TREATABILITY STUDY WORK PLAN FOR TCE AND ITS DEGRADATION PRODUCTS IN GROUNDWATER IN THE LOWLANDS GEOLOGY OF THE INDUSTRIAL AREA

For
Environmental Investigation at the Formerly Used Defense Site (FUDS)
at the Benicia Arsenal, Benicia, California

FUDS Site Number: J09CA075600

FINAL

Prepared for:

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OF THE INDUSTRIAL AREA
BENICIA ARSENAL, BENICIA, CALIFORNIA

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Plate 1. Trichloroethene Detected in Groundwater and Proposed Treatability Locations

LIST OF ACRONYMS AND ABBREVIATIONS

Arsenal	Former Benicia Arsenal
AWWA	American Water Works Association
bgs	below ground surface
CFU	colony forming units
cis-1,2-DCE	cis-1,2-dichloroethene
CPT	cone penetrometer testing
DoD	United States Department of Defense
FA/BC	Forsgren Associates/Brown and Caldwell
FID	flame ionization detector
FSIP	Field Site Investigation Plan
FUDS	Formerly Used Defense Site
GC	gas chromatography
HRC	Hydrogen Release Compound
IDW	investigation derived waste
MRC	Metals Remediation Compound
ORP	oxidation reduction potential
PID	photoionization detector
PVC	poly vinyl chloride
QA	quality assurance
QAPP	Quality Assurance Project Plan
QC	quality control
ORP	oxidation reduction potential
RI/FS	remedial investigation/feasibility study
SOPs	Standard Operating Procedures
SI	Site Investigation
SSHP	Site Safety and Health Plan
SRB	sulfate reducing bacteria

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

TCE	trichloroethene
TPC	total plate counts
trans-1,2-DCE	trans-1,2-dichloroethene
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound

1.0 PROGRAM GOALS AND PROJECT ORGANIZATION

The activities presented in this *Treatability Study Work Plan* (Work Plan) are being conducted at the former Benicia Arsenal (Arsenal), Benicia, California for the U.S. Army Corps of Engineers, Sacramento District (USACE) under General Services Administration Contract No. GS-10F-0101L and Veterans Affairs Purchase Order 674-V40113. This document is presented as an addendum to the *Expanded Site Inspection* (Expanded SI), *Field Site Investigation Plan* (Expanded SI FSIP) prepared by Brown and Caldwell in April 2004. This section of the document describes the Formerly Used Defense Sites (FUDS) program and identifies the personnel responsible for execution of the work described herein.

1.1 Project Overview

In accordance with FUDS program goals and USACE guidance documents, the remedial investigation/feasibility study (RI/FS) is being conducted to determine the presence or absence of chemicals that may have impacted the environment from past Department of Defense (DoD) activities at the former Arsenal. FUDS program funding can only be used to assess and remediate DoD liability at eligible property, which is defined as real property formerly owned by, leased by, possessed by, or otherwise under the jurisdiction of the Secretary of Defense or elements of the U.S. military. Under the FUDS program, land that was previously utilized by DoD and that has no "beneficial use" history will be characterized and, if necessary, remediated to an appropriate standard. "Beneficial use" of former DoD land is defined as activity by subsequent landowners or lessors that would either mask contamination caused by DoD or continue contamination in the same manner.

The purpose of the Work Plan is to describe field and laboratory activities that will be conducted to evaluate the treatability of specific site contaminants at the former Arsenal. The results of this treatability study will support the analysis of various remedial alternatives included in the Feasibility Study Report currently being prepared by Brown and Caldwell. The alternatives tentatively identified for groundwater remediation include monitored natural attenuation, groundwater extraction and ex situ treatment, and in situ enhanced bioremediation.

1.2 Project Organization

Figure 1-1 presents the organization chart for this project and lists the specific responsibilities of key USACE staff, Brown and Caldwell staff, and subcontractors.

1.3 Work Plan Organization

This Work Plan is organized into seven sections. Section 1.0 presents general information pertinent to the overall project. Section 2.0 describes the problem to be addressed by this Work Plan and provides background information for the project, including the geology, hydrogeology, history, historical use, and a brief summary of the volatile organic compounds (VOCs) identified in groundwater in the Industrial area at the former Arsenal. Section 3.0 presents the project objectives, activities, and schedule. Section 4.0 outlines the approach of this design and rationale of the investigative process in detail, including sampling objectives, sample types and matrices, sampling frequencies, and analytical methods. Sampling methods requirements are listed in Section 5.0. Section 6.0 describes the procedure for management of investigation derived waste (IDW). References are listed in Section 7.0.

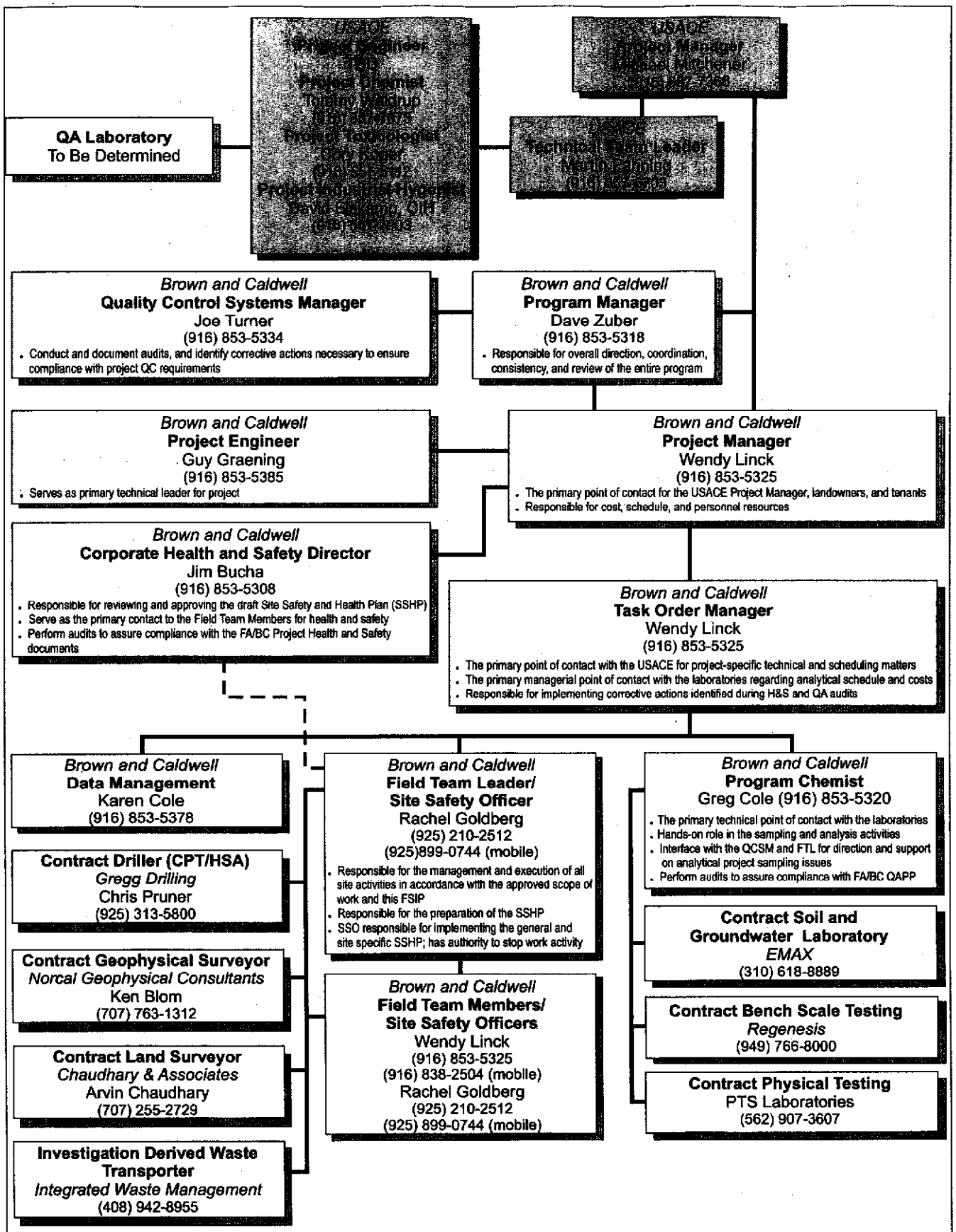

Figure 1-1
Organizational and Responsibility Chart
Treatability Work Plan
Benicia Arsenal

2.0 PROBLEM DEFINITION AND PROJECT BACKGROUND

The scope of the Work Plan will specifically address the treatability of volatile organic compounds adsorbed to saturated soil and dissolved in groundwater in the Lowlands geology within the industrial area of the Site. The specific analytes to be addressed are trichloroethene (TCE) and its breakdown products cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), and vinyl chloride (VC). The industrial area was selected as the general study location because it contains the highest TCE concentrations reported in groundwater at the Site. Additionally, there are no other VOCs of concern for this project.

This Work Plan proposes activities that will specifically evaluate the remediation of TCE and its daughter products in the shallow and deep water bearing zones of the Lowlands in the industrial area. Note that this Work Plan does not evaluate the remediation of other contaminants such as petroleum hydrocarbons and poly aromatic hydrocarbons. The remediation of these contaminants will be assessed in the Feasibility Study Report.

2.1 Arsenal and Industrial Area Site Location and Description

The former Arsenal is located about 25 miles northeast of San Francisco in Benicia, California, on the north side of the Carquinez Strait (Figure 2-1). During its active life (1849-1964), this facility served the U.S. Army as a principal depot for ordnance and ordnance stores, as well as the issuance, manufacture and testing of small arms. The former Arsenal eventually grew by land acquisition to a total of 2,728 acres (Jacobs, 1999). The industrial area is located in the southernmost portion of the former Arsenal.

The industrial area served as the main industrial and manufacturing area throughout the 115-year history of the facility and was the center of activity at the former Arsenal. Several machine shops, manufacturing shops, and cleaning and painting shops were housed here, along with a blacksmith shop, a welding shop, numerous vehicle and artillery repair shops, and a small arms shop. The industrial area also housed the former Arsenal's administrative offices, most of the permanent housing facilities, photographic laboratories, a firehouse, and a hospital. Fuel storage and dispensing facilities, a locomotive house, boiler houses, storehouse and warehouse facilities, open storage facilities, fillsites, and quarries were also located within this area.

2.2 Industrial Area Geology and Hydrogeology

The industrial area stratigraphy comprises of, from oldest to youngest, the Vine Hill Sandstone, older alluvium, Bay Mud, and artificial fill, as shown in the graphic to the right.

Youngest	Artificial fill	sandy silt, silt, clayey silt and sand	2 to 13 feet thick
to	Bay Mud	Organic rich clay	Up to 55 feet thick
	Older Alluvium	Silt to silty clay with lenses of sand and clay	0 to 45 feet thick
Oldest	Vine Hill Sandstone		

Stratigraphy of the Industrial Lowlands

Depth to the Vine Hill Sandstone ranges from 6 feet bgs near Building 116 to almost 105 feet at the southeast corner of Building 167. The shallow occurrences of sandstone are found adjacent to bedrock knolls. The topography of the top of the Vine Hill Sandstone indicates several valleys that have been partially covered with the older alluvium. The older alluvium was deposited in a fluvial environment.

Figure 2-1
Arsenal Location Map
Treatability Work Plan
Benicia Arsenal

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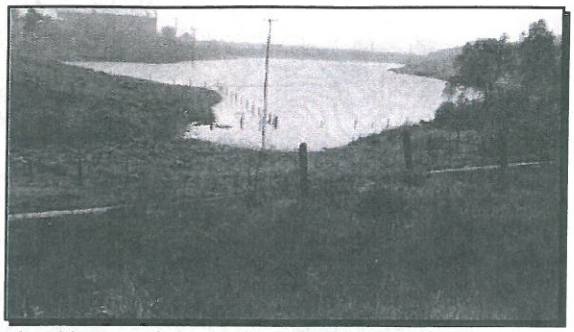
A rise in sea level beginning between 11,000 and 8,000 years ago inundated the region. Deposited on top of these older alluvial sediments was an estuarine mud known as the Bay Mud. Marshlands formed as the valleys filled with the unconsolidated mud in these quiet water environments (see photo to right).



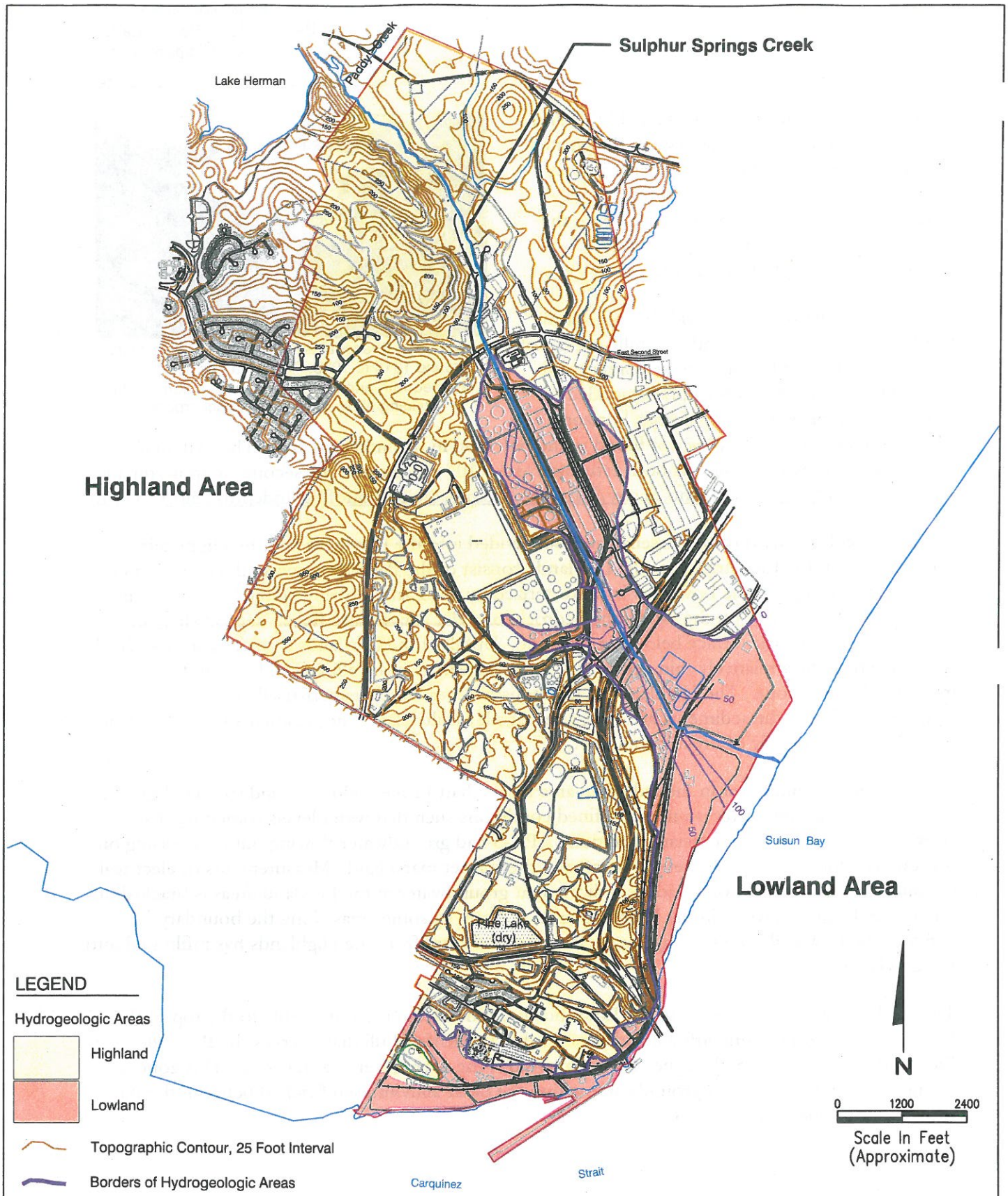
Looking southeast at the marshland. Photo taken around 1915 to 1920. The area has since been covered with artificial fill and now is a parking lot. Building 57 is shown in the background.

The Bay Mud deposits are found throughout the San Francisco Bay Region and generally consist of silty marine clays with high organic content and localized lenticular deposits of poorly graded sand, silt, peat beds, and fossiliferous horizons. These sand and silt lenses were not found in the Bay Mud in the industrial area. The hydraulic conductivity of the Bay Mud has been estimated at 1 x 10^{-6} centimeters per second or approximately 1 foot/year. (http://www.ciwmb.ca.gov/Landfills/ComplyStudy/Landfills/Indepth/PaloAlto.htm).

The hydrogeologic areas of the Arsenal were subdivided into the Lowlands and the Highlands (Figure 2-2). In the Industrial area, the Lowlands consist of the flat land associated with a former marsh. The geology of the Lowlands is characterized by artificial fill overlying the bay mud. The bay mud may lie directly on the sandstone bedrock, or older alluvial and fluvial deposits may be present on the bedrock surface below the bay mud. Uphill of the Lowlands is the Highlands, which is characterized by a relatively thin veneer (less than 40 feet) of older alluvial and fluvial deposits mantling the sandstone. The Highlands in the industrial area are characteristically similar to the Lowlands such that the sediments are comprised of silt to silty clay. The sediments in the Lowlands are comprised primarily of organic rich clay.

Depth to first groundwater in the industrial area is less than 12 feet below ground surface (bgs). At deeper depths, groundwater is under confined conditions such that water levels sometimes rise above the ground surface (artesian conditions). PZ-3 had groundwater flowing out of its casing on several occasions. This piezometer is located in the former marshland. Measurements of electrical conductivity and total dissolved solids indicate that groundwater in the Lowland areas is brackish to saline and the groundwater in the Highland areas is fresh. In some areas along the boundary between the Lowlands and the Highlands, fresh groundwater from the Highlands has infiltrated into the Lowlands.

The shallow water bearing zone in the Lowlands is defined from the water table to the top of the Bay Mud. This zone is unconfined and exists within the artificial fill that overlies the Bay Mud. The Bay Mud acts as an aquitard. Beneath the Bay Mud is the deep water bearing zone. This zone is defined by the occurrence of groundwater within the older alluvium sandwiched between the Bay Mud and the Vine Hill Sandstone.



Source of Thickness of Bay Mud in Lowlands is Edward Schwafel Engineers, 1969

Figure 2-2
Hydrogeologic Areas
Treatability Work Plan
Benicia Arsenal

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2.3 Arsenal History and Historical Chemical Use

The land for the Benicia Arsenal was acquired by the U.S. government in 1849 from the founders of the City of Benicia (Jacobs, 1999). Originally referred to as "the Post at Point near Benicia, California," the installation was later designated Benicia Barracks (Jacobs, 1999). In 1862, President Lincoln ordered that a plot of land at Benicia be segregated from the public lands for the purpose of a military reservation. Between 1849 and 1958, the United States acquired 1,790.48 fee acres, 351.12 public domain acres, 6.40 license acres, and 580.04 easement acres, for a total of 2,728.04 acres (Jacobs, 1999).

The former Arsenal served as a principal depot for ordnance and ordnance stores, issuance of supplies, ammunition, small arms parts and accessories, the testing of small arms, mobile and seacoast artillery targets, and vehicle maintenance for the Division of the Pacific. A massive expansion of the former Arsenal took place during World War II. Physical expansion included the addition of 1,847 acres and over 200 structures. Another full-scale expansion took place just prior to and following the Korean Conflict, with the addition of approximately 40 to 50 structures. Many of these additions were warehouses for inert materials and transitory shelters. Throughout the former Arsenal's history, the functions of many buildings and operation areas changed, in response to changing government needs.

The former Arsenal was continuously occupied by the military from its establishment in 1849 to its closure in 1964. Benicia Arsenal was declared excess by the DoD and was reported to the General Services Administration on 11 January 1963. Deactivation and closure of the former Arsenal was completed on 31 March 1964 (Jacobs, 1999).

The Army operated industrial and manufacturing shops, maintenance facilities, and fuel and waste storage areas. Potential sources of chemical releases from these activities include underground storage tanks (USTs), vapor degreasers, grease maintenance pits, degreasing tanks and waste disposal areas. Fuel-related petroleum hydrocarbons are expected at the former Arsenal due to known releases from former USTs and possibly from remaining USTs. The contents of these USTs included fuel oil, diesel fuel and gasoline. These petroleum products were used in vehicles, machinery and other equipment. In addition to fuel-related petroleum hydrocarbons, various chemicals were used in manufacturing processes that included coloring, cleaning, degreasing, and preserving.

2.4 Summary of TCE in Groundwater in the Industrial Area

The highest concentrations of TCE and its daughter products in groundwater were found near Building 165 and Building 120 (Plate 1). Another source of TCE in shallow groundwater was found near the 50 Series Complex but concentrations are up to 10 times less than at the other two buildings and access is being restricted by the landowner. This study is focusing on the areas surrounding Building 165 and Building 120 where the concentrations are the highest for the shallow and deep water bearing zones, respectively. More detailed information is provided in the *Expanded SI Report* (Brown and Caldwell, 2005)

3.0 PROJECT DESCRIPTION

This section describes the project objectives, activities, and schedule.

3.1 Objectives

The objectives of this Work Plan are to:

- Estimate the hydraulic conductivity[1] of the shallow and deep water bearing zones;
- Evaluate whether groundwater conditions are favorable for TCE biodegradation; and
- Evaluate whether TCE biodegradation can be enhanced or accelerated.

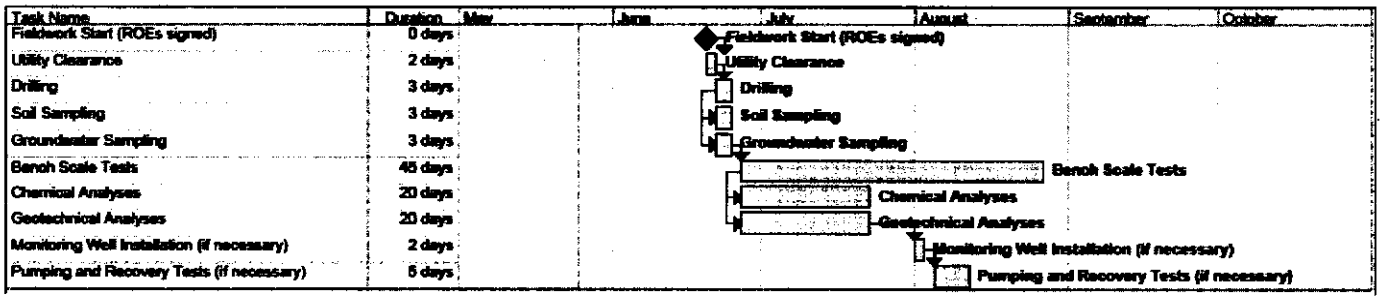
3.2 Activities

To accomplish the objectives, the following activities will be conducted:

- Collect saturated soil samples representative of the shallow and deep water bearing zones to determine hydraulic conductivity, porosity, bulk density, and total organic carbon of the samples through geotechnical analysis.
- Sample groundwater from the shallow and deep aquifers that represents conditions upgradient of, within, and downgradient of the contaminant plume and analyze for biodegradation parameters.
- Collect saturated soil and groundwater samples representative of the shallow and deep water bearing zones to support bench scale testing.
- Conduct bench scale tests of enhanced bioremediation on soil and groundwater samples from the shallow and deep aquifers.
- If necessary, install one groundwater monitoring well and two observation points to support pumping and recovery testing and conduct an 8 hour pumping and 72 hour recovery test in the deep water bearing zone to determine hydraulic conductivity.

3.3 Project Schedule

The activities described in this Work Plan will begin approximately three weeks after this document is finalized and Rights of Entry are secured. Field activities are expected to take two weeks. The bench scale testing is expected to take two months. A detailed timeline from the field activities is shown in the following graphic.



Estimated Timeline for the Treatability Study Fieldwork

[1] Hydraulic conductivity is defined as the capacity of a porous medium to transmit water (Driscoll, 1986).

4.0 PROJECT APPROACH

The general technical approach to accomplish the activities described in Section 3.0 is described in this section. The subsections below will describe the locations and methods to be used to collect samples for geotechnical, biodegradation, and bench scale parameters. Seven borings will be sampled for these parameters. Hydropunch™ samples will be collected from all seven borings for biodegradation parameters. Geotechnical soil samples will be collected from four of the seven locations. Two of the locations will be sampled for soil and groundwater to be used in the bench scale test. The proposed locations are shown on Plate 1. Field and analytical procedures included in this Work Plan will follow the Arsenal *Quality Assurance Project Plan* (QAPP) (Forsgren Associates/Brown and Caldwell [FA/BC], 2001). The Expanded SI Site Safety and Health Plan will be used for this field investigation (BC, 2005).

4.1 Soil Sampling

Three borings will be logged for lithology. In addition, saturated soil samples representative of the shallow and deep water bearing zones will be collected from four locations to determine hydraulic conductivities and support bench scale testing. Soil sampling will be performed using a cone penetrometer testing (CPT) rig and a direct push soil sampler. The Expanded SI CPTs logs (Brown and Caldwell, 2005) have been used to determine depth intervals for soil samples to be collected from the proposed borings for the geotechnical and bench scale test samples.

- Lithologic Description: CPT logs are available from the previous investigations for borings B165HP001, SHMP2002, and B120HP002. A CPT log will be generated at the following locations that are not next to Expanded SI CPT locations.
    - B165HP006
    - B004HP004,
    - FS001HP015
    - FS001HP016
- Geotechnical Tests: Geotechnical tests will be conducted on soil samples to determine intrinsic permeability/hydraulic conductivity by American Society of Testing and Materials (ASTM) method D5084, total/air-filled porosity by American Petroleum Institute (API) method RP 40, moisture content by ASTM D2216, and total organic carbon by Walkley Black. The proposed locations, depths, analyses and rationale are provided in Table 4-1. The samples will be collected in plastic sleeves using a direct push sampler from multiple depths.

Table 4-1. Proposed Soil Sample Locations, Analyses and Sample Depths for Geotechnical Tests

Proposed Location	Sample Depth (ft bgs)	Analysis	Rationale
B165HP007	10, 35	API RP40 ASTM D2216 ASTM D5084 Walkley-Black	Locate next to B165HP001. Sample depths correspond to the clayey artificial fill (0 to 12 feet bgs) (shallow WBZ) and the deeper silt and clay (28 to 38 feet bgs) (deep WBZ).
B004HP004	10, 35, 65		Locate approximately 55 feet southeast of B004HP001 downgradient of the plume. Samples depths should re-evaluated based on a new CPT log. The proposed sample depths are based on B004HP003 and correspond to the clayey artificial fill (0 to 11 feet bgs) (shallow WBZ), Bay Mud (11 to 48 feet bgs), and the deeper silt and clay (48 to 73 feet bgs) (deep WBZ).
FS001HP014	37		Locate next to B120HP002. Sample depths correspond to the deeper silt (35 to 42 feet bgs) (deep WBZ).
FS001HP015	8, 35, 40		Locate approximately 50 feet NW of trench L001TR001 and 40 feet SW of trench L001TR007. Samples depths should re-evaluated based on a new CPT log. The proposed sample depths are based on FS001HP008 and correspond to the clayey artificial fill (0 to 8 feet bgs) (shallow WBZ), Bay Mud (8 to 37 feet bgs), and the deeper silt and clay (37 to 42 feet bgs) (deep WBZ).

API RP 40 = total/air-filled porosity
ASTM D5084 = intrinsic permeability/hydraulic conductivity
WBZ = water bearing zone
ASTM D2216 = moisture content
Walkley Black = total organic carbon

- Bench Scale Test: A bench scale test is an important part of the RI/FS process since it provides a relatively quick and inexpensive way to evaluate a remedial technology for a particular site. Samples of contaminated soil or groundwater are sent to a laboratory where the remedial technology is applied and monitored under controlled conditions. The bench scale test provides an indication of the technology's effectiveness to remediate the contamination, remediation rate, cost of application, and any undesirable side effects. The results can be used to evaluate an alternative in the FS or determine if a pilot test should be conducted in the field.

  Two bench scale soil samples will be collected. An aliquot of soil will also be analyzed by EMAX Laboratories for metals by United States Environmental Protection Agency (USEPA) Methods 6000/7000 series to determine the ambient concentrations. The exact metals and analyses are listed in Table 4-2. The purpose of the metals testing is to complement the bench scale test to determine if metals in soil would also have the potential to mobilize in groundwater. Using the same equipment and sleeves as the geotechnical samples, one soil sample will be collected from the shallow and deep water bearing zones. These plastic sleeves will be capped and submerged in a 1-liter plastic bottle that contains groundwater collected as described in Section 4.2. The proposed locations, depths, analyses and rationale are provided in Table 4-2.

Table 4-2. Proposed Soil Sample Locations, Analyses and Sample Depths for Bench Scale Test in Soil

Proposed Location	Sample Depth (ft bgs)	Analysis	Rationale
B165HP007	10	Enhanced Bioremediation Bench Scale Test and Metals*	Locate next to B165HP001. Sample depth corresponds to the shallow water bearing zone.
FS001HP014	37		Locate next to B120HP002. Sample depth corresponds to the deep water bearing zone.

*For soil, metals consist of antimony, barium, beryllium, total chromium, cobalt, copper, manganese, molybdenum, nickel, silver, tin, vanadium and zinc by 6010B, cadmium and lead by 6010B ICP trace, arsenic by 7060A, selenium by 7740, thallium by 7841 and mercury by 7471A. These analyses will be performed in accordance with the Benicia Arsenal QAPP (FA/BC, 2001).

4.2 Groundwater Sampling

Groundwater samples will be collected from seven locations (B165HP006, B165HP007, SHMPZ002, B004HP004, FS001HP014, FS001HP015, and FS001HP016) using a Hydropunch™ for analysis of biodegradation parameters and to support the bench scale testing. Groundwater samples for biodegradation analysis will be collected from the shallow and deep aquifers that represent conditions upgradient of, within, and downgradient of the contaminant plume and analyzed for biodegradation parameters. These samples will be collected using a disposable bailer in accordance with procedures in the Benicia Arsenal *Quality Assurance Project Plan* (QAPP) for groundwater sampling (FA/BC, 2001). The results will be evaluated to determine whether TCE biodegradation has or continues to occur at the study location. In addition, groundwater samples representative of the shallow and deep water bearing zones will be collected to support bench scale testing.

- Biodegradation Parameters: To collect groundwater samples for biodegradation analysis, six Hydropunch™ borings will be drilled at locations shown on Plate 1. The other location is piezometer SHMP2002. The sampling locations were chosen to represent groundwater conditions upgradient of, within, and downgradient of the plume associated with Building 165 and Building 120. Four groundwater samples will be collected from the shallow water bearing zone near Building 165 and three groundwater samples will be collected from the deep water bearing zone near Building 120. As shown in Plate 1, the sampling locations at Building 165 represent the following areas:

  - Upgradient or lateral locations that are not impacted by the plume;
  - The most contaminated portion of the water bearing zone, generally referred to as the "source area";
  - Downgradient from the source area but still in the dissolved contaminant plume; and
  - Downgradient from the dissolved contaminant plume.

  At Building 120, sampling locations are proposed in the most contaminated portion of the deep water bearing zone, downgradient from the source area and downgradient of the dissolved contaminant plume. A sampling location could not be proposed upgradient of the contaminant plume because there is no upgradient location of the contaminant plume. Building 120 is located on the boundary between the Highlands, where no groundwater is present. A list of the proposed biodegradation parameters to be measured for this study is listed in Table 4-3 along with the interpretation gained from each parameter. The proposed locations, depths and rationale for groundwater samples analyzed for the biodegradation parameters are provided in Table 4-4. The methods, containers and preservative for the analyses proposed for the biodegradation parameters are listed in Table 4-5. The analyses presented are recommended by the USEPA in the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA, 1998).

Table 4-3. Parameters for Chlorinated Solvent Biodegradation Assessment in Groundwater

Parameter	Interpretation
Dissolved oxygen	value will indicate if reductive pathway is suppressed by oxidizing conditions
Nitrate	generally utilized first after dissolved oxygen has been depleted; at high concentrations may compete with reductive pathway
Manganese (IV)	utilized as the electron acceptor once nitrate concentrations are depleted; utilization of manganese (IV) as an electron acceptor results in the formation of the more soluble former (manganese II)
Iron II	The next electron acceptor once manganese (IV) is depleted; indicates a possible reductive pathway
Sulfate	at high concentrations may compete with reductive pathway
Sulfide	indicates a possible reductive pathway
Methane	indicates whether vinyl chloride will accumulate or oxidize
ORP	indicates oxidizing or reducing conditions
pH	indicates whether groundwater provides an optimal environment for reductive dechlorination
Temperature	at >72°F biochemical process is accelerated
Chloride	indicates final product of chlorinated solvent reduction.
Ethane/Ethene	indicates presence of a daughter product of vinyl chloride/ethene biodegradation
Alkalinity	indirect measure of carbon dioxide because it results from the interaction of carbon dioxide and saturated soil
Total Organic Carbon	Indicates the presence of electron donors that may support degradation processes
VOCs	daughter products of TCE indicate reductive dechlorination is occurring

ORP = oxidation reduction potential
TCE = trichloroethene
VOCs = volatile organic compounds

Table 4-4. Proposed Soil Sample Locations, Sample Depths, and Rationale for Groundwater Biodegradation Test

Proposed Location	Sample Depth Interval (ft bgs)	Rationale
B165HP006	10-15	Locate approximately 150 feet northeast of B165AHP002 upgradient of the shallow and deep contaminant plumes. Sample depth corresponds to the shallow water bearing zone (WBZ).
B165HP007	10-15	Locate next to Expanded SI CPT location B165HP001 in the most contaminated portion of the shallow water bearing zone at Building 165.
SHMPZ2002	10-15	Locate downgradient from the Building 165 source area but still in the dissolved contaminant plume. Sample depth corresponds to the shallow WBZ.
B004HP004	10-15	Locate approximately 55 feet southeast of B004HP001 downgradient of the contaminant plume. Sample depth should re-evaluated based on a new CPT log. Sample depth corresponds to the shallow WBZ.
FS001HP014	35-42	Locate next to B120HP002 in the most contaminated portion of the deep water bearing zone at Building 120. Sample depth corresponds to the deep WBZ.
FS001HP015	37-42	Locate approximately 50 feet northwest of trench L001TR001 and 40 feet southwest of next to trench L001TR007 but still in the dissolved contaminant plume. Sample depth should re-evaluated based on a new CPT log. The proposed sample depth is based on FS001HP008 and corresponds to the deep WBZ at 37 to 42 feet bgs.
FS001HP016	37-42	Locate approximately 170 feet southwest of FS001HP008 downgradient of the shallow contaminate plume and within the deep contaminant plume. Sample depth should re-evaluated based on a new CPT log. The proposed sample depth is based on FS001HP008 and corresponds to the deep WBZ at 37 to 42 feet bgs. NOTE based on a new CPT log for FS001HP003, located approximately 90 feet east of proposed location FS001HP016, the deep WBZ is from 60 to 84 feet bgs.

Table 4-5. Proposed Biodegradation Methods, Containers and Preservatives

Parameter	Method	Number of Containers and Container Type	Preservative
Dissolved oxygen	Field meter with flow thru cell	Not applicable	Not applicable
Nitrate/Sulfate/Chloride	E300	One 500-ml poly	None/filtered
Sulfide	E376.3	One 250-ml poly	NaOH and Zinc Acetate
ORP	Field meter	Not applicable	Not applicable
pH	Field meter	Not applicable	Not applicable
Temperature	Field Meter	Not applicable	Not applicable
Methane/Ethane/Ethene	RSK175	Three 40-ml glass vials	HCL
Manganese IV	Field Test Kit or USEPA 200.7	Not applicable	Not applicable
Alkalinity/Iron II	E310.1/SM3500	One 500-ml poly	None/filtered
Total Organic Carbon	9060	One 500-ml poly	H_2SO_4 or HCl
VOCs	SW8260B	Three 40-ml glass VOAs	HCL

HCL = hydrochloric acid
H_2SO_4 = hydrosulfuric acid
ORP = oxidation reduction potential
VOCs = volatile organic compounds

Bench Scale Test: Groundwater samples will be collected from boring B165HP007 in the shallow water bearing zone and from boring FS001HP014 in the deep water bearing zone. The groundwater sample will be collected in a 1-liter bottle so that the soil sleeves can be submerged as described in Section 4.1. The two boring locations were selected as the sampling points to collect groundwater for the bench scale test because they contained some of the highest TCE concentrations. The bench scale test will be more conclusive with significant TCE concentrations to treat.

The samples will be stored and shipped in chilled coolers. No other preservatives are required for this sample. The proposed locations, depths and rationale for groundwater samples analyzed for the bench scale test are provided in Table 4-6.

Table 4-6. Proposed Groundwater Sample Locations, Analyses and Sample Depths for Bench Scale Test

Proposed Location	Sample Depth (ft bgs)	Analysis	Rationale
B165HP007	10-15	Enhanced Bioremediation Bench Scale Test	Locate next to B165HP001. Sample depth corresponds to the shallow water bearing zones. Detected one of the highest TCE concentrations (32,000 ug/L) at B165HP001 in the shallow water bearing zones during the Expanded SI.
FS001HP014	35-42	Enhanced Bioremediation Bench Scale Test	Locate next to B120HP002. Sample depth corresponds to the deep water bearing zone. Detected one of the highest TCE concentrations (1,100 ug/L) at B120HP002 in the deep water bearing zone during the Expanded SI.

4.3 Monitoring Well and Observation Point Installation for Pump and Recovery Tests (if necessary)

A second step may be used to further refine the hydraulic conductivity values by conducting a pump and recovery test. Based on previous purging activities from existing piezometers screened across the shallow water bearing zone, yields are very low, in most cases piezometers are bailed dry with less than 1 inch of groundwater recovery within 2 hours. Because of these facts, a pumping or recovery test conducted in the shallow water bearing zone would not provide valuable data. Therefore, the first step is to collect saturated soil samples from the shallow and deep water bearing zones and have them tested to determine hydraulic conductivity through geotechnical analysis (see Section 4.1).

The hydraulic characteristics of the deep water bearing zone is unknown and there is a possibility that the groundwater could be pumped at a rate where the calculated hydraulic conductivity would be representative of the surrounding sediments. In areas where the deep water bearing zone is impacted near Building 120, if the average of the laboratory hydraulic conductivity values (see Section 4.1) is greater than 1×10^{-3} centimeter per second (typical of a silty sand), then a second step will be conducted to further refine those values. This step includes the following activities:

- Install one groundwater monitoring well and two observation points to support pumping and recovery testing;
- Conduct a 8 hour pumping and 72 hour recovery test in the deep water bearing zone to determine hydraulic conductivity.

Theses activities are described below.

4.3.1 Well Installation

One monitoring well and two observation points will be installed to support pumping and recovery testing. The proposed locations of the monitoring well and observation points will be centered around FS001HP016.

Prior to drilling, a drilling permit will be obtained from Solano County. Underground Service Alert will be notified at least 48 hours in advance and a utility clearance will be conducted in the investigation area. The borehole for installation of the groundwater monitoring well will be drilled to the top of the sandstone, which is estimated to be about 42 feet bgs. A licensed drilling subcontractor, using a truck-mounted drilling rig equipped with 8-inch diameter hollow stem augers will drill the borehole.

After drilling, a groundwater monitoring well will be constructed by lowering a 2-inch diameter Schedule 40 poly vinyl chloride (PVC) casing into the soil boring. The top of the screen and the filter pack will be located no higher than 37 feet bgs, the contact between the deeper water bearing zone and the Bay Mud with an anticipated screen interval from 38 to 42 feet bgs. Screen size and filter pack material will be determined based on the soil materials encountered during drilling but are anticipated to consist of 0.020 slotted screen and No. 3 sand. A PVC cap will be installed at the bottom of the screen. Filter pack will be placed to approximately 1 foot above the top of the screen interval.

After placement, the groundwater monitoring well will be bailed and surged to settle the filter pack and more sand added as necessary to return the level to a height of 1 foot above the top of the screen. A 2 to 3 foot thick seal of bentonite pellets will then be placed above the sand pack. After placement, water will be added to hydrate the pellets. The groundwater monitoring well will then be grouted with neat cement, leaving adequate space for placement of the above ground completion. The top of the groundwater monitoring well will be enclosed in a stove-pipe vault with locking cap, which will be held in place with concrete. A waterproof, locking well cap will be used to secure the top of the groundwater monitoring well. The well will be fully developed after completion.

The casing and development activities will be conducted in accordance with QAPP (FA/BC, 2001).

4.3.2 Pumping and Recovery Tests

The purpose of the pumping and recovery tests is to determine the hydraulic conductivity of the deep water bearing zones near Building 120. The hydraulic conductivity values will be used to estimate the rate of capture of the impacted groundwater in the area, and to estimate the time of travel for contaminants and groundwater.

Each pumping and recovery testing location will have enough observation points (up to two) to measure water level drawdown. The pumping and recovery tests will be conducted for eight hours or until the drawdown in the well reaches equilibrium, whichever is achieved first. Recovery of the pumped well will be measured for up to 72 hours or until 90% recovery is achieved. Transducers will be used to measure the water levels in the pumped well and the observation points. A background transducer will also be used to measure the effect of tides or other barometric changes in the wells. Detailed description of the procedures to be used for these tests is provided in Appendix A.

4.4 Bench Scale Tests of Enhanced Bioremediation

Bench scale tests will be conducted on soil and groundwater samples from the shallow and deep aquifers to evaluate whether TCE biodegradation can be enhanced or accelerated. Specifically, the bench scale tests will determine whether the soil contains microbes with the ability to reductively dechlorinate the TCE in a reasonable period of time with the assistance of Metals Remediation Compound (MRC) as the hydrogen source.

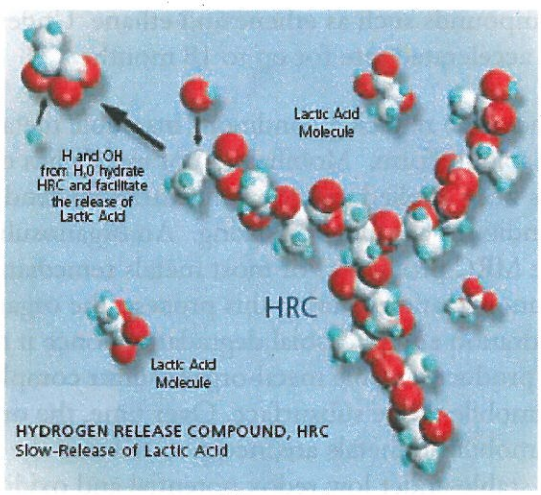


Diagram 1
Source: Regenesis Bioremediation Products, Inc.

4.4.1 Reductive Dechlorination and Metals Immobilization Background

MRC is supplied by Regenesis Bioremediation Products, Inc. (Regenesis) as a viscous liquid for direct injection into contaminated groundwater and saturated soils. The material is similar to Hydrogen Release Compound (HRC) by Regenesis, which is usually associated with reductive dechlorination. MRC is comprised of a polylactate polymer and a benign organosulfur compound

allowing for a controlled release of its active components for long-term chlorinated solvent and metals removal. This product slowly releases lactic acid upon contact with water (Diagram 1). This source of lactic acid is then metabolized by microbes to produce hydrogen which is then used in a natural process known as reductive dechlorination (Diagram 2). Reductive dechlorination results in the step-by-step biological degradation of chlorinated contaminants.

As discussed, reductive dechlorination is a term used to describe the mechanism by which chlorinated hydrocarbons are biologically degraded under anaerobic conditions. In this natural process, anaerobic microbes substitute hydrogen (H) for chlorine (Cl) on chlorinated contaminant molecules, thus dechlorinating the compound. Being a natural process, reductive dechlorination usually proceeds at very slow, unsustainable rates. HRC increases the rate of dechlorination up to several orders of magnitude, rapidly taking the contaminant through a step-wise dechlorination process that ultimately results in the production of non-toxic compounds such as ethene and ethane. Under the influence of HRC, this process may continue at an accelerated rate for up to 18 months.

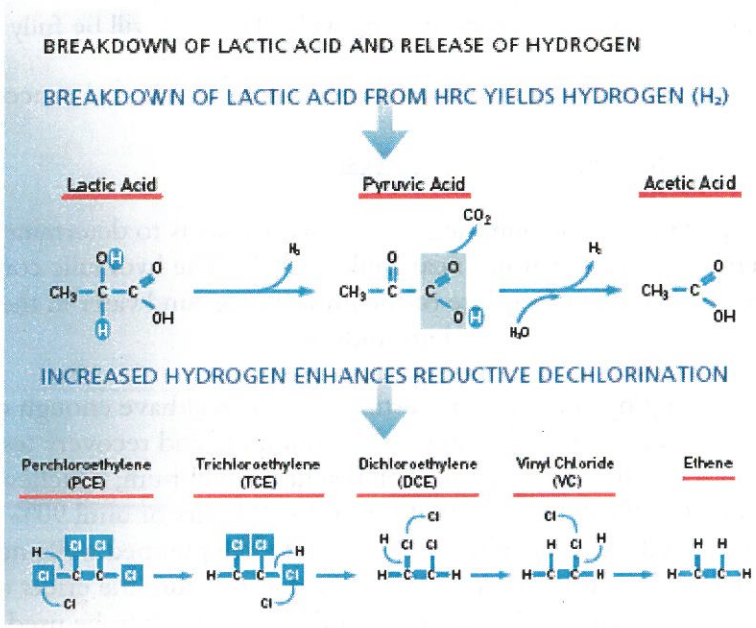


Diagram 2
Source: Regenesis Bioremediation Products, Inc.

Under the reducing conditions insoluble metals (e.g. arsenic) present in the soil may be reduced to its soluble form. Mobilization of metals has occurred at some sites where enhanced bioremediation has been applied, but the concentrations tend to decrease downgradient of the plume where conditions are more oxidizing. An organosulfur compound is added to the HRC product to form the MRC product. For most metals remediation with MRC, the primary process of removal is immobilization. During this process, the organosulfur compound in MRC is released upon hydration and microbial degradation, once it contacts metal ions, the organosulfur compound reacts to produce a stable metal-organosulfur complex. This complex sorbs strongly to soil and is immobile in the subsurface. Over time, the organic portion of the complex is biodegraded and the immobilized metals are incorporated into the soil matrix as sulfide solids. The sulfide solids tend to be stable under low redox potential and oxidizing conditions.

4.4.2 Bench Scale Test Description

The bench scale tests will be conducted by Regenesis in partnership with Applied Power Concepts, Inc. on the soil and groundwater samples collected from the shallow and deep water bearing zones. The following is a description of the bench scale test.

The soil samples will be homogenized by manual stirring and a 10-gram aliquot will be added to each of the 15 test tubes of approximately 200-ml total volume. In all of the test tubes, 150 ml of distilled water containing approximately 15 mg/L of TCE solution will be added along with 1.5 grams of glycerol polylactate MRC.

TCE and its daughter products are measured by gas chromatography using a silica column on a SRI GC outfitted with both a photoionization detector (PID) and a flame ionization detector (FID). Toluene will be used as the internal standard in a gas phase (head space) measurement. The hydrocarbons methane and ethane are also detected on this column, but the column conditions are not adequate to allow separation and quantification of the mixed hydrocarbons due to the presence of methane from the MRC degradation process.

The organic acids, lactic, pyruvic, acetic, propionic and butyric will be measured using liquid chromatography with a Restek C18 column and an ultraviolet detector. Citric acid will be used as the internal standard. In this test the column will be quantitatively calibrated for lactic acid only.

Bacterial counts will be made using standard plate pour techniques. Three populations will be measured. The first population will be aerobic total plate counts (TPC) based on a glucose nutrient agar plate. This is the normal test used for groundwater. The results will be reported as the number of colony forming units (CFU) per ml. Regenesis uses the same test media for anaerobes but incubates the plates anaerobically under nitrogen. These counts will be reported as anaerobic TPC. Finally, Regenesis will also use the standard AWWA (American Water Works Association) test for sulfate reducing bacteria (SRB) content in the water. The rationale for this test is that the SRBs thrive at a redox potential that is close to the optimum for dechlorination. Although the dechlorinators are not necessarily SRBs, the presence of SRB indicates that aquifer conditions may be suitable for reductive dechlorination. It is generally agreed that high rates of dechlorination, especially for recalcitrant chlorinated materials (e.g. dichloroethane) are expected at oxidation reduction potentials in the –200 mv to –250 mv range, the range in which SRBs thrive.

Metals will be analyzed in groundwater to determine if the reducing conditions created by the addition of MRC will mobilize metals, such as arsenic. If arsenic is mobilized, the test will be extended in time to determine the attenuation rate of arsenic.

5.0 SAMPLING METHOD REQUIREMENTS

The Standard Operating Procedures (SOPs) to be implemented during this project are listed in Table 5-1. These SOPs are located in Appendix F of the QAPP for environmental investigations at the former Arsenal (FA/BC, 2001). Requirements for sample containers, preservation methods and analytical holding times are also included in the QAPP.

Table 5-1. Applicable SOPs for the Treatability Study

SOP No.	SOP Title	Applicable	Not Applicable	Specific Aspects of SOP to be Implemented for this Work Plan
1.0	Field Logbook	X		All
2.0	Boring Log Development	X		All
3.0	Field Classification and Description of Soils	X		All
4.0	Sample Management	X		All
5.0	Field Measurement of Organic Vapors	X		1. A photoionization detector (PID) Model 580B OVM or equivalent will be used instead of a FID. 2. Direct reading colorimetric indicator tubes TCE (VOC related sites) will be used as prescribed in the SSHP
6.0	Utility Clearance	X		All except, no lock-out/tag-out procedures necessary for this Work Plan
7.0	Collection of Soil Samples	X		Depth-discrete soil samples will be collected using thin-walled tubes or ring-lined samplers, as appropriate.
8.0	XRF Soil Analysis		X	
9.0	Packing and Shipping of Environmental Samples	X		All
10.0	Sample Preservation and Analysis Methods	X		Subcontracting laboratories will provide preserved sample containers. Preserved groundwater samples from previous investigations have been checked for proper pH. These results indicate that correct pH aliquots are provided in the sample containers. Therefore, only periodic pH checks will be conducted. Preservatives are available at the site and will be added, if necessary.
11.0	Sampling Equipment Decontamination	X		All
12.0	Immunoassay		X	
13.0	*In Situ* Groundwater Sampling	X		Hydropunch® samples will be collected as part of this investigation.
14.0	Borehole Abandonment	X		Boreholes will be "plugged" according to this SOP.
15.0	Well Development	X		If wells are installed, then development shall be performed using the procedures for Microwell/Monitoring Wells.
16.0	Surface Water Sampling		X	
17.0	Groundwater Purging and Sampling	X		Disposable bailers attached to industrial-type twine will be used to collect groundwater samples from wells.
18.0	Geophysical Testing	X		For this utility clearance, ground penetrating radar and electromagnetic line locating methods will be used.

Table 5-1. Applicable SOPs for the Treatability Study (continued)

SOP No.	SOP Title	Applicable	Not Applicable	Specific Aspects of SOP to be Implemented for this WORK PLAN
19.0	Soil Gas Sampling		X	
20.0	Sludges and Sediments		X	
21.0	Well and Piezometer Installation	X		All
23.0	Field Measurement of Temperature	X		All
24.0	Field Measurement of Specific Conductance	X		All
25.0	Field Measurement of Water Levels	X		All
26.0	Photographic/Video Documentation	X		All
27.0	Drilling	X		If wells are installed, hollow stem auger drilling will be implemented.
28.0	Cone Penetrometer Drilling and Sampling Procedures	X		Cone Penetration Testing (CPT) methods will be use to collect lithologic data and groundwater samples.
29.0	Trenching		X	
30.0	Methanol Preservation for Volatile Organic Compounds in Soils		X	
31.0	Field Classification and Description of Rocks	X		All
32.0	Field Sampling with EnCore™		X	

XRF = X-Ray Fluorescence

6.0 INVESTIGATION DERIVED WASTE

The purpose of this section is to describe the specific procedures to be used for collection, characterization, storage, containerization, transport and disposal of IDW. The Arsenal-wide IDW Plan is described in detail in Section 4.5 of the *Investigation Workplan* (FA/BC, 1999).

The IDW generated by this Treatability Study will include soil from drilling, decontamination rinsate from drilling equipment, disposable protective clothing and ground covers, and groundwater generated during sampling. Soil and groundwater will be contained in the containers specified in the QAPP (FA/BC, 2001).

The soil and groundwater containers will be placed at a temporary staging area in Area I. This area is a secure site. Heavy equipment will be decontaminated near the staging area, according to procedures described in the QAPP (FA/BC, 2001). Decontamination of sampling equipment during groundwater purging and drum sampling activities will be staged at the Brown and Caldwell Benicia Arsenal Field Office at 942 Tyler Street, Benicia, California. If the pump test is performed, poly tanks will temporary located at the pumping well.

Excess disposable wastes derived from sampling, such as personal protective equipment, gloves and bailers, will be disposed by the local garbage service for the area.

Soil and water samples will be collected for the purpose of IDW characterization. Additional analytical work may be required based on requirements of the disposal facility. Soil derived from drilling and sampling activity will be segregated, if possible, based on visual and instrument readings from a PID and by the potential contaminant. For example, wastes with potential solvent impacts will be segregated from potential fuel-only impacts.

When IDW is characterized, the appropriate manifests will be generated and signed by USACE for transport to an off-site disposal state approved facility.

7.0 REFERENCES

Brown and Caldwell. 2005. *Expanded Site Inspection Report for the Benicia Arsenal.* Prepared for the U.S. Army Corps of Engineers, Sacramento, California. Draft. April.

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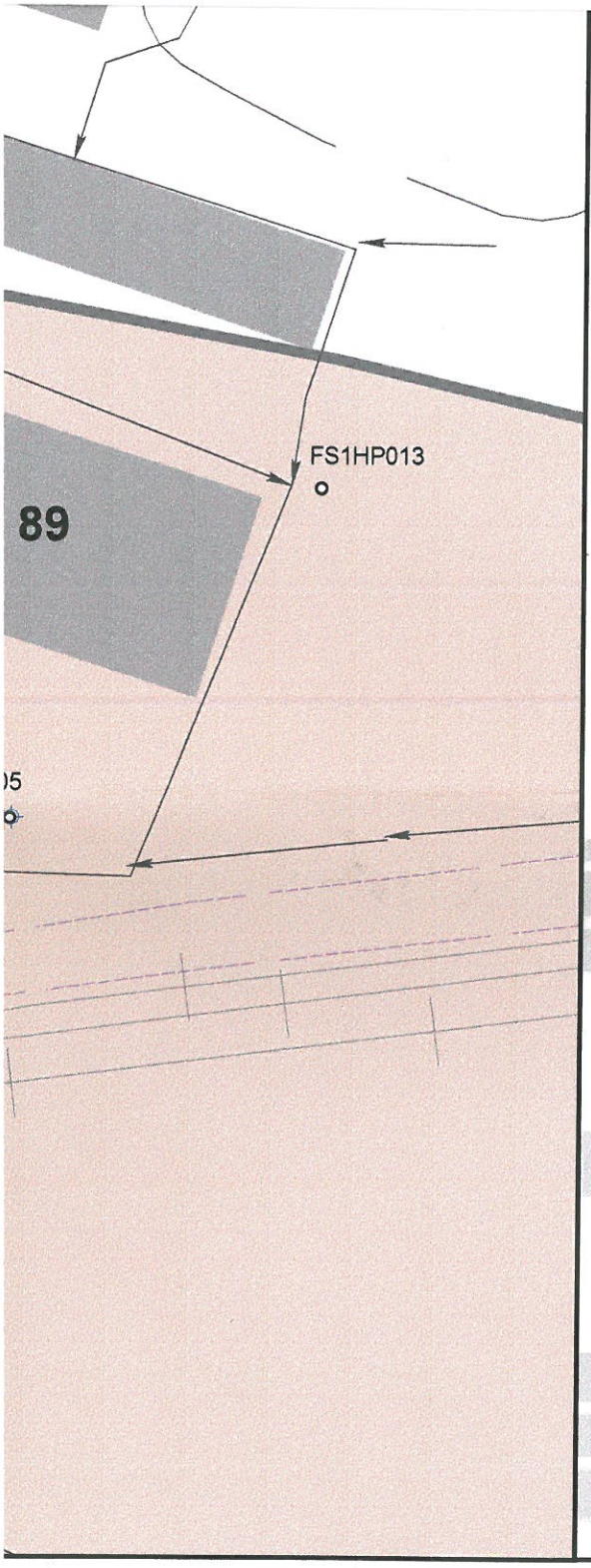
USEPA. 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. September. EPA/600/R-98/128

AVAILABLE FOR VIEWING
IN THE CITY ATTORNEY'S OFFICE.



PA Sites (Former building or site)

Sample Location	
Depth (ft. bgs.)	**Depth (ft. bgs.)**
Value	Value

Notes:
1- Unless otherwise noted, groundwater samples were collected at depths of < 15 ft bgs.

2 - All detected results are shown, including older data.

3 - Plumes delineated to non-detect

4 - * Denotes locations with NO detectable concentration at shallow and deep groundwater.

Plate 1

Trichloroethene Detected in Groundwater and Proposed Treatability Locations

SITE:

Benicia Arsenal, Benicia, California

PROJECT: 25952

DATE: 5/26/2005

BROWN AND CALDWELL

APPENDIX A

Aquifer Test Procedures

APPENDIX A

AQUIFER TEST PROCEDURES

This section discusses the applications and limitations of aquifer tests that are commonly used during site investigations. The applicable aquifer test selected for a site investigation will be based on data needs and a preliminary understanding of aquifer characteristics. Pumping tests are performed in wells to provide data from which aquifer transmissivity and storage coefficient can be calculated.

REQUIRED MATERIALS FOR PUMPING AND RECOVERY TEST

The materials required for aquifer testing differ by the methods chosen to use for the testing. The minimum required materials include:

- Bound field notebook.
- Lithologic logs of all of the wells to be tested.
- Construction log, or construction table that includes the screen zone interval of all wells to be tested.
- Water level indicator.
- Decontamination equipment for the water level meter, transducers, pump or bailer.
- Pump (capable of pumping at the desired rate),
- Control box for the pump, used to manipulate the pumping rate,
- Power supply (generator or electrical outlet and extension cords),
- Discharge hose,
- Rope for pump.
- Watch or stop watch.
- Personal protective equipment if necessary.
- Pressure transducer and data logger, or pressure transducers and laptop computer.
- Groundwater sampling equipment and bottles.
- Pump of the proper size that can produce the flow rates needed for the tests.
- Bucket to measure flow rates.
- Stopwatch to time the flow rate (gallons per minute)
- Totalizer to record number of gallons pumped
- Flow meter to monitor the flow rate.
- Storage for water extracted from wells for the tests (Baker Tank)
- Water quality instruments (e.g. pH, temperature, conductivity)

CONSTANT-RATE PUMPING, STEP-DRAWDOWN, AND RECOVERY TESTS

The most common test used to estimate the hydraulic properties of the aquifer material is the constant-rate pumping test. This test is performed by pumping a well at a **constant discharge rate** and recording the rate of drawdown in the pumping well and in the nearby observation wells. The number of wells required for a constant-rate pumping test are as follows:

- One pumping well,
- Preferably three observation wells, up gradient or cross gradient from the pumping well, and
- One background well.

The pumping rate at which the test is conducted can be estimated using equations for steady-state flow and estimates of the permeability coefficient for the formation as are discussed in numerous references (Walton, 1987; Freeze and Cherry, 1979; Driscoll, 1986; Todd, 1980). **Step-drawdown tests** can be performed prior to constant-rate to **establish the pumping rate** that can be sustained in the aquifer. If time and money do not allow for a step-drawdown test, then the development log of the pumping well in conjunction with some estimates of the pumping rate based on the lithology of the aquifer material will be helpful in assessing the pumping rate for the test.

A rule of thumb, if the test well is screened in relatively high-permeability material (i.e., $K = 10^{-1}$ centimeters per second [cm/sec]), only a fraction of the drawdown will occur in an hour. If it is screened in a low-permeability material (i.e., $K = 10^{-7}$ cm/sec), approximately 50 to 100 percent of the total drawdown will be produced in an hour of pumping. The pumping information should be used to estimate a discharge rate that is low enough to prevent pumping the well dry before the end of the test.

Step-Drawdown Test

The step-drawdown test is a single-well test developed to examine the performance of a well with turbulent flow (well efficiency). The step-drawdown test is conducted by pumping a well at a constant discharge rate for relatively short periods of time until the drawdown stabilizes (one step) (Driscoll, 1986, p 223). The pumping rate is then increased to a higher constant-discharge rate and pumped until the drawdown stabilizes once more. This process is then repeated through at least 3 steps, which should be of equal duration, from about 30 minutes to 2 hours each (Kruseman and de Ridder, 1991). The pumping time for each step is generally kept the same to simplify calculations of aquifer parameters from the test results. A step-drawdown test is commonly performed before a constant-rate pumping test to assess an optimum pumping rate for the test. The step-drawdown test should be performed at least 24 hours before the pumping test to allow the well sufficient time to fully recover (Driscoll, 1986).

The procedure followed for each successive step in a step-drawdown test is the same as the procedure for the constant-rate pumping test (please see Constant-Rate Pumping Test Procedures), except for the duration of the pumping.

Performing a preliminary step-drawdown test is the best way to select the pumping rate for either a confined or an unconfined aquifer-pumping test. For an unconfined aquifer the step progression should be least 20 percent drawdown. For a confined aquifer, the maximum yield is approached

when a step produces a drawdown increase significantly larger, in proportion, than previous steps, or when drawdown is in danger of dropping below the top of the confining unit for the aquifer.

The likely range of pumping rates for the step-drawdown test can be estimated from the development log for the well. Sometimes the log of pumping and drawdown during the well development provides enough information to proceed directly to the constant-rate aquifer test, particularly if overpumping is part of the development procedure, and this pumping illustrates the required relationship between pumping rates and drawdown.

Constant-Rate Pumping Test Procedures

The constant-rate test involves the following steps.

Establish background well. A background well should be established that is far enough from the pumping test that it will not be effected by the cone of influence set up by the pumping well. The background well should be monitored using a pressure transducer (readings every 5 or 10 minutes) or frequent water level indicator measurements (every hour) prior to the test (several days if possible) and during the pumping and recovery part of the test. The water levels collected from the background well can be used to correct the water level drawdown measurements from the observation wells if necessary (Walton, 1987).

Measure water levels. A complete round of water levels should be collected from all of the wells on the same day (synoptic water levels), even the wells that are not used for the test, in order to assess the background groundwater gradient. Water levels may be measured in all test wells for 1 or 2 days prior to starting the pumping test. Depth to water should be referenced to surveyed elevations at the top of each well casing. In coastal areas, pre-pumping levels should be recorded at constant intervals to observe possible tidal influence.

Sketch equipment layout. The test equipment layout, including locations and depths of pump and pressure transducers, should be sketched or described in the field notebook prior to starting the test. It is helpful to photograph the layout of the equipment for future reference.

Install and program the transducers. The pressure transducers should be installed into the pumping well and observation wells at **least ½ hour prior** to the start of the test. The transducers need to equilibrate to the temperature of the water in the well. Prior to the start of the test the transducers need to be programmed to collect the proper time intervals of pressure and or temperature data. The clock time for all the transducers should be synchronized to the same time. The transducers can be preprogrammed to start collecting data at a selected time or they can start collecting data and later the elapsed time can be adjusted based on the start of the pumping test. A static water level should be collected from the transducer and from the water level indicator prior to the test. These data should be recorded in the field notebook.

Install and test the pump. A pumping rate for the test that yields adequate drawdown should have been established days before the test in order for the well to recover fully. Install the pump in the well, the pump should be located in the screen zone. Secure the pump to the top of the well. Several hours before the test the flow rate for the pump should be checked using the control box, a bucket a stopwatch should be used to calibrate the flow meter.

Start the pump. After the water levels have stabilized (wait at least 24 hours or longer if the well has been pumped previously), start pumping at a constant rate. Note the start time for the pump in the field notebook.

Record drawdown. Using a digital data logger or manually using water-level indicators, record the depth to water in the pumping well and observation wells at the following suggested intervals. Transducers in the observation wells can be programmed to collect water level information every five minutes for the duration of the test, since it is not certain when the cone of depression will reach the observation wells. Water level measurements should be collected by hand using water level indicators in the pumping well and in at least one observation well during the first hours of the tests.

Monitor discharge rate. The discharge rate should be measured at least once per hour during the first hours of the test and adjusted as needed to assure that the rate is constant. The discharge rate should be measured at least once a day after the start of the test to assess that it is maintaining a constant rate. Discharge rates can be measured using a bucket and stopwatch. Compare this method to the flow meter and note results in the field logbook. Totalizer readings and the time of the readings should be recorded in the field logbook several times a day.

Record barometric pressure. Barometric pressure should be recorded before, during, and after a pumping test, and ambient weather conditions should be noted throughout the test, particularly if they change during the course of the test.

Note changes or disruptions. Describe any changes in pumping rate or disruptions of the test, and the times they occur in the field notebook.

Shut off pump and begin recovery test. Note the time pumping is terminated and continue recording water levels according to the same schedule of water-level measurement intervals described for the drawdown portion of the test. Record water levels until the groundwater levels in the observation wells stabilize, or until the plot of drawdown versus the logarithm of time is a straight line for each observation well.

Record Field Observations

It is important to document the actual procedures for each aquifer test in the field notebook. This information is invaluable when analyzing the data for aquifer parameters. An example of aquifer test data that should be recorded in the field notebook are listed on the field data sheet in Attachment A, and summarized as follows:

- Name of well, measuring point elevation, total depth of the well,
- Depth of transducer and/or pump in the well,
- Static water level elevation and static transducer pressure reading.
- Time that the pumping test began.
- Pumping rate of the well and how the rate was tested (e.g. using a bucket and timer),
- The flow meter reading,
- Water level indicator readings during the test.
- Any disruptions in the test (e.g. pump shuts off) and the time they occurred.

- Observations of weather, temperature, and any precipitation.
- Names of personnel conducting the test.
- Time the pump was shut off and recovery started.

QUALITY ASSURANCE/QUALITY CONTROL

Total gallons pumped should be noted, at least daily, from the totalizer on the pump outlet, to assess that the pumping rate is constant. The tally of the total amount of water extracted from a well during a pumping test can be used to check the pumping rate during the test. The amount of water divide by the period of pumping can be used as a general check of the rate of pumping. Pumping rates should also be checked daily during an aquifer pumping test using a bucket and stop watch method to check that the flow meter and control box for the pump are accurate.

WASTE DISPOSAL

If the pumping test is to be conducted in a contaminated aquifer, sampling, containment, storage, and disposal of the discharge water can be a major concern. Estimates of pumping rates and provisions for water sampling and disposal should be made during the design and costing phase of the test. If the water is not contaminated, discharge must be controlled to avoid interference with the test due to infiltration. Control might require containment or direction of discharge to storm drains or other surface disposal not resulting in infiltration of the test area. It may be necessary to obtain or rent a portable polyethylene tank to contain the pumped water until it can be disposed of properly.

REFERENCES

The following references, which may be consulted for more detailed information on aquifer testing, provide the basis for this procedure.

Driscoll, F.G. 1986. *Groundwater and Wells.* Johnson Division: St. Paul, MN.

Freeze, R. Allan and John A. Cherry. 1979. *Groundwater.* Prentice-Hall, Inc.

Todd, David Keith. 1980. *Groundwater Hydrology.* John Wiley and Sons.

Walton, W.C. 1987. *Groundwater Pumping Tests, Design and Analysis.* Lewis Publishers: Chelsea, MI.

ATTACHMENTS

A. Aquifer Pumping Test - Observation Well Form

Aquifer Test Data

Test Type: Constant rate _____ Constant Head _____ Slug test _____

Well type: Pumping _____ Observation _____

Pump on: Date _____ Time _____ (t_o)

Pump off: Date _____ Time _____ (t'_o)

Average Pumping rate: _____ gpm

Pump intake depth: _____ feet

Well radius or distance _____ feet

Water level measurement method _____

Tape No. _____ Transducer/airline depth _____

Transducer serial no. _____ Data file _____

Page _____ of _____

Job No. _____

Site _____

Well no. _____

Coordinates _____ N/S

_____ E/W

Measuring point _____

Elevation of measuring point _____ feet

Static water level elevation _____ feet

Recorded by _____

Q measurement method _____

Time data						Water level data			Q	
	Clock time									
Date	Hour	Min	Sec	Time since pump on (t) or off (t') (minutes)	t/t'	Depth to water (feet)	Correction or conversion	Water level change (feet)	Discharge measurement (gpm)	Remarks