COST and PERFORMANCE REPORT

for the

Geo-Cleanse® Process Treatment Demonstration

at

Naval Air Station Pensacola, FL
Operable Unit 10
Pensacola, Florida

Prepared for

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OPERABLE UNIT 10
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Cost and Performance Report
Naval Air Station Pensacola Florida/Operable Unit 10
Geo-Cleanse® Process Treatment Demonstration

I. Executive Summary

This project was initiated and scoped by Southern Division Naval Facilities Engineering Command (NAVFAC) in response to the Broad Agency Announcement (BAA) program (N47408-96-R-6342) solicitation, which is administered by the Naval Facilities Engineering Service Center (NFESC) to demonstrate innovative technologies for site remediation. Geo-Cleanse International, Inc. (GCI) performed the work, under Contract No. N47408-98-C-8013 awarded by NFESC with assistance from NAVFACCO under the BAA program. The contract was funded with environmental program funding under the NAVFAC Y0817 technology development and demonstration program that was administered by NFESC, and was supplemented with Navy Environmental Restoration (ER, N) funds provided by Southern Division NAVFAC. Southern Division NAVFAC and NFESC jointly managed the project for the Navy, and will publish a technology demonstration report on the In-Situ Chemical Oxidation of Organic Contaminants using Fenton's Reagent for NAVFAC based on this project.

GCI utilizes a patented technology, "the Geo-Cleanse® Process," to simultaneously inject hydrogen peroxide and catalysts into the subsurface to oxidize organic contaminants in soil and groundwater. The Geo-Cleanse® Process delivers a calculated mass of hydrogen peroxide and catalyst to the contaminated region via specially designed injection equipment. The injection methodology and equipment are the patented elements of the Geo-Cleanse® Process. The oxidative chemistry is based upon Fenton's reagent, a combination of hydrogen peroxide and ferrous iron catalyst that creates a hydroxyl free radical, a powerful oxidizer. Fenton's reagent oxidizes chlorinated volatile organic compounds (VOCs) to carbon dioxide, water, and chloride.

The purpose of the treatment demonstration at Naval Air Station (NAS) Pensacola Florida (NAS Pensacola) was to utilize the Geo-Cleanse® Process to chemically oxidize chlorinated solvent VOCs in groundwater in the vicinity of a former sludge drying bed. The objective of the treatment demonstration was to significantly reduce VOC contaminant concentrations at the source area to ensure that natural attenuation would be an effective remedy for downgradient groundwater. Hudson Environmental Services, Inc. (Hudson) was retained by GCI to prepare a Sampling and Performance Evaluation Plan (SPEP) to establish appropriate sampling dates, locations, and parameters to evaluate the effectiveness of the Geo-Cleanse® Process and to prepare this Cost and Performance Report.

GCI's site-specific treatment design entailed installation of fifteen (15) injection wells to depths between 10 and 40 feet below grade. Design calculations indicated that approximately 3,500 gallons of 50% hydrogen peroxide solution were necessary to treat an estimated 16, 500-gallons of groundwater contaminated with chlorinated solvent VOCs at the source area, and a six (6) day injection duration was initially estimated.

The Geo-Cleanse® Process treatment demonstration was conducted at the site ended with two (2) phases totaling 11 days of injection between November 1998 and May 1999. A total of 10,127 gallons of 50% hydrogen peroxide solution was injected. The increase in both the hydrogen peroxide volume and injection duration from the design calculations was attributed to elevated ferrous iron concentrations in the treatment area. The elevated ferrous concentrations consumed hydrogen peroxide and limited the initial injection radius of influence. Injection amendments in the second phase of injection using phosphoric acid overcame the effects of the elevated ferrous iron concentrations.

As part of the SPEP, the U.S. Geological Survey (USGS) and GCI performed sampling, and the results are summarized herein. Source area trichloroethene (TCE) concentrations were

reduced from a peak pre-treatment concentration of 3,600 ug/L to <5 ug/L. Based on sampling results, the Geo-Cleanse® Process treatment demonstration successfully reduced the source area chlorinated solvent VOC concentrations, and achieved the project goals.

The NAS Pensacola treatment demonstration was completed for a total cost of $178,338. Approximately ninety percent of these actual costs were associated with the installation of injection wells and treatment, while the remaining costs were associated with design and reporting.

At the request of the NFESC and the Southern Division NAVFAC, this report is formatted in accordance with the Federal Remediation Technologies Roundtable's Guide to Documenting and Managing Cost and Performance Information for Remediation Projects (EPA 542-B-98-007, October 1998). A detailed description of the Geo-Cleanse® Process treatment demonstration design and implementation, monitoring results, and costs incurred are presented herein.

II. SITE INFORMATION

A. Identifying Information

Identifying information for the treatment demonstration is summarized below.

Site Name: Naval Air Station Pensacola

Location: Pensacola, Florida

CERCLIS ID No.: 0401221

SIC Code: 9711 (National Security)

Regulatory Context: Florida Department of Environmental Protection (DEP) Enforcement Action for OU-10 based on Impact to Groundwater. Florida DEP accepted Innovative Technology Treatment Demonstration to address Groundwater Contamination

Type of Action: In-Situ Treatment Demonstration

B. Technology Application

Technology: In-Situ Chemical Oxidation using Fenton's Reagent (Geo-Cleanse® Process)

Period of Operation: Phase I December 9 – 12, 1998
Phase II May 11 –17, 1999
Post-Treatment Analytical Data Collected in January and June, 1999

Quantity of Material Treated:

Estimated 16,500 gallons of groundwater contaminated with chlorinated solvent VOCs at the source area

C. Background

Waste Management Practice That Contributed to Contamination:

Liquid wastes containing solvents were disposed into an unlined inactive sludge drying bed located at Operable Unit 10 (OU-10), the former Industrial Wastewater Treatment Plant (IWWTP).

Site History:

NAS Pensacola is a 5,800-acre naval facility located in southern Escambia County, Florida. OU-10 is located on 26 acres of Magazine Point Peninsula, in the northeast corner of the NAS. Former industrial processes that had been located on Magazine Point began generating wastewater in 1941 and portions of the IWWTP that served these processes remain operational at the present time. Industrial wastewater processed at the IWWTP has included painting and electroplating wastewater, organic solvents, and acids.

Remedy Selection:

A groundwater recovery system had been operated for over ten years under a Resource Conservation and Recovery Act (RCRA) Corrective Action program to control contaminated

groundwater migration. The Geo-Cleanse® Process was selected to significantly reduce source area chlorinated solvent VOC concentrations to ensure that natural attenuation would be an effective remedy for downgradient groundwater. The primary contaminant type (chlorinated solvent VOCs) as well as the hydrogeologic conditions in the former sludge drying bed area of concern represented favorable selection criteria for the Geo-Cleanse® Process treatment demonstration.

D. Site Logistics/Contacts

Responsible Party:	NAS Pensacola
Responsible Party Contact:	Tom Kelly Public Works Center NAS Pensacola (850) 452-8236
Lead Regulatory Agency:	Florida DEP
Lead Agency Contact:	Mark Stuckey Environmental Specialist III Hazardous Waste Regulation Section 2600 Blair Stone Road MS 4560 Tallahassee, FL 32399-2400 (850) 921-9246 email: stuckey_m@dep.state.fl.us
Oversight Agencies:	Naval Facilities Engineering Command SOUTHNAVFACENGCOM P.O. Box 190010 2155 Eagle Drive N. Charleston, SC 29419 Maxie Keisler (843) 820-7322 email: keislermr@efdsouth.navfac.navy.mil And Michael Maughon (843) 820-7422 email: maughonmj@efdsouth.navfac.navy.mil Naval Facilities Engineering Service Center 1100 23rd Avenue Port Hueneme, California 93043 D.B. Chan, Ph.D., P.E. ESC Code 411 (805) 982-4191 email: chandb@nfesc.navy.mil And Michael J. Carsley ESC Code 414 (805) 982-4890 email: carsleymj@nfesc.navy.mil

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III. MATRIX DESCRIPTION

A. Matrix Identification

Type of Matrix Processed by Treatment System: Groundwater

B. Contaminant Characterization:

Chlorinated solvent VOCs, primarily TCE, were the contaminants of concern in the groundwater within the treatment demonstration area at NAS Pensacola. Within OU-10, the contaminants of concern were detected in groundwater within the 35 to 45 foot below ground surface (bgs) interval. Monitoring well (MW) GM-66 was installed and screened from 37.5 to 40 feet bgs and served as the source area MW (see Figure 1). Chlorinated solvent VOCs historically detected above federal and state of Florida Maximum Contaminant Levels (MCLs) in GM-66 included TCE, vinyl chloride, 1,1-dichloroethene, 1,1-dichloroethane, chlorobenzene, 1,2-dichlorobenzene, 1,3-dichlorobenzene, 1,4-dichlorobenzene, and 1,2-dichloroethene. A significant reduction of at least an order of magnitude of source area chlorinated solvent VOC concentrations, TCE in particular, was the goal of the treatment demonstration.

In 1995, a Remedial Investigation of OU-10 was conducted by Ensafe/Allen & Hoshall and reported in a Final Remedial Investigation Report (September 1995). Miscellaneous IWWTP solid waste management units were identified in Site 35 of OU-10, including the former sludge drying bed. Groundwater sampling conducted hydraulically downgradient of the former sludge drying bed detected concentrations of VOCs, base neutral/acid extractable compounds, metals, and other organic and inorganic compounds above Florida DEP standards and U.S. Environmental Protection Agency (USEPA) MCLs. Groundwater sampling conducted in January 1998 and reported by HRP/Spectrum, Inc. in a Semi-Annual Groundwater Monitoring Report (March 1998) confirmed that many contaminants were detected at concentrations that exceeded MCLs.

No soil sampling has been performed either in the vadose zone or the saturated zone within the OU-10 targeted treatment area. Soil sampling conducted to the northwest of the treatment demonstration area exhibited low concentrations of pesticides (12.2 ug/kg) and polychlorinated biphenyls (PCBs) at 13 ug/kg. No VOCs or other organic compounds were detected in any of those soil samples.

C. Matrix Characteristics Affecting Technology Cost and Performance:

Table 1 below summarizes the matrix characteristics and factors that influence cost and performance for this technology. Values that represent site-specific data as compiled by GCI and/or other involved agencies are also presented below. Where appropriate, optimal ranges for the respective parameters as presented by GCI are shown in parentheses.

Table 1. Matrix Characteristics Affecting Treatment Cost and Performance And Associated Measurement Procedures

Parameter	Value	Measurement Procedure
Soil Classification and Clay Content	0 - 48 ft. bgs; Fine to medium quartz sand	ASTM Method D 2488-90
Depth to Groundwater	0-4 ft. bgs (> 5 ft bgs)	Groundwater Monitoring
Depth to Contamination	35 to 45 ft. bgs (> 5 ft. bgs)	Groundwater Monitoring
Porosity	> 15 percent (30 percent)	ASTM Method D 6031-96
Groundwater pH	3 to 6 (<6)	Field Test Kit
Hydraulic Conductivity	2 to 44 feet/day (> $3x10^{-5}$ ft/day)	ASTM D 4043-91

Non-Aqueous Phase Liquids	None Measured	SW 846/8240
Dissolved Iron	> 500 mg/L (5 to 100 mg/L)	Field Test Kit

D. Geology/Hydrogeology

The shallow soils in the region of NAS Pensacola are typified as marine terrace sands comprising part of the Surficial Aquifer. The Surficial Aquifer in the region is approximately 300 ft thick and subdivided into three zones, the surficial zone, the lower permeability zone and the main producing zone. The surficial zone is contiguous with the land surface. Within the OU-10 area, the lithology of the surficial zone is described as white to light brown, fine to medium quartz sand, which extends to a depth of 38 to 48 ft. bgs.

Chlorinated solvent VOC impacted groundwater in the treatment demonstration area had been detected at the base of the sandy tidally influenced unconfined surficial zone aquifer. The groundwater table ranged from 0 to 4 feet bgs, and this shallow aquifer extended to approximately 40 feet bgs. HRP/Spectrum, Inc. (March 1998**)** reported average hydraulic conductivity values of 44 feet/day (10-20 feet bgs) and 2 ft/day (approximately 36-48 feet bgs). The shallow aquifer is underlain by a confining clay formation.

The source area monitoring well (GM-66) is constructed to a depth of 40 feet bgs with a screened interval between 37.5 and 40 bgs. Historic pre-treatment groundwater sampling results indicated that groundwater at GM-66 was impacted primarily with TCE. An investigation conducted by the USGS in August 1998 delineated the TCE plume within the deep portion of the shallow aquifer (see Figure 1).

IV. TECHNOLOGY SYSTEM DESCRIPTION

A. Primary Technology

The Geo-Cleanse® Process is based upon Fenton's chemistry wherein a calculated mass of hydrogen peroxide, ferrous sulfate, and proprietary reagents are injected into the subsurface to produce a hydroxyl free radical which in turn will chemically oxidize organic contaminants in-situ. The essential reaction of the process is simplified below:

$$H_2O_2 + Fe^{+2} \rightarrow Fe^{+3} + OH\cdot + OH^-$$

where H_2O_2 is hydrogen peroxide, Fe^{+2} is ferrous iron, Fe^{+3} is ferric iron, $OH\cdot$ is the hydroxyl free radical, and OH^- is a hydroxyl ion. The primary chlorinated solvent VOC reported in the treatment demonstration area at NAS Pensacola was TCE. The oxidation of TCE by the hydroxyl free radical is illustrated below:

$$C_2Cl_3H + OH\cdot + H_2O \rightarrow CHCl_2COOH + 2H^+ + Cl^-$$

where C_2Cl_3H is TCE, $CHCl_2COOH$ is dichloroacetic acid, Cl^- is chloride ion, and H^+ is hydronium ion. In the continued presence of the hydroxyl free radical, dichloroacetic acid will be oxidized to formic acid and ultimately to carbon dioxide and water.

The injection process is designed to establish and maintain the optimal subsurface conditions to ensure efficiency of the essential reaction. GCI was incorporated in 1995 to commercially apply the Geo-Cleanse® Process. U.S. patents 5,525,008 and 5,611,642 protect the application technology. The technology is intended for in-situ oxidation of organic contamination in soil and groundwater. To date, GCI has applied the process at more than 50 sites in 17 states and Canada. As the Geo-Cleanse® Process is not selective in its destruction of organic material, naturally occurring or non-targeted anthropogenic organic material will consume injected reagents and affect treatment efficiency.

B. Supplemental Technologies

The Geo-Cleanse® Process rapidly oxidizes contaminants to carbon dioxide and water and therefore does not usually require any supplemental technologies such as vapor-phase treatment. Since this treatment demonstration was designed to effect chlorinated solvent VOC source reduction; groundwater hydraulic control was not a factor. Thus, no measures to control groundwater were necessary. However, GCI normally initiates their process at the source area perimeter and progress radially inward in order to minimize any potential for contaminant migration and/or spreading.

For this treatment demonstration, GCI monitored soil vapor using a Photoionization Detector (PID) to ensure that short-circuiting of VOCs did not occur due to volatilization resulting from the high heat generated by the exothermic reaction.

C. System Description/Operation

Upon arrival at the site, the GCI trailer is wired to an electrical power supply (220 volt, 100 amp, single phase power supply or a 6,000 watt (6 kW) generator) and connected to a potable water supply source. Injector mixing heads are attached to injection wells and delivery hoses are reeled from the trailer and connected to the mixing heads. Injector mixing heads are designed to operate at a maximum pressure of 110 pounds per square inch. Fittings are quick-connect and standard pipe thread. Initial mobilization set-up times are less than one day, subsequent daily set-ups are less than two hours, and demobilization entails less than one day.

Injection wells are constructed with black iron casing and stainless steel screen. Once injection wells are installed, GCI crews and injection equipment is mobilized. GCI crews

typically consist of three personnel; an injection specialist, injection assistant, and monitoring specialist. GCI personnel are trained in accordance with Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response regulations, and Level D personal protection levels are standard. GCI equipment is mobilized in a self-contained trailer and hydrogen peroxide is transported separately with its mode of storage (i.e. drums or trailers) dependent on site needs. Each GCI equipment trailer house pumps, air compressors, mixing tanks, delivery hoses, and injectors and mixing heads. Material of construction ranges from stainless steel to buna rubber, and is dependent upon the compatibility of reagent with equipment purpose.

D. Operating Parameters Affecting Technology Cost and Performance

A complete and thorough remedial investigation typically provides the data necessary for GCI to design a Geo-Cleanse® Process treatment for a site. Design parameters include reagent quantities, reagent concentrations, injector construction, injector spacing, and injection duration. Each are dictated by existing contaminant concentration and mass, and treatment goals. Table 2 summarizes the operating parameters for the Geo-Cleanse® Process.

Table 2. Operating Parameters Affecting Treatment Cost and Performance And Associated Measurement Procedures

Parameter	Value	Measurement Procedure
Injection Rate	0.25 to 3 gpm	Flow Indicators
Injection Pressure	5 to 110 psig	Pressure Indicators
pH	<8	Field Test Kits
Carbon Dioxide Evolution	5% to > 25%	Field Analyzer

There are no toxic or harmful residuals generated by the Geo-Cleanse® Process that require disposal. The only theoretical real-time injection residuals are carbon dioxide (gas) and oxygen (gas). Post-injection residual hydrogen peroxide solution in the aquifer degrades to oxygen and water, and ferrous iron catalyst precipitates as ferric iron. Chloride ions will result from the oxidation of chlorinated solvent VOCs.

Key design criteria are reagents (i.e. hydrogen peroxide and catalyst) concentrations and volume, injection rate and duration, and injector construction. Reagent concentrations and volume are dependent upon contaminant type, mass, and treatment goals. The duration to inject the design volume is dictated mainly by aquifer characteristics. Eight to ten-hour injection days are standard and total treatment times may range from one to more than 20 weeks. Injection rates range from less than one to four gallons per minute at each injector. GCI can simultaneously inject into multiple injection wells and total daily injected reagent volumes can reach 2,500 gallons. Injector construction is dictated by contaminant distribution. Because of pressures generated by the process, injector depth of more than five feet below ground surface (bgs) is necessary. GCI has successfully injected to 150 feet bgs.

E. Timeline

The Geo-Cleanse® Process treatment demonstration was initially designed to occur as a single-phase treatment consisting of:

- installation of fourteen (14) injection wells to depths between 10 and 40 feet bgs in the immediate vicinity and downgradient of the former sludge drying bed (see Figure 2),
- completion of the pre-treatment groundwater sampling event,
- injection of 3,528 gallons of 50% hydrogen peroxide solution (design estimate) and similar reagent quantities over a six day treatment duration, and
- completion of the post-treatment groundwater sampling event.

The actual Geo-Cleanse® Process demonstration treatment occurred in two phases, each consisted of injector installation, pre-injection sampling, injection, and post-injection sampling. The first phase was completed between November and December 1998 and entailed installation of fourteen (14) injection wells and four days of injection. A total of 4,089 gallons of 50% hydrogen peroxide and similar volumes of reagents were injected.

The second phase treatment was subsequently determined to be necessary and was completed between April and May 1999 and entailed installation of one (1) new injector and six days of injection. A total of 6,038 gallons of 50% hydrogen peroxide and similar volumes of reagents were injected in the second phase. Table 3 identifies the hydrogen peroxide injection volumes for each injector during the two phases of treatment. Table 4 presents the overall treatment timeline.

Table 3. Treatment Demonstration Hydrogen Peroxide Injection Volumes (gal.)

	Injection Well #															
	I-1	**I-2**	**I-3**	**I-4**	**I-5**	**I-6**	**I-7**	**I-8**	**I-9**	**I-10**	**I-11**	**I-12**	**I-13**	**I-14**	**I-15**	**Total**
Phase I	70	188	609	920	70	154	201	465	393	202	252	326	74	165	0	4089
Phase II	0	0	0	1395	0	434	40	605	25	502	0	74	1245	1223	495	6038
Total	70	188	609	2315	70	588	241	1070	418	704	252	400	1319	1388	495	10127

Table 4. Overall Project Timeline

Date	Activity
Nov. 4 – Nov. 6, 1998	Phase I Installation of 14 injection wells.
Dec. 1, 1998	Phase I pre-Treatment groundwater sampling
Dec. 7 – Dec. 12, 1998	Phase I Treatment
Dec. 29 – Jan. 1999	Phase I post-Treatment groundwater sampling
March 16, 1999	Phase II Installation of 1 new injection well.
April 7, 1999	Phase II pre-Treatment groundwater sampling
May 10 – May 17, 1999	Phase II Treatment
May 20 and June 21, 1999	Phase II post-Treatment groundwater sampling

V. TECHNOLOGY SYSTEM PERFORMANCE

A. Cleanup Goals/Standards

A SPEP was prepared in December 1998 to establish appropriate monitoring parameters, locations, and frequency to evaluate the effectiveness of the Geo-Cleanse® Process treatment demonstration. The SPEP specified pre-, active, and post-treatment groundwater sampling events. The pre-treatment event consisted of laboratory analysis for VOCs and total chloride and field analysis for temperature, pH, conductivity, dissolved oxygen, redox potential, and turbidity. Active treatment monitoring was specified to be conducted each morning of the treatment for VOCs. (In addition, GCI conducted real time injection monitoring twice daily for groundwater and approximately 3 to 5 times daily for gases using field instruments for carbon dioxide, oxygen, and VOCs via PID in the head space of treatment area monitoring wells.) The specified post-treatment sampling event parameters were the same as the pre-treatment event, and were to be conducted four and 30 days following treatment.

The SPEP also detailed the analytical procedures to be followed. In summary, an on-site NAS Pensacola laboratory (Navy Public Works Center, Environmental laboratory, Building 3887) analyzed the groundwater samples for VOCs via EPA Method 8260 and chloride via EPA Method 325.3. Table 5 summarizes the analytical program.

Table 5. Analytical Program

Analytical Parameter	Laboratory Methodology	Sampling Frequency
VOCs	EPA Method 8260	All parameters:
Cadmium	EPA Method 6010B	Twice during Pre-Treatment Phase
Total Chromium	EPA Method 6010B	Daily during Active Treatment Phase
Hexavalent Chromium	EPA Method 7196A	Twice during Post-Treatment Phase
Trivalent Chromium	Difference Between Total and Hex. Chromium	
Total Organic Carbon	EPA Method 9060	
Ferrous Iron	Standard Methods 3500-Fe D	
Chloride	EPA Method 325.3	

B. Performance Data

First phase of treatment TCE concentration trends in sosurce area MWs are summarized in Table 6 below. A complete summary of VOC analyses is presented in Appendix 1.

Table 6. Phase I Treatment TCE Concentration (ug/L) Trends

	Pre-Phase I Treatment			Phase I Treatment				Post-Phase I Treatment		
	7/98	8/20/98	12/1/98	12/9/98	12/10/98	12/11/98	12/12/98	12/29/98	1/99*	1/27/99
GM-66	3,600	2,440	2,040	3,000	180	200	130	485	190	415
USGS-5	NS	1,420	2,460	1,700	<1	830	<1	1,820	NS	2,100
USGS-6	NS	743	773	NS	NS	NS	NS	825	NS	926

Notes:

NS = Not sampled

*Exact sampling date unknown

The above TCE concentration trends indicated insufficient contaminant reduction in MWs USGS-5 and USGS-6. Prior to proceeding with additional treatment, GCI evaluated conditions that may have effected the treatment demonstration. The following conditions were explored:

- VOC contaminated soil remained in the source area,
- Groundwater contamination existed upgradient of the treatment zone,
- Native or anthropogenic organic matter existed, and
- Elevated transition element concentrations existed in the treatment area.

The occurrence of the first two conditions could have led to contaminant concentration rebound as unaccounted contamination migrated to the treated area, and the occurrence of either of the second two conditions would consume hydrogen peroxide and limit the treatment efficiency.

It was subsequently determined by GCI that ferrous iron concentrations exceeded 500 mg/L in the treatment area. Although ferrous iron catalyzes Fenton's reagent, exceptionally high ferrous iron concentrations reduce the efficiency of the hydrogen peroxide, and limit the treatment radius. GCI had learned that the presence of ferrous iron in groundwater was associated with a historic sulfuric acid spill, which resulted in a depressed groundwater pH and the reduction of ferric iron to ferrous iron. GCI subsequently adjusted their reagent mix to include dilute phosphoric acid. Phosphoric acid is commonly used to stabilize hydrogen peroxide and thus increase the contact time for treatment.

The second phase of treatment was subsequently completed between April and May 1999 and entailed installation of one (1) new injection well and six days of injection. A total of 6,038 gallons of 50% hydrogen peroxide and similar volumes of reagents were injected in the second phase of treatment.

The second phase of treatment TCE concentration trends are summarized in Table 7 below. A complete summary of VOC analyses is presented in Appendix 1.

Table 7. Phase II Treatment TCE Concentration (ug/L) Trends

	Pre-Treatment	Phase II Treatment						Post-Treatment	
	4/7/99	5/11/99	5/12/99	5/13/99	5/14/99	5/15/99	5/17/99	5/20/99	6/21/99
GM-66	460	310	<1	510	330	370	1	<1	<5
USGS-5	2,700	1,600	960	1,900	<1	120	110	79	100
USGS-6	890	500	45	81	590	550	<1	32	110

Notes:
NS; Not sampled

C. Performance Data Assessment

Favorable characteristics that affected the treatment demonstration performance included the types of contaminants, i.e., chlorinated solvent VOCs, and in particular, TCE, a low groundwater pH (<4) and the sandy (highly permeable) nature of the aquifer. Although not apparent until after the first phase of treatment, high ferrous iron concentrations (greater than 500 mg/L) reduced the effectiveness of the initial treatment as discussed above.

Based on the significant TCE concentration reductions detected following the second phase of treatment, the Geo-Cleanse® Process successfully reduced the source area TCE concentrations, and achieved the treatment demonstration goals.

D. Performance Data Quality

The majority of the performance data were obtained via field measurements using test kits and PIDs. Confirmatory soil and groundwater samples were analyzed using standard USEPA approved laboratory analytical methodologies/procedures. Other than the pre-, active and post-treatment analytical monitoring program described above, no other supplemental Quality Assurance/Quality Control (QA/QC) program was undertaken or deemed necessary for this treatment demonstration. No exceptions to the established monitoring procedures were noted. Site-specific considerations described in the Florida DEP acceptance letter, e.g., UIC monitoring, was performed by GCI and reported elsewhere.

VI. COST

A. Procurement Process

This project was initiated and scoped by Southern Division NAVFAC in response to the Broad Agency Announcement (BAA) program (N47408-96-R-6342) solicitation, which is administered by the Naval Facilities Engineering Service Center (NFESC) to demonstrate innovative technologies for site remediation. Geo-Cleanse International, Inc. (GCI) performed the work, under Contract No. N47408-98-C-8013 awarded by NFESC with assistance from NAVFACCO under the BAA program. The contract was funded with environmental funding under the NAVFAC Y0817 technology development and demonstration program that was administered by NFESC, and was supplemented with Navy Environmental Restoration (ER, N) funds provided by Southern Division NAVFAC. Southern Division NAVFAC and NFESC jointly managed the project for the Navy, and will publish a technology demonstration report on the In-Situ Chemical Oxidation of Organic Contaminants using Fenton's Reagent for NAVFAC based on this project.

B. Cost Data

A summary of the actual treatment demonstration costs as reported by GCI is presented below. These costs do not include electrical power or water supply, which were supplied by NAS Pensacola.

Table 8. Treatment Demonstration Cost

Cost Category Element	Cost
1. Capital Cost for Technology	
Mobilization, Setup and Demobilization	$57,901
Planning and Preparation	12,217
Site Work	0
Equipment and Appurtenances	
Structures	0
Process Equipment and Appurtenances/Construction	26,400
Other	0
Startup and Testing	0
Other	500
TOTAL CAPITAL COSTS	**$97,018**
2. O&M for Technology	
Labor	$22,100
Materials	48,800
Utilities and Fuel	0
Equipment Rental	1,000
Performance Testing and Analysis	8,320
Other	1,100
TOTAL OPERATION AND MAINTENANCE COSTS	**$81,320**
3. Other Technology-Specific Costs	
Compliance Testing and Analysis	0
Soil, Sludge and Debris Excavation, Collection and Control	0
Disposal of Residues	0
4. Other Project Costs	0
TOTAL OTHER TECHNOLOGY-SPECIFIC AND OTHER PROJECT COSTS	0
Total Cost (1998 Year Basis)	**$178,338**

The NAS Pensacola treatment demonstration was completed for a total cost of $178,338. Approximately ninety percent of these actual costs were associated with the installation of injection wells and treatment, while the remaining costs were associated with design and reporting.

The NAS Pensacola Geo-Cleanse® Process treatment demonstration removed greater than 99 percent of the target chlorinated solvent VOCs. Using an average chlorinated solvent VOC pre-treatment concentration of 2,000 ug/L in a source area volume of 16,500 gallons of groundwater, less than one pound of contaminants were removed. In this particular application, the total cost per pound of VOCs removed was quite high. This high unit cost for removal does not reflect the true cost efficiencies of the Geo-Cleanse® Process, which has shown much lower unit costs for removal when applied to source areas with significantly higher contaminant concentrations.

VII. REGULATORY/INSTITUTIONAL ISSUES

The only permit necessary to conduct the remediation was an Underground Injection Control (UIC) notification to the Florida DEP, the favorable timeliness of which did not have an impact on the remediation.

The Geo-Cleanse® Process was accepted as an innovative technology for site remediation in the State of Florida. The Florida Department of Environmental Protection (DEP) granted a variance from compliance with groundwater standards in their acceptance of the Geo-Cleanse® Process for the NAS Pensacola treatment demonstration. A one-year timetable was granted for achievement of compliance with naturally occurring background values for iron, sulfate, total dissolved solids, and pH. The DEP also required the submission and approval of a Remedial Action Work Plan and a detailed pre-, active and post-treatment groundwater-monitoring program. Interaction with the Florida DEP was positive during the project, and did not hinder project scheduling or adversely effect costs. The Geo-Cleanse® Process has gained acceptance by Federal and State regulators in numerous states, and has been chosen by the Navy, Army, and Air Force on several occasions to reduce chlorinated VOC concentrations in groundwater.

VIII. TECHNOLOGY APPLICABILITY AND ALTERNATIVES

A. Technology Applicability

The following information summarizes the current status of application of this technology:

- The Geo-Cleanse® Process has been demonstrated to remediate VOC-contaminated groundwater and VOC-contaminated soils, both in the vadose zone and saturated soils,
- Organic contaminants amenable to treatment with this technology include halogenated and non-halogenated, aromatic and aliphatic compounds,
- This technology is not well suited for cleanup of ketones such as acetone or carbon tetrachloride,

- The Geo-Cleanse® Process has also been demonstrated to address Dense, Non-Aqueous Phase Liquids (DNAPLs),
- This technology is not well suited for alkaline groundwater, for heterogeneous subsurface conditions, or for low permeability soils, and
- The Geo-Cleanse® Process is not as effective with low concentration plumes as it is with high concentration source areas. It can be used as a source reduction remedy in concert with other active or passive technologies, or as a single step remedy.

B. Competing Technologies

Competing techniques include air sparging and dual phase extraction, pump and treat systems, steam flooding, cosolvent flooding, surfactants, electrical heating, electrokinetics, in-well stripping, biodegradation and reactive barriers. The Geo-Cleanse® Process offers the following advantages for the treatment of chlorinated solvent VOC-contaminated groundwater:

- Contaminants are treated in-situ with no toxic or harmful residuals generated,
- Dissolved-phase contaminants can be treated at high concentrations, even In the presence of Non-Aqueous Phase Liquids (NAPL),
- The technology is capable of reducing contaminant concentrations to very low concentrations, including MCLs, and achieving clean-up goals, and
- Contaminant destruction can occur relatively quickly. The technology often provides a low overall treatment cost relative to other competing technologies.

The Geo-Cleanse® Process competes with the conventional baseline technologies such as pump and treat systems. Other in situ physical/chemical systems that have been demonstrated or are under development are also viewed as competing technologies. Table 8 includes the technologies that are considered competing technologies to the Geo-Cleanse® Process.

An alternate form of in situ chemical oxidation also competes with this technology. In Situ Chemical Oxidation with Potassium Permanganate is considered to be a direct competitor to the Geo-Cleanse® Process. Permanganate oxidation in general has a higher capital cost than hydrogen peroxide oxidation. This oxidant is considered to be more stable than hydrogen peroxide and effective over a broader pH range. Use of catalysts and pH control is also not necessary with Potassium Permanganate oxidation. The drawbacks of permanganate oxidation are that resulting oxide precipitation may reduce soil porosity and thus alter the physical properties of soils, and unreacted dissolved manganese will impart a purple color to groundwater. At the present time, hydrogen peroxide oxidation has had a much wider regulatory acceptance and greater use than permanganate oxidation. This fact may be due to the smaller number of vendors who are marketing permanganate oxidation technology, or because of the high success rate of hydrogen peroxide oxidation. It remains to be seen whether permanganate oxidation will achieve the same degree of usefulness in the marketplace as peroxide oxidation.

Table 9. Characteristics Affecting Cost and Performance for Competing Technologies

	MATRIX PROPERTIES						ORGANIC PROPERTIES									
Technology	**Hydraulic Conductivity**	**% Moisture**	**Permeability**	**pH**	**Porosity**	**Depth to Contamination**	**Total Organic Carbon**	**Total Petroleum Hydrocarbons**	**Non Aqueous Phase Liquids**	**Development Status**	**Residuals Produced**	**Applicability**	**Reliability**	**Cleanup Time**	**Operation and Maintenance or Capital Intensive**	**Overall Cost**
Air Sparging (AS)	Yes	No	Yes	No	Yes	Yes	No	No	Yes	Full Scale	Vapors	Better	Better	Ave.	O&M	Lower
Circulating Wells (UVB)	Yes	No	Yes	No	No	Yes	No	No	Yes	Pilot	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Cosolvents/Surfactants	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Full Scale	Liquids	Ave.	Ave.	Longer	O&M	Higher
Dual-Phase Extraction	Yes	No	Yes	No	Yes	Yes	No	Yes	Yes	Full Scale	Vapors	Better	Ave.	Ave.	O&M	Ave.
Dynamic Underground Stripping	Yes	No	Yes	No	Yes	Yes	No	No	Yes	Pilot	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
In Situ Chemical Oxidation (Fenton's Reagent)	Yes	No	No	Yes	No	Yes	No	No	No	Full Scale	Vapors	Better	Better	Shorter	O&M	Lower
In Situ Chemical Oxidation (Potassium Permanganate)	Yes	No	No	Yes	No	Yes	No	No	No	Full Scale	Vapors Solids	Better	Ave.	Shorter	O&M	Lower
Passive Treatment Walls	Yes	No	No	No	Yes	Yes	No	No	No	Full Scale	Solids	Better	N.A.	Longer	Capital	N.A.
Permeable Reaction Walls	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Full Scale	Solids Liquids	Better	N.A.	Longer	Capital	N.A.
Pump and Treat System	Yes	No	No	No	No	Yes	No	Yes	Yes	Full Scale	Vapors Liquids	Ave.	Ave.	Longer	O&M	Higher
Steam Flushing	Yes	No	Yes	No	No	Yes	No	Yes	Yes	Full Scale	Vapors	Ave.	Fair	Shorter	Capital	Better

N.A.-Data Not Yet Available

C. Technology Maturity

In Situ Chemical Oxidation via the Geo-Cleanse® Process is an established technology that has been used at over 50 sites across the United States. This technology, the Geo-Cleanse® Process, is available only through Geo-Cleanse International, Inc. Presently, this technology is being applied at a number of DOD sites across the country.

D. Intellectual Property Issues

GCI utilizes a patented technology, the Geo-Cleanse® Process, to simultaneously inject hydrogen peroxide and catalysts into the subsurface to oxidize organic contaminants in soil and groundwater. This technology vendor differentiates itself from other peroxide oxidation vendors by its method of injection (pressurized as opposed to gravity) and by its oxidant-catalyst mixing prior to injection. The injection methodology and equipment are the patented elements of the Geo-Cleanse® Process. As such, use of this peroxide oxidation technology rests solely with the patent holder, GCI.

IX. OBSERVATIONS AND LESSONS LEARNED

A. Cost Observations and Lessons Learned

The key factors that affected project cost were duration of treatment and quantity of reagents. The increase of each factor beyond the design estimates were caused by elevated ferrous iron concentrations in groundwater which limited the radius of treatment of the first phase and necessitated the second phase of treatment.

B. Performance Observations and Lessons Learned

As mentioned above, elevated ferrous concentrations in the aquifer resulted in deviation from the performance design. At the completion of Phase I, detected chlorinated solvent VOCs in source area groundwater had been reduced from a total pre-treatment concentration at MW-66 of approximately 5,000 ug/L (July, 1998 data) to approximately 570 ug/L (December 29, 1998 data). Corresponding reductions in TCE were 3600 ug/L to 485 ug/L. These results for TCE did not achieve the treatment demonstration goals. However, amendments to the process were successfully employed in the Phase II treatment, and based upon the post-treatment monitoring results, the treatment demonstration met its contaminant reduction goals. Post-treatment data for TCE in groundwater exhibited concentrations of <1 ug/L (May 20, 1999), which represents a greater than 99 percent reduction. The successful treatment demonstration essentially represents full-scale reduction of the source area concentrations in the area of concern, and additional injection is not planned at this time. Once the ferrous iron concentrations were accounted for, the demonstration treatment accurately met project predictions.

C. Other Observations and Lessons Learned

Although the total treatment duration exceeded design estimates, the overall timeframe to meet the project objectives was favorable.

The Geo-Cleanse® Process, although powerful and expeditious, should be preceded by a thorough remedial investigation, geochemical evaluation, underground utility clearance and geophysical survey. Should the technology be considered for source area reduction in chlorinated solvent VOC plumes, ferrous iron concentrations and other non-target oxidizable substrates, e.g., natural organic compounds must be evaluated prior to treatment. Specific geochemical parameters that should be considered include groundwater hardness, pH, ferrous iron, and chloride.

X. REFERENCES

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FIGURES