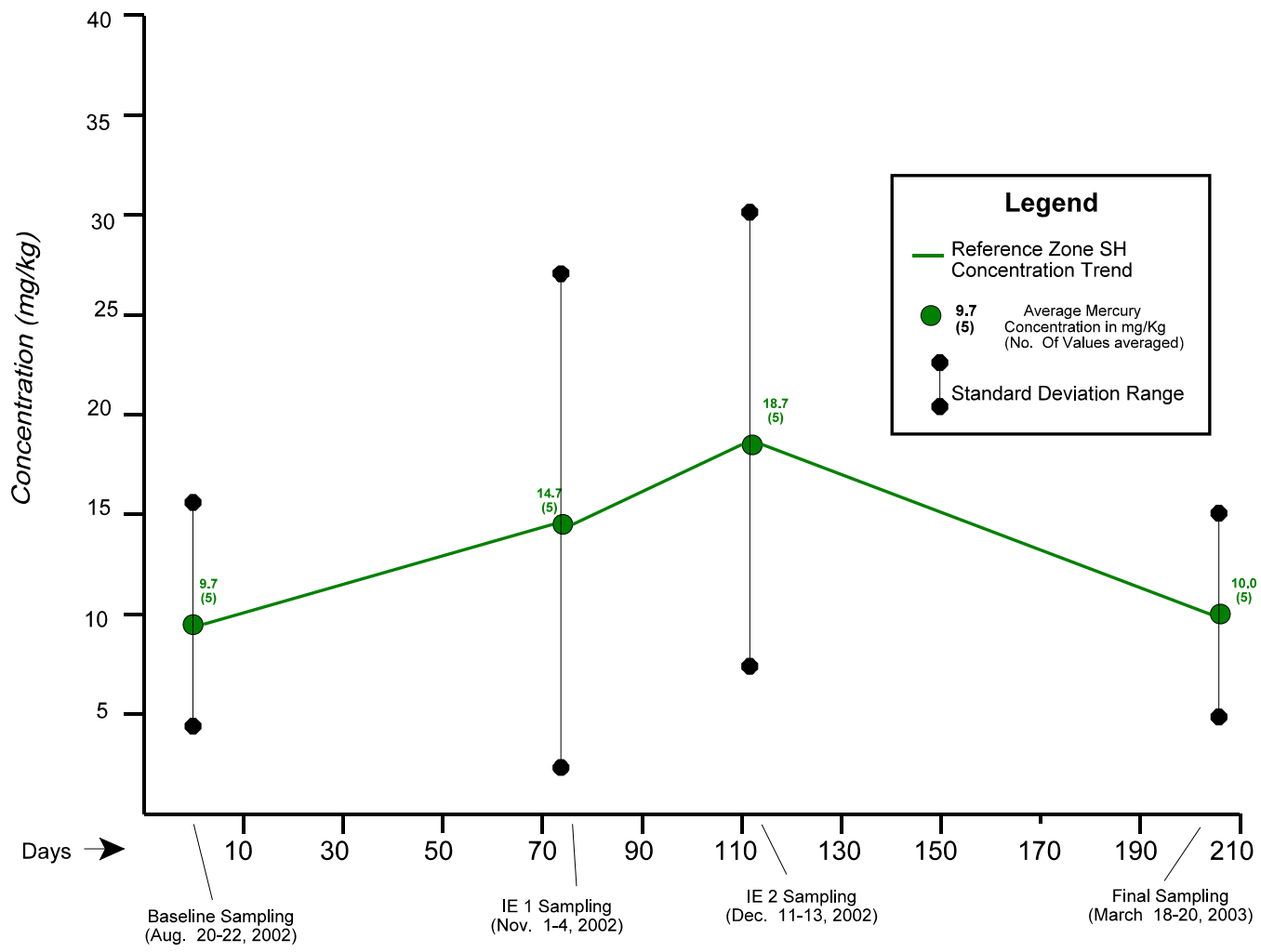


Figure 4-18. Average mercury concentrations in reference zone sediment horizon.

Table 4-3 provides the species list for the seining efforts. Shiner perch were the most abundant species at each location during the baseline event and first intermediate event, with the exception of the open water location in October. Shrimp were the most abundant species at each location during the January sampling event. The species list observed during the demonstration monitoring was consistent (albeit a subset) with the species observed in beach seines conducted in July and August, 2000 (Anchor Environmental 2000). No fish considered to be electro-sensitive such as the spiny dogfish, the spotted ratfish, or pacific lamprey, were observed during any of the seining or sampling events. In addition, no fish kills or erratic fish behavior were observed at any time during the operation of the ECRTs system.

Objective 8 was to evaluate potential contaminant flux

across the water-sediment interface. The cap material was analyzed for contaminants of concern at each location. Table 4-4 summarizes the mercury concentrations for each sampling event and study area.

On average, the sediment cap had a minor increase in mercury concentrations from baseline to post-demonstration. However, these results were not consistent, as seven of the twenty locations monitored during the demonstration exhibited a net decrease in mercury concentrations. The largest net change in mercury concentrations was at sampling point T5, located towards the center of the test plot. Since slight increases were observed at the test plot location, the extended zone, and reference area, it does not appear that these increases were a result of contaminant mobility. It is likely that the nominal changes in the mercury concentrations in the cap material are due to the

physical disruption of the cap from the large number of cores collected from the site. Incidental mixing of the cap with underlying sediments having elevated mercury concentrations may have occurred from material clinging to, and sloughing from, the outside of core tubes during

extraction. The relative larger concentration changes at single locations are indicative of the higher mercury concentration in the underlying sediments.

**Table 4-3 Fish and macroinvertebrate species present**

Sampling Event	Date	South Log Pond <sup>1</sup>	Mid-Log Pond <sup>2</sup>	North Log Pond <sup>3</sup>
Baseline	9/6/02	shiner perch dungeness crab bay pipefish	shiner perch	shiner perch starry flounder staghorn sculpin dungeness crab
First Intermediate	10/22/02	Shiner perch dungeness crab Starry flounder herring	No catch	Shiner perch
Second Intermediate	1/9/03	Bay pipefish shrimp dungeness crab	Dungeness crab shrimp	shrimp
Third Intermediate <sup>4</sup>	Canceled	n/a	n/a	n/a
Baseline <sup>5</sup>	Canceled	n/a	n/a	n/a

**Bold** typeface indicates most abundant species.

n/a: not applicable

1: The South Log Pond site coincided with the location of ECRTs electrode array, seining was conducted between the eastern shoreline and the electrode array to avoid entanglement with buoys and buoy-lines used to mark the underwater location of individual electrodes.

2: The mid-Log Pond location was in open water adjacent to Whatcom Waterway.

3: The North Log Pond location was adjacent to the pier and bulkhead along the northern shoreline to best simulate conditions similar to the ECRTs location, but outside its area of influence.

4: The third intermediate monitoring event was canceled since the ECRTs system was completely inoperable by late January.

5: The post-season fish monitoring was deemed unwarranted by project stakeholders and was canceled as a cost-savings measure.

**Table 4-4: Mercury concentrations in sediment cap samples**

Test Area	Baseline	Monitoring Event 1	Monitoring Event 2	Post-Demonstration	Mean	Net change <sup>1</sup>
T1	2.31	-	-	-	2.31	-
T2	0.55	7.34	-	0.24	0.40	-0.31
T3	0.65	.57	-	0.69	0.67	0.04
T4	7.72	0.26	1.11	2.13	3.37	-5.59
T5	1.72	0.82	2.55	15.30	5.10	13.58
T6	0.39	0.11	0.24	0.20	0.23	-0.19
T7	0.30	0.30	0.2	1.21	0.60	0.91
T8	2.63	0.20	0.19	0.74	0.94	-1.89
T9	0.05	0.07	0.28	0.15	0.16	0.1
T10	0.04	0.10	0.05	0.11	0.08	0.07
Mean	1.64	1.09	0.66	2.31	1.46	0.75
Extended Area						
X1	0.06	0.19	0.68	0.78	0.43	0.72
X2	0.04	0.09	0.15	2.27	0.64	2.23
X3	2.1	0.2	0.44	0.93	0.92	-1.17
X4	0.07	0.11	0.09	0.3	0.14	0.23
X5	0.04	0.03	0.03	0.02	0.03	-0.02
Mean	0.46	0.12	0.28	0.52	0.41	0.40
Reference Area						
R1	0.08	0.15	0.28	0.14	0.16	0.06
R2	-	0.09	-	0.06	0.08	0.06
R3	0.03	0.06	0.03	0.04	0.04	0.01
R4	0.06	0.06	0.06	0.18	0.09	0.12
R5	0.06	0.04	0.36	0.05	0.13	-0.01
Mean	0.06	0.08	0.18	0.09	0.10	0.03

**Notes:**

-: data not collected either due to insufficient quantity of cap material in core sample, or core was not collected during a given sampling event.  
 1: Change in mercury concentration (mg/kg dry wt.) from Baseline to Post-Demonstration sampling event, with the exception of Station R2, where change is from Event 1 to Post-Demonstration.

*Objective 9* evaluated migration of mercury towards the electrodes. Due to the methodology of electrode sample collection, a direct comparison between the anode and cathode results was not practical. The graphite plugs may understate the total mercury concentration on the anodes due to relatively low surface to volume ratio of electrode material. The mercury concentrations for the cathodes (surface scrapings) are therefore more representative of material directly adhered to the electrode surface.

The surface scrapings, could be best described as a powdery material comprised mainly of the oxidized surface of the steel plates (i.e.rust). The purpose for collecting any

sediment clinging to the electrodes at removal was to provide an indication of the mercury concentrations of material in direct contact with the electrodes. If mercury was being mobilized and concentrated, then the sediments in direct contact with the electrodes should be enriched in mercury relative to the contaminated sediment sampled from the test plot. Due to the relative particle size, the sediment samples consisted of a surface to volume ratio greater than the graphite plugs (anodes) but less than the surface scrapings (cathodes). Table 4-5 provides a summary of the analytical results for the electrode sampling.

**Table 4-5 Summary of Mercury Analyses for Post-Demonstration Electrodes**

Sample ID	Date Collected	Sample Matrix	Sample Type	Mercury (mg/kg dry wt.)
<b>Anodes<sup>1</sup></b>				
FIN-G0-PM-A	4/2/2003	graphite	time-zero	0.01 U
FIN-G0-PM-B	4/2/2003	graphite	time-zero	0.01 B
FIN-A1-PM-D	4/1/2003	graphite	solid plug	0.01 U
FIN-A2-PM-B	4/1/2003	graphite	solid plug	0.03
FIN-A3-PM-A	4/1/2003	graphite	solid plug	0.01 U
FIN-A4-PM-E	4/1/2003	graphite	solid plug	0.14
FIN-A5-PM-B	4/2/2003	graphite	solid plug	0.01 B
FIN-A6-PM-C	4/2/2003	graphite	solid plug	0.01 U
FIN-A7-PM-A	4/2/2003	graphite	solid plug	0.01 B
FIN-A8-PM-D	4/2/2003	graphite	solid plug	0.01 U
FIN-A9-PM-C	4/2/2003	graphite	solid plug	0.01 U
<b>Cathodes<sup>2</sup></b>				
FIN-S0-PM-A	4/4/2003	steel	time-zero	0.01 U
FIN-S0-PM-B	4/4/2003	steel	time-zero	0.01 U
FIN-C1-IS-B	4/2/2003	steel	surface scrape	4.05
FIN-C2-IS-C	4/2/2003	steel	surface scrape	15.4
FIN-C3-IS-B	4/2/2003	steel	surface scrape	11
FIN-C3-IS-C	4/2/2003	steel	surface scrape	23.8
FIN-C3-ES-D	4/2/2003	steel	surface scrape	10.6
FIN-C3-ES-E	4/2/2003	steel	surface scrape	16
FIN-C4-IS-B	4/2/2003	steel	surface scrape	13.1
FIN-C4-ES-C	4/2/2003	steel	surface scrape	8.56
FIN-C5-IS-D	4/2/2003	steel	surface scrape	3.5
FIN-C6-IS-C	4/2/2003	steel	surface scrape	10.7
FIN-C7-IS-A	4/2/2003	steel	surface scrape	3.28
FIN-C8-IS-B	4/2/2003	steel	surface scrape	10.5
FIN-C9-P M-C	4/2/2003	graphite	solid plug	0.02 B

Sediment Samples <sup>3</sup>				Mercury (mg/kg Dry Wt.)	Total Solids (%)
FIN-A2-S	4/1/2003	sediment	plate surface	25.9	66.6
FIN-A8-S	4/1/2003	sediment	plate surface	0.94	31.7
FIN-C1-S	4/1/2003	sediment	plate surface	0.28	81.8
FIN-C2-S	4/1/2003	sediment	plate surface	0.15	85.9
FIN-C3-S	4/1/2003	sediment	plate surface	10.1	56.2
FIN-C4-S	4/1/2003	sediment	plate surface	3.73	70.5
FIN-C5-S	4/1/2003	sediment	plate surface	1.35	76.6
FIN-C7-S	4/1/2003	sediment	plate surface	5.07	47.1
FIN-C8-S	4/1/2003	sediment	plate surface	2.86	52

**Notes:**

1: FIN-G0-PM-A and FIN-G0-PM-B represent samples of electrode material collected prior to installation and archived until the demonstration was complete; samples from the graphite anodes were collected using a 1" diameter hole-cutting drill bit, the entire 'plug' was submitted for analysis.

2: FIN-S0-PM-A and FIN-S0-PM-B represent samples of electrode material collected prior to ECRTs installation; time-zero samples were collected using a hack saw to remove a representative piece of material; post-demonstration samples were scraped from the surface of the electrodes and were representative of the electrode surface exposed to the sediment; the designations 'IS' and 'ES' within the sample ID indicate 'interior surface' and 'exterior surface' of the electrode in relation to the test plot, i.e. the interior faced the test plot and array of anodes; the sample for FIN-C9-PM-C was collected using a drill bit as described in Note 1 above since it was a graphite electrode used as a cathode.

3: Sediment samples consisted of the material that was loosely adhered to the electrodes at the time of removal. Due to the limited amount of sediment adhering to the electrodes samples were composited from material collected over the entire length of the respective electrodes. Sufficient material for analysis was not available on all electrodes; samples were collected when feasible. The purpose of these samples are to assess the relative concentration of mercury in sediments in direct contact with the electrodes.

**Qualifiers:**

U: The compound was analyzed for, but was not detected ("non-detect") at or above the MRL/MDL.

B: The result is an estimated concentration that is less than the MRL but greater than 10%, indicating a possible matrix interference in the sample.

Mercury concentrations ranged from 0.01 (U) to 0.14 mg/kg dry wt, on the graphite anodes which was no different than the time-zero samples (undetected at 0.01 mg/kg dry wt), with the exception of detected concentrations on A2 (0.03 mg/kg dry wt) and A4 (0.14 mg/kg dry wt). The two sediment samples collected from the anode surfaces had higher mercury concentrations ranging from 0.94 to 25.9 mg/kg dry wt, than measured directly from the electrode. The collection of surface scrapings from the graphite anodes was not practicable, as there were no visible accretions of material plated to the anode surfaces. Based on these findings it does not appear that appreciable quantities of mercury migrated towards the ECRTs anodes, with the possible exception of A4.

Mercury was detected on 12 of 13 cathode samples submitted, with concentrations ranging from 3.28 to 23.8 mg/kg dry wt on the steel plate electrodes. A graphite electrode that was placed in the cathode array during the demonstration had a mercury concentration estimated at 0.03 mg/kg dry wt. These concentrations were higher than

both the time-zero steel plates (0.01 U) and sediment adhering to the cathodes (0.15 to 10.1). At the time of removal the steel plate was reduced (black surface), with minor accretions (salt deposits) of solids in areas where the plates protruded above the mudline. Once exposed to the air, all of the steel plates oxidized and were covered in a thin layer of rust by the time (<24 hours) the surface scrapings were collected. Based on these data, it appears that some mercury did adhere to the cathode surfaces during the demonstration. However, based on the analytical results and visual assessments of the electrodes, the relative quantity of mercury plated to the cathodes was limited, not readily recoverable (from a remedial perspective), and may be an artifact of the sediment in direct contact with the electrode plates. It also does not appear that mercury was mobilized to the extent that enriched sediments near the electrodes, as the highest mercury concentrations measured during the demonstration were located elsewhere in the test plot.

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## Section 5.0 Other Technology Requirements

### 5.1 Environmental Regulation Requirements

State and local regulatory agencies may require permits prior to implementing the *in situ* ECRTs process. Most federal permits will be issued by the authorized state agency. If the ECRTs process is implemented on marine sediments *in situ*, appropriate permits are required. For example, for the demonstration a Joint Aquatic Resource Permits Application (JARPA) was required by the U.S. Army Corps of Engineers for conducting construction work in or near the water. In addition, SITE Program personnel were required to obtain a scientific collection permit for conducting fish community samples.

If remediation is conducted at a Superfund site, federal agencies, primarily the U.S. EPA, will provide regulatory oversight. If off-site disposal of contaminated waste (contaminated electrodes) is required, the waste must be taken to the disposal facility by a licensed transporter.

Section 2 of this report discusses the environmental regulations that may apply to the ECRTs process.

### 5.2 Personnel Issues

The number of personnel required to implement the ECRTs process is dependent on the size of the treatment system and the time desired for the installation. System installation activities are usually conducted by the licensee of the ECRTs process. The licensee would in most all cases use subcontracted specialized services to install the system.

During installation activities at a remediation site, the site remediation contractor (such as Weiss Associates) would be responsible for ensuring that installation of system components are conducted in accordance with design

specifications. These activities would require the services of at the developer and several contractors. At a minimum, an electrical contractor and a contractor equipped with heavy equipment (e.g., crane) are anticipated a minimum requirements. Marine applications of the ECRTs process may require specialized services.

Personnel are also required for sediment sample collection and monitoring. During the demonstration sampling events, a specialized vessel equipped with DGPS was required. Personnel present during sample collection activities at a hazardous waste site must have current OSHA health and safety certification.

For most sites, PPE for workers will include steel-toed shoes or boots, safety glasses, hard hats during installation operations, and chemical resistant gloves. Sampling marine sites from a pontoon boat requires safety floatation vests.

Depending on contaminant types, additional PPE (such as respirators) may be required. For example, respiratory protective equipment may be needed when VOCs are measured in the breathing zone exceeding predetermined levels. During the marine sediment sampling events performed during the demonstration, respirators were not required based on off-gas monitoring at the well heads.

Noise levels would be a short-term concern during vibracoring operations. Thus, noise levels should be monitored for such equipment to ensure that workers are not exposed to noise levels above the time weighted average of 85 decibels over an 8-hour day. If this level is exceeded and cannot be reduced, workers would be required to wear hearing protection and a hearing conservation program would need to be implemented.

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### 5.3 Community Acceptance

The short-term risk to the community from implementing this technology is minimal when the ECRTs process is implemented *in situ*. For marine applications, such as the demonstration, the level of environmental disturbance of a site would be dependent on the type of marine species potentially affected and would in most all instances require some sort of benthic monitoring. For example, for the demonstration project a series of measurements were conducted to evaluate the possible environmental effects

of the ECRTs process on the marine environment. These measurements included benthic in faunal sampling, purse seining, and the use of underwater video cameras.

Other than noise generated during drilling vibrohammering of the electrodes during system installation, noise disturbance is not anticipated. The benefits of site remediation would offset these minor disturbances. Most marine applications would be conducted just off the shoreline in industrial areas (e.g., shipyards) and thus would not create additional concern to the community.



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## Section 6.0 Technology Status

### 6.1 Previous Experience

P2-Soil Remediation, Inc., the electrochemical remediation company that developed the ECRTs process has been established since 1979 and has been reported to have remediated over 2 million metric tons of soils, sediments, and groundwater (McIlvride, W.A., F. Doering, et. al., April 2003). The demonstration conducted at the G-P Log Pond is believed to be the first application of the ECRTs process to marine sediments *in situ*.

The technology developer works with and licenses its ECRTs process to environmental engineering and consulting firms, such as Weiss Associates. Past reported experience using the ECRTs process includes treatment of 500 tons of PAH-contaminated silty soil in Enns, Austria; and treatment of elemental and methyl mercury-contaminated silt in Union Canal, Scotland (McIlvride, W.A., F. Doering, et. al., April 2003).

As of April 2003, other than the demonstration at the G-P Log Pond, funded ECRTs projects are reported to include remediation/treatment of metals or organics at the following

sites:

- ▶ PCB-contaminated soil and sediment at an Upland New York Site,
- ▶ Mercury-contaminated soil at the Y-12 plant in Oak Ridge, TN,
- ▶ PAH-contaminated sediments in Lake Superior, MN.
- ▶ Elemental mercury in clay soil at an NPL site.

### 6.2 Ability to Scale Up

Based on the nature of the technology, theoretically there is no limit to the areal extent of application, since the technology can be applied in modules. The areal extent of this ECRTs SITE Demonstration is considered a pilot-scale application of the technology, due to the limited area of treatment. The Demonstration "pilot-scale" area is not considered to be a typical remediation.

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## Section 7.0 References

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