ESTCP Cost and Performance Report

(CU-0113)



Cyclodextrin-Enhanced In Situ Removal of Organic Contaminants from Groundwater at Department of Defense Sites

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ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
ARAR	applicable or relevant and appropriate requirements
atm	Atmospheres
bgs	below ground surface
BTC	Breakthrough Curve
c CAA C/Co CD CDEF CERCLA	Means of 5 initial RFs for a compound Clean Air Act Relative Concentration cyclodextrin (specifically: hydroxypropyl-β-cyclodextrin) Cyclodextrin Enhanced Flushing Comprehensive Environmental Response Compensation and Liability Act
CMC	Critical Micelle Concentration
CFR	Code of Federal Regulations
CL	Camp Lejeune
CMCD	Carboxymethyl-β-cyclodextrin
Co-PI	Co Principal Investigator
COTS	commercial off-the-shelf
CPPT	cyclodextrin push-pull test
CSM	Colorado School of Mines
CWA	Clean Water Act
DERP	Defense Environmental Restoration Program
DNAPL	dense nonaqueous phase liquid
DO	Dissolved Oxygen
DoD	Department of Defense
EC	Electrical Conductivity
<i>E 1 through E 7</i>	extraction wells
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FFCA	Federal Facilities Compliance Act
FS	Feasibility Study
FRTR	Federal Remediation Technologies Roundtable
gpd	gallons per day
gpm	gallons per minute
GW	groundwater

ACRONYMS AND ABBREVIATIONS (continued)

HASP	Health and Safety Plan
He	Helium
HPCD	hydroxypropyl-β-cyclodextrin
HRSD	Hampton Road Sanitation District
11102	
I 1	Injection Well
IAS	Initial Assessment Study
I/E	Injection and Extraction
I/E I/E	injection/extraction test
IPA	
	Isopropyl Alcohol
IRI	Interim Remedial Investigation
IRP	Installation Restoration Program
ISE	Ion Selective Electrode
K	Hydraulic Conductivity
K _{NW}	NAPL-water portioning coefficients
IX NW	With L-water portioning coefficients
LANTDIV	Atlantic Division, Naval Facilities Engineering Command
LNAPL	light nonaqueous phase liquid
lpm	liters per minute
ipin	ners per minute
MCB	Marine Corps Base
MCL	maximum contaminant level
MIP	Membrane Interface Probe
MSDS	Materials Safety Data Sheet
MW	Monitoring Well or Molecular Weight
	Wolldening wen of Woleeular Weight
Ν	Number of calibration points (x,y data pairs)
Ne	Neon
NABLC	Naval Amphibious Base Little Creek
NACIP	Navy Assessment and Control of Installation Pollutants
NAPL	nonaqueous phase liquid
NPL	National Priorities List
NPV	net present value
	1
NTR	Navy Technical Representative
OVM	Organic Vapor Meter
OSHA	Occupational Health and Safety Administration
	1 5
РАН	polycyclic aromatic hydrocarbon
P&T	pump-and-treat
PCE	Tetrachloroethylene (tetrachloroethene)
PI	principal investigator
PID	Photoionization Detector
POTW	publicly-operated treatment works
	puonery operation treatment works

ACRONYMS AND ABBREVIATIONS (continued)

PPB	Parts per Billion (approximately 1 µg/L)
PPM	Parts per Million (approximately 1 mg/L)
PTT	partition tracer test
PVP	pervaporation
PWC	Public Works Center
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
RAB	Restoration Advisory Board
RCRA	Resource Conservation and Recovery Act
RF	fluorescence spectrometry
RF ₁	Average relative response factor from initial calibration
RF ₂	Response factor from continuing calibration.
RPD	Relative Percent Difference
RSD	Relative standard deviation
RVS	Round 1 Verification Step
SARA	Superfund Amendments and Reauthorization Act
SD	Standard deviation
SDWA	Safe Drinking Water Act
SEAR	surfactant enhanced aquifer remediation
SIC	Standard Industrial Classification
S _N	NAPL saturation
SOP	Standard Operation Procedure
SWDA	Solid Waste Disposal Act
T	Temperature
TCD	Thermal Conductivity Detector
TCE	trichloroethylene (trichloroethene)
TDP	Number of total samples obtained
TNS	6-(p-Toluidino)-2-naphthalenesulfonic acid, sodium salt
TNT	2,4,6-trinitrotoluene
TOC	total organic carbon
UF	ultrafiltration
UHP	Ultra-high purity
UA	University of Arizona
URI	University of Rhode Island
UTSA	University of Texas, San Antonio

ACRONYMS AND ABBREVIATIONS (continued)

VADEQ VDP VOC	Virginia Department of Environmental Quality Valid Data Points volatile organic compound
Х	Calibration concentrations
у	Instrument response (peak area)
1,1-DCA 1,1-DCE 1,2-DCE 1,1,1-TCA 2EH 22DMP 22DMP	1,1-dichloroethane 1,1-dichloroethane 1,2-dichloroethane 1,1,1-trichloroethane 2-ethyl-1-hexanol 2,2-dimethyl-3-pentanol
22DMPP 23DMB 26DMHP 44DMP 6MH	2,2-dimethyl-1-propanol 2,3-dimethyl-1-butanol 2,6-dimethyl-4-heptanol 4,4dimethyl-2-pentanol 6-methyl-2-heptanol

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Technical material contained in this report has been approved for public release.

1.0 EXECUTIVE SUMMARY

Nonaqueous phase liquid (NAPL) spills in the subsurface are considered the single most important factor limiting remediation of military and industrial organic-contaminated sites. The generally limited performance of conventional groundwater pump-and-treat (P&T) systems has led to consideration of chemically enhanced flushing methods such as cyclodextrin enhanced flushing (CDEF). Cyclodextrins are nontoxic, modified sugars that form complexes with hydrophobic pollutants such as trichloroethylene (TCE). Because of its nontoxicity, CDEF technology is an attractive alternative to other chemical flushing agents, such as many surfactants or cosolvent formulations.

CDEF generally begins with the injection of a water-based cyclodextrin solution. This solution is flushed through the contaminated aquifer and then extracted. Conventional injection and extraction wells can be used to control the flowfield of the flushing solution. This application scheme is in principle similar to conventional P&T systems, but due to the advantageous solubility enhancing properties of the cyclodextrin solution, mass removal rates are faster and, consequently, remediation times should be shorter.

Funded by the Environmental Security Technology Certification Program (ESTCP), this technology demonstration was intended to show the potential of CDEF under near full-scale operational conditions. The particular objectives of this demonstration were (1) evaluation of the cost and performance of cyclodextrin-enhanced removal of dense nonaqueous phase liquids (DNAPL) from polluted groundwater, (2) test unrefined liquid cyclodextrin (CD) as a substitute for CD powder, (3) evaluate membrane technology for recovering and reusing CD, (4) identify the most appropriate wastewater treatment technologies, and (5) conduct partition tracer test (PTT) for mass balancing.

Regulations that pertained to the implementation of this demonstration include the U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) and its amendments under the provision of Public Law 93-523. Under these provisions, maximum contaminant levels (MCL) for dissolved volatile organic compound (VOC) (and other compounds) are established. The Defense Environmental Restoration Program (DERP) provides for the identification, investigation, and cleanup of hazardous waste sites at Department of Defense (DoD) facilities. DERP focuses on cleanup of contamination associated with past DoD activities to ensure that threats to public health and the environment are eliminated. Section 2701 states as a goal "the identification, investigation, research and development, and cleanup of contamination from hazardous substances, pollutants, and contaminants."

The overall duration of the demonstration was 4 months, during which time approximately 32.5 kg TCE and 1,1,1-trichloroethane (1,1,1-TCA) plus an estimated 3 kg of 1,1-dichlorethene (1,1-DCE) and an unknown amount of other contaminants were removed. (Total DNAPL volume removed was approximately 30 liters). The resulting decrease in DNAPL saturation was approximately 70% to 81%. The principal performance measure for DNAPL removal were partition tracer tests conducted before and after the CDEF tests and mass balance calculations based on VOC recoveries during the demonstration. TCE concentrations in the reference wells declined between 38.5% to 99.4% (77.3% average) from their pre-CDEF levels. The original

performance objectives for this demonstration were to remove >90% of the DNAPL mass and reduce the aqueous TCE concentration to <1% of the initial TCE concentration. Neither criterion was not met during the relatively short duration of this demonstration.

A large fraction of DNAPL (approximately 57%) was removed during the PTTs because of the large volume of groundwater pumped during these tests. Based on identical extraction rates, however, about -68% more TCE was removed during the push-pull CDEF than during the PTTs. Similarly, based on operation time, about 3.5 times more TCE was removed on a daily basis during CDEF. These comparisons were based on a very conservative projection of the performance of a theoretical P&T remediation system.

The highest aqueous TCE concentrations measured during the CDEF demonstration were >200 mg/L or up to 9 times higher than the average pretreatment TCE concentrations. Even higher solubility enhancements (up to 19 times) were observed for 1,1,1-TCA. These values demonstrate clearly that CDEF significantly enhanced the contaminant removal rates.

Effluent treatment by air stripping lowered the TCE concentration in the effluent below the maximum contaminant level (MCL for TCE = 5 μ g/L). Four wells that were drilled by NABLC before the CDED demonstration served as a measure of the performance of CDEF treatment. The TCE concentrations in three wells declined between 38.5% and 99.4% (77.3% average) from their preremediation levels. The TCE in concentration in one well remained essentially unchanged at approximately 1 μ g/L, which is below the MCL for TCE (5 μ g/L). This project was intended as a technology demonstration only — the remediation of the entire test site was not a primary objective.

Liquid, technical grade CD has been demonstrated to perform as well as the more expensive powder CD tested during previous field applications. Further, CD solution recovered from the subsurface was reused after treatment without indications of decreased removal effectiveness. An ultrafiltration (UF) system was capable of reconcentrating recovered CD solution from 5% to 20% (wt/wt), but the treatment capacity of the UF used during this demonstration was low and prevented continuous operation in-line.

A conventional air stripper and a pervaporation (PVP) system were tested. Although full-scale assessment of the PVP was prevented due to damages that could not be repaired in the field, it achieved higher contaminant removal rates (99%) compared to the air stripper (90%). However, the operation of the PVP system required a system-dedicated field technician and consumed large amounts of electrical energy. In addition, the pervaporation process created a highly VOC-enriched effluent that had to be disposed of. In comparison, the air stripper was much easier to operate and required little maintenance. Also, substantially less energy was needed to run the air stripper.

The cost of the CDEF technology was evaluated based on two principal application schemes: injection/extraction of CD solution using several Injection and Extraction (I/E) wells test and application of CDEF in multi-well push-pull mode, cyclodetrixin push-pull test (CPPT). The I/E test was conducted by injecting 20% CD solution into injection wells. After passage through the DNAPL source zone, the flushing solution was recovered from a number of extraction wells,

treated, reconditioned, then reinjected. During push-pull application, a slug of 20% CD solution was injected then extracted from the same wells. The extracted flushing solution was reconditioned (i.e., the CD concentration was readjusted to 20%), then reinjected again. Up to three wells were treated in this way at the same time.

With regard to the cost of these treatment approaches, several full-scale cost estimates were developed. Overall, the CPPT approach generated only half the cost of a comparable I/E system. The full-scale implementation of a hypothetical site — about 10 times larger than the demonstration site — generated costs comparable to other conventional or innovative remediation technologies. The main cost savings are associated with much shorter remediation times that can be realized by using CDEF instead of P&T.

The primary goal in most military and industrial remediation projects is to achieve an environmentally acceptable expedited cleanup of a site at a fixed price. The demonstration addressed these issues by demonstrating that environmentally acceptable expedited cleanup of a DNAPL site at predictable cost and risk is possible. Points of contact and several reports summarizing the findings of the CDEF demonstration, including links to scientific research pertaining to CDEF, are available via www.ri-water.geo.uri.edu.

Although CDEF has great advantages compared to other existing remediation technologies, there are sites where this approach may not be appropriate or must be used in combination with other technologies. For example, CDEF technology has been used primarily for the removal of residual NAPL. If free-moving NAPL is encountered inside a well, other technologies, such as free-product skimming, should be applied prior to CDEF. Also, CDEF should not be expected to bring contaminant concentration to below MCL. However, CDEF technology may lower the contaminant concentration enough to permit the application of otherwise unfeasible remediation approaches, e.g., enhanced bioremediation.

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2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

Cyclodextrins are nontoxic sugars and are produced domestically in commercial quantities from corn Cyclodextrins were first starch. used for pharmaceutical purposes the food and in processing industry. The cyclodextrin molecule forms complexes with organic contaminants and, in some cases, with metals. For most nonpolar contaminants, residence in the hydrophobic interior of the cyclodextrin molecule (Figure 1) is more attractive than being dissolved in water. The formation cyclodextrin-contaminant of complexes significantly increases the apparent solubility of many low-solubility organic

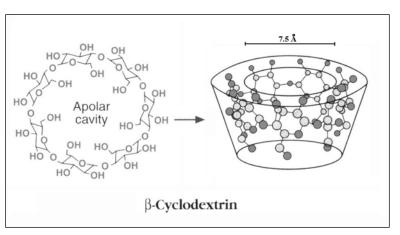


Figure 1. Two-Dimensional and Three-Dimensional Structure of the β -Cyclodextrin Molecule. (The interior of the molecule is hydrophobic and forms a complex with TCE. The exterior is hydrophilic and allows for a high water solubility of the cyclodextrin molecule [Boving and McCray, 2000]).

contaminants and is the basis for cyclodextrin use in groundwater remediation. Therefore, the solubility enhancement of low polarity organic compounds by cyclodextrin is analogous to that of certain surfactants and alcohols. However, many of the disadvantages associated with surfactants and alcohols (NAPL mobilization, sorption of surfactants to soils, toxicity of the chemical reagents, and difficulty in separating the agents from the contaminants in the waste stream) are not applicable to cyclodextrin-enhanced remediation.

The particular cyclodextrin used for this demonstration is hydroxypropyl- β -cyclodextrin (HPCD). If not stated otherwise, the term "cyclodextrin" in this report refers to HPCD. The use of cyclodextrins as an agent for chemically enhanced in-situ flushing was introduced by Brusseau and colleagues (Wang and Brusseau, 1993; Brusseau et al, 1994; Brusseau et al, 1997). Chemically enhanced-flushing technologies are based on flushing the contaminated porous medium with chemical agents to increase contaminant solubility. Concomitantly the mass removal rate is elevated, which reduces the time and cost of remediation. Chemically enhanced-flushing technologies are particularly useful for the treatment of DNAPL source zones. Chemical treatment of contaminated zones often becomes attractive where (1) alternative methods (e.g., bioremediation) are incompatible or will not function effectively with respect to rate or extent of treatment (Yin and Allen, 1999); (2) the site is composed of localized, highly contaminated zones in heterogeneous systems; or (3) access to the contaminated soil and groundwater is difficult due to restricting surface structures or uses. The selection of a particular chemical in-situ treatment technology depends on various factors, with the most important

factors typically being (1) the site-specific hydrologic and geologic conditions, (2) the contaminant inventory, and (3) the cost and environmental safety of the treatment method.

While cleaning up DNAPL contaminated sites is currently the most pressing problem, there are many other pollutants classes for which CDEF remediation technology is suitable. For example, previous field studies indicate that CD effectively removes light nonaqueous phase liquid (LNAPL) and pollutants sorbed to soil and aquifer materials (McCray et al., 2001). In addition, Wang and Brusseau (1993) showed that cyclodextrin enhances the solubility of the pesticide DDT up to 1,100 times. Similarly, CDEF significantly increased the solubility and (bio)availability of polycyclic aromatic hydrocarbons (PAH) and other petroleum hydrocarbons (Gruiz et al, 1996; Wang and Brusseau, 1998). Enhanced bioavailability, in return, may augment the bioremediation of these compounds. Cyclodextrins have been suggested for removing toxic metals, such as nickel and radiogenic isotopes from contaminated sediments (Szente et al, 1999), which could make the application of CDEF at nuclear waste sites possible. However, these applications of CDEF technology have not been field tested at this time.

Figure 2 shows а conceptual illustration of the CDEF. Cyclodextrin-enhanced in-situ flushing of contaminated porous media generally begins with the injection of а water-based cvclodextrin solution. There are two treatment options: using a system of designated injection and extraction wells to flush the source zone (see Figure 2) or injecting and extracting the flushing solution from one and the same wells, i.e., a push-pull operation. The first treatment option in principle similar is to

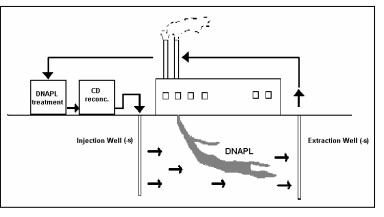


Figure 2. Conceptualized Application Scheme of the CDEF Technology.

conventional P&T systems. Independent of which treatment option is used, mass removal rates are faster and consequently remediation times shorter because of the advantageous solubility enhancing properties of the cyclodextrin solution. Conventional injection and extraction wells can be used to control the flowfield of the flushing solution. Because the magnitude of solubilization of organic contaminants is a linear function of the aqueous cyclodextrin concentration, the contaminant removal rate increases with the cyclodextrin concentration.

For this demonstration project, CD flushing solution was prepared from a 40% (wt/wt) CD stock solution (technical grade). The CD solution was delivered to the site by a tanker truck and stored in a 6,500 gal storage tank from which it was gravity fed into 4" PVC injection/extraction wells. The wells were screened over the lowermost 5 ft of the Columbia aquifer. The solution containing the cyclodextrin-TCE complex was pumped to the surface and passed through a 2 μ m sand filter to remove fines that may be suspended in the extract. Then the solution was passed through an air stripper. Air stripping separates the volatile contaminants from the cyclodextrin solution. TCE vapors removed from the air stream leaving the air stripper were removed by

passing them through activated carbon filters. The TCE removal efficiency was largely controlled by the solution's residence time in the air stripper. To sustain the required residence times, the contaminated solution was recirculated until the desired cleanup level was reached or a lower feed rate was maintained (ranging from 1 to 5 gallons per minute [gpm]).

After passage through the air stripper, the treated CD solution was either processed in a membrane filter (UF) that enriches the cyclodextrin in the aqueous phase, or it was reinjected into the subsurface or stored in a 6,500 gal storage tank until later reinjection. This recycling of the CD limits the material needs and increases the cost-effectiveness of the technology. The permeate leaving the UF consisted of water with minimal amounts of CD and TCE levels below MCL. The permeate was discharged into a nearby storm drain. Before reinjection, the CD solution was reconditioned with CD stock solution to maintain the desired CD concentration of the flushing solution (20% by weight). A number of sampling ports along the process line guaranteed control over the entire treatment train.

Prior to a CDEF application, the DNAPL treatment zone must be carefully characterized. Table 1 summarizes the minimum design parameters. The actual characterization requirements will vary from site to site. Each site requires careful evaluation of all parameters listed in Table 1. Some sites that exhibit unusually complex hydrogeologic conditions or otherwise unfavorable conditions (such as limited accessibility) may require additional considerations or may not be appropriate for CDEF at all. Similarly, the CDEF performance also varies from site to site.

Design Parameter	Key Design Questions
Source zone characterization	• Is there evidence for NAPL?
	• If so, how much NAPL is present and where is it residing (i.e., what is the volume and extent of contamination)?
	• What is the hydraulic conductivity and thickness of the source zone and is it sufficiently large to permit CDEF?
	• If the aquifer is sandwiched between other geologic strata, what are their permeabilities and hydraulic characteristics and how do they compare to the source zone aquifer?
Numerical simulation	• What is the appropriate number and constellation of the well field to accomplish (1) hydraulic containment and (2) optimal capture of the CD flushing solution?
	• What is the (potential) influence of subsurface heterogeneities (such as hydraulic conductivity variations or stratification) on the CD delivery to the DNAPL source zone?
	• Into how much mass of CD must be applied to reach the cleanup target? How many sweep volumes does this amount of CD mass translate?
Treatment train	• What is the most appropriate treatment method for the contaminated groundwater? Which regulatory requirements apply?
	• What is the most economic pump rate relative to the cost and size of the treatment equipment?
	• Is recovering the CD with a UF system more economical than replacing spent CD?

 Table 1. Key Design Parameter for CDEF.

During CDEF operation, aqueous samples of the extracted effluent and the injected, reconditioned flushing solution have to be collected at predetermined intervals. The principal sample parameters are the contaminant and the cyclodextrin concentration. For VOCs, standard EPA methods are appropriate for chemical analysis (e.g., purge-and-trap). Cyclodextrin concentrations can be determined with adequate accuracy using a standard total organic carbon analyzer (TOC) because, during a typical CDEF flush, the CD concentration will be orders of magnitude higher than any other compound in solution. As an added benefit, a TOC can be operated on site, which allows for real-time testing of the CD concentration. Local and state laws will dictate if and what other parameters may have to be analyzed, including the degree of treatment that has to be achieved before reinjection or discharge of effluent off site. If air stripping is used for treatment of the extracted flushing solution, periodic off-gas sampling must ensure the proper performance of the air filtration system (e.g., air-activated carbon filters). All sample locations must be properly identified and sample procedures must be specified in a work plan. In addition, Occupational Safety and Health Administration (OSHA) regulations regarding the health and safety of personnel working on a site must be followed (i.e., a health and safety plan must be prepared).

The implementation of CDEF is rather simple and requires minimal training beyond what is considered necessary for running a conventional P&T operation. The main differences are:

- Operator training for running the UF system for CD reconcentration is necessary.
- Fluctuating CD concentrations require monitoring and readjustment of the flushing solution strength. Training for performing TOC analysis of CD samples in the field and proper adjustment of CD solution is necessary.

CDEF inherits the limitations of other conventional and innovative remediation approaches that rely on the injection and extraction of liquids from the subsurface (e.g., P&T, surfactant or cosolvent flushing). The principal advantages of CDEF technology are the nontoxicity of the CD itself and its ability to quickly and effectively remove NAPL compared to conventional remediation methods such as P&T. Table 2 lists some of specific advantages of CDEF. For a complete review of laboratory research and the theory of cyclodextrin-enhanced solubilization, see Wang and Brusseau, 1993; Boving and McCray, 2000.

CDEF is an alternative to surfactant and cosolvent flushing (Lowe et al, 1999). In principle, cosolvent-, surfactant-, and cyclodextrin-enhanced flushing are essentially a modified P&T system and share the heterogeneity-induced mass transfer limitations inherent in such systems. The performance of these enhanced flushing technologies is site specific. A primary obstacle for in-situ chemical treatment technologies generally involves delivery, distribution, and mass transfer of chemical agents in the subsurface (Yin and Allen, 1999).

Property	Advantage
Nontoxic to humans and resident microbial populations	Cyclodextrins are widely used in pharmaceuticals, food processing, and cosmetics. There are minimal health-related concerns associated with the injection of cyclodextrin into the subsurface so that increases the regulatory and public acceptance for this technology.
Enhances solubility at all concentrations	Individual cyclodextrins molecules complex molecule(s) of contaminant so cyclodextrins do not require a minimum concentration as surfactants.
Flows freely through aquifers	Cyclodextrin and cyclodextrin/contaminant complexes do not adsorb or precipitate in aquifers (Brusseau et al, 1994). This is an issue of regulatory concern.
Optimal performance	Cyclodextrin's performance is uninfluenced by changes in pH, ionic strength, and temperature.
Does not persist in the environment	Cyclodextrins are resistant to biological and chemical degradation over short time periods (i.e., a few months, which is the expected time scale of remediation), but will ultimately degrade. For comparison, surfactants often persist in the environment for long periods of time.
Highly soluble	Cyclodextrin's solubility exceeds 800 μ g/L (Blanford et al, 2001). This is advantageous for field applications because relatively high initial concentrations of cyclodextrin flushing agent can be used.
Fluid properties do not greatly differ from water	No density-controlled problems are expected (Boving et al, 1999b; McCray et al, 2000). Therefore, flushing solution delivery systems are similar to those for traditional water flushing.
Moderate reduction of interfacial tension between NAPL and aqueous phase	Little or no mobilization potential. HPCD promotes NAPL solubilization instead of NAPL mobilization (Boving et al, 1999a; McCray et al, 2000). Thus, control of the remediation fluid and DNAPL phase can be maintained.
No partitioning into NAPL	HPCD behaves as a conservative tracer, i.e., its transport through the subsurface is not retarded (McCray, 1998; Boving et al, 1999).
Enhanced bioremediation of organic contaminants	Cyclodextrins can be used simultaneously for bioremediation as well as for enhanced solubilization (Wang et al, 1998; Brusseau et al, 1994; Gruiz et al, 1996).
Volatile contaminants can be separated from cyclodextrin solution by air stripping	Cyclodextrin solution can be safely and cost-effectively reinjected into the contaminated aquifer (Boving et al, 1999b; Blanford et al, 2000).

Table 2. Characteristics of the Cyclodextrin Technology.

As with any chemically enhanced flushing technology, losses of CD due to incomplete capture of the flushing solution are problematic, especially at sites where optimal hydraulic control is impossible. Also, mixing with groundwater will dilute the flushing solution. Although the CD solution can be reconcentrated, losses due to incomplete capture require adding certain amounts of CD to maintain the desired removal efficiency of the flushing solution.

Table 3 summarizes potential risks and limitations and possible resultant impacts on the performance of the proposed remediation technology. The listed shortcomings are not necessarily associated with CDEF only but are fairly typical risks and limitations that can affect the performance of other chemical flushing technologies as well.

Potential Risk or Limitation	Potential Impact On Technology Performance
Inhomogeneities of aquifer	Flushing solution cannot be delivered optimally to contaminated zone; preferential
	flow reduces contact time of flushing solution with contaminated material.
NAPL trapped in clay layers	Bypassing of flushing solution and hampering of mass transfer results in slower remediation times.
Poor hydraulic control and incomplete capture	Losses of flushing solution and dilution of flushing solution create "dead zones."

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The CDEF technology demonstration was deemed successful if (1) it led to a smaller plume and shorter remediation, (2) at least 90% of the contaminant mass was removed, (3) CDEF is a reliable, versatile, easy to use method, (4) there were no undesirable side effects, such as generation of process waste or hazardous compounds, and (5) it is cost effective. The effectiveness of the demonstration was evaluated based on the performance criteria listed in Table 4 and by applying the confirmation methods summarized in Table 5 and Table 6.

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance (Future)
Qualitative	Reduce contaminant source	Smaller source zone	Criterion met
	Reduce contaminant mobility	Smaller plume	Under investigation
	Faster remediation	Reach remediation goal faster	Criterion met
	Ease of use	Operator acceptance	Criterion met
Quantitative	Reduce contaminant mass	> 90%	70% to 81%
	Meet regulatory standard	< MCL (TCE)	Criterion met for effluent
	Recycle cyclodextrin solution	> 5 flushes per molecule	Criterion not met
	Reconcentrate cyclodextrin	Recovery > 80%	Criterion met, although not in continuous UF operation mode
	Remediation time	3 months	Criterion not met
	Endpoint criteria	Effluent TCE concentration < 1% initial	Criterion not met (average TCE concentration at 22.7% of initial)
	Maintenance	intenance Downtime < 10% of total operating time	
	Reliability	Downtime < 25 to 50% of total operating time (during demonstration)	Criterion met
	Factors affecting technology	1) Flow rate: 18,000 gallons per	7,200 gpd
	performance	day (gpd)	1 to 5 gpm
	-	2) Feed rate: 5 gpm	3% to 10%
		3) CD concentration: 10%	25°C
		4) Temperature: 17^{0} C	Silty sand
		5) Soil type: sand (boring logs)6) Particle size distribution:	Medium sand
		medium sand (sieve analysis) 7) Soil homogeneity:	Heterogenous
		homogenous (boring logs) 8) GW pH: near pH 7	near pH 7 DO < 5%
		9) Dissolved oxygen (DO): 50% saturated 10) Other contaminants: no interference	Iron precipitation

Table 4. Objectives Providing the Basis for Evaluating the Performance and Cost of the
CD Technology.

		Expected Performance	
	Performance Criteria	Metric (pre demo)	Performance Confirmation Method
P	RIMARY CRITERIA (Performanc		
	ontaminant mobility	Reduced smaller plume	Monitoring wells LS11 -MW02,
	-	-	-MW01T, -MW04D, -MW05D
Fa	aster remediation	Endpoint attained faster	Monitoring wells LS11 -MW02,
			-MW01T, -MW04D, -MW05D
E	ase of use	Minimal operator training	Experience from demonstration
		required	operations
	RIMARY CRITERIA (Performanc		
ĸ	educe contaminant mass	> 90% DNAPL removed	Pre- and post demonstration PTTs in combination with chemical analysis
			data
Н	azardous materials - generated	None (except PTT, which is	Analysis for possible toxic
	and a constant beneficient	not an intrinsic part of	degradation products
		CDEF technology)	
F_{ℓ}	actors Affecting Technology Perform		
	Flow rate	64 m ³ /d (18,000 gpd)	Certified ABB flow meter
			(Accuracy ±3%)
	Feed rate	$0.5 \text{ m}^3 / \text{hr}$	Certified ABB flow meter
	(D) ()		(Accuracy ±3%)
	CD concentration	20 to 40% at injection well 5 to 10% at extraction well	TOC and TNS-complexation (fluorescence spectrophotometer)
	Soil type	> 100 ft/d hydraulic	Pre demo slug test
	Son type	conductivity (medium sand	Fie denio siug test
		with some silty clayey	
		strata)	
	Particle size distribution	Fraction < 0.063 mm (very	Sieve analysis of cores (ASTM D422-
		fine sand) is less than 10%	63 method)
	Soil homogeneity	Predominantly sand > 90%	Thickness of strata in soil boring
		of screened interval	profile
	GW pH	pH varies between 6 and 8	Orion pH meter (accuracy $\pm 5\%$)
	Dissolved Oxygen (DO)	DO varies between 50 to	YSI 55 DO meter (accuracy $\pm 5\%$)
T	ana at Contamin ant	90% saturation	
10	arget Contaminant % reduction	Reduce TCE by 90%	Mass balance in combination with
	/010000000	Reduce ICE by 90%	PTT pre- and post demo test
	Regulatory standard	Attain TCE MCL (5 ppb)	U of A Method (GC-FID), duplicates,
	Regulatory standard	rumi i el mel (o ppo)	spikes, trips, blanks, RPD<60%,
			Recovery>90%, Complete>95%

Table 5. Summary of Primary Performance Criteria Metrics and Confirmation Methods.

	Expected Performance	
Performance Criteria	Metric (pre demo)	Performance Confirmation Method
SECONDARY PERFORMANCE CRIT	ERIA (Performance Objective	e) – Quantitative
Process waste		
Generated	None (except PTT tracers,	Observation
	which are not an intrinsic	
	part of CDEF technology)	
Plume size	Smaller	Monitoring wells LS11 -MW02,
		-MW01T, -MW04D, -MW05D
Reliability		
Downtime due to equipment failure	< 5% of demonstration time	Record keeping
Safety		
Hazards	None	Experience from demonstration
		operation
Protective clothing	None	Experience from demonstration
		operation
Versatility		
Continuous operation	Yes	Experience from demonstration
		operation
Intermittent operation	Yes	Experience from demonstration
		operation
Other application	Yes — push-pull injection	Experience from demonstration
		operation
Maintenance		
Required	Activated carbon exchange	Experience from demonstration
	Filter press clean out	operation
	CD storage tank exchange	
Scale-up constraints	t	
Engineering	Operating space	Monitoring during demonstration
Flow rate	Available equipment	operation
	capacity	
Contaminant concentration	None	

Table 6. Summary of Secondary Primary Performance Criteria Metrics and
Confirmation Methods.

3.2 SELECTION OF TEST SITE

The criteria and requirements used for selecting the demonstration site were:

- Well-characterized DNAPL site with a relatively small source zone in a shallow sandy and/or sandy-silty aquifer.
- Saturated zone bounded at the bottom by a relatively impervious layer (e.g., clay or siltyclay).
- Saturated zone not more than about 7 m (21 ft) thick.
- DNAPL mixture consisting primarily of chlorinated solvent components.
- DoD site.
- Good working relations with local stakeholders and regulators.

• Existing infrastructure (e.g. closeness to various supply stores, existing electrical and water hook-ups, shelter for analytical equipment).

For this ESTCP-funded demonstration project, full remediation of the demonstration site was not the primary consideration because of budgetary limitations and time constraints.

Demonstration costs were kept low by focusing the site search on a relatively shallow source zone bounded by an impermeable layer. These constraints were expected to limit dilution of CD solution during flushing as well as minimized well depths. Also, a well characterized, shallow source zone helped to avoid complex vertical hydraulic controls that are likely to be implemented at more complex sites. Overall, the contamination scenario at the demonstration site realistically reflects relatively small DNAPL source zones (consisting primarily of chlorinated solvent) on other DoD sites.

3.3 TEST SITE HISTORY AND CHARACTERISTICS

Naval Amphibious Base Little Creek (NABLC), in Virginia Beach, Virginia, provides logistic facilities and support services for local commands, organizations, home-ported ships, and other units to meet the amphibious warfare training requirements of the Armed Forces of the United States. The base is in the northwest corner of Virginia Beach and borders the city of Norfolk on its western boundary. The area surrounding this 2,147-acre facility, is low lying and relatively flat with several fresh water lakes. In addition to industrial land use, NABLC is used for recreational, commercial, and residential purposes. Specifically, the southeast corner of the base was developed for residential use. Land development surrounding the base is residential, commercial, and industrial. Little Creek Reservoir/Lake Smith, located upgradient of the base, serves as a secondary drinking water supply for parts of the city of Norfolk.

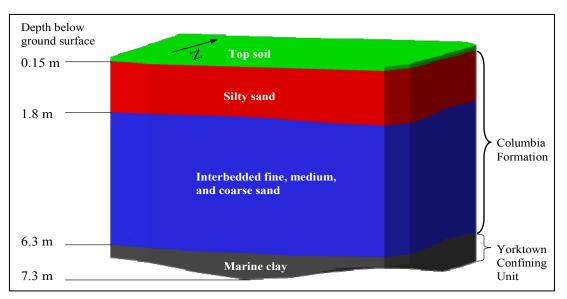
The demonstration was conducted to remove a chlorinated hydrocarbon DNAPL present in the subsurface adjacent to a former plating shop once operated by NABLC, School of Music, in Virginia Beach (Site 11). At this plating shop, chlorinated solvents and other industrial chemicals were discharged to a neutralization tank. These chemicals leaked from the tank and contaminated the surficial aquifer beneath. The neutralization tank, piping, and surrounding soils were removed in 1996. The contaminated area has been designated Installation Restoration Site 11-School of Music under the Navy's Installation Restoration Program. Site 11 is located east of Building 3650, the School of Music. The Standard Industrial Classification (SIC) code for Site 11 is 3471 (electroplating, plating, polishing, anodizing, and coloring). A small building (Building 3651), the former School of Music plating shop, is directly behind the School of Music. The main groundwater contaminants identified at Site 11 are listed in Table 7.

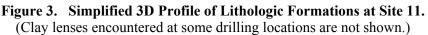
The geologic sediments in Virginia Beach were deposited in glacial, fluvial, and marine environments during the Holocene and Pleistocene. This shallow aquifer system at Virginia Beach is composed of the Columbia aquifer, the Yorktown confining unit, and the Yorktown aquifer, descending from the surface. The Columbia aquifer is composed primarily of poorly sorted sand with lenses of clay, silt, sand, peat, and shell fragments. Like Site 11, it is generally unconfined. It is underlain by the clay Yorktown confining unit. At Virginia Beach, the top of the Yorktown formation, including the Yorktown confining unit and the Yorktown aquifer, ranges from approximately 4.6 m to 24.4 m below sea level (Smith and Harlow, 2002) (see

Table 7. Maximum VOC Concentrations in Groundwater at Site 11 Found DuringHot-Spot Investigation, August 2001.

Chemical Name	Max Value (µg/L)	Max Location
Volatile Organic Compounds		
1,1,1-Trichloroethane	53,000D	LS11-GP412-11
1,1-Dichloroethane	24,000D	LS11-GP412-11
1,1-Dichloroethene	11,000D	LS11-GP412-11
Chloroform	1.000J	LS11-GP401-07
Chloromethane	2.00J	LS11-EB080401
cis-1,2-Dichloroethene	760.0J	LS11-GP410-10
Methylene chloride (Dichloromethane)	0.400J	LS11-GP401-07
Trichloroethene	390,000D	LS11-GP412-11

Figure 3 for details). Groundwater flow in the Columbia aquifer at Site 11 appears to be controlled by the overall base-wide groundwater flow direction (approximately ENE to WSW) and by seepage into a system of leaking sanitary sewer pipes that border the site on the east and south.





3.4 PHYSICAL SET-UP AND OPERATION

The CDEF demonstration at NABLC was carried out in several stages from June though September 2002. Site activities included well field installation, partition tracer tests before and after the technology demonstration, mobilization and demobilization of field equipment, and the actual CDEF field testing. The site layout is shown in Figure 4.

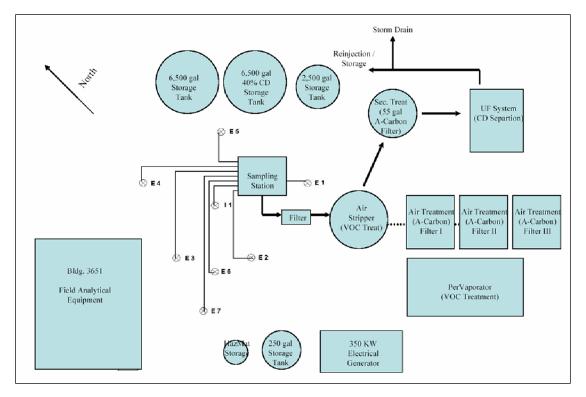


Figure 4. Site Layout During CDEF Demonstration.

The demonstration was interrupted for about 1 month (June/July) because the local publicly operated treatment works (POTW) withdrew permission to discharge treatment effluent to their system. The POTW withdrew initial consent to discharge because of a policy that restricted acceptance of any treated water from a site listed under the Superfund's National Priorities List (NPL). Since Site 11 was part of the Installation Restoration Program (IRP) at NABLC, which is on the NPL, the POTW could not accept effluent from the study into their POTW. In response, the field activities were curtailed while the Virginia Department of Environmental Quality (VADEQ) was approached for a concurrence to discharge to a storm water conveyance. VADEQ granted the discharge during early July and the field test resumed with the pre-PTT.

No remediation operations were ongoing at Site 11 before a year after the demonstration. This demonstration was performed under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) (42 USC 9601 et seq) statutory framework. Compliance with federal, state, and local statutes was maintained as applicable or relevant and appropriate requirements (ARAR). ARARs for this site included but were not limited to the Resource Conservation and Recovery Act (RCRA) (42 USC 6901, et seq), the Federal Facilities Compliance Act (FFCA), (42 USC 6901, Note 6908), the Clean Air Act (CAA) (42 USC 7401-7671q.), Executive Order 12088 (Federal Compliance with Pollution Control Standards), Executive Order 12580 (Superfund Implementation), the Clean Water Act (CWA) (33 USC 1251-1387), the Safe Drinking Water Act (SDWA) (42 USC 300f et seq), and the Virginia Water Quality Standards (9 VAC 25-260-5 et seq). These regulations established the performance criteria listed in Table 10. Under SDWA provisions, MCLs for dissolved VOC compounds (and others) are established. A complete list of current MCLs can be obtained via http://www.epa.gov/OGWDW/mcl.html. The MCL is the remediation goal for groundwater

clean up at Site 11 and needs to be reached before regulatory closeout of the site can be achieved. The CAA regulated discharge from the air stripper. The CWA and Virginia Water Quality Standards regulated discharge requirements for water treated below the MCL.

Eight wells were drilled for the CDEF demonstration. Figure 5 shows the well locations relative to Building 3651 and the former neutralization storage tank. Also included in this figure are photoionization detector (PID) readings obtained during well drilling and the approximate extent of a trough at the base of the Columbia aquifer. This trough appears to have governed the DNAPL migration pattern at the site, i.e., it directed DNAPL transport towards (and under) the building. The existence of the trough was unknown prior to drilling and necessitated modifications of the planned well field design and flushing scheme. The most important deviation from the demonstration plan was a shift of the treatment zone away from the five-star pattern described by wells E1 through E5 (where "E" designated extraction wells) and a central injection well (I1). The revised treatment zone was centered around well E6 and included wells I1, E2, E3, and E7 all of which were used as extraction or injection wells. A line-drive and a push-pull treatment scheme were tested. During the line-drive tests, 20% cyclodextrin solution was injected into wells E2, E6, and E7 and extracted from wells E3 and I1. Well E6 was converted to an extraction well about half-way into the linedrive test to achieve better control of the flow field.

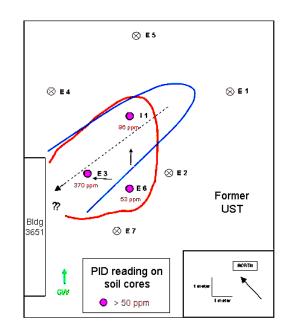


Figure 5. Location of Wells Drilled for the CDEF Demonstration in Relation to Building 3651. (Well E 6 marks the approximate location of a former underground neutralization tank. PID readings were taken on soil cores during well installation. Also shown (by the blue line) is the approximate extent of trough discovered during drilling. The trough axis (dashed line) slopes towards building 3651. The red line marks the approximate extent of the source zone. Note that groundwater (GW) flow at time of drilling was as indicated. However, GW flow direction changed by 180^o during the course of the demonstration.)

During the push-pull tests, cyclodextrin solution was injected and then extracted from wells I1, E3 and E6. Push-pull tests were either conducted on one well at a time or on all wells simultaneously.

3.5 SAMPLING/MONITORING

The sampling plan developed for this demonstration specified the number of sampling locations, frequency, methodology, chemical analyses, and reporting procedures to be used during the demonstration. The objective was to sample frequently enough to define recovery curves during each phase of operation.

The CDEF monitoring plan included regular sampling and analysis of the target contaminants (TCE, 1,1,1-TCA, 1,1-DCE, and chloroform), the CD flushing solution, and tracers used during

the pre-PTT and post-PTT. In addition, the field parameter pH, DO, electric conductivity, and water temperature were recorded. The sampling and monitoring procedures were in accordance with the sampling and monitoring provisions laid out in the demonstration plan.

Table 8 summarizes the sampling frequency and other sampling details. The principal sampling locations included injection and extraction wells, effluent discharge point, monitoring wells located in the vicinity of the demonstration site, and influent and effluent of the above ground treatment system (air stripper, UF system). Additional samples were collected from off-gas line of the air stripper and between and after the air-activated carbon filter. These gas samples served only as monitors for the loading status and as the activated carbon filters for monitoring the ambient air quality. These air samples were not used for mass balancing. Cyclodextrin and bromide concentrations were determined on site. Confirmatory samples were sent to Reed & Associates in Newport News, Virginia). All other aqueous samples were stored in an on-site refrigerator until express-shipped in coolers to the University of Arizona laboratory.

			Field Samples			Qualit	y Assurance	e Samples
Sample Matrix	Analysis	Method	Number of Locations	Samples Per Location	Total Per Day	Duplicates	Trip Blanks	Total Groundwater
GW	Target VOCs	GC	8	1 / 6hr	24	10% of total field number	1 per cooler	2 to 4
GW	CD	TOC & RF	8	1 / 6hr	24	10% of total field number	1 per cooler	2 to 4
GW	Tracers	GC	8	1 / 6hr	24	10% of total field number	1 per cooler	2 to 4

 Table 8. Daily Sample Summary as Provided in Demonstration Plan.

Actual sampling frequency was generally higher, i.e., more samples were collected for technology assessment purposes than necessary during a typical CDEF remediation. TOC: total organic carbon analyzer. RF: fluorescence spectrometry. GC: gas chromatography.

3.6 ANALYTICAL PROCEDURES

The analytical procedures, including quality assurance/quality control (QA/QC) requirements, were followed as outlined in the demonstration plan with the exception of two non-toxic conservative tracers that were added for the post-demonstration partition tracer test (fluorescein and deuterium). These tracers were added to prevent possible interference with bromide tracer remnants from the predemonstration partition tracer test. Table 9 summarizes the analytical methods used for this demonstration.

Analyte Type	Matrix	Method Name	Container Type	Container Size	Preservative	Analysis Location
Target VOCs	GW	GC/FID	glass	22 ml	None	Field & UA
CD	GW	TOC & RF	glass	20 ml	None	Field
Tracers	GW	GC/FID	glass	22 ml per set of tracers	None	BR: Field Alc/F/D: UA
Confirmatory Samples	GW	GC-MS	glass	40 ml	Yes	Reed & Associates

UA: University of Arizona, Allc: alcohol tracer (PTT), F: fluorescein, D: deuterium, Br: bromide. TOC: total organic carbon analyzer. RF: fluorescence spectrometry. GC: gas chromatography.

The VOC analytical methods used in the University of Arizona (UA) laboratory were similar to standard EPA methods, but were adapted for the presence of CD in the aqueous phase. Selected samples (confirmatory samples for effluent) were sent to a local laboratory, Reed & Associates in Newport News, because of shorter turnaround times.

During the predemonstration PTT, TCE concentration was also measured in the field using a portable GC. However, once cyclodextrin was present in the groundwater, i.e., after the first CD injection/extraction tests, the field GC regularly produced lower TCE concentrations compared to those determined in the UA and Reed & Associates laboratories. The discrepancy between the field GC results and laboratory results were caused by the complexation of TCE by the CD. Because the field GC method could not be adjusted to account for this discrepancy (e.g., by adding a purge-and-trap system), all samples collected during subsequent tests were sent to the laboratory at UA. The CD concentration was analyzed on site using a TOC and was later verified in the URI lab against a control method based on fluorescence spectrometry (RF). For further details regarding the analytical procedures, refer to the demonstration plan.

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4.0 PERFORMANCE ASSESSMENT

4.1 **PERFORMANCE DATA**

The format of the performance data summarized in Table 10 follows the recommendation of the Federal Remediation Technologies Roundtable (FRTR, 1998).

Types of samples collected	Aqueous samples (flushing solution, waste water) analyzed for TCE, 1,1,1-TCA, 1,1-DCE, chloroform, and cyclodextrin			
Sample frequency	Several times daily			
Quantity of material treated	About 50 tons of DNAPL source zone material (in situ)			
Untreated and treated contaminant concentrations	Substantial changes in groundwater TCE concentrations measured after end of demonstration (average TCE concentrations decreased 77.3%)			
Cleanup objectives	TCE mass removal > 90%			
Comparison with cleanup objectives	70%-81% of mass was removed based on partition tracer tests and mas balance calculations (approximately 30 liters TCE, 1,1,1-TCA, 1, DCE)			
Method of analyses	VOC: GC-FID CD: TOC and RF			
QA/QC	Detailed QA/QC protocols in demonstration plan			
Residues	VOC off-gas, decontamination fluids, fluids leftover from on-site chemical analysis			

Table 10. Performance Data for CDEF Demonstration at NABLC.

4.2 **PERFORMANCE CRITERIA**

The primary and secondary performance criteria used for the evaluation of CDEF were established in the demonstration plan. Table 11 and Table 12 summarize these criteria.

Well clogging due to iron precipitation in the injection wells made continuous injection and extraction of the cyclodextrin solution in closed-loop mode impossible. The iron precipitation may have been prevented by installing an anaerobic air stripper system. Time and budget constraints, however, prohibited the installation. In response to this unanticipated problem and in deviation from the demonstration plan, the CDEF application scheme was modified in favor of the (discontinuous) push-pull approach.

Table 11. Expected and Actual Primary Performance and Performance Confirmation Methods. (Refer to demonstration plan for details.)

	Expected Performance Metric	Performance Confirmation						
Performance Criteria	(Pre Demo)	Method	Actual (Post Demo)					
PRIMARY CRITERIA (Qualitative)								
Contaminant mobility	Reduced smaller plume	Monitoring wells LS11 -MW02, -MW01T, -MW04D, -MW05D	Under investigation ^(a)					
Faster remediation	Endpoint attained faster	Monitoring wells LS11 -MW02, -MW01T, -MW04D, -MW05D	TCE concentration declined by 77.3% on average					
Ease of use	Minimal operator training required	Demo experience	Except for UF system, minimal training required					
PRIMARY PERFORMANCE C	RITERIA (Quantitative)	·	· · · ·					
Hazardous materials - generated	None	Analysis for possible toxic degradation products	None directly related to CDEF					
Factors Affecting Technology Perf	formance							
Flow rate	64 m ³ /d (18,000 gpd)	Certified ABB flow meter (Accuracy ±3%)	27.2 m ³ /d (7,200 gpd)					
Feed rate	0.5 m ³ / hr	Certified ABB flow meter (Accuracy ±3%)	0.25 to 1 m ³ /hr (1 to 5 gpm)					
CD concentration	20 to 40% at injection well 5 to 10% at extraction well	TNS-complexation (RF) and TOC analysis	20 to 35% at injection well 2.7 to 6% at extraction well during line- drive, 5% to 33% during push- pull					
Soil type	> 100 ft/d hydraulic conductivity (medium sand with some silty clayey strata)	Pre demo slug test	2.4 to 25 ft/d hydraulic conductivity (medium sand, some silty-clayey layers)					
Particle size distribution	Fraction < 0.063 mm (very fine sand) is less than 10%	Sieve analysis of cores (ASTM D422-63 method)	Locally, high silt and clay fraction					
Soil homogeneity	Predominantly sandy material > 90% of screened interval	Thickness of strata in soil boring profile	Predominantly sandy material > 90% of screened interval					
GW pH	pH varies between 6 and 8	Orion pH meter (Accuracy $\pm 5\%$)	pH between 6 and 7					
DO	DO varies between 50 to 90% saturation	YSI 55 DO meter (Accuracy +/- 5%)	DO < 5%					
Target contaminant								
% reduction	Reduce TCE by 90%	Mass balance in combination with PTT pre- and post demo test	70% - 81% reduction					
Regulatory standard	Attain TCE MCL (5 ppb)	UA Method (GC-FID), duplicates, spikes, trip, blanks, RPD<60%, Recovery>90%, Complete>95%	MCL attained in air stripper effluent. GW concentration still exceeds MCL in most wells.					

^(a) The effect of the CDEF demonstration on the TCE plume size is currently not known. NABLC is planning an extensive sampling campaign (including MIP and Geoprobe measurements) in September 2003. This field campaign will follow-up on the predemonstration hot-spot investigation conducted in August 2001 and should give conclusive information about how the demonstration affected the TCE plume at Site 11.

Table 12. Expected and Actual Secondary Performance and Performance Confirmation Methods. (Refer to demonstration plan for details.)

	Expected Performance	Performance Confirmation	
Performance Criteria	Metric (Pre Demo)	Method	Actual (Post Demo)
	NCE CRITERIA (Quantitative)		
Process Waste			
Generated	None	Observation	On-site chemical analysis fluids
Plume Size	Smaller	Monitoring wells LS11 - MW02, -MW01T, -MW04D, -MW05D	Under investigation
Reliability			
Downtime due to equipment failure	< 5% of demonstration time	Record keeping	ca. 25% of demonstration time
Safety			
Hazards	None	Demo experience	None
Protective clothing	None	Demo experience	None
Versatility			_
Continues operation	Yes	Demo experience	Yes (line-drive) No (push-pull)
Other application	Yes	Demo experience	Low DO indicates degradation of CD — enhanced biodegradation ?
Maintenance			
Required	Activated carbon exchange Filter press clean out CD storage tank exchange	Demo experience	A-carbon exchange, sand filter cleaning, well rehabilitation, UF back- flushing
Scale-up constraints			
Engineering	Operating space	Monitoring during	Site-specific
Flow rate	Available equipment capacity	demonstration operation	Budget constrains
Contaminant concentration	None		Presence of NAPL — not for plume treatment

4.3 PERFORMANCE ASSESSMENT

The data gathered during the CDEF demonstration illustrate that most, but not all, of the performance objectives have been met (see demonstration plan). First, CDEF technology proved to enhance the removal of TCE and other VOCs under full-scale operating conditions. The amount of DNAPL was reduced by 70% to 81% (based on pre- and post-PTTs and mass balance calculations), which is 9% to 20% short of the performance objective >90% DNAPL removal. The TCE concentrations in the reference wells declined by 78% on average. The original performance objectives for this demonstration were to remove >90% of the DNAPL mass and reduce the aqueous TCE concentration to <1% of the initial TCE concentration. Neither criterion was met during the comparably short duration of this demonstration. The less than expected performance in terms of decreasing the aqueous TCE concentration underlines the fact that CDEF is primarily a source zone treatment technology that, like most other chemical enhanced treatment approaches, must be assisted by other (subsequent) remediation approaches. The MCL, however, was reached for effluent treated by air stripping. These results were achieved within 2 months of active remediation (not counting time spent on site mobilization/ demobilization and tracer tests). Thus, during the relatively short period of this demonstration, a

significant amount of contaminant mass was removed, which will eventually translate in shorter remediation duration once a decision is made how to cleanup Site 11.

Table 13 shows that during all CDEF tests (line-drive and push-pull) about 29% of the total recovered DNAPL was removed while the remainder was flushed out during the PTTs and other tests. This seemingly disproportional low performance of CDEF was caused by the comparably short operational time of the CDEF technology relative to the other tests.

Table 13. Overall Mass Balance Yielding the Approximate 30 L Removal Estimate Cited in the Report, As Well As the Estimated Mass Remaining After All Testing.

Test or Activity	Voc Mass Removed (g)	DNAPL Volume Removed ¹ (liters)	Percentage of DNAPL Mass Removed During Demonstration ² (%)	Percentage of DNAPL Remaining In Subsurface ³ (%)
Pretest PTT	14,434	10.3	35	73
Hydraulic test and other ⁴	5,880	4.2	14	61
I/E test	3,995	2.9	10	53
CPPT single-well tests	3,555	2.6	9	46
CPPT multiwell tests	4,076	2.9	10	38
Post-test PTT	9,377	6.7	22	20
TOTAL	38,517	29.6	100	20

¹ Assumes all VOCs were DNAPL

² Based on the volume of DNAPL (ca. 30 l) removed during all site activities.

³ Based on the initial DNAPL volume present at the site before beginning of this demonstration (ca. 38 l). The initial DNAPL volume was determined on PTT analysis (best estimate).

⁴ Best estimate. Sample frequency during hydraulic tests was lower than during CDEF and PTT tests.

The demonstration of CDEF in pushpull operation was not anticipated in the demonstration plan. However, the same performance objectives and assessment strategies for the evaluation of the CDEF line-drive demonstration were applied. Of the two treatment schemes, push-pull evidently outperformed the line-drive demonstration. For example, during push-pull the average solubility of TCE increased up to 6.5 times over conventional P&T, whereas it increased only up to 3.2 times during line-drive. Also, the highest aqueous TCE concentrations measured during the CDEF demonstration were >200 mg/L or up to 9 times higher than the average pretreatment TCE concentrations. Even higher solubility enhancements (up to 19 times) were observed for 1,1,1-TCA.

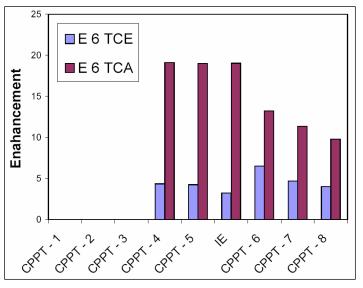


Figure 6. Average Solubilization Enhancements **During Line-Drive (IE) and Push-Pull Tests.** (Note that the solubilization of 1,1,1-TCA is enhanced much more compared to TCE.)

These values demonstrate clearly that CDEF significantly enhanced the contaminant removal rates. (see Figure 6). Cyclodextrin concentrations were easily monitored in real time by using an

on-site TOC analyzer. On-site measurements of aqueous TCE concentration using a gas chromatograph without purge-and-trap capabilities proved unreliable.

Compared to similar treatment approaches (e.g., P&T, in-situ oxidation), our experience with CDEF demonstrates that this technology is easy to use. The only pieces of equipment that required special training¹ were the UF system used for CD reconcentration and on-site analytical equipment (i.e., GC and TOC). During operation (either in line-drive or push-pull mode), the CD concentration of the flushing solution has to be monitored and, if necessary, adjusted. The use of in-line analytical equipment and remote control of the CDEF operation (including installation of automatic mixing valves) can significantly decrease the number of onsite operating hours. Regular maintenance of the UF system was required (e.g., back-flushing membrane filters). The air stripper required infrequent decontamination to remove iron precipitates (a site specific problem). With regard to health and safety requirements, none of the processes and technologies involved in CDEF remediation poses risks that exceed those of comparable remediation approaches. In fact, CD is preferable over many other remediation agents (such as permanganate or many cosolvent/surfactant formulations) because it is nontoxic and appears to readily (bio)degrade.

However, there were some unanticipated technical problems that affected the overall performance of this remediation technology. For example, the aeration of the flushing solution during air stripping resulted in the precipitation of iron inside the air stripper, and more important, clogging of the injection wells. Besides increased air stripper maintenance time, the clogged injection wells did not permit continuous operation of CDEF in line-drive mode at this demonstration site. Although time and budget constraints during this demonstration prevented us from taking appropriate countermeasures, there are commercial solutions available to run an air stripper under anaerobic conditions (e.g., under a nitrogen atmosphere). Conversely, well clogging was avoided by using the push-pull approach. This was because the recycled CD flushing solution — after passing through the air stripper — quickly became anaerobic again when kept in on-site storage tanks for 12 to 24 hours (depending on outside temperature). It appears that the naturally occurring degradation of the CD consumed the DO present in the flushing solution. The rate at which the CD was degraded, however, was slow and did not cause any noticeable CD mass losses or changes in the effectiveness of the flushing solution. The additional holding time did not delay the remediation because sufficient storage capacity existed at the site (two 6,500 gal commercial storage tanks) and at least 12 hours passed between extraction and reinjection of the flushing solution.

Another issue was the lower than expected treatment capacity of the UF system. The UF was designed to treat 5 gpm on a continuous basis and increase the CD concentration to 20% in the process. The actual flow rates achieved ranged between 0.5 and 2 gpm. A scale-up (i.e., using a larger membrane area) would have been required to permit in-line, continuous operation.

¹ The use of a pervaporation system for VOC removal from the flushing solution was also field tested. However, the cost and performance assessment of the pervaporation system was inconclusive because the equipment was damaged during site mobilization. When operational, the pervaporation system removed up to 99% of VOC, but it required a significant amount of electrical energy and constant supervision by a field engineer. It also generated a stream of highly VOC-enriched waste water. Based on our field experience with this treatment approach (and compared to the air stripper system we used), we cannot recommend pervaporation technology.

Although the flow rates did not permit continuous operation of the UF in-line, the desired concentration enhancement to 20% was achieved. Thus, the usefulness of the UF system for CD reconcentration was demonstrated.

4.4 TECHNOLOGY COMPARISON

Table 14 provides a technology comparison of CDEF to selected alternative DNAPL removal technologies and conventional P&T technology. It is important to note that currently there is no single DNAPL removal technology available that can be used under any site conditions. The selection of an appropriate remediation technology has always been site-specific and requires sufficient source zone characterization. The difficulties encountered in this demonstration should serve as an example that even under seemingly "simple" hydrogeologic conditions unexpected problems can be encountered. The need for site characterization and the difficulty in adequately describing all its aspects have direct impact on the design, cost, and performance of all technologies.

Table 14. Technology Comparison: Advantages and Disadvantages of Selected DNAPL Removal Technologies (Modified from NFESC 2001.)

	Surfactant/Cosolvent Flooding	Cyclodextrin Flushing	In-Situ Chemical Oxidation	Pump-And-Treat
Applicability	Applicable to NAPLs	Applicable to NAPLs	Applicable to NAPLs and dissolved contaminants	Applicable to dissolved contaminants, least effective for NAPLs
Laboratory design	Extensive laboratory testing	Some laboratory testing	Some laboratory testing	No laboratory testing
Field design	 Detailed site characterization required Locate source zone and delineate its extent Map hydrostratigraphy Measure basic aquifer and soil parameters Characterize the capillary barrier (aquitard) relative to NAPL mobilization design Simulation of well field design 	 Detailed site characterization required Locate source zone and delineate its extent Map hydrostratigraphy Measure basic aquifer and soil parameters Characterize the capillary barrier (aquitard) relative to NAPL mobilization design 	 Detailed site characterization required Locate source zone and delineate its extent Map hydrostratigraphy Measure basic aquifer and soil parameters Simulation of well field design and injection/extraction scheme 	 Detailed site characterization required Locate source zone and delineate its extent Map hydrostratigraphy Measure basic aquifer and soil parameters Simulation of well field design and injection/extraction scheme
Hydrogeologic constraints	and injection/extraction scheme Sufficiently high aquifer thickness and permeability necessary. Mobility control of NAPL is recommended.	and injection/extraction scheme Sufficiently high aquifer thickness and permeability necessary	Not amenable to mobility control	Not amenable to mobility control
Effect on subsurface	Demonstrated reduction in NAPL saturation to less than 0.05%	Demonstrated reduction of DNAPL saturation by 20% at site with low initial DNAPL saturation (Sn=0.7%). Long- term effects may include enhanced biodegradation facilitate by cometabolism of CD.	NAPL destroyed in situ in aqueous phase. Potentially destroys (oxidizes) natural organic matter. Risk of sterilizing the treatment zone. Risk of clogging the aquifer.	Large volumes of water need to be extracted to remove relatively little contaminant mass. Not amenable for NAPL removal.
NAPL mobilization	Likely, but can be minimized with proper hydraulic controls and tailoring the surfactant flushing solution	NAPL mobilization is generally not a cause for concern.	NAPL mobilization is generally not a cause for concern.	NAPL mobilization is generally not a cause for concern.
Performance assessment	Surfactant residuals in the subsurface may affect performance assessment by PTT.	PTT can be used for performance assessment.	Limited by dissolution rate of NAPL. Change in NAPL composition can affect performance assessment.	PTT can be used for performance assessment.

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5.0 COST ASSESSMENT

5.1 COST REPORTING

The cost report for the CDEF technology was prepared based on guidelines provided by the Federal Remediation Technologies Roundtables (FRTR) *Guide to Documenting and Managing Cost and Performance Information for Remediation Projects* (FRTR, 1998). This cost reporting format distinguishes between several cost categories — (capital (predominantly fixed), operational and maintenance (predominantly variable), and other technology specific costs — and relates the cost of treatment to the mass of media/volume removed and treated. Most system specifications used in the cost reports are identical to those employed at NABLC. However, a few modifications have been made based on lessons learned during the CDEF demonstration. These modifications, where applicable, are outlined in the following paragraphs.

Table 15 summarizes the site conditions at Site 11, NABLC, under which the CDEF demonstration was performed. If not noted otherwise, these values were used in the preparation of the cost report.

Parameter	Value
Depth to water table	2.1-2.4 m below ground surface (bgs) (7-8 ft bgs)
Depth to aquitard	7-8 m bgs (21-24 ft bgs)
Porosity of aquifer	31%
Hydraulic conductivity of DNAPL treatment zone	$8 \times 10^{-4} \text{ cm/sec}$
Hydraulic conductivity of aquitard	$3x10^{-8}$ cm/sec
Treatment flow rate	3.4 gpm
Number of wells	8
CD slug size per application	9 m ³
Mass of soil treated	49 tons
Surface area above treatment zone	$30.3 \text{ m}^2 (326 \text{ ft}^2)$
Average pre-CDEF VOC concentration ^(a)	38.3 mg/L
Initial DNAPL saturation $(S_N)^{(b)}$	0.67%
90% DNAPL removal criterion ^(c)	34.2 liter or 48 kg DNAPL

Table 15. Summary of the Actual Demonstration Site Conditions at Site 11, NABLC.

^(a) Sum of TCE, 1,1,1-TCA, and 1,1-DCE, as determined during PTTs

^(b) Pre-PTT weighted best estimate

^(c) Total DNAPL volume recovered during entire demonstration was approximately 30 liters (based on TCE, 1,1,1-TCA, and 1,1-DCE concentrations in extracted solutions). Difference in DNAPL saturation between pre-PTT and post-PTT indicated that this volume equals 70% to 81% DNAPL mass removal. Thus, about 38 liter DNAPL was initially present at demonstration site, 90% of which are 34.2 liter.

The effluent treatment cost estimates reflect sites without on-site effluent treatment facilities. Under these circumstances, as was the case at NABLC, cost for an effluent treatment system (such as air stripping) becomes part of the overall technology cost. It was assumed that any off-site effluent discharge from a treatment system must meet all applicable effluent discharge standards.

After 6 to 8 months, the cumulative rental expenditures exceed the equipment purchase price in most cases. Hence, it was assumed that all equipment was purchased if the remediation project lasted longer than 6 to 8 months. Only the cost for an activated carbon filter system necessary to

treat the VOC off-gas was calculated on per-month basis, even if the treatment duration exceeded 6 months. This approach was selected because spent activated carbon had to be replaced by fresh carbon on a regular basis.

For the ESTCP demonstration, partition tracer tests served as the principal means for DNAPL source zone characterization and performance assessment. The PTT technology is patented to Duke Engineering and license fees may apply. The use of this technology was considered optional for developing cost estimates for full-scale CDEF application. Therefore, the cost for conducting a pre- and post-PTT test are not included in any real-world cost assessments.

A DNAPL source zone investigation was considered part of the CDEF remediation. However, it was assumed that the approximate extent of the DNAPL source zone is already known from previous site investigations (as was the case at this demonstration site).

Actual Demonstration Cost. Using the FRTR methodology, the actual cost of the CDEF demonstration was approximately \$863,000 (including PTTs). A detailed cost report is provided in Appendix B. Based on the mass of VOC contaminants removed and treated during the flushing with CD (25.8 lbs²), the VOC treatment cost was approximately \$33,000 per lb. When relating the treatment cost to the volume of groundwater extracted and treated, the cost was \$1.03 per gal. In terms of soil mass treated, the cost was approximately \$17,500 per ton of soil.

Cost of Real-World Implementation. This CDEF technology demonstration varied from a realworld implementation in several ways. For example, considerable effort was spent collecting and analyzing samples for technology performance demonstration purposes. Also, in preparation for this demonstration a series of laboratory tests were conducted that provided information directly applicable to most, if not all, future CDEF sites. For example, extensive investigations have been conducted to test different sources and quality grades of CD. Future users of the CDEF technology would not need to repeat these tests. In addition, local rules and regulations required the continuous presence of personnel at the site during operation and the implementation of the body system. The requirement for continuous personnel was in place to ensure that no system failures would occur without personnel present to promptly respond. At a typical real-world CDEF implementation, a computerized SCADA system would be installed to fully automate the pumping operations. In case of system failures, a designated responder is paged, which alleviates the need for manning the operation full time. Also, two treatment approaches (I/E and CPPT) were tested, and two VOC treatment alternatives (air stripping and pervaporation) were evaluated as part of this demonstration. On most real-world sites, only one treatment approach and method is implemented. In addition, universities (students and their supervisors) performed most of the work at salaries that differ from commercial contractors. All these activities affected the cost of this demonstration.

For this real-world cost assessment, all one-time, demonstration-related costs were removed (such as experimentation, process optimization, nonrouting analysis and testing, and excessive sampling and analysis used to evaluate and refine the demonstration). It was assumed that one VOC and two CD analyses were carried out on a daily basis (see Table 16) over a period of 2 months. It was further assumed that no pervaporation equipment was used and that no partition

² The overall VOC mass recovered during the entire demonstration (incl. PTTs) was about 78 lbs.

tracer tests were conducted. Also, a SCADA system was implemented, decreasing the number of field personal hours. All remaining costs reflect the actual spending during the ESTCP demonstration. Under these conditions, the real-world CDEF implementation cost is \$392,000. A detailed cost report is provided in Appendix C. Based on the 25.8 lbs VOC removed and treated, the VOC treatment cost was approximately \$15,200 per lb. When relating the treatment cost to the volume of groundwater extracted and treated, the cost is \$0.47 per gal. In terms of soil mass treated, the cost is approximately \$7,900 per ton of soil.

Criterion	Value
Type of CD	Hydroxyl-β-cyclodextrin; technical grade; unstabilized 40% aqueous solution with pH near neutral
Treatment area	$30 \text{ m}^2 (300 \text{ ft}^2) \text{ small site}$ 234 m ² (2,500 ft ²) large site
Contaminant removal process ^(a)	Air stripping
Efficiency of contaminant removal process	> 90%
CD recovery from subsurface treatment zone	CPPT: 97% I/E: 79%
Average injection well CD concentration	20%
Assumed efficiency decrease of CDEF due to decrease in global S_N over remediation period ^(b)	25%
Efficiency of CD recovery from subsurface	Batch operation: 97% Continuous operation: 79%
Efficiency of CD recovery by UF (batch mode)	Batch operation: 90% Continuous operation: 68%
CDEF operation time	I/E: Continuous CPPT: 3 - 6 flushes per week
CD mass used	Determined by model
CD cost	\$2.00 / lbs (\$4.50 / kg)
Tank requirements ^(c)	2 x 6,500 gal tank (demo scale) 2 x 21,000 gal tank (full-scale)
Analytical requirements ^(d)	Continuous operation: 1 VOC and 2 CD analyses per day Batch operation: 1 VOC and 2 CD analyses per flush
Labor requirements ^(e)	Continuous operation: 6 man hrs per day Batch operation: 8 man hrs per day

Table 16. Criteria Used to Develop Remediation Cost, CD Recovery Cost, and Full-Scale Remediation Time Estimates.

^(a) Performance evaluation of PVP not considered because of insufficient data.

^(b) CDEF efficiency decrease was observed during multiwell CPPTs at the end of the CDEF demonstration. Efficiency decrease was most likely caused by decreasing NAPL saturation in the flushing zone. Value is a conservative estimate.

(c) One tank was required for 40% CD stock solution storage; second tank was required for storage of recovered CD flushing solution.

Hypothetical Full-Scale System. Another significant difference between this ESTCP technology demonstration and a real-world implementation of CDEF technology was the comparably small size of the treatment zone and the scale at which the demonstration was performed (see Table 15). For example, the mass of soil treated during this demonstration was about 50 tons. Many contaminated sites, however, require treatment of several hundred tons of soil or more. Also, the UF system for CD reconcentration used in the demonstration was not operated continuously (i.e.,

^(d) One VOC analysis of the extracted and injected solution per day was performed to monitor remediation progress and efficiency, one CD analysis of the extract to confirm effectiveness of the flushing solution, and a second CD analysis after UF system to confirm flushing solution target concentration of 20% before reinjection. Additional sampling of the effluent may be required, depending on the characteristics of the discharge (i.e. presence of inorganics).

^(e) Labor requirements during I/E operation include daily system check and maintenance and effluent sampling, assuming that the SCADA system is used for system monitoring during remaining times. Additional work requirements during batch operation include switching treatment system from injection to extraction mode and back. Local rules may require 24/7 site staffing and/or implementation of the body system (as was the case during this demonstration).

the UF treatment rates were smaller than the flushing solution extraction rates). The treatment capacity of a full-scale UF system requires treatment capacities that at least equal the volume of extracted flushing solution.

To account for these size and scale issues, a cost report was prepared for a hypothetical full-scale system. It was assumed that a site approximately 11 times larger (600 tons contaminated soil or 109 m³ flushing volume) than the demonstration site was remediated using CDEF technology. The remediation area was 234 m² (2,500 ft²). The global degree of contamination (initial DNAPL saturation = 0.67%) and the site conditions (see Table 15) were assumed to be the same as during the ESTCP demonstration. The remediation goal was 90% DNAPL mass removal, i.e., 1,415 lbs VOC. It was assumed that a limited DNAPL source zone investigation was needed prior to the CDEF implementation. Table 16 summarizes the remediation system performance parameters used to calculate remediation cost and duration.

The full-scale site conditions were carefully chosen to closely reflect the conditions encountered at Site 88, Marine Corp Base Camp Lejeune (CL), North Carolina. At this site, an ESTCP-sponsored technology demonstration of surfactant enhanced aquifer remediation (SEAR) flushing was recently conducted, and detailed costs and performance data are available (NFESC, 2001). The advantage of basing the full-scale CDEF cost assessment on CL site conditions permits cost and performance comparisons of different DNAPL treatment approaches under very similar boundary conditions.

The full-scale cost report was based on air stripping as the sole VOC treatment technology. An alternative (pervaporation) was not considered because of insufficient cost and performance data. The cost of a full-scale UF treatment system was estimated based on manufacturer's information. However, actual cost of the UF system may deviate by as much as 25% depending on treatment capacity, rental duration, and availability. Also, it was assumed that the membrane filter inside the UF must be replaced twice a year³.

Two different treatment approaches were evaluated: line-drive (I/E) and multiwell push-pull (CPPT) treatment. The line drive treatment was assumed to run continuously. It was assumed that six CPPTs were run per week when running the UF in continuous mode. In case the CPPT/ UF system was operated in batch mode, two flushes were realized per week. The remaining time was necessary to reconcentrate the recovered CD flushing solution. It was assumed that the UF system for CD reconcentration performed as determined during this demonstration (Table 16). This conservative estimate leaves ample room for cost improvements because the UF used in the demonstration was a comparably low-efficient proto-type. Finally, a cost assessment was provided in case no UF system is used. Table 17 summarizes the various scenarios assessed and provides a comparison of the number of wells needed for treating at full scale.

³ There was no need to replace the membrane filter during the demonstration. Replacement interval is therefore a best estimate.

Table 17. Comparison of Well Requirements for Full-Scale CDEF Application (2,500 ft²) at a Hypothetical Site Similar to NABLC.

Application	UF Operation Mode	Number of Injection/ Extraction Wells	Number of Injection Wells	Number of Extraction Wells	Number of Hydraulic Control Wells
I/E	Continuous	-	14	24	8
I/E					
CPPT	Continuous	40 ⁽¹⁾	-	-	_(2)
CPPT	Batch	$40^{(1)}$	-	-	_(2)
CPPT		$40^{(1)}$	-	-	_(2)

⁽¹⁾ Injection/extraction wells used for push-pull treatment are identical in construction to injection, extraction, or hydraulic control wells used during I/E. (2) No hydraulic control wells are necessary if groundwater flow velocities are 0.5 cm or less.

An EXCEL model was developed to estimate remediation duration and amount of CD mass needed for achieving the 90% DNAPL mass removal criterion. The model requires as input most of the data summarized in Table 15, Table 16, and Table 17. It was first fitted to the initial DNAPL mass present at the ESTCP demonstration site. After good agreement was reached between DNAPL mass and remediation performance (as determined during this demonstration), the flushing volume was increased from 9 m³ to 109 m³ (or, in terms of soil mass, from 49 tons to 600 tons). The model simulations are shown in the Appendix IV.

The relatively short duration of the ESTCP demonstration added some additional uncertainty to the cost report. For example, towards the end of the CDEF demonstration, the VOC removal efficiency decreased as the result of decreasing NAPL saturation. The rate of CDEF efficiency decrease could not be quantified. Because of this shortcoming, it was assumed that the efficiency decreased by 25% over the remediation period. Based on this assumption, the total number of flushing cycles necessary to reach the remediation end-point criterion (90% mass reduction criterion) was multiplied by an uncertainty factor of 1.25 (see model simulations in Appendix D). The full-scale CDEF flushing durations for each treatment scenario are summarized in Table 18.

Table 18.	Comparison of Full-Scale CDEF Flushing Durations at a Hypothetical Site
	Under Conditions Similar to Those at NABLC.

		CD Flushing Durati	ion (PV/Total months)
Application	UF Operation Mode	Small Site ⁽¹⁾ 300 ft ²	Large Site ⁽²⁾ 2,500 ft ²
I/E	Continuous	2	19
I/E	None		19
CPPT	Continuous	2	2
CPPT	Batch	4	6
СРРТ	None	-	2

⁽¹⁾. Contaminated soil mass = 49 tons, pore volume = 9 m^3

⁽²⁾ Contaminated soil mass = 600 tons, pore volume = 109 m^3

The total life-cycle costs for the three full-scale CDEF treatment scenarios with a UF in operation are summarized in Table 19. The life-cycle costs are reported as net present value (NPV). Overhead costs or contingency fees were not included. Associated unit treatment costs for each scenario are also included (on VOC mass and soil mass basis). Detailed cost reports for each scenario (including those two in which no UF was used) are summarized in Appendix E. A second full-scale cost assessment was developed for a smaller site (see Table 16). Refer to Appendix F for details. Table 20 shows the implementation cost at the smaller site.

			Cost Scenario	
<u> </u>	-	I/E Approach	CPPT Approach	CPPT Approach
Cost		With UF	With UF	With UF
Category	Subcategory	(Continuous Mode)	(Continuous Mode)	(Batch Mode)
		FIXED COSTS		
Capital Cost	Mobilization/demobilization	\$17,928	\$17,928	\$17,928
	Planning/preparation/engineering	\$52,020	\$52,020	\$52,020
	Site investigation	\$101,850	\$101,850	\$101,850
	Site work	\$18,600	\$18,600	\$18,600
	Equipment-structures	\$ -	\$ -	\$ -
	Equipment-process equipment	\$288,039	\$60,974	\$60,974
	Start-up and testing	\$16,880	\$16,880	\$16,880
	Other-nonprocess equipment	\$11,300	\$8,050	\$11,300
	Other — installation	\$119,303	\$117,854	\$117,854
	Subtotal:	\$626,130	\$394,156	\$397,406
	V	ARIABLE COSTS		
Operation and	Labor	\$150,377	\$23,026	\$58,277
Maintenance	Materials/consumables	\$3,251,620	\$1,796,000	\$838,880
	Utilities/fuel	\$52,921	\$5,808	\$9,401
	Equipment cost (rental)	\$161,301	\$86,025	\$236,779
	Chemical analysis	\$70,925	\$7,380	\$35,160
	Other	\$28,522	\$8,358	\$18,070
	Subtotal:	\$3,715,666	\$1,926,597	\$1,196,567
Other Technology	Disposal, well cuttings	\$16,500	\$16,500	\$16,500
Specific Cost	Disposal, liquid waste	\$5,100	\$500	\$1,500
	Site restoration	\$1,080	\$1,080	\$1,080
	Subtotal:	\$22,680	\$18,080	\$19,080
	TOTAL	\$4,364,475	\$2,338,833	\$1,613,053
	Quantity treated – soil (tons)	600	600	600
Unit cost	(per lbs VOC removed and treated)	\$7,274	\$3,898	\$2,688
	Quantity treated – VOC mass (lbs)	1,415	1,415	1,415
Unit cost	(per lbs VOC removed and treated)	\$3,085	\$1,653	\$1,140

Table 19. Cost of Full-Scale CDEF Implementation(Treatment Area: 234 m² or 2,500 ft²).

			Cost Scenario		
Cost Category	Sub Category	I/E Approach With UF (Continuous Mode)	CPPT Approach With UF (Continuous Mode)	CPPT Approach With UF (Batch Mode)	
		FIXED COSTS			
Capital Cost	Mobilization/demobilization	\$17,928	\$17,928	\$17,928	
	Planning/preparation/engineering	\$38,020	\$38,020	\$38,020	
	Site investigation	\$17,065	\$17,065	\$17,065	
	Site work	\$6,400	\$6,400	\$6,400	
	Equipment - structures	\$ -	\$ -	\$ -	
	Equipment-process equipment	\$14,456	\$14,456	\$14,456	
	Start-up and testing	\$8,640	\$8,640	\$8,640	
	Other-nonprocess equipment	\$8,050	\$8,050	\$8,050	
	Other — installation	\$36,784	\$32,229	\$32,229	
	Subtotal:	\$147,343	\$147,343	\$142,787	
	V	ARIABLE COSTS			
Operation and	Labor	\$23,026	\$19,429	\$50,371	
Maintenance	Materials/consumables	\$469,400	\$151,280	\$73,320	
	Utilities/fuel	\$4,818	\$4,756	\$9,513	
	Equipment cost (rental)	\$55,273	\$55,267	\$110,547	
	Chemical analysis	\$7,380	\$7,380	\$6,480	
	Other	\$8,716	\$8,358	\$8,716	
	Subtotal:	\$568,613	\$248,470	\$258,947	
Other Technology	Disposal, well cuttings	\$3,900	\$3,900	\$3,900	
Specific Cost	Disposal, liquid waste	\$500	\$500	\$1,000	
	Site restoration	\$1,080	\$1,080	\$1,080	
	Subtotal:	\$5,480	\$5,480	\$5,980	
	TOTAL	\$721,436	\$397,801	\$407,714	
	Quantity treated – soil (tons)	49	49	49	
Unit cost	t (per lbs VOC removed and treated)	\$14,723	\$8,118	\$8,231	
	Quantity treated – VOC mass (lbs)	105	105	105	
Unit cost	t (per lbs VOC removed and treated)	\$6,871	\$3,789	\$3,883	

Table 20. Cost of Full-Scale CDEF Implementation (Treatment Area: 30 m² or 300 ft²).

5.2 COST ANALYSIS

Compared to the actual demonstration cost, the real-world CDEF implementation cost is approximately 55% less. The difference is attributed to one-time, demonstration-related costs, such as experimentation, process optimization, nonrouting analysis and testing, and excessive sampling and analysis used to evaluate and refine the demonstration.

The full-scale cost analysis reveals that scale and treatment approach determine the treatment cost. At small and large scale, respectively, the implementation of the multiwell push-pull approach was approximately 53% to 64% less expensive than the line-drive CDEF. The main cost driver for the line-drive CDEF was the material cost (i.e., the amount of CD mass needed to achieve the remediation goal). The line-drive material cost accounted for 65% (small site) and 75% (large site) of the total life-cycle costs. Compared to the push-pull approach, significantly more CD was needed because of the comparably low CD recovery efficiencies during line-drive flushing. Another cost driver was the comparably long remediation time necessary (19 months) when implementing the line-drive approach at large scale sites (see Table 18). Longer remediation times resulted in much higher labor and equipment rental and purchase cost compared to the shorter multiwell push-pull treatment scenarios.

The lowest costs overall were realized by implementing multiwell push-pull CDEF and running the UF in batch mode. Under these conditions, 185 tons of CD were applied at the large site (accounting for 52% of the total life-cycle costs). If the UF were to run in continuous mode, the amount of CD needed would increase to 407 tons (accounting for 78% of the total life-cycle cost). Although running the UF continuously resulted in shorter remediation durations, the additional CD costs exceeded the cost savings realized because of lower labor and equipment rental costs.

Very similar life-cycle costs were generated when operating the UF in batch or continuous mode at the small scale (Table 20). The main reason for this similarity was that the remediation duration decreased from 6 to 4 months when using the batch mode approach at the smaller scale (see Table 18). Under the same conditions, the duration of the continuous treatment approach remained essentially unchanged because of hydraulic flow constriction and UF treatment capacity issues. In terms of unit treatment costs, the small scale unit treatment cost was more than twice as high as that at the large site. This is mainly due to the fact that much more effort (site investigation, mobilization/demobilization etc.) has to be expended to implement CDEF at small sites.

5.3 COST COMPARISON

In this section, the cost of CDEF treatment for DNAPL removal is compared to the cost of a conventional remediation technology (P&T DNAPL source zone containment) and two innovative in-situ treatment methods (surfactant enhanced flushing, SEAR, and six-phase resistive heating). The cost comparison was developed for the large site scenario at NABLC (Section 5.1 and 5.2). As Table 21 shows, the site and operating conditions were very similar to the conditions encountered at the at the 2,500 ft² Site 88 at the Marine Corp Base (MCB) Camp Lejeune, North Carolina (NFESC, 2001). Both sites were contaminated by similar volumes and types of DNAPL and can be remediated within a few months. The site area, hydrogeologic conditions, including treatment volume and aquifer thickness treated, and treatment approach (enhanced flushing) were very similar. Two main differences are noted. First, a lower initial DNAPL saturation at NABLC (0.67% versus 2% at MCB CL) may affect (= underestimate) the performance of CDEF technology relative to SEAR. Second, the remediation end-point criterion was defined differently.

In addition to the site and operation similarities, the SEAR costs estimate was developed based on the same ESTCP-approved cost assessment strategies used for this CDEF cost report. For example, the cost of pre- and post-treatment site characterization of the DNAPL source zone were not included in the either the SEAR (including resistive heating) or the CDEF cost assessments. Also, it was assumed that the technology vendors will be presented with a wellcharacterized site (as was the case for the CDEF cost assessment). Because of these similarities, we feel highly confident in using the SEAR costs reported by NFESC (including those for the resistive heating alternative) and compare them with our CDEF cost estimates.

 Table 21. Comparison of Site Conditions at NABLC, and MCB Camp Lejeune, North Carolina. (Site information compiled from NFESC, 2001.)

Parameter	CDEF Full-Scale	Camp Lejeune
Report date	2003	2001
Surface area	2,500 ft ²	$2,500 \text{ ft}^2$
Depth to water table	2.1-2.4 m bgs (7-8 ft bgs)	2.1-2.7 m bgs (7-9 ft bgs)
Depth to aquitard	7-8 m bgs (21-24 ft bgs)	6-7.7 m bgs (18-20 ft bgs)
Porosity of aquifer	31%	30%
Hydraulic conductivity of DNAPL treatment	8×10^{-4} cm/sec	1×10^{-4} cm/sec (low k)
zone		
Hydraulic conductivity of aquitard	$3x10^{-8}$ cm/sec	$2x10^{-7}$ cm/sec
Number of wells	46 line-drive ⁽¹⁾	46 line-drive ⁽¹⁾
	40 push-pull	
Type of treatment	Enhanced flushing	Enhanced flushing
Flushing agent	Cyclodextrin (20 wt%)	Surfactant (4 wt%)
		Cosolvent (8 wt%)
Treatment flow rate	6 gpm	6 gpm
Duration of operation	19 months (I/E)	4.25 months (127 days)
	2–6 months (CPPT)	
Tankage requirements	2 x 21,000 gal steel tanks	2 x 21,000 gal steel tanks
Primary contaminant	TCE and 1,1,1-Tri	PCE
Contaminant removal process	Air stripping	Air stripping
Average initial DNAPL saturation $(S_N)^{(2)}$	0.67%	2%
Initial DNAPL volume ⁽²⁾	413.5 liter	397 liter ⁽³⁾
End-point criterion	90% reduction of DNAPL	Natural attenuation becomes possible

⁽¹⁾ 24 injection wells, 14 extraction wells, 8 hydraulic control wells

⁽²⁾ Initial DNAPL saturation (SN) is PTT-based

⁽³⁾ See NFESC, 2001, p. 72.

Table 22 provides a cost comparison of CDEF, SEAR, resistive heating, and P&T. The cost category format was adapted from NFESC, 2001. All innovative remediation alternatives were assumed to last a few months only. The exception is the CDEF line-drive approach, which lasted 19 months. Conventional P&T costs were incurred over a 30-year period. All costs were based on present value (NFESC, 2001). The treatment alternative, "multiwell push-pull with UF operating in continuous mode," was not included in Table 22 because, unless a more effective UF system becomes available, this approach cannot compete with the multiwell push-pull approach and with the UF running in batch mode.

Based on the cost comparison provided in Table 22, CDEF in push-pull mode can compete with SEAR. Both innovative remediation technologies are only a little less expensive (on present day value basis) compared to conventional P&T. However, in contrast to P&T, much shorter remediation times are realized. This reduces the hazardous waste exposure time and results in returning a site to the real estate market much earlier (or permits earlier re-use). CDEF in line-drive operation was the most expensive innovative remediation technology, and resistive heating was the least expensive.

Table 22. Summary of CDEF and Alternative Technology Cost for Full-Scale Applicationfor Remediation of a DNAPL Source Zone Similar to NABLC. (All costs are rounded to
nearest thousand.)

Cost Category	CDEF Line-Drive UF Operating Continuously	CDEF Push-Pull UF Operating In Batch Mode	SEAR ⁽¹⁾	P&T ⁽¹⁾⁽³⁾	Resistive Heating ⁽¹⁾
Capital investment ⁽²⁾	\$524,000	\$296,000	\$890,000	\$120,000	\$347,000
Contaminant disposal cost	\$5,000	\$2,000	\$4,000	\$30,000	\$94,000
O&M cost	\$3,716,000	\$1,197,000	\$498,000	\$1,385,000	\$198,000
Total present-day cost	\$4,245,000	\$1,495,000	\$1,392,000	\$1,535,000	\$639,000

⁽¹⁾ Costs were developed for MCB CL (NFESC, 2001). Very similar site conditions and the implementation of similar cost assessment strategies permit comparison of these cost estimates with (hypothetical) full-scale CDEF implementation at NABLC.

⁽²⁾ The cost of characterizing DNAPL source zone before and after treatment is not included. Post treatment monitoring of site may be required. Cost not included.

⁽³⁾ Undiscounted present-day value of reoccurring and periodic O&M cost in today's dollars spread over 30 years of operation. This total includes \$45,000 of recurring annual operating and maintenance cost incurred over every year of operation, \$13,000 in periodic maintenance incurred every 20 years (NFESC, 2001).

Simply looking at the bottom line may be attractive in many cases, but each technology inherits distinct advantages that set it apart from the rest. For example, cyclodextrin is nontoxic and eventually degrades in the subsurface. These are important acceptance criteria for state and federal regulators, which may favor the implementation of CDEF in some cases. Which remediation technology to use is very site-specific and depends on local customs and regulations. Future advances in treatment technology, such as the availability of a more effective UF filter material, may decrease the implementation cost.

6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

Much effort went into preparation of the CDEF demonstration, including extensive site investigations and negotiations with regulators and suppliers of specialized equipment and services. In several instances, these efforts were wasted. A few of the unexpected obstacles encountered include:

- Withdraw of consent to discharge to POTW
- Damaged equipment
- Treatment zone heterogeneities
- High-level base security

Most of these problems were defused in the field because of excellent working relations with local and regional decision makers or because of the ease of adapting the CDEF system to changing boundary conditions. Problems that could not be solved in the field, e.g., repair of damaged equipment, required in a few instances modification or scaling back of the demonstration objectives.

Procurement issues: Although this was the first time a membrane filter was used for cyclodextrin recovery, the underlying technology is commercial off-the-shelf (COTS). All other major pieces of equipment (e.g., air stripper, UF, sand filters, and pumps) are also COTS. With a few exceptions (e.g., air stripper), none of the major pieces of equipment was purchased for this demonstration. Equipment purchase may be more economical if more than just one site is being remediated by CDEF technology or if a particular site requires more than 6 to 8 months of remediation time.

6.2 **PERFORMANCE OBSERVATIONS**

In deviation from the demonstration plan (see Appendix I), CDEF was implemented in continuous line-drive fashion as well as push-pull mode. The reasons that led to the change of the implementation approach have been outlined in Section 4 and in the CDEF Final Report (Boving et al, 2003). Also, delays imposed from the outside (e.g., base security and withdrawal of consent to discharge to POTW) affected the progress and performance of the demonstration. Consequently, not all performance criteria were met. Most notably, the DNAPL saturation after the end of the demonstration was not reduced by 90% (actual reduction was approximately 81%) and the end-point criteria of attaining the MCL for TCE was not reached. While the first criterion most likely would have been reached if the demonstration had continued for a few more weeks, the second criterion would not have been reached even if the treatment had continued. In retrospect, setting the remediation end point at MCL level was never realistic because, at most sites, enhanced flushing technology is implemented to remove the bulk DNAPL mass. Once removed, other remedial approaches, such as natural attenuation, take over and target the remaining contaminants more effectively. A more realistic end-point criterion would be the threshold concentration below which natural attenuation becomes effective. This concentration, however, is strongly site-specific and this criterion may not be applicable to every site.

6.3 SCALE-UP

As with most remediation projects, the CDEF technology demonstration had to be customized for application at this particular site. Customization issues included (1) design of the well field and sampling protocols, (2) scaling of the treatment units to site specifications (i.e., type and concentration of target contaminants), and (3) other site-specific conditions, such as local regulations and customs. Because the major pieces of equipment are COTS, up-scaling CDEF should not be problematic. Of all pieces of equipment, the UF requires the largest investments (either rental or purchase) and may be custom ordered to suite the scale of a remedial operation. Because of the limited number of vendors, UF rental or purchase costs are comparably high and depend in part on availability of adequately sized filtration systems.

The cost of cyclodextrin appears to be linked to the price of corn (CD is manufactured from corn starch). Thus, CD cost may fluctuate and may vary significantly on the international market.

To the best of our knowledge, no patents or other proprietary claims complicate the adaptation of CDEF technology.

6.4 OTHER SIGNIFICANT OBSERVATIONS

The injection of any kind of flushing solution, including cyclodextrin, into the subsurface requires sufficiently high permeability (>> 1×10^{-5} cm sec⁻¹) of the DNAPL source zone. If lower permeability strata are treated or if the treatment zone is very heterogeneous, the overall treatment duration (and success) will be determined by these low permeability zones. Thus, there are certain sites at which CDEF technology should not be considered.

The implementation of remediation technologies requires frequent and unhindered access to the field site. Unless a significant amount of money is spent on remote site surveillance and fully automated sample collection/analysis, access to military sites likely becomes restricted during times of national crisis (as was the case during this demonstration). Under these circumstances, system shut-downs may become necessary and can lead to the loss of hydraulic control of the flushing solution. Preventive hydraulic control measures need to be considered to prevent this loss from happening.

6.5 LESSONS LEARNED

Future applications of CDEF will profit from several lessons learned during this ESTCPsponsored field demonstration. The following is a summary of the most important lessons from this demonstration.

<u>CDEF outperformed conventional P&T</u>. The presence of CD in the flushing solution enhanced the contaminant mass removal up to 19 times. Overall, CDEF removed three times as much VOC per day (CPPT) as conventional P&T.

<u>CPPT approach outperformed I/E approach</u>. The assessment of line-drive and push-pull treatment approaches showed that CPPT outperformed the I/E in several ways. For example, CPPT is significantly cheaper than I/E and most likely achieves the remediation goals faster.

Cyclodextrin solution can be reconcentrated but further improvements of the UF process are needed. The demonstrated CD reconcentration efficiencies of the UF system ranged from 68% in continuous mode to 90% in batch mode. Additional technology developments may benefit the economics of CD recovery. For example, if the UF efficiency in continuous mode operation can be enhanced from 68% to 80%, the resulting cost savings are substantial.

<u>Conventional air stripping is preferred over PVP</u>. Although the VOC removal efficiency of the PVP system tested during the demonstration was higher compared to a conventional air stripper, the PVP required significantly more operational effort. Besides the problems caused by running a damaged PVP, the logistics necessary to operate the PVP during this demonstration included a dedicated field technician and the presence of a large diesel electric generator to provide the necessary electrical power. Also, the PVP produced a stream of VOC-enriched effluent that had to be disposed of off site or, if available, in an adequate on-site treatment facility. The air stripper, on the other hand, did not produce any hazardous waste. The only major maintenance problem encountered running the air stripper was caused by iron precipitation. This commonly encountered problem can be addressed by operating the air stripper under anaerobic conditions. Although the demonstration field data did not support a reliable cost assessment of the PVP system, the overall cost of operating a PVP was significantly higher when compared to air stripping technology.

<u>PTT may have practical quantification limit</u>. There is growing concern in the scientific community about the performance of the PTT technology at low DNAPL saturations. The PTT technology is probably most useful when $S_N > 0.5\%$. At many sites, the probable remediation end-point criterion is 0.05%. PTT technology may not provide an accurate measure of the cleanup performance at these low NAPL saturation levels. It is suggested that the PTT results be supported by other mass balancing means, for example by membrane interface probe (MIP) or Geoprobe measurements. Using a numerical model is critical for the design of PTTs. Without such a model in place, the tracer breakthrough time during this demonstration would have been underestimated, possibly resulting in a miss of the tracer breakthrough.

<u>Base security status affects operation</u>. This demonstration was carried out during times of national crises, i.e., shortly after the 9/11 events and war overseas. During the demonstration, base security at NABLC base was very strict. Personnel working on base were subjected to extensive background checks lasting from a few days to 2 weeks. These security requirements caused significant delays bringing in personnel (e.g., truck drivers or service technicians) without prior security clearance. This had direct consequences for the demonstration because fast response to broken equipment in need of repair was difficult.

<u>Collaboration with local consultant</u>. The demonstration would have benefited from having a local consultant on the payroll. Limited services were provided by CH2MHill, the Naval Facilities Engineering Command, Commander Navy Mid-Atlantic Region, and NABLC's public works department. A local consultant could have assisted in obtaining unforeseen services and in negotiating with suppliers, giving the Principal Investigator (PI) more time to spend on advancing the demonstration.

<u>Additional field demonstration at larger site may benefit the economics of CDEF</u>. The demonstration site at NABLC was comparably small. A repeat of the CDEF demonstration at a larger site would provide further insight into the economics of the remediation alternative. The lessons learned during this ESCTP sponsored study could be implemented and would contribute to an even more robust economic data base.

6.6 END-USER ISSUES

This demonstration has received national and international attention. For example, the cyclodextrin technology was featured in *Business Week*, the *Civil Engineering Magazine*, and in radio interviews. Presentations of the CDEF technology have been given for interested parties in the environmental remediation industry and to the scientific community. CDEF technology has been presented on more than 20 occasions, including papers that have appeared in scientific journals. A Website (www.cyclodextrin.geo.uri.edu) under construction to promote CDEF technology will provide links to this report and other technical and scientific information pertaining to CDEF.

As a direct result of this CDEF demonstration and the information dissemination efforts, several applications of modified cyclodextrin technology are already under way or planned for the immediate future (e.g., Patrick Air Force Base, Florida). National and international consulting companies are making many inquiries about this CDEF demonstration. Those directed to NABLC are forwarded to the PIs of this report. Finally, NABLC is considering CDEF as one of several remediation approaches that may be implemented at Site 11.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

Since identifying NAB Site 11 as a potential test site, close working relations were established with representatives of the Navy, appropriate regulatory agencies involved, and local community members. About a year before the ESTCP demonstration, a Partnering Meeting was held to present the concept of the study. At this meeting, which was attended by VADEQ, Navy, EPA, CH2MHill, and all PIs of this project, the technology was presented, and a discussion followed on what was required to implement the technology demonstration at Site 11 during summer 2002. This first meeting was followed by conference calls and frequent information exchanges to obtain the necessary concurrence and to prepare the field test.

A kickoff meeting was held at NABLC. This meeting established the rules for the demonstration (e.g., defined the chain-of-command and security requirements while working on the Little Creek base) and laid out an emergency response plan.

During the entire ESTCP demonstration, any issues requiring regulator input, such as obtaining permission for discharging treated effluent to the storm drain, were closely coordinated with the appropriate personnel or agencies. The community was informed of the CDEF activities at Site 11 via the NABLC Restoration Advisory Board (RAB), which consisted of members from the public, regulators, and members of the military environmental restoration community. The exchange of information and results with NABLC are still taking place.

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APPENDIX A

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APPENDIX B

ACTUAL DEMONSTRATION COST

Cyclodextrin Enhanced Flushing at Naval Amphibious Base Little Creek, VA

CAPITAL COST (actual cost of demonstration)

Assumptio	ons									
Flushing V Soil mass:	ol):		.0 m .3 to			Power Con Cost / KWF	sumption in: KV I \$ 0.05725	V		Number of wells, type and depth needed for remediation 3 injection wells (22.5 ft)
: Princip	al Investigato	r				Note: Most	electrical power	was provided by	generators.	3 extraction wells (22.5 ft) 2 hydraulic control wells (22.5 ft)
evelopm	ent Study (C	vclodextr	in Sel	ection)						
					not some size of f			din n		
tudies we	ere carried out	t for demo	nstrati		- not required t	or commerc	al CDEF applica	ition		
Units	No of units	Unit labo cost (hr		Unit mat cost	Labor cost	Mat cost	Item cost	Total cost	Power consumption	Item description
A		\$16,599.0			\$ 16,599	\$ 1,440			consumption	Lab techician (grad. Student)
A		\$ 5,213.0			\$ 5,213	\$ -				Senior Geochemist (PI)
EA EA	1		\$ \$		s - s -	\$ 5,600 \$ 3,000				Lab equipment Report preparation (PI)
~		\$ -	φ	3,000	-	\$ 3,000	φ 3,000		Total Cyclod	extrin Selection
ench Sca	ale Treatmen	t Equipm	ent Te	esting						
		Unit labo	or	Unit mat					Power	
Units	No of units	cost		cost	Labor cost	Mat cost	Item cost	Total cost	consumption	
A	1	+	\$	2,550	s -	\$ 2,550				Membrane selection, testing, and equipment
A A		\$10,309.0	00 \$ \$		\$ 10,309 \$ -	\$ - \$ 7.200	\$ 10,309 \$ 7,200			Lab techician (grad. Student) Lab equipment
A			э \$		s -	\$ 3,000				Report preparation
		Ŷ	Ŷ	0,000	Ŷ	¢ 0,000	φ 0,000		Total Bench	Scale Treatment Equipment Testing
PTIONAL	L Pre-trial Pa	artition Tr	acer	Fest (PTT)						
					evaluation pure					
i i is opti	onai anu was				evaluation purp	Coco Only			_	
Units	No of units	Unit labo cost	or	Unit mat cost	Labor cost	Mat cost	Item cost	Total cost	Power consumption	Item description
									•	Pre-treatment site characterization
A		\$ 6,397.0		-	\$ 6,397	s -	\$ 6,397			(hydrauylic and transport modeling) (Co-PI)
A		\$ 6,687.0		-	\$ 6,687	s -				Tracer selection testing (lab) (grad student)
A		\$24,038.0 \$-	00 \$ \$	8,700	\$ 24,038 \$ -	\$ - \$ 8,700	\$ 24,038 \$ 8,700			Lab techician (grad student) Tracer (alcohols and gases)
EA .		\$24,610.0			\$ 24,610	\$ 0,700 \$ -	\$ 24,610			Field lab technician (grad student)
Ā		\$ -	\$		s -	\$ 700				Specialized injection/collection equipment
A	1	\$ -	\$	2,970	s -	\$ 2,970				Field supplies
EA		\$ -	\$		s -	\$ 4,725				Travel and subsidence at field site
EA EA	1		32 \$ \$		\$ 8,032 \$ -	\$ - \$ 100	φ 0,00L			Chemical analysis (alcohol tracers)
A	1	ə -	\$	100	s -	\$ 100	\$ 100		Total Pre-tria	License for PTT (to Duke Eng.) Il Partition Tracer Test (PTT)
PTIONAL	L Post-trial F	Partition T	racer	Test (PTT)						
					evaluation purp	oses only				
1110 000					eralaalon parp					
Units	No of units	Unit labo cost	or	Unit mat cost	Labor cost	Mat cost	Item cost	Total cost	Power consumption	Item description
EA	1		\$		\$ -	\$ 8,700			consumption	Tracer (alcohols and gases)
A		\$19,032.0		-	\$ 19,032	s -	\$ 19,032			Field lab technician (grad student)
A	1	\$ -	\$		s -	\$ 2,970				Field supplies
A	1	+	\$		s -	\$ 4,725				Travel and subsidence at field site
A	1	\$ - \$ 8,03	\$ 32 \$	22,753	\$ - \$ 8.032	\$ 22,753 \$ -				Report preparation (Co-PI) Chemical analysis (alcohol tracers)
A	1	\$ 0,0	ο∠ φ	-	\$ 0,032	ş -	\$ 8,032	\$ 66,212	Total Post-tr	ial Partition Tracer Test (PTT)
	ource Zone C	haractori	ration					,		· · · · · · · · · · · · · · · · · · ·
					or to demonstrat	tion.				
		Unit labo		Unit mat					Power	
Units	No of units	cost (hr		cost	Labor cost	Mat cost	Item cost	Total cost	consumption	
A	1	\$ -	\$ \$	1,600	s - s -	\$ 1,600 \$ 7,000				Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity
EA EA		\$ 95.0		3,500	\$ - \$ 475	\$ 7,000	\$ 7,000			Operator per diem
A	2		,0 \$ \$		s 4/5	\$ 2,500				In Situ GW/Soil sampling
A		\$ -	\$		s -	\$ 1,890				Lab Analysis (TCL Volatile Organic Compound)
A	60	\$ 50.0	00 \$	-	\$ 3,000	\$ -	\$ 3,000			Labor (2 Person Field Crew)
A	3	\$ -	\$	200	\$ -	\$ 600	\$ 600	\$ 17,065	Total DNAPI	Equipment and Expendables Source Zone Characterization (in-kind contribution)
ostabilit	y Study (Site	soil tost	na)	_			_	,,,,,,,,		
satabilit	.y otady (one			I lait court					Power	
Units	No of units	Unit labo cost (hr		Unit mat cost	Labor cost	Mat cost	Item cost	Total cost	Power consumption	Item description
EA		\$10,696.0		-	\$ 10,696	\$ -	\$ 10,696		sonsumption	Lab techician (soil column tests)
EA	1		\$		s -	\$ 2,550				Lab equipment
EA	1	\$ -	\$	3,000	s -	\$ 3,000	\$ 3,000			Report preparation

3,000 Report preparation \$ 16,246 Total Cyclodextrin Selection

Engineeri	ing, Design, a	nd Mo	delina													
Units A A	No of units	Unit cc \$17,9	labor st 83.00	Ur	nit mat cost 1,770 2,500				Mat co 5 1,7 5 2,5		\$	m cost 23,77 2,50		Total cost 26.270	Power consumption	Item description Work Plan, H&S plan, Site Management Plan (Project leader) Permits and licences, estimated (in-kind contribution) ering, Design, and Modeling
echnolo	gy Mobilizati	on. Se	tup, an	d Dei	mobilizat	ion								., .	J	
Units A	No of units 1	Unit cc	labor	Ur	nit mat cost 21,911	La	bor cos		Mat co 3 21,9			m cost 21,91	1 \$	Total cost 21,911	Power consumption Total Perform	Item description Travel to and from site (incl. accommodation) nance Assessment
ite Work	t.															
ite Set-u	ıp															
Units EA EA EA EA	No of units 1 1 80 1	5 5 5			nit mat cost 1,000 1,450 - 193	La S S S S	bor cos 4,00	- 5	5 1,4	000		m cost 1,00 1,40 4,00 19	0	Total cost 6,593	Power consumption Total Site Set	Secondary containment (berm) Electricity hook-up (in-kind contribution) Plumbing (temporary) On-site sanitary installations
quipmer	nt and Appur	enanc	es													
Units ft EA EA	d Installation No of units 177 1 4	cc \$ \$ \$	-		nit mat cost 77 552 552	La S S S		t - s	6 5		\$ \$	m cost 13,57 55 2,20	2	Total cost 16,336	Power consumption Total Well Ins	Injection/Extraction well installation Grunfos submersible pumps (Model 5S) Grunfos submersible pumps (Model 5S) (in-kind)
Units ft EA EA EA EA ft ft thrs EA	60 24 1 1 1	Unit \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	50.00		nit mat cost 2 78 20 45 294 2 9 - 400 980 36	La S S S S S S S S S S S S S S S S S S S	1,20			900 524 540 176 270 516 	\$ \$ \$ \$ \$ \$ \$	m cost 90 62 32 54 1,17 51 1,20 40 98 3	4 D D 6 D 6 D 0 D 0 D 0 D	Total cost 6,962	Power consumption	Item description Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing Connection of air stripper (6 in PVC) Plumbing air stripper and off-gas treatment train (in kind) Connection of UF Connection of Pervap Pressure transducer (injection wells) Ground Piping
Demobilia Units EA	zation No of units 1	CC	labor st		nit mat cost 14,464		bor cos		Matco 5 14,4			m cost 14,46	4 \$	Total cost	Power consumption Total Demobi	Freight (Palletizing, loading, and shipping of equipmemt)
Startun a	nd Testing												•	14,404	lotal Domobi	
Units hrs hrs	No of units 96 210	сс \$	labor st 50.00 50.00	\$	nit mat cost - -	La S S	bor cos 4,80 10,50	0 \$			lte \$ \$	m cost 4,80 10,50		Total cost 15,300	Power consumption Total Startup	Operator Training (6 people field crew) System shake-down, well testing, etc.
Other (no	n-process re	ated)														
Units EA EA EA	No of units 1 3 1	\$ \$	labor st - -		nit mat cost 4,800 550 1,600	La S S S		t - s - s	5 1,6	300	\$ \$	m cost 4,80 1,65 1,60	D	Total cost 8,050	Power consumption Total Other	Item description Office and admin. equipment (computer, printer, etc) H&S training (OSHA) Field safety equipment, various
													\$ \$ \$ \$	24,373 54,911 153,171 357,278	CDEF Techno In-kind contrib Demo related Optional PTTs Total Direct C	utions studies (one-time studies) s sapital
													\$ \$	90,658	Contingency Total Indirec	t Capital

OPERATING AND MAINTENANCE COST (actual cost of demonstration)

	person per sh				eek								
ote: Labo	or cost based o												
		Unit labor		Unit mat									
Units	No of units	cost		cost	La	abor cost	N	lat cost		Item cost	1	Total cost	Item description
rs	1900 3		\$		\$		\$	-	\$	19,000			Operating labor
rs	3860 \$			-	\$		\$	-		38,600			Monitoring labor
rs	600 \$	\$ 24.50	\$	-	\$	14,700	\$	-	\$	14,700		70 000	Supervision (PI and Co-PI's)
											\$	72,300	Total Labor Cost
Aterials													
		Unit labor		Unit mat									
Units	No of units	cost		cost		abor cost		lat cost		Item cost	٦	Fotal cost	Item description
_B	14000 ÷		\$	1.75 13,789.00	\$ \$	-	\$ \$	24,500 13,789	\$ \$	24,500 13,789			Cyclodextrin, tech grade Consumable supplies
EA EA	1				ŝ			10,514		10,514			Corrective maintenance
											\$	38,289	Total Material Cost
			_				_						
tilities a	nd Fuel	Unit labor		Unit mat									
Units	No of units	cost		cost	La	abor cost	N	lat cost		Item cost	1	Fotal cost	Item description
WH	22651	5 -	\$		\$	-	\$	1,297	\$	1,297			Electricity cost (in-kind)
al	1224		\$		\$		\$	2,448		2,448			Fuel
1000 gal	91 \$	ş -	\$	0.44	\$	-	\$	40	\$	40	\$	3 795	Water (in-kind) Total Utilities and Fuel Cost
											ş	3,165	i otai ounties anu r'uel oost
quipmen	nt Ownership a												
		Unit labor		Unit mat									
Units A	No of units 1	cost	\$	cost 10,101		abor cost		fat cost 10,101		Item cost 10,101	٦	Fotal cost	Item description Air stripper incl. blower (200 cfm, purchase)
:A nonths	8 5			10,101		3,592	э \$	10,101	э \$	3,592			Air stripper incl. blower (200 crm, purchase) 2 x 6,500 gal holding tank (rental)
nonths		\$ 8,000.00		-	\$		ŝ	-	\$	16,000			UF membrane unit for CD reconcentration (rental)
nonths	2 3	\$15,000.00	\$		\$	30,000	\$	-	\$	30,000			PVP unit for VOC treatment (rental)
A	1 5		\$		\$	-		16,979	\$	16,979			4000 lbs air activated carbon filter system (rental)
nonths A	4 3	\$ 832.00) \$ \$	- 368.00	s s	-,	\$ \$	368	\$ \$	3,328 368			Suspended solid filter system (rental) 250 gal mixing tank (purchase)
nonths	4 5	\$ 54.00		- 366.00		216		- 300	э \$	216			On-site sanitation (rental)
nonths		5,498.00			ŝ	10,996		-	\$	10,996			Diesel electric generator (480 V, 350KW) (rental)
nonths		\$ 1,497.00			\$		\$	-	\$	1,497			Diesel electric generator (480 V, 22KW) (rental)
EA .	1		\$	19,835				19,835		19,835			TOC Analyzer for CD analysis (purchase)
EA	1 5	\$ -	\$	10,000	\$	-	\$	10,000	\$	10,000	\$	122 912	On-site gas chromatograph, incl. accesoirs (purchase) Total Equipment Ownership and Rental Cost
											•	,	
	nce Testing ar	nd Analysi	s										
	Cost - off-site			Linit met									
Analysis (Cost - off-site	Unit labor		Unit mat	La	abor cost	M	fat cost		Item cost	1	Total cost	Item description
Analysis (Units	Cost - off-site No of units			Unit mat cost	La \$	abor cost 56,325	N S	fat cost		Item cost 56,325		Fotal cost	Item description VOC analysis (UA/URI labs)
Analysis (Units	Cost - off-site No of units	Unit labor cost									5		
Units	Cost - off-site No of units 1	Unit labor cost											VOC analysis (UA/URI labs)
Units	Cost - off-site No of units	Unit labor cost \$56,325.00	\$	cost -									VOC analysis (UA/URI labs)
Analysis (Units A	No of units No of units 1 Cost - on-site	Unit labor cost	\$		\$	56,325	\$	-	\$	56,325	\$	56,325	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site
Analysis (Units EA Analysis (Cost - off-site No of units 1	Unit labor cost \$56,325.00 Unit labor cost	\$	cost - Unit mat cost	\$		\$ N		\$		\$		VOC analysis (UA/URI labs)
Analysis (Units Analysis (Units	Cost - off-site No of units 1 S Cost - on-site No of units	Unit labor cost \$56,325.00 Unit labor cost \$ -	\$	Cost Unit mat Cost 550	\$ La	56,325 abor cost	\$ N	- Mat cost 550	\$	56,325 Item cost	\$	56,325 Fotal cost	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies
Units A Malysis (Units A	Cost - off-site No of units 1 : Cost - on-site No of units 1 :	Unit labor cost \$56,325.00 Unit labor cost \$ -	\$	Cost Unit mat Cost 550	\$ La \$	56,325 abor cost	\$ N \$	- Mat cost 550	\$	56,325 Item cost 550	\$	56,325 Fotal cost	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies
nalysis (Units A nalysis (Units A A	Cost - off-site No of units 1 \$ Cost - on-site No of units 1 \$ 1 \$ 1 \$ 1 \$ 1 \$ 1 \$ 1 \$ 1 \$ 1 \$ 1 \$	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ -	\$	Cost Unit mat Cost 550	\$ La \$	56,325 abor cost	\$ N \$	- Mat cost 550	\$	56,325 Item cost 550	\$	56,325 Fotal cost	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies
Analysis (Units Analysis (Units A	Cost - off-site No of units 1 : Cost - on-site No of units 1 :	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ -	\$	Cost Unit mat Cost 550	\$ La \$	56,325 abor cost 	\$ N \$	- Mat cost 550	\$	56,325 Item cost 550 1,600	\$	56,325 Fotal cost	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies
Analysis (Units EA Analysis (Units EA EA Dther (nor EA	Cost - off-site No of units 1 Cost - on-site No of units 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$	\$\$\$	cost Unit mat cost 550 1,600 2,480	\$ La \$ \$	56,325 abor cost - - 22,993	\$ N \$ \$	fat cost 550 1,600 2,480	\$ \$	56,325 Item cost 550 1,600 25,473	\$	56,325 Fotal cost	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI)
Analysis (Units Analysis (Units A A D ther (no) A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$	56,325 Fotal cost	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip.
Analysis (Units Analysis (Units A A D ther (no) A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$\$\$	cost Unit mat cost 550 1,600 2,480	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993	\$ N \$ \$	fat cost 550 1,600 2,480	\$ \$ \$	56,325 Item cost 550 1,600 25,473	\$ \$	56,325 Total cost 2,150	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples
nalysis (Units A Units A A A ther (nor A A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$	56,325 Total cost 2,150	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip.
Units A Units A Units A A Other (nor A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$	56,325 Total cost 2,150 33,232	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related)
Analysis (Units Analysis (Units A A D ther (no) A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$	56,325 Total cost 2,150 33,232 327,656	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology
Units A Units A Units A A Other (nor A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$ \$	56,325 Total cost 2,150 33,232 327,656 1,337	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions
Analysis (Units Analysis (Units A A D ther (no) A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$	56,325 Total cost 2,150 33,232 327,656 1,337	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology
Analysis (Units EA Analysis (Units EA EA	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$ \$ \$ \$	56,325 Total cost 2,150 33,232 327,656 1,337 328,993	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions Total Direct Capital
Analysis (Units Analysis (Units A A D ther (no) A A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$ \$	56,325 Fotal cost 2,150 33,232 327,656 1,337 328,993 79,966 -	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions Total Direct Capital Overhead and Administration Contingency
Analysis (Units Analysis (Units A A D ther (no) A A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496	\$ \$ \$ \$ \$ \$ \$ \$	56,325 Fotal cost 2,150 33,232 327,656 1,337 328,993 79,966 -	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions Total Direct Capital Overhead and Administration
Analysis (Units EA Analysis (Units EA EA Dther (nor EA EA	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496 3,263	\$ \$ \$ \$ \$ \$ \$ \$ \$ \$	56,325	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions Total Direct Capital Overhead and Administration Contingency Total Indirect Operational
Analysis (Units Analysis (Units A A D ther (no) A A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496 3,263	\$ \$ \$ \$ \$ \$ \$ \$ \$	56,325	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions Total Direct Capital Overhead and Administration Contingency
nalysis (Units A Units A A A ther (nor A A	Cost - off-site No of units 1 Cost - on-site No of units 1 1 n-process rela 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	Unit labor cost \$56,325.00 Unit labor cost \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ - \$ -	\$ \$ \$	cost Unit mat cost 550 1,600 2,480 4,496	\$ \$ \$ \$ \$	56,325 abor cost - - 22,993 -	\$ N \$ \$ \$ \$	- Mat cost 550 1,600 2,480 4,496	\$ \$ \$	56,325 Item cost 550 1,600 25,473 4,496 3,263	\$ \$ \$ \$ \$ \$ \$ \$ \$ \$	56,325	VOC analysis (UA/URI labs) Total Performance Testing and Analysis - off site Item description Miscellaneous lab supplies Miscellaneous field supplies Total Performance Testing and Analysis - on site Final report preparation (PI) PID for H&S survey, personal protective equip. S/H of samples Total Other (non-process related) CDEF Technology In-kind contributions Total Direct Capital Overhead and Administration Contingency Total Indirect Operational

 Compliance Testing and Analysis

 Unit labor
 Unit mat

 Units
 Cost
 Cost
 Labor cost
 Item description

 Units
 No of units
 cost
 cost
 Labor cost
 Mat cost
 Item cost
 Total cost
 Compliance sampling (VOC and Copper), Reed Labs, VA

 EA
 \$
 \$
 992
 Total Compliance Testing and Analysis

Disposal	of Hazardeou														
		Unit labo	r l	Jnit mat										Power	
Units	No of units	cost		cost	La	abor co	st	Mat	cost	1	tem cost	Total cos	st	consumption	Item description
EA	1	\$-	\$	3,900	\$		-	\$	3,900	\$	3,900			Off-site dispos	al of drill cuttings (in-kind contribution)
EA	1	\$ -	\$	600	\$		-	\$	600	\$	600			Off-site dispos	al of liquid wastes (in-kind contribution)
												\$4,	500	Total Disposal of Hazardeou	us Waste (in-kind)
												\$	992	CDEF Technology	
												\$ 4,	500	In-kind contributions	
												\$ 5,	492	Total Direct Other Technol.	Specific Cost
												s	291	Overhead and Administration	
												s	-	Contingency	
												\$	291	Total Indirect Other Techno	I. Specific Cost
												\$ 5,	783	TOTAL OTHER TECHNOL.	SPECIFIC COSTS

OTHER PROJECT COSTS (actual cost of demonstration)

 Site Restoration

 Unit labor

 Unit labor
 Unit mat

 Units
 Cost
 Cost

 Units
 No of units
 Cost
 Cost

 EA
 8
 50.00
 \$
 \$
 400
 Site restoration (landscaping)

 EA
 8
 \$
 50.00
 \$
 \$
 400
 Total Site Restoration

 400 CDEF Technology - In-kind contributions 400 Total Direct Other ProjectCost \$ \$ \$ \$ \$ \$ 117 Overhead and Administration
 Contingency
 117 Total Indirect Other Project Cost \$ 517 TOTAL OTHER TECHNOL. SPECIFIC COSTS

COST SUMMARY (actual cost of demonstration)

 \$ 863,195
 Total Cost (demonstration) * PTT's and demonstration specific activities not considered

 Unit Cost - Quantity of Contaminant Removed and Treated 25.8 Quantity of Media Removed and Treated (lbs VOC) \$ 33,457.17
 Calculated Unit Cost (\$/lbs)

 VOC removed Basis for Quantity Treated
 Voc
 Voc

Unit Cost - Quantity of Groundwater Treated

APPENDIX C

COST OF REAL-WORLD IMPLEMENTATION

Cyclodextrin Enhanced Flushing at Naval Amphibious Base Little Creek, VA

CAPITAL COST (real-world cost) Assumptions Flushing Vol): 9.0 m3 Power Consumption in: KW Number of wells, type and depth needed for remediation 3 injection wells (22.5 ft) 3 extraction wells (22.5 ft) 2 hydraulic control wells (22.5 ft) Cost / KWH \$ 0.05725 Note: Most electrical power was provided by generators Soil mass: 49.3 tons Treatment duration 2 months DNAPL Source Zone Characterization Assume: Approximate extent of plume is know Unit labor Unit mat Power No of units Units cost (hr) cost Labor cost Mat cost Item cost Total cost consumption Item description s 1,600 1 \$ Mob/Demob Geoprobe/Membrane Interface Probe (MIP) ΕA s \$ 1,600 \$ 1,600 7,000 475 2,500 MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling EA EA EA EA \$ 3,500 s s \$ 7,000 99 09 5 \$ 95.00 475 ŝ 2 \$ 1,250 2,500 \$ Lab Analysis (TCL Volatile Organic Compound) 15 \$ 60 \$ 126 s \$ 1.890 \$ 1.890 50.00 š ŝ Ś 3.000 Ś 3.000 Labor (2 Person Field Crew) Equipment and Expendables 17,065 Total DNAPL Source Zone Characterization EA 3 \$ ŝ 200 ŝ ŝ 600 ŝ 600 ŝ Treatability Study (Site soil testing) Unit labor Unit mat Power units cost (hr) 120 \$ 85.00 \$ cost Mat cost Total cost consumption Item description EA EA 10,200 10,200 Lab techician (soil column tests) \$ \$ \$ \$ \$ 2,550 2,550 1 \$ s \$ 2,550 Lab equipment EA 24 \$ 125.00 s 3.000 ŝ ŝ 3,000 Report preparation 15,750 Total Cyclodextrin Selection ŝ Engineering, Design, and Modeling Unit labor Unit mat Powe Units No of units cost 125.00 cost 1,770 Labor cost Mat cost Total cost consumption Item description Item cost EA EA 144 \$ \$ 1,770 \$ \$ 2,500 \$ 19,770 Work Plan, H&S plan, Site Management Plan (Project leader) s 1,770 \$ 2,500 \$ 18,000 Permits and licences, estimated 1 \$ 2,500 22,270 Total Engineering, Design, and Modeling Technology Mobilization, Setup, and Demobilization Unit labor Unit mat Power Units No of units cost cost Labor cost Mat cost Item cost Total cost consumption Item description , 1 \$ s 21,911 \$ EA - \$ 21,911 \$ 21,911 Travel to and from site (incl. accommodation) \$ 21,911 Total Performance Assessment Site Work Site Set-up Unit I Unit mat Powe cost 1,000 Mat cost Total cost consumption No of units Item description Units cost Labor cost Item cost 1,000 1\$ s ΕA 1.000 \$ Secondary containment (berm) s \$ \$ \$ \$ \$ \$ \$ \$ 1,400 4,000 193 Electricity hook-up Plumbing (temporary) On-site sanitary installations ΕA ŝ 1,450 1 400 s EA 80 \$ 50.00 4.000 EA 193 193 \$ 6,593 Total Site Set-up Equipment and Appurtenances Well Field Installation Unit labor Power Unit mat No of units Units cost cost Labor cost Mat cost Item cost Total cost consumption Item description 177 \$ s s s 77 13,576 \$ 2,760 \$ 14,800 \$ 13,576 2,760 14,800 \$ \$ \$ ft -\$ \$ \$ Injection/Extraction well installation 5 \$ 1 \$ 552 14,800 Grunfos submersible pumps (Model 5S) SCADA system, automated flow control EA EA \$ 31,136 Total Well Installation Above Ground Plumbing Unit labo Unit mat cost Powe Units No of units Mat cost Total cost consumption Item description cost Labor cost Item cost 900 500 \$ 2 Well piping, 3/4 in PVC and flex tubing s ft 900 \$ \$ 624 320 540 1,176 270 EA EA 8 \$ s 78 20 s s \$ \$ 624 Flowmeters Flow control valves 16 ŝ ŝ 320 540 1,176 270 45 294 12 \$ ŝ ŝ In-line sample ports EA ft ft hrs hrs EA s s Transfer pumps Waste water disposal piping, 3/4 in flex tubing 4 \$ 150 \$ \$ \$ \$ \$ \$ \$ 2 9 \$ 60 \$ s \$ 516 516 Connection of air stripper (6 in PVC) 1,200 400 36 24 8 \$ 50.00 s s 1,200 Plumbing air stripper and off-gas treatment train Connection of UF 50.00 400 36 Pressure transducer (injection wells) 36 1 \$ s s \$ \$ \$ 5,982 Total Above Ground Piping Demobilization Powe Unit labor Unit mat Labor cost Mat cosι - \$ 5,464 \$ Units No of units Item cost Total cost consumption Item description cost cost 1\$ s EA 5.464 S Freight (Palletizing, loading, and shipping of equipment) 5.464 ŝ 5.464 Total Demobilization

Startup an	nd Testing															
Units	No of units		nit labor cost	1	Unit mat cost	La	bor cost	Ma	t cost		Item cost		Total cost	Power consumption		Item description
hrs hrs	32 112			s s	:	\$ \$	1,600 5,600	\$ \$	-	\$ \$	1,600 5,600			0	perator Training (2 people system shake-down, well to	e field crew)
		*	00.00	Ť		•	0,000	*		*	0,000	\$	7,200	Total Startup an		
Other (no	n-process rel				le la secol									Design		
Units	No of units		nit labor cost		Unit mat cost		bor cost		t cost		Item cost		Total cost	Power consumption		Item description
EA EA	1		-	s s	4,800 1,600	s s	-		4,800 1,600	\$ \$	4,800 1,600				office and admin. equipme ield safety equipment, var	
												\$	6,400	Total Other		
												\$ \$		CDEF Technolog Total Direct Cap		
												\$ \$	-	Overhead and Ad Contingency		
												\$		Total Indirect C		
												\$	160,657	TOTAL CAPITAI	L	
OPERA	TING AN	DI	MAINT	EN	ANCE C	os	T (real	wo	rld co	st)					
Labor	person field c	rew	8 hrs/da	v 7	days/week	2 m	onths SC4		echnolo	av i	sused					
7 (000mmo. 2	. person neia e				Unit mat	2	511115, 007		00111010	97 -	5 4564					
Units	No of units		nit labor cost		cost		bor cost		t cost		Item cost		Total cost			Item description
hrs hrs	640	\$ \$	50.00 50.00	s s	-	\$ \$	16,000 32,000	\$ \$	-	\$ \$	16,000 32,000			M	perating labor Ionitoring labor	
hrs	60	\$	90.00	s	-	\$	5,400	\$	-	\$	5,400	\$	53,400	S Total Labor Cos	upervision at	
Materials													,			
			nit labor		Unit mat								T . I . I I			New description
Units LB		\$	cost	s	cost 2.00	\$	bor cost -	\$ 2		\$	Item cost 28,000		Total cost		yclodextrin, tech grade	Item description
EA EA	1	\$ \$		s s	5,689.00 2,720.00	\$ \$			5,689 2,720	\$ \$	5,689 2,720				onsumable supplies orrective maintenance	
											_,	\$	33,689	Total Material C		
Utilities a	nd Fuel															
Units	No of units		nit labor cost	'	Unit mat cost	La	bor cost	Ma	t cost		Item cost		Total cost			Item description
KWH gal		\$ \$		s s	0.05725 2.00	\$ \$			1,297 2,448	\$ \$	1,297 2,448				lectricity cost uel	
1000 gal	91		-	ŝ	0.44	ŝ	-	\$	40	\$	40	s	3 785		Vater	
-			_	_		_				_		\$	3,765	Total Ounties at	la Fuel Cost	
Equipmen	nt Ownership	Ur	nit labor		Unit mat											
Units EA	No of units 1		cost -	s	cost 10,101		bor cost		t cost 10,101		Item cost 10,101		Total cost	А	ir stripper incl. blower (20	Item description 0 cfm, purchase)
months months	4		449.00 3,000.00	s s	-	s s	1,796 16,000	\$ \$	-	\$ \$	1,796 16,000			2	x 6,500 gal holding tank (IF membrane unit for CD r	rental)
EA	1	\$	-	s	16,979	\$	-	\$ 1	6,979	\$	16,979			4	000 lbs air activated carbo	on filter system (rental)
months EA	4 1	\$	832.00	s s	368.00	\$ \$	3,328	\$ \$	- 368	\$ \$	3,328 368				uspended solid filter syste 50 gal mixing tank (purcha	
months months	4		54.00 1,497.00	s s	-	\$ \$	216 2,994	\$ \$	-	\$ \$	216 2,994			0	on-site sanitation (rental) biesel electric generator (4	80 V. 30KW) (rental)
montaio	-	Ť	.,	Ť		Ť	2,001	Ŷ		Ť	2,001	\$	51,782		t Ownership and Rental	
	nce Testing a		Analysis													
Analysis (Cost - off-site		nit labor		Unit mat											
Units EA	No of units 120		cost 124.00	s	cost -	La \$	bor cost 14,880		t cost	\$	Item cost 14,880		Total cost	v	OC analysis	Item description
	.20	Ŧ		-		÷	,000	Ŧ		-	. 1,000	\$	14,880		ice Testing and Analysis	s - off site
Analysis (Cost - on-site				1											
Units	No of units		nit labor cost		Unit mat cost	La	bor cost	Ma	t cost		Item cost		Total cost			Item description
EA EA	120 120	\$		s		\$	3,000 6,000	\$	-		3,000 6,000				D analysis (TOC method ield parameters (set of pH)
EA	120		-	s	1,000		6,000 -		1,000		1,000			M	liscellaneous field lab sup	plies
												\$	1,000	rotal Performan	nce Testing and Analysis	s - on site
Other (no	n-process rel		1)													
hrs EA	160 1		125	s s	4,496		20,000		- 4,496		20,000 4,496				inal report preparation (PI ID for H&S survey, persor	
EA	60			s	4,490				1,500		1,500		05 000	S	/H of samples	an proceeding organity.
												\$		Total Other (non-		
												\$	184,532	Total Direct Cap	bital	
												\$ \$		Overhead and Ad Contingency	dministration	
												э \$		Total Indirect O	perational	
												\$	227,940	TOTAL OPERAT	TIONAL	

OTHER TECHNOLGOY SPECIFIC COSTS (real-world cost)

Complian									
	nce Testing ar	nd Analysis							
		Unit labor	Unit mat						
Units	No of units	cost	cost	Labor cost	Mat cost	Item cost	Total cost	Item descrip	tion
EA	8	\$-	\$ 124.	- \$ 00	\$ 992	\$ 992		Compliance sampling	
							\$ 992	Total Compliance Testing and Analysis	
Disposal	of Hazardeou	us Waste							
		Unit labor	Unit mat					Power	
Units	No of units	cost	cost	Labor cost	Mat cost	Item cost	Total cost	consumption Item descrip	tion
EA	1	\$-	\$ 3,9	- \$ 00	\$ 3,900	\$ 3,900		Off-site disposal of drill cuttings	
							\$ 3,900	Total Disposal of Hazardeous Waste (in-kind)	
							\$ 4,892	Total Direct Other Technol, Specific Cost	
							• .,		
							\$ 1,433	Overhead and Administration	
							\$ -	Contingency	
							\$ 1,433	Total Indirect Other Technol. Specific Cost	
							\$ 6,325	TOTAL OTHER TECHNOL, SPECIFIC COSTS	
							• •,•20		
OTHE	R PROJEC	CT COST	S (real-w	orld cost)					
OTHEI	R PROJEC	CT COST	S (real-w	orld cost)					
		CT COST	S (real-w	orld cost)					
		Unit labor	S (real-w	orld cost)					
				orid cost)	Mat cost	Item cost	Total cost	Item descrip	tion
Site Rest Units	toration No of units	Unit labor	Unit mat			Item cost \$ 400	Total cost	Item descrip Site restoration (landscaping)	tion
Site Rest Units	toration No of units	Unit labor cost	Unit mat	Labor cost					tion
Site Rest Units	toration No of units	Unit labor cost	Unit mat	Labor cost			\$ 400	Site restoration (landscaping) Total Site Restoration	tion
Site Rest	toration No of units	Unit labor cost	Unit mat	Labor cost			\$ 400	Site restoration (landscaping)	tion

\$ \$ Contingency
 Total Indirect Other Project Cost

\$ 517 TOTAL OTHER TECHNOL. SPECIFIC COSTS

COST SUMMARY (real-world cost)

\$ 395,440 Total Cost (demonstration)

- Unit Cost Quantity of Contaminant Removed and Treated 25.8 Quantity of Media Removed and Treated (Ibs VOC) \$ 15,327.12 Calculated Unit Cost (\$/Ibs) VOC removed Basis for Quantity Treated

- Unit Cost Quantity of Groundwater Treated 837270.0 Quantity of Media Removed and Treated (gal groundwater) 9.0.47 Calculated Unit Cost (Sgal) GW treated Basis for Quantity Treated
- Unit Cost Quantity of Soil Treated 49.3 Quantity of Media Removed and Treated 8 8,021.09 Calculated Unit Cost (\$/ton) Soil treated Basis for Quantity Treated

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APPENDIX D

SIMULATION OF REQUIRED CD MASS AND REMEDIATION DURATION Large Scale 2,500 ft²

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-DCE)	
Treatment approach:	Multi-Well Push-Pull (CPPT) with UF in batch ope	rati
1.a Extent of contaminated area:		
Width	15.3 m	
Length	15.3 m	
Vertical extent	1.5 m	
Area treated Vol _{soil}	234 m2 351 m3	
Soil weight based on bulk density = 1.7 t/m3	597 tons (soil density = 1.7 t/m3)	
rho _{contaminant} (Density)	1400 kg/m3	
n (Porosity)	0.31	
F removal NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug)	108.9 m3	
Injection Conc HPCD	20 % 200 kg/m3	
Cost HPCD	4.50 \$/kg	
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone	97 %	
Q (Pumping rate) (injection rate = extraction rate)	32.6 m3/d 6.0 gpm	
For CPPT only: ratio injection/extraction time	0.67	
For CPPT only: extracted vol. per CPPT	72.9 m3	
1. b: Degree of contamination - Contaminant mass		
m initial	643 kg 459.5 liter	
m _{20%}	579 kg 413.5 liter	
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soil}	
1. c: Treatment rate		
Slug size per well (CPPT)	2.7 m3	
Injection/extraction rate (CPPT) per well	8 m3/day 1.5 gpm	
Number of wells needed to treat one PV	40 wells	
Time needed to inject and extract flushing solution (CPPT)	0.34 days 8.1 hours	
UF treatment capacity	32.6 m3/day 6.0 gpm	
Time necessary to recycle one PV flushing solution using UF	3.3 days	
2. Calculate theoretical mass and volume of CD required to remov	ve 90% NAPL	
VOC mass removed per kg CD Mass of CD necessary to remove 90% NAPL W/O recycling	0.0021 kg 276 tons	
Vol. of 20% CD solution to remove 90% NAPL	1378 m3	
3. Calculate number of total PV's necessary to remove contaminar	nt	
PV fluehed = m 90% / F removal / PV Uncertainty factor of :	38.3 PV 1.25	
Uncertainty factor of : Actual number of PV needed;	47.8 PV	
Actual number of PV needed:	47.0 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc $_{CD}$ x m ³ /PV =	21770 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface		
=CD mass per PV - (CD mass per PV x CD _{recovery})	653 kg	
4.c) CD mass recoverd by UF	19006 kg	
assume:	90% UF recovery efficiency	
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	3418 kg	
4.e) Total mass of CD needed to achieve 90% removal	185.2 tons	
4.e) Total mass of CD needed to achieve 50% removal	185.2 1015	
4.f) Total cost CD	\$833,613	
4. g) Material cost savings due to CD reuse	\$3,852,032	
5. Remediaiton time estimate for 90% mass removal		
No. of CPPT application per week:	2.1	
Estimated duration to achieve end-point	5.7 months	
Estimated duration to acmeve end-point	<u></u>	

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1	-DCE)
Treatment approach:	Multi-Well Push-Pull (CPF	PT) with UF in continuous operation
1.a Extent of contaminated area:		
Width	15.3 m 15.3 m	
Length Vertical extent	1.5 m	
Area treated	234 m2	
Vol _{soil}	351 m3	
Soil weight based on bulk density = 1.7 t/m3	597 tons (soil dens	sity = 1.7 t/m3)
rho _{contaminant} (Density)	1400 kg/m3	
n (Porosity)	0.31	
F removal NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug)	108.9 m3	
Injection Conc HPCD	20 %	200 kg/m3
Cost HPCD	4.50 \$/kg	
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone	97 %	
Q (Pumping rate) (injection rate = extraction rate)	32.6 m3/d	6.0 gpm
For CPPT only: ratio injection/extraction time	0.67	
For CPPT only: extracted vol. per CPPT	72.9 m3	
1. b: Degree of contamination - Contaminant mass		
m initial	643 kg	459.5 liter
m _{90%}	579 kg	413.5 liter
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soil}	
1. c: Treatment rate		
Slug size per well (CPPT)	2.7 m3	15
Injection/extraction rate (CPPT) per well Number of wells needed to treat one PV	8 m3/day 40 wells	1.5 gpm
Time needed to inject and extract flushing solution (CPPT)	0.34 days	8.1 hours
The needed to inject and exclusioning condition (or 1.17)	0.01 dayo	0.1 110410
UF treatment capacity Time necessary to recycle one PV flushing solution using UF	32.6 m3/day 3.3 days	6.0 gpm
2. Calculate theoretical mass and volume of CD required to remove 9	0% NAPL	
VOC mass removed per kg CD	0.0021 kg	
Mass of CD necessary to remove 90% NAPL W/O recycling	276 tons	
Vol. of 20% CD solution to remove 90% NAPL	1378 m3	
3. Calculate number of total PV's necessary to remove contaminant		
PV _{flushed} = m _{90%} / F _{removal} / PV	38.3 PV	
Uncertainty factor of :	1.25	
Actual number of PV needed:	47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc _{cD} x m ³ /PV =	21770 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface =CD mass per PV - (CD mass per PV x CD $_{\rm recovery})$	653 kg	
4.c) CD mass recoverd by UF	14360 kg	
assume:	68% UF recovery et	fficiency
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	8064 kg	
4.e) Total mass of CD needed to achieve 90% removal	407.5 tons	
4.f) Total cost CD	\$1,833,530	
4. g) Material cost savings due to CD reuse	\$2,852,115	
5. Remediaiton time estimate for 90% mass removal		
No. of CPPT application per week:	6.0	
Estimated duration to achieve end-point	2.0 months	

Simulation of CDEE Remediation		
Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-	DCE)
Treatment approach:	Multi-Well Push-Pull (CPP	f) with no UF
1.a Extent of contaminated area:		
Width	15.3 m 15.3 m	
Length Vertical extent	15.3 m 1.5 m	
Area treated	234 m2	
Vol _{soil}	351 m3	
Soil weight based on bulk density = 1.7 t/m3	597 tons (soil densi	ty = 1.7 t/m3)
rho _{contaminant} (Density)	1400 kg/m3	
n (Porosity)	0.31	
F removal NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug) Injection Conc HPCD	108.9 m3 20 %	200 kg/m3
Cost HPCD	4.50 S/kg	200 kg/113
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone	97 %	
Q (Pumping rate) (injection rate = extraction rate)	32.6 m3/d	6.0 gpm
For CPPT only: ratio injection/extraction time For CPPT only: extracted vol. per CPPT	0.67 72.9 m3	
	12.0 110	
1. b: Degree of contamination - Contaminant mass		
m initial	643 kg	459.5 liter
m initial m 90%	579 kg	413.5 liter
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soli}	
1. c: Treatment rate		
Slug size per well (CPPT)	2.7 m3	
Injection/extraction rate (CPPT) per well Number of wells needed to treat one PV	8 m3/day 40 wells	1.5 gpm
Time needed to inject and extract flushing solution (CPPT)	0.34 days	8.1 hours
UF treatment capacity	32.6 m3/day 3.3 days	6.0 gpm
Time necessary to recycle one PV flushing solution using UF	5.5 days	
2. Only late the profile large and values of OD required to remove 0	00/ NADI	
2. Calculate theoretical mass and volume of CD required to remove 9	U% NAPL	
VOC mass removed per kg CD	0.0021 kg	
Mass of CD necessary to remove 90% NAPL W/O recycling	276 tons	
Vol. of 20% CD solution to remove 90% NAPL	1378 m3	
3. Calculate number of total PV's necessary to remove contaminant		
PV flushed = m 90% / F removal / PV	38.3 PV	
Uncertainty factor of :	1.25	
Actual number of PV needed:	47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc _{cD} x m ³ /PV =	21770 kg	
- ay ob mass applied per r v = obio cp x m / v =	21770 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface		
=CD mass per PV - (CD mass per PV x CD recovery)	653 kg	
4.c) CD mass recoverd by UF	0 kg	
assume:	0% UF recovery effi	ciency
	00.000	
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	22423 kg	
4.e) Total mass of CD needed to achieve 90% removal	1094.3 tons	
4.f) Total cost CD	\$4,924,181	
4. g) Material cost savings due to CD reuse	\$0	
waterial cost savings due to CD reuse	\$0	
5 Demodiaiten time entirente fan 000/ maar menste		
5. Remediaiton time estimate for 90% mass removal		
No. of CPPT application per week:	6.0	
Estimated duration to achieve end-point	2.0 months	

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-	DCE)
Treatment approach:	Line drive (I/E) with UF in o	continuous operation
1.a Extent of contaminated area:	15.3 m	
Width Length	15.3 m	
Vertical extent	1.5 m	
Area treated	234 m2	
Vol _{soil}	351 m3	
Soil weight based on bulk density = 1.7 t/m3	597 tons (soil densi	ty = 1.7 t/m3)
rho _{contaminant} (Density)	1400 kg/m3	
n (Porosity)	0.31	
F removal NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug)	108.9 m3	
Injection Conc HPCD	20 %	200 kg/m3
Cost HPCD	4.50 \$/kg	
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone	79 %	
Q (Pumping rate) (injection rate = extraction rate)	32.6 m3/d	6.0 gpm
For CPPT only: ratio injection/extraction time	0.67	
For CPPT only: extracted vol. per CPPT	72.9 m3	
1. b: Degree of contamination - Contaminant mass		
m _{initial}	643 kg	459.5 liter
m _{90%}	579 kg	413.5 liter
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soil}	
1. c: Treatment rate		
Time needed to treat 1 PV	11.6 days	
Number of injection wells	14 wells	
Number of extraction wells Number of hydraulic control wells	24 wells 8 wells	
Total number of injection and extraction wells	38 wells	
UF treatment capacity Time necessary to recycle one PV flushing solution using UF	8 m3/day 13.6 days	1.5 gpm
2. Calculate theoretical mass and volume of CD required to remove 9	00% NAPL	
VOC mass removed per kg CD	0.0016 kg	
Theor. mss of CD necessary to remove 90% NAPL W/O recycling Vol. of 20% CD solution to remove 90% NAPL	362 tons 1809 m3	
3. Calculate number of total PV's necessary to remove contaminant		
PV _{flushed} = m _{s0%} / F _{removal} / PV	38.3 PV	
Uncertainty factor of :	1.25	
Actual number of PV needed:	47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc $_{CD} x m^3$ /PV =	21770 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface =CD mass per PV - (CD mass per PV x CD _{recovery})	4572 kg	
4.c) CD mass recoverd by UF assume:	11695 kg 68% UF recovery eff	iciency
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	14647 kg	c.c.oy
4.e) Total collinass needed to recondition masning solution to 20% per PV 4.e) Total mass of CD needed to achieve 90% removal	722.3 tons	
	122.3 1005	
4.f) Total cost CD	\$3,250,469	
4. g) Material cost savings due to CD reuse	\$1,435,176	
5. Remediaiton time estimate for 90% mass removal		
Estimated duration to achieve end-point	18.5 months	
Losing to dome to dome to end-point	10.5 11011115	

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-	DCE)
Treatment approach:	Line-Drive (I/E) with no UF	
1.a Extent of contaminated area: Width Length Vertical extent	15.3 m 15.3 m 1.5 m	
Area treated Vol _{kol}	234 m2 351 m3	
Soil weight based on bulk density = 1.7 Vm3	597 tons (soil densi	ty = 1.7 t/m3)
rho _{contaminant} (Density) n (Porosity) F _{removal} NAPL mass removal per m3 flushed PV (vol of injected CD slug) Injection Conc _{NPCD} Cost _{MPCD} R (Efficiency of contamiant removal)	1400 kg/m3 0.31 0.139 kg 108.9 m3 20 % 4.50 \$/kg 90 %	200 kg/m3
CD _{recovery} from treatment zone	79 %	
Q (Pumping rate) (injection rate = extraction rate) For CPPT only: ratio injection/extraction time	32.6 m3/d 0.67	6.0 gpm
For CPPT only: extracted vol. per CPPT	72.9 m3	
1. b: Degree of contamination - Contaminant mass		
m initial	643 kg	459.5 liter
m sow Avg. Contaminant concentration in solid matrix	579 kg 970 mg _{cont} /kg _{soil}	413.5 liter
1. c: Treatment rate		
Time needed to treat 1 PV	11.6 days	
Number of injection wells	14 wells	
Number of extraction wells Number of hydraulic control wells	24 wells 8 wells	
Total number of injection and extraction wells	38 wells	
		4.5
UF treatment capacity Time necessary to recycle one PV flushing solution using UF	8 m3/day 13.6 days	1.5 gpm
2. Calculate theoretical mass and volume of CD required to remove 9	0% NAPL	
VOC mass removed per kg CD	0.0016 kg	
Theor. mss of CD necessary to remove 90% NAPL W/O recycling Vol. of 20% CD solution to remove 90% NAPL	362 tons 1809 m3	
3. Calculate number of total PV's necessary to remove contaminant		
PV flushed = m sovs / F removal / PV	38.3 PV	
Uncertainty factor of : Actual number of PV needed:	1.25 47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc $_{\rm CD}$ x m³/PV =	21770 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface =CD mass per PV - (CD mass per PV x CD $_{\rm recovery})$	4572 kg	
4.c) CD mass recoverd by UF assume:	0 kg 0% UF recovery eff	ciency
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	26342 kg	
4.e) Total mass of CD needed to achieve 90% removal	<u>1281.7</u> tons	
4.f) Total cost CD	\$5,767,597	
4. g) Material cost savings due to CD reuse	\$0	
5. Remediaiton time estimate for 90% mass removal		
	10 E monthe	
Estimated duration to achieve end-point	18.5 months	

Small Scale 300 ft²

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-DC	E)
Treatment approach:	Multi-Well Push-Pull (CPPT)	with UF in batch operation
1.a Extent of contaminated area:		
Width	4.4 m 4.4 m	
Length Vertical extent	4.4 m 1.5 m	
Area treated	19 m2	
Vol _{soil} Soil weight based on bulk density = 1.7 t/m3	29 m3 49 tons (soil density =	1.7.t(m2)
Soli weight based on buik density = 1.7 pms	49 tons (soli density -	1.7 (///3)
rho _{contaminant} (Density)	1400 kg/m3 0.31	
n (Porosity) F _{removal} NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug)	9.0 m3	
Injection Conc HPCD	20 %	200 kg/m3
Cost HPCD	4.50 \$/kg	
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone Q (Pumping rate) (injection rate = extraction rate)	97 % 18.5 m3/d	3.4 gpm
For CPPT only: ratio injection/extraction time	0.67	3.4 gpm
1. b: Degree of contamination - Contaminant mass		
m intel	53 kg	38.0 liter
m initial m _{90%}	53 kg	38.0 liter 34.2 liter
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soil}	
1. c: Treatment rate		
Number of wells needed to treat one PV	6 wells	
Slug size per well (CPPT)	1.5 m3	
Injection/extraction rate (CPPT) per well	5.5 m3/day	1.0 gpm
UF treatment capacity	9.0 m3/day	1.7 gpm
Time necessary to recycle one PV flushing solution using UF	1.0 days	1.1 gpm
2. Calculate theoretical mass and volume of CD required to remove 90	% NAPL	
VOC mass removed per kg CD	0.0021 kg	
Mass of CD necessary to remove 90% NAPL W/O recycling	23 tons	
Vol. of 20% CD solution to remove 90% NAPL	114 m3	
3. Calculate number of total PV's necessary to remove contaminant		
PV _{fushed} = m _{90%} / F _{removal} / PV Uncertainty factor of :	38.3 PV	
Actual number of PV needed:	1.25 47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc _{CD} x m ³ /PV =	1800 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface		
=CD mass per PV - (CD mass per PV x CD recovery)	54 kg	
(a) CD more recovered by UE	1570	
4.c) CD mass recoverd by UF assume:	1572 kg 90% UF recovery efficie	ncy
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	283 kg	
4.e) Total mass of CD needed to achieve 90% removal	15.3 tons	
4.f) Total cost CD	\$68,942	
4. g) Material cost savings due to CD reuse	\$318,576	
	<i>tt</i> , <i>t</i> , <i>t</i> , <i>t</i>	
5. Remediaiton time estimate for 90% mass removal		
No. of CPPT application per week:	3.0	
Estimated duration to achieve end-point	4.0 months	

Simulation of CDEF Remediation	
Shaded cells mark variables	
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-DCE)
Treatment approach:	Multi-Well Push-Pull (CPPT) with UF in continuous operation
1.a Extent of contaminated area:	
Width	4.4 m 4.4 m
Length Vertical extent	4.4 m 1.5 m
Area treated Vol _{soil}	19 m2 29 m3
Soil weight based on bulk density = 1.7 t/m3	49 tons (soil density = 1.7 t/m3)
rho _{contaminant} (Density)	1400 kg/m3
n (Porosity)	0.31
F removal NAPL mass removal per m3 flushed PV (vol of injected CD slug)	0.139 kg 9.0 m3
Injection Conc HPCD	20 % 200 kg/m3
Cost HPCD	4.50 \$/kg
R (Efficiency of contamiant removal)	90 %
CD _{recovery} from treatment zone	97 % 32.6 m3/d 6.0 gpm
Q (Pumping rate) (injection rate = extraction rate) For CPPT only: ratio injection/extraction time	0.67
1. b: Degree of contamination - Contaminant mass	
m initial	53 kg 38.0 liter
m _{90%}	48 kg 34.2 liter
Avg. Contaminant concentration in solid matrix	970 mg _{conf} /kg _{soil}
1. c: Treatment rate	
Number of wells needed to treat one PV	6 wells
Slug size per well (CPPT)	1.5 m3
Injection/extraction rate (CPPT) per well	5.5 m3/day 1.0 gpm
UF treatment capacity Time necessary to recycle one PV flushing solution using UF	9.0 m3/day 1.7 gpm 1.0 days
2. Calculate theoretical mass and volume of CD required to remove 9	0% NAPL
VOC mass removed per kg CD	0.0021 kg
Mass of CD necessary to remove 90% NAPL W/O recycling	23 tons
Vol. of 20% CD solution to remove 90% NAPL	114 m3
3. Calculate number of total PV's necessary to remove contaminant	
PV fushed = m 90% / F removal / PV	38.3 PV
Uncertainty factor of :	1.25
Actual number of PV needed:	47.8 PV
4. Calculate total mass of CD needed to remove contaminant	
4.a) CD mass applied per PV = Conc _{CD} x m ³ /PV =	1800 kg
	-
4.b) CD mass added to make-up for incomplete mass recovery from subsurface =CD mass per PV - (CD mass per PV x CD _{recovery})	54 kg
4.c) CD mass recoverd by UF	1188 kg
assume:	68% UF recovery efficiency
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	667 kg
4.e) Total mass of CD needed to achieve 90% removal	33.7 tons
4.f) Total cost CD	\$151,639
4. g) Material cost savings due to CD reuse	\$235,879
5. Remediaiton time estimate for 90% mass removal	
No. of CPPT application per week:	6.0
Estimated duration to achieve end-point	2.0 months
Estimated duration to achieve end-point	2.0 11011015

Simulation of CDEF Remediation Shaded cells mark variables Contaminant: VOC (TCE+1,1,1-TCA+1,1-DCE) Treatment approach: Multi-Well Push-Pull (CPPT) with no UF 1.a Extent of contaminated area: Multi-Well Push-Pull (CPPT) with no UF Vidth 4.4 m Length 4.4 m Vertical extent 1.5 m Area treated 1.9 m2 Vol _{sol} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 0.31
Contaminant: VOC (TCE+1,1,1-TCA+1,1-DCE) Treatment approach: Multi-Well Push-Pull (CPPT) with no UF 1.a Extent of contaminated area:
Treatment approach: Multi-Well Push-Pull (CPPT) with no UF 1.a Extent of contaminated area: 4.4 m Width 4.4 m Length 4.4 m Vertical extent 1.5 m Area treated 19 m2 Vol _{soil} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho_contaminant (Density) 1400 kg/m3
1.a Extent of contaminated area: Width 4.4 m Length 4.4 m Vertical extent 1.5 m Area treated 19 m2 Vol _{soit} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 1400 kg/m3
1.a Extent of contaminated area: Width 4.4 m Length 4.4 m Vertical extent 1.5 m Area treated 19 m2 Vol _{soit} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 1400 kg/m3
Width 4.4 m Length 4.4 m Vertical extent 1.5 m Area treated 19 m2 Vol _{soil} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 1400 kg/m3
Vertical extent 1.5 m Area treated 19 m2 Vol _{soit} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 1400 kg/m3
Area treated 19 m2 Vol _{soil} 29 m3 Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 1400 kg/m3
Soil weight based on bulk density = 1.7 t/m3 49 tons (soil density = 1.7 t/m3) rho _{contaminant} (Density) 1400 kg/m3
rho _{contaminant} (Density) 1400 kg/m3
· · · · · · · · · · · · · · · · · · ·
n (Porosity) 0.31
F removal NAPL mass removal per m3 flushed 0.139 kg
PV (vol of injected CD slug) 9.0 m3
Injection Conc HPCD 20 % 200 kg/m3 Cost HPCD 4.50 \$/kg
Cost HPCD 4.50 \$/kg R (Efficiency of contamiant removal) 90 %
CD _{recovery} from treatment zone 97 %
Q (Pumping rate) (injection rate = extraction rate) 32.6 m3/d 6.0 gpm
For CPPT only: ratio injection/extraction time 0.67
1. b: Degree of contamination - Contaminant mass
m initial 53 kg 38.0 liter
m 90% 48 kg 34.2 liter
Avg. Contaminant concentration in solid matrix 970 mg _{cont} /kg _{sol}
1. c: Treatment rate
Number of wells needed to treat one PV 6 wells
Slug size per well (CPPT) 1.5 m3
Injection/extraction rate (CPPT) per well 5.5 m3/day 1.0 gpm
UF treatment capacity 9.0 m3/day 1.7 gpm
Time necessary to recycle one PV flushing solution using UF 1.0 days
2. Calculate theoretical mass and volume of CD required to remove 90% NAPL
VOC mass removed per kg CD 0.0021 kg Mass of CD necessary to remove 90% NAPL W/O recycling 23 tons
Vol. of 20% CD solution to remove 90% NAPL 114 m3
3. Calculate number of total PV's necessary to remove contaminant
PV _{fished} = m _{50%} / F _{removal} / PV 38.3 PV
Uncertainty factor of : 1.25
Actual number of PV needed: 47.8 PV
4. Calculate total mass of CD needed to remove contaminant
4.a) CD mass applied per PV = Conc _{cD} x m ³ /PV = 1800 kg
4.b) CD mass added to make-up for incomplete mass recovery from subsurface
=CD mass per PV - (CD mass per PV x CD recovery) 54 kg
4.c) CD mass recoverd by UF 0 kg
assume: 0% UF recovery efficiency
4.d) Total CD mass needed to recondition flushing solution to 20% per PV 1854 kg
4.e) Total mass of CD needed to achieve 90% removal 90.5 tons
4.f) Total cost CD \$407,246
4.f) Total cost CD \$407,246 4. g) Material cost savings due to CD reuse \$0
4. g) Material cost savings due to CD reuse \$0 5. Remediaiton time estimate for 90% mass removal
4. g) Material cost savings due to CD reuse \$0

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-DCE)	
Treatment approach:	Line drive (I/E) with UF in continuous operation	m
1.a Extent of contaminated area:		
Width	4.4 m	
Length	4.4 m	
Vertical extent	1.5 m	
Area treated	19 m2 29 m3	
Vol _{soll} Soil weight based on bulk density = 1.7 t/m3	49 tons (soil density = 1.7 t/m3)	
Soli weight based on burk density = 1.7 mills		
rho _{contaminant} (Density)	1400 kg/m3	
n (Porosity)	0.31	
F removal NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug)	9.0 m3	
Injection Conc HPCD	20 % 200 kg/m3	
Cost HPCD	4.50 \$/kg	
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone	79 %	
Q (Pumping rate) (injection rate = extraction rate)	32.6 m3/d 6.0 gpm	
1. b: Degree of contamination - Contaminant mass		
m _{initial}	53 kg 38.0 liter	
m 90%	48 kg 34.2 liter	
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soil}	
1. c: Treatment rate		
Time needed to treat 1 PV	1.0 days	
Number of injection wells	3 wells	
Number of extraction wells	3 wells	
Number of hydraulic control wells	2 wells	
UF treatment capacity Time necessary to recycle one PV flushing solution using UF	9.0 m3/day 1.7 gpm 1.0 days	
The necessary to recycle one PV hushing solution using OP	1.0 days	
2. Calculate theoretical mass and volume of CD required to remove 90% NAPL		
VOC mass removed per kg CD	0.0016 kg	
Theor. mss of CD necessary to remove 90% NAPL W/O recycling	30 tons	
Vol. of 20% CD solution to remove 90% NAPL	150 m3	
3. Calculate number of total PV's necessary to remove contaminant		
PV fushed = m 90% / F removal / PV	38.3 PV	
Uncertainty factor of :	1.25	
Actual number of PV needed:	47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc _{CD} x m ³ /PV =	1800 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface =CD mass per PV - (CD mass per PV x CD recovery)	378 kg	
4.c) CD mass recoverd by UF	967 kg	
assume:	68% UF recovery efficiency	
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	1211 kg	
	-	
4.e) Total mass of CD needed to achieve 90% removal	59.7 tons	
4.f) Total cost CD	\$268,824	
4. g) Material cost savings due to CD reuse	\$118,694	
5. Remediaiton time estimate for 90% mass removal		
	16 months	
Estimated duration to achieve end-point	1.6 months	

Simulation of CDEF Remediation		
Shaded cells mark variables		
Contaminant:	VOC (TCE+1,1,1-TCA+1,1-DCE)	
Treatment approach:	Line-Drive (I/E) with no UF	
1.a Extent of contaminated area:		
Width	4.4 m	
Length	4.4 m	
Vertical extent Area treated	1.5 m 19 m2	
Vol _{soli}	29 m2	
Soil weight based on bulk density = 1.7 t/m3	49 tons (soil density = 1.7 t/m	3)
the (Density)	1400 1-1-1-2	
rho _{contaminant} (Density) n (Porosity)	1400 kg/m3 0.31	
F removal NAPL mass removal per m3 flushed	0.139 kg	
PV (vol of injected CD slug)	9.0 m3	
Injection Conc HPCD		kg/m3
Cost HPCD	4.50 \$/kg	(grino
R (Efficiency of contamiant removal)	90 %	
CD _{recovery} from treatment zone	79 %	
Q (Pumping rate) (injection rate = extraction rate)	32.6 m3/d 6.0 g	apm
1. b: Degree of contamination - Contaminant mass		
m _{initial}	53 kg 38.0 I	iter
m 90%	48 kg 34.2 l	iter
Avg. Contaminant concentration in solid matrix	970 mg _{cont} /kg _{soil}	
1. c: Treatment rate		
Time needed to treat 1 PV	1.0 days	
Number of initialize wells	3 wells	
Number of injection wells Number of extraction wells	3 wells	
Number of hydraulic control wells	2 wells	
UF treatment capacity	9.0 m3/day 1.7 g	gpm
Time necessary to recycle one PV flushing solution using UF	1.0 days	
2. Calculate theoretical mass and volume of CD required to remove 90	% NADI	
2. Calculate theoretical mass and volume of CD required to remove 90	% NAFL	
VOC mass removed per kg CD	0.0016 kg	
Theor. mss of CD necessary to remove 90% NAPL W/O recycling	30 tons	
Vol. of 20% CD solution to remove 90% NAPL	150 m3	
2 Calculate number of total DV/a necessary to remove contaminant		
3. Calculate number of total PV's necessary to remove contaminant		
PV flushed = m 90% / F removal / PV	38.3 PV	
Uncertainty factor of :	1.25	
Actual number of PV needed:	47.8 PV	
4. Calculate total mass of CD needed to remove contaminant		
4.a) CD mass applied per PV = Conc _{CD} x m ³ /PV =	1800 kg	
4.b) CD mass added to make-up for incomplete mass recovery from subsurface		
=CD mass per PV - (CD mass per PV x CD recovery)	378 kg	
	0.1.1	
4.c) CD mass recoverd by UF assume:	0 kg 0% UF recovery efficiency	
assume.	070 OF recovery enciency	
4.d) Total CD mass needed to recondition flushing solution to 20% per PV	2179 kg	
4.e) Total mass of CD needed to achieve 90% removal	106.0 tons	
4.f) Total cost CD	\$476,999	
,		
4. g) Material cost savings due to CD reuse	\$0	
5. Remediaiton time estimate for 90% mass removal		
	10	
Estimated duration to achieve end-point	1.6 months	

APPENDIX E

HYPOTHETICAL FULL-SCALE COST SYSTEM — 2,500 FT² SCALE

Cyclodextrin Enhanced Flushing at a hypothetical site

CAPITAL COST (hypothetical full-scale system)

CAPITA		і (пур	οτη	etical fu	III-scale	system			
Assumptions	s								
Treatment ap	proach: N	/lulit-w	ell p	ush-pull	with UF i	1 batch m	node		
Flushing Vol: Soil mass: Area: Project durati			109 m 600 to 234 m 6 m	ons		Power Con Cost / KWH Note: Elec	1	F is provided by g	enerators.
Number of we	ells, type and	d depth n	eeded	for remediation	on				
40 In	jection/extra	ction well	s	22.5 ft					
DNAPL Sour Assume: appr				already know	n				
	lo of units 1 \$ 10 \$ 40 \$ 20 \$ 75 \$ 480 \$ 15 \$	Unit lab cost (hr 5 5 5 5 5 5 5	or	Unit mat cost 5 1,600 5 3,500 5 1,250 5 1,250 5 126 5 -	Labor cost \$ \$ 3,800 \$ \$ \$ 24,000	- \$ 25,000 - \$ 9,450	\$ 35,000 \$ 3,800 \$ 25,000 \$ 9,450 \$ 24,000	Total cost \$ 101,850	Power consumption Item description Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew) Equipment and Expendables Total DNAPL Source Zone Characterization
Treatability S	Study (Site :	soil testi	ng)						
Units N EA EA EA	lo of units 120 \$ 1 \$ 24 \$	\$			Labor cost \$ 10,200 \$ 3,000	- \$ 2,550	+,	Total cost	Power Item description Lab techician (soil column tests) Lab equipment Report preparation
								\$ 15,750	Total Cyclodextrin Selection
Engineering,	, Design, an	nd Modeli	ng						
Units N EA EA	lo of units 144 \$ 1 \$		or 125 - 5		Labor cost \$ 22,000 \$	Mat cost) \$ 1,770 - \$ 12,500		Total cost	Power consumption Work Plan, H&S plan, Site Management Plan (Project manager) Permits and licences, estimated Total Engineering, Design, and Modeling
Technology Assume: Loca									
	lo of units 280 \$ 2 \$	Unit lab cost		Unit mat cost	Labor cost \$ 7,000 \$	Mat cost) \$ - - \$ 10,928		Total cost \$ 17,928	Power consumption Item description Travel to and from site (incl. accommodation) Freight (Palletizing, loading, and shipping of equipmemt) Total Technology Mobilization and Demobilization
Site Work									
Site Set-up Units N EA EA EA	lo of units 1 \$ 1 \$ 540 \$	\$	or - 9 - 9 30 9	1,450		Mat cost - \$ 1,000 - \$ 1,400	\$ 1,400	Total cost	Power consumption Item description Secondary containment (berm) Electricity hook-up Plumbing
EA	540 3	₽	30 3	p -	φ 16,200		\$ 16,200	\$ 18,600	Total Site Set-up
Installation of	of Equipmer	nt and Ap	purte	nances					
Well Field In	stallation		or	Lipit mot					Power
ft EA	lo of units 900 \$ 40 \$	\$	- 3	552	\$	Mat cost - \$ 69,030 - \$ 22,080	\$ 22,080	Total cost	Power consumption Item description Injection/Extraction well installation Grunfos submersible pumps (Model 55) COOD extension extended forum entrel
EA	1 \$	-	- (14,800	ψ	- \$ 14,800	\$ 14,800	\$ 105,910	SCADA system, automated flow control Total Well Installation
Above Groun Units N ft EA EA	nd Appurter lo of units 2000 \$ 44 \$ 44 \$	Unit lab cost	or - 5 - 5	5 78 5 20	\$ \$	Mat cost - \$ 3,600 - \$ 3,432 - \$ 880	\$ 3,432	Total cost	Power consumption Item description Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves
EA EA ft ft	44 9 4 9 200 9 60 9	5 5 5		45 294 2	\$ \$		\$ 1,980 \$ 1,176 \$ 360	\$ 11,944	In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing Connection of air stripper (6 in PVC) Total Above Ground Piping
									Total Installation of Equipment and Appurtenances
								↓ 117,054	rotal instantion of Equipment and Appurtenances

quipmer	nt Ownership				linit met								
Units	No of units		Unit labor cost		Unit mat cost	Labor cost		at cost		tem cost		⊤otal cost	ltem description
\	1 1	\$	-	\$	60,606 368.00	\$- \$-	\$	60,606 368	\$ \$	60,606 368	\$	60,974	Air stripper incl. blower 250 gal mixing tank Total Equipment Ownership and Rental Cost
	nd Testing	ι	Unit labor	l	Unit mat								Power
Units		\$	cost 30	\$	cost -	Labor cost \$ 2,880	\$	at cost -	\$	tem cost 2,880		Total cost	consumption Item description Operator Training (6 people field crew)
5	280	\$	50	\$	-	\$ 14,000	\$	-	\$	14,000	\$	16,880	System shake-down, well testing, etc. Total Startup and Testing
ther (no	n-process re		d) Unit labor		Unit mat								Power
Units A	No of units 1		cost -		cost	Labor cost \$-		at cost 4,800	\$	tem cost 4,800		⊤otal cost	consumption Item description Office and admin. equipment (computer, printer, etc)
4	6 1		-	\$ \$	550 3,200	\$- \$-	\$ \$	3,300 3,200	\$ \$	3,300 3,200		44.000	H&S training (OSHA) Field safety equipment, various
											\$	11,300	Total Other
											\$	397,406	TOTAL CAPITAL (year 1)
st Yea	ar OPER/	١T	ING ANI	DN	AINTEN		DST	(hypo	oth	etical ful	II-s	cale syst	em)
abor ssume: 1	l person, 8 hrs	/da	iy, 7 days/w	eek,	SCADA tec	hnology is use	ed						
Units	No of units	ι	Unit labor cost	1	Unit mat cost	Labor cost	м	at cost		tem cost		Total cost	Item description
rs rs	480	\$ \$	30 30	\$ \$		\$ 14,386 \$ 28,771	\$	-	\$ \$	14,386 28,771			Operating labor Monitoring labor
s	168	\$	90	\$	-	\$ 15,120	\$	-	\$	15,120	\$	58,277	Supervision Total Labor Cost
aterials			Unit labor		Unit mat								
Units 3	No of units 407440		cost -	\$	cost	Labor cost \$-		at cost 314,880	\$	tem cost 814.880		Total cost	Item description Cyclodextrin, tech grade
A onths	1	\$	15,000		-	\$ 15,000 \$ -		3,000	s s	15,000 3,000			Replacement membranes for UF unit H&S survey, personal protective equip.
onth	6		-			\$-		6,000	\$	6,000	\$	838,880	Consumable supplies, repairs Total Material Cost
tilities a	nd Fuel		Le Malerie e		1 - 1 1								
Units WH	No of units 106128	\$	Unit labor cost	\$	Unit mat cost 0.05725	Labor cost \$	М \$	at cost 6,076	\$	tem cost 6,076		Total cost	Item description
al 200 gal	1605 264	\$	-	\$ \$ \$	2.00	\$- \$-	\$ \$	3,209 116	s s	3,209 116			Fuel for dissel electric generator Water
				·		•					\$	9,401	Total Utilities and Fuel Cost
	nt Ownership		Unit labor		Unit mat								
Units onths	No of units 6		cost	\$		Labor cost \$ - \$ -	\$	at cost 157,500	\$ \$	tem cost 157,500 8,982		Total cost	Item description UF membrane unit for CD reconcentration Diesel electric generator (480 V, 22KW)
A nonths nonths	6 6 12			\$ \$		\$- \$-		8,982 4,992 14,368	э \$ \$	4,992 14,368			Suspended solid filter system 2 x 21,000 gal holding tank
nonths	6	\$	-	\$		\$ -	\$	50,937	\$	50,937	\$	236,779	Air activated carbon filter system Total Equipment Ownership and Rental Cost
	nce Testing a		Analysis										
-	Cost - off-site		Unit labor		Unit mat	Leks		at a		tona		Total	
Units A	No of units 210		cost	\$	cost 85	Labor cost \$-		at cost 17,850		tem cost 17,850	\$	Total cost 17.850	Item description VOC analysis (short list) Total Performance Testing and Analysis - off site
nalysis	Cost - on-site											11,000	
Units	No of units		Unit labor cost		Unit mat cost	Labor cost		at cost		tem cost		Total cost	Item description
A A	1050 26			\$ \$	15 60	\$- \$-		15,750 1,560	\$ \$	15,750 1,560			CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week
thor (P. Process	o.fr	d)								\$	17,310	Total Performance Testing and Analysis - on site
ther (no 's	n-process rel	ate	a)	s	125	\$	ŝ	10,000	s	10,000			Final report preparation (Project Manager)
Anonths	1	\$	-			\$ -	\$	4,496 324	\$ \$	4,496 324			PID for H&S survey, personal protective equip. On-site sanitation (rental)
A	130	\$	-	\$	25		\$	3,250		3,250	\$	18,070	S/H of samples (5 shipments per week) Total Other (non-process related)
											_		
											\$		TOTAL O&M (year 1)

Disposal	of Hazardeou	ıs Wa	ste									
		U	nit labor	Unit mat								Power
Units	No of units		cost	cost	Labor	cost	M	at cost	Item cost	T	otal cost	consumption Item description
EA	1	\$	-	\$ 16,500	\$	-	\$	16,500	\$ 16,500			Off-site disposal of drill cuttings
months	6	\$	-	\$ 250	\$	-	\$	1,500	\$ 1,500			Off-site disposal of liquid wastes
										\$	18,000	0 Total Disposal of Hazardeous Waste
Site Rest	oration											
		U	nit labor	Unit mat								
Units	No of units		cost	cost	Labor	cost	M	at cost	Item cost	T	otal cost	Item description
hrs	24	\$	30		\$	720	\$	-	\$ 720			Field crew
hrs	4	\$	90		\$	360	\$	-	\$ 360			Supervision
										\$	1,080	0 Total Site Restoration
												0 TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 2)

Summary

C t C . t	oull with UF in batch mode (6 months)	$C \rightarrow (\Phi)$
Cost Category	Sub Category	Cost (\$)
	FIXED COSTS	
1. Capital Cost	Mobilization/Demobilization	\$ 17,928
	Planning/Preparation	\$ 52,020
	Site Investigation	\$ 101,850
	Site Work	\$ 18,600
	Equipment Cost - Structures	\$ -
	Equipment Cost - Process Equipment	\$ 60,974
	Star-up and Testing	\$ 16,880
	Other - Non Process Equipment	\$ 11,300
	Other - Installation	\$ 117,854
	Other - Engineering (1)	\$ -
	Other - Management Support (2)	\$ -
	Sub-Total:	\$ 397,406
	VARIABLE COSTS	
2. Variable Cost	Labor	\$ 58,277
	Materials / Consumables	\$ 838,880
	Utilities / Fuel	\$ 9,401
	Equipment Cost (rental)	\$ 236,779
	Chemical Analysis	\$ 35,160
	Other	\$ 18,070
	Sub-Total:	\$ 1,196,567
3. Other	Disposal of well cuttings	\$ 16,500
Technology	Disposal of liquid waste	\$ 1,500
Specific Cost	Site Restoration	\$ 1,080
	Sub-Total:	\$ 19,080
	TOTAL COSTS	
	Total Technology Cost	\$ 1,613,053
	Quantity Treated - VOC mass	1415
	Unit Cost	\$ 1,140

(1) Included in planning/preparation

CAPITAL COST (hypothetical full-scale system)

Assumpt	tions														
		Mulit.	woll	nue	sh-pull	with	LIE in	c 01	ntinuo	ie n	node				
Flushing Soil mass Area: Project di	Vol:	Munt	109 600 234	- m3 tons		vvitii	UP III	Pow Cost	er Consur / KWH	r\$	0.05725	s pr	ovided by gene	erators.	
Number o	of wells, type a	nd depth	neede	d for	remediatio	'n									
40	Injection/ext	raction v	vells		22.5 ft										
	Source Zone C														
Assume:	approximate e				,	1									
Units EA EA EA EA EA EA EA	No of units 1 10 20 75 480 15	\$ \$ \$	(hr) - 95 -	\$		Lab \$ \$ \$ \$ \$ \$ \$ \$	or cost - 3,800 - 24,000 -	\$	lat cost 1,600 35,000 - 25,000 9,450 - 3,000	\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	tem cost 1,600 35,000 3,800 25,000 9,450 24,000 3,000	\$	Total cost 101,850	Power consumption	Item description Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew) Equipment and Expendables Source Zone Characterization
Treatabil	ity Study (Site	e soil te	sting)												
Units EA EA EA	No of units 120 1 24	\$	(hr)	ر چ چ	Jnit mat cost 2,550	Lab \$ \$ \$	or cost 10,200 - 3,000	\$ \$	at cost - 2,550 -	\$	tem cost 10,200 2,550 3,000	\$	Total cost 15,750	Power consumption Total Cyclode	Item description Lab techician (soil column tests) Lab equipment Report preparation xtrin Selection
Engineer	ring, Design, a	and Mod	leling												
Units EA EA	No of units 144 1	Unit I co \$ \$		\$ \$	Jnit mat cost 1,770 12,500	Lab \$ \$	or cost 22,000 -	₽ \$	lat cost 1,770 12,500	\$ \$	tem cost 23,770 12,500	\$	Total cost 36,270	Power consumption Total Enginee	Item description Work Plan, H&S plan, Site Management Plan (Project manager) Permits and licences, estimated rring, Design, and Modeling
	ogy Mobilizati Local contract														
Units hrs EA	No of units 280	Unit I co	abor		Jnit mat cost 5,464	Lab \$ \$	or cost 7,000 -		lat cost - 10,928	\$ \$	tem cost 7,000 10,928	\$	Total cost 17,928	Power consumption Tota Technolo	Item description Travel to and from site (incl. accommodation) Freight (Palletizing, loading, and shipping of equipmemt) ogy Mobilization and Demobilizatior
Site Wor	k														
Site Set- Units EA EA EA	up No of units 1 1 540	\$		ر چ چ	Unit mat cost 1,000 1,450	Lab \$ \$ \$	or cost - 16,200	\$ \$	lat cost 1,000 1,400 -	\$ \$ \$	tem cost 1,000 1,400 16,200	\$	Total cost 18,600	Power consumption Total Site Set	Item description Secondary containment (berm) Electricity hook-up Plumbing -up
Installati	on of Equipm	ent and	Appur	tena	nces										
Well Fiel	d Installation													_	
Units ft EA EA	No of units 900 40 1	\$		s s s	Init mat cost 77 552 14,800	Lab \$ \$ \$	or cost - - -	₽ \$ \$	lat cost 69,030 22,080 14,800	\$ \$ \$	tem cost 69,030 22,080 14,800	s	Total cost 105.910	Power consumption Total Well Ins	Item description Injection/Extraction well installation Grunfos submersible pumps (Model 5S) SCADA system, automated flow control tallation
Above C	round Plumb	na										Ŷ	,		
Units ft EA EA EA EA EA ft ft	No of units 2000 44 44 44	Unit I co \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	st - - - - -	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	78 20 45 294	Lab \$ \$ \$ \$ \$ \$ \$ \$		> \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	lat cost 3,600 3,432 880 1,980 1,176 360 516	\$ \$ \$ \$ \$ \$ \$	tem cost 3,600 3,432 880 1,980 1,176 360 516	s	Total cost	Power consumption	Item description Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing Connection of air stripper (6 in PVC) Fround Plaing
												\$	117,854	i otal Installat	tion of Equipment and Appurtenances

Units	it Ownership t	und Rent Unit lat		1	Unit mat											
	No of units	cost		, c	cost		or cost	Mat c			m cost	Т	otal cost			Item description
	1 :	6	-	\$	60,606	\$	-			\$	60,606				Air stripper incl. blower	
`	1			\$	368.00	\$	-	\$	368	\$	368	\$	60.074		250 gal mixing tank	`ost
												Ş	60,974	i otai Equipme	nt Ownership and Rental C	Jost
artup ar	nd Testing	L la it la l			la it mat									Damas		
Units	No of units	Unit lat cost	DOL	U.	Unit mat cost	Labo	or cost	Mat c	ost	lte	m cost	т	otal cost	Power consumption		Item description
S	96 3		30	\$	-	\$	2,880	\$		\$	2,880				Operator Training (6 people	field crew)
rs	280	5	50	\$	-	\$	14,000	\$	-	\$	14,000		46 990		System shake-down, well te	sting, etc.
												\$	16,000	Total Startup a	na resung	
ther (no	n-process rela	ted) Unit lat	or		Unit mat									Power		
Units	No of units	cost	01		cost	Labo	or cost	Mat c	cost	lte	m cost	Т	otal cost	consumption		Item description
A	1		-	\$	4,800		-			\$	4,800				Office and admin. equipmen	t (computer, printer, etc)
A A	3 :		-	\$ \$	550 1,600	\$ \$				s s	1,650 1,600				H&S training (OSHA) Field safety equipment, vario	auc
~		-		Ŷ	1,000	Ŷ		Ψ	1,000	Ŷ	1,000	\$	8,050	Total Other	field safety equipment, van	
											1	\$	394,156	TOTAL CAPIT	AL (year 1)	
st Yea	ar OPERA	TING	AND	D M	IAINTEN	NANC	CE CO	ST (h	ypoth	etic	al full-	sca	le syster	n)		
abor					001511											
ssume: 1	person, 8 hrs/	day, 7 da	iys/we	eek,	SCADA tec	shnolog	y is used	1								
		Unit lat	oor	ι	Unit mat											
Units	No of units	cost	20	~	cost		or cost	Mat c			m cost	Т	otal cost		Operating labs-	Item description
rs rs	160 320		30 30	\$ \$	-	\$ \$	4,795 9,590	\$ \$		\$ \$	4,795 9,590				Operating labor Monitoring labor	
rs	96		90	ŝ	-	\$	8,640	\$		s	8,640				Supervision	
												\$	23,026	Total Labor Co		
laterials																
	No. 16 19	Unit lat	oor	ι	Unit mat											Here de colories
Units B	No of units 896500	cost	-	\$	cost 2.00	Labo \$	or cost -	Mat c \$ 1,79			m cost ,793,000	T	otal cost		Cyclodextrin, tech grade	Item description
nonths	2 3	6	-		500	\$	-	\$	1,000	š	1,000				H&S survey, personal protect	tive equip.
nonth	2 3	5	-	\$	1,000	\$	-	\$	2,000	\$	2,000				Consumable supplies, repair	rs
												\$	1,796,000	Total Material	Cost	
Jtilities ar	nd Fuel	L la M La k			la it an at											
Units	No of units	Unit lat cost	or	U	Unit mat cost	Labo	or cost	Mat c	ost	Ite	m cost	Т	otal cost			Item description
<wh< td=""><td>35376</td><td>5</td><td>-</td><td>\$</td><td>0.05725</td><td>\$</td><td>-</td><td>\$</td><td></td><td>\$</td><td>2.025</td><td></td><td></td><td></td><td>Electricity cost</td><td></td></wh<>	35376	5	-	\$	0.05725	\$	-	\$		\$	2.025				Electricity cost	
			-	\$	2.00	\$					2,025					
jal	1872						-			\$	3,744				Fuel for diesel electric gener	ator
	88		-	\$	0.44	\$	-	\$ \$				s	5,808		Fuel for diesel electric gener Water	ator
000 gal	88 :	5	-				:			\$	3,744	\$	5,808		Fuel for diesel electric gener Water	ator
000 gal		5	-	\$:			\$	3,744	\$	5,808		Fuel for diesel electric gener Water	ator
000 gal quipmen Units	88 s at Ownership a No of units	and Rent Unit lat cost	- al bor	\$	0.44 Unit mat cost	\$ Labo	- - or cost	\$ Mat c	39 cost	S S Ite	3,744 39 m cost		5,808 Total cost	Total Utilities a	Fuel for diesel electric gener Water Ind Fuel Cost	Item description
000 gal Equipmen Units nonths	88 s nt Ownership a No of units 2 s	and Rent Unit lat cost	- al bor -	\$ 5	0.44 Unit mat cost 30,000	\$ Labo \$		\$ Mat c \$ 6	39 cost 0,000	S S Ite S	3,744 39 m cost 60,000			Total Utilities a	Fuel for diesel electric gener Water und Fuel Cost UF membrane unit for CD re	Item description concentration
000 gal Equipmen Units	88 s at Ownership a No of units	and Rent Unit lab cost	- al bor	\$ 5	0.44 Unit mat cost	\$ Labo		\$ Mat c \$ 6 \$ 3	39 cost 0,000 2,994	S S Ite	3,744 39 m cost			Total Utilities a	Fuel for diesel electric gener Water Ind Fuel Cost UF membrane unit for CD re Diesel electric generator (48	Item description concentration
000 gal quipmen Units nonths nonths nonths nonths	88 s nt Ownership a No of units 2 s 2 s 2 s 2 s	and Rent Unit lat cost	- bor - - -	\$ \$ \$ \$ \$ \$	0.44 Unit mat cost 30,000 1,497 997 832	\$ Labo \$ \$ \$		\$ Mat c \$ 60 \$ 2 \$ \$	39 cost 0,000 2,994 1,993 1,664	S S Ite S S S S	3,744 39 m cost 60,000 2,994 1,993 1,664			Total Utilities a	Fuel for diesel electric gener Water Ind Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster	Item description concentration 0 V, 22KW)
000 gal quipmen Units nonths nonths nonths nonths nonths	88 s nt Ownership a No of units 2 s 2 s 2 s 2 s 2 s 2 s 2 s 2 s	and Rent Unit lat cost	- xal Dor - - - -	\$	0.44 Unit mat cost 30,000 1,497 997 832 1,197	\$ Labo \$ \$ \$ \$ \$ \$		\$ Mat c \$ 60 \$ 3 \$ \$ \$	39 cost 0,000 2,994 1,993 1,664 2,395	s s lte s s s s s s	3,744 39 m cost 60,000 2,994 1,993 1,664 2,395			Total Utilities a	Fuel for diesei electric gener Water und Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster 21.000 gal holding tank	Item description concentration 0 V, 22KW) n
ooo gal quipmen Units nonths nonths nonths nonths nonths	88 s nt Ownership a No of units 2 s 2 s 2 s 2 s	and Rent Unit lat cost	- bor - - -	\$	0.44 Unit mat cost 30,000 1,497 997 832	\$ Labo \$ \$ \$		\$ Mat c \$ 60 \$ 3 \$ \$ \$	39 cost 0,000 2,994 1,993 1,664 2,395	S S Ite S S S S	3,744 39 m cost 60,000 2,994 1,993 1,664	т	otal cost	Total Utilities a	Fuel for diesei electric gener Water und Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster 21.000 gal holding tank Air activated carbon filter syst	Item description concentration 0 V, 22KW) n stem
000 gal quipmen Units onths onths onths onths onths onths	No of units 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	und Rent Unit lat cost	- bor - - - -	\$	0.44 Unit mat cost 30,000 1,497 997 832 1,197	\$ Labo \$ \$ \$ \$ \$ \$		\$ Mat c \$ 60 \$ 3 \$ \$ \$	39 cost 0,000 2,994 1,993 1,664 2,395	s s lte s s s s s s	3,744 39 m cost 60,000 2,994 1,993 1,664 2,395		otal cost	Total Utilities a	Fuel for diesei electric gener Water und Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster 21.000 gal holding tank	Item description concentration 0 V, 22KW) n stem
ooo gal quipmen Units nonths nonths nonths nonths nonths nonths nonths nonths nonths	No of units 2 2 2 2 2 2 2 2 2 3 2 3 2 4 2 4 2 4 2 4 2 4 2 4 2 4 2 4	und Rent Unit lat cost	- bor - - - -	\$	0.44 Unit mat cost 30,000 1,497 997 832 1,197	\$ Labo \$ \$ \$ \$ \$ \$		\$ Mat c \$ 60 \$ 3 \$ \$ \$	39 cost 0,000 2,994 1,993 1,664 2,395	s s lte s s s s s s	3,744 39 m cost 60,000 2,994 1,993 1,664 2,395	т	otal cost	Total Utilities a	Fuel for diesei electric gener Water und Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster 21.000 gal holding tank Air activated carbon filter syst	Item description concentration 0 V, 22KW) n stem
000 gal quipmen Units nonths nonths nonths nonths nonths nonths nonths nonths	No of units 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	und Rent Unit lat cost	- bor - - - - sis	\$ \$ \$ \$ \$ \$ \$	0.44 Unit mat cost 30,000 1,497 997 832 1,197	\$ Labo \$ \$ \$ \$ \$ \$		\$ Mat c \$ 60 \$ 3 \$ \$ \$	39 cost 0,000 2,994 1,993 1,664 2,395	s s lte s s s s s s	3,744 39 m cost 60,000 2,994 1,993 1,664 2,395	т	otal cost	Total Utilities a	Fuel for diesei electric gener Water und Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster 21.000 gal holding tank Air activated carbon filter syst	Item description concentration 0 V, 22KW) n stem
000 gal quipmen Units nonths nonths nonths nonths nonths Performar <i>Inalysis</i> (Units	No of units No of units 2 : 2 : 2 : 2 : 2 : 1 : 1 : 2 : 2 : 2 : 2 : 2 : 2 : 2 : 2	unit lat cost s s d Analy Unit lat cost	- all - - - - - - - - - - - - - - - - -	\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	0.44 Linit mat cost 30,000 1,497 832 1,197 8,490 Unit mat cost	\$ Labo \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	- or cost - - - - - - - - - - 	\$ Mat c \$ 60 \$ 5 \$ \$ 10 \$ \$ 10	39 cost 0,000 2,994 1,993 1,664 2,395 6,979	s s s s s s s s s s s s s s s s s s s	3,744 39 m cost 60,000 2,994 1,993 1,664 2,395 16,979 m cost	т \$	otal cost	Total Utilities a	Fuel for diesei electric gener Water und Fuel Cost UF membrane unit for CD re Diesel electric generator (48 PID for H&S survey Suspended solid filter syster 21,000 gal holding tank Air activated carbon filter syst nt Ownership and Rental C	Item description concentration 0 V, 22KW) n stem
000 gal quipmen Units nonths nonths nonths nonths nonths hoths	No of units 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2	unit lat cost s s d Analy Unit lat cost	- bor - - - - sis	\$ \$ \$ \$ \$ \$ \$	0.44 Linit mat cost 30,000 1,497 832 1,197 8,490 Unit mat cost	\$ Labo \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	- or cost - - - -	\$ Mat c \$ 60 \$ 5 \$ \$ 10 \$ \$ 10	39 cost 0,000 2,994 1,993 1,664 2,395 6,979	s s tte s s s s s s s	3,744 39 m cost 60,000 2,994 1,993 1,664 2,395 16,979	т \$	otal cost 86,025	Total Utilities a	Fuel for diesei electric gener Water and Fuel Cost UF membrane unit for CD re Diesei electric generator (48 PID for H&S survey Suspended solid filter syster 21,000 gal holding tank Air activated carbon filter syst nt Ownership and Rental C	Item description concentration 0 V, 22KW) n stem Sost
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Disposal	of Hazardeou	is Was	te										
		Uni	labor	Unit mat									Power
Units	No of units	с	ost	cost	Labor	cost	M	at cost		Item cost		Total cost	consumption Item description
EA	1	\$	-	\$ 16,500	\$	-	\$	16,500	s	16,500			Off-site disposal of drill cuttings
months	2	\$	-	\$ 250	\$	-	\$	500	\$	500			Off-site disposal of liquid wastes
											\$	17.000	0 Total Disposal of Hazardeous Waste
Site Resto	oration												
		Uni	labor	Unit mat									
Units	No of units	с	ost	cost	Labor	cost	M	at cost		Item cost		⊤otal cost	Item description
nrs	24	\$	30		\$	720	\$	-	\$	720			Field crew
nrs	4	\$	90		\$	360	\$	-	s	360			Supervision
											S	1.080	0 Total Site Restoration
												.,	
											\$	18.080	0 TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 2)

Summary

Cost Category	Sub Category		Cost (\$)
	FIXED COSTS		
1. Capital Cost	Mobilization/Demobilization	\$	17,92
	Planning/Preparation (1)	\$	52,02
	Site Investigation	\$	101,85
	Site Work	\$	18,60
	Equipment Cost - Structures	\$	
	Equipment Cost - Process Equipment	\$	60,974
	Star-up and Testing	\$	16,88
	Other - Non Process Equipment	\$	8,05
	Other - Installation	\$	117,854
	Other - Engineering (1)	\$	
	Other - Management Support (2)	\$	
	Sub-Total:	\$	394,156
	VARIABLE COSTS		
2. Variable Cost	Labor	\$	23,02
	Materials / Consumables	\$	1,796,00
	Utilities / Fuel	\$	5,80
	Equipment Cost (rental)	\$	86,023
	Chemical Analysis	\$	7,38
	Other	\$	8,358
	Sub-Total:	\$	1,926,597
3. Other	Disposal of well cuttings	\$	16,50
Technology	Disposal of liquid waste	\$	50
Specific Cost	Site Restoration	\$	1,08
	Sub-Total:	\$	18,080
	TOTAL COSTS	_	
	Total Technology Cost	\$	2,338,833
	Quantity Treated - VOC mass (lbs)		1413
I /	nit Cost (per lbs VOC removed and treated)	\$	1,653

(1) Included in planning/preparation

CAPITAL COST (hypothetical full-scale system)	
Assumptions	
Treatment approach: Multi-well push-pull with no UF system (no reuse)
Flushing Vol: 109 m3 Power Consul \$ 0.05725 Soil mass: 600 tons Cost / KWH Area: 234 m2 Project duration: 2 months	
Number of wells, type and depth needed for remediation	
40 Injection/extraction wells 22.5 ft	
DNAPL Source Zone Characterization	
Assume: approximate extent of plume is already known Unit labor Unit mat Units No of units cost (hr) cost Labor cost Mat cost Item cost EA 1 \$ - \$ 1,600 \$ - \$ 1,600 \$ - \$ 1,600 \$ - \$ 3,600 \$ - \$ 3,600 \$ - \$ 3,600 \$ - \$ 3,800 \$ - \$ 3,800 \$ - \$ 3,800 \$ - \$ 3,800 \$ - \$ 3,800 \$ - \$ 3,800 \$ - \$ 3,800 \$ 2,5,000 \$ 2,5,000 \$ 2,5,000 \$ 2,5,000 \$ 2,5,000 \$ 2,4,000 \$ - \$ 2,4,000 \$ 3,000 \$ 3,000 \$ 3,000 \$ 3,000 \$ 3,000 \$	MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew)
Treatability Study (Site soil testing)	
Unit labor Unit mat Units No of units cost (hr) cost Labor cost Mat cost Item cost EA 120 \$ 85 \$ - \$ 10,200 \$ - \$ 10,200 EA 1 \$ - \$ 2,550 \$ - \$ 2,550 \$ 2,550 \$ 2,550 \$ 2,550 \$ 2,550 \$ 2,550 \$ 2,550 \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - \$ 3,000 \$ - <	Lab equipment
Engineering, Design, and Modeling	
Unit labor Unit mat Units Cost Cost Labor cost Mat cost Item cost EA 120 \$ 125 \$ 1,770 \$ 22,000 \$ 1,770 \$ 23,770 EA 1 \$ - \$ 12,500 \$ - \$ 12,500 \$ 12,500	
Technology Mobilization and Demobilization	
Assume: Local contractors perform field work Unit labor Unit mat Units No of units cost cost Labor cost Mat cost Item cost hrs 280 \$ 25 \$ 7,000 \$ - \$ 7,000 EA 2 \$ - \$ 1,964 \$ - \$ 3,928 \$ 3,928	
	\$ 10,928 Total Technology Mobilization, Setup, and Demobilization
Site Work Site Set-up Unit labor Unit mat Units No of units cost cost Labor cost Mat cost Item cost EA 1 \$ - \$ 1,000 \$ - \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,000 \$ 1,400 \$ 1,400 \$ 1,400 \$ 1,400 \$ 1,400 \$ 1,400 \$ 1,400 \$ 1,5480 \$ \$ 15,480 \$ \$ \$ 1,5480 \$ \$ \$ 1,5480 \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ <td>Electricity hook-up</td>	Electricity hook-up
Installation of Equipment and Appurtenances	
Well Field Installation Unit labor Unit mat Units No of units cost cost Labor cost Mat cost Item cost ft 900 \$ - \$ 77 \$ - \$ 69,030 \$ 69,030 EA 40 \$ - \$ 552 \$ - \$ 22,080 \$ 22,080 EA 1 \$ - \$ 14,800 \$ \$ 14,800 \$ 14,800	Grunfos submersible pumps (Model 5S)
Above Ground Plumbing Unit labor Unit mat Units No of units cost cost Labor cost Mat cost Item cost 1 1800 \$ \$ \$ \$ \$ \$ 3,240 \$ 3,240 EA 44 \$ - \$ 78 - \$ 3,432 \$ 3,432 EA 44 \$ - \$ 78 - \$ 880 \$ 880 EA 44 \$ - \$ 45 - \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 1,980 \$ 3,600 \$ 3,600 \$	Flowmeters Flow control valves In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing
	\$ 117,494 Total Installation of Equipment and Appurtenances

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Disposal	of Hazardeous	Waste									
		Unit labor	Unit mat								Power
Units	No of units	cost	cost	Labor	cost	M	at cost	Item cost		Total cost	consumption Item description
EA	1 \$		\$ 16,500	\$	-	\$	16,500	\$ 16,500			Off-site disposal of drill cuttings
months	2 \$		\$ 250	\$	-	\$	500	\$ 500			Off-site disposal of liquid wastes
									s	17,000	0 Total Disposal of Hazardeous Waste
											•
Site Rest	oration										
		Unit labor	Unit mat								
Units	No of units	cost	cost	Labor	cost	M	at cost	Item cost		Total cost	Item description
hrs	24 \$	30		\$	720	\$	-	\$ 720			Field crew
hrs	4 S	90		\$	360	\$	-	\$ 360			Supervision
									s	1.080	0 Total Site Restoration
										-,	
									S	18.080	0 TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 2)

Summary

	le CDEF implementation	
	oull with no UF system (no reuse) (2 Month	
Cost Category	Sub Category	Cost (\$)
	FIXED COSTS	
1. Capital Cost	Mobilization/Demobilization	\$ 10,928
	Planning/Preparation	\$ 52,020
	Site Investigation	\$ 101,850
	Site Work	\$ 17,880
	Equipment Cost - Structures	\$
	Equipment Cost - Process Equipment	\$ 60,974
	Star-up and Testing	\$ 13,040
	Other - Non Process Equipment	\$ 8,050
	Other - Installation	\$ 117,494
	Other - Engineering (1)	\$ -
	Other - Management Support (2)	\$ -
	Sub-Total:	\$ 382,236
	VARIABLE COSTS	
2. Variable Cost	Labor	\$ 27,120
	Materials / Consumables	\$ 4,817,920
	Utilities / Fuel	\$ 6,115
	Equipment Cost (rental)	\$ 86,025
	Chemical Analysis	\$ 7,380
	Other	\$ 8,608
	Sub-Total:	\$ 4,953,168
3. Other	Disposal of well cuttings	\$ 16,500
Technology	Disposal of liquid waste	\$ 500
Specific Cost	Site Restoration	\$ 1,080
	Sub-Total:	\$ 18,080
	TOTAL COSTS	
	Total Technology Cost	\$ 5,353,484
	Quantity Treated - VOC mass (lbs)	1415
U	nit Cost (per lbs VOC removed and treated)	\$ 3,783

(1) Included in planning/preparation

CAPITAL COST (hypothetical full-scale system)

Assumpt	ions													
Treatmen	t approach:	L	ine-dri	ve (l	/E) with	UF in cont	ino	us mod	e <u>()</u>	<u>(ear 1)</u>				
Flushing ' Soil mass Area: Project du	c.		6 2	09 m 00 to 34 m 19 m	ns 2		Cost	er Consum t / KWH e: Electrica	\$	0.05725	s prov	rided by gene	rators.	
Number o	of wells, type	and	depth ne	eded f	or remediatio	on								
14 24 8	Injection Extraction Hydraulic	well			22.5 ft 22.5 ft 22.5 ft									
	ource Zon				Iready know	n								
Units EA EA EA EA EA EA EA	No of uni		Unit labo cost (hr)		Unit mat cost 1,600 3,500 1,250 126	Labor cost \$ - \$ 3,800 \$ - \$ - \$ 24,000	\$\$	fat cost 1,600 35,000 - 25,000 9,450 - 3,000	\$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$ \$	tem cost 1,600 35,000 3,800 25,000 9,450 24,000 3,000	\$	Total cost 101,850	Power consumption	Item description Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity Operator per diem In Situ GWS/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew) Equipment and Expendables Source Zone Characterization
freatabil	ity Study (S	Site s	oil testin	g)										
Units EA EA EA		ts 20 \$ 1 \$ 24 \$		r 35 \$ - \$ 25		Labor cost \$ 10,200 \$ - \$ 3,000	\$ \$	/at cost 2,550 -	\$ \$ \$	tem cost 10,200 2,550 3,000	\$	Total cost 15,750	Power consumption Total Cyclode	Item description Lab techician (soil column tests) Lab equipment Report preparation xtrin Selection
Engineer	ing, Desigr	ı, an	d Modelir	g										
Units EA EA	No of uni 14	ts 14 \$ 1 \$		r 25 \$ - \$		Labor cost \$ 22,000 \$ -		fat cost 1,770 12,500	5 \$	tem cost 23,770 12,500	\$	Total cost 36,270	Power consumption Total Enginee	Item description Work Plan, H&S plan, Site Management Plan (Project manager) Permits and licences, estimated rring, Design, and Modeling
	gy Mobiliz Local contra													
Units hrs EA	No of uni 2		Unit labo cost		Unit mat cost	Labor cost \$ 7,000 \$ -		/at cost 10,928	s \$	tem cost 7,000 10,928	\$	Fotal cost 17,928	Power consumption Total Technol	Item description Travel to and from site (incl. accommodation) Freight (Palletizing, loading, and shipping of equipment) logy Mobilization and Demobilizatior
Site Wor														
Site Set- Units EA EA EA	No of uni	ts 1 \$ 1 \$ 10 \$		r - \$ - \$ 30 \$	1,450	Labor cost \$ - \$ - \$ 16,200	\$ \$	fat cost 1,000 1,400	\$ \$ \$	tem cost 1,000 1,400 16,200	\$	Total cost 18,600	Power consumption Total Site Set	Item description Secondary containment (berm) Electricity hook-up Plumbing -up
Installati	on of Equip	men	it and Ap	ourter	nances									
Well Fiel Units ft EA EA				- \$ - \$ - \$	552		\$ \$	fat cost 79,385 13,248 14,800	\$ \$	tem cost 79,385 13,248 14,800	s	Fotal cost 107,433	Power consumption Total Well Ins	Item description Injection/Extraction well installation Grunfos submersible pumps (Model 5S) SCADA system, automated flow control tallation
Above G Units ft EA EA EA EA ft ft	20		Unit labo cost	- \$ - \$ - \$ - \$ - \$ - \$	78 21 45 294 2	\$ - \$ - \$ - \$ - \$ - \$ -	\$	At cost 3,600 3,588 1,050 1,710 1,176 440 516	~~~~	tem cost 3,600 3,588 1,050 1,710 1,176 440 516	s	Total cost	Power consumption	Item description Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing Connection of air stripper (6 in PVC)
											\$ \$			ion of Equipment and Appurtenances
											÷	,		

Equipmon	t Ownership and Re	ontal										
Units EA EA EA EA	Unit No of units cc 1 \$ 2 1 1	labor	\$ \$ \$	210,000 6,656	Labor cost \$ - \$ - \$ - \$ -	\$ \$ \$	Mat cost 30,303 28,736 210,000 6,656	\$ \$ \$ \$	Item cost 30,303 28,736 210,000 6,656		Total cost	Item description Air stripper incl. blower (200 cfm) 21.000 gal holding tank UF membrane unit for CD reconcentration Suspended solid filter system
EA EA	1 1		\$		\$ - \$ -	\$ \$	368 11,976	\$	368 11,976	\$	288,039	250 gal mixing tank Diesel electric generator (480 V, 22KW) Total Equipment Ownership and Rental Cost
Startup an Units hrs hrs		30		nit mat cost - -	Labor cost \$ 2,880 \$ 14,000	\$	Mat cost - -	\$ \$	ltem cost 2,880 14,000	\$	Total cost 16,880	Power consumption Item description Operator Training (6 people field crew) System shake-down, well testing, etc. Total Startup and Testing
Other (nor	n-process related)	labor	1.1	nit mot								Power
Units EA EA EA	Unit Unit Co 1 \$ 6 \$ 1 \$	ost -		nit mat cost 4,800 550 3,200	Labor cost \$ - \$ - \$ -	\$	Mat cost 4,800 3,300 3,200	\$ \$ \$	Item cost 4,800 3,300 3,200	\$	Total cost 11,300	consumption Consumption Office and admin. equipment (computer, printer, etc) H&S training (OSHA) Field safety equipment, various Total Other
										\$	626,130	TOTAL CAPITAL (year 1)
1st Yea	r OPERATIN	g and	D M/	AINTEN	ANCE CO	DST	(hypot	het	ical full-	sca	ale syster	n)
Labor												
Labor Assume: 1	person, 8 hrs/day, 7	days/we	ek, S	SCADA tec	hnology is use	d						
Units hrs hrs hrs	Unit No of units co 719 \$ 1439 \$ 336 \$	30 30		nit mat cost - -	Labor cost \$ 21,578 \$ 43,157 \$ 30,240	\$ \$	Mat cost - -		ltem cost 21,578 43,157 30,240	\$	Total cost 94,975	Item description Operating labor Monitoring labor Supervision Total Labor Cost
Materials												
Units LB EA months month	Unit No of units co 1003616.8 \$ 2 12 \$ 12 \$	-			Labor cost \$ - \$ - \$ - \$ -	\$ \$ \$	Mat cost 2,007,234 30,000 6,000 12,000	\$ \$ \$ \$	ltem cost 2,007,234 30,000 6,000 12,000	\$	Total cost 2,055,234	Item description Cyclodextrin, tech grade Replacement membranes for UF unit H&S survey, personal protective equip. Consumable supplies, repairs Total Material Cost
Utilities ar				1								
Units KWH gal 1000 gal	Unit Unit Co 231702 \$ 11388 \$ 528 \$	-		nit mat cost 0.05725 2.00 0.44	Labor cost \$ - \$ - \$ -	\$	Mat cost 13,265 22,776 232	\$ \$ \$	ltem cost 13,265 22,776 232	\$	Total cost 36,273	Item description Electricity cost Fuel for diesel electric generator Water Total Utilities and Fuel Cost
Equipmen	t Ownership and Re	ental labor	U	nit mat								
Units months	No of units co 12 \$	-		cost 8,490	Labor cost \$-	\$	Mat cost 101,874		Item cost 101,874	\$	Total cost 101,874	Item description Air activated carbon filter system Total Equipment Ownership and Rental Cost
	nce Testing and Ana Cost - off-site		1.1	nit met								
Units EA		labor ost		nit mat cost 85	Labor cost \$-	\$	Mat cost 31,025		Item cost 31,025	\$	Total cost 31,025	Item description VOC analysis (short list) Total Performance Testing and Analysis - off site
Analysis (Cost - on-site Unit	labor	1.6	nit mat								
Units EA EA	No of units co 730 52			cost 15 60		\$	Mat cost 10,950 3,120	\$	Item cost 10,950 3,120	\$	Total cost 14,070	Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site
Other (nor	n-process related)											
hrs EA months EA	40 1 \$ 12 260 \$	-	\$	125 4,496 54 25	\$ - \$ -	\$ \$ \$ \$ \$	5,000 4,496 648 6,500	\$ \$ \$ \$	5,000 4,496 648 6,500	\$	16,644	Semi-annual report preparation (Project Manager) PID for H&S survey, personal protective equip. On-site sanitation (rental) S/H of samples (5 shipments per week) Total Other (non-process related)
										\$	2,248,221	TOTAL O&M (year 1)

Disposal	of Hazardeous	s Waste	Ð										
		Unit	abor	Unit mat								Power	
Units	No of units	co	st	cost	L	abor cos	st	Ν	lat cost	Item cost	Total cost	consumption	Item description
EA	1 \$	\$	-	\$ 16,500	\$		-	\$	16,500	\$ 16,500			Off-site disposal of drill cuttings
months	12 5	\$	-	\$ 250	\$		-	\$	3,000	\$ 3,000			Off-site disposal of liquid wastes
											\$ 19,500) Total Disposal	of Hazardeous Waste
											\$ 19,500	TOTAL OTHER	R TECHNOL. SPECIFIC COSTS (year 1)

Treatment approach: Line-drive (I/E) with UF in continous mode (Year 2)

CAPITAL COST (hypothetical full-scale system)

No capital (fxed) cost after year 1

2nd Year OPERATING AND MAINTENANCE COST (hypothetical full-scale system)

Labor											
	person, 8 hrs/	day, 7 days/	week	SCADA tec	hnology is used						
Units hrs hrs hrs	No of units 420 839 196	5 3	D \$	Unit mat cost - -	\$ 25,175	\$ -	\$ \$ \$	ltem cost 12,587 25,175 17,640	\$	Total cost 55,402	Item description Operating labor Monitoring labor Supervision Total Labor Cost
Materials											
Units LB EA months month	No of units 585443.16 1 7 5 7	B	- S - S - S	500		Mat cost \$ 1,170,886 \$ 15,000 \$ 3,500 \$ 7,000	S S	Item cost 1,170,886 15,000 3,500 7,000	\$	Total cost 1,196,386	Item description Cyclodextrin, tech grade Replacement membranes for UF unit H&S survey, personal protective equip. Consumable supplies, repairs Total Material Cost
Utilities ar	nd Fuel										
Units KWH gal 1000 gal	No of units 59532 \$ 6552 \$ 308 \$	5	- \$ - \$ - \$	Unit mat cost 0.05725 2.00 0.44	Labor cost \$- \$- \$-	Mat cost \$ 3,408 \$ 13,104 \$ 136		Item cost 3,408 13,104 136	\$	Total cost 16,648	Item description Electricity cost Fuel for diesel electric generator Water Total Utilities and Fuel Cost
Equipmen	t Ownership a	and Rental									
Units months	No of units 7 \$	Unit labor cost	- \$	Unit mat cost 8,490	Labor cost \$-	Mat cost \$59,427	s	ltem cost 59,427	\$	Total cost 59,427	Item description Air activated carbon filter system Total Equipment Ownership and Rental Cost
	nce Testing an	nd Analysis									
Units EA	Cost - off-site No of units 210	Unit labor cost	\$	Unit mat cost 85	Labor cost \$-	Mat cost \$ 17,850	s	ltem cost 17,850	\$	Total cost 17,850	Item description VOC analysis (short list) Total Performance Testing and Analysis - off site
Analysis (Cost - on-site	l la it la baa		1 1							
Units EA EA	No of units 420 28	Unit labor cost	5 5	Unit mat cost 15 60	Labor cost \$- \$-	Mat cost \$ 6,300 \$ 1,680		Item cost 6,300 1,680	\$	Total cost 7,980	Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site
Other (nor	n-process rela	ited)									
hrs EA months	40 \$ 260 \$ 7		5 \$ - \$ \$	- 25 54		\$ - \$ 6,500 \$ 378		5,000 6,500 378	\$		Semi-annual report preparation (Project Manager) S/H of samples (5 shipments per week) On-site sanitation (rental) Total Other (non-process related)
									\$	1,365,571	TOTAL O&M (year 2)
OTHER	TECHNO	LGOY S	PEC	CIFIC CO	STS (hype	othetical	full	-scale sy	ste	em)	
Disposal	of Hazardeous	Wasto		_		_		_		_	
Disposal	or nazarueous	Unit Isbor		Linit mot							Power

Labor cost M - \$ Unit mat Unit labor Powe Mat cost \$ 2,100 \$ Total cost Item description Units No of units cost cost Item cost consumption - s ່ 300 \$ Off-site disposal of liquid wastes 2,100 Total Disposal of Hazardeous Waste months 7 6 2,100 \$ Site Restoration Mat cost s - s - s Unit labor Unit mat No of units 24 \$ 4 \$ Units hrs hrs Laborcost M \$ 720 \$ \$ 360 \$ Item cost 720 360 Item description cost cost Total cost Field crew Supervision 1,080 Total Site Restoration 30 90 s s \$

\$ 3,180 TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 2)

2,500 ft3 Full-scal	le CDEF implementation	
	vith UF in continous mode (19 months)	
Cost Category	Sub Category	Cost (\$)
	FIXED COSTS	
1. Capital Cost	Mobilization/Demobilization	\$ 17,928
	Planning/Preparation	\$ 52,020
	Site Investigation	\$ 101,850
	Site Work	\$ 18,600
	Equipment Cost - Structures	\$
	Equipment Cost - Process Equipment	\$ 288,039
	Star-up and Testing	\$ 16,880
	Other - Non Process Equipment	\$ 11,300
	Other - Installation	\$ 119,513
	Other - Engineering (1)	\$ -
	Other - Management Support (2)	\$ -
	Sub-Total:	\$ 626,130
	VARIABLE COSTS	
2. Variable Cost	Labor	\$ 150,377
	Materials / Consumables	\$ 3,251,620
	Utilities / Fuel	\$ 52,921
	Equipment Cost (A-carbon, rental)	\$ 161,301
	Chemical Analysis	\$ 70,925
	Other	\$ 28,522
	Sub-Total:	\$ 3,715,666
3. Other	Disposal of well cuttings	\$ 16,500
Technology	Disposal of liquid waste	\$ 5,100
Specific Cost	Site Restoration	\$ 1,080
	Sub-Total:	\$ 22,680
	TOTAL COSTS	
	Total Technology Cost	\$ 4,364,475
	Quantity Treated - VOC mass (lbs)	1415
U	nit Cost (per lbs VOC removed and treated)	\$ 3,085

Summary

(1) Included in planning/preparation

Assumpti Treatment Flushing \						CAPITAL COST (hypothetical full-scale system)										
	t approach:	Li	ne-driv	e (I/	E) with	no UF	(Yea	<u>r 1)</u>								
Soil mass Area: Project du	:		600 234	m3 ton m2 mo	1S 2			Cost /			0.05725 er for UF is	provide	ed by gene	rators.		
Number o	f wells, type	and o	lepth need	ed fo	or remediatio	n										
14 24 3	Injection we Extraction v Hydraulic c	wells			22.5 ft 22.5 ft 22.5 ft											
	ource Zone approximate				readv knowr	ı										
Units EA EA EA EA EA EA	No of units 10 40 20 75 480	5 1 5 5 5 5 5	Unit labor cost (hr)	\$ \$ \$ \$ \$	Unit mat cost 1,600 3,500 - 1,250	Labor o \$ \$ \$ 3 \$ \$	cost 	\$ \$ \$ \$ \$		\$ \$ \$ \$ \$ \$ \$	em cost 1,600 35,000 25,000 9,450 24,000 3,000	Tot	tal cost 101,850	Power consumption	Item description Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew) Equipment and Expendables Source Zone Characterization	
[reatabili	ty Study (Si	te so	il testing)													
Units EA EA EA	1		Unit labor cost (hr) 85 - 125	\$	Unit mat cost 2,550	\$		Ma \$ \$ \$	t cost 2,550 -	lti S S S	em cost 10,200 2,550 3,000	Tot \$	tal cost 15,750		Item description Lab techician (soil column tests) Lab equipment Report preparation xtrin Selection	
Engineeri	ing, Design,	and	Modeling													
Units EA EA			Unit labor cost 125 -		Unit mat cost 1,770 12,500	Labor o \$22 \$	cost 2,000 -	Ma \$ \$	t cost 1,770 12,500	lti S S	em cost 23,770 12,500	Tot \$	tal cost 36,270	Power consumption Total Enginee	Item description Work Plan, H&S plan, Site Management Plan (Project manager) Permits and licences, estimated rring, Design, and Modeling	
	gy Mobilizat Local contrac															
Units hrs EA	No of units 280		Unit labor cost 25		Unit mat cost	Labor o \$7 \$		Ma \$ \$	t cost 3,928	\$	em cost 7,000 3,928	⊤ot \$	tal cost 10,928		Item description Travel to and from site (incl. accommodation) Freight (Palletizing, loading, and shipping of equipment) logy Mobilization and Demobilizatior	
Site Work	¢.															
Site Set-u Units EA EA EA	No of units	1\$ 1\$	Unit labor cost - 30	\$	Unit mat cost 1,000 1,450 -	Labor o \$ \$ \$ 16	cost - - 5,200		t cost 1,000 1,400 -		em cost 1,000 1,400 16,200	Tot \$	tal cost	Power consumption Total Site Set	Item description Secondary containment (berm) Electricity hook-up Plumbing	
nstallatio	on of Equips	nent	and Appu	rtena	ances							•	,			
	l Installation															
Units t EA EA	No of units 1035 24	;	Unit labor cost - -	\$	Unit mat cost 77 552 14,800	Labor o \$ \$ \$	-	\$ \$	t cost 79,385 13,248 14,800	\$ \$	em cost 79,385 13,248 14,800		tal cost	Power consumption	Item description Injection/Extraction well installation Grunfos submersible pumps (Model SS) SCADA system, automated flow control	
												\$	107,433	Total Well Ins	tallation	
Above Gr Units t EA EA EA EA t t	50 42 3 200	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	-	\$ \$	Unit mat cost 78 21 45 294 2 9	Labor o \$ \$ \$ \$ \$ \$ \$ \$ \$	cost - - - - - -	\$ \$ \$ \$ \$	t cost 3,420 3,588 1,050 1,890 882 360 516	\$ \$ \$ \$ \$ \$	em cost 3,420 3,588 1,050 1,890 882 360 516	Tot	tal cost	Power consumption	Item description Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing Connection of air stripper (6 in PVC)	
		Ŧ		+	5				2.0		2.5	\$	11,706	Total Above G		
												\$	119,139	Total Installat	ion of Equipment and Appurtenances	

quipmer	nt Ownership	and	d Rental													
Units	2	ι \$ \$	Jnit labor cost	-	ل \$ \$ \$	Jnit mat cost 30,303 14,368 6,656	Lat \$ \$ \$	oor cost - - -	\$ \$	Mat cost 30,303 28,736 6,656	\$		cost 30,303 28,736 6,656		Total cost	Item description Air stripper incl. blower (200 cfm) 21,000 gai holding tank Suspended solid filter system
	1	\$		-	\$	368.00	\$	-	\$	368	\$		368	\$	66,063	250 gal mixing tank Total Equipment Ownership and Rental Cost
tup a	nd Testing		lait labar			la it maat										Deurae
nits	No of units		Jnit labor cost			Jnit mat cost		or cost		Mat cost	~		cost		Total cost	Power consumption Item description
	48 236				\$	-	\$ \$	1,440 11,800		-			1,440 11,800	\$	13,240	Operator Training (6 people field crew) System shake-down, well testing, etc. Total Startup and Testing
er (no	n-process re		d) Jnit labor	r	ι	Jnit mat										Power
nits	6	\$	cost	-	\$	cost 4,800 550 3,200	Lat \$ \$ \$	oor cost - -	\$	Mat cost 4,800 3,300 3,200	\$		4,800 3,300 3,200		Total cost	consumption Item description Office and admin. equipment (computer, printer, etc) H&S training (OSHA) Field safety equipment, various
														\$	11,300	Total Other
														\$	393,140	TOTAL CAPITAL (year 1)
Yea	ar OPER	AT	ING A	ND	M	AINTEN	NAN	CE CO	OST	Г (hypot	he	tica	l full∹	sci	ale systen	1)
ne: 1	person, 8 hr	s/da	y, 7 days	/we	ek,	SCADA teo	chnolo	gy is use	ed							
nits	No of units	ι	Jnit labor cost	r	ι	Jnit mat cost	1.04	oor cost		Mat cost		Iter	cost		Total cost	Home description
nus	360		3		\$ ¢	-	\$	10,800	\$	-			10,800		Total Cost	Item description Operating labor Monitoring labor
	1440 336				\$ \$	-	\$ \$	43,200 30,240		-			43,200 30,240			Monitoring labor Supervision
														\$	84,240	Total Labor Cost
rials	No. of the	ι	Jnit labor	r	ι	Jnit mat									T-1-1	
nits	No of units 1780888		cost	-		cost 2.00	\$	oor cost -	\$	Mat cost 3,561,777	\$	3,5	cost 61,777		Total cost	Item description Cyclodextrin, tech grade
hs h	12 12				\$	500 1,000	\$ \$	-	- T	6,000 12,000			6,000 12,000	\$	3,579,777	H&S survey, personal protective equip. Consumable supplies, repairs Total Material Cost
ies a	nd Fuel	ι	Jnit labor	r	L	Jnit mat										
nits	No of units 231702		cost		\$	cost 0.05725	Lat \$	oor cost	\$	Mat cost 13,265	s		cost 13,265		Total cost	Item description Electricity cost
gal	528				\$	0.44	\$	-		232			232	\$	13.497	Water Total Utilities and Fuel Cost
pmer	nt Ownership	and	d Rental											•	,	
nits	No of units		Jnit labor cost		U	Jnit mat cost	Lat	oor cost		Mat cost		ltem	cost		Total cost	Item description
ths	12	\$		-	\$	8,490		-	\$	101,874	\$		01,874	\$		Air activated carbon filter system Total Equipment Ownership and Rental Cost
	nce Testing a		Analysis	5												
-	Cost - off-site		Jnit labor	r	ι	Jnit mat										
nits	No of units 365	\$	cost 8	35	\$	cost -	\$	or cost 31,025		Mat cost -	\$		cost 31,025		Total cost	Item description VOC analysis (short list)
														\$	31,025	Total Performance Testing and Analysis - off site
	Cost - on-site		Jnit labor	r	ι	Jnit mat				Mater		u -			Tatal	
nits	No of units 730	\$	cost 1	15		cost	\$	or cost 10,950	\$		s		cost 10,950		Total cost	Item description CD analysis (TOC method)
	52				\$	60	\$	-	\$	3,120	\$		3,120	\$	14,070	Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site
r (no	n-process re	late	d)													
	40			25		-		5,000			\$		5,000			Semi-annual report preparation (Project Manager)
hs	1 12	\$		54	\$	4,496	\$	648	\$	4,496	\$		4,496 648			PID for H&S survey, personal protective equip. On-site sanitation (rental)
	260	\$		-	\$	25	\$	-	\$	6,500	\$		6,500	\$	16,644	S/H of samples (5 shipments per week) Total Other (non-process related)
														•	0 700 05-	
														\$	3,739,253	TOTAL O&M (year 1)
HE	RTECHN	OL	GOY S	SPI	EC	IFIC CC	OSTS	S (hyj	pot	hetical f	ull	-sca	ale sy	ste	em)	
osal	of Hazardeo	us V	Vaste													
nits	No of units		Unit labor cost	r	ι	Jnit mat cost	La	por cost		Mat cost		Item	cost		Total cost	Power consumption Item description
ths		\$ \$			\$ \$	16,500 250	\$		\$ \$	16,500 3,000			16,500 3,000			Off-site disposal of drill cuttings Off-site disposal of liquid wastes
1113	12	φ		-	φ	250	φ		φ	3,000	Ş		3,000	\$	19.500	Total Disposal of Hazardeous Waste

	1	\$	-	\$ 16,500	\$	-	\$ 16,500	\$ 16,500		Off-site disposal of drill cuttings
s	12	\$	-	\$ 250	\$	-	\$ 3,000	\$ 3,000		Off-site disposal of liquid wastes
									\$ 19,500	Total Disposal of Hazardeous Waste
									\$ 19,500	TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 1)

Treatment approach: Line-drive (I/E) with no UF (Year 2)

CAPITAL COST (hypothetical full-scale system)

No capital (fxed) cost after year 1

2nd Year OPERATING AND MAINTENANCE COST (hypothetical full-scale system)

Labor	a company O have	(days 7 days fo		00404			e al							
Assume: 1	person, 8 hrs	ruay, r days/v	veek	, SCADA teo	nnoio	yy is use	вa							
		Unit labor		Unit mat										
Units	No of units	cost		cost		or cost		lat cost		Item co			Total cost	Item description
hrs hrs	210 840		\$ \$	-	\$ \$	6,300 25,200	\$ \$	-	\$ \$,300 .200			Operating labor Monitoring labor
hrs	336		ŝ	-	\$	30,240		-	ې \$,200			Supervision
		• ••	*		•	00,2.0	*		*		,	\$	61,740	Total Labor Cost
Materials		Unit labor		Unit mat										
Units	No of units	cost		cost	Lab	or cost	N	lat cost		Item co	st		Total cost	Item description
LB	1038851.6		\$	2.00	\$	-		,077,703	\$	2,077			1010100001	Cyclodextrin, tech grade
months	7		\$		\$	-	\$	3,500			,500			H&S survey, personal protective equip.
month	7	\$-	\$	1,000	\$	-	\$	7,000	\$	7.	,000			Consumable supplies, repairs
												\$	2,088,203	Total Material Cost
Utilities a	nd Fuel													
		Unit labor		Unit mat										
Units	No of units	cost	s	cost		or cost		lat cost		Item co			Total cost	Item description
KWH 1000 gal	33100 308		s S		\$ \$	-	\$ \$	1,895 136			,895 136			Electricity cost Water
rooo gai	000	Ý -	Ŷ	0.44	Ŷ		Ψ	100	Ŷ		100	\$	2,031	Total Utilities and Fuel Cost
Equipmer	nt Ownership	and Rental Unit labor		Unit mat										
Units	No of units	Cost		cost	Lab	or cost	N	lat cost		Item co	st		Total cost	Item description
months	7		\$	8,490		-	\$	59,427	\$,427			Air activated carbon filter system
												\$	59,427	Total Equipment Ownership and Rental Cost
Destaura	-	and Annahuata			_									
	nce Testing a Cost - off-site													
rinaryono	0000 011 0110	Unit labor		Unit mat										
Units	No of units	cost		cost		or cost		lat cost		Item co			Total cost	Item description
EA	28		\$	85	\$	-	\$	2,380	\$	2	,380			VOC analysis (short list)
												\$	2,380	Total Performance Testing and Analysis - off site
Analysis	Cost - on-site													
		Unit labor		Unit mat										
Units EA	No of units 56	cost	s	cost 15	Lab \$	or cost	∿ \$	lat cost 840	\$	Item co	st 840		Total cost	Item description CD analysis (TOC method)
EA	28		ŝ		э \$	-	э \$	1,680			,680			Field parameters (set of pH, DO, T, EC), once per week
								.,			,	\$	2,520	Total Performance Testing and Analysis - on site
0.0		0												
Other (no	n-process rel	ated)												
hrs	80		\$	125	\$	-	\$	10,000	\$	10	,000,			Final report preparation (Project Manager)
EA	140	\$-	\$		\$	-	\$	3,500			,500			S/H of samples (5 shipments per week)
months	7		\$	54	\$	-	\$	378	\$		378		0.070	On-site sanitation (rental)
												\$	3,878	Total Other (non-process related)
												\$	2,220,178	TOTAL O&M (year 2)
												-		
OTHER	RTECHNO				-	S (by	not	hotica	l fi	ull-ee	ماد	ev.	stom)	
OTHER		1001 3			531	U (ny	μοι	netica	i Il	an-50	ale	зу	stem)	
Disposal	of Hazardeou			11-21-2-21										Dever
Units	No of units	Unit labor cost		Unit mat cost	l ah	or cost	۸.	lat cost		Item co	et		Total cost	Power consumption Item description
months	No of units		s		\$		\$	1,750	s		,750		Total COSt	Off-site disposal of liquid wastes
	,		-	200	-		*	.,	Ť			\$	1,750	Total Disposal of Hazardeous Waste
Olto Di						_								
Site Rest	oration	Unit labor		Unit mat										
Units	No of units	cost		cost	Lab	or cost	Ν	lat cost		Item co	st		Total cost	Item description
hrs	24	\$ 30			\$	720	\$	-			720			Field crew
hrs	4	\$ 90			\$	360	\$	-	\$		360			Supervision
												\$	1,080	Total Site Restoration
												\$	2.830	TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 2)
													2,000	

	le CDEF implementation vith no UF (19 Months)	
Cost Category	Sub Category	Cost (\$)
	FIXED COSTS	
1. Capital Cost	Mobilization/Demobilization	\$ 10,923
	Planning/Preparation	\$ 52,02
	Site Investigation	\$ 101,85
	Site Work	\$ 18,60
	Equipment Cost - Structures	\$
	Equipment Cost - Process Equipment	\$ 66,06
	Star-up and Testing	\$ 13,24
	Other - Non Process Equipment	\$ 11,30
	Other - Installation	\$ 119,13
	Other - Engineering (1)	\$
	Other - Management Support (2)	\$
	Sub-Total:	\$ 393,14(
	VARIABLE COSTS	
2. Variable Cost	Labor	\$ 145,98
	Materials / Consumables	\$ 5,667,98
	Utilities / Fuel	\$ 15,52
	Equipment Cost (A-carbon, rental)	\$ 161,30
	Chemical Analysis	\$ 49,99
	Other	\$ 20,522
	Sub-Total:	\$ 6,061,305
3. Other	Disposal of well cuttings	\$ 16,50
Technology	Disposal of liquid waste	\$ 4,75
Specific Cost	Site Restoration	\$ 1,08
	Sub-Total:	\$ 22,330
	TOTAL COSTS	
	Total Technology Cost	\$ 6,476,775
	Quantity Treated - VOC mass (lbs)	141
U	nit Cost (per lbs VOC removed and treated)	\$ 4,577

Summary

(1) Included in planning/preparation

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APPENDIX F

HYPOTHETICAL FULL-SCALE COST SYSTEM — 300 FT²

Cyclodextrin Enhanced Flushing at a hypothetical site

CAPITAL CO	OST (hypothetical	demo-scale syste	em)		
Assumptions		aomo soare syste	,		
	000 ft0 M Ht				
Treatment approach Flushing Vol:	9 m3	push-pull with UF i	ns \$ 0.05725		
Soil mass: Area: Project duration:	49 tons 19 m2 4 months	Cost / KW Note: Ele	/H ctrical power for UF i	is provided by ge	enerators.
Number of wells, typ	e and depth needed for remed	ation			
6 Injection/	Extraction wells 22.5 ft				
DNAPL Source Zon	e Characterization				
Approximate extent of	of plume is already known				
	1 \$ - \$ 1,6 2 \$ - \$ 3,5 5 \$ 95.00 \$ 2 \$ - \$ 1,2 15 \$ - \$ 1,2 60 \$ 50.00 \$	00 \$ - \$ 7,00 - \$ 475 \$ 50 \$ - \$ 2,50 26 \$ - \$ 1,89	1,600 1,600 5 7,000 - \$ 475 10 \$ 2,500 10 \$ 1,890 - \$ 3,000	Total cost	Power Item description Item description Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew) Equipment and Expendables Total DNAPL Source Zone Characterization
Treatability Study (Site soil testing)			,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
Units No of un EA 1 EA	Unit labor Unit mat	Labor cost Mat cos - \$ 10,200 \$ 50 \$ - \$ 2,55 \$ 3,000 \$	- \$ 10,200	Total cost \$ 15,750	Power consumption Item description Lab techician (soil column tests) Lab equipment Report preparation Total Cyclodextrin Selection
Engineering, Desig	n, and Modeling				
Units No of un EA 1 EA	Unit labor Unit mat its cost cost 44 \$ 125.00 \$ 1.7 1 \$ - \$ 2.5		0 \$ 19,770	Total cost \$ 22,270	Power consumption Item description Work Plan, H&S plan, Site Management Plan (Project manager) Permits and licences, estimated Total Engineering, Design, and Modeling
	zation and Demobilizatior actors perform field work				
Units No of un	Unit labor Unit mat its cost cost 80 \$ 25	Labor cost Mat cos \$ 7,000 \$ 54 \$ - \$ 10,92	- \$ 7,000	Total cost \$ 17,928	Power consumption Travel to and from site (incl. accommodation) Freight (Palletizing, loading, and shipping of equipment) Total Technology Mobilization and Demobilization
Site Work					
Site Set-up Units No of un EA EA EA	Unit labor Unit mat its cost cost 1 \$ - \$ 1,0 1 \$ - \$ 1,4 80 \$ 50.00 \$		00 \$ 1,000 00 \$ 1,400 - \$ 4,000	Total cost \$ 6,400	Power consumption Item description Secondary containment (berm) Electricity hook-up Plumbing Total Site Set-up
Installation of Equi	pment and Appurtenances				•
Well Field Installati Units No of un	on Unit labor Unit mat its cost cost 35 \$ - \$ 6 \$ - \$ 5	Labor cost Mat cos 77 \$ - \$ 10,35	i5 \$ 10,355 2 \$ 3,312 10 \$ 14,800	Total cost	Power Item description Injection/Extraction well installation Grunfos submersible pumps (Model 5S) SCADA system, automated flow control
				\$ 28,467	Total Well Installation
EA EA EA EA	Unit labor Unit mat its cost cost 00 \$ - \$ 8 \$ - \$ 10 \$ - \$ 10 \$ - \$ 6 \$ - \$	Labor cost Mat cos 2 \$ - \$ 90 78 \$ - \$ 62 15 \$ - \$ 21 45 \$ - \$ 22 45 \$ - \$ 88 2 \$ - \$ 88 2 \$ - \$ 36 3 - \$ 36 4 - \$ 5 36 5 - \$	10 \$ 900 14 \$ 624 0 \$ 210 70 \$ 270 12 \$ 882	Total cost	Power consumption Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves In-line sample ports Transfer pumps Waste water disposal piping, 3/4 in flex tubing
	60 \$ - \$		6 \$ 516 \$		Connection of air stripper (6 in PVC) Total Above Ground Piping
			:	\$ 32,229	Total Installation of Equipment and Appurtenances

Unit like Unit like <t< th=""><th>Equipmer</th><th>nt Ownership</th><th>and Ren</th><th>tal</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></t<>	Equipmer	nt Ownership	and Ren	tal													
Unit bit of early in a control Unit met (4 4 8 0 0 1 8 0 - 2 8 7 200 1 0 - 2 8 7 200 1 0 - 2 8 7 200 1 0 - 2 8 7 200 1 0 - 2 8 7 200 1 0 - 2 8 8 0 - 2 8 7 200 1 0 - 2 8 8 - 2 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8 8 0 - 2 8		No of units 1 4	Unit la cost \$	bor _	\$	cost 10,101 997	\$ \$	-	\$ \$	10,101 3,987	\$ \$		10,101 3,987			PID for H&S survey 250 gal mixing tank	(200 cfm)
Unite Nort Cont Late Total cont To	Startup a	nd Testing	11-21-1-1													D	
Unit Bio	Units hrs hrs	48	cost \$	30	\$	cost -	\$	1,440	\$	-	\$	ltem	1,440			consumption Operator Training (3 pe System shake-down, w	eople field crew)
Unit is of out of out of out of out	Other (no	n-process rel	ated)														
1st Year OPERATING AND MAINTENANCE COST (hypothetical full-scale system) Laker Assume: 1 person, 8 Insider, 7 depreveek. SCADA technology is used Unit labor vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 30 8 · . 8 19191 8 · . 8 1910 vis 20 8 5 8 1000 8 · . 8 1910 vis 20 8 5 8 1000 8 · . 8 1910 vis 20 8 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 vis 20 8 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 vis 20 8 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 vis 20 8 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 vis 20 8 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 vis 1000 8 · . 8 1000 8 · . 8 1000 8 · . 8 1000 vis 1000 8 · . 8 1000 8 · . 8 1000 vis 1000 8 · . 8 1000 8 · . 8 1000 vis 1000 8 · . 8 1000 8 · . 8 1000 vis 1000 8 · . 8 1000 8 · . 8 1000 vis 1000 8 · . 8 1000 8 · . 8 1000 vis 10 · . 8 1000 vis 10 · . 8 1000 vis 1000 · . 8 1000 vis 1000 · . 8 1000 vis 1000 · . 8 000 0 · . 8 1000 vis 1000 · . 8 000 0 · . 8 1000 vis 1000 · . 8 000 0 · . 8 000 vis 1000 · . 8 000 0 · . 8 000 vis 100,677 Total cost · tem description vis 1000 · . 8 00 0 · . 8 000 0 · . 8 000 vis 0 0 · . 8 0	Units EA EA	No of units 1 3	Unit la cost \$ \$	-	\$	cost 4,800 550	\$ \$	-	\$ \$	4,800 1,650	\$ \$	Item	4,800 1,650			consumption Office and admin. equip H&S training (OSHA) Field safety equipment,	pment (computer, printer, etc)
1st Year OPERATING AND MAINTENANCE COST (hypothetical full-scale system) Labor Assume: 1 person, 8 maldar, 7 daysweek, SCADA technology is used Unit boor is a 20 \$ 00 \$ 1 \$ 0.500 \$ 1 \$ 0.500 \$ 1 \$ 0.500 \$ 1 \$ 0.500 \$ 1000 Cost is a 20 \$ 00 \$ 1 \$ 0.500 \$ 1000 \$ 0.500 \$ 1000 Cost is a 20 \$ 00 \$ 1 \$ 0.500 \$ 1000 \$ 50,771 Total cost incenting 4 \$ 0 \$ 1 \$ 000 \$ 1 \$ 0.000 \$ 20,000 is a 20 \$ 0 \$ 1 \$ 0.000 \$ 1 \$ 0.000 \$ 1000 Cost incenting 4 \$ 0 \$ 1 \$ 0.000 \$ 1 \$ 0.000 \$ 1000 \$ 20,000 is a 20 \$ 0 \$ 7,320 Total Material Cost incenting 4 \$ 0 \$ 1 \$ 0.000 \$ 1 \$ 0.728 \$ 1.988 \$ 1.948 incenting 4 \$ 0 \$ 1 \$ 0.000 \$ 1 \$ 0.728 \$ 1.948 \$ 1.948 incenting 4 \$ 0 \$ 1 \$ 0.000 \$ 1 \$ 0.728 \$ 1.948 \$ 1.948 incenting 4 \$ 0 \$ 1 \$ 0.000 \$ 1 \$ 0.000 \$ 1 \$ 0.728 \$ 1.948 \$ 1.948 incenting 4 \$ 0 \$ 1 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$ 0.000 \$														s	142.787	OTAL CAPITAL (vear 1)	
Labor Assemt: 1 person, 8 hrs/day, 7 days/week, SCADA technology is used Unit abor solution and the solution is a solution and the solution is a solution is															,		
Units Out Unit Cost Labor cost Mate cost Nate cost	Labor									(hyp	oth	etic	al fu	II-s	cale syst	m)	
Units ins Oct units 330 Cost 5 Cost 5 <	Assume: 1	i person, 8 nrs					nnoid	gy is use	a								
Unit labor Unit mat Unit mat Unit mat Unit mat Unit mat Unit mat Item cost Total cost Total cost Item description LB 33660 \$	Units hrs hrs hrs	320 639	cost \$ \$	30 30	\$	cost -	\$ \$	9,590 19,181	\$ \$	-	\$ \$	1	9,590 19,181			Monitoring labor Supervision	Item description
Units No of units Unit mate Cost Labor cost Mate cost Item cost Total cost Total cost Total cost Item description LB 33660 S - S 7,320 S 6,7320 HS No function Consumalie supplies, repairs months 4 S - S 7,320 Total Activity Consumalie supplies, repairs Willies No funds cost Labor cost Nat cost Item description Vints No funds cost Labor cost Nat cost 19,448 Fuel for diseel electric generator Vints No funds cost Labor cost Mat cost 1048 Fuel for diseel electric generator Vints No fund cost Labor cost Mat cost Item cost 75000 Vints No fund cost Labor cost Mat cost Item cost 75000 Vints No fund s 1,475 - \$7,5000 75000 Total cost Umembrane unit for D reconcentration </td <td>Materials</td> <td></td>	Materials																
Unit labor (WH Unit mat ossis Cossis Labor cost Mit cost Item cost Total cost Total cost Item description 1000 gal 176 5 2.00572 S - S 7.488 5 1.446 Electricity cost Fuel for desidectric generator Water 1000 gal 176 S 2.044 S - S 7.78 7.77 5 9.513 Total Utilities and Fuel Cost Electricity cost Electricity cost Water S 9.513 Total Utilities and Fuel Cost Unit mat Unit mat Unit mat Electricity cost 1000 Not mat S 5.988 5.988 S 5.988 S 5.988 S 5.988 Supported Sold filter system 2.48.000 V_22KW) 2.48.000	Units LB months	33660 4	cost \$ \$	-	\$	cost 2.00 500	\$ \$:	\$ \$	67,320 2,000	\$ \$		67,320 2,000			H&S survey, personal p Consumable supplies, r	e protective equip.
Unit Bor Unit Rator Item cost Total cost Total cost Item description KWH 34018 5 - S 7.48 S 1.948 S 7.485 S 7.48 S 1.948 S 7.485 Fuel for diseel electric generator Water S 9.513 Total Utilities and Fuel Cost Water S 9.513 Total Utilities and Fuel Cost Water S 9.513 Total Utilities and Fuel Cost Unit Rator Unit Rator Unit Rator Unit Rator Unit Rator S <t< td=""><td>I Itilitice o</td><td>nd Euol</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>,</td><td></td><td></td></t<>	I Itilitice o	nd Euol													,		
Unit labor Unit mat Total cost Total cost Total cost Item description months 4 \$ </td <td>Units KWH gal</td> <td>No of units 34018 3744</td> <td>cost \$ \$</td> <td>-</td> <td>\$</td> <td>cost 0.05725 2.00</td> <td>\$ \$</td> <td>-</td> <td>\$ \$</td> <td>1,948 7,488</td> <td>\$ \$</td> <td>Item</td> <td>1,948 7,488</td> <td></td> <td></td> <td>Fuel for diesel electric g Water</td> <td></td>	Units KWH gal	No of units 34018 3744	cost \$ \$	-	\$	cost 0.05725 2.00	\$ \$	-	\$ \$	1,948 7,488	\$ \$	Item	1,948 7,488			Fuel for diesel electric g Water	
Units months A of units 4 Cost 5 Labor cost 5 Mat cost 5 Item cost 5 Total cost 5 Total cost UF membrane unifor CD reconcentration Diesel electric generator (480 V, 22kW) months 4 5 - 5 5,988 5,988 Diesel electric generator (480 V, 22kW) months 4 5 - 5 3,292 5 3,259 S 2,26,509 Air activate carbon filter system months 4 5 - 5 5,660 5 - 5 3,592 S 2,26,509 Air activate carbon filter system months 4 5 - 5 5,660 S 2,26,598 S 110,547 Total Equipment Ownership and Rental Cost Performance Testing and Analysis Analysis Cost - off-site Units No of units Cost Labor cost Mat cost Item cost Total cost Total cost Item description Unit labor Unit mat Cost Cost Labor cost Mat cost Item cost	Equipmer	nt Ownership															
Analysis Cost - off-site Unit labor Unit mat Cost Labor cost Mat cost Item cost Total cost VOC analysis (short list) EA 48 - \$ 85 \$ - \$ 4,080 VOC analysis (short list) EA 48 - \$ 85 \$ - \$ 4,080 VOC analysis (short list) Analysis Cost - on-site Unit labor Unit mat Volt labor cost Mat cost Item cost Total cost Total Performance Testing and Analysis - off site Mailysis Cost - on-site Unit labor Unit mat Unit mat CD analysis (TOC method) Ed 5 0 \$ \$ 1,440 S - \$ 1,440 S - \$ 1,00 Field parameters (set of pH, DO, T, EC), once per week \$ 2,400 Total Performance Testing and Analysis - on site S 2,400 Total Performance Testing and Analysis - on site S 2,400 Total Performance Testing and Analysis - on site S 2,400 Total Performance Testing and Analysis - on site S 2,400 Total Performance Testing and Analysis - on site S	months months months months	4 4 4 8	cost \$ \$ \$ \$	-	\$ \$ \$ \$	cost 18,750 1,497 832 449	\$ \$ \$		\$	75,000 5,988 3,328 3,592	\$ \$ \$ \$	7	75,000 5,988 3,328 3,592			Diesel electric generato Suspended solid filter s 2 x 6,500 gal holding ta Air activated carbon filte	CD reconcentration or (480 V, 22KW) system ink er system
Unit labor Unit mat Unit No of units cost Labor cost Mat cost Item cost Total cost VOC analysis (short list) EA 48 \$ - \$ 85 \$ - \$ 4,080 YOC analysis (short list) Analysis Cost - on-site Unit labor Unit mat Voc analysis (short list) YOC analysis (short list) Units No of units cost cost Labor cost Mat cost Item cost EA 96 \$ 15 \$ - \$ \$ 1,440 \$ - \$ \$ EA 16 \$ - \$ \$ 1,440 \$ - \$ \$ 1,240 \$ Cost cost cost Labor cost Mat cost Item cost Total cost CD analysis (TOC method) EA 16 \$ - \$ 1,440 \$ - \$ \$ 1,440 \$ CD analysis (TOC method) EA 16 \$ - \$ 1,440 \$ - \$ \$ 1,440 \$ CD analysis (TOC method) Field parameters (set of pi, LO), T, EC), once per week \$ Cother (non-process related) - \$ 2,16 \$ 2,16 \$ 2,16 \$ 0n-s				sis													
Unit labor Unit mat Units Cost cost Labor cost Mat cost Item cost Total cost CD analysis (TOC method) EA 16 \$ - \$ 1,440 \$ - \$ 1,440 \$ Field parameters (set of pH, DO, T, EC), once per week EA 16 \$ - \$ 60 \$ \$ 960 \$ 960 \$ 960 \$ EA 16 \$ - \$ 60 \$ \$ 8 960 \$ 960 \$ Cher (non-process related) - - \$ 8,000 \$ \$ 8,000 \$ The formance of the for	Units EA	No of units 48	Unit la cost \$			cost		oor cost -				Item					t)
EA 96 \$ 15 \$ - \$ 1,440 \$ - \$ 1,440 \$ CD analysis (TOC method) EA 16 \$ - \$ 60 \$ - \$ 960 \$ 960 \$ 960 \$ Field parameters (set of pH, DO, T, EC), once per week Cher (non-process related) - \$ 125 \$ - \$ 8,000 \$ 8,000 \$ Final report preparation (Project Manager) months 4 \$ - \$ 54 \$ - \$ 216 \$ 216 \$ On-site sanitation (rental) EA 20 \$ - \$ \$ 500 \$ 500 \$ 500 \$ 500 \$ S/H of samples (5 shipments per week)	Analysis	Cost - on-site		bor	1	Unit mat											
hrs 64 \$ - \$ 125 \$ - \$ 8,000 \$ 8,000 \$ Final report preparation (Project Manager) months 4 \$ - \$ 54 \$ - \$ 216 \$ 216 On-site sanitation (rental) EA 20 \$ - \$ 25 \$ - \$ 500 \$ 500 \$ S/H of samples (5 shipments per week) \$ 8,716 Total Other (non-process related) 8,716 Total Other (non-process related)	EA EA	96 16	\$	15		-	\$	1,440	\$	-	\$	Item	1,440			Field parameters (set of	hod) f pH, DO, T, EC), once per week
months 4 \$ - \$ 216 On-site sanitation (rental) EA 20 \$ \$ 500 \$ 500 S/H of samples (5 shipments per week) EA 20 \$ \$ \$ \$ \$ \$ S 4.5 \$ \$ \$ \$ \$ \$ A 20 \$ - \$ \$ \$ \$ \$ S 7.16 Total Other (non-process related) \$ \$ \$ \$		-															
\$ 148,400 TOTAL O&M (year 1)	hrs months EA	4	\$	-	\$	54	\$		\$	216	\$		216	\$	8,716	On-site sanitation (renta S/H of samples (5 shipr	al)
														\$	148,400	OTAL O&M (year 1)	

Disposal	Disposal of Hazardeous Waste													
		Unit labo	r	Unit mat									Power	
Units	No of units	cost		cost	Labor	r cost	M	at cost	1	Item cost	Tot	al cost	consumption	Item description
EA	1	\$	- \$	3,900	\$	-	\$	3,900	\$	3,900			Off-sit	e disposal of drill cuttings
months	4	\$	- \$	250	\$	-	\$	1,000	\$	1,000			Off-sit	e disposal of liquid wastes
											\$	4,900	Total Disposal of Ha	zardeous Waste
Site Rest	oration													
		Unit labo	r	Unit mat										
Units	No of units	cost		cost	Labor	r cost	M	at cost	1	Item cost	Tot	al cost		Item description
hrs	24	\$	30		\$	720	\$	-	\$	720			Field of	crew
hrs	4	\$	90		\$	360	\$	-	\$	360			Super	vision
											\$	1,080	Total Site Restoration	on
														HNOL. SPECIFIC COSTS (year 1)

Summary

Cost Category	Sub Category	(Cost (\$)
	FIXED COSTS		
1. Capital Cost	Mobilization/Demobilization	\$	17,928
	Planning/Preparation	\$	38,020
	Site Investigation	\$	17,065
	Site Work	\$	6,400
	Equipment Cost - Structures	\$	
	Equipment Cost - Process Equipment	\$	14,456
	Star-up and Testing	\$	8,640
	Other - Non Process Equipment	\$	8,050
	Other - Installation	\$	32,229
	Other - Engineering (1)	\$	
	Other - Management Support (2)	\$	
	Sub-Total:	\$	142,78
	VARIABLE COSTS		
2. Variable Cost	Labor	\$	50,37
	Materials / Consumables	\$	73,320
	Utilities / Fuel	\$	9,513
	Equipment Cost (rental)	\$	110,54
	Chemical Analysis	\$	6,48
	Other	\$	8,71
	Sub-Total:	\$	258,94
3. Other	Disposal of well cuttings	\$	3,90
Technology	Disposal of liquid waste	\$	1,000
Specific Cost	Site Restoration	\$	1,080
	Sub-Total:	\$	5,98
	TOTAL COSTS		
	Total Technology Cost	\$	407,714
	Quantity Treated - VOC mass		10
	Unit Cost	\$	3,883

(1) Included in planning/preparation

CAPITAL COST (hypothetical full-scale system)

Assumpt	tions														
Freatmen	t approach:	300	ft2 Mı	ılit-	well pu	sh-pı	ıll wit	h UF	in co	ntir	uous m	lod	le		
Flushing ` Soil mass Area: Project du	s:		49 19	m3 tons m2 mor				Cost /			0.05725 ver for UF i	s pro	ovided by gene	erators.	
Number c	of wells, type a	nd dej	pth neede	ed for	remediatio	on									
6	Injection/Ext	ractio	n wells		22.5 ft										
	Source Zone C approximate e				eedy knowr	n									
Units EA EA EA EA EA EA EA EA	No of units 1 2 5 2 15 60	Un co \$ \$ \$ \$ \$	it labor st (hr) 95.00 50.00		Jnit mat cost 1,600 3,500 - 1,250 126 - 200		475 3,000	Mat \$ \$ \$ \$ \$ \$ \$ \$ \$	1,600 7,000 2,500 1,890 - 600	~ ~ ~ ~ ~ ~	tem cost 1,600 7,000 475 2,500 1,890 3,000 600	\$	Total cost 17,065	Power consumption	Item description Mob/Demob Geoprobe/Membrane Interface Probe (MIP) MIP with Electrical Conductivity Operator per diem In Situ GW/Soil sampling Lab Analysis (TCL Volatile Organic Compound) Labor (2 Person Field Crew) Equipment and Expendables Source Zone Characterization
Treatabil	ity Study (Site	e soil	testing)												
Units EA EA EA	No of units 120 1 24	co \$ \$	it labor st (hr) 85 - 125		Jnit mat cost 2,550		or cost 10,200 - 3,000	Mat \$ \$ \$	2,550	\$	em cost 10,200 2,550 3,000	s	Total cost	Power consumption	Item description Lab techician (soil column tests) Lab equipment Report preparation xtrin Selection
Engineer	ing, Design, a	and M	odeling					_				2	13,730	Total Cyclode	
Units EA EA	No of units 144	Un	it labor cost 125.00	ر \$ \$	Unit mat cost 1,770 2,500		or cost 18,000	Mat \$ \$	t cost 1,770 2,500	s s	em cost 19,770 2,500	\$	Total cost 22,270	Power consumption Total Enginee	Item description Work Plan, H&S plan, Site Management Plan (Project manager) Permits and licences, estimated ring, Design, and Modeling
	ogy Mobilizati														
Units hrs EA	No of units 280	Un	it labor cost 25		Jnit mat cost 5,464	Labo \$ \$	7,000 -	\$	t cost - 10,928		em cost 7,000 10,928	\$	Total cost 17,928	Power consumption Tota Technolo	Item description Travel to and from site (incl. accommodation) Freight (Palletizing, loading, and shipping of equipmemt) gy Mobilization and Demobilizatior
Site Worl	k														
Site Set-o Units EA EA EA	No of units	\$ \$	it labor cost - 50.00	ر چ چ	Unit mat cost 1,000 1,450	Labo \$ \$ \$	er cost - 4,000	Mat \$ \$ \$	t cost 1,000 1,400	s s s	em cost 1,000 1,400 4,000	\$	Total cost 6,400	Power consumption Total Site Set	Item description Secondary containment (berm) Electricity hook-up Plumbing up
Installatio	on of Equipm	ent ar	nd Appur	tena	nces										
Well Fiel	d Installation		it lek		In it as -1									De	
Units ft EA		\$ \$	it labor cost - -	\$	Jnit mat cost 77 552 14,800	Labo \$ \$ \$	or cost - -		t cost 10,355 3,312 14,800	\$ \$	em cost 10,355 3,312 14,800		Total cost	Power consumption	Item description Injection/Extraction well installation Grunfos submersible pumps (Model 55)
EA	1	\$	-	\$	14,000	Ψ	-	Ψ	4,000	\$	14,000	\$	28,467	Total Well Ins	SCADA system, automated flow control tallation
Units	round Plumbi No of units 500 8 10	Un \$ \$ \$		\$	21	\$ \$ \$	or cost - - -	\$	e cost 900 624 210 270	\$ \$ \$	em cost 900 624 210 270		⊺otal cost	Power consumption	Item description Well piping, 3/4 in PVC and flex tubing Flowmeters Flow control valves In-line sample ports Transfer pumps
ft EA EA EA ft ft	6 3 200	\$ \$	-	\$		\$	-	\$	882 360 516	\$	882 360 516				Waste water disposal piping, 3/4 in flex tubing
EA EA EA EA	6 3	\$ \$	-		2		-			\$		\$	3,762	Total Above G	Waste water disposal piping, 3/4 in flex tubing Connection of air stripper (6 in PVC)

Units		and Rer Unit la			Unit mat									
	No of units	cos			cost		or cost		Aat cost		n cost		Total cost	Item description
	1 :	\$	-	\$ \$	15,152 368.00		-	\$ \$	15,152 368	\$ \$	15,152 368			Air stripper incl. blower
	1			Φ	308.00	Φ	-	Э	368	3	368	\$	15.520	250 gal mixing tank Total Equipment Ownership and Rental Cost
							_					Ť		
tartup a	nd Testing	Unit la	ibor		Unit mat									Power
Units	No of units	COS	t		cost		or cost		lat cost		n cost		Total cost	consumption Item description
rs	48	\$	30	\$	-		1,440	\$:	S	1,440			Operator Training (6 people field crew)
rs	144 :	\$	50	\$	-	\$	7,200	\$	-	\$	7,200	\$	8 640	System shake-down, well testing, etc. Total Startup and Testing
												ş	0,040	
Other (no	n-process rela	a ted) Unit la	hor		Unit mat									Power
Units	No of units	COS			cost	Labo	or cost	N	lat cost	Iter	n cost		Total cost	consumption Item description
ΕA	1 :		-	\$	4,800		-	\$	4,800	\$	4,800			Office and admin. equipment (computer, printer, etc)
EA EA	3 1		-	\$ \$	550 1,600	\$ \$	-	\$ \$	1,650 1,600	\$ \$	1,650 1,600			H&S training (OSHA) Field safety equipment, various
		Ŷ		Ψ	1,000	Ψ		Ŷ	1,000	Ŷ	1,000	\$	8,050	Total Other
												S	143,851	TOTAL CAPITAL (year 1)
													,	
st Ye	ar OPERA	TING	AN	D N		NANC	CE CC	ST	(hypot	hetic	al full	-sc	ale syste	m)
5116			AN	J 10					inypot	notic	arrun	00	ale syster	,
							_							
abor ssume:	1 person, 8 hrs/	day 7 d	avs/w	eek	SCADA ter	chnolog	IV IS USA	d						
sourne.	, person, o m8/		ayarw		SOUDA IEU	anolog	, 13 use	-						
114.9 -	No of the	Unit la			Unit mat	1 - 5			lat an -1				Total cost	Marine Marine Marine
Units	No of units 120	cos \$	t 30	\$	cost		or cost 3,596	\$	lat cost	lter \$	n cost 3,596		Total cost	Item description Operating labor
ns	240		30	\$	-	\$ \$	7,193	9 \$	-	s	7,193			Monitoring labor
nrs	96		90	\$	-	\$	8,640	\$	-	ŝ	8,640			Supervision
												\$	19,429	Total Labor Cost
laterials														
L In Ye	No of code	Unit la			Unit mat	15			lat an -t				Total cost	Normal Accession Sector
Units .B	No of units 74140	cos \$	t -	\$	cost 2.00	Labo \$	or cost -	\$ \$	148,280 148,280	lter \$	n cost 148,280		Total cost	Item description Cyclodextrin, tech grade
nonths	2		-		500	\$	-	\$	1,000	š	1,000			H&S survey, personal protective equip.
nonth	2 3	\$	-	\$	1,000	\$	-	\$	2,000	\$	2,000			Consumable supplies, repairs
												\$	151,280	Total Material Cost
Jtilities a	nd Fuel													
منتعرا	No of units	Unit la cos			Unit mat cost	l ek-	or occi		lot occt	li.c	n 00**		Total cost	lion description
Units <wh< td=""><td>No of units 17009</td><td></td><td>· -</td><td>\$</td><td>0.05725</td><td></td><td>or cost -</td><td>\$</td><td>lat cost 974</td><td>\$</td><td>n cost 974</td><td></td><td>Total cost</td><td>Item description</td></wh<>	No of units 17009		· -	\$	0.05725		or cost -	\$	lat cost 974	\$	n cost 974		Total cost	Item description
gal	1872 3		-	\$	2.00	\$	-	\$	3,744	\$	3,744			Fuel for diesel electric generator
1000 gal	88 3	\$	-	\$	0.44	\$	-	\$	39	\$	39		4 750	Water
												\$	4,755	Total Utilities and Fuel Cost
Equipme	nt Ownership a													
Linite	No of unite	Unit la cos			Unit mat cost	labe	or cost	P.	lat cost	lter	n cost		Total cost	Item description
Units nonths	No of units 2 3	cos \$	t -	\$	18,750	Labo \$	or cost	\$	fat cost 37,500	s lter	n cost 37,500		i otali cost	Item description UF membrane unit for CD reconcentration
	2 3	\$	-	\$	1,497	\$	-	\$	2,994	\$	2,994			Diesel electric generator (480 V, 22KW)
nonths		\$	-	\$	997	\$	-	\$	1,993	s	1,993			PID for H&S survey
nonths	2 4		-	\$ \$	832 449	\$ \$		\$ \$	1,664 1,796	s s	1,664 1,796			Suspended solid filter system 21,000 gal holding tank
nonths nonths			-	э \$	5,660	э \$		э \$	11,319	s	11,319			Air activated carbon filter system
nonths nonths nonths	2 3											\$	57,267	Total Equipment Ownership and Rental Cost
nonths nonths nonths	2 3			_										
nonths nonths nonths nonths		nd Anal	vsis											
nonths nonths nonths nonths Performa	nce Testing ar Cost - off-site													
months months months months Performa Analysis	nce Testing ar Cost - off-site	Unit la	ibor		Unit mat	1 - 6			lat as -1	14.			Total cost	
nonths months months months Performa Analysis Units	nce Testing ar Cost - off-site No of units	Unit la cos	ibor	\$	cost		or cost		Mat cost 5.100		n cost 5.100		Total cost	Item description
nonths nonths nonths nonths Performa Analysis Units	nce Testing ar Cost - off-site No of units	Unit la	ibor			Labo \$	or cost -	∿ \$	fat cost 5,100	lter \$	n cost 5,100	\$		Item description VOC analysis (short list) Total Performance Testing and Analysis - off site
nonths nonths nonths nonths Performa Analysis Units	nce Testing ar Cost - off-site No of units 60 \$	Unit la cos	ibor		cost		or cost -					\$		VOC analysis (short list)
nonths nonths nonths nonths Performa Analysis Units	nce Testing ar Cost - off-site No of units	Unit la cos \$	ibor t -	\$	cost 85		or cost -					\$		VOC analysis (short list)
nonths nonths nonths Performa Analysis Units EA	nce Testing ar Cost - off-site No of units 60 \$	Unit la cos	ibor t -	\$	cost	\$	or cost - or cost	\$		\$		s		VOC analysis (short list)
nonths nonths nonths nonths Performa Analysis Units EA Units EA	nce Testing ar Cost - off-site No of units 60 : Cost - on-site No of units 120 :	Unit la cos \$ Unit la cos \$	ibor t - ibor t 15	\$	cost 85 Unit mat cost	\$ Labo \$	- or cost 1,800	\$ N \$	5,100 Nat cost	\$ Iter \$	5,100 n cost 1,800		5,100	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method)
nonths nonths nonths nonths Performa Analysis Units EA Units EA	nce Testing ar Cost - off-site No of units 60 : Cost - on-site No of units	Unit la cos \$ Unit la cos \$	ibor t - ibor t	\$	cost 85 Unit mat cost	\$ Labo \$	- or cost 1,800	\$	5,100 Nat cost	\$ Iter \$	5,100 m cost		5,100 Total cost	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week
nonths nonths nonths nonths Performa Analysis Units Analysis Units A Analysis Analysis	nce Testing ar Cost - off-site No of units 60 ± Cost - on-site No of units 120 ± 8 ±	Unit la cos \$ Unit la cos \$ \$	ibor t - ibor t 15	\$	cost 85 Unit mat cost	\$ Labo \$	- or cost 1,800	\$ N \$	5,100 Nat cost	\$ Iter \$	5,100 n cost 1,800		5,100 Total cost	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method)
nonths nonths nonths nonths Performa Analysis Units EA Units EA EA	nce Testing ar Cost - off-site No of units 60 : Cost - on-site No of units 120 :	Unit la cos \$ Unit la cos \$ \$	ibor t - ibor t 15	\$	cost 85 Unit mat cost	\$ Labo \$	- or cost 1,800	\$ N \$	5,100 Nat cost	\$ Iter \$	5,100 n cost 1,800		5,100 Total cost	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week
nonths nonths nonths Performa Analysis Units EA Units EA Dther (no	nce Testing ar Cost - off-site No of units 60 : Cost - on-site No of units 120 : 8 : m-process rela	Unit la cos \$ Unit la cos \$ \$ ated)	ibor t - ibor t 15 -	\$	cost 85 Unit mat cost 60	\$ Labo \$ \$	- pr cost 1,800 -	\$ \$ \$	5,100 fat cost 480	s Iter s s	5,100 n cost 1,800		5,100 Total cost	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site
nonths nonths nonths nonths Performa Analysis Units EA Units EA EA	nce Testing ar Cost - off-site No of units 60 ± Cost - on-site No of units 120 ± 8 ±	Unit la cos \$ Unit la cos \$ \$ ated)	abor t 15 -	\$	cost 85 Unit mat cost 60	\$ Labo \$ \$ \$	- or cost 1,800 - -	\$ \$ \$	5,100 Mat cost 480 8,000 108	s Iter s s s	5,100 n cost 1,800 480 8,000 108	\$	5,100 Total cost	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site Final report preparation (Project Manager) On-site sanitation (rental)
nonths months nonths Performa Analysis Units EA Units EA Units EA Other (no	nce Testing ar Cost - off-site No of units Cost - on-site No of units 120 : 8 : m-process rela	Unit la cos \$ Unit la cos \$ \$ ated) \$	abor t 15 -	\$	cost 85 Unit mat cost 60	\$ Labo \$ \$ \$	- or cost 1,800 - -	\$ \$ \$ \$	5,100 Aat cost 480 8,000	s Iter s s s	5,100 n cost 1,800 480 8,000	\$	5,100 Total cost 2,280	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site Final report preparation (Project Manager) On-site sanitation (rental) S/H of samples (5 shipments per week)
nonths nonths nonths Performa Analysis Units EA Units EA Units EA Dunits EA Dunits EA	nce Testing ar Cost - off-site No of units 60 : Cost - on-site No of units 120 : 8 : en-process rela 64 : 2 :	Unit la cos \$ Unit la cos \$ \$ ated) \$	abor t 15 -	\$	cost 85 Unit mat cost 60	\$ Labo \$ \$ \$	- or cost 1,800 - -	\$ \$ \$	5,100 Mat cost 480 8,000 108	s Iter s s s	5,100 n cost 1,800 480 8,000 108	\$	5,100 Total cost 2,280	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site Final report preparation (Project Manager) On-site sanitation (rental)
nonths nonths nonths Performa Analysis Units EA Units EA Units EA Dther (no	nce Testing ar Cost - off-site No of units 60 : Cost - on-site No of units 120 : 8 : en-process rela 64 : 2 :	Unit la cos \$ Unit la cos \$ \$ ated) \$	abor t 15 -	\$	cost 85 Unit mat cost 60	\$ Labo \$ \$ \$	- or cost 1,800 - -	\$ \$ \$	5,100 Mat cost 480 8,000 108	s Iter s s s	5,100 n cost 1,800 480 8,000 108	\$	5,100 Total cost 2,280	VOC analysis (short list) Total Performance Testing and Analysis - off site Item description CD analysis (TOC method) Field parameters (set of pH, DO, T, EC), once per week Total Performance Testing and Analysis - on site Final report preparation (Project Manager) On-site sanitation (rental) S/H of samples (5 shipments per week)

Disposal	of Hazardeou	C 10	lacto												
Disposal															
	Unit labor Unit mat														Power
Units	No of units		cost		cost	La	abor co	ost	Ma	at cost		Item cost		Total cost	consumption Item description
EA	1	\$		- \$	3,900	\$		-	\$	3,900	s	3,900			Off-site disposal of drill cuttings
months	2			- \$				-		500		500			Off-site disposal of liquid wastes
montina	2	Ψ		- ψ	200	Ψ		-	Ψ	500	Ŷ	500		4 400	
													\$	4,400	0 Total Disposal of Hazardeous Waste
Site Rest	oration														
		ι	Jnit labor		Unit mat										
Units	No of units		cost		cost	La	abor co	ost	Ma	at cost		Item cost		Total cost	Item description
hrs	24	\$	30	1		\$		720	\$		s	720			Field crew
hrs	4		90			ŝ		360			š	360			Supervision
1113	-4	φ	50	,		φ		300	φ	-	φ	500			
													Ş	1,080	0 Total Site Restoration
													S	5.480	0 TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 1)

Summary

	F implementation		
	oull with UF in continuous mode (2 months)		
Cost Category	Sub Category	- (Cost (\$)
	FIXED COSTS		
1. Capital Cost	Mobilization/Demobilization	\$	17,928
	Planning/Preparation	\$	38,020
	Site Investigation	\$	17,065
	Site Work	\$	6,400
	Equipment Cost - Structures	\$	
	Equipment Cost - Process Equipment	\$	15,520
	Star-up and Testing	\$	8,640
	Other - Non Process Equipment	\$	8,050
	Other - Installation	\$	32,229
	Other - Engineering (1)	\$	
	Other - Management Support (2)	\$	
	Sub-Total:	\$	143,851
	VARIABLE COSTS		
2. Variable Cost	Labor	\$	19,429
	Materials / Consumables	\$	151,280
	Utilities / Fuel	\$	4,756
	Equipment Cost (rental)	\$	57,267
	Chemical Analysis	\$	7,380
	Other	\$	8,358
	Sub-Total:	\$	248,470
3. Other	Disposal of well cuttings	\$	3,900
Technology	Disposal of liquid waste	\$	500
Specific Cost	Site Restoration	\$	1,080
	Sub-Total:	\$	5,480
	TOTAL COSTS		
	Total Technology Cost	\$	397,801
	Quantity Treated - VOC mass (lbs)		105
U	nit Cost (per lbs VOC removed and treated)	\$	3,789

(1) Included in planning/preparation

CAPITAL COST (hypothetical demo-scale system)

CAPITAL COST (hypothetical demo-sca	ale system;												
Assumptions													
Treatment approach: 300 ft2 Line-drive (I/E) with U	JF in continous mode												
Flushing Vol: 9 m3 Soil mass: 49 tons Area: 19 m2 Project duration: 2 months	Power Consumption In: KW Cost / KWH \$ 0.05725 Note: Electrical power for UF is provided by generator.												
Number of wells, type and depth needed for remediation													
3 Injection wells 22.5 ft 3 Extraction wells 22.5 ft 2 Hydraulic control wells 22.5 ft													
DNAPL Source Zone Characterization Assume: approximate extent of plume is already known													
Unit labor Unit mat cost (hr) Dut mat EA 1 (\$) 0 (\$) 5 EA 1 (\$) \$ 1,600 (\$) EA 2 (\$) \$ 3,500 (\$) EA 5 (\$) 9500 (\$) \$ EA 2 (\$) \$ 1,250 (\$) EA 2 (\$) \$ 1,250 (\$) EA 15 (\$) \$ 1,260 (\$) EA 60 (\$) \$<00 (\$)	- \$ 1,600 Mob/Demob Geoprobe/Membrane Interface Probe (MIP) \$ 7,000 \$ 7,000 75 \$ - \$ 475 75 \$ - \$ 475 76 \$ 2,500 \$ Derator per diem - \$ 2,500 In Situ GW/Soil sampling - \$ 1,890 \$ Lab Analysis (TCL Volatilig												
Treatability Study (Site soil testing)	\$ 17,055 Total DNAPL Source Zone Characterization												
Unit labor Unit mat Units No of units cost (hr) cost Labor cos EA 120 \$ 85 \$ - \$ 10,20 EA 1 \$ - \$ 2,550 \$	Power Power 00 \$ - \$ 10,200 Lab techician (soil column tests) - \$ 2,550 \$ 2,550 Lab equipment 00 \$ - \$ 3,000 Report preparation 5 15,750 Total Cyclodextrin SoleCtion												
Engineering, Design, and Modeling													
Unit labor Unit mat Units No of units cost cost Labor cos EA 144 \$ 125.00 \$ 1,770 \$ 18,00 EA 1 \$ - \$ 2,500 \$	Power Item cost Total cost consumption Item description 00 \$ 1,770 \$ 19,770 \$ 19,770 Work Plan, H&S plan, Site Management Plan (Project manager) - \$ 2,500 \$ 2,500 Permits and licences, estimated \$ 22,270 Total Engineering, Design, and Modeling												
Technology Mobilization and Demobilization Assume: Local contractors perform field work													
Unit labor Unit mat Units No of units cost cost Labor cos	Power st Mat cost Item cost Total cost consumption Item description 00 \$ - \$ 7,000 Travel to and from site (incl. accommodation) - \$ 10,928 \$ 10,928 Freight (Palletizing, loading, and shipping of equipment) \$ 17,928 Total Technology Mobilization and Demobilizatior												
Site Work													
Site Set-up Unit labor Unit mat Units No of units cost cost Labor cost EA 1 \$ - \$ 1,000 \$ EA 1 \$ - \$ 1,450 \$ EA 10 \$ - \$ 1,450 \$	Power Item cost Total cost consumption Item description - \$ 1,000 \$ 1,000 \$ 1,000 Secondary containment (berm) - \$ 1,000 \$ 1,400 Electricity hook-up 00 \$ - \$ 4,000 Plumbing \$ 6,400 Total Site Set-up												
Installation of Equipment and Appurtenances													
Well Field Installation Unit labor Unit mat Units cost cost Labor cost tf 180 \$ - \$ 7 \$ EA 8 \$ - \$ 552 \$ EA 1 \$ - \$ 14,800 \$	Power Power t Mat cost Item cost Total cost consumption Item description - \$ 13,806 \$ 13,806 Injection/Extraction well installation - \$ 4,416 \$ 4,416 Grunfos submersible pumps (Model 5S) - \$ 14,800 \$ SCADA system, automated flow control												
Above Ground Plumbing Unit labor Unit mat Cost Labor cost Units No of units cost cost 2 \$ ft 500 \$ - \$ 2 \$ EA 8 - \$ 2 \$ EA 10 - \$ 21 \$ EA 6 - \$ 45 \$ EA 6 - \$ 45 \$ EA 6 - \$ 29 \$ ft 200 - \$ 2 \$ ft 60 - \$ 9 \$	Power												
	· ····································												

		and Ren Unit la		U	Jnit mat									
Units	No of units	cost			cost		oor cost		Mat cost		Item cost		Total cost	Item description
4 onths	1	\$ \$	-	\$ \$	10,101 997	\$ \$	-	\$ \$	10,101 3,987	\$ \$	10,101 3,987			Air stripper incl. blower (200 cfm) PID for H&S survey
A	1			\$	368.00	\$	-		368	\$	368			250 gal mixing tank
												\$	14,456	Total Equipment Ownership and Rental Cost
tartup a	nd Testing													
Units	No of units	Unit la cost	oor	ι	Jnit mat cost	Lah	or cost		Mat cost		Item cost		Total cost	Power consumption Item description
rs		\$	30	\$	-	\$	1,440	\$	-	\$	1,440		Total cost	Operator Training (6 people field crew)
rs	144	\$	50	\$	-	\$	7,200	\$	-	\$	7,200	\$	8 640	System shake-down, well testing, etc. Total Startup and Testing
												Ψ	0,040	
ther (no	on-process rel	ated) Unit Iai	oor		Jnit mat									Power
Units	No of units	cost	501		cost	Lab	or cost		Mat cost		Item cost		Total cost	consumption Item description
A	1 3	\$	-	\$ ¢	4,800 550	\$ \$	-	\$ \$	4,800 1,650	\$ \$	4,800 1,650			Office and admin. equipment (computer, printer, etc) H&S training (OSHA)
A.	1		-		1,600	\$	-		1,600	\$	1,600			Field safety equipment, various
												\$	8,050	Total Other
												\$	147,343	TOTAL CAPITAL (year 1)
st Yea	ar OPERA	TING	AN	D M	IAINTEN	IAN	CE CO	DST	「(hypot	het	tical full-	sc	ale syster	n)
abor														
ssume: "	1 person, 8 hrs	/day, 7 da	ays/we	eek,	SCADA teo	hnolo	igy is use	d						
		Unit la	oor	ι	Jnit mat									
Units	No of units 160	cost	30	\$	cost -	Lab \$	or cost 4,795	\$	Mat cost	\$	Item cost 4,795		Total cost	Item description Operating labor
rs rs	320		30	э \$	-	э \$	9,590	э \$	-	5 5	4,795 9,590			Operating labor Monitoring labor
rs		\$	90	\$	-	\$	8,640	\$	-	\$	8,640		00.000	Supervision
												\$	23,026	Total Labor Cost
laterials	i de la companya de l	Lie M. I			loit or -t									
Units	No of units	Unit la cost	JOL	U	Jnit mat cost	Lab	or cost		Mat cost		Item cost		Total cost	Item description
в	233200	\$	-	\$	2.00	\$	-	\$	466,400	\$	466,400			Cyclodextrin, tech grade
nonths nonth	2	\$	-	\$ \$	500 1,000	\$ \$	-	\$ \$	1,000 2,000	\$ \$	1,000 2,000			H&S survey, personal protective equip. Consumable supplies, repairs
Ionun	2	Ş	-	φ	1,000	φ	-	Ģ	2,000	φ	2,000	\$	469,400	Total Material Cost
Itilition o	and Eucl													
Jtilities a	ina ruei	Unit la	oor	ι	Jnit mat									
Units	No of units	cost			cost		or cost		Mat cost		Item cost		Total cost	Item description
(WH al	18089 1872		-	\$ \$	0.05725 2.00	\$ \$	-	\$ \$	1,036 3,744	\$ \$	1,036 3,744			Electricity cost Fuel for diesel electric generator
000 gal	88		-		0.44	\$	-		39	ŝ	39			Water
												\$	4,818	Total Utilities and Fuel Cost
quipme	nt Ownership	and Ren	tal											
Units	No of unite	Unit la cost		ι	Jnit mat cost	oh	or cost		Mat cost		Item cost		Total cost	Item description
nonths	No of units 2			\$	cost 18,750	Lat \$	JUI COST -	\$	Mat cost 37,500	\$	37,500		TOTAL COST	Item description UF membrane unit for CD reconcentration
nonths	2	\$	-	\$	1,497	\$	-	\$	2,994	\$	2,994			Diesel electric generator (480 V, 22KW)
nonths nonths	2 4		-	+	832 449	\$ \$	-	\$ \$	1,664 1,796	\$ \$	1,664 1,796			Suspended solid filter system 2 x 6,500 gal holding tank
nonths	2		-	-	5,660	\$	-	\$	11,319	\$	11,319			Air activated carbon filter system
												\$	55,273	Total Equipment Ownership and Rental Cost
erforma	nce Testing a	nd Analy	sis											
	Cost - off-site				lait met									
Units	No of units	Unit la cost		U	Jnit mat cost	Lab	or cost		Mat cost		Item cost		Total cost	Item description
A	60			\$	85	\$	-	\$	5,100	\$	5,100			VOC analysis (short list)
												\$	5,100	Total Performance Testing and Analysis - off site
nalysis	Cost - on-site													
		Unit la	oor	ι	Jnit mat	1.05	or oper		Mat cost		Item cost		Total cost	lion description
Units A	No of units 120	cost		\$	cost 15		or cost	\$	Mat cost 1,800	\$	Item cost 1,800		Total cost	Item description CD analysis (TOC method)
A	8			\$	60			\$		\$	480			Field parameters (set of pH, DO, T, EC), once per week
												\$	2,280	Total Performance Testing and Analysis - on site
)ther (no	on-process rel	ated)												
	64			\$	125	\$		\$	8,000	\$	8,000			Final report preparation (Project Manager)
nrs nonths	64 4				125		-	э \$	8,000	5 5	8,000			On-site sanitation (Project Manager)
	20		-		25			\$		\$	500			S/H of samples (5 shipments per week)
ĒA												\$	8,716	Total Other (non-process related)
ΞA														
ΞA														
A												\$	513,340	TOTAL O&M (year 1)

Disposal	of Hazardeou	s Wa	ste												
		Ur	it labor		Unit mat									Power	
Units	No of units		cost		cost	Labor	cost	M	at cost	li li	em cost		Total cost	consumption Item description	
EA	1	\$	-	\$	3,900	\$	-	\$	3,900	s	3,900			Off-site disposal of drill cuttings	
months	2	\$	-	\$	250	\$	-	\$	500	s	500			Off-site disposal of liquid wastes	
		+		-		•		+		•		s	4 400	0 Total Disposal of Hazardeous Waste	
												•	1,100		
Site Rest	Restoration														
	Unit labor Unit mat														
Units	No of units		cost		cost	Labor	cost	М	at cost	ľ	em cost		Total cost	Item description	
hrs	24	\$	30			\$	720	\$	-	s	720			Field crew	
hrs	4		90			ŝ	360			ŝ	360			Supervision	
		*				•		•		•		s	1 080	0 Total Site Restoration	
												•	1,000		
												\$	E 490	0 TOTAL OTHER TECHNOL. SPECIFIC COSTS (year 1)	

Summary

Cost Category	Sub Category	(Cost (\$)
	FIXED COSTS		
1. Capital Cost	Mobilization/Demobilization	\$	17,928
	Planning/Preparation	\$	38,020
	Site Investigation	\$	17,065
	Site Work	\$	6,400
	Equipment Cost - Structures	\$	
	Equipment Cost - Process Equipment	\$	14,456
	Star-up and Testing	\$	8,640
	Other - Non Process Equipment	\$	8,050
	Other - Installation	\$	36,784
	Other - Engineering (1)	\$	
	Other - Management Support (2)	\$	
	Sub-Total:	\$	147,343
	VARIABLE COSTS		
2. Variable Cost	Labor	\$	23,020
	Materials / Consumables	\$	469,400
	Utilities / Fuel	\$	4,81
	Equipment Cost (A-carbon, rental)	\$	55,273
	Chemical Analysis	\$	7,380
	Other	\$	8,716
	Sub-Total:	\$	568,613
3. Other	Disposal of well cuttings	\$	3,900
Technology	Disposal of liquid waste	\$	500
Specific Cost	Site Restoration	\$	1,080
	Sub-Total:	\$	5,480
	TOTAL COSTS		
	Total Technology Cost	\$	721,436
	Quantity Treated - VOC mass (lbs)		105
U	nit Cost (per lbs VOC removed and treated)	\$	6,871

(1) Included in planning/preparation



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