Final
Operable Unit Carbon Tetrachloride Plume Groundwater Remedial Investigation/ Feasibility Study
Former Fort Ord, California

Volume I – Remedial Investigation

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Sacramento District
1325 J Street
Sacramento, California 95814-2922

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Michael Taraszki, PG, CHG
Principal Hydrogeologist

CERTIFIED HYDROGEOLOGIST
MICHAEL D. TARASZKI
No. 586
EXP. 12/06
STATE OF CALIFORNIA

Carlene Merey
Senior Principal Environmental Scientist

May 19, 2006

MACTEC Engineering and Consulting, Inc.
600 Grand Avenue, Suite 300
Oakland, CA 96510 - (510) 451-1001

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ACRONYMS AND ABBREVIATIONS

ACL	aquifer cleanup level
AE	average exposure
ARARs	Applicable or Relevant and Appropriate Requirements
ARCH	air rotary casing hammer
Army	U.S. Department of the Army
ASTM	American Society for Testing and Materials
bgs	below ground surface
BLM	Bureau of Land Management
BRAC	Base Realignment and Closure
btoc	below top of casing
Cal-EPA	California Department of Environmental Protection Agency
CDFG	California Department of Fish and Game
CDQMP	Chemical Data Quality Management Plan
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	chloroform
cfu/ml	colony forming units per milliliter
cis-1,2-DCE	cis-1,2-dichloroethene
CIW	Community Involvement Workshops
CME	Central Mine Equipment
cm/sec	centimeter per second
CNPS	California Native Plant Society
COC	chain of custody
COPC	chemical of potential concern
CRT	cathod ray tube
CT	carbon tetrachloride
1,2-DCA	1,2-dichloroethane
1,2-DCE	1,2-dichloroethene
DI	daily intake
DO	dissolved oxygen
DQO	data quality objectives
DTSC	Department of Toxic Substances Control
ELAP	California Department of Health Services Environmental Laboratory Accreditation Program
EPA	Environmental Protection Agency
EPC	exposure pont concentrations
ESA	Endangered Species Act
EW	extraction well
F	degrees Fahrenheit
FAAF	Fritzsche Army Airfield
FOD	frequency of detection
FORA	Fort Ord Reuse Authority
FO-SVA	Fort Ord—Salinas Valley Aquitard
FS	Feasibility Study
ft^2/day	square feet per day
GAC	granulated activated carbon
GC/MS	gas chromatography/mass spectrometer
GMS	groundwater modeling system

gpd/ft	gallons per day per foot
gph	gallons per hour
gpm	gallons per minute
GPR	ground penetrating radar
GPS	global positioning system
GWTS	Groundwater Treatment System
Harding ESE	Harding ESE, Inc. (formerly HLA; now MACTEC)
HHRA	Human health risk assessment
HLA	Harding Lawson Associates (now MACTEC)
HMP	Habitat Management Plan
HQ	Hazard quotient
K_d	distribution coefficient of an organic chemical
K_{oc}	distribution coefficient
K_{ow}	octanol-water coefficient
kW	kilowatt
LDC	Laboratory Data Consultant
LVDC	light vehicle driving course
MACTEC	MACTEC Engineering and Consulting, Inc.
MCL	maximum contaminant level
MCWD	Marina Coast Water District
MEK	methyl ethyl ketone
mg	milligrams
mg/kg	milligrams per kilograms
mg/L	milligrams per liter
MHz	megahertz
micoSiemens/cm	micoSiemens per centimeter
ml	milliliter
MNA	monitored natural attenuation
MP	multiple port
MPN	most probable number
MRWPCA	Monterey Regional Water Pollution Control Agency
MSL	mean sea level
MW	monitoring well
N_2	nitrogen
NAD 83	North American Datum of 1983
NT	not tested
NTU	nephelometric turbidity unit
O&M	operations and maintenance
OEHHA	Office of Environmental Health Hazard Assessment
ORP	oxidation/reduction potential
OU1	Operable Unit 1
OU2	Operable Unit 2
OUCTP	Operable Unit Carbon Tetrachloride Plume
PCE	tetrachloroethene
PDB	passive diffusion bag
PDS	passive diffusion
PS-CT-IW	bio-treatability pilot study injection well
psi	pounds per square inch
ppb (v/v)	parts per billion by volume
ppm	parts per million
ppm (v/v)	parts per million by volume

PVC	poly-vinyl chloride
QC	quality control
RA	Risk Assessment
RFD	reference dose
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RME	reasonable maximum exposure
ROD	Record of Decision
RWQCB	Regional Water Quality Control Board
SAR	sodium adsorption ratios
Sequoia	Sequoia Analytical
Shaw	Shaw Environmental, Inc.
slug	solid three-foot long PVC cylinder
SOP	standard operating procedures
SUMP	Site Use Management Plan
SVA	Salinas Valley Aquitard
SVE	soil vapor extraction
the slug	a solid 3 feet long PVC cylinder
TAH	total anaerobic heterotrophs
TCE	trichloroethene
TDS	total dissolved solids
THMs	trihalomethanes
TOC	total organic carbon
TROLL	In-Situ, Inc. Troll MP9000
µg/L	micrograms per liter
USACE	United States Army Corps of Engineers
USFWS	United States Department of the Interior, Fish and Wildlife Services
VC	vinyl chloride
VOC	volatile organic compound
WDC	Water Development Company

EXECUTIVE SUMMARY

This remedial investigation and feasibility study (RI/FS) presents evaluations and interpretations of a variety of geologic, chemical, and hydrogeologic data collected in an area of the former Fort Ord known as the Operable Unit Carbon Tetrachloride Plume or the OUCTP. This area includes underground, water-bearing zones or aquifers along with their surface expression. Several of these aquifers have measurable amounts of volatile organic compounds, primarily carbon tetrachloride. Carbon tetrachloride was presumably used at the former Fort Ord Army base as a cleaning solvent. The data collected to characterize these aquifers have then been used to assess the feasibility – or how difficult, time-intensive and expensive – to implement one of several options to remove or reduce carbon tetrachloride contamination in groundwater. This RI/FS has been undertaken as part of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) activities ongoing at the former Fort Ord by the United States Department of the Army (Army) under its Base Realignment and Closure (BRAC) program. The Army is the lead agency in a Federal Facilities Agreement (FFA) with the US Environmental Protection Agency (EPA), the California EPA (Cal/EPA) Department of Toxic Substances Control (DTSC) and the Cal/EPA Central Coast Regional Water Quality Control Board (RWQCB). The latter three agencies provide regulatory oversight for the project and review and approve all significant steps in the process. MACTEC has prepared this report for the United States Army Corps of Engineers (USACE) under Contract No. GS-10F-0157K in accordance with the scope of work dated March 8, 2002.

The objective of the cleanup will be to reduce the health risk, protect the environment, and protect the waters of the state from further degradation caused by the presence of carbon tetrachloride contamination in groundwater. A separate human health risk assessment is also presented as part of this RI/FS. This assessment uses recent groundwater chemistry analyses produced from water samples collected from monitoring and water supply wells in the study area.

Conceptual Model Elements

A conceptual model of the subsurface was developed that could be used during evaluation of different clean-up scenarios. It includes characterization – describing, quantifying, and theorizing about historical processes – of the soil, groundwater, and soil vapor. It also addresses the interpreted travel path of the contamination following its apparent surface release. After describing how the current conditions were developed, the present-day receptors for this contamination are identified.

The Carbon Tetrachloride Source

The source of the carbon tetrachloride contamination remains unknown. No records exist to indicate exactly when, how often, or how much carbon tetrachloride (CT) may have been used, stored, or disposed of. However, by delineating the areas of highest concentration in the groundwater and in the soil vapor (or "air" within the pore spaces of the unsaturated subsurface), the apparent carbon tetrachloride disposal location has been identified. Historical practices (cleaning electronic equipment and radios) gleaned from personal interviews and the knowledge that carbon tetrachloride was a very commonly-used solvent from the 1940's through the 1960's, lead to the hypothesis that used CT was likely disposed of to the ground over a period of years at a former training facility in the vicinity of what is now Lexington Court, Marina.

Soil Characterization

No contamination in soil samples was discovered during this study. No further search for soil contamination is recommended given the age of the release and the lack of any indication that CT remains in the soil.

Soil Vapor Characterization

The CT contamination release hypothesis presumes that after release, CT traveled through the unsaturated dune sands and entered the A-Aquifer. To confirm this hypothesis, a study of the soil vapor was conducted in the vicinity of a small storage shed or 'oily' that had been identified in aerial photos dated 1949 and 1955. This shed was located just east of a small area of an apparently residual mass of CT detected in soil vapor to depths of 80 feet below ground surface (bgs). Soil vapor discovered beneath the cul-de-sac of Lexington Court in 2002 has confirmed the presumed source area of CT contamination in the groundwater of the underlying A-Aquifer. Concentrations of CT in soil vapor were generally low from the near-surface down through the unsaturated dune sands. This vertical distribution suggests that the mass represented a residual mass, not a recent or continuing one. Groundwater immediately beneath the source area contains only very low concentrations of CT, which suggests that an insufficient mass of CT remains in the vadose zone to significantly contribute to the A-Aquifer.

Groundwater Characterization

The evaluation of lithologic and hydrostratigraphic information obtained from drilling boreholes and installing monitoring wells yields a hydrogeologic model of the subsurface. This model is consistent with previous studies conducted to date and confirms the presence of several aquifers separated by clays or silty sands. The uppermost unsaturated dune sand deposit rests above a clay layer known as the Fort Ord-

Salinas Valley Aquitard (FO-SVA). There is a saturated thickness of 20 to 30 feet, known as the A-aquifer, supported by the FO-SVA. The depth to the top of the groundwater can vary from as little as 20 feet to as large as 120 feet. Groundwater flows northwest or west. Hydraulic communication between this A-Aquifer and underlying aquifers (known as the Upper 180-Foot Aquifer, the Lower 180-Foot Aquifer and the 400-Foot Aquifer in descending order) is limited to those areas west of the OUCTP where the FO-SVA clay unit pinches out, or where it has been penetrated by wells without adequate sanitary seals. Two such vertical conduits have been identified and have resulted in the migration of CT from the A-Aquifer to the underlying Upper and Lower 180-Foot Aquifers. Horizontal hydraulic conductivity values of this aquifer range from about 20 feet/day midway along the A-Aquifer CT plume to as high as 540 feet/day near the toe of the plume. Fine-grain sand observed near the source area suggest values less than 20 feet/day in this area.

The FO-SVA consists of a thick, dense clay unit deposited in a marine environment, as indicated by observations of seashells in borehole samples. Samples analyzed for total organic carbon confirm that this unit contains significant organic content, occasionally in the form of peat lenses. Although two to three sand units, each up to 15 feet thick, appear to lie within this aquitard and extend laterally throughout the OUCTP study area, only very little advective flow occurs through this unit except where penetrated by wells with inadequate sanitary seals. Vertical hydraulic conductivity values of the clay have been measured (via permeameter tests) at approximately 10^{-6} to 10^{-8} centimeter per second (cm/sec).

The Upper 180-Foot Aquifer consists of about 60 feet of fine to coarse sand and some gravel and is laterally extensive throughout the OUCTP study area. Groundwater flows eastward and southeastward under largely confined conditions except within the southern portion of the OUCTP study area where the overlying FO-SVA clay rises above the potentiometric surface, thus resulting in locally unconfined conditions. The direction of flow appears controlled by the degree of hydraulic communication with the underlying Lower 180-Foot Aquifer, separated by the Intermediate 180-Foot Aquitard, where present. Where this aquitard pinches out, groundwater from the Upper 180-Foot Aquifer drains into the Lower 180-Foot Aquifer.

The Intermediate 180-Foot Aquitard consists of approximately 50 feet of interbedded clay and clayey sand layers, occasionally mixed with coarse gravel, suggesting a high-energy depositional environment, possibly colluvial. This aquitard hydraulically isolates the Upper and Lower 180-Foot Aquifers from one another but pinches out in the southern portion of the OUCTP study area, allowing recharge to the Lower 180-Foot Aquifer to occur.

The Lower 180-Foot Aquifer consists of approximately 200 feet of coarse sand and gravel and has historically been and continues to be a significant source of potable water for the former Fort Ord and City of Marina area. Significant pumping from this aquifer since the 1940's, both locally and regionally, has resulted in seawater intrusion that extends within the northern portion of the OUCTP study area. Horizontal hydraulic conductivity values have been difficult to determine, given waste discharge limitations, but have been successfully simulated at 700 feet/day. This aquifer is the local equivalent of the regional 180-Foot Aquifer and passive groundwater elevation monitoring clearly illustrates seasonal and daily pumping cycles from irrigation wells located in the Salinas Valley, east of the OUCTP study area.

Pumping from the Salinas Valley has reversed the direction of flow within the Upper 180-Foot and Lower 180-Foot Aquifer. Beneath the site, groundwater in the Upper 180-Foot Aquifer flows to the southeast toward the apparent edge of the underlying Intermediate 180-Foot Aquitard where it then recharges the Lower 180-Foot Aquifer. Groundwater primarily migrates to the east in the Lower 180-Foot Aquifer but oscillates between a northeast direction in the summer (in response to increased pumping from the Salinas Valley) and a more southeast direction (locally in response to the Marina Coast Water District [MCWD] Well Nos. 29, 30, and 31).

Vertical flow through the FO-SVA and Intermediate 180-Foot Aquitard is limited to locations at vertical conduits. Should these vertical conduits persist, groundwater may further migrate into the Lower 180-Foot Aquifer.

No contamination has been observed in the 400-Foot Aquifer wells and no CT has been detected in the active drinking water wells serving the Fort Ord community.

Contamination Flow Characterization

Higher CT concentrations in groundwater are observed approximately 2,000 feet north or downgradient of the source area but have not been detected at concentrations exceeding 20 micrograms per liter (µg/L). The state maximum contaminant level for CT in groundwater is 0.5 µg/L. As the CT plume migrated north and then northeast, it intercepted two wells that allowed for downward migration into the underlying Upper 180-Foot and Lower 180-Foot Aquifers. This resulted in a convoluted migration pathway where the Upper 180-Foot Aquifer plume underlies the A-Aquifer but migrates in the opposite direction. Continued downward CT migration through the same vertical conduits caused two plumes to develop within the Lower 180-Foot Aquifer.

Groundwater Simulation

A numerical simulation of groundwater flow (MODFLOW-2000) was constructed to substantiate the preceding contamination flow hypothesis. It incorporates lithologic data, groundwater elevation data, and contaminant concentrations to represent the dynamic interaction of seasonal recharge, current pumping, and natural conditions with the migration of CT through the A-Aquifer, Upper 180-Foot Aquifer, and the Lower 180-Foot Aquifer. Particle pathlines (MODPATH) were used to represent the axes of each plume and illustrate the rate of groundwater migration. This analysis generally indicates that groundwater requires approximately 20 years to travel from the CT source area to the downgradient extent of the CT plume. Particle pathlines were also used to evaluate the effectiveness of groundwater extraction remedial alternatives. Finally, a mass transport model was constructed to account for dispersion of the CT plume and evaluate various remedial alternatives. Results indicate that approximately 50 years are required to attain the current distribution of CT in the A-Aquifer, which is consistent with the conceptual model. The apparent retardation factor of 2.5 represents dispersion as chemical reactions were not simulated.

Foreshadowing Feasibility Unknowns – Pilot Studies

In parallel with characterization activities, studies about possible remediation or clean-up technologies were conducted. The first was designed to evaluate the applicability of enhanced biotreatment using lactose in the A-Aquifer, the second to evaluate the potential to remove or extract residual CT in the vadose zone soil vapor. Both pilot studies successfully achieved their respective objectives.

The injection of lactose into the A-Aquifer resulted in an almost immediate dechlorination of CT in the injection well and nearby monitoring wells (within 15 feet) and dramatically lower dissolved oxygen (DO) values sustained for at least nine months. The decreased DO values strongly indicate that the environment proximal to the injection well has been successfully converted from aerobic to anaerobic conditions, which are more favorable for CT dechlorination.

The soil vapor extraction (SVE) pilot study, operated for a total of four months, was conducted in two phases and resulted in the removal of 0.78 pounds of CT from the vadose zone under the presumed source area of CT contamination using SVE wells and monitoring wells installed in the lower portion of the vadose zone (approximately 80 feet thick beneath the source area). After completion of the SVE pilot study, monitoring indicated CT and other volatile organic compounds (VOCs) present in soil gas in the vadose zone had been reduced to within the detection level range; therefore, no additional remedial activity is required or recommended for soil gas formerly associated with OUCTP.

Human Health Risk Assessment (HHRA)

The HHRA (Volume II) for the OUCTP was conducted to evaluate potential risks to residents resulting from potential exposure to VOCs detected in groundwater and soil gas from the OUCTP, and was conducted using groundwater and soil gas data collected at the site. The HHRA consisted of reviewing the groundwater and soil gas data collected at the site, identifying chemical of potential concern (COPCs), selecting appropriate exposure assumptions and toxicity criteria, and estimating carcinogenic risk and noncarcinogenic hazards.

Data Evaluation and Chemicals of Potential Concern

A detailed evaluation of the available groundwater and soil gas data was conducted to identify data applicable to the HHRA. The following criteria were used to select appropriate and representative data for inclusion in the HHRA: sample location, sample date, sample depth, duplicate samples, analyte, and data validation and assigned qualifiers.

COPCs are the chemicals in groundwater and soil gas that, based on concentration and toxicity, are most likely to contribute significantly to risks calculated for the exposure pathways evaluated in this HHRA. All chemicals that were detected in soil gas were included in the HHRA evaluation, but a screening process was used to select the COPCs in groundwater. For each groundwater data set (or aquifer), a chemical was selected as a COPC if the frequency of detection (FOD) was greater than 2.5 percent in the HHRA data set. This criterion was used for COPC selection so that chemicals that have either been routinely detected in each aquifer and/or recently detected within the last year would be evaluated in the HHRA. Additionally, chemicals were qualitatively evaluated to remove chemicals from the evaluation due to suspect results from sampling equipment and techniques or well construction (i.e., acetone, methyl ethyl ketone [MEK], and vinyl chloride [VC]), and to include chemicals (i.e., bromoform) that were not frequently detected but have a weight-of-evidence classification as probable human carcinogens. The following chemicals were selected as COPCs for each data set (or aquifer) and further evaluated in this HHRA:

- A-aquifer: bromodichloromethane, bromoform, CT, chloroform, dibromochloromethane, tetrachloroethene (PCE), and trichloroethene (TCE).
- Upper 180 foot aquifer: CT, chloroform, and chloromethane.
- Lower 180 – 400 foot aquifer: 1,2-dichloroethane (1,2-DCA), CT, chloroform, and toluene.

- Soil Gas: CT, chloroform, PCE, and TCE.

Exposure Assessment

The exposure assessment identifies complete and potentially complete exposure pathways under current and future land use conditions, and quantifies the degree of exposure. Future child and adult residents were evaluated as the potential receptors that may come into contact with the contamination associated with the OUCTP. The following potentially complete exposure pathways were identified and quantitatively evaluated in the HHRA:

- Ingestion of groundwater – Exposure to contaminants in groundwater due to use of contaminated groundwater as a source of drinking water;

- Dermal contact with groundwater – Exposure of residents to groundwater contaminants may result from dermal contact while to showering and/or bathing;

- Inhalation of vapors from groundwater in indoor air – Exposure of residents to contaminants may result from volatilization of volatile contaminants during showering and bathing; and

- Inhalation of contaminant vapors from groundwater in the A-aquifer and soil gas in indoor air – Exposure of residents to contaminants may result from the migration of volatile contaminants from the subsurface into indoor air. Volatilization of contaminants to indoor air from the Upper 180- and Lower 180-400 foot aquifers is presumed to be prevented by the overlying A-aquifer, and was not evaluated.

Groundwater within the OUCTP currently is not used by residents within the former Fort Ord area for domestic household purposes, and the installation of drinking water wells at the former Fort Ord is restricted under Monterey County Ordinace No. 04011, dated April 1999.

The exposure point concentration (EPC) is the average concentration contacted at the exposure point(s) over the duration of the exposure period. The typical concept of human exposure at a site or within a defined exposure area is that individuals contact the contaminated medium on a periodic and random basis. Because of the repeated nature of such contact, exposure does not typically occur at a fixed point but rather at a variety of locations with equal likelihood that contact with any given point within the exposure area may occur at any given time. Use of the arithmetic average is consistent with EPA toxicity criteria, which are based on lifetime average exposures, and also accounts for uneven spatial distribution of contaminant concentrations. For these reasons, EPCs for contaminants in groundwater were calcuated as the average concentration over the entire OUCTP plume. Because it is not possible to know the true mean, the mean concentration is represented by the upper 95th percent confidence limit on the arithmetic mean. Groundwater EPCs were used to evaluate the ingestion and dermal contact pathways, and to estimate inhalation exposures resulting from household uses of contaminated groundwater,. EPCs in indoor air due to vapor intrusion from subsurface contamination (soil gas or groundwater) were calculated using the Johnson and Ettinger Model.

The daily intake (DI), or average daily dose, was estimated for each pathway evaluated in the HHRA. A DI represents an estimate of a chemical dose that a receptor would receive on a daily basis. Standard exposure factors recommended by EPA and Cal/EPA were used to estimate the DIs. Two exposure scenarios were evaluated in this HHRA: a reasonable maximum exposure (RME) and an average exposure (AE). RME, as defined by the EPA, is the "highest exposure that is reasonably expected to occur" and is estimated using a combination of average and upper-bound values for human exposure assumptions (*EPA, 1989*). For the RME scenario, it was assumed that residents would be exposed to VOCs for 350 days per year for a total duration of 30 years. These assumptions are considered to be conservative and protective of even sensitive subgroups of the potentially exposed population. For the AE scenario, exposure durations of 9 and 6 years were assumed for adult and child residents, respectively.

To evaluate vapor intrusion to indoor air, the DTSC version of the Johnson and Ettinger Model was used. The model is a one-dimensional analytical model that incorporates both advective and diffusive mechanisms of vapor transport into indoor air (*Cal/EPA, 2005*). It calculates an attenuation coefficient (α) that relates vapor concentration in indoor air to the vapor concentration at the source of contamination in either subsurface soils or groundwater located directly beneath the building, which can then be used to estimate the contaminat concentrations in indoor air. The model results can also provide an estimate of the incremental risk associated with indoor concentrations, based on the default exposure assumption of exposure for 350 days per year for 30 years. For this analysis, the DTSC version of the model uses toxicity criteria developed by Office of Environmental Health Hazard Assessment (OEHHA), and also utilizes certain soil properties that are more representative of the soil types encountered at sites within California (*Cal/EPA, 2005*). The potential for vapor intrusion into indoor air was evaluated at three separate locations: CTP-SGP-35 using soil gas data collected in March 2004, and at MW-BW-49A and MW-BW-53A using groundwater data collected in September 2004 and September 2005.

Toxicity Assessment

The toxicity assessment is composed of two steps: (1) hazard identification and (2) dose-response assessment. Hazard identification is a determination of whether exposure to a chemical may result in an adverse health effect in humans, and consists of characterizing the nature of the effect and the strength of the evidence that the chemical will cause the observed effect. Dose-response assessment characterizes the relationship between the dose and the incidence and/or severity of the adverse health effect in the exposed population.

The methodologies used to develop toxicity factors differ, depending on whether the COPC is a potential carcinogen (i.e., has the potential to cause cancer) and/or has noncancer adverse effects. As part of the toxicity assessment, cancer and noncancer toxicity values were compiled for each COPC from both California and EPA-derived toxicity values for use in the risk characterization process.

Risk Characterization

The risk characterization integrates the exposure and toxicity assessments to describe the risks to individuals in terms of the nature and likelihood of potential adverse health risks. The risk characterization process involved integrating the exposure intakes and toxicity values to estimate both cancer risk and noncancer hazards to potential residential receptors from exposure to COPCs in groundwater at the site. Because cancer risk and noncancer effects are quantified differently, different methods were used to evaluate these effects. Cancer risk is expressed as an increased probability of developing cancer over a lifetime as a result of the estimated exposure. Cancer risk characterization methodology is predicated on the assumption that cancer induction does not have a threshold, and any dose, no matter how small, is associated with some incremental increased risk of developing cancer.

Noncancer effects were evaluated by comparing the average daily dose with the chronic reference dose (RfD) to arrive at a ratio called the hazard quotient (HQ). The HQ represents the ratio of the exposure level to an exposure level presumed to be without the potential for adverse health risks. The HQ approach assumes that there is a level of exposure (e.g., RfD) below which it is unlikely that even sensitive populations would experience adverse health effects. If the exposure level exceeds the threshold (i.e., if HQ is greater than 1), there may be concern for potential noncancer effects.

The following conclusions were drawn from the risk characterization:

- The cumulative RME cancer risk estimates associated with exposure to contaminants in the A-aquifer is 3E-5. The estimated RME cancer risks are 2E-5 for the Upper 180 foot aquifer, and 2E-5 for the 180-400 foot aquifer. The estimated cancer risks associated with the vapor intrusion pathway are approximately twice the estimated risk associated with household water use when groundwater data were used to estimate the indoor air concentrations (at MW-BW-49A and MW-BW-53A).

Conversely, the estimated cancer risk associated with the vapor intrusion pathway were neglible compared to direct contact pathways associated with household uses of groundwater when soil gas data was used to estimate indoor air concentrations at CTP-SGP-35.

- The cumulative noncancer hazards did not exceed 1 at any sampling location and /or aquifer. .
- Because groundwater from the OUCTP is not currently supplied for domestic use residents are likely to have no risk from direct exposure to the groundwater COPCs within the OUCTP.

1.0 INTRODUCTION

The study area comprising this remedial investigation (RI) was located at the former Fort Ord in Monterey County, California (Plate 1). MACTEC has prepared this report for the United States Army Corps of Engineers (USACE) under Contract No. GS-10F-0157K in accordance with the scope of work dated March 8, 2002.

1.1 Purpose and Objectives of RI/FS Report

This RI report (Volume I) has been written to present the characterization of and to document the lithologic, chemical, and hydrogeologic data that has been collected to determine the lateral and vertical extent of contamination, specifically carbon tetrachloride (CT), detected in groundwater of the A-Aquifer, Upper 180-Foot Aquifer, and Lower 180-Foot Aquifers. The human health risk assessment (HHRA; Volume II) was conducted to evaluate potential risks to residents based on exposure to volatile organic compounds (VOCs) detected in groundwater and soil gas from this operable unit carbon tetrachloride plume (OUCTP) using groundwater and soil gas data collected at the site. The feasibility study (FS) report (Volume III) was conducted to evaluate alternative remedial solutions with associated cost estimates based on data contained in the RI and HHRA.

1.1.1 Report Organization

The collective RI/FS report has been divided into three volumes, the first including the RI, the second containing the HHRA, and the third containing the FS. The RI (Volume I) includes a description of physical characteristics, summary of field programs, nature and extent of contamination, additional characteristics, data management, data evaluation, and a groundwater flow simulation, followed by a summary and conclusions section. The HHRA (Volume II) is based on observed VOC concentrations in groundwater and presents an exposure assessment, a toxicity assessment, a risk characterization, and an uncertainty analysis, followed by a summary and conclusions section. The FS (Volume III) includes a description of the remedial action objectives, development and screening alternatives, a description of remedial alternatives, an evaluation and comparison of alternatives, a detailed analysis of alternatives, and the selection of the preferred alternative, followed by a summary and conclusions section.

1.2 Site Background

The former Fort Ord is adjacent to Monterey Bay in northwestern Monterey County, California, approximately 80 miles south of San Francisco (Plate 1). The base consists of approximately 28,000 acres within and adjacent to the cities of Seaside, Sand City, Monterey, and Del Rey Oaks to the south and Marina to the north. Highway 1 passes through the western part of the former Fort Ord, separating the beachfront portions from the rest of the base. The south and southeast portions of the former Fort Ord are bordered by unincorporated portions of Monterey County, and include several communities as well as the Laguna Seca Recreation Area and Toro Regional Park. Land use immediately east of the former Fort Ord is primarily agricultural.

Beginning with its founding in 1917, Fort Ord served primarily as a training and staging facility for infantry troops. From 1947 to 1974, Fort Ord was a basic training center. After 1974, the 7th Infantry Division occupied Fort Ord. Fort Ord was selected in 1991 for decommissioning, but troop reallocation was not completed until 1993. Although Army personnel still operate the base, no active Army division is currently stationed at the former Fort Ord.

1.2.1 Site Description

The apparent source of the OUCTP is located on what is now Lexington Court, part of the Abrams Housing Development, in the northern portion of former Fort Ord. A groundwater contaminant plume emanating from this area ultimately extends across a large area bounded by Del Monte Boulevard, Abrams Drive, Neeson Road, and Blanco Road (Plate 2). This area encompasses the lateral extent of CT detected in three different aquifers up to 550 feet below ground surface (bgs) that define the area of study of this report. Further details of the source and subsurface extents follows.

1.2.2 Site History

An evaluation of historical land use for the OUCTP area was undertaken to attempt to determine whether additional data regarding the source area exists since the source of or use of CT at the former Fort Ord was not documented as part of the earlier basewide RI/FS (*HLA, 1994b*). Current land use throughout the OUCTP area is also discussed below to provide information concerning potential remedial solutions for each of the impacted aquifers.

Historical land use for the area encompassing the source area of OUCTP is based on a thorough review of Fort Ord facility/training maps dating from 1945, aerial photos from 1941 to present, investigation records from the Former Fort Ord Basewide RI/FS (*HLA, 1994b*), and recent interviews with Army personnel stationed at Fort Ord prior to 1960. Aerial photos of the source area from 1941, 1949, 1956, 1966, 1978, and 2003 are presented in Appendix J.

Although undocumented, personnel interviews and aerial photo interpretation have revealed that a small storage area or training facility had been located immediately north of what is now Lexington Court. This facility is reported to have stored CT cleaning solvent in five-gallon cans, which presumably included the use and disposal of CT, as described below. The facility can be seen in the insert shown on Plate 2 and on the enhanced aerial photos from 1949 and 1955 presented in Appendix J; additional aerial photos from 1941, 1966, 1978, and 2003 have been included to illustrate that this structure was not present in 1941 or in photos after 1966.

The area south of Reservation Road on the former Fort Ord property within the OUCTP area was primarily used as an Army light vehicle driving course (LVDC) and a wireman training course. The area north of Reservation Road within the OUCTP area was used for general Army training exercises. The eastern portion of Marina was primarily used for civilian agriculture and livestock until the 1960s when the area was converted to residential use.

In the late 1960's several drinking water production wells penetrating the Lower 180-Foot Aquifer were installed by the Army and the City of Marina to serve the growing local population and replace older production wells that had been impacted by seawater intrusion. The names and locations of these wells are shown on Plate 3. Specifically, Army production wells FO-26, FO-27, and FO-28 were installed in August 1962, October 1968, and September 1968, respectively. Marina production Well Nos. 8, 8a, and 11 were installed in April 1972, December 1982, and January 1986, respectively. Finally, a private irrigation well (Mini-Storage well) was installed in November 1996. The construction of each of these wells was carefully reviewed to determine which, if any, provided vertical conduits for contamination from the shallowest (A-Aquifer) to deeper aquifers (the Upper and Lower 180-Foot Aquifers).

In the 1975, the USACE conducted a study in the Fritzsche Army Airfield (FAAF) area to assess the feasibility of aerially spraying treated wastewater in the area (*CH2M Hill, 1974*). As part of that study, several monitoring wells were installed in the area to document the depth to groundwater and the thickness of the underlying clay aquitard (FO-SVA). Three of these wells (MW-B-12-A, MW-B-14-A, and MW-B-13-180) were installed within the footprint of the CT plume in the A-Aquifer (Plate 3). MW-B-13-180 penetrated the underlying clay aquitard and now appears to have potentially been acting as one of potentially several vertical conduits in the area that may have allowed groundwater to flow between aquifers that had not previously been in hydraulic communication.

In the late 1980s, the Abrams and Preston Park residential housing areas were constructed over a significant portion of what had been a training area and the LVDC. The OUCTP A-Aquifer plume originates from the northernmost portion of the Abrams housing area, specifically Lexington Court, and migrates to the north beneath Preston Park. Residents living on Lexington Court and Ready Court are closest to the apparent source area of the CT plume although the A-Aquifer and Upper 180-Foot Aquifer plumes currently underlie much of the northern extent of the Preston Park housing area.

The Former Fort Ord area north of Reservation Road, south of Neeson Road, and west of Imjin Road was transferred in 1995 to the University of California to form a biological reserve and partially overlies the OUCTP A-Aquifer plume. The A-Aquifer plume terminates west of the biological reserve beneath a residential and light industrial section of the City of Marina in the vicinity of Seacrest Avenue and Reservation Road.

Contamination in the Upper 180-Foot Aquifer originates from two areas immediately north of Reservation Road beneath the light industrial section of the City of Marina and a portion of the biological reserve. They extend in parallel from these areas to the southeast where they underlie Preston Park and Abrams housing areas. The ‘west’ plume is shorter and terminates beneath Abrams housing area whereas the ‘east’ plume terminates east of Imjin Road and north of Abrams Drive in the vicinity of Bunker Hill Drive (part of the Schoonover housing area) and appears to continue into the underlying Lower 180-Foot Aquifer.

The OUCTP Lower 180-Foot Aquifer plumes originate in two areas that are coincidental with the source and terminal areas of the Upper 180-Foot Aquifer plumes. Both plumes extend east from their respective source areas. The ‘north’ plume extends beneath (1) a portion of the biological reserve; (2) land occupied by the Monterey Bay Education Science and Technology Center of the University of California, Santa Cruz, leasing to a variety of light industrial, commercial, and educational tenants; and (3) a portion of land occupied by the Marina Airport, which serves light fixed-wing aircraft and helicopters. The ‘south’ plume is less extensive and underlies property owned by California State (residential land use) and University of California (biological reserve). The Lower 180-Foot Aquifer provides potable water to the former Fort Ord community.

Planned land uses in this area are primarily based upon the Fort Ord Reuse Authority (FORA) March 1997 Fort Ord Base Reuse Plan (*FORA, 1997*) and the July 1995 USACE and Bureau of Land Management (BLM) Site Use Management Plan (SUMP) (*USACE, 1995*). Other sources of future land use information were provided in public benefit conveyance, negotiated sale requests, and transfer documents, and in the *Installation-Wide Multi-Species Habitat Management Plan for Former Fort Ord, California* (HMP) (*HLA, 1997a*). The Reuse Plan identified approximately 20 land use categories at the former Fort Ord (*FORA, 1997*) including habitat management, open space/recreation, institutional/public facilities, commercial, industrial/business park, residential, tourism, mixed use, and others.

The HMP presents the revised boundaries of the habitat reserve areas and describes special land-use controls and habitat monitoring requirements for target species within the HMP reserve and development areas. The HMP confirms locations of low-intensity uses such as the HMP reserve areas; it also specifies an allowance for development within the reserve areas for public access support facilities in as much as 2 percent of the area.

1.2.3 Previous Investigations

Previous investigations at the former Fort Ord have reviewed chemical use, storage, and disposal, although most of these reviews were not specific to the OUCTP site. The following sections summarize the results of previous investigations relevant to the OUCTP site and present the conceptual site model.

Several Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigations have been conducted at the former Fort Ord that included the area now referred to as OUCTP. The confirmation of CT in groundwater did not occur until 1992 when sample results from two monitoring wells (MW-B-14-A and MW-B-13-180) that had been installed in 1975 for reasons unrelated to the CERCLA investigations indicated its presence in both the A-Aquifer and the Upper 180-Foot Aquifer. The subsequent delineation of the nature and extent of CT in groundwater was significantly hindered by the lack of any documented use of CT at Fort Ord or the identification of potential CT sources that could explain its presence at these two monitoring wells. The following summarizes pertinent portions of previous investigations that led to the final identification of the source of CT in groundwater.

1.2.3.1 Summary of Investigation Reports

The following investigation reports relevant to OUCTP are summarized below.

Preliminary Hydrogeologic Investigation

The presence of CT in groundwater and soil gas at what is now OUCTP was first documented in the Preliminary Hydrogeologic Investigation *(HLA, 1990*). Chemical analysis of drinking water from water supply well nos. FO-26, FO-27, and FO-28 indicated the sporadic presence of CT but often could not be confirmed in subsequently collected samples. Operation of these wells was terminated in the mid- to late-1980's due to the progressive intrusion of seawater into the drinking water aquifer and activation of newly installed drinking water wells located about two miles to the east in 1985. The sporadic detection of CT in water samples was a secondary incentive to cease operation of the older supply wells.

As part of characterization activities for the Fort Ord landfills, the extent of VOCs in soil gas was evaluated in the area surrounding the formerly used landfills in 1985 (*HLA, 1990*). Due to the uncertain extent of landfill materials, field operations were designed to respond to real-time data and expand the area of interest as needed. CT in soil gas was generally not detected in the vicinity of the landfills but low levels were noted in a small area north of the landfills and 16 samples were eventually collected. The highest concentration of CT was 0.3 micrograms per liter (µg/L), which equates to about 46.2 parts per billion by volume (ppb[v/v]). Most detections of CT in this area were below 0.1 µg/L and were considered unreliable or insignificant; however, the consistent distribution of CT in soil gas suggested that a source may have been present. Consequently, a geophysical survey was conducted in the area to determine whether an undocumented landfill cell was present in this area or other sources of CT contamination (e.g., drums) existed. Results indicated that the ground had not been disturbed and no debris suggestive of a CT source was found. Furthermore, a subsequent basewide review did not result in the discovery of the use of CT within the OUCTP area that would explain its presence in soil gas or groundwater. No further action related to the investigation of CT in this area was taken or seemingly warranted at the time the Preliminary Hydrogeologic Investigation was conducted.

Basewide Hydrogeologic Characterization

Quarterly groundwater sampling began in September 1992 and included all existing monitoring wells in the northern portion of the base to establish baseline conditions (*HLA, 1994a*). These included several wells that had been installed surrounding the FAAF in 1974 and 1975 to characterize the site for potential disposal of treated sewage (*CH2M Hill, 1974*). The wells were installed to document the depth to groundwater in both the A-Aquifer and the underlying Upper 180-Foot Aquifer. The sewage disposal project was not continued but the wells were left intact.

Samples collected in 1992 from two of these wells, MW-B-14-A and MW-B-13-180, indicated the presence of CT at concentrations slightly above the Federal action level at the time of 5.0 µg/L; CT was not detected[1] in samples collected at the same time further west from MW-B-11-A and MW-B-12-A, both screened in the A-Aquifer downgradient from MW-B-14-A. The remote location of MW-B-14-A and MW-B-13-180 and their distance from known potential sources (most notably the formerly used Fort Ord landfills) made the presence of CT, a VOC not often detected elsewhere in groundwater at Fort Ord, appear dubious. Furthermore, these two wells were screened in different aquifers that are separated by a significant regional aquitard (FO-SVA). The explanation for CT in groundwater at this location thus required (1) an undocumented source and (2) a method of vertical migration through a substantial aquitard. The likelihood of both of these conditions appeared to be low. Nonetheless, these two wells

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[1] The reporting limit was initially 5.0 µg/L but was lowered to 0.50 µg/L in samples collected after 1992.

remained in the quarterly monitoring program for VOC analysis.

Carbon Tetrachloride Study Area Reports

Continued quarterly groundwater sampling illustrated a consistent presence of CT at MW-B-14-A and MW-B-13-180, although detections were somewhat erratic in the A-Aquifer. Concentrations fluctuated from below the reporting limit to 9.1 µg/L in the A-Aquifer and from below the reporting limit to 9.8 µg/L in the Upper 180-Foot Aquifer. The persistence of CT in groundwater at these two monitoring wells provided the rationale to further investigate and delineate its potential extent in the A- and Upper 180-Foot Aquifers and, eventually, the Lower 180-Foot and 400-Foot Aquifers. The site investigations conducted to further characterize the site and delineate the extent of CT in groundwater prior to declaring the site an Operable Unit are documented in the following reports:

- Harding Lawson Associates (HLA), 1999. *Draft Final Carbon Tetrachloride Investigation Report, Fort Ord, California.* Prepared for the U.S. Army Corps of Engineers, Sacramento District. November 10.

  This report summarized lithologic and analytical data from historic sampling of the nearby Fort Ord and Marina Coast Water District (MCWD) municipal drinking water wells and from MW-B-14-A and MW-B-13-180. It also described the field program for installation of four additional A-Aquifer monitoring wells (MW-BW-15-A through MW-BW-18-A), four Upper 180-Foot Aquifer monitoring wells (MW-BW-19-180 through MW-BW-22-180), and the collection of several HydroPunch samples.

- Harding ESE, 2001d. *Draft Final Carbon Tetrachloride Study Area, Drilling Letter Report, Former Fort Ord, California.* Prepared for the U.S. Army Corps of Engineers, Sacramento District. July 16.

  This report summarized the drilling field program for installation of six additional A-Aquifer monitoring wells (MW-BW-23-A through MW-BW-28-A) and three Upper 180-Foot Aquifer wells (MW-BW-25-180, MW-BW-26-180, and MW-BW-29-180) were installed.

- Harding ESE, 2002a. *Draft Final Carbon Tetrachloride Study Area, Drilling Letter Report – Wells MW-BW-30-A through MW-BW-42-A, Former Fort Ord, California*. Prepared for the U.S. Army Corps of Engineers, Sacramento District. January 31.

  This report summarized the drilling field program for installation of six additional A-Aquifer monitoring wells (MW-BW-30-A through MW-BW-42-A).

- Harding ESE, 2002b. *Draft Final Carbon Tetrachloride Study Area, Drilling Letter Report – Monitoring Wells MW-BW-43-A through MW-BW-54-A, Former Fort Ord, California*. Prepared for the U.S. Army Corps of Engineers, Sacramento District. February 6.

  This report summarized the drilling field program for installation of six additional A-Aquifer monitoring wells (MW-BW-43-A through MW-BW-54-A) were installed.

- Harding ESE, 2002e. *Draft Final Natural Attenuation Summary Report, Carbon Tetrachloride Investigation, Former Fort Ord, California*. Prepared for the U.S. Army Corps of Engineers, Sacramento District. November 29.

  This report summarized the collection and analysis of groundwater samples that were analyzed for various compounds indicative of natural attenuation processes (dissolved oxygen [DO], oxidation/reduction potential [ORP], major cations and anions, total dissolved solids [TDS], dissolved gases (methane, carbon dioxide, ethane, and ethene), and VOCs. A molar ratio of CT versus the daughter product chloroform in samples along the plume pathway was constructed to determine whether changes in concentration were inversely proportional, which would indicate natural attenuation/biological degradation of CT was occurring within the plume.

- Harding ESE, 2002d. *Draft Final Carbon Tetrachloride Investigation, Drilling Letter Report – Westbay Wells, Former Fort Ord, California.* Prepared for the U.S. Army Corps of Engineers, Sacramento District. August 13.

Additional investigations in the vicinity and pertinent to this RI/FS include:

- 215-C Reservation Road, Former Don’s One Hour Cleaners: This site centered around tetrachloroethene (PCE) contamination from previous dry cleaning operations. The business is closed and the investigation has recently been closed. Initial soil samples taken from beneath the building indicated the presence of PCE); a subsequent grab sample collected from groundwater beneath the building indicated PCE at a concentration of 1,000 ppb (*Light, Air & Space Construction, 2001*). Three monitoring wells were then installed in 1999 and PCE has since been consistently detected in groundwater at concentrations typically ranging from 3.3 to 174 ppb (*Cap Rock Geology, 2001 and 2003*). Characterization of the top of the FO-SVA clay and the lower portion of the A-Aquifer apparently could not be carried out due to the presence of heaving sands during investigative drilling activities. No remediation is planned for this site and a request to terminate annual sampling has recently been granted by the Central Coast RWQCB. The three monitoring wells still exist and are located slightly downgradient of the A-Aquifer CT plume and CT has not been detected in this area. Groundwater elevations measured at these monitoring wells is recommended to be incorporated with future monitoring of the A-Aquifer.

- 3184 Del Monte Boulevard, Former Marina Exxon: The investigation has been closed and the property has since been redeveloped. Up to 14 wells had been installed at this former Exxon gas station but none deep enough to confirm the top of the FO-SVA. Petroleum hydrocarbon monitoring and remediation began in 1989 (*Weber, Hayes & Associates, 1996 and 1997*); by 1998 the analyte list had apparently been extended from petroleum compounds to also include chlorinated solvents. PCE was thereby detected at concentrations up to 30 ppb (*Weber, Hayes & Associates, 1997,*); however, the Army has not reviewed a comprehensive historical record of detections. Groundwater elevations had been miscalculated to indicate a northward direction of flow within the A-Aquifer, whereas elevation data collected from the Army's monitoring wells surrounding this site reflect the anticipated westward flow in this area. All wells associated with this investigation have been destroyed but MW-BW-76-A is located just west (downgradient) of the former site. CT has not been detected in this area.

- 266 Reservation Road #N, Peninsula Dry Cleaners: A brief investigation was conducted at this site that culminated with the installation of three borings and the collection of associated grab groundwater samples. PCE was detected in one sample at about 0.75 µg/L, however, additional characterization or remedial investigation was not conducted. The borings were located slightly downgradient of the current extent of the A-Aquifer CT plume and CT had not been reported in analytical results.

Data collected from each of these sites indicated PCE contamination in groundwater at varying concentrations, which may be associated with the unexplained but temporary detection of PCE at MP-BW-37, MP-BW-39, and MP-BW-42 in 2002 and 2003 quarterly monitoring events following their respective installation activities, as discussed further in Section 4.2.3.

1.2.3.2 Summary of Personnel Interviews

Interviews that had been conducted as part of the Basewide RI/FS (*HLA, 1994b*) did not yield information that indicated a known source of CT contamination associated with OUCTP. The following interviews were conducted as part of this OUCTP RI:

Interview with Mr. Jay Varette

Mr. Jay Verette of the USACE was interviewed concerning the construction of the Abrams and Preston Park housing areas, including Lexington Court. He indicated that no debris or potential sources of chemicals had been excavated during development of the site. No knowledge regarding the source of CT was identified.

Interview with Mr. Jim Rapose

A meeting with Mr. Jim Rapose occurred on August 1, 2002 while sighting locations for monitoring wells on Marina Airport property. Mr. Rapose is an employee at the airport and was a Master Sergeant for the Army in the 1950's who indicated he was aware of CT use at Fort Ord until the late 1950s. A follow-up interview was scheduled for August 14, 2002 with a USACE representative.

During the August 14, 2002 interview Mr. Rapose describe his past work experiences at Fort Ord. Historical training maps of Fort Ord were made available to help describe areas where he had knowledge of historical activities. Mr. Rapose had primarily been involved with work at several motor pools and oversaw the Engineering Divisions on base. No motor pools were located within the OUCTP area. He stated very clearly and in vivid detail that CT had routinely been used for parts cleaning until it was replaced by other solvents in the late 1950's or early 1960's. Apparently CT was favored for cleaning motor vehicle parts because it dried quickly and left no residue on the parts being cleaned.

Mr. Rapose indicated CT was provided to Army personnel in five-gallon cans; drums were not used because too much material would volatize if someone left the top open. It was not clear if drums had originally been used but found to be problematic or if five-gallon cans had always been used at Fort Ord.

Use of CT at the motor pools usually resulted in a small amount (one or two gallons) in a parts cleaning tray that would be taken outside of the motor pool building and "tossed out" on the ground. This disposal method was followed routinely by all motor pool workers. He believes that most of the waste CT evaporated in mid-air, based on his familiarity with this solvent. Mr. Rapose specifically stated that they did not take CT to the landfills; however, he did imply that the replacement solvent (presumably trichloroethene [TCE]) was taken to the landfills, although the reason for the change in disposal methods was not made clear.

Mr. Rapose indicated that all motor pools used and disposed of CT in this manner routinely, and that CT was, in general, used by everyone on base for any number of cleaning tasks, including dry cleaning. He described the areas now referred to as Site 23 (near the old Quonset huts), Site 12, and Site 20 as being large motor pools where CT was frequently used and would have been disposed of by pouring the used CT on bare ground as described above. He could not estimate how much CT may have been routinely used during the 1950's at the motor pools at the former Fort Ord. He also did not know if CT had been used in the 1940's as he had not been stationed at Fort Ord then before the 1950s.

Mr. Rapose was shown enhanced aerial photos (from 1949 and 1956; described below in Section 1.2.3.4) and asked him if he recognized the fenced structures within a clearing which is now Lexington Court. He stated that it was one of the 24th Signal Corps training facilities (pole climbing) that had been used for storage and cleaning equipment (he referred to the apparent building as an "oily"). Based upon his understanding of the popularity of CT, he thought it highly likely that CT would have been used on-site for parts cleaning purposes by the Signal Corps. However, it is possible that he did not have firsthand experience with Signal Corps cleaning activities. He mentioned that the U.S. Air Force had also been active in the area, but he was not sure what type of training they conducted or if they may have used CT.

Mr. Rapose was shown several training maps and described several areas illustrated as "testing area 5-12" on the 1953 map (within the OUCTP area) as carpentry buildings where large targets were assembled (glued), hung to dry, and eventually picked up for delivery to the ranges for target practice.

The 1958 map indicated an area with radial arrows pointing away from the center and labeled RRST and MST. When Mr. Rapose was asked what these abbreviations stood for, he thought it may have been something like "relay station". He seemed to have good knowledge of the land use at the time, and stated that he knew of a Mr. John Robotti that he had served with at Fort Ord that may be able to remember additional details about CT use and disposal at Fort Ord.

Phone Interview with Mr. John Robotti

As a follow-up to the interview with Mr. Jim Rapose, Mr. John Robotti was called on August 26, 2002 to discuss his recollections of CT use at Fort Ord.

Mr. Robotti started work at Fort Ord in the late 1950s and stated that by that time, CT had been largely phased out and replaced by hot wash water cabinets for routine cleaning jobs. He also stated that CT would not have been used in large quantities before the 7th Light Infantry Division arrived because the level of mechanization was low until that time. He indicated that CT would have only been used in small quantities.

He did not know anything about the 24th Signal Corps, but he speculated that radio repair or cleaning (with CT) would have been conducted at the instrument shops, not in the field. He also speculated that the fenced building seen in 1948 and 1956 aerial photos may have been a radio relay station, although he had not seen the photos. Of the photos, he also suggested that the well houses, airfield, and early landfills were potential sources of CT, although he was unaware that these areas had already been ruled out as potential sources based on current soil gas and groundwater analytical data.

1.2.3.3 Carbon Tetrachloride Usage History at Fort Ord

There has been no documented use of CT at Fort Ord beyond the statements submitted in personnel interviews and the inclusion of this compound on a list of wastes discharged to the former Fort Ord landfills documented in the earlier Basewide RI/FS (*HLA, 1994a, b*). Although associated with the landfills, CT is and has been detected in the Operable Unit 2 (OU2) groundwater plume only intermittently and at low concentrations, suggesting that there is not a substantial source of CT in the landfills. This is consistent with the apparent phase-out of CT in the 1950’s and the construction of the former Fort Ord landfills in 1958.

Mr. Rapose’s statements, however, suggest that significant amounts of CT may have been stored and disposed of near the OUCTP source area. Insufficient data exist to estimate the cumulative volume of CT that may have been present; however, mass transport modeling suggests that between 300 and 1,000 gallons may have been cumulatively disposed of in this area (Section 9.0).

1.2.3.4 Aerial Photo Analysis

Aerial photos taken in the 1940s and 1950s were reviewed in conjunction with the interviews with Mr. Rapose upon learning that CT may have been used during this time interval. Exposures of photos taken in 1949 and 1956 showed the faint image of a partial structure that warranted further evaluation. The original negatives of these exposures (photo number ABG 5R 33) were located at the EPA office in Nevada (*EPA, 1992*) and were submitted to their Dayton, Ohio photo laboratory for enhancement. The enhanced photos clearly reveal the presence of a fenced area containing either two small buildings or one building with a possible tower adjacent to it (Appendix J, Plate K). A second fenced area joined to the first does not appear to contain any structures. No records had been found that documented what this fenced area had been used for, although the location generally coincides with a signal corps training facility indicated by the acronym “ST-11” on a 1958 map that may represent a radio relay station. Further analysis of aerial photos since the 1950s revealed a similar-looking structure along the north side of Intergarrison Road that coincides with another training facility referred to as “ST-4” on the same 1958 training facility map. Therefore, it is concluded that the most likely CT source area of OUCTP was the use, storage, or disposal of CT associated with the training facility known in 1958 as “ST-11”. The duration of this training facility cannot be determined prior to 1949 and after 1956, except that it does not appear in aerial photos taken in 1966 (Appendix J, Plate M) or later photos. Other than cleared areas and trails, no other features were identified in the source area.

1.2.3.5 Conceptual Site Model

Based on the history of CT use at Fort Ord, known hydrogeologic characteristics, history of production and monitoring well installation, and directions of groundwater flow in the A-, Upper 180-Foot and Lower 180-Foot Aquifers, a conceptual site model of aquifer contamination by CT can be developed. Apparently, an unknown quantity of CT was spilled, leaked, or otherwise improperly disposed to soils in the vicinity of what is now Lexington Court circa 1950. The CT solvent likely percolated through at least 100 feet of dune sand in the unsaturated (vadose) zone and reached the A-Aquifer within a relatively short period of time because the dune sands are very permeable. CT mass suspended within the vadose zone, however, apparently allowed contamination to the A-Aquifer to continue for several decades thereafter, based on observed residual CT in soil vapor beneath the source area in 1985 and 2003. The direction of groundwater flow at this location is to the north and slightly west. Based on the estimated time of release to the A-Aquifer (circa 1950), the apparent source location (what is now Lexington Court), and the current downgradient extent of the CT plume (approximately 9,500 feet), CT has migrated through the A-Aquifer a rate of about 0.5 feet/day.

In the late 1960s, new drinking water production wells (FO-26, FO-27, and FO-28) were installed by the Army along a utility road and Reservation Road. At least one of these wells (FO-26) is known to have been constructed as a vertical conduit that would have allowed groundwater to migrate from the A-Aquifer downward through the underlying aquitards into the Upper and Lower 180-Foot Aquifers. The MCWD also owns one well in this vicinity that appears to have been constructed as a vertical conduit (MCWD Well No. 8). All of these wells have since been destroyed to eliminate the potential for them to continue to serve as vertical conduits between the aquifers. MCWD Well No. 8a, the replacement well for MCWD Well No. 8, also penetrates the Lower 180-Foot Aquifer but does not appear to have been constructed in a manner that it would act as a vertical conduit.

By the time Fort Ord and MCWD production wells were installed, CT would have already migrated through the A-Aquifer and reached these well locations and, providing a vertical conduit existed, cross-contamination could have occurred. It is likely that the Upper and Lower 180-Foot Aquifers were not impacted by CT as long as the pumps were operational. While the production wells were in operation, groundwater from the A-Aquifer that may have contained CT would have been drawn into the water supply system of Fort Ord and removed from the groundwater flow regime rather than migrating further into these aquifers.

In 1974, a feasibility study for the disposal of treated sewage effluent at the FAAF included the installation of several monitoring wells, including one that penetrated the FO-SVA that was screened in the Upper 180-Foot Aquifer (MW-B-13-180; *CH2M Hill, 1974*). The construction log of this well suggests that the 'sanitary seal' installed to prevent hydraulic communication between aquifers was present throughout the majority of the aquitard. However, data from additional wells installed in the vicinity as part of the OUCTP RI confirm that MW-B-13-180 was either constructed as or otherwise became a vertical conduit. One scenario is that the sanitary seal on this well was compromised soon after installation, and the data suggests it failed shortly after its construction and subsequently allowed groundwater from the A-Aquifer to migrate downward through the FO-SVA and into the Upper 180-Foot Aquifer.

A privately owned well in this area, referred to as the Mini-Storage well, was installed in 1996 and was designed to penetrate the Lower 180-Foot Aquifer. Although the well construction log indicates that the Mini-Storage Well was not constructed in a manner that would act as a vertical conduit. CT has consistently been detected in groundwater samples from this well at concentrations ranging from about 4 to 7 µg/L. Trihalomethanes (THMs) have also been consistently detected in groundwater samples from this well (0.73 to 1.0 µg/L in the past year), suggesting that a vertical conduit to the Upper and Lower 180-Foot Aquifers may co-exist with this well or be located nearby. Municipal water contains THMs as a by-product of chlorine-based disinfection processes; the concentrations observed in the Mini-Storage well are consistent with those observed in the Fort Ord "sand tank" reservoir, which represent post-disinfection conditions. Municipal water for irrigation or water from a leaking line at or near the storage facility would percolate into the A-Aquifer and migrate westward (downgradient). If a vertical conduit is located at or near the Mini-Storage well, A-Aquifer groundwater could migrate downward through the FO-SVA clay unit into the Upper 180-Foot Aquifer and then through the Intermediate 180-Foot Aquitard into the Lower 180-Foot Aquifer.

A detection of bromodichloromethane, another disinfection by-product, at nearby MP-BW-37-328 in May 2004 (0.26 µg/L) is likely related to the THMs detected at the Mini-Storage well. This is supported by the fact that CT has been consistently detected at similar concentrations in both MP-BW-37 and the Mini-Storage well, and consistently at lower concentrations in monitoring wells located downgradient of the Mini-Storage well.

Once contamination enters the Upper 180-Foot Aquifer via a vertical conduit, it generally migrates southeastward toward until it reaches an area where the underlying aquitard pinches out and recharges to the Lower 180-Foot Aquifer occurs. Continued migration through the vertical conduit to the Lower 180-Foot Aquifer appears to have occurred at or near previously used production wells or the Mini-Storage well. However, as mentioned above, pumping of the production wells would have limited the migration of CT-impacted groundwater until their operation was discontinued in the late 1980's, at which point CT-impacted groundwater could then have migrated into the deeper aquifers through vertical conduits provided by the compromised well seals. The Mini-Storage well, however, is used relatively infrequently and capture would not be significant.

The eastern and longer plume emanates from MW-B-13-180, which had existed for a longer period of time. The western and shorter plume seems to emanate from or near the Mini-Storage well, which had not existed prior to 1996. Historical migration through other MCWD or Fort Ord production wells also undoubtedly contributed to contamination within the Upper and Lower 180-Foot Aquifer; however, these well have been destroyed and are no longer active conduits. It is unknown whether MCWD Well No. 8 (now destroyed) represented another vertical conduit in this area, but the construction log indicates that it probably had been a vertical conduit and could account for the historical detection of CT at other nearby production wells (e.g., MCWD Well No 8a, FO-27, and FO-28).

The formation of CT plumes within the Upper 180-Foot Aquifer could have begun with the installation of MW-B-13-180, providing faulty installation, and with the construction of the Mini-Storage well in 1975 and 1996, respectively. CT emanating from MW-B-13-180 would likely have been captured by pumping from FO-27, which was partially screened within the Upper 180-Foot Aquifer. Pumping from this well ceased in approximately 1988, upon which the eastern CT plume probably began to assume its current shape. A comparison of the length and potential age ratios of the western and eastern Upper 180-Foot Aquifer plumes support this hypothesis. The western and eastern Upper 180-Foot Aquifer plumes are approximately 3,500 feet and 4,500 feet long, respectively, resulting in a length ratio of 0.77. The effective age of each of the potential vertical conduits are 9 years (since the Mini-Storage well was installed) and 16 years (since the cessation of pumping from FO-27), resulting in an age ratio of 0.56. These ratios do not match unless the continued length of the eastern CT plume into the Lower 180-Foot Aquifer is also considered. The CT plume within the Lower 180-Foot Aquifer appears to be an extension of the eastern Upper 180-Foot Aquifer plume and is approximately 1,500 feet long. Thus the total length of the eastern CT plume is 6,000 feet which results in a distance ratio of 0.58. This ratio closely matches the ratio of potential ages of the suspected conduits and supports that Mini-Storage well and MW-B-13-180 are the two currently active vertical conduits in the area. That the western Upper 180-Foot Aquifer CT plume and the northern Lower 180-Foot Aquifer CT plume are both coincident with the

Mini-Storage well supports that a vertical conduit exists at or near this well.

Once contamination was present within the Lower 180-Foot Aquifer, migration continued to the east toward the regional collective pumping center of the Salinas Valley in response to intense pumping of regional groundwater for agricultural irrigation. Contamination entered the Lower 180-Foot Aquifer in two locations. The first was the vertical conduit represented by the production well or wells and has resulted in the larger (northern) of the two plumes within the Lower 180-Foot Aquifer. The highest concentrations of CT have consistently been observed at the Mini-Storage well. Prior to its installation in 1996 it is possible that CT reached the Lower 180-Foot Aquifer via MCWD Well No. 8 until this well was destroyed in 1992.

The second pathway into the Lower 180-Foot Aquifer is a natural vertical conduit located near Bunkerhill Court that has resulted in a smaller CT plume located south of Reservation Road. This southern plume could potentially have more immediate impacts on the active drinking water well field and the closest active drinking water wells, MCWD Well Nos. 29 and 30, although the CT plume has consistently remained at least 1,000 feet upgradient of this area and has not been detected in these supply wells.

1.3 Community Relations Activities During Site Characterization

Community Involvement Workshops (CIW) were routinely conducted throughout the duration of the site characterization steps comprising the RI. Summaries of the groundwater investigation process were presented to the public approximately every six months and included a description of site geology and hydrogeology; groundwater elevations and flow directions; locations and depths of contaminant contamination; updated statistical descriptions of the three active groundwater remediation treatment systems in operation at the former Fort Ord; and a discussion of water supply issues related to these remedial activities. Specific attention was paid to the OUCTP program, including a description of the contamination including historical use of CT at Fort Ord; the design and results of pilot studies; and probable remedial solutions.

As the definition of the A-Aquifer CT plume improved, the Army purchased newspaper advertisements to supply Marina residents with contact information should they own and operate a private well and were concerned about their water quality. The Army offered to sample residents' private wells for VOCs to determine if the plume had impacted private water supplies. Wells tested did not indicate the presence of CT.

The Army also conducted several door-to-door surveys to specifically determine the potential for private wells located in the eastern portion of Marina to serve as vertical conduits from the A-Aquifer to underlying aquifers. Drilling activities also included the notification of neighborhoods as to the anticipated schedule and noise levels and to provide contact information. Information regarding contamination and ongoing investigative activities were presented to specific neighborhood organizations, such as the Preston Park housing area.

2.0 Physical Characteristics of Study Area

The following sections summarize the existing and historical infrastructure and physical setting of Fort Ord, as well as a general description of geologic and hydrogeologic features at OUCTP. A brief description of the Deep Aquifer which underlies the OUCTP study area aquifers is included because this aquifer is used as a drinking water source for the City of Marina although it is hydraulically isolated from the OUCTP aquifers and was not characterized as part of the OUCTP remedial investigation.

Infrastructure components within the study area boundaries include the current and historical water supply system, the storm drain system, the sanitary sewer system, and conveyance associated with the OU2 groundwater treatment system (GWTS). The active water supply and sanitary sewer systems at the former Fort Ord were transferred to the MCWD in the year 2000. All four infrastructure components are described below.

2.1 Water Supply System

Two water supply systems are located within the study area boundaries (Plate 2) - the Fort Ord system, and the MCWD system. A more detailed history of the Fort Ord water supply system has been described in reports prepared for the Army for planning or permitting purposes (*Kingman, 1961; Kaiser, 1975; Geotechnical Consultants, Co. 1986; Ace Pacific Co., 1988*). Within the OUCTP area, the Fort Ord water supply system historically included conveyance from drinking water well nos. 26, 27, and 28 (also called FO-26, FO-27, and FO-28) and currently includes MCWD well Nos. 29, 30, and 31 (also called FO-29, FO-30, FO-31 prior to 2000). A fourth drinking water well (FO-32) has been decommissioned due to chronic mechanical problems.

Fort Ord Drinking Water Supply System

Well Nos. 26, 27, and 28 were constructed in 1963 and 1968 as part of the expanding Fort Ord water supply system to account for the loss of potable water from other wells due to seawater intrusion. By 1988, Well Nos. 26 and 27 had been impacted by seawater intrusion and had been placed in ‘Standby-Active’ status. This meant that these wells remained physically connected to the water supply system but were not being used to extract (produce) water.

Although the Army routinely collected samples for general chemical analysis, volatile organic compounds were not a required constituent of sample analysis until 1985 (Assembly Bill 1803). Samples in 1985 indicated the presence of CT in Wells Nos. 26, 27, and 28 at concentrations ranging from 0.5 to 0.54 μg/L, 0.5 to 1.7 μg/L, and 1.7 to 6.0 μg/L, respectively. CT was detected in Well No. 28 at 9.1 μg/L in 1986 and was abandoned following the activation of well nos. FO-29, FO-30, FO-31, and FO-32. All three wells were destroyed in 1999 and the connection to the water system was disconnected. The common water line still exists in the area, but has been isolated from the remaining water system. Cross sections showing Well Numbers FO-29, FO-31, and FO-32 are provided on Plates 3 and 4 of the *OU 2 Plume Delineation Investigation Report* (*Harding ESE, 2001c*).

Well Nos. 29, 30, 31, and 32 were recommended for installation in 1975 (*Kaiser, 1975*) in response to the continued intrusion of seawater primarily in the 180-Foot Aquifer at the approximate rate of 500 feet/year. At that rate in 1975, it was anticipated that the existing active supply wells at the time (including Well No. 28) would not be capable of producing potable water beyond 1982. Chloride concentrations exceeded the 250 milligrams per liter (mg/L) potable threshold at Well No. 26 in 1978, and in Well No. 27 in 1981. Due to the threat of continued degradation of the water supply from seawater intrusion, Kaiser recommended an eight-well field located east of Blanco Road, and north and south of Reservation Road. Following this recommendation, the Army installed four of the wells in 1984 which were activated in September 1985. Of these four new wells, Well No. 32 was abandoned in 1990 due to chronic mechanical/electrical problems. The remaining three wells (Well Nos. 29, 30, and 31) comprise the current well field supplying the former Fort Ord community. These wells primarily obtain water from the Lower 180-Foot Aquifer and are located beyond but downgradient of the OUCTP area. CT has not been detected above the 0.50 µg/L reporting limit in quarterly samples collected from these wells to date.

Marina Coast Water District Drinking Water Supply System

The MCWD drinking water system within the study area boundary historically included Well Nos. 5, 8, and 8a and, since 1986, Well No. 11. Pumping from wells screened within the Lower 180-Foot Aquifer (Well Nos. 1 through 9) resulted in a large ‘cone of depression’ (lowered groundwater elevations) centered beneath the eastern portion of the City of Marina that persisted into the mid-1980s (*Geotechnical Consultants Inc., 1986*). Several of these wells were screened in the Lower 180-Foot Aquifer and constructed with a long gravel pack that provided vertical conduits from the A-Aquifer (e.g., Well No. 5). Others wells (e.g., MCWD Well No. 8) were constructed with multiple seals that were not properly located within the aquitards as required to prevent hydraulic communication between the aquifers that also provided a vertical conduit from the A-Aquifer to the Lower 180-Foot Aquifer. In particular, the potential implications of MCWD Well No. 8 serving as a historical vertical conduit (until its destruction in 1992) for migration of CT within these aquifers is further discussed in Section 4.2.3.

Like many of the Fort Ord wells screened in the Lower 180-Foot Aquifer, MCWD wells had been abandoned and destroyed by the mid- to late-1980s due to water quality degradation by seawater intrusion. Depressed groundwater elevations beneath Marina have since recovered and groundwater now flows eastward toward Salinas Valley in the Lower 180-Foot Aquifer. Of the three wells within the OUCTP area, Well Nos. 5 and 8 have been destroyed and Well No. 8a has been converted by the Army into a groundwater monitoring well. Well No. 11 is active but screened within the Deep Aquifer, which is hydraulically isolated from the OUCTP area. VOCs have not been detected in Well No. 11 to date.

CT had been detected in samples collected from MCWD Well No. 8a between 1987 and 1991; concentrations ranged from 0.74 to 2.5 µg/L and were consistent with those detected at the nearby Fort Ord Well Nos. 26, 27, and 28 during the same period. Samples were not collected after 1991 because corrosion from seawater intrusion rendered its pump inoperable and the well was subsequently abandoned. Pumping equipment was removed from MCWD Well No. 8a in 2001 as part of this RI and CT has not been detected in subsequent samples, including those collected during aquifer testing as discussed in Section 3.6.3.

Private Wells

A private irrigation well also exists within the study area boundaries and is located at a storage facility called “Marina Mini-Storage”; hence, the well is referred to as the Mini-Storage well. This well extracts water from the upper portion of the Lower 180-Foot Aquifer and irrigates a small landscaped portion of the property (Plates 6 and 7). Potable water at this property originates from the municipal water system supplied by the MCWD. The frequency of operation and maximum capacity of the pump are not known but the property management has indicated that this well is used relatively infrequently to irrigate a small portion of the property. The well head and pressure tanks were moved to a subsurface vault by the property owner in 2004. As discussed in Sections 1.2.3.5, 4.2.2, and 4.2.3, a vertical conduit may co-exist with this well and CT may be migrating from the A-Aquifer to the underlying Upper and Lower 180-Foot Aquifers at or near this location.

Several other private wells were identified within the greater City of Marina area as part of advertising to locate such wells to further delineate the extent of the OUCTP footprint in each aquifer. Wells sampled include the “Jayne” well at 3137 Crescent Avenue and the “Reeves” well at 358 Reservation Road. Both appear to have been constructed within the Upper and Lower 180-Foot Aquifers, respectively, and CT was not detected at either location. Other wells discovered are located further west near Del Monte Boulevard, generally beyond the OUCTP study area.

2.2 Storm Drainage and Sanitary Sewer Systems

As of 2004, MCWD has been responsible for the storm drainage and sanitary sewer systems throughout the former Fort Ord. Within the OUCTP area, these systems are in place throughout the Preston Park Housing area and within the eastern portion of the City of Marina. Storm drains located within the former Fort Ord footprint collectively discharge into Monterey Bay whereas storm drains within the eastern portion of Marina drain to local catchments within the residential neighborhoods. Storm water collected within the commercial (central) district and more recently developed northern portion of Marina discharge into the Patton Park pond located west of Del Monte and north of Reservation Road. This pattern of storm water collection and discharge has implications regarding net recharge to the A-Aquifer and its simulation in the groundwater model as discussed in Section 9.0.

2.3 OU2 Groundwater Treatment System Conveyance

Groundwater has been regularly extracted from 13 wells in the A-Aquifer and two wells in the Upper 180-Foot Aquifer since 1995 as part of the OU2 GWTS (expanded in 2000 to include three additional A-Aquifer and four additional Upper 180-Foot Aquifer extraction wells). Treated groundwater from these wells was originally returned to the aquifers via three injection wells and an infiltration gallery located just west of the CT source area in Preston Park (along Macarthur Drive; Plate 2). The infiltration gallery consisted of five 50-foot deep wells that each received an average of 60 gallons per minute (gpm) and operated from October 1995 to March 2000. Schematic drawings of the infiltration gallery wells were presented in the *Draft Final, Conceptual Design Analysis OU2 Groundwater Remedy, Operable Unit 2, Fort Ord Landfills, Fort Ord, California*, dated May 17, 1995. Use of the third injection well (IW-OU2-03-180) also stopped in 2000. The expansion of the OU2 GWTS in 2000 required that approximately 50 percent of the treated water be diverted to the Sites 2/12 GWTS to aid in the maintenance of a groundwater mound to deflect seawater intrusion from the extraction wells located closer to the coastline.

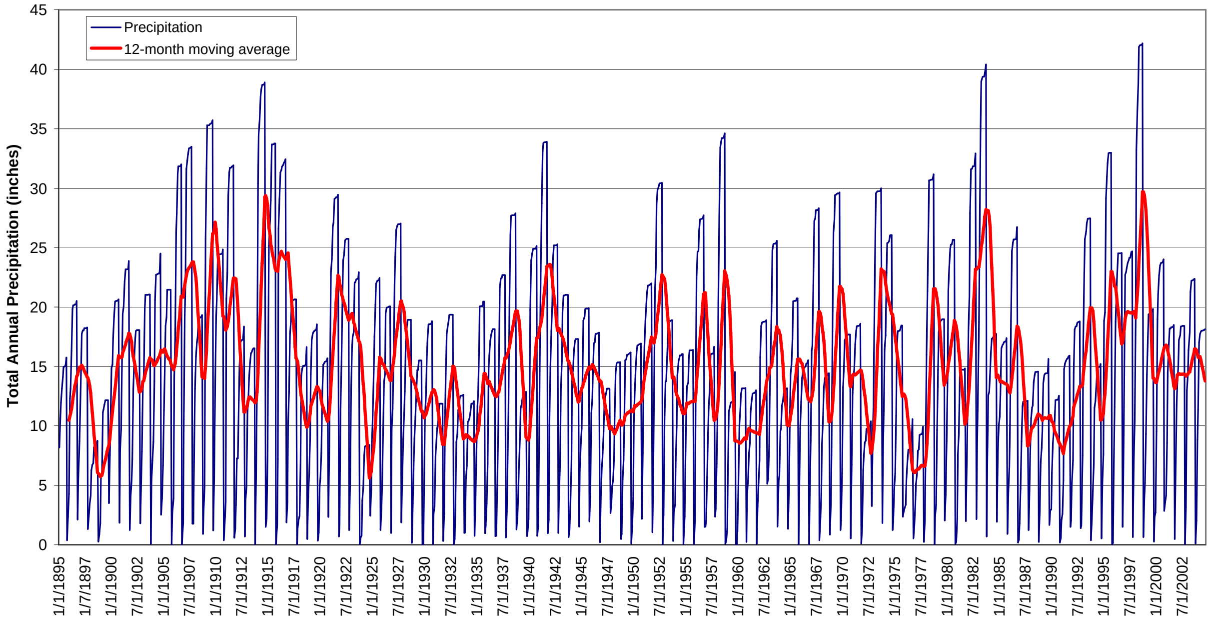
Monitoring wells had not been located sufficiently close to the OU2 infiltration gallery to observe groundwater elevations directly beneath the area but numerical modeling has indicated that a groundwater mound (rise of groundwater elevations) of approximately 20 feet may have resulted from this treated groundwater infiltration activities. Groundwater elevations at MW-OU2-08-A, located approximately 1,000 feet to the southwest of the infiltration galleries, rose three feet in response to infiltration activities, and then rose an additional six feet in response to the 1997/98 “El Niño” event as discussed in the following section.

The proximity of the CT plume in the A-Aquifer to the infiltration gallery was not known until 2000 and it now appears that the extent of groundwater mounding beneath the infiltration gallery was sufficient to shift the groundwater divide west of its current location and allow a small portion of the plume to migrate eastward. As indicated by the presence of CT at MW-BW-16-A and MW-BW-57-A, the extent of this eastward migration appears to be minimal. The groundwater divide returned to its present, and presumably historical, orientation once operation of the infiltration gallery ceased.

2.4 Climate

The area's climate is characterized by warm, dry summers and cool, rainy winters. The Pacific Ocean is the principal influence on the climate at Fort Ord, and the source of fog and onshore winds that moderate temperature extremes. Daily ambient air temperatures typically range from 40 to 70 degrees Fahrenheit (F), but temperatures in the low 100s have occurred. Thick fog is common in the morning throughout the year. Winds are generally from the west.

The average annual rainfall of 14 inches occurs almost entirely between November and April. Because the predominant soil is permeable sand, runoff is limited and stream flow occurs only intermittently and within the very steep canyons in the southeastern portion of Fort Ord. No surface water is located within the OUCTP area. An anomalously large amount of rainfall associated with an "El Niño" event dropped 42 inches of rain during the rainy season of 1997/1998. This resulted in a significant increase in groundwater recharge and storage within the A-Aquifer, as discussed in Section 9.0. Precipitation since 1895 is illustrated below:



As illustrated above, significant precipitation events since 1950 occurred during the winters of 1952, 1958, and 1983, in addition to the "El Niño" event in 1997. Precipitation events prior to 1950 are probably not relevant to this investigation because the source of OUCTP appears to have originated around this time, although drought conditions seem to have preceded this period.

2.5 Ecological Setting

Fort Ord is located on California's central coast, a biologically diverse and unique region. The range and combination of climatic, topographic, and soil conditions at Fort Ord support many biological communities. Field surveys were conducted from 1991 through 1994 to provide detailed site-specific, as well as basewide, information regarding plant communities, botanical resources, observed and expected wildlife, and biological resources of concern. Plant communities were mapped for the whole base as described in the *Draft Basewide Biological Inventory, Fort Ord, California* (*HLA, 1992*).

The OUCTP area is typically described as including the following plant communities: central maritime chaparral; Coast live oak woodland; grassland; and developed/landscaped areas. Central maritime chaparral is the most extensive natural community at Fort Ord, occupying approximately 12,500 acres in the south-central portion of the base. Grasslands, located primarily in the southeastern and northern portions of the base, occupy approximately 4,500 acres. The remaining approximately 11,000 acres of the base are considered fully developed and not defined as ecological communities.

Special-status biological resources are those resources, including plant and wildlife taxa and native biological communities, that receive various levels of protection under local, state, or federal laws, regulations, or policies. The closure and disposal of Fort Ord is considered a major federal action that could affect several species of concern and other rare species that are listed by the California Department of Fish and Game (CDFG) and/or the California Native Plant Society (CNPS), or listed as threatened or endangered under the federal Endangered Species Act (ESA). The United States Department of the Interior, Fish and Wildlife Service's (USFWS's) final *Biological Opinion for the Disposal and Reuse of Fort Ord* (*USFWS, 1993*) required that a HMP (*USACE, 1997*) be developed and implemented to reduce the incidental take of listed species and loss of habitat that supports these species. The HMP for Fort Ord complies with the USFWS Biological Opinion and establishes the guidelines for the conservation and management of wildlife and plant species and habitats that largely depend on Fort Ord land for survival (*HLA, 1997a*). Of the 12 plant communities identified at Fort Ord, two are considered rare or declining and of highest inventory priority by the CDFG (*1997*): central maritime chaparral and valley needlegrass grassland. Special-status taxa that occur or potentially occur in the plant communities at Fort Ord include 22 vascular plants, 1 invertebrate, 4 reptiles, 1 amphibian, 9 birds, and 2 mammals.

Within the area of OUCTP, specific resources of concern include Monterey spineflower (Chorizanthe p. pungens), sand gilia (Gilia tenuiflora arenaria), sandmat manzanita (Arctostaphylos pumila), toro manzanita (Arctostaphylos montereyensis), coast wallflower (Erysimum ammophilum), Monterey ceanothus (Ceanothus cuneatus rigidus), Eastwood's goldenbush (Ericameria fasciculata), and the black legless lizard (Anniella pulchra nigra). Coast live oak (Quercus agrifolia) woodland is considered to be potential habitat for the Monterey ornate shrew (Sorex ornatus salarius) and the Monterey dusky-footed woodrat (Neotoma fuscipes luciana).

2.6 Topography and Surface Waters

Elevations at Fort Ord range from approximately 900 feet above mean sea level (MSL) near Wildcat Ridge, on the east side of the base, to sea level at the beach. Topographic elevations within the OUCTP area range from about 40 to 180 feet MSL (Appendix F). The predominant topography of the area reflects morphology typical of the dune sand deposits that underlie the western and northern portions of the base, including the area currently under investigation for CT contamination. In these areas, the ground surface slopes gently west and northwest, draining toward Monterey Bay. Runoff is minimal because of the high rate of surface-water infiltration into the permeable dune sand. Consequently, well-developed natural drainages are absent throughout much of this area. Closed drainage depressions typical of dune topography are common.

Topography within the source area of OUCTP has changed significantly with the Preston Park and Abrams housing developments. Cut and fill operations potentially changed the grade by tens of feet, which is relatively obvious by examining the topography surrounding each housing area. For instance, the portion of Abrams housing development on Lexington Court appears to have resulted primarily resulted in a 'cut' operation, where the previous hillside has been topped and as much as 20 feet of sediment removed.

The only surface waters near the OUCTP area includes the Salinas River to the east and a pond associated with Locke Paddon Park to the west. Both of these features appear to interact with the water table of the A-Aquifer and do not interact with groundwater in the 180-Foot Aquifer. The A-Aquifer CT plume does not extend toward the Salinas River; however, it does migrate westward on a trajectory that may allow contamination to eventually migrate south of the Locke Paddon Park pond. Water quality data for this pond were not obtained or generated as part of this RI because groundwater samples from nearby monitoring wells indicate that the plume has not reached the vicinity of the pond.

2.7 Geology

Fort Ord is within the Coast Ranges Geomorphic Province. The region consists of northwest-trending mountain ranges, broad basins, and elongated valleys generally paralleling the major geologic structures.

In the Coast Ranges, older, consolidated rocks are characteristically exposed in the mountains but are buried beneath younger, unconsolidated alluvial fan and fluvial sediments in the valleys and lowlands. In the coastal lowlands, these younger sediments commonly interfinger with marine deposits.

Fort Ord is at the transition between the mountains of the Santa Lucia Range and the Sierra de la Salinas to the south and southeast, respectively, and the lowlands of the Salinas River Valley to the north. The geology of Fort Ord generally reflects this transitional condition; older, consolidated rock is exposed at the ground surface near the southern base boundary and becomes buried under a northward-thickening sequence of poorly consolidated deposits to the north. Fort Ord and the adjacent areas are underlain, from depth to ground surface, by one or more of the following older, consolidated units:

- Mesozoic granitic and metamorphic rocks;
- Miocene marine sedimentary rocks of the Monterey Formation; and
- Upper Miocene to lower Pliocene marine sandstone of the Santa Margarita Formation (and possibly the Pancho Rico and/or Purisima Formations).

Locally, these units are overlain and obscured by geologically younger sediments, including:

- Plio-Pleistocene alluvial fan, lake, and fluvial deposits of the Paso Robles Formation;
- Pleistocene eolian and fluvial sands of the Aromas Sand;
- Pleistocene to Holocene valley fill deposits consisting of poorly consolidated gravel, sand, silt, and clay;
- Pleistocene and Holocene dune sands;
- Recent Beach Sand; and
- Recent alluvium.

The geology of Fort Ord is described in detail in Volume II of the Basewide RI, Basewide Hydrogeologic Characterization (*HLA, 1994a*).

2.8 Hydrogeology

Hydrostratigraphic units of interest within OUCTP include aquifers within the dune sands, valley fill deposits, and the Aromas Sand/Paso Robles Formation. The A-Aquifer is located within the recent dune sands and is perched above a regional aquitard called the FO-SVA. The valley fill deposits contain both the Upper and Lower 180-Foot Aquifers, and portions of the 400-Foot Aquifer (locally). The Aromas Sand and Paso Robles Formation contain the 400-Foot Aquifer and the Deep Aquifer. The following sections describe the present groundwater monitoring well locations relevant to OUCTP, and the general characteristics of the four affected aquifers. The lithologic cross-sections indicated on Plate 3, are illustrated on Plates 4 through 7, respectively. Additional characteristics of the hydrostratigraphy of Former Fort Ord have been presented in previous investigation reports discussed in Section 1.2.3.1.

2.8.1 Existing Groundwater Monitoring Well Locations

Plates 3 illustrates existing monitoring well locations used to monitor groundwater quality and elevations in the vicinity of each CT plume in the A-Aquifer, the Upper 180-Foot Aquifer, and the Lower 180-Foot/400-Foot Aquifers. Additionally, previously used municipal wells (including those now destroyed and one inactive well), an active drinking water well, and the Mini-Storage irrigation well are also illustrated on Plate 3.

2.8.1.1 A-Aquifer

The A-Aquifer is generally located within recent dune sands overlying a gently dipping marine clay unit (FO-SVA) that generally controls the direction of groundwater flow in this aquifer. Groundwater flows under unconfined conditions throughout this aquifer. A significant facies ‘change’ (an area where the geologic and hydrogeologic characteristics of the aquifer are significantly different than in other parts of the unit) has been observed west of MW-BW-44-A. In this area, the vertical horizon typically associated with the upper 35 feet of the FO-SVA clay unit instead appears to contain a clean beach sand and gravel unit. Dune sand overlies this beach sand and gravel unit, with groundwater appearing to preferentially flows through the coarser beach sand and gravel unit, causing an abrupt 20-foot drop in groundwater elevation that coincides with the facies change. The sand and gravel unit appears to have been deposited in a marine environment as indicated by traces of shell fragments in drilling cuttings. Coarse material including polished chert pebbles and well-rounded granite gravel up to 1.5 inches in diameter, was observed at MW-BW-44-A. The abrupt transition of the upper surface of the FO-SVA between wells MW-BW-43-A and MW-BW-44-A (about 800 feet) combined with the lithologic contents is suggestive of a wave-cut terrace. The coarse material was probably transported by littoral currents although the ultimate origin has not yet been determined. A cross-sectional view of the A-Aquifer along the axis of the CT plume is illustrated on Plate 4; transverse cross-sections of the A-Aquifer are illustrated on Plate 5.

The recent dune sands are primarily well-graded fine- to medium-grain or fine- to coarse-grain sand, usually with a minor silt component. The saturated portion of the dune sands, the A-Aquifer, is composed of fine- to coarse-grain, well-graded sand east of the wave-cut terrace. Typically, the base of the A-Aquifer was confirmed during well construction by penetrating the underlying FO-SVA by at least one foot at each A-Aquifer borehole.

Elevations of the top of the FO-SVA range from 36 feet below MSL at MW-BW-76-A to 58 feet above MSL at MW-BW-54-A. Data indicate the top of the FO-SVA uniformly dips to the west beneath the CT plume area until reaching the terrace where elevations abruptly drop about 30 feet further west. The water table in the A-Aquifer mimics and is controlled by the upper surface of the FO-SVA.

The apparent erosive removal of the upper portion of the FO-SVA west of the wave-cut terrace does not appear to change the aquitard status of this clay unit. The FO-SVA was confirmed at MW-BW-76-A and is suspected to extend 1,250 feet farther west based on lithologic logs from various wells in the area. The consistent slope of the water table west of the wave-cut terrace suggests that the lower clay units of the FO-SVA are laterally continuous between MW-BW-44-A and MW-BW-76-A.

The facies change from dune sand to clean beach sand and gravel in the downgradient area of the CT plume may be of particular significance with respect to its potential for continued migration. Although no channels have been observed, groundwater velocities are higher in the sand and gravel unit than in the dune sand unit and will result in a higher migration rate of the CT plume west of the wave-cut terrace.

Groundwater flows through the A-Aquifer northwest from the suspected source area to about MW-BW-27-A from which point groundwater flows more to the west (Plate 9). West of MW-BW-45-A, groundwater flow appears to subtly shift toward the south. This subtle change in flow direction is apparently related to the facies change discussed above and probably reflects the orientation of the western pinch-out (portion of the clay unit that thins out and eventually disappears) of the underlying FO-SVA unit and eventual drainage into the Upper 180-Foot Aquifer. Groundwater gradients in the A-Aquifer across the site vary from 0.005 feet/foot near the suspected source area to 0.008 feet/foot farther downgradient. West of the facies change, the gradient is an order of magnitude less (about 0.0009 feet/foot) which reflects the higher hydraulic conductivity of the beach sand and gravel unit relative to the dune sand as discussed in Section 9.0.

Hydrographs from representative A-Aquifer monitoring wells are illustrated on Plate 12 and indicate that groundwater elevations are relatively stable yearlong, despite significant regional groundwater extraction for irrigation uses to the east from the Salinas Valley. The stability in groundwater elevations within the A-Aquifer support that this aquifer is hydraulically isolated from pumping stresses induced within the deeper 180-Foot and 400-Foot Aquifers.

A notable exception to these stable elevations was observed during the 1997/98 winter season when unusually large amounts of rainfall occurred as part of an El Niño event. This event resulted in a higher water table throughout much of the area overlying the FO-SVA (between 4 and 9 feet higher groundwater elevations throughout the OUCTP area). Within the Main Garrison area, less of an effect on groundwater elevations from the event were observed, probably because storm water drainage in this area effectively limits the potential for direct recharge to the A-Aquifer. The rise in groundwater elevations typically did not peak until 2000 due to the thickness of the vadose zone and the buffering effect it has with respect to recharge events. Additionally, the subsequent drop in groundwater elevations following the El Niño event has not been consistent throughout the area. Although groundwater elevations rose at least five feet throughout much of the area, those areas closer to the Main Garrison recovered quickly (i.e., by 2001) possibly illustrating the effect of groundwater extraction related to the OU2 GWTS. Distal areas (e.g., along Reservation Road) still have not fully recovered as of September 2004; the varying degree of recovery probably reflects the local variability in A-Aquifer hydraulic properties (e.g., storativity and hydraulic conductivity) and may also reflect the storativity of the overlying vadose zone.

The A-Aquifer thickness varies from about 12 feet at MW-BW-42-A to about 32 feet at MW-BW-35-A based on groundwater elevations measured in January 2001. The aquifer generally thins from the source area (about 30 feet) to areas east of the wave-cut terrace (less than 20 feet); however, it generally increases west of the wave-cut terrace to a maximum of 44 feet at MW-BW-76-A due to the continual drop in elevation of the underlying FO-SVA clay.

Data from MW-BW-51-A and MW-BW-54-A was used to further refine the location of the A-Aquifer groundwater divide just east of the source area. The location of the divide appears to be generally controlled by the surface of the FO-SVA and appears to have prevented the CT plume from migrating eastward in the A-Aquifer.

As discussed above, the detection of CT at MW-BW-16-A and MW-BW-57-A (east of the groundwater divide) at low concentrations appears to be the result of a temporary westward shift of the groundwater divide in response to operation of the OU2 infiltration gallery between 1995 and 2000. The influx of treated groundwater appears to have been sufficient to effectively push the CT plume in the A-Aquifer eastward resulting in the low detections of CT at these two wells. Since infiltration operations in the A-Aquifer have ceased at OU2, the groundwater divide is again located east of the CT plume.

2.8.1.2 Fort Ord – Salinas Valley Aquitard

The FO-SVA is a clay unit up to about 80 feet thick and of marine origin, as indicated by seashells commonly observed in the middle to lower half of the unit. Its lateral extent is illustrated on Plate 9; its presence beneath Fort Ord is limited to the northern half of the former base, although it appears to correlate with the Salinas Valley Aquitard (SVA) east of Fort Ord. It appears that the FO-SVA clay was deposited in a lagoonal environment, possibly protected by dune sands lining the coast (presumably located west of where the FO-SVA pinches out).

Lithologic data collected from previous investigations have been incorporated with new data collected during this remedial investigation and are consistent with previous interpretations of the apparent lateral extent of this significant aquitard. As shown on Plate 9, the FO-SVA extends westward almost to Highway 1 and southward to almost to Eucalyptus Road (*Harding ESE, 2001c*). The southern extent of the FO-SVA appears controlled by an unconformable contact with the Aromas Sand unit and Paso Robles Formation (*Harding ESE, 2001a*). The westward and southern extent of the FO-SVA has significant implications regarding recharge to the underlying Upper 180-Foot Aquifer as discussed in Section 9.0.

The surface of the FO-SVA appears to reach its highest elevation within the study area at MW-BW-54-A at 58 feet MSL (Plates 6, 7, and 8; Appendix F). The FO-SVA extends to the northwest (off-post) at greater depths than observed elsewhere on the former base (as low as 36 feet below MSL at MW-BW-76-A). The northward dip of the FO-SVA is attributed to continued tectonic uplift centered on the Santa Lucia Range south of Fort Ord. A subtle east-west arch along the top of the FO-SVA produces a north-south trending groundwater divide in the overlying A-Aquifer, roughly coincident with Imjin Road just east of the source area of the OUCTP. Groundwater west of this divide flows to the west and either drains into the Upper 180-Foot Aquifer where the FO-SVA pinches out or into Monterey Bay; groundwater east of this divide flows to the east toward the Salinas River.

The surface of the FO-SVA has been examined in previous investigations both for OUCTP and OU2 and elevation contours were illustrated in Plate 3 of the *Draft Final Carbon Tetrachloride Study Area Drilling Report – Wells MW-BW-30-A through MW-BW-42-A (Harding ESE, 2002a)*. Although it may be reasonable to expect some channel formation to have formed on the surface of the FO-SVA as it was uplifted (but before being buried by A-Aquifer dune sand), continuous low-lying patterns are not discernable in the OUCTP area. Variations within the surface of the FO-SVA are generally subtle and insignificant relative to the 20 to 30 foot thickness of the overlying A-Aquifer and coarse-grain material (e.g., coarse sand or gravel) has not been observed within the isolated low-lying surfaces of the FO-SVA. It is therefore concluded that subtle surface variations in the surface of the FO-SVA are not indicative of significant channels within the OUCTP area. A-Aquifer groundwater elevations within the OUCTP area, as in other areas in the Fort Ord area, generally mimic the westward slope of the FO-SVA surface. The direction of groundwater flow in the A-Aquifer along with the direction of CT migration is consistent with sub-regional flow directions and are not dependent upon channels within the FO-SVA surface.

Additional data from this investigation indicate that the thicknesses of the FO-SVA varies from 6 to 119 feet throughout the study area and averages 50 feet thick (Appendix F). However, up to three laterally extensive sand units have been observed directly (especially from continuous core obtained by sonic drilling) or indirectly from geophysical data (e.g., downhole resistivity logs) within the FO-SVA throughout the OUCTP study area, suggesting that either minor regression events or possibly storm events distributed 5 to 10 feet of sand or silty sand into the lagoon at a time (Plates 6, 7, and 8). The presence of these sandy layers apparently does not impact the ability of the FO-SVA to significantly retard groundwater movement downward from the overlying A-Aquifer to the underlying Upper 180-Foot Aquifer where the clay is present, as groundwater elevation data in the A-Aquifer is laterally consistent and does not indicate the presence of local downward flow. No aquitard, including the FO-SVA, is perfectly impermeable; some downward movement of groundwater is to be expected. However, the thickness and low vertical hydraulic conductivity (see Section 3.6.5) of the FO-SVA combined with the high concentration of organic carbon (see Section 5.2) result in little or no CT migration through this aquitard into the underlying Upper 180-Foot Aquifer except where penetrated by vertical conduits of municipal or monitoring wells with inadequate sanitary seals.

Examination of continuous core from Upper 180-Foot Aquifer monitoring wells installed using sonic drilling methods produced significant density of seashells or shell fragments in the vicinity of MW-BW-43-180 and MW-BW-45-180, with a clear decrease in density in the eastward direction. Shells were noted at depths of 98, 128 and 143 feet bgs at MW-BW-19-180R, generally near the top of each clay subunit comprising the FO-SVA, and ranged in size from 2 to 12 cm. The presence of shells and shell fragments diminished further east in additional borehole advanced with sonic drilling, which is indicative of the depositional patterns (e.g., depth) of the lagoon in which the FO-SVA clays settled. A layer of peat was also noted in this area near the bottom of the FO-SVA (depth of 147 feet bgs at MW-BW-19-180R). Shell and peat material was submitted to Stanford University for age dating via carbon-14 analysis. Results are summarized in Section 2.5 of this report.

2.8.1.3 Upper 180-Foot Aquifer

Data from monitoring wells screened within the Upper 180-Foot Aquifer within the OUCTP area indicate an average thickness of about 70 feet and a typical consistency of fine to coarse sand that grades to a sand and gravel layer near its base (Plate 6, 7, and 8; Appendix F). Although the hydraulic conductivity of this aquifer within the OUCTP area has not been quantified, examination of lithology from continuous core material indicate that values are consistent with aquifer tests conducted in association with OU2 investigations and are considerably higher than that of the A-Aquifer. Groundwater in the Upper

180-Foot Aquifer throughout the Main Garrison area of Fort Ord generally flows eastward toward Salinas Valley; however, gradients within the OUCTP area reflect a local southeastern flow direction (Plate 10). This local discrepancy reflects discharge to the Lower 180-Foot Aquifer southeast of OUCTP which is consistent with lithologic data that indicate the underlying aquitard is absent beneath the Fredericksburg housing area (in the vicinity of MP-BW-41 and MW-OU2-61-180).

Groundwater elevations within this aquifer vary across the site with a small gradient of about 0.001 feet/foot; however, seasonal stresses are significant and result in annual groundwater elevation fluctuations of about eight feet at distal points from the discharge area (e.g., MW-B-13-180). The magnitude of these fluctuations decreases with proximity to the western and southern edges of the FO-SVA unit (e.g., MW-OU2-28-180), however, as illustrated on Plate 13. This discrepancy reflects recharge that probably occurs along the southern extent of the overlying FO-SVA unit, as discussed in Section 9.0.

Hydrographs of Upper 180-Foot Aquifer wells in the study area indicate that groundwater in the Upper 180-Foot Aquifer reflects a seasonal pattern previously observed during basewide monitoring that matches the schedule of groundwater pumping from Salinas Valley (Plate 13). South and east of the study area, seasonal fluctuations in Upper 180-Foot Aquifer groundwater elevations drop groundwater elevations slightly below the bottom of the FO-SVA, creating unconfined conditions. Within the majority of the study area, however, groundwater elevations remain above the bottom of the FO-SVA thus maintaining confined conditions yearlong.

Groundwater elevation data from wells screened within the upper unit do not indicate a significant vertical gradient when compared to groundwater elevations from wells screened within the lower portion of this aquifer. However, data from newly installed wells MW-OU2-78-180 and EW-OU2-07-180, adjacent to MW-OU2-61-180 and overlying the apparent pinch-out of the underlying Intermediate 180-Foot Aquifer, will provide additional information regarding the vertical gradient (downward) in this area as the configuration of these three wells will provide a vertical pressure profile where the Upper 180-Foot Aquifer is in hydraulic communication with the Lower 180-Foot Aquifer and significant recharge occurs.

2.8.1.4 Intermediate 180-Foot Aquitard

The collection of continuous core material from sonic drilling has greatly improved our understanding of the Intermediate 180-Foot Aquitard. Previous investigations concluded that this unit is comprised of one to three laterally extensive clay units about 5 to 15 feet thick each, separated in some areas by thin sand or clayey sand layers, with an overall thickness of about 50 feet (Plates 6, 7, and 8; Appendix F).

Monitoring wells MW-OU2-65-180, MW-OU2-67-180, MW-OU2-71-180, and Westbay ports MP-BW-30-282, MP-BW-32-287, and MP-BW-33-272 were all installed in or near a sand unit within the Intermediate 180-Foot Aquitard and a comprehensive evaluation of groundwater elevation data from these wells suggest significant hydraulic communication with the underlying Lower 180-Foot Aquifer.

New data generated from this investigation indicate that the top of this unit is often identified as a partially consolidated ‘pebbly mudstone,’ typified by a dense conglomerate of angular gravel within a gray/brown clay matrix (Appendix A). The mélange of coarse and fine-grained material and partial consolidation indicate that this particular bed may represent colluvial processes (e.g., mass wasting) that could have occurred as the Salinas Valley walls were being eroded by ancient stream flow. The extent of this bed is correlative with the lateral extent of the aquitard itself and is not distinguishable except in high-integrity continuous core.

The aquitard underlying the ‘pebbly mudstone’ is often characterized by a significant fraction of coarse sand and/or gravel, thus partially explaining the previously determined hydraulic communication with the underlying Lower 180-Foot Aquifer. Fragments of siltstone embedded in the lower portion of this clay zone were often angular, suggesting rapid deposition and short travel distances. Although not as thick as the FO-SVA, the lateral extent of the thin clay layers within the Intermediate 180-Foot Aquitard is notable because the sand and gravel units above and below appear to be of fluvial origin, which usually produces laterally discontinuous clay lenses. These clays may thus represent continental material and possibly over-bank flood deposits, which could explain the embedded gravel and angular siltstone within some of the clay layers. Because the clay layers are relatively thin and no seashells have been observed (as in the FO-SVA), the clays may not be of marine origin. The Intermediate 180-Foot Aquitard extends west to the Monterey Bay coastline but apparently does not extend south as far as the FO-SVA.

Although approximately 50 feet thick near the western extent of the Upper 180-Foot Aquifer plumes (in the vicinity of MW-BW-43-180), this aquitard feathers out near MP-BW-41 but is present again near MW-OU2-69-180 (Plate 7). Further south, lithologic data from MW-OU2-28-400 and groundwater elevation data from surrounding wells indicate that this aquitard may not be present, suggesting that the southern extent of the intermediate roughly parallels, but is located north of, that of the FO-SVA. The observation of a cobble layer (about five feet thick) and small boulders underlying the Intermediate 180-Foot Aquitard at MP-BW-41 at about 290 feet bgs may be illustrative of the apparent pinch-out of this aquitard this area. An area containing very coarse sediment such as cobbles would have been less subject to erosion processes and perhaps when the sediment comprising what is now the Lower 180-Foot Aquifer were emergent this area was left topographically elevated such that subsequent burial by sediments comprising what is now the Intermediate 180-Foot Aquitard were not deposited. This scenario would have resulted in an area into which the fine-grain sediments comprising the Intermediate 180-Foot Aquitard would feather out and ultimately not be present, which is consistent with our observations.

The importance of the integrity of this aquitard within its upper portion is evident from groundwater elevation data at MW-BW-19-180R, a replacement well to MW-BW-19-180. The new well was constructed with a 40 foot long screen, intentionally placed across what appeared to be the top of the Intermediate 180-Foot Aquitard (a one-foot thick clay noted at 226 feet). The construction thus includes 20 feet of screen penetrating the bottom portion of the Upper 180-Foot Aquifer and 20 feet of screen penetrating sediments comprising the Intermediate 180-Foot Aquitard. Resultant groundwater elevations are approximately two feet lower than surrounding wells penetrating only the Upper 180-Foot Aquifer and more correlative with groundwater elevations from the Lower 180-Foot Aquifer. This behavior indicates that a significant amount of aquitard integrity occurs within the uppermost 20 feet, and possibly less.

2.8.1.5 Lower 180-Foot and 400-Foot Aquifers

The Lower 180-Foot Aquifer underlies the Intermediate 180-Foot Aquitard and is hydraulically distinct except where the overlying aquitard is absent and significant downward flow from the overlying Upper 180-Foot Aquifer occurs (Plate 7). Sand and/or gravel of the Lower 180-Foot Aquifer is typically observed in drilling cuttings to approximately 100 feet below the Intermediate 180-Foot Aquitard, although continuous core and geophysical logs indicate several thin clay or silt units that appear to be somewhat laterally continuous throughout the study area. As mentioned above, a local cobble or boulder field was observed at MP-BW-41 from 285 to 290 feet bgs; cleaved sections of granite up to 12 inches long were recovered from the 4-inch core barrel. Cobbles of this size were not observed at any other boreholes advanced with sonic drilling techniques; historical rotary drilling at Former Fort Ord has not resulted in similar observations but this method would likely only produce fragments of cobbles or boulders with little left intact. Coarse-grain sediment commonly found within the Lower 180-Foot Aquifer suggests that the primary depositional environment was fluvial.

Although the predominant lithology of the Lower 180-Foot is sand and gravel, resistivity values measured in six recently installed boreholes are atypically low (less than 20 ohm-meters[2]) through this depth range, especially to the west of the study area. The now-destroyed drinking water wells that had been installed into the Lower 180-Foot Aquifer in the area were abandoned during the 1980s due to seawater intrusion. The low resistivity data indicate that the Lower 180-Foot Aquifer is still impacted by seawater intrusion indicated by high chloride concentrations despite the cessation of groundwater production in the area from this aquifer. The lowest resistivity values were observed in boreholes MW-BW-30-180 and MW-BW-31-180, closest to the previous drinking water wells and to Monterey Bay. Groundwater sample results indicate significantly elevated concentrations of chloride (as high as 6,900 mg/L) within this aquifer.

The 400-Foot Aquifer, the deepest aquifer included in the study area, underlies the Valley Fill Deposits and probably consists of Aromas Sand or Paso Robles Formation sediments. A significant aquitard was not observed to separate the Lower 180-Foot Aquifer from the underlying 400-Foot Aquifer within the OUCTP. However, natural gamma logs typically indicate (except at MW-BW-35-180) lower counts in the 400-Foot Aquifer than in the Lower 180-Foot Aquifer; gamma values increase primarily in response to the presence of potassium, which is usually found in concentrated amounts in clay units, but also in granitic rocks (feldspar). The differing amounts of potassium in the Lower 180-Foot and 400-Foot Aquifers may reflect different depositional environments. As granite weathers, feldspar is quickly removed leaving behind silica grains that ultimately become sand. At least a portion of the sediments within the 400-Foot Aquifer were deposited in an eolian environment (*Dupre, 1975 and 1990*) which may have removed much of the original potassium via physical weathering. Sediments within the Lower 180-Foot Aquifer were primarily deposited in a fluvial environment with relatively less weathering, possibly resulting in larger residual potassium concentrations relative to the 400-Foot Aquifer.

Resistivity data indicating seawater intrusion appears to terminate slightly deeper than the gamma shift, and groundwater samples from the 400-Foot Aquifer do not indicate elevated chloride concentrations. A fine-grained unit was not observed in drilling cuttings or in samples from the continuous core at MW-BW-32-180 near the location of the gamma shift, although examination of continuous cores indicate that fine-grained, reddish-brown, silty sand sediments are generally found at depths of approximately 385 feet (e.g., MP-BW-42).

An aquitard between these two aquifers is apparent in the well logs of the active Fort Ord drinking water wells about a mile east of the OUCTP area and thus the hydraulic communication between the Lower 180-Foot and 400-Foot Aquifers likely varies laterally throughout the Fort Ord area. The hydraulic contact between the Lower 180-Foot and 400-Foot Aquifers within the OUCTP area appears to be one of contrast in the hydraulic conductivity of two permeable units deposited under different depositional environments. It can be inferred that the conductivity of the Lower 180-Foot Aquifer is the higher of the two because elevated chloride concentrations associated with seawater intrusion are primarily found within this aquifer and not in the 400-Foot Aquifer. Seawater, as well as any contaminant, will migrate along the pathway of least resistance (highest hydraulic conductivity) and towards the lowest area(s) of groundwater elevation. Because historical pumping in the area has primarily focused on withdrawal from the Lower 180-Foot Aquifer, it is perhaps not surprising that the highest chloride concentrations are found within this aquifer. More recent pumping has, however, increasingly depended upon the 400-Foot Aquifer and it has not yet been shown that the contrast in hydraulic conductivity will sufficiently prevent seawater from impacting groundwater quality in this deep aquifer.

Two clay units were observed within the 400-Foot Aquifer; a yellow-brown or olive gray/green unit and a distinctive reddish-brown unit. The reddish-brown clay observed at these boreholes is about 200 feet deeper than the red clay marker referenced in the 1975 Kaiser report that defined the 180-Foot Aquifer from the 400-Foot Aquifer and appears to be unrelated (*Kaiser, 1975*).

Groundwater generally flows to the east or southeast within both the Lower 180-Foot and 400-Foot Aquifers, however, there appears to be more complex vertical flow patterns that may reflect heterogeneities within each aquifer. Based on data collected in December 2001 and March 2002, a vertical potential exists from the 400-Foot to the Lower 180-Foot Aquifer in the western portion of OUCTP. This trend appears to be reversed somewhat in the eastern portion of OUCTP where groundwater pressures are locally lower in the 400-Foot Aquifer than in the Lower 180-Foot Aquifer. Seasonal patterns of flow within these two aquifers have not yet been identified by evaluating data from wells within OUCTP.

Hydrographs of Lower 180-Foot Aquifer wells at Fort Ord indicate that groundwater elevations reflect a seasonal pattern previously observed during basewide monitoring that matches the schedule of groundwater pumping from Salinas Valley (Plate 14). Annual fluctuations within the Lower 180-Foot Aquifer increase significantly with proximity to the Salinas Valley as indicated by groundwater elevation data collected at MP-BW-40 (near the valley) and MP-BW-30 (near Marina).

Groundwater elevations appear to remain above the bottom of the Intermediate 180-Foot Aquitard, thus maintaining confined conditions; however, elevations typically remain below sea level and thus the Lower 180-Foot Aquifer remains susceptible to continued seawater intrusion yearlong.

2.8.1.6 Deep Aquifer

Although the Deep Aquifer will not specifically be investigated as part of this program MCWD owns and operates three drinking water wells completed in this aquifer, one of which (MCWD Well No. 11) is located within the study boundary of the OUCTP investigation. This aquifer is therefore considered a potential receptor of contamination from the overlying 180- and 400-Foot Aquifers although little is known about hydraulic interaction between these aquifer systems. The Deep Aquifer refers to the aquifer(s) contained in the middle or lower portions (the "B" and "C" members) of the Paso Robles Formation and includes what have been called the 800-foot, 900-foot, 1,000-foot, and 1,500-Foot Aquifers (*Thorup, 1976 and 1985; Geoconsultants, 1993*). The drinking water well MCWD-11 is located within the lateral study boundary, but is completed to a depth of 1,650 feet bgs with perforated intervals beginning 970 feet bgs, considerably deeper than where CT has been detected to date.

Due the greater depth and higher cost of installation, most production wells (municipal or agricultural) have not penetrated the Deep Aquifer. However, wells have been installed progressively deeper to avoid saline contaminated water; therefore, future production from the Deep Aquifer may increase. Generally, water from this aquifer contains higher natural concentrations of salt and has high sodium adsorption ratios (SAR). For this reason, growers in the Salinas Valley have found the Deep Aquifer to be less desirable as a source of irrigation water. Seawater intrusion has not been documented at the few wells that penetrate this aquifer; however, chloride concentrations typically range from 100 to 130 mg/L at MCWD Well No. 12 and are typically about 60 mg/L at MCWD Well No. 10 and in Well No. 11 (*MCWD, 2001*) (250 mg/L is the potable threshold).

2.8.2 Quarterly Monitoring Program

Groundwater elevations and samples have been measured and collected, respectively, on a quarterly basis from monitoring wells located throughout the northern portion of former Fort Ord since September 1992. Monitoring wells are typically sampled following the development process and analyzed for general mineral chemicals (i.e., sodium, calcium, magnesium, potassium, chloride, sulfate, bicarbonate alkalinity, and nitrate) and also for VOCs as a screening tool. Once installed and developed, each monitoring well is automatically incorporated into the quarterly monitoring program with the following quarterly sampling event; groundwater samples are analyzed for VOCs using EPA Test Method 8260. Historically, various test methods have been used including 8010, 8020, and 8240. Water quality results from the local production wells have also been sampled for VOCs quarterly since 1997 using EPA Test Method 524.

Groundwater elevations and analytical results are reported on a quarterly basis and are illustrated in an annual report of quarterly monitoring activities. These data comprise the majority of groundwater elevation and quality data relied upon in this RI (up to and including data from the September 2004 sampling event). Additional elevation data has been generated as part of aquifer testing activities or passive monitoring of groundwater elevations using transducers and continually recording dataloggers. Samples are also collected during aquifer tests to determine if groundwater quality changes while the aquifer is being stressed. Additional non-VOC analytes that are analyzed for quarterly include chloride and TDS collected from Westbay monitoring ports screened in the Lower 180-Foot Aquifer to monitor the presence of seawater intrusion. Results of the quarterly monitoring program are incorporated throughout this RI and are discussed in more detail in Section 4.0.

3.0 Field Investigation Program

The following section describes the various field investigation methods employed as part of the OUCTP RI. They include monitoring well installation, soil gas surveys, the conversion of a formerly used municipal well (MCWD Well No. 8a) to a monitoring well, tracer tests, geophysical investigations, natural attenuation sampling, and aquifer testing. All field work followed the Fort Ord Health and Safety Plan (*Harding Lawson Associates, 1997c*), Chemical Data Quality Management Plan (CDQCMP) requirements (*Harding ESE, 2002f*), and regulator-approved work plans (*Harding Lawson Associates, 1998; Harding ESE, 2001b, 2001e, 2002c, 2003d*).

3.1 Monitoring Well Installation

Monitoring wells were installed in various phases of the OUCTP RI to further characterize the A-Aquifer, the Upper 180-Foot Aquifer, the Lower 180-Foot Aquifer, and the 400-Foot Aquifer as summarized in Section 1.2.3. Monitoring wells consisted either of single-screen standpipe construction or multiple-screen Westbay construction. Westbay wells allow for the simultaneous monitoring of multiple aquifers within a single borehole. Appendix A includes lithologic logs and well construction details for all OUCTP monitoring wells. Monitoring wells installed since October 2002 as part of the OUCTP RI are discussed below. Wells installed prior to October 2002 were described in previously published documents referenced in Section 1.2.3.1.

3.1.1 A-Aquifer Monitoring Well Installation

Monitoring wells MW-BW-55-A through MW-BW-76-A were installed as part of the OUCTP RI to better delineate the A-Aquifer CT plume (Plate 3). Lithologic logs and well construction data for all monitoring wells are presented in Appendix A.

Prior to drilling, County permits and subsurface utility clearances were obtained for each well location. Biological clearances were obtained as necessary. Monterey County well installation permit numbers assigned for each monitoring well are:

Well Name	**Permit Number**	**Installation Date**
MW-BW-55-A	HZ-752	8/12/2002
MW-BW-56-A	HZ-753	8/7/2002
MW-BW-57-A	HZ-754	8/8/2002

Well Name	Permit Number	Installation Date
MW-BW-58-A	HZ-755	8/10/2002
MW-BW-59-A	HZ-756	8/11/2002
MW-BW-60-A	HZ-757	8/9/2002
MW-BW-61-A	HZ-993	6/2/2003
MW-BW-62-A	HZ-994	5/29/2003
MW-BW-63-A	HZ-995	6/3/2003
MW-BW-64-A	HZ-996	6/4/2003
MW-BW-65-A	HZ-997	5/30/2003
MW-BW-66-A	HZ-998	5/16/2003
MW-BW-67-A	HZ-999	5/15/2003
PZ-BW-44-A	HZ-992	5/13/2003
MW-BW-71-A	HZ-1362	8/25/2004
MW-BW-72-A	HZ-1361	8/25/2004
MW-BW-73-A	HZ-1364	8/24/2004
MW-BW-74-A	HZ-1363	8/23/2004
MW-BW-75-A	HZ-1365	8/25/2004
MW-BW-76-A	HZ-1366	8/24/2004

Boreholes for wells MW-BW-55-A through MW-BW-60-A were drilled using a truck-mounted hollow-stem auger rig (CME-75); boreholes for wells MW-BW-65-A through MW-BW-67-A were drilled with a B-61 hollow stem auger rig; and boreholes for wells MW-BW-71-A through MW-BW-76-A were installed using a B-81 hollow stem auger rig. Boreholes fore wells MW-BW-61-A through MW-BW-64-A, however, were drilled with an air-rotary casing hammer rig because a sufficiently large auger rig was not available. These wells were installed using drilling equipment owned and operated by Water Development Company (WDC) of Zamora, California, except for wells MW-BW-71-A through MW-BW-76-A, which were installed by Woodward Drilling, of Rio Vista, California. Field operations were overseen by a MACTEC geologist and were supervised by a California registered geologist.

All boreholes were logged from the drill cuttings; soil was classified according to American Society for Testing and Materials (ASTM) D 1586-84. The total depth of each borehole was determined by the confirmation of the FO-SVA clay. Most augered boreholes were first drilled with 8-inch diameter augers and then reamed with 12-inch diameter augers; wells within the same proximity (within about 300 feet) were subsequently drilled only with 12-inch diameter augers. The top of the FO-SVA clay was confirmed by observing clay on the 8-inch diameter augers upon their removal from the borehole and again by drilling rig response with the 12-inch diameter augers. The lithologic log of each well is presented in Appendix A.

Most A-Aquifer wells were constructed with 5-inch diameter Schedule 80 PVC casing and 30 feet of poly-vinyl chloride (PVC) screen (0.020-inch slot size). PZ-BW-44-A was installed as a two-inch diameter observation well (piezometer) for the MW-BW-44-A aquifer test. Wells MW-BW-61-A through MW-BW-64-A were constructed with two screens (one in the vadose zone) to allow for potential soil gas extraction if necessary. Remaining wells were installed with one screen to fully penetrate the A-Aquifer. Centralizers were installed immediately above and below the well screen and every 40 feet above the well screen to provide a minimum 2-inch clearance between the borehole wall and the well casing during construction activities.

Monitoring well filter packs consisted of #3 Lonestar sand tremmied into place from the bottom of the boring to approximately five feet above the screens. A minimum of five feet of hydrated bentonite chips were placed above the filter pack. A bentonite-cement slurry was placed from the bentonite seal to the ground surface. Well construction details are presented in Appendix A.

3.1.2 Upper 180-Foot Aquifer Monitoring Well Installation

Monitoring wells MW-BW-43-180 through MW-BW-56-180 were installed to better delineate the extent of the CT plume in the Upper 180-Foot Aquifer. Well MW-BW-19-180R was installed to replace MW-BW-19-180, which had been destroyed by vandalism (Plate 3). Prior to drilling, County permits and subsurface utility clearances were obtained for each well location. Biological clearances were not necessary because all wells were installed in developed areas. Monterey County well installation permit numbers obtained for each well are:

Well Name	Permit Number	Installation Date
MW-BW-19-180R	HZ-905	12/18/2002
MW-BW-43-180	HZ-906	3/3/2003

Well Name	Permit Number	Installation Date
MW-BW-44-180	HZ-907	2/27/2003
MW-BW-45-180	HZ-908	2/24/2003
MW-BW-47-180	HZ-910	3/29/2003
MW-BW-49-180	HZ-912	4/1/2003
MW-BW-50-180	HZ-913	6/26/2003
MW-BW-51-180	HZ-914	4/15/2003
MW-BW-52-180	HZ-915	4/4/2003
MW-BW-53-180	HZ-916	4/12/2003
MW-BW-54-180	HZ-1055	6/21/2003
MW-BW-55-180	HZ-1054	6/9/2003
MW-BW-56-180	HZ-1053	6/29/2003

Each Upper 180-Aquifer borehole was drilled using a sonic drill rig owned and operated by Prosonic Corporation of Chandler, Arizona, under the field supervision of a MACTEC geologist. All work was supervised by a California registered geologist. All boreholes were logged from continuous core samples; soil was classified according to ASTM D 1586-84. Boreholes were first drilled with a 4-inch diameter core-barrel and 6-inch diameter steel casing. Once the targeted depth had been cored and logged, 7-inch diameter steel casing was driven to the targeted depth, allowing the 6-inch diameter casing to be removed and the well to be installed. The 7-inch diameter casing was removed as annular materials were placed. Lithologic logs for each well are presented in Appendix A.

All Upper 180-Foot Aquifer wells were constructed with 3-inch diameter Schedule 80 PVC casing and 20 to 40 feet of screen (0.020-inch slot size). Centralizers were installed immediately above and below the screen and every 40 feet above the well screen to provide a minimum 2-inch clearance between the borehole wall and the well casing during construction activities.

Monitoring well filter packs consisted of #3 Lonestar sand tremmied into place from the bottom of the boring to approximately three feet above the screens. A minimum of five feet of hydrated bentonite chips (plug) were placed above the filter pack. A bentonite slurry was placed from the bentonite plug to 25 feet below ground surface. A bentonite/cement grout was placed from the top of the slurry to two feet below ground surface. Each well was completed below grade in a locking vault. Well construction details are presented in Appendix A.

3.1.3 Multiple Aquifer Monitoring Well Installation

Due to the presence of multiple aquifers at significant depths, Westbay monitoring wells were installed at select locations to evaluate groundwater within the Lower 180-Foot and 400-Foot Aquifers. The Westbay MP38 System was selected because it consists of a casing (38 millimeter diameter) designed to allow the monitoring of multiple discrete levels in a single borehole, thus minimizing drilling costs. Each monitoring zone has a valved connection to a central access tube that is sealed along its entire length maintaining the natural distribution of fluid pressures and chemistry.

Data is collected by one or more tethered probes with sensors that are lowered down the delivery tube or casing to each monitoring zone to measure fluid pressure and temperature, collect fluid samples or test hydrogeologic parameters. This approach eliminates the need to purge the well and minimizes the time required to collect a sample. Typically up to one liter of water may be retrieved from each port at a time; collecting more than one liter of water requires that the port be revisited.

Westbay MP38 System Installation

To aid in the installation of the individual sand pack and bentonite seals associated with each monitoring port, a three-inch diameter PVC overshot pipe was temporarily installed over the Westbay MP38 System within the steel drive casing to protect each monitoring port during seal placement. The overshot pipe was sequentially raised to expose each port for installation of the sand pack until each sand pack had been installed. A centralizer installed at the end of the overshot pipe maintained a minimum 2-inch annulus during well construction activities.

Because each Westbay well consists of multiple monitoring zones, each zone has been named according to its depth from ground surface. The name of each monitoring port is based on (1) the name of the borehole names listed above (replacing the “MW” with “MP”), and (2) the depth of each monitoring port from ground surface. “MP” stands for multiple port. The monitoring well as a whole (including all ports) is referred to by the well name (e.g., MP-BW-37) and individual ports are referred to by the complete monitoring port name (e.g., MP-BW-37-282). The monitoring well names that will appear when reporting groundwater pressure or quality data are shown on Table 1, as are the elevation and aquifer association of each port.

The installation process for each well included: confirming the total depth of the well; design of the well;

laying out each Westbay component on-site; assembling the couplings to each component; and then assembling each component with the assistance of the drill rig. The assembly process includes pressurizing each component joint for approximately one minute to ensure that the O-ring completely seals the joint. Once each joint was fitted together, a shear wire was installed to attach the coupling to the Westbay casing. Each Westbay system is designed to be entirely water tight upon completion to ensure that formation water only enters the well when the sampling tool is attached to a sample port.

Monitoring zones were also installed within the A-Aquifer and Upper 180-Foot Aquifer where plumes in these two aquifers overlay the plumes in the Lower 180-Foot Aquifer. Between four and seven Westbay monitoring ports were installed at each of the eight locations, for a total of 46 monitoring ports. Prior to installing the boreholes, Monterey County permits and subsurface utility and biological clearances were obtained for each well location. Because each borehole was completed with multiple monitoring ports, each monitoring port was named, rather than the well itself, to reflect its relative depth. The Monterey County permit numbers obtained for each well installed as part of this remedial investigation (referenced by borehole name) are listed below:

Well Name	**Permit Number**	**Installation Date**
MP-BW-37	HZ 872	12/10/2002
MP-BW-38	HZ 873	10/29/2002
MP-BW-39	HZ 874	11/16/2002
MP-BW-40	HZ 875	10/21/2002
MP-BW-41	HZ 876	3/17/2003
MP-BW-42	HZ 877	2/1/2003
MP-BW-46	HZ 909	2/16/2003
MP-BW-48	HZ 911	2/12/2003

Each borehole was drilled using a sonic drill rig owned and operated by Prosonic Corporation of Chandler, Arizona, under the field supervision of a MACTEC geologist. All work was supervised by a California registered geologist. All boreholes were logged from continuous core samples; soil was classified according to ASTM D 1586-84. Boreholes were first drilled with a 4-inch diameter core-barrel and 6-inch diameter steel casing. Once the targeted depth had been cored and logged, 7-inch diameter steel casing was driven to the targeted depth, allowing the 6-inch diameter casing to be removed and the well to be installed. The 7-inch diameter casing was removed as annular materials were placed. Larger casing (up to 10-inch diameter) was installed over smaller diameter casing (reverse telescoping) at locations where resistance was more significant and the 7-inch diameter casing could not be advanced to the target depth. The addition of larger diameter drive casings reduces the skin friction with the surrounding formation, although an increase in diameter significantly limits the associated depth penetration of that casing (i.e., 10-inch casing was able to penetrate only about 100 feet of sediments whereas 8-inch casing was able to penetrate 250 feet of sediments and 6-inch casing was able to penetrate 500 feet of sediments). Nonetheless, the incremental reduction in skin friction from even 100 feet of 10-inch casing permitted the 6-inch casing to reach its maximum depth. Lithologic logs for each well are presented in Appendix A.

The data from the lithologic log obtained from the continuous cores were used to design the Westbay monitoring system. MP-BW-38, MP-BW-39, and MP-BW-40 were each designed with four to five monitoring ports in the Lower 180-Foot and 400-Foot Aquifers. MP-BW-37, MP-BW-41, and MP-BW-42 were each designed with seven monitoring ports in the Upper and Lower 180-Foot Aquifers. Wells MP-BW-46-180 and MP-BW-48-180 were designed with monitoring ports in both the A- and the Upper 180-Foot Aquifers.

Monitoring well sand packs consisted of #3 Lonestar sand tremmied into place from the bottom of the boring to approximately three feet above and below each screen. A bentonite chip plug was then tremmied into place above each sand pack to limit invasion from the overlying bentonite seal into the sand pack. A bentonite slurry placed from the uppermost sand pack through the FO-SVA to within 25-feet of ground surface. The sanitary seal (bentonite/cement slurry) was then placed to the ground surface. Each well was completed below grade within a lockable vault. Well construction details are presented in Appendix A.

3.1.4 Well Development and Sampling

After the grout had set for at least 24 hours, most new wells were developed by swabbing, bailing, and pumping using a well development rig. Indicator parameters (turbidity, pH, temperature, and conductivity) were monitored and recorded during development. Stabilization criteria are presented in the Chemical Data Quality Monitoring Plan (CDQMP; *HLA, 1997b).* Purged groundwater was transferred to a storage tank for chemical characterization and disposal. No VOCs were detected in the sample collected from the storage tank analyzed using EPA Test Method 8260B.

The CDQMP states that well development will continue until the indicator parameters stabilize or 15 well volumes of groundwater are removed. However, this volume often does not adequately reestablish pre-drilling water quality conditions and therefore additional water was removed to accelerate the recovery period.

To evaluate groundwater quality, one screening sample was collected at the end of the development process and analyzed for VOCs using the EPA Test Method 8260B. A screening sample was not collected from PZ-BW-44-A due to its proximity to MW-BW-44-A. The additional purging conducted as part of the development process appears to have improved the quality of the screening samples as analytical results generally match results of subsequent samples collected during ensuing quarterly sampling events. Exceptions include wells MW-BW-61-A through MW-BW-64-A. The use of an air rotary casing hammer (ARCH) rig to install the boreholes for these wells most likely aerated the surrounding formation water and essentially sparged nearby groundwater of any VOCs present.

Rotary-installed Westbay wells were developed prior to the installation of the Westbay MP38 system. The outer wells that receive the Westbay system were installed by first installing a packer below each screen interval followed by alternatively swabbing, bailing, and purging the screen. Each screen was developed in this fashion until development criteria were met. Wells MP-BW-30 and MP-BW-32 were inspected by video log to confirm that drilling materials had been removed. The Westbay systems were installed following the development process and further development has not been necessary.

Sonic-installed Westbay wells were developed in a distinctly different fashion due to this unique installation method. Because these wells were installed directly into the boreholes, with no outer casing, development was conducted through the Westbay system. The narrow diameter (1.75 inches) and somewhat jointed extent of casing presented challenges in addition to the relatively limited yield from each purge port. Each monitoring zone was partially developed by first removing water from within the inner casing using a Waterra™ pump (maximum production rate of about 2 gpm) and then opening one purge port to surge the zone and flood the well. The purge port was then closed and the process repeated as necessary for each monitoring zone. Well development typically continued until the turbidity values dropped below 50 nephelometric turbidity units (NTU); lower values are desirable but were generally not achievable due to physical limitations of developing through Westbay port equipment. Each zone typically produced low-turbidity water relatively soon because the sonic drilling process does not rely on heavy drilling mud to advance the casing. The thin drilling mud used at the greater depths to lubricate the casing to reach the target depths apparently did not result in a significant mud cake on the borehole walls.

Several Westbay ports (including MP-BW-38-341, MP-BW-38-353, and MP-BW-41-396) have been difficult to develop and collect samples from, apparently because additional silt or other fine-grained material was present in the formation at those depths that have at least partially plugged the purge port screen. Monitoring ports at wells MP-BW-38-341 and MP-BW-38-353 have repeatedly been difficult to sample from as the port tends to ‘stick’ shut. The port at well MP-BW-41-396 has not been accessible for monitoring because of the large amount of silt overlying the sampling port at the bottom of this well. Even where active development has not been possible, formation water will eventually displace any drilling-placed non-native water used during installation activities as groundwater passively migrates through the formation at each monitoring zone.

3.1.5 Surveying

Monitoring wells were surveyed by California-licensed surveyor Bestor Engineering of Monterey, California. Horizontal and vertical control measurements were made to establish reference elevations and to document sampling and monitoring locations. Horizontal coordinates for well locations were surveyed using a global positioning system (GPS) device and presented in the North American Datum of 1983 (NAD 83) coordinate system. Vertical coordinates of water-level monitoring stations (e.g., well casing reference elevations) were measured to +/- 0.01 foot using a MSL datum of NGVD 29. Survey results are presented with the lithologic logs in Appendix A.

3.1.6 Waste Management

Soil cuttings from drilling activities were temporarily contained in soil bins near the borehole locations and either disposed of at the formerly used Fort Ord landfills (open portion of Cell E) or at select areas at the Marina Airport or Jefferson Ranch. Historical waste characterization of soil has typically not indicated the presence of VOCs at Fort Ord since the majority of contamination is present only in groundwater at low concentrations.

Soil characterization with respect to VOC contamination was conducted from soils in the first storage bin for each drilling project. As such, soil cuttings from the installation of MP-BW-38, PZ-BW-44-A, MW-BW-66-A, MW-BW-67-A, MW-BW-61-A, MW-BW-63-A, and MW-BW-64-A were collected for VOC analysis (EPA Test Method 8260). No VOCs were detected in any of these soil samples and the soils were disposed of as clean fill.

Purge water from the developing of monitoring wells was temporarily contained in a storage container (approximately a 4,000 gallon capacity) at the staging yard (west of Imjin Road) until analytical samples were collected and evaluated. Samples were collected on November 6, 2002; April 15, 2003; and October 3, 2003 in association with various stages of drilling projects. Additional quality control samples were also collected from the water source used for drilling (fire hydrant) and associated storage bins (e.g., USACE mobile poly tank, driller's storage tank) on February 17, 2003. Once results confirmed that VOCs were not present, the water was either siphoned off to the ground surface or to a nearby sanitary sewer line.

3.2 Soil Gas Surveys

Soil gas surveys were conducted as part of the OUCTP RI to confirm the presence of CT in the vadose zone, as samples collected in 1987 had indicated (*HLA, 1990*), and to determine whether sufficient CT mass remained in the vadose zone to constitute a residual source that might potentially continue to contaminate the A-Aquifer.

Results from samples collected in 1987 at depths of six feet indicated low concentrations (ranging from 0.001 to 0.3 ppb) that were unlikely to pose significant exposure risks to residents. At the time, the Preston Park housing area had not yet been constructed and the residents nearest to these soil gas sample stations were located on Lexington Court. As described in Section 1.2.3.1, a geophysical survey was conducted in the area to determine if disturbed soil or buried material may be present but none were found. Given the low soil gas concentrations and negative geophysical survey results, no further investigation was conducted.

Following the discovery of contamination in the groundwater and juxtaposition of the apparent source area with the 1987 soil gas data, several phases of soil gas investigations were undertaken to define the extent of CT contamination within the vadose zone and gather additional information in order to assess potential risks to residents in the Preston Park and Abrams housing areas.

3.2.1 Phase I Soil Gas Survey

The first soil gas survey was conducted in July 2002 and included samples collected from 24 locations (boring numbers SG-1 through SG-24) spaced throughout the Preston Park housing area. These screening samples were collected from discrete depths (6 feet to 60 feet bgs) using a direct push drilling rig (owned and operated by Vironex, Inc.). Each sample was collected by purging the ¼-inch tubing from the specific depth and transferring the soil gas into a 200-milliliter (ml) glass sample bottle. Samples were analyzed in an onsite mobile analytical laboratory owned and operated by Centrum Laboratories of Riverside, California. All samples were analyzed for CT, chloroform, PCE, and TCE using EPA Test Method 8260 and had a reporting limit of 79 ppb (v/v). This reporting limit is higher than would be available from a non-mobile laboratory but was deemed appropriate for screening purposes.

Results indicated CT was present in soil gas samples from samples from four borings in the southern portion of Preston Park housing, near Lexington and Ready Courts. CT was detected at borings SG-3 (60 feet), SG-4 (60 feet), SG-05 (45 feet), and SG-10 (60 feet) at concentrations of 100 ppb (v/v), 160 ppb (v/v), 160 ppb (v/v), and 86 ppb (v/v), respectively. A trace detection of CT below the reporting limit was noted at SG-12 with an estimated concentration of 46.2 ppb (v/v) at a depth of 55 feet. Chloroform, PCE, or TCE were not detected in any of the Phase I samples.

Each direct push borehole was backfilled with grout to ground surface once all samples had been collected.

3.2.2 Phase II Soil Gas Survey

The second soil gas survey was conducted in March 2003 with a refined sampling grid focused on the southern portion of the Phase I area near SG-3, SG-4, and SG-10. Six borings (SG-26, SG-27, SG-28, SG-29, SG-30, and SG-31) were installed on or near Lexington Court and samples were collected from depths of 6 to 86 feet bgs, again using a direct push drilling rig owned by Vironex, Inc. of San Leandro, California. Samples were collected using 6-liter Suma canisters and shipped to Severn Trent Laboratory (Santa Ana, California) for analysis in order to achieve lower reporting limits than in the Phase I screening mobile laboratory. All samples were analyzed for CT, chloroform, PCE, and TCE using Compendium Method TO-15 and had a reporting limit of 0.20 ppb (v/v).

Results confirmed the presence of CT, chloroform, PCE, and TCE in the vicinity of Lexington Court area at all depths with concentrations increasing linearly with increasing depth as summarized in the table below.

Phase II Soil Gas Analytical Data Summary

Analyte	Maximum Concentration (ppb v/v)	Minimum Concentration (ppb v/v)
Carbon Tetrachloride	280 (59 and 78 feet)	0.20 (19 feet)
Chloroform	14 (78 feet)	0.24 (6 feet)
Tetrachloroethene	6.7 (59 feet)	0.42 (40 feet)
Trichloroethene	38 (44 feet)	0.40 (6 feet)

The low concentration of CT (0.20 ppb [v/v]) detected at 19 feet appeared anomalous for this location because the lowest CT concentrations were detected at a depth of 6 feet throughout the Lexington Court area. The fact that this low detection matches the reporting level suggests that this value may represent a false negative. Otherwise, the distribution of CT concentrations were consistent both laterally and vertically and suggested increasing concentrations with depth within a relatively small (five acre) footprint.

Each direct push borehole was backfilled with grout to ground surface once all samples had been collected.

3.2.3 Phase III Soil Gas Survey

The third soil gas survey was conducted in May 2003 to provide additional data surrounding the Phase II area and to install permanent soil gas probes at a six-foot bgs depth to allow for repeatable sample collection. Sixteen borings (SG-33, SG-34, SP-35, SG-36, SP-37, SG-38, SG-39, SP/SG-40, SP/SG-41, SP/SG-42, SG-43, SP-44, SP-45, SG-46, SG-47, and SP-48) were installed near Ready Court and Lexington Court and samples were collected from depths of 6 to 75 feet bgs. Eight of these borings (SP-35, SP-37, SP-40, SP-41, SP-42, SP-44, SP-45, and SP-48) were converted into permanent soil gas probes. The permanent soil gas probes were installed from 5.5 to 6.3 feet bgs. The vapor monitoring wells were constructed with a one-foot long screen placed at the bottom of each well. The borings were backfilled with sand to approximately 1-foot above the screen, after which a 1-foot thick bentonite seal was installed prior to grouting to the surface with a Christy box completion. A wider sampling grid area was selected to provide additional data on the presence of CT in the vadose zone throughout the southern portion of the Preston Park housing area. Samples were again collected using a direct push drilling rig owned by Vironex, Inc. using 6-liter Suma canisters. All samples were analyzed by Severn Trent Laboratories (Santa Ana, California) for CT, chloroform, PCE, and TCE using Compendium Method TO-15 with a reporting limit of 0.20 ppb (v/v).

As with the Phase II results, Phase III sample results confirmed the presence of CT, chloroform, PCE, and TCE in the vicinity of Lexington and Ready Courts at all depths with concentrations increasing linearly with increasing depth as summarized in the table below.

Phase III Soil Gas Analytical Data Summary

Analyte	Maximum Concentration (ppb v/v)	Minimum Concentration (ppb v/v)
Carbon Tetrachloride	290 (75 feet)	0.38 (30 feet)
Chloroform	16 (75 feet)	0.31 (6 feet)
Tetrachloroethene	6.9 (75 feet)	0.21 (30 feet)
Trichloroethene	1.8 (75 feet)	0.20 (6 feet)

Of the eight soil gas probes, chloroform was detected at all locations, CT was detected at seven locations, PCE was detected at five locations (and only in samples that also contained CT), and TCE was not detected at any of the locations. Concentrations were similar to those measured in the six-foot direct-push samples with the exception of TCE, which was not detected.

Six-Foot Soil Gas Probes Analytical Data Summary

Analyte	Maximum Concentration (ppb v/v)	Minimum Concentration (ppb v/v)
Carbon Tetrachloride	16	0.90
Chloroform	5.6	0.29
Tetrachloroethene	0.76	0.41
Trichloroethene	Not detected	Not detected

Each direct push borehole was backfilled with grout to ground surface once all samples had been collected.

3.2.4 Dual-Screen Deep Vadose/Groundwater Monitoring Wells

The surface of the A-Aquifer water table was encountered at a depth of about 110 feet bgs throughout much of the Preston Park housing area. However, the direct push drilling rig was generally not capable of penetrating to depths greater than 70 feet bgs. Therefore, the extent of contamination within the lowest portion of the vadose zone could not be determined using this method. To assess deep vadose zone conditions, four dual-screen monitoring wells (MW-BW-61-A through MW-BW-64-A) were installed in the vicinity of Lexington Court. The upper screen extended from approximately 80 to 100 feet bgs and the lower screen fully penetrated the A-Aquifer. The intent of this design was to provide, at a later date, the ability to extract soil vapor from the upper screen as part of a soil vapor extraction (SVE) pilot study.

Initial testing of and analytical results of samples collected from the vadose zone screens are described in Section 3.10.

3.2.5 Waste Management

Soil cuttings were not generated as part of the collection of soil gas samples as most drilling was conducted with a direct push drilling rig, which does not produce drilling cuttings as do rotary drilling techniques. Wells MW-BW-61-A through MW-BW-64-A, however, were completed as dual-screen monitoring wells and waste management associated with that activity is discussed in Section 3.1.6.

Incidental waste (e.g., trash, packaging) generated as part of the soil gas investigation was properly discarded as municipal garbage.

3.3 MCWD Well No. 8a Conversion

MCWD owned a previously used drinking water production well (MCWD Well No. 8a) that is located immediately adjacent to a currently active drinking water production well (MCWD Well No. 11; Plate 3). MCWD Well No. 8a extends to a depth of 420 feet bgs with perforated zones from 280 to 300 feet, 320 to 360 feet, and 390 to 410 feet bgs (all entirely within the Lower 180-Foot Aquifer). MCWD Well No. 11 is screened within the Deep Aquifer with perforations between 970 and 1,650 feet bgs.

MCWD Well No. 8a was installed in 1982 to replace MCWD Well No. 8 (which is suspected to have been a conduit before it was destroyed) but became unusable by 1985 due to seawater intrusion. It was converted to use only for construction water production until the pump seized in 1988. Due to the poor water quality, no efforts were made to repair or inspect the pump and the well sat idle.

Because MCWD Well No. 8a is located so close to an active drinking water well which may be susceptible to contamination and also to a potential historic vertical conduit, it represented an ideal location for a monitoring well to evaluate groundwater quality in the Lower 180-Foot Aquifer. This well is also located upgradient of the existing Lower 180-Foot Aquifer monitoring well network (Plate 3), albeit slightly cross-gradient from the apparent OUCTP. The MCWD signed a right-of-entry on the basis that removed pump components (including the generator) be relocated to the MCWD lay-down yard to be used to maintain pumps in its other wells. They also requested that the pump house be entirely removed from the site.

The pump (a “Vertiline” Layne-Bowler model) had been installed with an intake depth of 282 feet bgs, at the top of the uppermost perforated zone. The pump motor, generator, pump bowls, and intake screen were all removed from the well on August 1, 2002 by Zim Industries, of Fresno, California. Once the components were removed from the pump house and well, the total depth of the well was measured to determine how much, if any sand may have collected into the well over time. The total depth was initially measured at 410 feet bgs. The accumulated sand and debris was bailed from the well bottom and the final total depth was measured at 422 feet bgs. Welenco, from Salinas, California, was contracted to conduct a video survey of the well to inspect the condition of the well screen. The screen sections were not visibly out of round and were visible to a depth of 403 feet bgs; however, the turbidity levels were excessive in the lowermost screen (390 to 410 feet bgs) and visibility below 362 feet bgs was poor.

Following the development of the well, a 2-inch diameter flush-threaded PVC insert was installed by hanging it from a custom bracket at the wellhead to allow the well to be secured. The PVC screen was designed to leave sufficient annulus for a large-diameter submersible pump to be installed for a future aquifer test. The PVC insert comprised 280 feet of three-inch casing and a single 140-foot long screen that extended from the uppermost to the lowermost MCWD Well No. 8a perforation (280 to 410 feet bgs).

3.4 Tracer Tests

Analysis of CT distribution within the Upper 180-Foot Aquifer led to the possibility that Well MW-B-13-180 had been a vertical conduit between the A-Aquifer and the Upper 180-Foot Aquifer through the FO-SVA as described in Section 1.2.3.5. An active vertical conduit of concern must meet two criteria: (1) the aquitard was penetrated, and (2) its location intercepts the A-Aquifer CT plume. If both criteria are not met, even if a conduit exists, then the A-Aquifer OUCTP cannot migrate vertically into underlying aquifers and a conduit of concern does not exist. MW-B-13-180 met both of these criteria and a tracer test was initiated to determine whether it could be proven.

The tracer test included the installation of an A-Aquifer monitoring well (MW-BW-60-A) immediately upgradient (within the A-Aquifer) of MW-B-13-180. Although MW-B-14-A is located immediately adjacent to MW-B-13-180, it is located downgradient of the suspected conduit and would not serve the needs of the tracer test. The tracer test consisted of injecting approximately 100 grams of potassium bromide (bromide) mixed with 50 gallons of bottled water into the bottom of MW-BW-60-A on November 11, 2003 using a tremie pipe and monitoring its arrival at MW-B-13-180 using a specific-ion probe, calibrated for the detection of bromide. Although the lateral travel time between these two wells was expected to be very short, it could not be determined how long migration through the conduit (assuming it exists) could take. The datalogger was programmed to read the probe every 30 minutes until the test was terminated on January 8, 2004. Quality control samples were collected from both wells to ensure that the probe was functioning properly.

Although the analytical data indicated the migration and dilution of the bromide tracer within MW-BW-60-A, neither the bromide probe nor the analytical samples indicated its arrival at MW-B-13-180. A single sample collected from MW-B-14-A near what became the end of the tracer test pathway indicated that bromide had arrived and had thus passed beyond the suspected conduit at MW-B-13-180. The test was terminated with inconclusive results.

A second test was initiated on January 23, 2004 using a higher concentration of potassium bromide to reduce the risk that an insufficient mass had been used in the initial test. Approximately 200 grams of potassium bromide were dissolved into 125 gallons of deionized water and injected into MW-BW-60-A using the same methodology as in the initial test. The bromide probe was recalibrated and again installed at MW-B-13-180. Quality control samples were again collected from the bottom of MW-BW-60-A and the top of MW-B-13-180. The arrival of bromide at MW-B-13-180, however, was not detected and again the tracer test was terminated with inconclusive results. It was concluded that an insufficient mass of bromide was provided to counteract the effects of dilution within the A-Aquifer.

3.5 Geophysical Investigation

MACTEC performed a one-day pilot study test to determine if ground penetrating radar (GPR) could achieve sufficient investigation depth to delineate the top of the FO-SVA and/or image facies changes within the FO-SVA unit. Briefly, GPR uses radar technology to produce a graphical profile of the subsurface using an antenna pulled along the ground surface. After reflecting off buried objects, soil layers, and other electromagnetic and/or geologic interfaces, some of the radar energy returns to the surface where it is detected by the same antenna (or a second antenna) and routed to a processor that stores and displays the returning radar energy in a graphical format that resembles a sub-surface a cross-section.

The OUCTP GPR test was performed along the unpaved site boundary road near MW-BW-44, where an abrupt change in the FO-SVA surface elevation is observed and where it appears that the FO-SVA clay has been replaced by clean beach sand and gravel as described in Section 2.8.1.1. The FO-SVA occurs at a depth of approximately 85 feet bgs in this area, which is relatively shallow for the FO-SVA, but is an extremely deep target for GPR in terms of the technical capabilities of this tool. Accordingly, a specialized data collection procedure called “stacking” was employed. Stacking entails taking several repeat readings at the same location (station) to enhance any weak but coherent GPR reflections that may have come from a deeply buried geologic interface. Stacking causes coherent signals to increase in amplitude (“grow”) relative to random noise. Additionally, a special low-frequency (120 megahertz [MHz]) GPR antenna was used for data acquisition. In general, lower frequency GPR signals penetrate more deeply than higher frequency signals, although they typically provide lower resolution in terms of the size of subsurface targets that can be imaged.

GPR test data were obtained using a G.S.S.I. Model SIR-10A GPR system connected to a 120-MHz antenna. The SIR-10A was mounted on a field vehicle which was also used to tow the large, bulky GPR antenna along the survey transects. The antenna was towed 30 feet behind the vehicle. Using a fiberglass tape measure, the survey lines were first marked with PVC pin flags at 10-foot intervals. The GPR antenna was activated and positioned at the first data station where a reflected radar signal was captured.

The reflected signal was digitally recorded onto 8mm data tape and was also viewed as a wiggle trace on the SIR-10A's CRT monitor. Approximately fifteen additional GPR traces were added (stacked) for a total of stack count of 16 at each station. The number of stacks was determined by observing the wiggle trace. The stack count was deemed sufficient when no additional changes in the wiggle trace were apparent. The GPR antenna was towed 10 feet forward to the next station and the process was repeated until the end of the line was reached. GPR data were obtained along two test lines designated GPR-1 and GPR-2 (Appendix B, Plate B1). Together, the two lines extended 2800 feet and contained 282 GPR measurement stations.

Results

To facilitate a geologic interpretation of the GPR data, the GPR profiles were converted to depth (elevation) using a simple velocity function of 4 nanoseconds (two-way travel time) per foot, a typical value for clean, dry, sand. The resulting GPR profiles for lines GPR-1 and GPR-2 are presented on Appendix B, Plates B2, and B3, respectively. Elevations shown on the profiles are approximate.

In general, both profiles showed several laterally continuous reflections that may have geologic significance. Foremost of these reflections is a continuous, sub-horizontal reflection at an elevation of about 160 feet on GPR-1 which may represent the top of the A-Aquifer. Additionally, three shallower dipping reflectors were apparent towards the west end of GPR-1. These dipping reflectors may represent layers of moisture or fine-grained material within the recent dune sand deposits. No coherent reflection patterns were apparent on the east end of GPR-1. GPR-2 exhibits a series of short shallow dipping reflectors, similar to those on GPR-1, and a short horizontal reflection on the south end of the line that may also represent the top of the A-Aquifer.

A coherent reflection pattern that mimics the ground surface topography was apparent on both lines. Because this reflection's occurrence appeared so constant in time, it is MACTEC's opinion that it may be a GPR reflection from the back of the field vehicle which, as a cargo van, provided an ideally large metal reflective surface for the stray GPR signals radiating from the unshielded 120-MHz antenna. Accordingly, it has no geologic significance. Improvised shielding may eliminate this reflection from future GPR surveys.

Conclusions

The GPR test survey appeared to image hydrogeologic variations within the shallower beach deposits, and may have also imaged the top of the A-Aquifer. However, it did not appear that the GPR signal penetrated deeply enough to provide information about facies changes within the FO-SVA.

3.6 Aquifer Testing

Aquifer testing was conducted as part of the OUCTP RI to better estimate hydraulic characteristics (e.g., hydraulic conductivity, transmissivity, and storativity) of the A-Aquifer and Lower 180-Foot Aquifers. No testing was conducted on the Upper 180-Foot Aquifer because adequate data was available from the results of aquifer testing conducted as part of earlier OU2 investigations (*HLA, 1994b; Harding ESE, 2001c*).

Each aquifer was tested using either pumping tests or slug tests; either method is designed to monitor the response to a stress applied to the aquifer. Pumping tests include extracting water from one well at a constant discharge rate and observing drawdown in a number of nearby observation wells. A slug test is conducted by inserting a solid 3-foot long PVC cylinder (the slug) into a single well to temporarily displace water upward. The water levels are continuously monitored as they fall back down to the original level (a falling head test). Once the original depth to water is reached, the slug is quickly removed and water levels are again continuously monitored as they rise to the original depth (a rising head test).

Pumping tests usually provide a much more accurate approximation of aquifer characteristics because they influence a much larger area and data can be used to test the pumping efficiency of the well. Slug tests typically only stress the aquifer in the immediate proximity of the test well, are often biased by the sandpack material, and do not provide data concerning the pumping efficiency. The combined results of both types of tests are often useful for approximating hydraulic properties.

Hydraulic properties of the A-Aquifer were estimated from two pumping tests (MW-B-14-A and MW-BW-44-A) and numerous slug tests. Hydraulic properties of the Lower 180-Foot Aquifer were estimated from a pumping test at MCWD Well No. 8a. Samples were also collected and analyzed for VOC’s throughout the test. The results are discussed below along with hydraulic parameters observed from each test.

3.6.1 MW-B-14-A Pumping Test

A 24-hour aquifer test at MW-B-14-A was proposed to stress the A-Aquifer and induce drawdown at observation wells MW-BW-15-A and MW-BW-60-A, located approximately 181 feet and 17 feet away, respectively. Because a sanitary sewer line that could directly receive discharge water during the test was not present near the site of the aquifer test, discharge water produced throughout the test was contained in three 6,500 gallon poly tanks supplied by Baker Tanks of Pittsburg, California. The combined volume of these tanks limited the test duration to 24 hours at the anticipated pumping rate of about 13 gpm. The discharge tanks were delivered to the site on July 17, 2003.

The constant rate discharge aquifer test began on July 22, 2003 at 0800 hours. A step test was not conducted and the constant rate discharge test began and was sustained at a discharge rate of 7 gpm. Due to technical difficulties (possibly an overheating pump), the test was interrupted at 1415 hours until 1520 hours the same day. Subsequently, the test was extended an additional three hours and was concluded on July 23, 2003 at 1500 hours. Groundwater elevations were measured until August 1, 2003 at 1040 hours to monitor recovery from the constant rate discharge test as well as ambient fluctuations.

Drawdown was only observed at MW-BW-60-A and reached approximately 0.7 feet at the end of the constant rate discharge test. No drawdown was observed at MW-BW-15-A and ambient groundwater fluctuations were negligible. Curve matching of drawdown and recovery data from MW-BW-60-A and MW-B-14-A indicate that transmissivity varies from 790 square feet per day (ft^2/day) to 878 ft^2/day, respectively. Given the aquifer thickness of 25 feet, the hydraulic conductivity of the A-Aquifer at this location was estimated at approximately 30 to 35 feet/day; storativity was estimated at about 0.007, consistent with an unconfined aquifer.

Groundwater samples were collected from the discharge line at MW-B-14-A on July 22, 2003 at 0940 hours, 2010 hours, and on July 23, 2003 at 0630 hours and were submitted to Sequoia Analytical Laboratories for VOC analysis by EPA Test Method 8260B. CT was detected at concentrations of 2.9 µg/L, 5.0 µg/L, and 5.3 µg/L, respectively. Lower concentrations (below or near the 0.50 µg/L detection level) of chloroform and trichloroethene were also detected and remained below the state maximum contaminant level (MCL).

Because the discharge water was contaminated with CT at concentrations exceeding the MCL of 0.5 µg/L, both tanks were gravity-drained through a carbon drum (supplied by Baker Tanks of Pittsburg, California) on August 7, 2003, after the conclusion of the recovery test. No VOCs were detected in the carbon sampled on September 9, 2004 and the carbon drum was subsequently removed from the site by Baker Tanks services.

3.6.2 MW-BW-44-A Pumping Test

A 24-hour aquifer test at MW-BW-44-A was proposed to stress the A-Aquifer and induce drawdown at observation wells PZ-BW-44-A, MW-BW-45-A, and MW-B-11-A, located approximately 21 feet, 277 feet, and 377 feet away, respectively. Because a sanitary sewer line is not present near the site of the aquifer test, discharge water produced throughout the test was contained in three 6,500 gallon poly tanks supplied by Baker Tanks of Pittsburg, California. The combined volume of these tanks limited the test duration to 24 hours at the anticipated pumping rate of about 13 gpm. The discharge tanks were delivered to the site on July 17, 2003.

The constant rate discharge aquifer test began on July 23, 2003 at 1745 hours and was sustained at a discharge rate of 6.5 gpm. Drawdown was not observed in any of the nearby wells throughout the duration of the test and thus the plumbing was reconfigured and a second test was initiated on July 31, 2003 at 1250 hours at a flow rate of 15 gpm. The constant rate discharge test continued at a pumping rate of 13 to 15 gpm until 2020 hours the same day due, and was ended when the storage tank was full. Groundwater elevations were measured until August 1, 2003 at 1050 hours to monitor recovery from the constant rate discharge test as well as ambient fluctuations.

Drawdown was only observed at PZ-BW-44-A and reached approximately 0.17 feet at the end of the constant rate discharge test. No drawdown was observed at MW-BW-45-A or MW-B-11-A and ambient groundwater fluctuations were negligible. Curve matching of drawdown and recovery data from PZ-BW-44-A indicate a transmissivity value of 9,800 ft^2/day. Given the aquifer thickness of 18 feet, the hydraulic conductivity of the A-Aquifer at this location was estimated at approximately 544 feet/day; storativity was estimated at approximately 0.001, consistent with an unconfined aquifer These values were consistent with the gravelly sand observed and recorded on the lithologic logs of several monitoring wells in this area.

Groundwater samples were collected from the discharge line at MW-BW-44-A on July 23, 2003 at 1945 hours, July 24 2003 at 0730 hours, and at 1230 hours and were submitted to Sequoia Analytical Laboratories for VOC analysis by EPA Test Method 8260B. VOCs were not detected in any of the samples.

Because the discharge water was not contaminated, gravity-drainage of the tanks to the ground beyond the apparent radius of influence from pumping (near MW-B-11-A) began on July 31, 2003, at 2200 hours.

3.6.3 MCWD Well No. 8a Pumping Test

MCWD Well No. 8a was previously used by the MCWD as a potable water supply well until chloride concentrations exceeded secondary drinking water quality guidelines. Elevated chloride concentrations originated from seawater intrusion and were monitored in excess of 2,000 parts per million (ppm) prior to abandonment circa 1988. This well was converted to a monitoring well in August 2002 as discussed in Section 3.3. Well screens fully penetrate the Lower 180-Foot Aquifer and the sanitary seal prevents hydraulic communication with shallower aquifer units.

After obtaining rights-of-entry from MCWD and obtaining a sanitary sewer discharge permit from the Monterey Regional Water Pollution Control Agency (MRWPCA), WDC Exploration and Wells of Zamora, California was contracted to supply and install a six-inch submersible pump and flow meter capable of monitoring discharge rates ranging from 50 to 400 gpm for the purposes of stressing the Lower 180-Foot Aquifer at MCWD Well No. 8a and inducing drawdown at nearby monitoring wells MP-BW-30-342, MP-BW-31-332, and MP-BW-37-328, located approximately 204, 656, and 512 feet away, respectively (Plate 3). Westbay purge ports for each observation well were opened for the duration of this test to allow for the use of In-Situ Troll 4000 dataloggers/transducers to monitor groundwater elevations continuously. Elevations were monitored on a logarithmic interval for 10 minutes and at a 10-minute interval thereafter from the observation wells and MCWD Well No. 8a.

The aquifer test was initiated on May 5, 2003 with a step test at 1015 hours to determine the optimal pumping rate from MCWD Well No. 8a. Discharge water was sent through three-inch diameter lay-flat hose to the storm drain located at the intersection of Salinas Avenue and Reservation Road. Discharge rates stepped up from 100 gpm to 200 gpm to 300 gpm until 1500 hours that day when the pump was shut off and recovery began. A maximum of 2.93 feet of drawdown was observed but less than 0.20 feet of drawdown was observed just prior to shut down due to an ambient rise in water levels. Pumping resumed at the highest discharge rate ranging from 320 to 345 gpm (valve wide open) at 1045 hours on May 6, 2003 and continued until 1045 hours on May 8, 2004 (48 hours). The final totalizer reading recorded a total discharge of 699,808 gallons during all pumping activities. Groundwater elevation monitoring continued until May 15, 2003.

Due to the high transmissivity of the Lower 180-Foot Aquifer at this location (the lithologic log for MCWD Well No. 8a indicated the presence of boulders) and the significant background noise from pumping wells in the area (ambient amplitude of two feet with a diurnal frequency), drawdown was not immediately apparent from data collected at any of the observation wells, and corrections were made by removing noise recorded at the Airfield well (beyond the radius of influence) from observation well data. Because the Airfield well is located closer to the Salinas Valley, fluctuations in groundwater elevation are more significant and thus the observation data may have been over-corrected. However, reasonable drawdown was discernable from the observation wells and estimates of transmissivity and storativity were calculated. Hydraulic conductivity values were calculated by dividing transmissivity values by 140 feet (the length of screen at MCWD Well No. 8). The following table summarizes aquifer properties calculated for the Lower 180-Foot Aquifer at this location.

Lower 180-Foot Aquifer Pump Test Results

Well Name	Transmissivity (ft^2/day)	Storativity	Hydraulic Conductivity (feet/day)
MP-BW-30-342	30,700	3.19e-4	220
MP-BW-31-332	40,900	2.07e-4	292
MP-BW-37-328	68,500	5.18e-4	489

Based on the results of the pumping test, it was concluded that the cumulative effect of daily pumping activities from wells within the Salinas Valley are sufficient to induce up to two feet of drawdown in the vicinity of MCWD Well No. 8a. In addition, significant correction is required to discern drawdown at extraction rates less than 340 gpm. Although there was difficulty in discerning drawdown and recording recovery from the pumping well (datalogger failure), it is estimated that the transmissivity of the Lower 180-Foot Aquifer in the vicinity of MCWD Well No. 8a is approximately 45,000 ft^2/day and the storativity is approximately 0.00035, all of which is consistent with a high-producing confined aquifer. This average transmissivity value is generally consistent with the transmissivity estimates based on the measured average specific capacity of 112.7 gpm/foot recorded on February 10, 1983, soon after MCWD Well No. 8a was installed. Using the method detailed in Driscoll (*Driscoll, 1986; page 1021*) for estimating transmissivity from specific capacity data from confined aquifers, this pumping characteristic yields an approximate transmissivity of 224,400 gallons per day per foot (gpd/ft) or 30,130 ft^2/day. Given an approximate aquifer thickness of 140 feet, the approximate hydraulic conductivity of the Lower 180-Foot Aquifer is 330 feet/day.

Groundwater samples were collected after 2 hours, 22 hours, 32 hours, and 47 hours of pump operation and tested for VOCs using EPA Test Method 8260. CT was not detected in any of these samples, despite the close proximity of detections at the Mini-Storage well located on the opposite side of Reservation Road and the historic detection of CT in samples at MCWD Well No. 8a in the 1980's, prior to its abandonment. Depth-discrete samples collected quarterly prior to and since this aquifer test also have not indicated the presence of VOCs at this location within the Lower 180-Foot Aquifer.

3.6.4 Slug Tests

Slug tests were conducted at numerous wells to more broadly estimate the hydraulic conductivity of the

A-Aquifer throughout the OUCTP area. The advantage of slug tests over other aquifer testing procedures is the significantly lower cost, less hardware and equipment, and less labor involved with each test. A slug test consists of two steps called the rising head test and the falling head test. When the slug is lowered into the well below the depth to water, water levels initially rise and then fall back to initial levels. This step is called the rising head test and results are generally more difficult to analyze due to splashing associated with quickly lowering the slug. Once water levels have stabilized, the slug is quickly removed from the well and water levels initially drop and then rise to the initial levels. This second step is called the falling head test and results are generally easier to analyze because there is much less noise associated with removing the slug from the well. The following table summarizes the wells tested, the date of the test, and results of the east test.

Slug Test Results

		Hydraulic Conductivity (feet/day)	
Well name	**Date of Test**	**Rising Head Test**	**Falling Head Test**
MW-BW-50-A	4/30/2003	27.6	34.8
MW-OU2-75-A	4/30/2003	13.4	13.6
MW-OU2-08-A	4/30/2003	40.2	27.9
MW-OU2-07-A	4/30/2003	33.8	14.0
MW-OU2-76-A	4/30/2003	72.3	68.8
MW-BW-51-A	5/01/2003	17.7	26.7
MW-BW-54-A	5/01/2003	23.7	26.9
MW-OU2-30-A	5/01/2003	23.9	16.3
MW-BW-55-A	5/01/2003	34.6	31.3
MW-BW-45-A	5/02/2003	10.7	10.4
MW-BW-44-A	5/02/2003	54.7	80.8
MW-BW-41-A	5/02/2003	19.3	16.5
MW-BW-38-A	5/02/2003	54.9	22.4
MW-BW-34-A	5/02/2003	32.1	25.3
MW-BW-39-A	5/02/2003	48.2	51.4
MW-BW-42-A	5/02/2003	98.3	81.5
MW-B-12-A	5/02/2003	34.0	41.6
MW-BW-30-A	5/07/2003	24.8	18.8
MW-BW-24-A	5/01/2003	15.1	11.7
MW-B-14-A	5/01/2003	18.2	28.7
MW-BW-31-A	5/01/2003	25.1	25.3
MW-BW-35-A	5/01/2003	62.5	76.6
MW-B-11-A	5/01/2003	16.1	30.6

Well name	Date of Test	Hydraulic Conductivity (feet/day) Rising Head Test	Hydraulic Conductivity (feet/day) Falling Head Test
MW-BW-43-A	5/01/2004	16.4	15.6

Estimated values of hydraulic conductivity from slug tests are typically higher than those from constant rate discharge tests because a smaller area surrounding the well screen is stressed and a large portion of the area includes the sand pack, which is usually more permeable than the surrounding formation. For instance, MW-B-14-A and MW-BW-44-A were tested both by constant rate discharge tests and slug tests. A two minute falling head slug test was initiated at well MW-BW-44-A on May 2, 2003 at 0939 hours resulting in a 0.985 foot change in water level. Following this, a two minute rising head slug test was performed at the same well at 0942 hours resulting in a 0.88 foot drop in water level. As tabulated above, the resultant hydraulic conductivity estimates ranged from 54.7 to 80.8 feet/day. A two minute falling head test was also initiated at well MW-B-14-A on May 1, 2003 at 1541 hours resulting in a 0.5 foot change in water level. Following this, a two minute rising head test was performed at 1551 hours resulting in a 1.07 rise in water level. As tabulated above, the resultant hydraulic conductivity estimates ranged from 18.2 to 28.7 feet/day.

These slug test results compare poorly to constant rate discharge test results from MW-BW-44-A (544 feet/day) but compare well with constant rate discharge test results from MW-B-14-A (23.5 feet/day). The reason for this discrepancy is that the very high hydraulic conductivity of the beach gravel material screened at MW-BW-44-A is not sufficiently stressed by a slug test and consequently tests are more likely representative of sand pack material. The similarity in results at MW-B-14-A, which is screened in dune sand, support the validity of the slug test results at other wells screened in similar dune sand material.

3.6.5 Permeameter Testing

In addition to in-situ aquifer testing, geotechnical laboratory testing was conducted on select soil samples to evaluate vertical permeability. Aquitard materials were targeted because groundwater flow through fine-grain sediment is typically vertical as it slowly migrates between surrounding aquifers. Samples were collected at discrete depths at MP-BW-38 using brass sleeves fit within the sonic drive casing for additional hydraulic testing (ASTM D 5084; Method C: falling head/rising tailwater) by Cooper Testing Labs of Mountain View, California. The sample depths, lithologic description, and average hydraulic conductivity are tabulated below.

Permeameter Testing Results

Sample Number	Depth (feet bgs)	Sample #	Lithology	Avg. Vertical Hydraulic Conductivity (cm/sec)
MP-BW-38	277-277.5	P2120004-15A	grayish brown CLAY w/sand	2e-8
MP-BW-38	277.5-278	P2120004-16A	grayish brown CLAY	2e-8
MP-BW-38	278-278.5	P2120004-17A	brown CLAY	2e-8
MP-BW-38	286.5	P2120004-18A	olive brown fine sandy CLAY (silty)	6e-7
MP-BW-38	287	P2120004-19A	olive brown CLAY, (silty)	1e-6
MP-BW-38	287.5	P2120004-20A	olive brown CLAY w/fine sand, (silty)	2e-7

These clay samples consist of the lower portion of the FO-SVA and demonstrate the very low vertical hydraulic conductivity of this aquitard. The complete reports from Cooper Testing Labs are included in Appendix E.

3.7 Natural Attenuation Sampling

In order to evaluate monitored natural attenuation as a potential remedial strategy for the CT contamination, CT and chloroform concentrations measured between March and December 2000 were specifically evaluated and molar ratios were calculated to assess the extent to which biological degradation of CT within the aquifer was occurring as evidenced by the presence of its daughter product chloroform. Additional groundwater samples were collected in April 2003 and analyzed for specific parameters that could indicate whether natural attenuation was occurring, including ferric and ferrous iron, sulfate, nitrate and nitrite, and dissolved gasses. Field parameters, including titrated alkalinity, ORP and DO were also collected during the four sampling periods. These data, along with the lithologic data collected from additional monitoring wells installed during and after these sampling periods were used to evaluate whether CT dissolved in groundwater is actively degrading under natural conditions within the OUCTP plume. Details of the natural attenuation investigation conducted in 2000 were published in the *Draft Final Natural Attenuation Summary Report, Carbon Tetrachloride Investigation, Former Fort Ord, California* (*Harding ESE, 2002e*), and are summarized below in conjunction with recent data from natural attenuation sampling conducted in 2003.

Natural attenuation is defined as “naturally occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in those media. These in-situ processes include biodegradation, dispersion, dilution, adsorption, vitalization, and chemical or biological stabilization or destruction of contaminants” (*OSWER, 1996*). A monitored natural attenuation (MNA) program is one that assesses the contaminated environment and establishes its condition relative to natural attenuation processes. The natural attenuation sampling that occurred between March and December 2000, was conducted to investigate the premise of monitored natural attenuation as a remedial solution to this contamination.

The field program for natural attenuation sampling in 2000 included eleven monitoring wells in the A-Aquifer and seven monitoring wells in the Upper 180-Foot Aquifer. Prior to the collection of groundwater samples for inorganic and organic analyses, field parameters including DO, ORP, and alkalinity were measured prior to purging the well. DO and ORP were measured with a YSI probe, model numbers 6920 and 610-D, and alkalinity was estimated from field titrated samples to compare against laboratory reported results. Samples for inorganic and organic analyses were collected following adequate purging of the well with a four-inch pump and stabilization of temperature, pH, turbidity, and conductivity, as described in the CDQMP. Samples collected for inorganic and organic analyses were submitted to a USACE certified laboratory for analysis.

3.7.1 ORP, DO, and Alkalinity

The ORP and DO data collected over the four monitoring periods indicate an overall oxidized environment (positive values) in both the A-Aquifer and Upper 180-Foot Aquifer. ORP and DO values were typically higher in the A-Aquifer monitoring wells, reflecting the unconfined nature of this aquifer and the clean dune sand stratigraphy. Alkalinity was estimated by titration in the field, resulting in higher concentrations than those reported by the laboratory. Previous inorganic analyses had indicated a slight ion imbalance in the groundwater, which may have been caused by a low bias in the reporting of alkalinity concentrations by the laboratory due to sample handling and shipping time, and an analytical holding time of 14 days. Ion balance calculations based on the field titrated alkalinity results indicated a close to neutral (zero value) ion balance in the groundwater.

3.7.2 Inorganic Analyses and Reductive Dechlorination

As described above, the ORP and DO data indicate that the groundwater in the A-Aquifer and Upper 180-Foot Aquifer in the OUCTP area is an overall oxidizing environment. However, reducing conditions are typically more favorable for the degradation of many chlorinated solvents, including CT. In addition to ORP and DO, several inorganic compounds can be used to evaluate whether the groundwater environment is in a reduced or oxidized state. For example, in a reduced, oxygen-depleted environment, nitrate will convert to nitrogen (N_2) and be released to the atmosphere. If nitrate concentrations are low or unavailable for microbial metabolism, microorganisms will convert ferric iron to ferrous iron. Therefore, the absence of nitrate, and the presence of ferrous iron, or other byproducts of microbial respiration (such as carbon dioxide) would be indicative of reducing conditions that would be conducive to the biological degradation of CT.

3.7.2.1 A-Aquifer

The overall groundwater environment in the A-Aquifer is typically oxidized; however, data collected during the four monitoring periods of the natural attenuation sampling indicated the occasional detection of reduced compounds (e.g., ferrous iron), suggesting that localized areas of reductive microbial activity may be present but are minimal. By-products of microbial respiration (e.g., carbon dioxide) were detected only once during the four sampling periods in MW-BW-14-A at 12 ug/L, which may be indicative of locally reduced conditions at this monitoring well. Field parameters measured at this well also indicated a reduced environment, and strongly suggest that CT is being attenuated locally at this monitoring well by microbial processes The source of electron donors responsible for driving these processes are, however, not well understood as non-detectable concentrations of total organic carbon have been noted in soil samples collected within the A-Aquifer. At least one residential septic tank may contribute organic carbon near MW-BW-43-A, as indicated by motile bacteria and fungus growth in the groundwater sample collected as part of the microcosm study (Section 3.8.1); however, any locally induced reducing environment appears insufficient to halt the migration of CT as the plume is present at least 1,000 feet further downgradient from this area.

3.7.2.2 Upper 180-Foot Aquifer

Like the A-Aquifer, the groundwater environment in the Upper 180-Foot Aquifer is also generally oxidized although to a lesser extent, due to the confined nature of the Upper 180-Foot Aquifer where recharge is limited to the edge of the overlying FO-SVA clay. While inorganic compounds indicative of locally reduced environments were detected in the Upper 180-Foot monitoring wells during the four monitoring periods, the detection of CT in this aquifer was not consistent, and the relationship between the inorganic data and CT data collected was not as clear as in the A-Aquifer. For example, in monitoring well MW-BW-20-180, nitrite, ferrous iron, and a single detection of methane were detected during the monitoring periods, possibly indicating a reducing environment. CT, however was not detected in this well during the monitoring periods, suggesting either that (1) the locally reducing environment at this well is not related to the microbial degradation of CT and is naturally driven by an unknown electron donor or (2) that CT concentrations at this well were historically higher and have been degraded beyond detection over time or (3) that these indicator compounds at this location are unrelated to the CT plume entirely and perhaps reflect local ambient conditions of the Upper 180-Foot Aquifer. Alternatively, negative ORP values and the presence of nitrite and ferrous iron at monitoring well MW-BW-22-180, where CT concentrations are typically among the highest in the Upper 180-Foot Aquifer, suggest that the locally reduced groundwater environment at this well is a result of microbial degradation of oxidizable organic compounds.

3.7.3 Organic Compounds

The microbial degradation of CT results in daughter products chloroform, dichloromethane, chloromethane, and ultimately, methane. During the four sampling periods of the study, CT and it’s first daughter product, chloroform were most often detected in both the A-Aquifer and Upper 180-Foot Aquifers. Additional detections of toluene, TCE, and 1,2-DCA were also frequently detected, but are not related to the degradation of CT.

3.7.3.1 A-Aquifer

Of the daughter products associated with the dechlorination of CT, chloroform was most frequently detected in the samples collected during the four monitoring periods, at a rate of 29 percent. Infrequent, low concentrations of chloromethane (5 percent) and methane (2.5 percent) indicate that the reduced environment present in the A-Aquifer is only sufficient to primarily degrade CT to chloroform but may have been active only near the source area historically (*Harding ESE, 2002e*). The correlation between CT and chloroform in the three areas of highest concentrations suggest that chloroform is migrating advectively with CT rather than as a product of reductive dechlorination. The reason for higher concentrations at these three areas, however, is debatable and may simply reflect the monitoring well orientation rather than suggest three periods of CT release to the environment.

3.7.3.2 Upper 180-Foot Aquifer

As observed in the A-Aquifer, samples collected from the Upper 180-Foot Aquifer during the four monitoring periods also showed a correlation between high CT concentrations, and detection of chloroform. None of the other daughter products of CT dechlorination (dichloromethane, chloromethane or methane) were observed in the samples from the Upper 180-Foot Aquifer. Consistent with the indication of locally reduced conditions and microbial activity in MW-BW-22-180, it appears that CT is degrading to chloroform within this aquifer; however, as in the A-Aquifer, the presence of chloroform may be a product of historical dechlorination and not current dechlorination processes.

3.7.4 Molar Ratios

In addition to molecular degradation, physical processes such as dilution, adsorption, and dispersion may contribute to the attenuation of chlorinated VOCs. In order to determine the dominant influence of CT attenuation in the A-Aquifer, the molar ratios of CT and chloroform were evaluated within the plume (*Harding ESE, 2002e*). If biological processes were the main or only factor responsible for the attenuation of CT and the subsequent presence of chloroform, the molar ratio of CT to chloroform should decrease as the plume moves downgradient. The unit molar ratio of CT to chloroform is approximately 1.29. A molar ratio of greater than 1.29 as the plume moves downgradient would indicate that the mole fraction of chloroform exceeds that of CT, and that other processes are contributing to the presence of chloroform. A molar ratio of less than 1.29 as the plume moves downgradient would indicate that the presence of chloroform could be the result of molecular degradation. Results from the four sampling periods indicate that the molar ratio of CT and chloroform exceeds 1.29 along the entire axis of the plume, and appears to increase in the downgradient direction, suggesting that physical processes may be the dominant influence in CT attenuation in the A-Aquifer plume. This further supports that historical dechlorination near the source probably generated the chloroform, which has since migrated through the plume advectively and not as a product of continued dechlorination.

3.7.5 Physical Processes

Of the physical properties that may contribute to the attenuation of CT in the A-Aquifer, advection and dispersion appear to have the most influence within the CT plume. Advection is a process that describes the physical movement of water through an aquifer. As water moves through the aquifer, the plume spreads out and is mixed with fresh water ahead of the plume, and from surface infiltration in the A-Aquifer. As a result, concentrations of dissolved compounds decrease in the downgradient direction. Although advection rates can be calculated specifically from known aquifer properties, they can also be inferred from lithologic data and groundwater gradients. Typically, an increase in gradient leads to an increase in advection rate. Lithologic data from A-Aquifer wells installed after the March through December 2000 sampling period, in June 2001 indicate a significant facies change (very coarse sand and gravel) near the toe of the plume that resemble a wave-cut terrace buried by recent dune sands (*Harding ESE, 2001b*). Groundwater gradients along the axis of the plume are less than 0.01 feet/foot, and spike to 0.03 feet/foot in the vicinity of the wave-cut terrace reflecting convergent flow as groundwater drains into the zone of higher hydraulic conductivity to the west. The lowest groundwater gradients were found to be west of the wave-cut terrace where hydraulic conductivity values are highest. Despite the low gradient in this area, groundwater velocity is expected to be much higher and, in fact, CT concentrations have recently increased rapidly at MW-BW-49-A although they remain relatively low (less than 5 μg/L). The apparently rapid migration of the CT plume downgradient of the wave-cut terrace indicates that dispersion associated with the wave-cut terrace cannot be relied upon as an attenuating factor and that continued migration to the west is likely if left unchecked.

3.7.6 Conclusions

Based on the data collected during the March, June, September, and December 2000 natural attenuation sampling periods, and on lithologic data collected during and after the four sampling periods, natural attenuation appears to be occurring at the site in the A-Aquifer via microbial and physical processes. Inorganic and organic chemical results from the sampling periods indicate the presence of locally reductive environments conducive to microbial processes. Physical processes were indicated by groundwater flow patterns and molar ratios between CT and chloroform, particularly in the downgradient area of the plume at the wave-cut terrace. The overall increasing trend in the molar ratio between CT and chloroform observed along the axis of the plume indicates that (1) biodegradation processes may be present along the entire axis of the plume, but predominate near the suspected source area despite observing local areas with reducing conditions throughout the plume, and (2) physical processes appear to control the downgradient extent of the CT in the A-Aquifer; however, are inadequate to attenuate continued westward migration of the plume.

The data collected during the four periods of sampling also indicate that natural attenuation via microbial degradation is occurring in the Upper 180-Foot Aquifer of the CT plume under locally reduced conditions. Inorganic data (observed nitrite, ferrous iron and methane) and organic data (chloroform) indicate that microbial processes are occurring in the Upper 180-Foot Aquifer of the CT plume.

3.8 Bench Scale Microcosm Studies

The consistent detection of chloroform, the primary daughter product from CT dechlorination, throughout the A-Aquifer indicates that natural attenuation is occurring in groundwater in the OUCTP. As discussed in Section 3.7.4, these processes were evaluated by calculating molar ratios and determining that dechlorination may be occurring within the upper third of the A-Aquifer plume. Additional data was required, however, to further evaluate whether these processes could be enhanced to remediate the OUCTP by increasing the rate of CT degradation. Bench scale evaluations of bacterial assays and microcosms were designed in two phases and additional field indicators of natural attenuation were measured in soil and groundwater in preparation for a field scale bio-treatability pilot study (Section 3.9).

3.8.1 Bench Scale Test Phase I

To further evaluate the microbial population within the A-Aquifer, a bench scale test was designed to evaluate groundwater from three portions of the A-Aquifer CT plume. Groundwater samples were collected from MW-BW-23-A, MW-BW-27-A, and MW-BW-43-A, which represent three areas of the CT plume with relatively higher concentrations. Samples were collected using bailers from the bottom of each well, tapping the bottom to collect incidental sediment with potentially sorbed microbial growth. These samples were shipped to CytoCulture Analytical Technology (CytoCulture) in Point Richmond, California, where microcosms of each were prepared and subsequently analyzed for nitrate-reducing bacteria and total anaerobic heterotrophic bacteria assays. Microcosms were also prepared to determine the efficacy of natural attenuation of spiked CT in each sample. A complete report of the bench scale results from CytoCulture is included in Appendix H1.

Nitrate reducers are enumerated using a “most probable number” (MPN) assay in which the groundwater samples are diluted ten-fold over eight log dilutions into an aerobic growth medium (Difco Bcto® Nitrate broth) that contains only nitrate as the sole alternate terminal electron acceptor. The reaction was allowed to continue within a Coy® anaerobic glove box for 30 days.

Total anaerobic, heterotrophic, bacterial assays were separately conducted with a growth medium prepared with Brewer’s Anaerobic Agar (Difco®) containing a wide range of carbon sources derived from yeast extract, tryptone, pancreatic digest of casein and glucose. The medium includes alternative terminal electron acceptors such as sulfate, nitrate, and iron. Plates were poured in a Coy® anaerobic glove box and held under anaerobic conditions for 14 days at 30 degrees Celsius. The plate count is reported as colony forming units per milliliter (cfu/ml) of sample. Each enumeration value represents a statistical average of the plate count data obtained from two of the four inoculating log dilutions assayed. The results of the nitrate-reducing and total anaerobic heterotroph assays are tabulated below.

Bench Scale Test Phase I Results

Sample Name	Sample Date	Anaerobic Nitrate Reducers (cfu/ml)	Anaerobic Total Heterotrophs (cfu/ml)
MW-BW-23-A	3/12/2003	2 x 10^6	3 x 10^4
MW-BW-27-A	3/12/2003	5 x 10^6	3 x 10^4
MW-BW-43-A	3/12/2003	2 x 10^5	2 x 10^2*
Sterile Water Control	3/13/2003	No signal	0
Air Control	3/13/2003	NT	0
Positive Control	3/25/2003	1 x 10^7	2.5 x 10^7

* Motile bacteria and fungal growth precluded growth and counting of distinct bacteria colonies; the density of bacteria reported here is probably much lower than total bacteria present in the water; this sample was replaced several days later but a similar result was obtained (averaged value is presented). NT = not tested.

These values indicate that all three groundwater samples from the A-Aquifer contain significant bacterial populations that could potentially generate anaerobic conditions if given a sufficient source of food (carbon source). Given the positive results of these assays, a microcosm of each groundwater sample was prepared to evaluate the efficacy of natural attenuation of CT within the A-Aquifer.

Each microcosm was prepared from 90-milliliters (ml) of groundwater in 160-ml sterile glass serum bottles and inoculated 10 ml of a minimal salts medium containing sodium lactate as an electron donor and yeast extract as a source of essential vitamins and growth factors. Chemical assays were performed on each microcosm, including pH, DO, and ORP as tabulated in Appendix H. Each microcosm was spiked with 100 ml of 1 percent CT dissolved in 95 percent ethanol (400 milligrams [mg] per 40 ml in a VOA vial). An azide-killed (biologically sterile) control and negative control (water) were also evaluated as part of the microcosm study. Each microcosm was allowed to grow for nine weeks, and was sampled at 0, 4 and 9 weeks, respectively. The results of the assays are summarized below.

Microcosm Study Phase I Results

Microcosm	[CT] T = 0 weeks (initial)	[CT] T = 4 weeks (midpoint)	[CT] T = 9 weeks (final)	Average % Reduction
MW-BW-23-A	6,700 mg/L	4,300 mg/L	4,600 mg/L	34%
MW-BW-27-A	6,900 mg/L	3,900 mg/L	3,900 mg/L	43%
MW-BW-43-A	7,300 mg/L	3,700 mg/L	3,600 mg/L	51%
AZ-slurry*	7,200 mg/L	840 mg/L	NT	88%
Negative Control	7,500 mg/L	NT	5,000 mg/L	33%

*Azide preservative appeared to react with the CT resulting in unanticipated reduction. NT = not tested.

All three groundwater samples appeared to degrade CT under anaerobic conditions by four weeks; however, continued degradation after four weeks appears to have been arrested as there was insignificant additional reduction in CT concentration by nine weeks. The azide-treated slurry produced a surprising reduction in CT concentration that was proposed by CytoCulture to represent a chemical reaction between the azide and CT, perhaps catalyzed by the fine clay particles, which resulted in the displacement of chloride ions with azide ions. The resulting products, alkyldiazonium compounds, would were not analyzed for or have been reported from the EPA Test Method 8260 and thus this chemical reaction cannot be confirmed. The reduction in CT concentration within the negative control was attributed by CytoCulture as potentially the result of abiotic mechanisms (e.g., evaporation or leakage through the septum seal) and some biodegradation from anaerobic bacteria that may have been in the spring water at time zero. It is likely that these same abiotic mechanisms contributed to decreases in the other (non-control) microcosms; which would indicate that the extent of CT biodegradation was limited. The leveling-off of CT concentrations within the groundwater samples may indicate that biodegradation activity could have been inhibited by the accumulation of breakdown products or changes in microcosm conditions. It is unlikely that anaerobic organisms depleted the added carbon source (sodium lactate) or other essential macronutrients during this time period. The concentrations of CT used in these tests were approximately three orders of magnitude higher than the CT concentrations in groundwater at the site. It is possible that these high concentrations of CT may have inhibited biological activity within each microcosm that essentially prevented or limited biodegradation of CT.

Results of the microcosm study indicate that groundwater in the A-Aquifer contains bacteria capable of degrading CT under anaerobic conditions that favor reductive dechlorination mechanisms (e.g., electron donors present, strong negative ORP, nutrients, etc.). These results justified a second phase of testing, including an evaluation of the effectiveness of different carbon sources that could potentially enhance biodegradation rates of CT as described in the following section.

3.8.2 Bench Scale Test Phase II

The second phase bench scale test included the evaluation of enhanced biodegradation from a single source (MW-BW-23-A) inoculated with three different carbon sources: sodium lactate, molasses, and soybean oil. The goals of this bench scale test were to (1) determine which electron donor would be the most effective at reducing CT concentrations, (2) determine whether supplemental nutrients would be necessary to effectively enhance CT biodegradation under actual field conditions when injected in the OUCTP aquifer, (3) provide an estimate of carbon source (donor) concentrations necessary to effectively induce enhanced biodegradation conditions in the field, and (4) provide an indication of the carbon source residence time necessary to initiate biological activity and sustain effective CT biodegradation.

A groundwater sample collected from MW-BW-23-A and a soil sample from PS-CT-01 were submitted to CytoCulture on September16, 2003 to be used in the construction of a soil slurry and preparation for microcosms comprising the Phase II bench scale. Results were reported to the USACE on March 19, 2004 (Appendix H1) and are summarized again below.

The soil slurry microcosms preparations associated with each electron donor were allowed to grow for 19 weeks. Samples were withdrawn from preparation at 0, 6, 12, and 19 weeks and analyzed using EPA Test Method 8260 to measure concentrations of CT and chloroform, the primary daughter product of CT biodegradation (dechlorination). The initial CT concentrations used in these studies were: 8,300 µg/L, 8,800 µg/L, 8,700 µg/L, 6,900 µg/L, and 6,500 µg/L in the positive control, lactate, molasses, oil, and negative control microcosms, respectively. Of the three carbon source amendments, sodium lactate appeared to have the most effectiveness in reducing the spiked CT concentrations as shown in the table below.

Microcosm Study Phase II CT Results

CT Delta %	**T=0 wks**	**T=6 wks**	**T=12 wks**	**T= 19 wks**	**TAH**
Sample	**9/25/2003**	**11/4/2003**	**12/15/2003**	**2/3/2004**	**2/3/2004**
Positive control	0%	-46%	-61%	-71%	2e+5
Lactate	0%	-1%	-42%	-38%	8e+5
Molasses	0%	-2%	-14%	-10%	1e+6
Oil	0%	-7%	-25%	-16%	1e+6
Negative control	0%	0%	-29%	-48%	7e+1

TAH = total anaerobic heterotrophs

CT concentrations leveled off between the 12th and 19th week of monitoring for all three carbon source donors. The negative control samples in the final two monitoring events indicated significant reductions in CT concentrations. Chloroform was also generated in each amended microcosm as shown in the table below.

Microcosm Study Phase II Chloroform Results

Chloroform Delta %	**T=0 wks**	**T=6 wks**	**T=12 wks**	**T= 19 wks**
Sample	**9/25/2003**	**11/4/2003**	**12/15/2003**	**2/3/2004**
Positive Control	0%	1260%	2100%	1660%
Lactate	0%	360%	940%	920%
Molasses	0%	0%	140%	380%
Oil	0%	66%	480%	-100%
Negative control	0%	0%	-100%	-100%

The results of the study indicated there was a consistent reduction in CT concentrations and corresponding increase in chloroform production in the positive and lactate-amended microcosms. Based on these results, it appears that enhanced microbial cometabolism of CT did occur within each of the carbon source amendments, but the lactate carbon source was the most effective in enhancing the CT biodegradation process. The results indicate some biodegradation of CT within the negative control appear to be anomalous. Each final microcosm was also tested for the population of total anaerobic heterotrophs (TAH) to compare which amendment spurred the most microbial growth. As tabulated above, the amended microcosms each had very similar TAH counts. The TAH count from a groundwater sample collected from MW-BW-23-A in March 2003 (Section 3.8.1) resulted in a count of 3e+4, which indicated that the addition of various carbon source donors resulted in substantial microbial population growth.

Based on these results, it was concluded that native microbes do exist in the A-Aquifer that, when stimulated with 600 ppm of lactate as in the study, are capable of generating reductive conditions necessary for the biodegradation of CT into chloroform. Due to problems with the controls, the results are difficult to interpret, and there is a considerable amount of uncertainty in the data. However, a substantial body of scientific literature does support the notion that biodegradation of CT can be stimulated by creating reducing conditions via addition of electron donor. That reducing conditions were established was further illustrated by the dramatic color change to black between weeks 6 and 12 for all lactate microcosms; no color change was noted for the other electron donors (including the positive control sample). The color change reflects the reduction of ambient iron oxides present in groundwater and precipitation of iron sulfides in response to microbial population growth. Following the evaluation of the Phase II bench scale, recommendations were submitted to the USACE to continue with a field phase bio-treatability pilot study, as is discussed in Section 3.9.

3.8.3 In-Well Profiling

Downhole profiles of DO, ORP, conductivity, pH, temperature, and pressure were collected from the water column in wells MW-B-12-A, MW-BW-15-A, MW-BW-27-A, MW-BW-39-A, MW-BW-42-A, MW-BW-43-A, MW-BW-44-A, MW-BW-53-A, MW-BW-54-A, and MW-BW-59-A with a In-Situ Troll-9000 datalogger system to determine whether vertical stratification of these natural attenuation indicator parameters could be discerned within the A-Aquifer. Once calibrated to manufacturer-provided standards, the Troll/datalogger was set to record data at a 10 second interval and was slowly lowered through the water column until reaching the well bottom and then slowly raised back to the surface. The resultant profile thus indicates both downhole and uphole data recordings, which were correlated to determine whether stratified zones favorable for natural degradation of CT are present within the A-Aquifer. Depth profiles of conductivity, DO, and ORP data are illustrated in Appendix D5.

Results of in-well profiling indicate that the A-Aquifer, as expected, is predominantly aerobic with DO values typically ranging from 6 to 10 mg/L; however, several areas with lower DO values were noted, particularly near the bottom of the A-Aquifer and at wells MW-BW-15-A, MW-BW-27-A, and MW-BW-45-A. The lower half of the A-Aquifer at these locations indicated DO concentrations reaching 2 mg/L, which may indicate local zones of oxygen depletion.

ORP values also typically indicate oxidizing conditions within the A-Aquifer with values ranging from 50 to 250 millivolts. Similar to the DO profiles, several areas with lower values were noted, including MW-BW-44-A and MW-B-11-A; vertical stratification was not noted to be as significant as with DO values. ORP values at MW-BW-44-A ranged from 60 to -60 millivolts, however the extreme was not noted at the same depth between the uphole and downhole record and appears to be anomalous. Development activities at MW-B-11-A subsequent to its profiling indicated that this well screen has become blocked somehow, as it could not sustain the typical 5 to 10 gpm rate expected from A-Aquifer monitoring wells. For this reason, the profiled ORP results from MW-B-11-A also appear to be anomalous.

Conductivity results were the most consistent between each well and typically ranged from approximately 1,500 to 2,500 micoSiemens per centimeter (micoSiemens/cm). These results reflect the relative consistent inorganic signature (i.e., cation and anion concentrations) within the A-Aquifer and do not appear to be indicative of natural attenuation processes.

3.8.4 Soil Sampling

As part of the installation of monitoring wells for the bio-treatability pilot study, a soil sample was collected from PS-CT-01 and submitted to Sequoia Analytical ([Sequoia] Morgan Hill, California) for analysis of speciated iron since iron may be commonly present in soil and could represent a terminal electron receptor during the field pilot study. Results indicate a concentration of 2,500 milligrams per kilograms (mg/Kg) ferric iron (oxidized) and no detection of ferrous iron (reduced).

No other soil samples, besides those associated with waste management, were collected as part of the RI.

3.9 Bio-Treatability Pilot Study

The field scale bio-treatability pilot study was designed as an extension of the Phase II microcosm bench scale test as described in the OUCTP RI/FS Work Plan Addendum (*MACTEC, 2003*). To determine whether lactate would effectively lead to the dechlorination of CT in the A-Aquifer, a cluster of nine monitoring wells (PS-CT-01 through -09) were installed to fully penetrate the A-Aquifer surrounding a recirculation well (PS-CT-recirculation) just upgradient of MW-BW-23-A. The lithologic logs and construction details of these wells are included in Appendix A and their locations are included on Plate 3. The recirculation well was designed with two screens within the A-Aquifer to allow lactate to be injected in one screen, forced into the formation, and withdrawn from the other, such that a hydraulic cycle would be established with lactate saturating the A-Aquifer approximately 15 feet radially from the recirculation well.

3.9.1 System Description, Installation, and Startup

The recirculation system was originally designed to extract water from the upper portion of the screen and re-inject the groundwater/lactate solution into the lower portion of the screen. However, during field testing, it was discovered that the 10 gpm design extraction rate could not be sustained by extracting water from the upper screen. Subsequently, the system was modified to extract water from the bottom screen and re-inject the groundwater/lactate solution into the upper screen.

The lactate injection system installation began on April 14, 2004 and was completed on April 19, 2004. The lactate injection system was installed in well PS-CT-IW and consisted of a 500 gallon trailer-mounted water tank, above and below ground water recirculation piping, an in-line mixer, a water extraction pump, an inflatable well packer, and a trailer-mounted electrical generator.

The 500 gallon open top tank was filled with a mixture of 275 gallons of sodium lactate (60% solution) and 225 gallons of water. The recirculation piping consisted of one-inch diameter Schedule 40 PVC pipe and related valves and sampling ports. To facilitate the mixing of the sodium lactate and the extracted groundwater, the lactate solution was injected upstream of a one inch diameter in-line PVC static-tube mixer. The extracted groundwater was measured using an in-line rotameter. An inflatable pass-through packer was installed at approximately 123 feet below the top of casing (btoc) to isolate the upper and lower screens of the well. The packer was inflated in accordance with the manufacturer’s instructions to an internal pressure of 50 pounds per square inch (psi). The groundwater extraction pump was operated by a 24 kilowatt (kW), “Whisper Quiet” portable generator. A 15 by 15 foot, 6 foot high fence enclosure equipped with privacy slates was installed around the system for security purposes as well as for sound control in consideration of nearby residences.

The system was started on Monday, April 19, 2004. The observed groundwater extraction rate was 15 gpm with the depth to groundwater stabilizing in the upper screen at 97 feet btoc.

3.9.2 Bromide Solution Injection

A potassium bromide (bromide) solution was passively injected into the bottom screen of well PS-CT-IW on April 14, 2004 prior to the injection of the lactate solution. The purpose of the bromide injection was to trace the flow of groundwater using this indicator as described for the tracer test in Section 3.4. The injected bromide solution consisted of five kilograms of potassium bromide mixed with 75 gallons of water. The bromide solution was injected into the lower screen using a one-inch diameter PVC pipe installed with the inflatable packer to isolate the upper and lower screens.

3.9.3 Lactate Injection System Operation

The system was started on April 19, 2004. The observed groundwater extraction rate was 15 gpm with groundwater stabilizing in the upper screen at 97 feet btoc. The water recirculation and lactate injection system operated from April 19 through April 24, 2004. Based on the built-in meter in the portable generator, the system operated for approximately 127 hours (5.3 days). The system recirculated approximately 114,300 gallons (average of 14 gpm) of groundwater and injected 275 gallons of 60% sodium lactate solution diluted with 225 gallons of water.

During the operation of the groundwater recirculation/lactate injection system, depth to groundwater measurements were collected on a daily basis at the injection well (PS-CT-IW) and nearby monitoring wells PS-CT-01 through -04. These measurements indicated that the water level in the lactate injection well steadily increased from 106.00 feet btoc (the baseline measurement prior to system startup on April 19) to 90.05 feet btoc prior to system shutdown on April 24. No significant groundwater elevation changes were noted in the surrounding wells.

3.9.4 Baseline Sampling and Dissolved Oxygen Profiling

Prior to system installation, baseline groundwater samples were collected on, April 12, 2004 from wells PS-CT-IW, PS-CT-01 through -09. Groundwater samples were collected and submitted to Sequoia Analytical (Sequoia) in Morgan Hill and Petaluma, California. Submitted samples were analyzed for VOCs by EPA Test Method 8260B, bromide, sulfate, nitrate, and nitrite by EPA Test Method 300.0, ferrous iron by SM3500, total organic carbon (TOC) by EPA Test Method 415.1, and methane by RSK 175.

Groundwater samples for VOCs analysis were collected from passive diffusion bag (PDB) samplers installed at various intervals along the length of the water column inside each well. In general, each pilot study well contained three passive diffusion (PDS) bags (top, middle and bottom of the water column) with the exception of well PS-CT-IW which contained two PDS bags (middle of each screen). Non-VOC analyses (lactate, cations/anions, methane, TOC) water samples were collected from the bottom portion of the water column for wells PS-CT-01 through -09, and from the bottom screen at well PS-CT-IW using Hydrasleeve® sampling bailers. Analytical results of the baseline sampling are presented in Appendix H2.

In addition to collecting baseline water samples for analysis, in-situ, depth-discrete, DO readings were collected from wells PS-CT-IW and PS-CT-01 through -09 using a CHEMetric® DO kit K-7512 on Monday April 12, 2004. DO readings were taken from the bottom portion of the screen intervals. The baseline DO readings using the CHEMetric® kit were collected by snapping off the tip of the self-filling reagent ampoules inside the collected water samples and conducting a visual comparison of the ampoule against the provided color standards for given DO concentrations. The baseline CHEMetric® DO measurements are presented in Appendix H2. In addition to the CHEMetric® DO measurements, baseline, in-well, DO profiling using a In-Situ, Inc. Troll MP9000 (TROLL) multi-meter probe was also conducted in wells PS-CT-01 through -09, PS-CT-IW, and MW-BW-23A. Baseline TROLL DO profiling graphs are presented in Appendix H2.

3.9.5 Post Lactate Injection Analysis

Groundwater Sampling

After lactate injection within the A-Aquifer, groundwater sampling was conducted at approximate 6-week intervals on June 2 and 3, and July 13 and 14, 2004 from wells PS-CT-IW, PS-CT-01 through -09 and MW-BW-23A. VOC analysis water samples were collected from the PDS bags installed along the length of the water column for all sampling events. Non-VOC analyses (metals, methane, TOC) water samples were collected from the bottom portion of the water column for wells PS-CT-01 through -09 and MW-BW-23A, and from the bottom screen at well PS-CT-IW during each sampling event. Lactate samples were collected from the middle of the water column for wells PS-CT-02, -03, and -05 and from the bottom screen at well PS-CT-IW on during the June 2 and 3 sampling event. During the July 13 and 14, 2004 sampling event, lactate samples were collected from the bottom of the water column at well PS-CT-02, through -05 and from the bottom screen at well PS-CT-IW. Collected samples were submitted to Sequoia. Analytical results for post-lactate sampling are presented in Appendix H2.

Dissolved Oxygen Profiling

Following the shutdown of the lactate injection system on April 24, 2004, in-well DO profiling measurements were collected throughout the post-lactate injection monitoring phase using three different methods: CHEMetric® dissolved oxygen ampoules, a TROLL multi-meter probe, and a YSI 58 DO meter. The results of DO profiling using each of the three different methods are described below.

CHEMetric® Dissolved Oxygen Profile Results

CHEMetric® DO readings were collected on April 27, May 5, May 19, May 28, June 2, June 29, June 30, and July 13, 2004. Collection of the DO readings using the CHEMetric® DO measuring ampoules was accomplished with the use of a "snapper" tool that allowed for collection of in-well samples for DO analysis. The ampoule was inserted at one end of the tool and subsequently lowered into the well. Once the desired depth was reached, the tool was quickly pulled up by means of the lowering rope. The rope jerking action allowed an internal spring loaded hammer to "snap" the tip of the ampoule thus allowing the collection of the sample. Once the sample was collected and brought to the surface, a color comparison could be made between the collected sample and the standards provided with the DO kit. DO measurements collected using the CHEMetric® are presented in Appendix H2.

In-Situ, Inc. Troll MP9000 Dissolved Oxygen Profile Results

Following the injection of the lactate solution, TROLL DO profiling was conducted on June 3 at wells PS-CT-01 through -09, PS-CT-IW, and MW-BW-23A. The DO profiling was conducted by gently lowering the DO probe the entire length of the water column at each well while the probe recorded DO concentrations every 5 seconds (Appendix H2).

Due to possible equipment malfunctions during this event, collected DO readings for various wells showed sporadic spikes in the DO readings. DO readings as high as >100 mg/L were recorded by the TROLL; concentrations exceeding approximately 12 mg/L are inconsistent with ambient conditions measured elsewhere within the A-Aquifer. Due to the uncertainty of the DO readings collected by the TROLL, the use of this equipment was suspended as a method of conducting in-well DO profiling. The TROLL has been used previously at former Fort Ord successfully and it is not known what may have caused these aberrant readings.

YSI 58 Dissolved Oxygen Meter Profile Results

Subsequent DO profiling data were obtained using a YSI 58 DO meter. This meter was used to measure DO concentrations on June 29, July 13, July 14 and December 13, 2004. DO readings were collected by lowering the meter down the well at five-foot intervals from the top of the water column to the bottom of the well. The recorded DO readings represent the stabilized DO readings detected by the meter (no change in DO reading for at least 10 seconds). DO profiling using the YSI 58 meter were conducted on well PS-CT-01 through -09, PS-CT-IW, and MW-BW-23A (Appendix H2).

3.9.6 Bio-treatability Pilot Study Results

Results of the bench-scale microcosms and field-scale pilot study are illustrated and tabulated in Appendix H1 and H2, respectively. The addition of lactate during the field-scale pilot study resulted in the essentially immediate and lasting reduction in CT concentrations in monitoring wells proximal to the recirculation well. For instance, initial concentrations at PS-CT-02, located approximately 15 feet west of the recirculation well, ranged from 3 to 4 µg/L at three discreet depths within the screen interval prior to the injection of lactate. Samples collected two months later indicate CT was not detected at the middle and bottom sampling positions, where lactate had been injected, whereas concentrations remained elevated (5.3 µg/L) at the upper position. CT concentrations at the injection well itself initially ranged from 4 to 4.5 µg/L but were non-detect following the recirculation of lactate. Concentrations at PS-CT-01, -03, and -05, the next closest monitoring wells to the recirculation well, also indicated consistent decreases in CT concentrations, especially in the downgradient direction.

Changes in chloroform concentrations also reflected the immediate response to injecting lactate into the A-Aquifer. The primary daughter product from CT dechlorination is chloroform and concentrations are expected to increase once dechlorination of CT begins. In fact, the wells showing the greatest decrease in CT concentrations also show the greatest increase in chloroform concentrations. For instance, PS-CT-02 chloroform concentrations ranged from non-detect (0.50 µg/L) to 0.55 µg/L prior to lactate injection, but rose to 1.3 µg/L immediately thereafter, among the highest chloroform concentration observed to date within the OUCTP A-Aquifer plume.

TOC, lactate, speciated iron, nitrate, bromide, and dissolved oxygen are also useful indicators of the radius of influence of the lactate injection. These and other inorganic analytical results are summarized in Table 7 and discussed below:

TOC includes the mass of carbon associated with the 250 gallons of 60 percent lactate material itself. Background concentrations measured prior to lactate injection ranged from 0.29 to 0.54 mg/L but rose to concentrations of 1,000 mg/L at the re-circulation well following injection. That TOC concentrations also rose in the downgradient direction at PS-CT-04 from 0.39 to 420 mg/L illustrates the ‘shadow’ effect downgradient of the injection area surrounding the re-circulation well.

Lactate was analyzed in samples collected from the re-circulation well and the nearest monitoring wells PS-CT-02, PS-CT-03, and PS-CT-05. Initial concentrations in groundwater during the injection phase were observed from 3,840 to 6,780 mg/L at the re-circulation well. Following the injection phase, lactate concentrations in the re-circulation well dropped to 15 mg/L in June 2004 and to below 0.5 mg/L in July

2004. The initial lactate concentration at PS-CT-02 was 1.1 in June 2004 and was not detected in July 2004; however, lactate was visibly present in groundwater samples collected for DO analysis using the CHEMetric® "snapper" from the re-circulation well, PS-CT-02, PS-CT-03, and PS-CT-04.

Ferrous and total iron (the difference equating ferric iron) were also analyzed in baseline and post-injection samples collected on April 12, 2004. Ferrous iron (indicative of reducing conditions) was not detected in baseline samples but rose at the re-circulation well to 7.4 and 4.8 mg/L in June and July 2004, respectively. Similarly, concentrations rose from non-detect to 1.2 to 4.0 mg/L for the same respective sample events at PS-CT-02, PS-CT-04, and PS-CT-05. Estimated concentrations of ferrous iron (below the reporting limit) were observed during the July 2004 sampling event at PS-CT-01, PS-CT-03, PS-CT-06, PS-CT-07, PS-CT-08, PS-CT-09, and MW-BW-23-A, indicating a relatively widespread change in conditions within the pilot study area.

Nitrate and nitrite was also analyzed in baseline and post-injection samples from the pilot study wells; nitrite was only reported in samples collected post-injection because copious groundwater quality data elsewhere at Fort Ord consistently indicate non-detection under typical conditions. Baseline nitrate concentrations ranged from 1.9 to 3.2 mg/L at the pilot-study wells but rose significantly in all wells in June 2004 with concentrations ranging from non-detect (below 0.5 mg/L) at PS-CT-IW and PS-CT-02 to 16 mg/L at MW-BW-23-A. The reason for the increase in nitrate concentrations is not well understood, but the non-detection at PS-CT-IW and PS-CT-02 is coincident with induced reducing conditions at these wells. It is interesting to note that nitrite was not detected at any well in June 2004, but was detected at PS-CT-01, PS-CT-07, PS-CT-08, PS-CT-09, and MW-BW-23-A during the July 2004 event; these are the wells upgradient or furthest away from the re-circulation well. As DO concentrations (discussed below) indicate that denitrification conditions were achieved, it is possible that the distribution of nitrite detections represents the lateral effect of lactate injection at that time.

A bromide tracer was added to the lactate solution during the injection phase of the pilot study to provide a conservative compound that could ideally be used to delineate the radius of influence of the re-circulation process. Bromide concentration at the re-circulation well immediately following the injection phase was observed at 42 mg/L. June 2004 sample results indicated the presence of bromide at PS-CT-IW and PS-CT-02 (11 to 14 mg/L) in the lower half of the screen, which is consistent with injection to the lower half of the A-Aquifer. July 2004 sample results reflect the presence of bromide throughout much of the study area at concentrations ranging from 0.29 to 18 mg/L. The highest detections (1.9 to 18 mg/L) were observed at PS-CT-02, PS-CT-04, PS-CT-05, and PS-CT-IW, although were detected in all wells associated with the pilot study to J-qualified levels (0.29 mg/L with a reporting limit of 1.0 mg/L). The distribution of bromide detections suggests that groundwater flows slightly west of MW-BW-23-A from the re-circulation well.

DO values were typically between 8 and 10 mg/L prior to the injection phase but dropped dramatically at the re-circulation well and PS-CT-02 following the injection phase. Low concentrations of 0.1 mg/L have been repeatedly measured in the lower half of both of these wells and concentrations have also dropped to below 5 mg/L at PS-CT-03, PS-CT-04, PS-CT-05, and PS-CT-07. This distribution is consistent with other compounds in that the western portion of the pilot study area seems to have been more influenced by lactate injection than the eastern portion of the study area. DO was measured more frequently than samples were collected for laboratory analysis due to the lower associated costs and its values as an indicator of reducing conditions throughout the pilot study area. Measurements collected in December 2004 were very similar to those measured immediately following the injection phase in April 2004. Concentrations in the lower half of PS-CT-IW, PS-CT-02, and PS-CT-04 remained below 1.0 mg/L and were measured at each location (using a YSI meter) as low at 0.1 mg/L, indicating reducing conditions.

The reduction in nitrate, ferric iron, and sulfate concentrations all indicate that denitrifying, iron-reducing, and at least sulfur-reducing concentrations (if not methanogenic) conditions were attained at least locally within the pilot study area. Methanogenesis is indicated by the detection of methane at PS-CT-IW (up to 1.7 mg/L) in June and July 2004 and a J-qualified detection at PS-CT-04 in July 2004; however, a widespread or enduring level of methanogenic conditions is not apparent. DO values indicate that the effects of lactate injection to the A-Aquifer are long-lasting and that the re-circulation method of injection produces desirable results with a radius of influence of at least 20 feet cross-gradient and up to 60 feet downgradient.

3.10 Soil Vapor Extraction Pilot Study

Following a review of soil vapor concentration data collected by MACTEC (*MACTEC, 2004*), Shaw Environmental, Inc.(Shaw) designed, constructed, and performed a pilot SVE study to remediate vadose zone soils as a direct result of soil gas and groundwater CT detections in samples (Sections 3.2 and 4.2, respectively) collected in the vicinity of Lexington Court and Ready Court. The soil gas and groundwater samples suggested that a source of CT was present in the vadose zone soils in this area. The pilot study objective was to provide source control for the CT groundwater plume and to alleviate the potential for vapor intrusion into the nearby housing area. The complete SVE pilot study report by Shaw is included in Appendix G.

3.10.1 SVE System Construction

Construction of the SVE system began on February 10, 2004, and included the installation of three SVE wells and the temporary conversion of the two existing dual-screen monitoring wells (MW-BW-62-A and MW-BW-63-A) into extraction wells. All five extraction wells were connected to common conveyance via pipeline to the vapor treatment system installed in an unused garage at 6277 Lexington Court. The treatment system used two 2,000-pound granulated activated carbon (GAC) units to remove CT and other VOCs from the extracted soil vapor. Twelve newly installed nested monitoring probes and three existing shallow probes were used during Phase I to monitor system performance, both in terms of induced pressure drop and reduction in CT concentrations.

3.10.2 Phase I SVE Pilot Study

Phase I of the SVE pilot study started April 6, 2004 and a rapid decrease in CT concentrations was observed throughout the study area. Following the confirmed, significant reduction in CT mass in the vadose zone, the system was shut down on June 14, 2004. Samples collected from the system influent on April 6, 2004, which represented a composite sample from all five vapor extraction wells, reported concentrations of 180 ppb (v/v), 8.5 ppb (v/v), 7.4 ppb (v/v), and 10 ppb (v/v) for CT, chloroform (CF), TCE, and PCE, respectively. Concentrations for the samples collected from the system influent on June 14, 2004 were 4.7 ppb (v/v), 4.2 ppb (v/v), 0.32J ppb (v/v), and 1.2 ppb (v/v) for CT, CF, TCE, and PCE, respectively. The system operated at 83 percent utilization during this phase of the study; down time (17 percent) occurred for initial system adjustments and periodic maintenance.

After the system was shut down on June 14, 2004, three additional rounds of sampling were conducted in two probes over a three month period to monitor for rebound of VOC concentrations in soil gas. There was a small increase in concentrations in both probes after system shut down; however, they remained significantly lower than originally observed. It was noted, however, that the northern extent of contamination had not been entirely delineated and to further address this area, four additional monitoring probes were added following evaluation of Phase I data and prior to Phase II (*Shaw, 2004*).

3.10.3 Phase II SVE Pilot Study

Although the Phase I successfully removed the vast majority of CT and other VOCs from the vadose zone, the Army agreed to continue operating the system for a second phase, in particular to further evaluate the extent of CT just north of the source area.. Phase II of the pilot study started September 9, 2004 and was shut down on November 8, 2004. Samples collected from the system influent on September 9, 2004 reported concentrations of 5.9 ppb (v/v), 3.4 ppb (v/v), 0.5J ppb (v/v), and 1.5 ppb (v/v) for CT, CF, TCE, and PCE, respectively. Final samples were collected from the system influent on November 8, 2004 and concentrations had were 1.9 ppb (v/v), 2.1 ppb (v/v), <0.82 ppb (v/v), and 0.51J ppb (v/v) for CT, CF, TCE, and PCE, respectively. During this phase the system operated at 98 percent utilization; system down time (2 percent) occurred only for periodic maintenance.

The total mass of CT estimated to have been removed during both phases of the pilot study was 0.73 pounds. The mass was calculated from influent analytical results, flow rates, and operation times. A mass of 0.31 pounds of CT was calculated using a three-dimensional computer modeling of the monitoring probe results. This method yielded a lower mass because the model was artificially truncated to the north of the SVE pilot study area where there was not enough previous data to contour this area (*Shaw, 2004*).

4.0 Nature and Extent of Contamination

The CT plume appears to have originated from a training facility referred to in 1958 as "ST-11", near what is now Lexington Court (Plate 3), and migrated through the vadose zone beneath the vicinity of this facility and into groundwater of the A-Aquifer, the Upper 180-Foot Aquifer, and the Lower 180-Foot Aquifer; CT has not been detected in the 400-Foot Aquifer. A review of historical land and solvent uses at Fort Ord indicates that the CT was only used prior to 1960. However, personnel interviews and aerial photo analyses indicate that CT may have been used at this facility sometime in the late 1940s or 1950s, although no documentation has been found that substantiates the use of CT during this time period or the volume or frequency of CT disposal. The location of the CT source area is supported by the presence of elevated concentrations of VOCs in soil vapor (Section 3.2) in the immediate vicinity of the former training facility "ST-11". Surface geophysical surveys conducted throughout this area in 1987 confirmed that no other evidence (e.g., buried drums, disturbed ground) of the source material was present (*HLA, 1990*).

In addition to CT, chloroform, TCE, and PCE are also present both within the vadose zone (vapor phase) and groundwater near the source (dissolved phase) near the source. CF is a biodegradation product of CT whose presence in OUCTP suggests there are native microbial bacteria acting within the subsurface to biodegrade CT. The presence of PCE and TCE in soil gas near the source area suggests these compounds were also disposed of in this area, presumably during the use of the same training facility. Based on available data collected as part of the OUCTP RI, it appears that OUCTP originated from a single source area in the former training facility "ST-11". Other source areas at Fort Ord do not appear to be related to OUCTP contamination.

Based on the OUCTP RI data, it appears there is no longer a source of VOC contamination to groundwater in OUCTP as follows:

- At the time the SVE pilot study was conducted in 2004, soil gas concentrations indicated there was not a sufficient mass of VOCs present to represent a current source of underlying groundwater contamination.

- Concentrations of VOCs suspended in soil vapor appear to represent a low-level residual mass from previous infiltration of contamination following the disposal of solvents approximately 50 years ago.

- VOC concentrations in groundwater underlying the contaminated portion of the vadose zone have consistently been detected at very low concentrations (in the ppb range), indicating there is no longer an ongoing contribution of VOCs into groundwater from a surface or soil vapor source.

- Over the last 50 years, it appears that non-contaminated groundwater upgradient of the area has continued to migrate beneath the site, effectively flushing residual VOCs from the A-Aquifer.

In summary, it appears that by the time the OUCTP RI began, the mass of VOCs suspended in the vadose zone from solvent disposal activities circa the 1950s was depleted and is no longer serving as a source of groundwater contamination to OUCTP.

4.1 Soil Gas

Prior to the soil vapor extraction system, CT was present throughout the vadose zone within an area measuring approximately 500 by 500 feet, centered on the source area near Lexington Court (Appendix G, Figure 1-2). Concentrations in soil gas surveys conducted in 2002 and 2003 ranged from 0.2 ppb (v/v) to 290 ppb (v/v) and increased almost linearly with increasing depth. Samples were collected from 6 feet to almost 80 feet bgs during the three soil gas surveys. Samples from the four dual-screen wells provided additional data to describe the deepest portion of the vadose zone. These wells were tested as part of the SVE pilot study and CT concentrations ranged from 140 to 200 as described in Appendix G, Table 5-2B.

The presence of CF in soil gas indicates that, even within the vadose zone, anaerobic biodegradation (dechlorination) has occurred to some extent, even though conditions appear to be highly aerobic and probably have been since before the plume originated. An explanation for the dechlorination of CT under these conditions is not clear.

The presence of TCE and, to a lesser extent PCE, in groundwater beneath the site could have potentially originated from the formerly used landfills, especially Landfill Cell F (Plate 16). TCE and PCE are indicator compounds of the OU2 plume although the majority of the associated OU2 A-Aquifer plume is located in an area typically interpreted as occurring either downgradient or cross-gradient of the OUCTP area. It was for this reason that PCE and TCE were included on the analyte list as part of the OUCTP soil gas surveys in order to assess this possibility.

PCE and TCE were detected at relatively shallow depths in soil gas near the OUCTP source area. Therefore, it is unlikely that their presence is associated with disposal of solvents deep within the landfill. Instead it is assumed that these solvents were also used for cleaning parts at the former “ST-11” training facility and were disposed onsite in a similar manner as CT.

As described in Section 3.2 and Appendix G, several phases of a soil vapor investigations conducted between 2002 and 2003 led to the installation of an SVE pilot study in 2004 that successfully remediated residual concentrations of VOCs in vadose zone soil gas. After completion of the SVE pilot study, follow-up soil vapor monitoring indicated VOC soil gas concentrations throughout the study area were generally close to the reporting limit of 0.5 ppb (v/v).

4.2 Groundwater

Groundwater contaminated by CT and investigated as part of the OUCTP RI occurs within the three aquifers shown on Plates 15, 16, and 17, respectively: (1) the A-Aquifer, (2) the Upper 180-Foot Aquifer, and (3) the Lower 180-Foot Aquifer. Contamination by CT or its biodegradation daughter products (e.g., chloroform) has not been observed in the underlying 400-Foot Aquifer or Deep Aquifer at the former Fort Ord. The following sections summarize the results of groundwater sampling within the three OUCTP aquifers, respectively.

4.2.1 A-Aquifer

The groundwater contamination signature in the A-Aquifer is dominated by dissolved CT and its primary daughter product chloroform. The source area has been defined by review of historical photos and the presence of soil gas beneath Lexington Court. Interviews from personnel present on base in the 1950s indicate that a small shed located in this area was used by military personnel to clean electronic equipment (e.g., radios) with CT, thus explaining the presence of CT and chloroform in soil gas and groundwater. PCE and TCE were also detected at lower concentrations in soil gas, but only TCE has been consistently detected in groundwater downgradient from the source area. It is possible that PCE and/or TCE were also used as a cleaning solvent after CT had been phased out, which apparently took place in the late 1950s.

Other VOCs detected inconsistently in the A-Aquifer over the past year (September 2003 through September 2004) include: acetone, bromodichloromethane, bromoform, chloroform, chloromethane, dibromochloromethane, methyl ether ketone (MEK), PCE, toluene, and vinyl chloride (VC).

- Acetone and MEK detections have been identified as false positives as they appear to originate from the PDB material or associated hardware, as documented in the 2003/2004 Annual Report of Quarterly Monitoring (*MACTEC, 2005a*).
- Bromodichloromethane, bromoform, and dibromochloromethane are consistently detected only at MW-BW-16-A and MW-BW-57-A (located adjacent to one another) and are signature compounds for potable water disinfected with chlorine products. The source of potable water at this location is

unclear as both wells are distant from irrigated land and no known pipelines are located nearby.

- CF is the primary daughter product of CT and its presence throughout the CT plume indicates that some degree of natural attenuation (i.e., dechlorination) has occurred.

- Chloromethane (detected once at MW-BW-64-A) is the daughter product of CF and may be indicative of more advanced dechlorination. As the distribution of these daughter products is contained by the CT plume footprint, it is considered synonymous with the CT plume and not discussed except with respect to biodegradation processes.

- PCE has been detected in the A-Aquifer within a limited area upgradient of the CT source area. Wells with historical PCE detections exceeding the reporting limit (0.5 µg/L) include MW-BW-50-A (0.82 to 1.3 µg/L) and MW-BW-63-A (0.51 to 0.67 µg/L). These PCE detections are most likely related to elevated PCE concentrations beneath landfill Cell F (OU2) south of and slightly upgradient of the OUCTP area, which are currently being captured at least in part by EW-OU2-16-A, approximately 1,000 feet south of the CT source area. The potential use of PCE as a cleaning solvent near the OUCTP source area cannot, however, be dismissed entirely. Regardless, concentrations have remained low with stable to decreasing trends.

- Toluene is a common field contaminant that originates from a variety of sources. The single detection at MW-B-11-A at 0.76 is highly suspect as several other detections at this well are not consistent with detections in surrounding monitoring wells.

- VC has been detected once below the reporting limit at MW-BW-61-A and may be related to the OU2 plume, as does PCE, which has historically been identified with a low-concentration VC plume. The only other detection of VC historically within the A-Aquifer CT plume footprint has been twice at MW-B-11-A (0.28 in June 2002 and 0.58 µg/L in March 2003), which are very suspect because VC is not a daughter product of CT and no other wells in this area have had even qualified detections of VC. As with the detection of toluene at this location, it is concluded that these VC detections are false positives and are not related to or indicative of contamination associated with OUCTP.

CT and CF concentrations have ranged from 0.25 to 19 µg/L and from 0.25 to 1.9 µg/L since groundwater monitoring was initiated in 1992, respectively. As indicated from data collected in September 2004, the CT plume extends from Lexington Court to the north and then northeast and terminates in the vicinity of Seacrest Avenue in the City of Marina (Plates 15A and 15B). TCE concentrations range from 0.05 to 6.4 µg/L but are limited in extent to the upper third portion of the CT plume. The relatively limited extent of TCE is consistent with its potential use and disposal after that of CT. Because CT has migrated the furthest distance in the A-Aquifer, OUCTP has been defined and is typically characterized as a CT plume. Other contaminants present in groundwater within OUCTP (e.g., PCE and TCE) are also discussed herein and are included in subsequent evaluations in the Risk Assessment (RA; Volume II) and Feasibility Study (FS; Volume III).

As of December 2004, CT has been detected a distance of 1.6 miles northwest of the source area and ranges from 500 to 750 feet in width (Plates 15A and 15B). Seasonal variations in concentration or lateral extent are negligible in the A-Aquifer. One upgradient well (MW-BW-50-A) and four downgradient wells (MW-BW-73-A, MW-BW-74-A, MW-BW-75-A, and MW-BW-76-A) bracket the longitudinal extent of the plume. Various wells (MW-BW-54-A, MW-BW-55-A, MW-BW-28-A, MW-BW-30-A, MW-BW-34-A, MW-BW-36-A, MW-BW-38-A, MW-BW-41-A, MW-BW-44-A, MW-BW-48-A, MW-BW-59-A, and MW-BW-67-A have also been installed to bracket the transverse extent of the plume. CT has also never been detected in monitoring wells associated with the Operable Unit 1 (OU1) area north of the OUCTP area. The chloroform footprint lies within the CT footprint.

CT concentrations have generally decreased since monitoring began in 1992 at MW-B-14-A with only sporadic detections since 2001, although concentrations have generally risen to over 10 μg/L at MW-BW-15-A, as illustrated below. The concentration drop observed at MW-BW-27-A resulted from the change in sampling technique in 2001although this phenomenon has not been noted elsewhere. Groundwater samples prior to this time were collected using a purge-and-bail method whereas subsequent samples have been collected using PDB samplers. MW-BW-27-A represents one of the few wells where significant concentration differences are apparent between the two sampling techniques and indicates that a zone of higher CT concentrations is located within the purge-and-bail capture area but does not passively intersect with the well screen. This appears not to be typical at the other numerous wells defining groundwater conditions at former Fort Ord and thus is not indicative of PDB sampling limitations. It should also be noted that PDB samples can and often are collected from discreet depths during a given sampling event to provide information regarding vertical stratification within the saturated well screen. The following charts thus include multiple concentration data for a given time for various wells following the adoption of PDB sampling techniques.

The detection of CT at MW-BW-16-A and MW-BW-57-A (east of the groundwater divide) at low concentrations appears to be the result of a temporary westward shift of the groundwater divide in response to operation of the OU2 infiltration gallery between 1995 and 2000. The influx of treated groundwater appears to have been sufficient to effectively push the CT plume in the A-Aquifer eastward resulting in the low detections of CT at these two wells (Plate 15A). Since infiltration operations in the A-Aquifer have ceased at OU2, the groundwater divide is again located east of the CT plume.

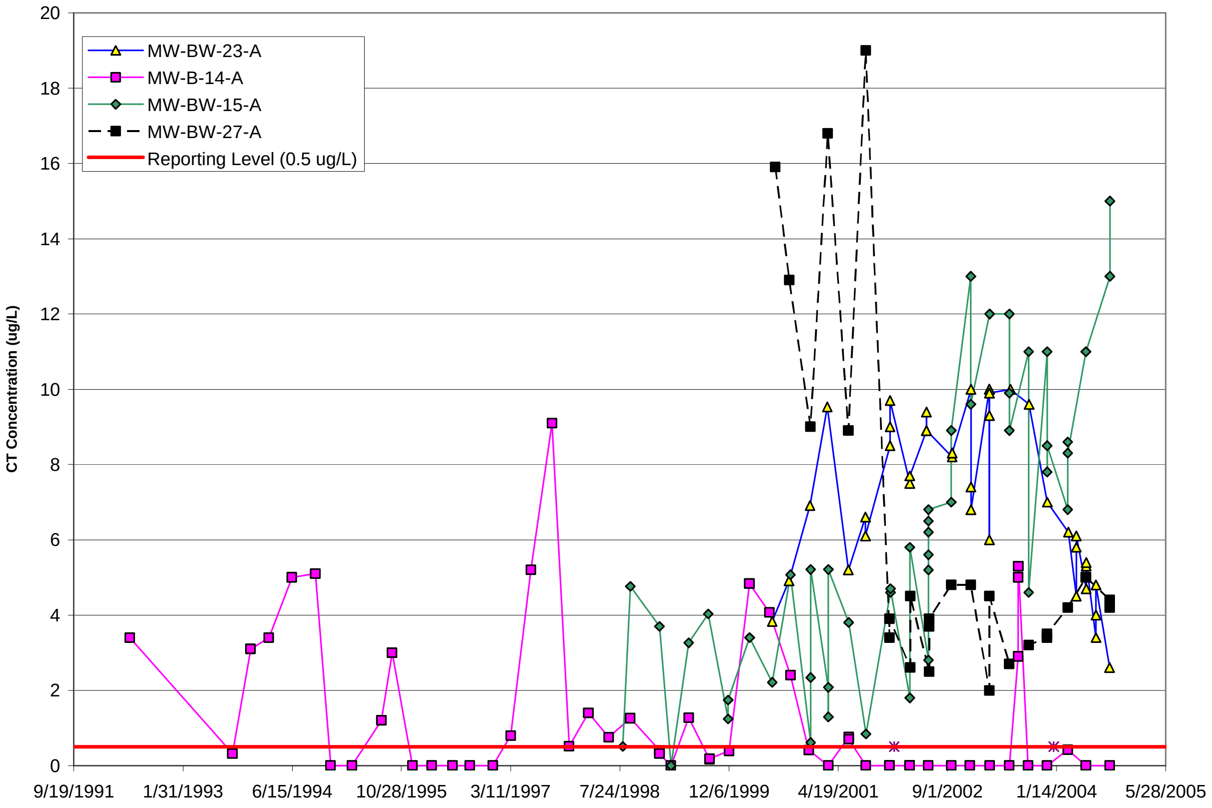


Figure 1. Carbon Tetrachloride Concentrations, A-Aquifer Plume Near Source

As illustrated below, concentrations defining the middle portion of the plume have decreased at MW-B-12-A and MW-BW-42-A but are increasing further downgradient at MW-BW-43-A and MW-BW-66-A and near the toe of the plume at MW-BW-49-A. The wave-cut terrace located immediately downgradient of MW-BW-43-A is a significant feature that influences groundwater gradient and subsequent rates of CT migration. The hydraulic conductivity of A-Aquifer material downgradient of this terrace is at least 10 times that of the material upgradient, and thus the CT has migrated much more quickly once it reached this area. The resultant change in groundwater flow velocity accounts for the decrease in CT concentrations at MW-B-12-A and MW-BW-42-A and increases in concentration further downgradient.

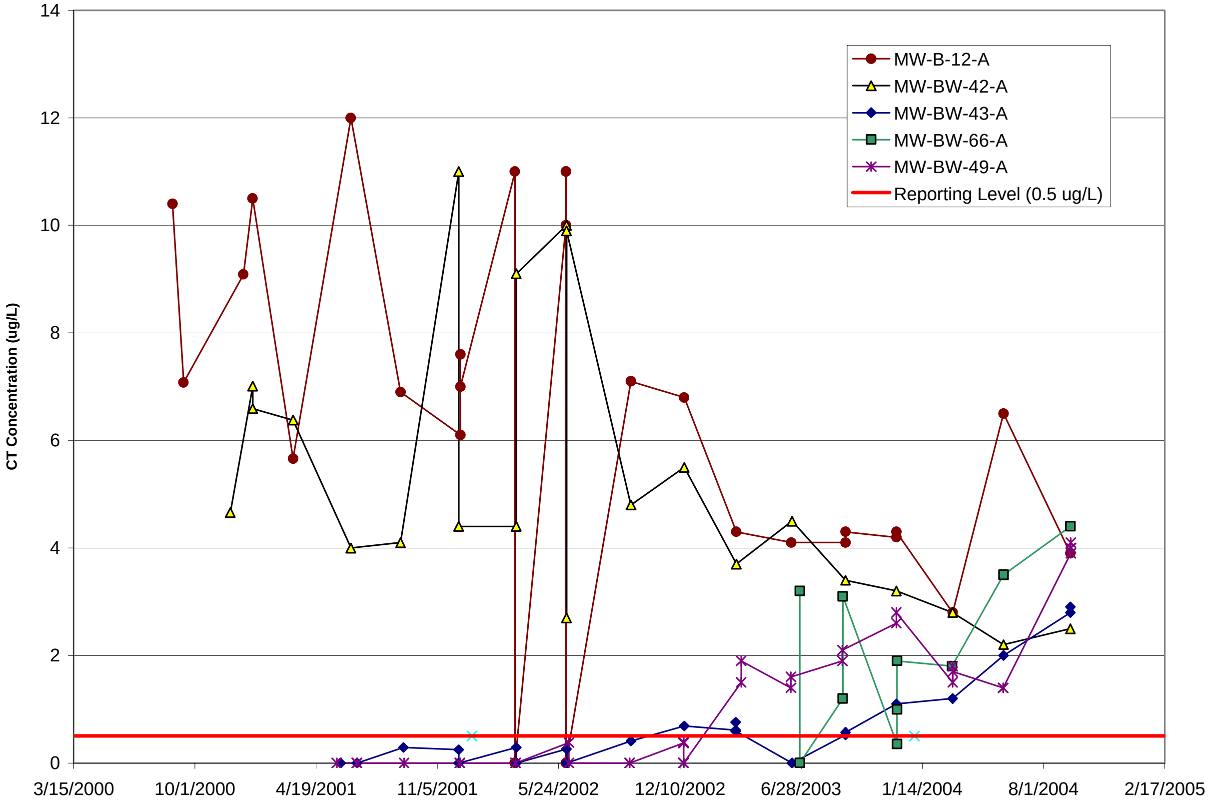


Figure 2. Carbon Tetrachloride Concentrations, A-Aquifer Near Toe

TCE has been detected above 1.0 µg/L at monitoring wells MW-BW-15-A, MW-BW-23-A, MW-BW-53-A, and MP-BW-46 and elsewhere at lower concentrations at MW-BW-17-A, MW-BW-26-A, and MW-BW-27-A. Temporal changes in concentrations are illustrated below:

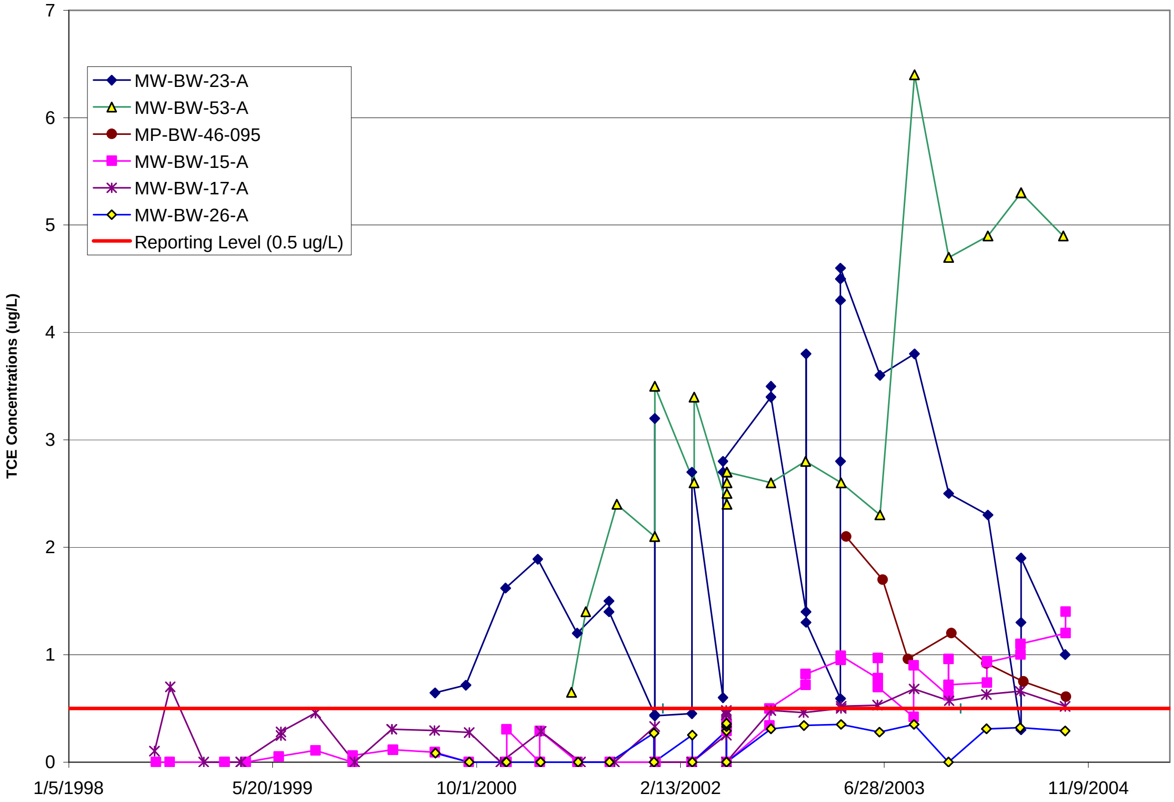


Figure 3. TCE Concentrations, A-Aquifer Near Source

Detections observed since 2000 indicate that concentrations at MW-BW-23-A increased from the detection level (0.5 µg/L) to 4.5 µg/L in 2003 with a steady decrease to about 1 µg/L subsequently. Concentrations have similarly risen at MW-BW-53-A (downgradient of MW-BW-23-A) and have remained stable at about 5 µg/L since 2003. Further downgradient at MP-BW-46-095 (bottom of the A-Aquifer), TCE concentrations have decreased steadily since monitoring began in early 2003. Concentrations have risen from the detection level (0.5 µg/L) in 2002 to 1.4 µg/L in 2004 at MW-BW-15-A but have remained below 1 µg/L at MW-BW-17-A and MW-BW-26-A. The downgradient extent of TCE is delimited by infrequent low-concentrations detections at MW-BW-27-A. This overall pattern suggests the migration of a ‘slug’ of low-concentration TCE that apparently has passed beyond MW-BW-23-A and is currently ‘cresting’ at MW-BW-53-A. The TCE plume will presumably continue to migrate downgradient at increasingly lower concentrations as various natural attenuation processes proceed. TCE has not been detected beyond the CT footprint (*MACTEC, 2005b*).

4.2.2 Upper 180-Foot Aquifer

As illustrated with data collected in September 2004, CT and associated chloroform have been observed in two narrow plumes migrating toward the southeast parallel to one another from two apparent vertical conduits through the overlying FO-SVA clay (Plate 16). The eastern plume emanates from monitoring well MW-B-13-A (built in 1975), where the sanitary seal was either inadequate or somehow failed resulting in hydraulic communication between the A- and Upper 180-Foot Aquifers. The western plume appears to emanates from a vertical conduit at or near the Mini-Storage well (built in 1996), although the sanitary seal appears to have be adequate to prevent cross-communication between aquifers.

Other VOCs observed within the Upper 180-Foot Aquifer include: 1,2-DCA, benzene, chloroform, chloromethane, MEK, VC, and xylenes.

1,2-DCA was detected once at MW-BW-29-180 (0.28 µg/L; September 2003) and appears to be a spurious detection not associated with the CT source. The infrequent detection of this compound at low concentrations within a very limited area does not warrant further discussion.

Benzene and xylenes are typically associated with petroleum products (e.g., gasoline) and are most likely representative of non-groundwater contamination, especially since these compounds have not been detected in the A-Aquifer. Benzene has been detected five times at MP-BW-41-231 between August 2003 and September 2004 at concentrations ranging from 1.5 µg/L to 4.2 µg/L. Benzene was also detected once at MP-BW-41-202 in August 2003 at 0.3 µg/L and not since. It appears that the detection of benzene is related to the installation of MP-BW-41 itself (installed in March 2003) and does not reflect formational conditions as concentrations have decreased rapidly and are not observed in surrounding monitoring wells.

Chloroform (CF) is the primary daughter product of CT and its presence throughout the CT plume indicates that some degree of natural attenuation (i.e., dechlorination) has occurred.

Chloromethane (detected once at MP-BW-41-286, MW-BW-45-180, and MW-BW-54-180) is the daughter product of chloroform and may be indicative of more advanced dechlorination. As the distribution of these daughter products is contained by the CT plume footprint, it is considered synonymous with the CT plume and not discussed except with respect to biodegradation processes.

MEK, as in the A-Aquifer, has been associated with hardware used to install the PDB samplers and is not related to the CT source.

VC (not related to the dechlorination of CT) has been detected once at MW-BW-54-180 (three discrete depths), once at MP-BW-41-231, six times at MP-BW-41-256, and twice at MP-BW-42-215 at concentrations ranging from 0.23 to 0.37 µg/L. The detection at MW-BW-54-180, located upgradient of the western CT plume is spurious and has not been confirmed with repeated samples. The detections at MP-BW-41 and MP-BW-42 are suspect because, as in the Lower 180-Foot Aquifer, VC is only detected repeatedly in Westbay monitoring wells, suggesting that the Westbay sampling method is capable of detecting VC off-gassing from the PVC monitoring well material. No other parent compound (i.e., TCE) is present in these Westbay ports that could explain the presence of VC by dechlorination. The potential VC source from PVC casing is discussed further in Section 4.2.3 where additional data from Westbay wells are illustrative to this point. The low concentrations and limited extent of VC in the Upper 180-Foot Aquifer does not warrant further consideration in this report or the risk assessment (Volume II) as it is not related to true groundwater quality conditions.

The detection of THMs in samples from the Mini-Storage well (screened in the Lower 180-Foot Aquifer) suggests that a vertical conduit co-exists with this well which, necessarily, passes through the Upper 180-Foot Aquifer and probably contributes to the western CT plume. THMs are present within municipal water that is used for landscape irrigation at the eastern portion of the storage facility and is the most plausible source of THMs. One mechanism for THMs reaching the Lower 180-Foot Aquifer beneath the storage facility is through a vertical conduit co-existing at the Mini-Storage well, although construction records indicate a continuous sanitary seal correlates with both the FO-SVA and the Intermediate 180-Foot Aquitard and the well was installed under oversight by a Monterey County Health Department inspector. Should a vertical conduit co-exist with this well, it would be an active conduit because the A-Aquifer CT plume passes beneath the storage facility and probably intercepts the well casing, thus leading to continuous contamination of the Upper and Lower 180-Foot Aquifers.

The plausibility of MCWD Well No. 8 as an historical conduit stems from its construction log, which indicates that the two sanitary seals do not correlate with either the FO-SVA or the Intermediate 180-Foot Aquitard, although analytical data from this well do not exist relative to VOCs, including CT. This well was destroyed according to County regulations in 1996 and it is likely that any continued migration that may have occurred at this location has been stemmed.

Besides the detection of THMs at the Mini-Storage well, the presence of vertical conduits is also supported at the Mini-Storage well and confirmed at monitoring well MW-B-13-180 by the non-detection of CT in nearby monitoring wells. MW-BW-54-180 and MP-BW-37 are both upgradient of the Mini-Storage well in the Upper 180-Foot Aquifer and CT has not been detected; MW-BW-55-180 is located immediately upgradient of MW-B-13-180 and also has not had detections of CT. The western CT plume in the Upper 180-Foot appears to be emanating from a vertical conduit co-existing with the Mini-Storage well whereas the eastern CT plume in the Upper 180-Foot Aquifer emanates from MW-B-13-180.

The two CT plumes in the Upper 180-Foot Aquifer appear to be similar in composition, and concentrations as in the overlying A-Aquifer are referred to as the western and eastern plumes. The western plume contains low concentrations of CT (typically below 1 µg/L) with slightly higher concentrations (2 to 3 µg/L) observed at MW-BW-26-180 (screened near the bottom of the Upper 180-Foot Aquifer), as illustrated below:

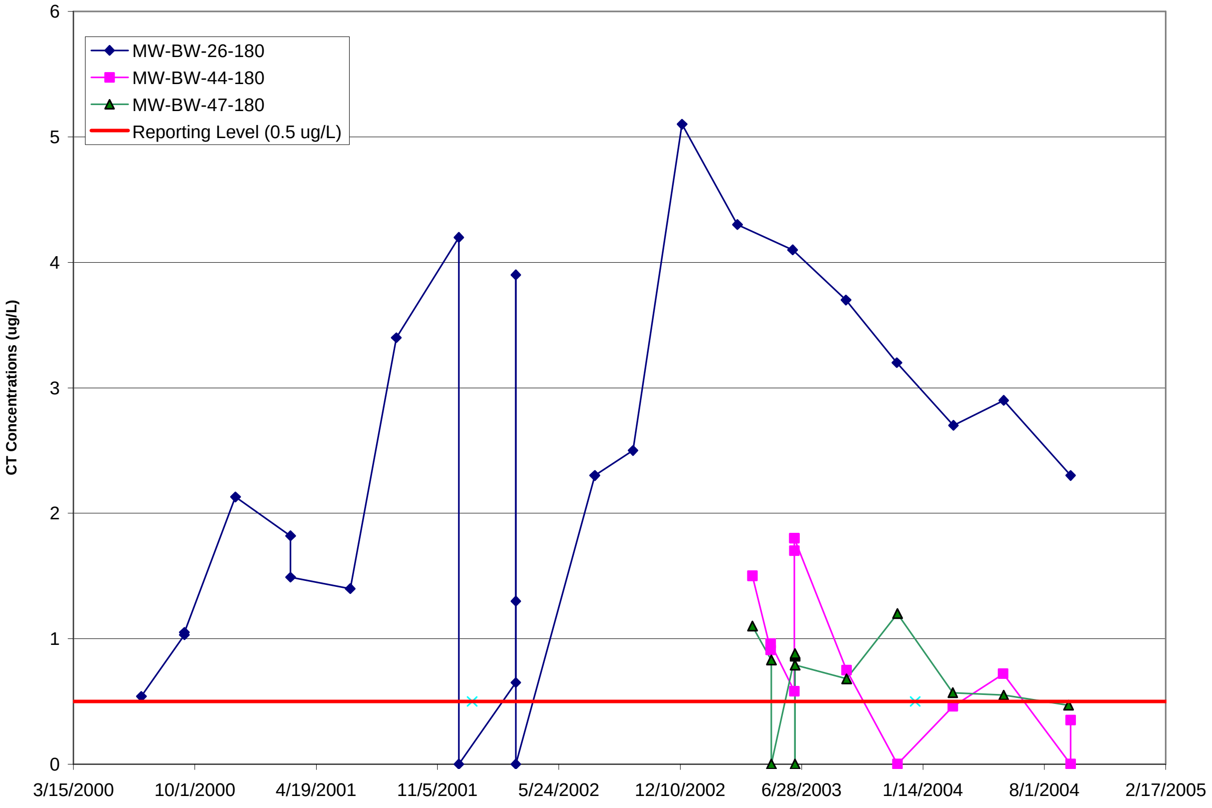


Figure 4. Carbon Tetrachloride Concentrations, Western Upper 180-Foot Aquifer Plume

The western plume emanates at least in part from an apparent vertical conduit co-located with the Mini-Storage well and is apparently very narrow as only a few of the monitoring wells intercept it, despite the relatively high density of coverage. This could be partly explained by the flow mechanism of a vertical conduit that intercepts multiple aquifers. In this case, the lowest groundwater elevations are in the Lower 180-Foot Aquifer and, as such, CT migrating downward from the A-Aquifer will ultimately reach this depth, given a pathway. The transport through the Upper 180-Foot Aquifer likely also results in some contamination at this depth, but to a lesser extent, as the bulk of the CT mass will continue to migrate into the Lower 180-Foot Aquifer in response to the associated lower groundwater elevation. The net result is that more CT reaches the Lower 180-Foot Aquifer than the Upper 180-Foot Aquifer; the width of the resultant plume is also greater in the Lower 180-Foot Aquifer than in the Upper 180-Foot Aquifer because of the larger amount of mass.

The eastern plume contains slightly higher concentrations than the western plume and range from the detection limit to over 5 µg/L. The higher concentrations may indicate that MW-B-13-180 intercepted the A-Aquifer plume closer to the high concentration zone relative to the western plume vertical conduit or is simply less diluted because the vertical conduit at MW-B-13-180 terminates in only one aquifer. Concentrations of CT in the eastern plume have generally decreased over time as illustrated below:

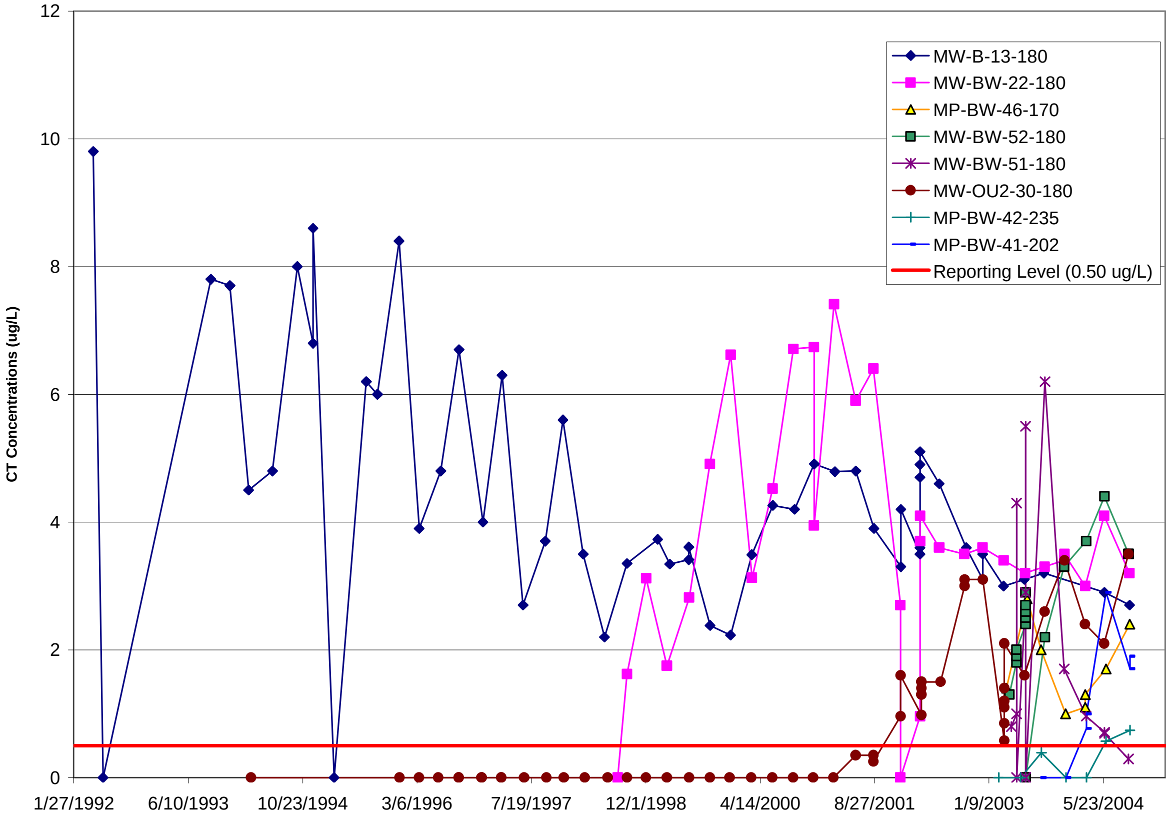


Figure 5. Carbon Tetrachloride (CT) Concentrations, Eastern Upper 180-Foot Aquifer Plume

CF concentrations typically are detected at less than 2 µg/L and, as in the A-Aquifer, are generally not observed beyond the footprint of the CT plume. TCE concentrations have not been detected in OUCTP

Upper 180-Foot aquifer monitoring wells, but are observed near the confluence of the OUCTP and OU2 plumes, generally below the Fredericksburg housing area where the underlying Intermediate 180-Foot Aquitard is absent and groundwater flows from the Upper 180-Foot Aquifer into the Lower 180-Foot Aquifer.

4.2.3 Lower 180-Foot Aquifer

As illustrated with data collected in September 2004, CT in the Lower 180-Foot Aquifer is present in two locations: the northern plume apparently emanating from a vertical conduit co-located with the Mini-Storage well and the southern plume emanating from where the Intermediate 180-Foot Aquitard is absent and allows groundwater from the Upper 180-Foot Aquifer to recharge the underlying Lower 180-Foot Aquifer. The northern plume is the larger of the two and is considered related to the western plume in the Upper 180-Foot Aquifer; the southern plume represents a continuation of the eastern plume in the Upper 180-Foot Aquifer.

Both plumes are characterized by relatively low concentrations of CT and chloroform, similar to the A- and Upper 180-Foot Aquifers, however, the southern plume also includes the OU2 plume signature as the two plumes commingle in this area. CT concentrations in the northern plume typically range from 3 to 7 µg/L at the Mini-Storage Well, from 1 to 5 µg/L at MP-BW-31 and MP-BW-37; and are less than 1 µg/L at MP-BW-34 and MP-BW-35. The highest concentrations are consistently observed at the Mini-Storage well.

Other VOCs observed in the Lower 180-Foot Aquifer include: 1,2-DCA, 1,2-dichloroethene (1,2-DCE), bromodichloromethane, chloroethane, CF, chloromethane, cis-1,2-dichloroethene (cis-1,2-DCE), ethylbenzene, PCE, toluene, TCE, trihalomethanes, VC, and xylenes.

1,2-DCA has been detected at MP-BW-38-327 and MP-BW-39-350 in 2003 and 2004 at low concentrations (0.25 to 1.7 µg/L) and is unrelated to the dechlorination of CT.

1,2-DCE (total, consisting entirely of cis-1,2-DCE) and TCE have both been detected consistently at wells MP-BW-41 and MP-BW-42 at concentrations ranging from 0.3 to 0.44 µg/L and 0.34 to 3.5 µg/L, respectively. 1,2-DCE is a dechlorination daughter product of TCE and, as such, its presence and the presence of TCE is associated with the OU2 plume and represents the area of co-mingling where the Upper 180-Foot Aquifer drains into the Lower 180-Foot Aquifer.

Bromodichloromethane and THMs are signature compounds of potable water disinfected with chlorine products and are not relevant to CT contamination. The single detection of bromodichloromethane at

MP-BW-37-328 in May 2004 (0.26 µg/L) is likely related to the consistent detection of THMs at the nearby Mini-Storage well (0.73 to 1.0 µg/L). These concentrations are consistent with those observed in the Fort Ord “sand tank” reservoir, which represent post-disinfection conditions. The presence of disinfection by-product compounds in the Lower 180-Foot Aquifer beneath this property suggests that a vertical conduit is co-located with the Mini-Storage well or in its immediate vicinity. THMs could have originated from the use of municipal water to irrigate the eastern portion of this storage facility or from a leaking water line near the property. As discussed in the previous section, a vertical conduit co-located with the Mini-Storage well plausibly explains the detection of CT at this well and wells located downgradient; however, historical vertical conduits in the area have been suspected and the complex interaction between multiple vertical conduits cannot be ruled out.

Chloroethane and chloromethane are daughter products of CT dechlorination and have only been detected infrequently at low concentrations (0.25 to 0.48 µg/L). The presence of these compounds are contained within the CT plume and are thus discussed synonymously with the CT plume footprint.

Ethylbenzene, toluene, and xylenes are all indicative of petroleum products (e.g., gasoline) and their infrequent detection (ethylbenzene was detected once and xylenes were detected twice) suggests incidental field-contamination. As mentioned above, various sources could account for the presence of toluene. None of these compounds represent formational contamination.

The presence of PCE at concentrations exceeding the reporting limit (0.5 µg/L) in Lower 180-Foot Aquifer groundwater has been limited to Westbay monitoring ports MP-BW-37-303, MP-BW-37-328, MP-BW-37-368, MP-BW-37-398, MP-BW-37-460 (400-Foot Aquifer), MP-BW-39-310, MP-BW-39-330, and MP-BW-42-345 and monitoring wells MW-OU2-66-180, MW-OU2-69-180, and MW-BW-72-180 (the latter three all related to the OU2 plume). PCE detections in the Westbay monitoring ports were observed for up to six months following the installation of each monitoring well; the highest concentration was detected at MP-BW-37-328 (7.8 µg/L) in January 2003 but has not been detected again since June 2003. PCE was last detected at MP-BW-37-398 at 0.67 µg/L in June 2003, but has not been detected again since then. The temporary detection of PCE at monitoring ports associated with MP-BW-37 shortly after their installation is particularly interesting as it strongly indicates that a portion of the Upper or Lower 180-Foot Aquifer contaminated with PCE had been intercepted, but that none of the monitoring ports were installed at that depth(s) to allow repeated monitoring. The transient presence of PCE in the Lower 180-Foot Aquifer is further discussed below.

The presence of VC (not a daughter product of CT dechlorination) in groundwater in the Lower 180-Foot

Aquifer has been limited to Westbay monitoring wells. Specifically, VC has been detected in Lower 180-Foot Aquifer Westbay monitoring ports MP-BW-30-317, MP-BW-30-342, MP-BW-30-467 (top of 400-Foot Aquifer), MP-BW-31-362, MP-BW-33-397, MP-BW-37-303, MP-BW-38-327, MP-BW-38-341, MP-BW-38-3*88++53, MP-BW-38-368, and MP-BW-39-350. Concentrations range from 0.25 to 1.9 µg/L. It appears most likely that the Westbay sampling technique leads to biased VC detections, assuming that the PVC material comprising the monitoring well casing is the source of VC. This would not differ significantly from other PVC monitoring wells; however, the Westbay sampling technique provides an extremely high-quality samples since almost no sample handling occurs during the collection process. That the Westbay sampling technique is capable of detecting VC off-gassing from standard PVC monitoring well materials is further supported by the fact that VC has never been detected in the only three non-Westbay monitoring wells screened within the Lower 180-Foot Aquifer (MCWD Well No. 8a, Mini-Storage, and Airfield). The fact that these non-Westbay monitoring wells are located adjacent to or are surrounded by detections derived from Westbay wells strongly suggests that the presence of VC is not formational but rather is an artifact of well construction and sampling technique.

CT is typically observed at the Airfield well between 1 and 3 µg/L. Locations available for installing monitoring wells to penetrate the Lower 180-Foot Aquifer were limited due to prohibitions on ground disturbance in the habitat reserve area located north of Reservation Road. Thus monitoring wells were anticipated in locations acceptable to the reserve stewards and effectively monitor the perimeter of the plume. As such, CT has only been regularly detected at MP-BW-37, MP-BW-31, the Airfield well, MP-BW-34, and MP-BW-35 and once at MP-BW-32.

Concentrations have generally decreased over time as illustrated below:

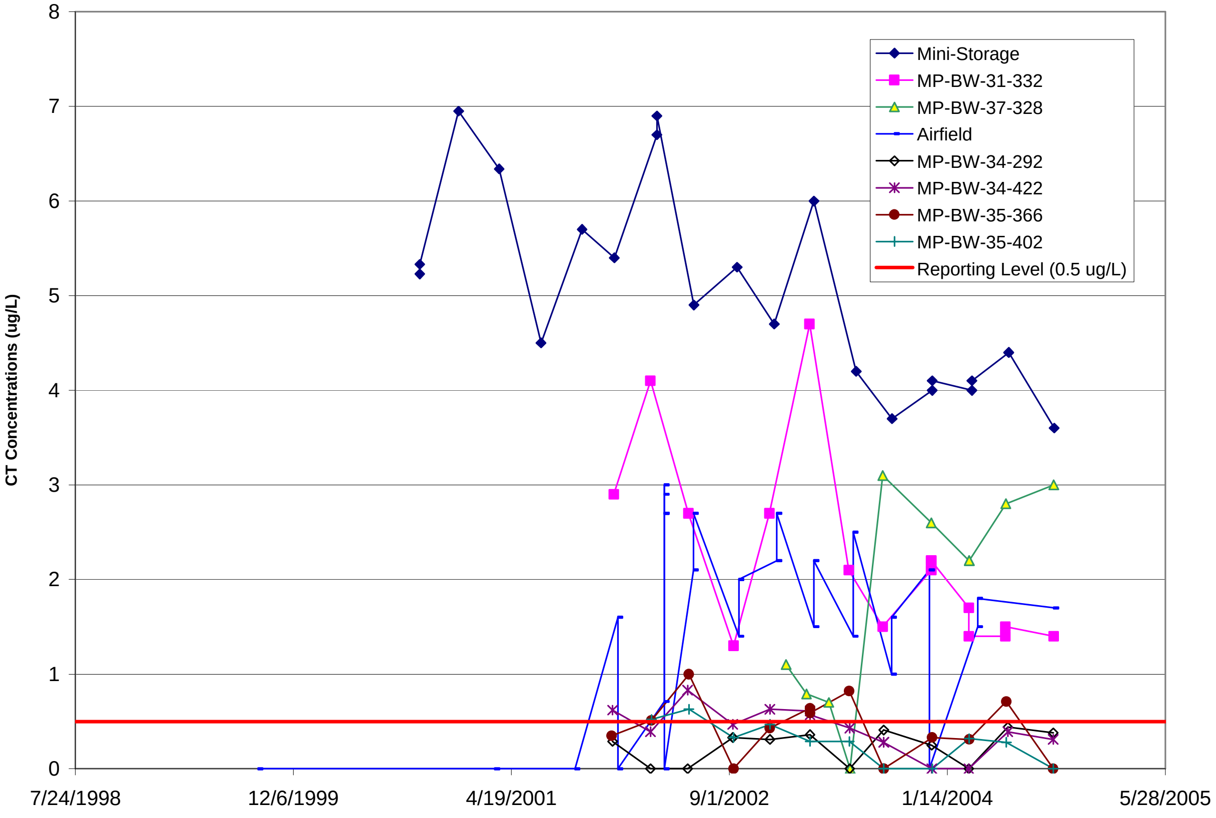


Figure 6. Carbon Tetrachloride Concentrations, Northern Lower 180-Foot Aquifer

CT concentrations in the southern plume are generally lower, do not exceed 1 μg/L, and are only detected at MW-OU2-66-180 and MW-OU2-69-180. Assigning the presence of VOCs to either OU2 or OUCTP is complicated by the commingling plumes in this area, although CT appears to have been phased out before the former Fort Ord landfills became active in 1958. Thus, the low concentrations of CT in this area of the Lower 180-Foot Aquifer appear to be an extension of the eastern Upper 180-Foot Aquifer plume.

Concentrations have remained low as illustrated below:

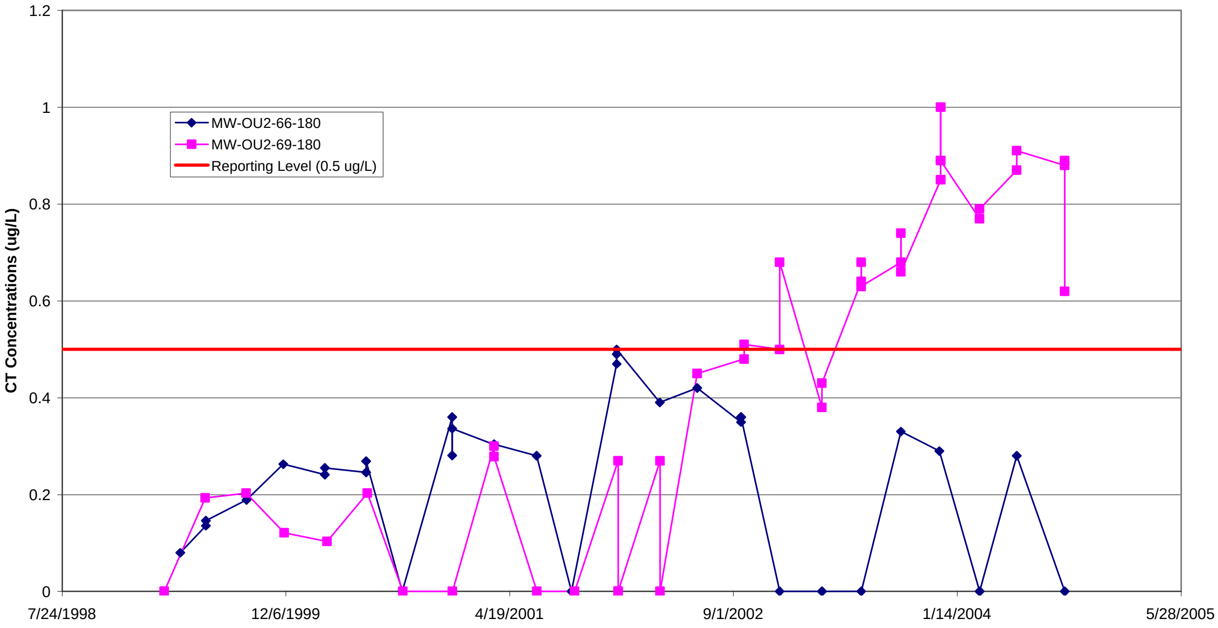


Figure 7. Carbon Tetrachloride Concentrations, Southern Lower 180-Foot Aquifer Plume

The Lower 180-Foot CT plume footprint has remained stable since monitoring began; however, active municipal wells located approximately 1,500 feet downgradient from MW-OU2-69-180 and the state MCL of 0.5 µg/L will require continued monitoring to ensure that MCWD Well Nos. 29, 30, and 31 are not impacted. Expansion of the OU2 groundwater treatment system is planned to include an additional extraction well near Bunkerhill Court that is designed to capture VOCs prior to migrating downward from the Upper 180-Foot Aquifer to the Lower 180-Foot Aquifer. Once operational, CT concentrations in the Lower 180-Foot Aquifer are expected to attenuate over time.

As mentioned in Section 1.2.3.1, contamination from several dry cleaning businesses located in the City of Marina just upgradient of the terminus of the FO-SVA is associated with elevated concentrations of PCE in the Lower 180-Foot Aquifer of OUCTP. Contamination associated with these sources have had relatively limited site characterization. PCE is clearly not related to CT dechlorination and its presence within the Lower 180-Foot Aquifer is not related to the OUCTP source, rather its presence is probably related to the continued migration of PCE from one or more of the dry cleaners further west and upgradient of the Fort Ord area within these aquifers. The Regional Water Quality Control Board (RWQCB) was notified of the Army's concerns regarding this matter in February 2004. As mentioned above, concentrations of PCE observed soon after the installation of MP-BW-37-328 were initially high

(7.3 µg/L; January 2003) but had decreased to levels below the reporting limit within three quarters and have not been observed at this or other Lower 180-Foot Aquifer monitoring wells since.

5.0 Additional Site Characterization

This section describes additional characterization of the OUCTP area, particularly of the FO-SVA. Soil samples collected from continuous core material were analyzed for the carbon-14 isotope (to estimate the age of organic material) and total organic carbon to aid in the calculation of CT retardation in mass transport equations.

5.1 Age Dating

Organic material observed near the bottom of the FO-SVA at MW-BW-19-180R (at a depth of 147 feet bgs) was determined to consist of a peat soil, which has been observed within the FO-SVA in previous investigations (*HLA, 1994a, b*). Additional organic material in the form of seashells were also noted at shallower depths within the same borehole as described in Section 2.2.8.1.2. Samples from depths of 149 feet (peat soil) and 128.5 feet (seashell) were collected and submitted on August 7, 2003 to the Center for Accelerator Mass Spectrometry of the Lawrence Livermore National Laboratory via Stanford University for carbon-14 analysis to determine the approximate age of the FO-SVA. Peat soil is expected to result in more accurate results because it is less likely to be relocated without becoming dispersed, whereas seashells can be transported into material of different age and also decay in a fashion that can 'partition' into different isotopes of carbon. Results indicated that the peat soil sample was 38,940 ± 440 year of age whereas the seashell sample was greater than 51,700 years of age and was indistinguishable from background. Its age was reported as a lower limit at 2 sigma after Stuiver and Polach. The quoted ages are in radiocarbon years using the Libby half life of 5,568 years and following the conventions of Stuiver and Polach (ibid.).

Because the peat soil was located near the base of the FO-SVA, it is concluded that a transgression event occurred about 40,000 years ago and was followed by the deposition of fine-grained material into an ancient lagoon located throughout much of the northern Salinas Valley. The SVA clay in the Salinas Valley has been associated with a transgression event following the Wisconsin glaciation period by Tinsley (*Tinsley, 1975*). This even lasted from approximately 80,000 to 12,000 years before present. Age estimates of the peat soil then suggest that the lower portion of FO-SVA clay was perhaps deposited during an early glacial melt period (circa 40,000 years before present) and that shallower portions of the FO-SVA were deposited during later portions of this glacial period. It is further concluded that the FO-SVA represents and extension of the SVA underlying the Salinas Valley floor.

5.2 Total Organic Carbon

Soil samples were collected from aquifer and aquitard materials out of the continuous core material associated with monitoring wells MP-BW-37, MP-BW-38, MP-BW-42, and MW-BW-19-180R. TOC was consistently not detected in samples collected from aquifer materials (reporting level of 1,000 mg/kg) but were reported at concentrations as high as 14,000 mg/kg within the FO-SVA (associated with the peat soil described above). The very low concentrations of TOC within the aquifer materials, including the A-Aquifer and the Upper 180-Foot and Lower 180-Foot Aquifers, in part explains the length of the VOC plumes observed beneath former Fort Ord, despite relatively low concentrations. In the absence of TOC, VOCs are able to travel long distances relatively quickly through the porous aquifer materials without being sorbed onto TOC-containing soil particles that would tend to slow their migration.

The affinity for an organic chemical to sorb onto a soil particle rather than remain in water is referred to as the octanol-water coefficient (K_{OW}) and can be correlated to the distribution coefficient (K_{OC}) which describes partitioning between water and a pure carbon source (octanol). The distribution coefficient of an organic chemical (K_d) (e.g., CT) is calculated as the product of K_{OC} for that chemical and the fraction of organics in the soil matrix when the latter is greater than 0.001 (0.1 percent). The larger the K_{OC} value, the greater affinity for sorption onto organic carbon surfaces. K_{OC} values are derived empirically and logarithmic estimates for CT typically vary from 1.6 to 2.8 (similar to PCE and TCE).

In the absence of organic carbon in soil, however, the K_{OC} remains very low thus allowing the dissolved CT to remain mobile and migrate with groundwater movement, even at low concentrations. Higher organic carbon concentrations within the FO-SVA clay do not mitigate the migration rate of CT because the aquifers (not the aquitards) provide the preferential pathway for migration.

5.3 Mineralogical Analysis

Continuous core samples from MP-BW-41 were collected at a depth of 194 feet bgs on March 13, 2003 due to the presence of what appeared to an ash deposit. This depth corresponds to the Upper 180-Foot Aquifer although a similar unit was observed at this location at a depth of 325 feet bgs, which correlates with the Lower 180-Foot Aquifer. Soils at these depths were olive-gray in color, fine-grained, powdery and very dry, and distinct from cored soil above and below these intervals. Sonic drilling through this soil zone was difficult and resulted in relatively high temperatures which further distinguished them from shallower and deeper soils. Ash deposits are valuable for geologic investigations as they provide a distinct geochemical signature that can be associated with previous age-dated volcanic events as well as physical ‘marker beds’ that can improve lateral lithologic correlation across an area.

Approximately two pounds of soil was collected on March 13, 2003 from the continuous core into a wide-mouth glass jar, half of which was submitted to the USGS for mineralogical analysis to determine if the sediment was of a volcanic ash deposit. Mr. Andrei M. Sarna-Wojcicki provided the following mineralogical analysis of the soil on March 19, 2003 via email:

The sample consists completely of detrital minerals, mostly quartz and feldspar, with a very few occasional other minerals present (hornblende; epidote, etc.). The sample is poorly sorted and appears to be bimodal. The finer fraction is angular to subrounded, and looks like wind-blown material. The angularity of many of the grains and shard-like outlines suggest that this is silt-sized loess. The coarser fraction is made up mostly of subrounded to rounded, sand-sized grains. These look like typical dune sand that has been transported by streams and reworked by wind. There are also a few rare plant fragments. The suggestion that one of our people, Jim Walker, made, is that the deposit represents an intradunal pond that was intermittently wet and dry. During wet periods, the pond would support some vegetation and act as a dust trap. During dry times, it would develop a fine crust at the surface that would protect it somewhat from deflation. It did indeed look like a dirty ash in hand sample, but the petrographic microscope revealed its true nature.

A similar soil zone was also observed at MP-BW-46 (25 feet bgs), corresponding with the A-Aquifer, although it is possible that other zones were observed but not recognized and recorded as a distinct unit at other boreholes. The sporadic observations indicate that this unit represents a local depositional environment and is not laterally continuous. It should be noted that this unit was only observed in continuous core generated from the sonic drilling technique and have not otherwise been observed with other drilling techniques, nor would they expected to be due to the low level of in-situ preservation afforded by rotary drilling techniques.

Although these results refute the presence of an ash sample, they indicate that the Upper 180-Foot Aquifer consists of soils that were deposited under apparently brief periods of a subaerial environment supporting dune formation. This is significant in that our previous interpretation of the Upper 180-Foot Aquifer was that sediments were deposited under fluvial conditions and that dune sand was only present within the A-Aquifer. That these ‘intradunal’ deposits are sporadically present in the A-Aquifer and the Upper 180-Foot Aquifer may have further implications concerning barriers either to percolation through the vadose zone overlying the A-Aquifer or to local horizontal flow patterns within the 180-Foot Aquifer sediments. However, their primary importance appears to be related to the indication of depositional environments within the 180-Foot Aquifer sequence.

6.0 Laboratory Analytical Procedures and Data Validation

In order to maximize efficiency and reduce costs associated with the remedial investigation field program, a combination of both non-USACE certified and USACE certified laboratories were used to analyze the data collected during various stages of the program. At a minimum, data collected as investigative or confirmation samples were subject to independent third party data validation, as described in the CDQMP (*HLA, 1997b*). Data collected as screening samples were subject to cursory in-house review, but were not subject to third party data validation. Whenever possible, USACE certified laboratories were used for analysis of the samples. Permission was obtained from the USACE Sacramento District chemist for the former Fort Ord to use laboratories without USACE certification for mobile laboratory soil gas analysis, limited inorganic analyses with short analytical holding times, and specialty analyses used during the Bio-Treatability Pilot Study Program.

6.1 Non-USACE Certified Laboratories

As described in Section 3.2.1, Centrum Laboratories, of Riverside California was used for analysis of samples collected during Phase I of the soil gas survey conducted in July 2002. Due to the investigative nature of this phase of the project, a mobile, on-site laboratory able to conduct immediate analysis of each soil gas sample was considered preferable to a fixed site laboratory which would require a longer turn around time for sample results. Centrum Analytical mobile laboratories, were certified through the California Department of Health Services Environmental Laboratory Accreditation Program (ELAP) during the investigation, but were not a USACE certified laboratory. Prior to the start of the investigation, permission was obtained from the USACE Sacramento District Chemist to use Centrum Analytical for analysis of VOCs by EPA Test Method 8260B (gas chromatography/mass spectrometer[GC/MS]) for this phase of the program. Under the direction of the USACE project chemist, a field audit of the laboratory was conducted by MACTEC on July 9, 2002, and included:

- Inspection of on-site laboratory facilities equipment for compliance with industry accepted standards;
- Inspection of the laboratory equipment and supporting documentation for compliance with EPA Test Method 8260B;
- Review of laboratory Standard Operating Procedure for Active Soil Gas Investigation (Centrum, 2002) for compliance with EPA Test Method 8260B; and
- Review of analytical data generated for precision, accuracy, and sensitivity goals as defined by EPA Test Method 8260B.

Results of the field audit were reported to USACE in a memorandum, *Carbon Tetrachloride Soil Gas Investigation – On Site Lab Audit* (*MACTEC, 2002*). Centrum Analytical was found to be compliant with the above reviewed parameters, and analyzed the soil gas samples for VOCs by EPA Test Method 8260B, with a reporting limit of 79 parts per million by volume (ppm [v/v]).

Sequoia, in Petaluma and Morgan Hill California were used for the analysis of the majority of the samples collected throughout the investigation for one or more of the following: VOCs by EPA Test Method 8260B, bromide, sulfate, nitrate and nitrite by EPA Test Method 300.0, ferrous iron by SM3500, TOC by EPA Test Method 415.1, and methane by RSK 175. While Sequoia Petaluma is a USACE certified laboratory, the Morgan Hill laboratory, which is not USACE certified (but is ELAP certified), was selected to perform the analysis of short holding time inorganic analyses including nitrate and nitrite by EPA Test Method 300.0, and ferrous iron by SM3500 due to its close proximity to the former Fort Ord.

In order to assess and monitor the amount of lactate being injected into the aquifer during the Bio-Treatability Pilot Study, a specialty lab was subcontracted by Sequoia for this analysis. EPA does not have an analytical method designed for the analysis of lactate in groundwater, and as a result, an in-house method for the analysis of lactate was performed by West Coast Analytical in Santa Fe Springs, California. Prior to the start of the pilot study, the laboratory standard operating procedures (SOP) for their in-house developed method was reviewed by the USACE project chemist, and considered acceptable for generating data suitable for monitoring the amount of lactate being successfully injected into the aquifer.

6.2 USACE Certified Laboratories

As described in Sections 3.2.2 and 3.2.3, soil gas samples collected during Phase II and III of the soil gas survey were analyzed by Severn Trent Laboratory in Los Angeles, California for VOCs by Compendium Method TO-15. Severn Trent Laboratory maintained both USACE and ELAP certification throughout the project. Compendium Method TO-15 (GC/MS) was selected for analysis during Phases II and III of the soil gas survey in order to achieve a reporting limit of 0.20 ppb (v/v).

During Phases I and II of the Bench Scale Test performed by CytoCulture, in Richmond, California, samples were collected in December 2003 and February 2004, and sent to Curtis and Tompkins Laboratory in Berkeley, California for analysis of VOCs by EPA Test Method 8260B. Curtis and Tompkins Laboratory was USACE and ELAP certified during the period of analysis.

The majority of the samples collected during the investigation were analyzed by Sequoia in Petaluma, California for one or more of the following: VOCs by EPA Test Method 8260B, TOC by EPA Test

Method 415.1, and bromide and sulfate by EPA Test method 300.0. Samples were also submitted for ferric iron analysis by EPA Test Method 6010B, methane by EPA Test Method RSK-175, ferrous iron by EPA Test Method 8146 and nitrate and nitrite by EPA Test Method 300.0, and were analyzed by Sequoia in Morgan Hill, California. As previously described, the Petaluma facility of Sequoia maintained USACE and ELAP certification throughout the project, while the Morgan Hill laboratory, with ELAP certification only was used for short holding time analyses.

6.3 Data Validation

Independent, third party data review and validation was performed on soil gas data generated from Centrum Analytical and Severn Trent Laboratories by DataVal, Inc in San Rafael, California. Data validation of EPA Test Method 8260B (Centrum) and Compendium Method TO-15 (Severn Trent) was performed in accordance with the *U.S. EPA Contract Laboratory Program National Functional Guidelines for Organic Data Review* (*EPA, 1999a*). EPA Level III data review was performed on all analytical results reported by the laboratories and included a review of the following:

- Analytical Holding Times;
- Laboratory Method Blanks;
- GC/MS Instrument Performance Check (Tune);
- Initial and Continuing Calibrations;
- Surrogate Recoveries;
- Laboratory Spike Control Samples;
- Matrix/Matrix Spike Duplicates; and
- Field Duplicate Samples.

EPA Level IV raw data review was additionally performed on a minimum of 10% of the soil gas sample results reported from the laboratories. The EPA Level IV review includes all of the parameters reviewed under EPA Level III validation plus a review of the following:

- Internal Standards
- Target Compound Identification and Quantification

The complete data validation reports provided by DataVal are presented in Appendix I.

Data generated from Curtis and Tompkins Laboratory from the Bench Scale Tests performed by CytoCulture and analyzed for EPA Test Method 8260B was subject to third party data validation, performed by Laboratory Data Consultants (LDC), in Carlsbad, California. Data validation was performed by LDC in accordance with the *USACE Environmental Data Quality Management Program Specifications, USACE District, Version 1.08* and *U.S. EPA Contract Laboratory Program National Functional Guidelines for Organic Data Review* (*EPA, 1999b*). EPA Level III review was performed on all sample results reported, and EPA Level IV raw data review was performed on selected sample results, with no significant findings reported by LDC. The complete validation reports as submitted by LDC are presented in Appendix I.

Data validation was performed by LDC on groundwater samples collected on April 12 and 13, 2004, April 24, 2004, June 2 and 3, 2004, and July 14, 2004 and analyzed by Sequoia Analytical in Petaluma and Morgan Hill, California. EPA Level III review was performed on all sample results from the above specified sampling dates for the following analyses: VOCs by EPA Test Method 8260B, ferric iron by EPA Test Method 6010B, methane by EPA Test Method RSK-175, TOC by EPA Test Method 415.1, nitrate and nitrite as N by EPA 353.2, nitrate, nitrite, bromide and sulfate by EPA Test Method 300.0, and ferrous iron By EPA Test Method 8146. Additional EPA Level IV raw data review was performed on selected sample results. EPA level III and IV validation was performed by LDC in accordance with *USACE Environmental Data Quality Management Program Specifications, USACE District, Version 1.08, U.S. EPA Contract Laboratory Program National Functional Guidelines for Organic Data Review* (*EPA, 1999b*) and *U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review* (*EPA, 1994*).

Appendix D2 and D3 present the inorganic and organic data collected during the OUCTP RI, and applied data validation qualifiers where applicable.

7.0 Data Management Procedures

The following sections describe the data management protocols used for samples collected during the OUCTP RI to maintain the integrity and security of the analytical data. The general objectives of the data management plan include:

- Proper field documentation of all samples collected;
- Track samples from the field to analytical laboratories, track analytical results to the project team, and ultimately enter results to the Fort Ord SQL Database;
- Track data validation and enter data validation qualifiers into SQL Database; and
- Provide format and protocols for laboratory data deliverables to facilitate data validation.

7.1 Field Documentation

Soil gas, soil, and groundwater samples collected during the OUCTP RI were, at a minimum, recorded in bound field log books and chain of custody (COC) forms as described in the *Draft Final Basewide Chemical Data Quality Management Plan (CDQMP), Former Fort Ord, California (Harding ESE, 2002f*). Field documentation was completed at the time of sample collection, and was designed to achieve the following:

- Each sample is uniquely and correctly identified;
- Each sample is traceable to its source/ point of origin;
- Sample representativeness is preserved;
- Sample alteration, such as by preservation or filtration is documented; and
- Establish a record of sample integrity throughout the custody process.

Samples were delivered to the analytical laboratories under COC protocols as described in the CDQMP. Sample custody was maintained and documented in the field, during shipment, and at the analytical laboratory. At a minimum, COC documentation included the following information:

- Project Name
- Project Location

- Date and time of sample collection
- Unique sample number for each sample
- Analysis required
- Sample type
- Sample description (location and matrix)
- Number of sample containers submitted
- Sample preservation
- Field sampler’s signature
- Courier and or laboratory signature.

7.2 Sample Management and Tracking

Samples collected during the OUCTP RI were tracked from the time of sample collection, through laboratory analysis and data validation, and final entry into the SQL database by the MACTEC Project Chemist. All laboratory data deliverables, including EPA Level II, III, and IV data packages and data validation reports will be kept in archive and accessible through the project file for a period of 10 years.

7.3 Laboratory Data Deliverables and Fort Ord SQL Database

Laboratory data deliverables included EPA Level III and Level IV data packages for data validation, and electronic data deliverables for upload into the Fort Ord SQL database. The format for electronic deliverables was provided to each laboratory before samples were submitted. Data generated from West Coast Analytical for lactate during the Bio-Treatability Pilot Study was not provided in electronic format, and was hand entered into the SQL database from the laboratory report. Screening data not requiring validation was reported as EPA Level II (sample results and quality control [QC] only) by the laboratories.

All EPA Level III data packages included the following to facilitate data validation:

- Case narrative;
- Laboratory sample receipt form and completed COC;

- Analytical results;
- Laboratory QC sample results (including method blanks, laboratory control samples, matrix spike and matrix spike duplicates and laboratory duplicates);
- Surrogate recovery results; and
- Initial and continuing calibration results.

In addition to the above parameters, raw data for each analysis was provided by the laboratories for selected samples requiring Level IV validation. Laboratories were notified of the samples for which raw data was required after the analytical process had been initiated, but before sample results were reported.

Data from all samples collected during the OUCTP RI was entered into the Fort Ord SQL database via hand entry from laboratory level II reports, or uploaded to the database from electronic deliverables provided by the laboratory. Sample results provided in electronic format were checked against the laboratory hardcopy report for accuracy before upload into the SQL database. Following data validation, qualifiers were added to the SQL database record for each sample as applicable.

8.0 Data Evaluation

This section includes a discussion of the data evaluation process regarding physical and chemical characteristics of each aquifer, source characteristics, nature and extent of contamination, and contaminant fate and transport.

8.1 Physical and Chemical Characteristics

This section describes the hydraulic parameters, groundwater flow directions, inorganic chemistry, and reduction/oxidation potentials observed in each aquifer.

8.1.1 A-Aquifer

Due to its relatively shallow depth and the fact that the highest concentrations of CT have been observed in the A-Aquifer, more monitoring wells have been installed in the A-Aquifer than in either the Upper or Lower 180-Foot Aquifers and hence relatively more data is available from this aquifer. This is consistent with the fact that the highest concentrations of CT have been observed in the A-Aquifer.

Groundwater generally flows to the north through much of the A-Aquifer beneath the Main Garrison of former Fort Ord and is defined by a north-south groundwater divide, relative to which the OUCTP source area is located to the west. Thus, the plume emanating from this source area has migrated northward and then westward toward Monterey Bay. Groundwater elevations within the OUCTP area range from about 85 feet MSL near the source area to about 5 feet MSL near Del Monte Boulevard. The gradient of the A-Aquifer water table mimics the slope of the top of the underlying aquitard (the FO-SVA) and abruptly flattens west of what appears to be a wave-cut terrace near Crescent Avenue. The dune sand through which most groundwater in the A-Aquifer flows throughout former Fort Ord overlies coarse beach gravel material west of the wave cut terrace that was apparently placed upon erosion of the underlying aquitard materials, presumably as it became emergent.

Aquifer testing conducted upgradient of the wave-cut terrace indicates that hydraulic conductivity of the dune sands varies from 20 to 90 feet/day, although the higher values may be more indicative of non-native sand pack materials placed within the borehole annulus. Testing conducted downgradient of the wave-cut terrace is limited to those at MW-BW-44-A but clearly indicates higher hydraulic conductivity values as high as 560 feet/day. This is consistent with lithologic logs and the observed change in gradient.

Inorganic data are collected from each well within a year of its installation to establish baseline conditions with respect to general mineral concentrations (i.e., calcium, magnesium, sodium, potassium, chloride, bicarbonate, sulfate, and nitrate). Several wells have been associated with multiple sampling events that indicate stable conditions with respect to inorganic values. As reported in previous annual reports of quarterly monitoring and OU2 Plume Delineation Reports, inorganic signatures have been noted that define, in part, the OU2 plume. Samples from wells beyond the OU2 plume footprint were distinguished primarily by lower proportional concentrations of bicarbonate and were assigned a signature Group I. Monitoring wells used to delineate OUCTP belong to this group and further evaluation of inorganic data has not lead to further subdivisions based on the inorganic concentration signatures.

ORP has been measured in several wells along the axis of the CT plume as discussed in Section 3.8.3. These results generally indicate that the A-Aquifer is oxidized except in several pockets generally near the base of the aquifer where microbial activity may have been enhanced either by contaminant concentrations, variations in the underlying aquitard material, or by local land uses (e.g., residential septic tanks). ORP values generally range from about 50 millivolts (in limited areas) to 250 millivolts and related dissolved oxygen concentrations have ranged from about 2 (in limited areas) to 10 mg/L.

Speciated iron, nitrogen, and sulfur concentrations all indicate relatively strongly oxidized conditions predominate throughout the A-Aquifer included within the OUCTP area. For example, ferric iron (oxidized) concentrations measured in 15 A-Aquifer monitoring wells in May 2003 ranged from 0.43 to 28 mg/L whereas ferrous iron (reduced) was not detected above 0.10 mg/L. Similarly, nitrate (oxidized) concentrations ranged from non detect (5.0 mg/L reporting limit) to 46 mg/L whereas nitrite (reduced) was not detected. These results are consistent with an oxidized environment, although they may not reflect the local pocket of slightly reducing conditions indicated by profiles of ORP and DO discussed in Section 3.7.1.

8.1.2 Upper 180-Foot Aquifer

Groundwater in this aquifer is confined by the overlying aquitard (FO-SVA) and flows east-southeastward toward a natural pinch-out of the underlying aquitard (Intermediate 180-Foot Aquitard) where the flow merges with that in the underlying Lower 180-Foot Aquifer (*Harding ESE, 2001c*). The effect of this natural drain is far-ranging as contours throughout the Main Garrison area and northern extent of former Fort Ord reflect a concave pattern indicating radial flow toward this area. In fact, the pattern of groundwater elevations were the strongest indication that a natural drain of this sort exists as lithologic data were not available previous to the OUCTP RI field program. Subsequent installation of boreholes and monitoring wells have confirmed that the Intermediate 180-Foot Aquitard does pinch out east of Imjin Road near Bunkerhill Drive. The complete configuration and orientation of pinches out has not yet been determined.

Groundwater elevations within the OUCTP area in the Upper 180-Foot Aquifer range from about -7 to -12 feet MSL, although as much as an 8-foot fluctuation has been consistently observed that reflects the seasonal irrigation pattern in the Salinas Valley, which propagates through the natural pinch-out. Groundwater flow becomes slightly unconfined in the same vicinity of this pinch-out both because of the local depression in groundwater elevation as well as a regional upward warp in the overlying aquitard. Several wells in this area seasonally ‘whistle’ through vent holes as air trapped beneath the FO-SVA is compressed during the wet season when irrigation demands are reduced and groundwater pressures increase. During summer months when groundwater elevations drop, the ensuing vacuum beneath the FO-SVA makes the removal of un-vented caps from Upper 180-Foot Aquifer wells in the area nearly impossible, thus requiring the installation of vent holes. Quarterly measurements of groundwater elevation thus need to account for their stabilization following the removal of the well cap.

Aquifer testing in this aquifer has been conducted as part of the design and installation of the OU2 groundwater treatment system. Data closest to the OUCTP plumes in this aquifer derive from extraction wells EW-OU2-05-180 and EW-OU2-06-180. These and other results indicate that hydraulic conductivity of the Upper 180-Foot Aquifer ranges from 100 to over 1,000 feet/day which is consistent with the generally clean sand to gravelly sand noted in most lithologic logs.

Inorganic data collected from wells throughout the OUCTP area indicate that chemical signature of the Upper 180-Foot Aquifer is very similar to that of the A-Aquifer. As with the samples from the A-Aquifer, samples from wells delineating most of the OUCTP in the Upper 180-Foot Aquifer indicate a Group I inorganic signature. Only near MW-OU2-61-180, where the two plumes commingle, does this not hold true and a Group II signature emerges.

8.1.3 Lower 180-Foot Aquifer

Groundwater in the Lower 180-Foot Aquifer flows under confined conditions to the east toward the Salinas Valley under a gradient that is largely driven by seasonal irrigation demand. Groundwater elevations typically range from -10 to -18 feet MSL, however, a seasonally steeper gradient develops during late summer months when elevations in the easternmost wells drops to -24 feet MSL.

Although groundwater primarily flows east-northeastward toward the Salinas Valley, the direction of groundwater flow does vary seasonally near the Marina municipal wells (MCWD Well Nos. 29, 30, and 31) that supply the former Fort Ord community. The local gradient toward these municipal wells increases during the winter months when the regional gradient toward the Salinas Valley lessens.

Measurements of the hydraulic properties of this aquifer are relatively limited due to the logistical difficulties of stressing a high-permeability aquifer. Specific capacity tests conducted at MCWD Well No. 8a, and data from MCWD Well Nos. 29, 30, and 31 indicate a transmissivity value of approximately 45,000 ft^2/day, which is consistent with the gravel content and presence of boulders observed in this aquifer. The aquifer test conducted at MCWD Well No. 8a as part of the OUCTP RI induced approximately one foot of drawdown in observation wells at distances of about 200 to 500 feet by pumping 320 gpm. With a thickness of 140 feet, this value is equivalent to a hydraulic conductivity of 330 feet/day. The storativity of the Lower 180-Foot Aquifer at this location was estimated at 3.4e-4, consistent with a confined aquifer.

The inorganic signature is dominated by the presence of seawater intrusion which includes chloride concentrations of almost 7,000 mg/L at MP-BW-30 at the base of the aquifer. Concentrations attenuate at shallower depths and eastward typical of a seawater ‘wedge’. Seawater intrusion plagued many historical Fort Ord and MCWD municipal wells until the mid-1980’s when pumping near the coastline ended and either deeper aquifers or more inland locations were instead relied upon for water supply. The mass of seawater that had intruded beneath the City of Marina, however, did not retract to Monterey Bay upon cessation of pumping. Instead, it has continued to migrate inland in response to the regional gradient toward the Salinas Valley. To date it appears that chloride concentrations exceeding 1,000 mg/L could extend as far east as Blanco Road, north of Reservation Road.

8.2 Source Characteristics

The source area has been identified by the persistence of CT and chloroform unrelated to other known sites at the former Fort Ord within the vadose zone beneath what is now the Preston Park housing area near Lexington Court. CT had been detected within a relatively small footprint (five acre) to depths ranging from 6 to 85 feet bgs. Concentrations ranged from below 10 ppb/v near the surface to about 300 ppb/v at the greatest depths. The presence of CT and chloroform in soil vapor overlying these same compounds in groundwater downgradient but not upgradient from this location confirms that the source of the CT plume has been identified.

Low concentration detections of PCE and TCE in soil vapor within the same footprint indicates that these solvents also had been used at the site but in apparently lower volumes. The fact that PCE and TCE are also located upgradient in association with the OU2 landfills does not mean that the OU2 plumes commingle with the OUCTP in this aquifer. The OU2 plume has been clearly shown to migrate to the south of the OUCTP area in the A-Aquifer and the PCE and TCE detected in soil vapor and in groundwater downgradient of Lexington Court are associated with historical solvent usage at the OUCTP source area.

Based on the length of the plume in the A-Aquifer, estimated hydraulic properties of the aquifer, and measured rate of groundwater movement, the age of the OUCTP plume is estimated to be approximately 50 years old and was probably released to the environment circa 1950. This is corroborated by the fact that CT has generally not been a constituent of the OU2 plume, which emanates from landfills that were first operated in 1958. Thus, it appears that the use of CT near what is now Lexington Court probably occurred between 1945 and 1955 and its general use at Fort Ord ceased prior to the opening of the former landfills, which is consistent with personnel interviews.

8.3 Nature and Extent of Contamination

The primary OUCTP contaminant is CT and thus it is described below in terms of the extent of CT even though several other contaminants (e.g., CF) are also present. No other contaminants are located beyond the CT footprint in any aquifer.

CT migrated from the source area to the north and northeast within the A-Aquifer along a trajectory consistent with groundwater elevations. A natural groundwater divide is located just east of the source area and hence all migration has been contained to the west of this divide. However, the brief operation of an injection well field (1995 to 1999) just west of the source area, prior to knowledge of the presence of CT, did apparently push the plume eastward as indicated by the low concentrations at MW-BW-16-A and MW-BW-57-A. However, the cessation of injection appears to have resulted in groundwater elevations that must have predominated since well before 1995 to account for the orientation and configuration of the A-Aquifer plume.

At least two wells were installed in the 1970s which apparently penetrated the A-Aquifer plume and allowed it to migrate into the underlying aquifers. The first, MCWD Well No. 8, was installed in 1972 and was constructed in a manner that did not include a sanitary seal that extended to the top of the FO^{-}SVA. Although a second ‘formation’ seal had been installed, it did not correspond with the Intermediate 180-Foot Aquitard. Hence, MCWD Well No. 8 appears to have potentially represented a vertical conduit from the A-Aquifer through the FO-SVA into the Upper 180-Foot Aquifer and through the Intermediate 180-Foot Aquitard into the Lower 180-Foot Aquifer. However, the installation of the Mini-Storage well in 1996 has complicated this conclusion as a vertical conduit may also co-exist at or near this location. MCWD Well No. 8 was abandoned in 1980 when the pump and potentially also the well screen collapsed apparently as a results of corrosion from seawater intrusion. It was reportedly destroyed in 1992 by injecting grout; however, it is not known whether the casing had been knifed to seal the gravel pack or if the open casing had simply been filled with grout/cement. The Mini-Storage well is currently active but infrequently used for irrigation purposes.

MW-B-13-180 was installed in 1975 by CH2M Hill as part of a treated-sewage effluent disposal study. Several wells had been installed surrounding the FAAF, of which only MW-B-13-180 penetrated the FO-SVA (*CH2M Hill, 1974*). The well construction log indicates that a sanitary seal had been placed within at least the upper half of the FO-SVA clay, which should have sufficiently prevented the formation of a vertical conduit between the A- and Upper 180-Foot Aquifers. However, the presence of CT at MW-B-13-180 versus its consistent non-detection at MW-BW-54-180, located immediately upgradient, confirms that the sanitary seal of MW-B-13-180 was either incorrectly installed or incorrectly recorded or that it somehow failed since 1975. To account for the length of the eastern Upper 180-Foot Aquifer plume, either the seal was inadvertently incorrectly installed or it failed shortly after its installation.

CT continued to migrate down the vertical conduit at MCWD Well No. 8 and entered the Lower 180-Foot Aquifer; however, the effective migration away from this or other active production wells is not known since pumping activities would have likely removed any contaminant emanating from this vertical conduit. Active migration may be occurring at or near the Mini-Storage well where CT continues to migrate east/northeast toward the Salinas Valley, comprising the northern CT plume in the Lower 180-Foot Aquifer. This plume appears to terminate beneath the Marina Airport (previously known as the FAAF). The Upper 180-Foot Aquifer plume emanating from MW-B-13-180, however, migrated southeast toward the natural pinch-out of the underlying Intermediate 180-Foot Aquifer where is also entered the Lower 180-Foot Aquifer. The CT plume commingles with the OU2 TCE plume at this location and both contaminants appear to be migrating eastward toward the MCWD municipal wells. To date, CT has not been detected in any of these drinking water wells; however, TCE has been detected at MCWD Well No. 29 at concentration ranging from 0.51 to 0.81 µg/L, with the higher concentrations consistently being detected during late summer months.

8.4 Contaminant Fate and Transport

Natural attenuation processes are occurring within the A-Aquifer plume as discussed in Section 3.7. The dominant process appears to be dilution with limited dechlorination from indigenous microbial populations that may have flourished historically when the mass of CT had been more concentrated after its initial release. There appear to be local areas of some microbial activity, indicated by areas of lower ORP values and DO concentrations. Migration within the Upper and Lower 180-Foot Aquifer appears to be primarily in response to advective forces with little chemical or biological degradation.

Total organic carbon in soil samples was analyzed for in all three aquifers and both the FO-SVA and Intermediate 180-Foot Aquitard during the installation of wells MP-BW-37, MP-BW-42, and MW-BW-19-180R. Results indicate that organic carbon is not present in any of the aquifers but that concentrations are quite high within the FO-SVA as indicated by the occasional presence of peat deposits. The combination of low organic carbon concentrations and the relatively low partitioning coefficient of CT results in the potential for relatively long plumes of contamination, controlled primarily by advective (i.e., groundwater flow) and dispersive processes. Thus, the direction and rate of groundwater movement is of paramount importance to understand the potential for mass transport of CT in groundwater beneath former Fort Ord.

The aerobic environment within each aquifer, particularly in the A-Aquifer, also reduces the tendency for CT to naturally degrade. Dechlorination processes are more apt in anaerobic environments which usually include reducing conditions favorable to the successive removal of chlorine atoms from chlorinated solvents such as CT. These conditions are generally found in environments with an abundant source of organic matter that provide a food source for microbes native to the area. The consumption of food by anaerobic microbes generally results in the consumption of dissolved oxygen and the development of reducing conditions. Chlorinated solvents within such an environment often are reduced to simpler forms (i.e., CT dechlorinates to CF, which contains one less chlorine atom). This process may continue until only methane (or upon its oxidation, carbon dioxide) remains and all the chlorine atoms have been disassociated from the original chemical solvent.

Thus, the non-detection of organic carbon in aquifer materials, the relatively low affinity for sorption to non-organic material by CT, and the low natural population of microbes in an aerobic environment all contribute to the relatively long length of CT plumes emanating from the source area as many as 50 years ago. In the absence of reducing conditions generated from microbial activity, CT dissolved in groundwater can be very persistent.

The following section describes the numerical simulation in which groundwater data, including elevations, gradients, rates of movement, chemical data, and the effects of current and historical pumping in the area upon the distribution of CT in the A-, Upper 180-Foot, and Lower 180-Foot Aquifers are incorporated.

9.0 Groundwater Flow Simulation

A three-dimensional transient mass transport model was constructed using MODFLOW-2000 (*Harbaugh A.W., et al, 2000*) with the Groundwater Modeling System (GMS, version 5.0, September 29, 2004) pre-and post-processor application (*EMRL, 2004*). A detailed illustration of the model, including its construction, calibration process, verification, sensitivity analysis, and illustration of simulated groundwater elevations and CT concentrations over time, is included in Appendix F.

The objectives of this model were to:

- Evaluate and illustrate lithologic, aquifer parameter, and groundwater extraction information collated from previous investigations and the remedial investigation program;
- Simulate groundwater elevations in the A-, Upper 180-Foot, and Lower 180-Foot Aquifers;
- Account for vertical conduits through the FO-SVA and Intermediate 180-Foot Aquitard;
- Use particle traces to confirm the direction of groundwater flow and CT migration (sans dispersive processes);
- Simulate the formation of the A-Aquifer CT plume from the source area near what is now Lexington Court; and
- Evaluate various remedial options by introducing potential changes to the simulated hydraulic and/or chemical conditions in the model.

9.1 Model Construction

Lithologic data from all monitoring wells within the model domain were incorporated into the model to construct contacts between each aquifer/aquitard (Appendix A). Topography was extrapolated from measurements with a two-foot resolution (provided by the USACE, Sacramento District; prepared by Hammen, Jensen, Wallen and Associates using digital orthophotography and topology with 1994 aerial photos).

Each aquifer is simulated with a single layer although hydraulic conductivity values vary according to available measurements from aquifer tests conducted as part of this remedial investigation as well as results from previous OU2 investigations. Layer 1 had been originally constructed as an upper portion of the A-Aquifer but was deactivated through the process of calibration as discretization of the A-Aquifer was deemed unnecessary. The model layers are thus correlated with stratigraphy as follows:

Model Layer	Aquifer/Aquitard Name
1	Inactive
2	A-Aquifer
3	Fort Ord – Salinas Valley Aquitard
4	Upper 180-Foot Aquifer
5	Intermediate 180-Foot Aquitard
6	Lower 180-Foot Aquifer

The model grid was telescoped around MW-B-13-180 and in the vicinity of the Mini-Storage well, due to the presence of vertical conduits at or near these two locations, as well as at EW-OU2-02-180 and the recently installed extraction well EW-OU2-07-180 near Bunkerhill Drive. Grid cell sizes range from 10 feet on a side to 500 feet on a side and allow for the effect of pumping or vertical conduits to be evaluated without constructing an unnecessarily large model with a constant small-cell grid. Vertical discretization of the model was based on observed lithology interpolated from borehole logs located within the model domain.

Ongoing pumping within the model domain occurs at ten OU 2 extraction wells within the A-Aquifer, five OU2 extraction wells within the Upper 180-Foot Aquifer, and at the three active drinking water wells within the Lower 180-Foot Aquifer. Injection of treated water to the A-Aquifer occurred from 1995 to 2000. The model grid was telescoped around MCWD Well No. 8 and MW-B-13-180 due to the presence of vertical conduits at these two locations as well as at EW-OU2-02-180 and EW-OU2-07-180. Grid cell sizes range from 10 feet on a side to 500 feet on a side and allow for the effect of pumping or vertical conduits to be evaluated without constructing an unnecessarily large model with a constant small-cell grid.

Recharge was applied to the model in two zones, the largest being applied to the former Fort Ord area and a smaller zone covering the most developed portion of the City of Marina. The second zone was included on the basis that storm water within the city is more effectively captured and removed from the groundwater system within the model domain. Storm water in other areas of the model is collected in many small retention ponds and ultimately allowed to enter the groundwater system. The concentration of storm water at these retention ponds does not appear to be significant enough to warrant their specific simulation and hence recharge is simulated over the entire area as if they were not present.

9.2 Advective Flow

The model was constructed with steady-state conditions prior to incorporation of transient conditions, as is typical for complex groundwater simulations (*ASTM, D-5981-96*). Boundary conditions defining the steady-state simulation correlate with June 2004 observed data within each layer. Hydraulic conductivity and June 2004 groundwater elevations were varied throughout the model domain of each aquifer to optimize calibration results of the steady-state simulation. Polygonal areas within each layer were constructed with unique hydraulic conductivity values and altered while honoring aquifer test results to obtain a good fit with observed groundwater elevations.

The model was subsequently developed with the transient conditions which required inclusion of additional hydraulic characteristic of storage and time-varying head values assigned to each boundary; however, these results were ultimately not incorporated into the final product. Changes in A-Aquifer groundwater elevation typically are minor and are adequately simulated with time-constant boundary conditions. Even the significant increase in A-Aquifer groundwater elevations during the 1997/98 El Niño event did not effectively change the gradient within the OUCTP area. However, it is notable that groundwater elevations did not peak following this event at many monitoring wells until the year 2000/2001, representing a three-year lag time indicative of the buffering capacity of the thick vadose zone. Although of hydraulic interest, the impact of this significant precipitation event has not been apparent in the distribution or migration rate of CT within the A-Aquifer. Transient changes in the Upper and Lower 180-Foot Aquifer were simulated with excellent calibration to historical observations; however, the seasonal nature ultimately does not change the average directions of groundwater flow simulated under steady-state conditions.

Calibration of a groundwater model is accomplished in three stages. Level 1 refers to calibration to groundwater elevations, Level 2 refers to calibration to groundwater flow directions, and Level 3 refers to calibration to contaminant migration rates. Level 1 calibration was conducted with observed groundwater elevations from monitoring wells located within the OUCTP model domain for each aquifer using June 2004 data in the steady-state simulations and a variety of historically observed data for the transient simulations. Results and an error summary for each aquifer are discussed in detail in Appendix F.

9.3 Particle Analysis

Flow directions within the A-, Upper and Lower 180-Foot Aquifers were evaluated using particle pathways generated with MODPATH (*Pollock, 1994*). This evaluation does not account for the cumulative effects of dispersion, chemical reaction, or other processes that effectively retard the migration rate of CT. Particles were originated near the source area in the A-Aquifer, at the two suspected vertical conduit locations in the Upper 180-Foot Aquifer and at the suspected anthropogenic vertical conduit in the Lower 180-Foot Aquifer.

Level 2 calibration to known directions of groundwater flow led to the conclusion that anisotropy was required in the A-Aquifer to attain a direction of flow consistent with the CT plume footprint. Simulations with isotropic conditions (no anisotropy) resulted in westward groundwater flow from the source area with little to no displacement to the north. The A-Aquifer is comprised of dune sand and, as such, preferential pathways (e.g., channels) are not expected to be present and have not been observed in lithologic logs at numerous boreholes, including continuous core analysis. The prevailing wind direction in the area is to the east/northeast and dune sand faces are expected to result in heterogeneity that may account for the apparent need for simulated anisotropy. Anisotropy values in the steady-state simulation range from 1 (isotropic) to 1.5 (50 percent northward anisotropy) with values increasing generally with higher topographic elevations, as illustrated in Appendix F. This conceptual model implies that dune faces and associated paleosols were more developed inland, which resulted in a slight northward anisotropy in the A-Aquifer. Homogenous conditions were simulated in the Upper and Lower 180-Foot Aquifers.

Forward-tracing particles were simulated from the vicinity of the Mini-Storage well in both the Upper and Lower 180-Foot Aquifers and from MW-B-13-180 in the Upper 180-Foot Aquifer to evaluate the direction of groundwater flow. As shown on plate F15, Upper 180-Foot Aquifer particle traces accurately follow each of the two CT plumes migrating to the southeast, with the eastern plume continuing to migrate eastward through the Lower 180-Foot Aquifer. Particle traces in the Lower 180-Foot Aquifer indicate that future migration of the northern plume will continue north of the currently active MCWD Well Nos. 29, 30, and 31. However, migration of the southern CT plume in the Lower 180-Foot Aquifer could eventually influence water quality at MCWD Well Nos. 29 and 30.

9.4 Mass Transport

Following calibration of advective flow within each aquifer (discussed in Appendix F), mass transport of CT in the A-Aquifer was simulated using MT3D (*Zheng, 1990*). The source of CT is suspected to have originated circa 1950 and, as such, the mass transport simulation begins in 1950 and continued to 2004. A number of assumptions were required for the source terms, given the unknowns surrounding the use, storage, and disposal of CT near what is now Lexington Court. As discussed in Section 1.2.3.2, five-gallon cans of CT were preferred to drums to avoid mass waste of product when drum lids were not replaced; however, this implies that drums had been used at one time at Fort Ord. The size of the apparent training facility suggests that relatively small quantities of CT were probably stored at any one time, however, the duration of activity at this facility is not clear. For purposes of simulating mass transport of CT, it is assumed that one five-gallon can was disposed of each month for at least six years, resulting in a cumulative release of 360 gallons of CT at the source area. As discussed in Appendix F, this volume seems to account for the historical migration of CT through the A-Aquifer and probable migration through the Upper and Lower 180-Foot Aquifers.

Simulation of mass transport of CT was limited to the A-Aquifer due to complexity associated with historical pumping and vertical conduits (both their location and time of construction). Calibration of mass transport is limited to analytical data available from previously used supply wells from 1985 to the early- to mid- 1990's, three A-Aquifer and one Upper 180-Foot Aquifer monitoring wells in 1992, continued quarterly results from one A-Aquifer and one Upper 180-Foot Aquifer monitoring wells until 1997, and an increasing number of monitoring wells since. In 1992, CT had been detected in MW-B-14-A at about 6 µg/L but was not detected at MW-B-12-A (with a reporting limit of 5 µg/L). Transient mass transport simulation results are consistent with these data as the simulation illustrates CT concentrations exceeding 5 µg/L in 1992 had reached MW-B-14-A but were still located upgradient of MW-B-12-A. Subsequent migration to the west has also been simulated consistent with the progressive delineation of the CT plume in the A-Aquifer. Simulated results for 2004 indicate an acceptably larger plume footprint in the toe area, which provides slightly conservative starting conditions for predictive analyses used to evaluate remedial alternatives (Volume III).

A detailed description of the model construction, calibration, verification, sensitivity analysis, and illustrated results are included in Appendix F. The steady-state solution reflects a very good calibration with groundwater elevations and groundwater flow directions in the A, Upper 180-Foot, and Lower 180-Foot Aquifers. Particle pathway tracking confirms the central axis of each plume and progression from one aquifer to the next underlying aquifer. As discussed in Volume III, however, remedial alternatives have already been initiated by the Army to prevent this from continuing.

10.0 Summary and Conclusions

This section includes a summary of the findings from the OUCTP RI field program and their subsequent evaluation as well as conclusions to be considered as part of the risk assessment (Volume II) and the feasibility study (Volume III) of this report.

10.1 Lithology and Hydrostratigraphy

Lithologic and hydrostratigraphic information obtained from drilling boreholes and installing monitoring wells confirmed the presence and lateral extent of the A-Aquifer, FO-SVA clay unit, Upper 180-Foot Aquifer, Intermediate 180-Foot Aquitard, Lower 180-Foot Aquifer, and the 400-Foot Aquifer.

The A-Aquifer consists primarily of dune sands but also consists of coarse sand and gravel west of a significant wave-cut terrace in the underlying FO-SVA near Crescent Avenue. Saturated thickness generally range from 20 to 30 feet but depth to groundwater can vary from as little as 20 feet to as large as 120 feet. Groundwater elevations range from approximately 85 to 5 feet MSL and groundwater contaminated with CT flows northwest or west. Hydraulic communication between the A-Aquifer and underlying aquifers is limited to those areas west of the OUCTP where the FO-SVA clay unit pinches out or where it has been penetrated by wells without adequate sanitary seals. Two such vertical conduits have been identified and have resulted in the migration of CT from the A-Aquifer to the underlying Upper and Lower 180-Foot Aquifers. Horizontal hydraulic conductivity values of this aquifer range from about 20 feet/day midway along the A-Aquifer CT plume to as high as 540 feet/day near the toe of the plume. Fine-grain sand observed near the source area suggest values less than 20 feet/day in this area.

The underlying aquitard is called the FO-SVA and consists of a thick, dense clay unit deposited in a marine environment, as indicated by various observations of seashells. Samples analyzed for total organic carbon confirm that this unit contains significant organic content, occasionally in the form of peat lenses. Although two to three sand units, each up to 15 feet thick, appear to lie within this aquitard and extend laterally throughout the OUCTP study area, only very little advective flow occurs through this unit except where penetrated by wells with inadequate sanitary seals. Vertical hydraulic conductivity values of the clay have been measured (via permeameter tests) at approximately 10^{-6} to 10^{-8} cm/sec.

The Upper 180-Foot Aquifer consists of about 60 feet of fine to coarse sand and some gravel and is laterally extensive throughout the OUCTP study area. Groundwater flows eastward and southeastward under largely confined conditions except within the southern portion of the OUCTP study area where the overlying FO-SVA clay rises above the potentiometric surface, thus resulting in locally unconfined conditions. The direction of flow appears controlled by the degree of hydraulic communication with the underlying Lower 180-Foot Aquifer, separated by the Intermediate 180-Foot Aquitard, where present. Where this aquitard pinches out, groundwater from the Upper 180-Foot Aquifer drains into the Lower 180-Foot Aquifer.

The Intermediate 180-Foot Aquitard consists of approximately 50 feet of interbedded clay and clayey sand layers, occasionally mixed with coarse gravel, suggesting a high-energy depositional environment, possibly colluvial. This aquitard hydraulically isolates the Upper and Lower 180-Foot Aquifers from one another but pinches out in the southern portion of the OUCTP study area, allowing recharge to the Lower 180-Foot Aquifer to occur.

The Lower 180-Foot Aquifer consists of approximately 200 feet of coarse sand and gravel and has historically been and continues to be a significant source of potable water for the former Fort Ord and City of Marina area. Significant pumping from this aquifer since the 1940’s, both locally and regionally, has resulted in seawater intrusion that extends within the northern portion of the OUCTP study area. Horizontal hydraulic conductivity values have been difficult to determine, given waste discharge limitations, but have been successfully simulated at 700 feet/day. This aquifer is the local equivalent of the regional 180-Foot Aquifer and passive groundwater elevation monitoring clearly illustrates seasonal and daily pumping cycles from irrigation wells located in the Salinas Valley, east of the OUCTP study area.

10.2 Groundwater Flow Directions

Groundwater generally moves northward through the A-Aquifer but west and east of a north/south trending groundwater divide approximately located beneath Imjin Road, just east of the CT source area. Pumping from the Salinas Valley has reversed the direction of flow within the Upper 180-Foot and Lower 180-Foot Aquifer. Beneath the site, groundwater in the Upper 180-Foot Aquifer flows to the southeast toward the apparent edge of the underlying Intermediate 180-Foot Aquitard where it then recharges the Lower 180-Foot Aquifer. Groundwater primarily migrates to the east in the Lower 180-Foot Aquifer but oscillates between a northeast direction in the summer (in response to increased pumping from the Salinas Valley) and a more southeast direction (locally in response to the MCWD Well Nos. 29, 30, and 31).

Vertical flow through the FO-SVA and Intermediate 180-Foot Aquitard is limited to locations at vertical conduits surrounding either MW-B-13-180, the Mini-Storage well, or, historically, MCWD Well No. 8 and possibly one or more Fort Ord supply wells (e.g., FO-26, FO-27, and FO-28). MW-B-13-180 and possibly the Mini-Storage well are active vertical conduits that permit groundwater to migrate from the

A-Aquifer into the Upper 180-Foot Aquifer. If a vertical conduit co-exists with the Mini-Storage well, it would allow groundwater to further migrate into the Lower 180-Foot Aquifer.

10.3 Carbon Tetrachloride Source Area

The apparent source of CT is located at what is now Lexington Court, part of the Abrams housing area west of Imjin Road and north of Abrams Avenue. No records of CT use at Fort Ord have been found, but personnel interviews indicate that CT was used by the Army for radio communication training (signal corps) prior to 1960. A small storage shed or 'oily' was identified in aerial photos dated 1949 and 1955. This shed was located just east of a small area of an apparently residual mass of CT detected in soil vapor to depths of 80 feet bgs (detected in 2002). CT was asserted to have been used and stored at this location to clean electronic equipment (e.g., radios). No records exist to indicate exactly when, how often, or how much CT may have been used, stored, or disposed of at or near this storage shed.

10.4 Soil Vapor and Groundwater Plumes

Soil vapor discovered beneath the cul-de-sac of Lexington Court in 2002 confirmed the source area of CT contamination in the groundwater of the underlying A-Aquifer. Concentrations were generally low and the vertical distribution suggests that the mass represented a residual mass. Groundwater immediately beneath the source area contains only very low concentrations of CT, suggesting that an insufficient mass of CT existed in the vadose zone to significantly contribute to the A-Aquifer recently. Higher CT concentrations in groundwater are observed approximately 2,000 feet north of the source area but have not been detected at concentrations exceeding 20 µg/L. The state maximum contaminant level for CT is 0.5 µg/L.

As the CT plume migrated north and then northeast, it intercepted two wells that allowed for downward migration into the underlying Upper 180-Foot and Lower 180-Foot Aquifers. This resulted in a convoluted migration pathway where the Upper 180-Foot Aquifer plume underlies the A-Aquifer but migrates in the opposite direction. Continued downward CT migration through the same vertical conduits caused two plumes to develop within the Lower 180-Foot Aquifer. No contamination has been observed in the 400-Foot Aquifer wells and no CT has been detected in the active drinking water wells serving the Fort Ord community.

10.5 Pilot Studies

Two pilot studies were conducted as part of the RI, the first designed to evaluate the applicability of enhanced biotreatability using lactose in the A-Aquifer, the second to evaluate the potential to remove residual CT in the vadose zone soils and soil vapor. Both pilot studies were successful.

The injection of lactose into the A-Aquifer resulted in an almost immediate dechlorination of CT in the injection well and nearby monitoring wells (within 15 feet) and dramatically lower DO values sustained for at least nine months. The decreased DO values strongly indicate that the environment proximal to the injection well has been successfully converted from aerobic to anaerobic conditions, which are more favorable for CT dechlorination.

The SVE pilot study was conducted in two phases and resulted in the removal of 0.78 pounds of CT from the vadose zone using five SVE wells and monitoring wells installed in the lower portion of the vadose zone (approximately 80 feet thick beneath the source area) and operated for a total of four months. After completion of the SVE pilot study, monitoring indicated CT and other VOCs present in soil gas in the vadose zone had been reduced to within the detection level range; therefore, no additional remedial activity is required or recommended for soil gas formerly associated with OUCTP.

10.6 Groundwater Simulation

A numerical simulation of groundwater flow (MODFLOW) was constructed to incorporate lithologic data, groundwater elevation data, and contaminant concentrations to represent the dynamic interaction of seasonal recharge, historical and current pumping, and natural conditions with the migration of CT through the A-Aquifer, Upper 180-Foot Aquifer, and the Lower 180-Foot Aquifer. Particle pathlines (MODPATH) were used to represent the axes of each plume and illustrate the rate of groundwater migration. This analysis generally indicated that groundwater requires approximately 50 years to travel from the CT source area to the further downgradient extent of the CT plume, consistent with the conceptual model. Particle pathlines were also used to evaluate the effectiveness of groundwater extraction remedial alternatives, discussed in Volume III. Finally, a mass transport model was constructed to account for dispersion of the CT plume and evaluate various remedial alternatives, also discussed in Volume III.

10.7 Data Gaps

The following data gaps have been identified that may require additional information to resolve:

- Volume and timing of CT disposal near what is now Lexington Court – mass transport simulations indicate that approximately 2,500 gallons of CT had been disposed of; however, the non-unique nature of numerical simulations prevent the calculation of a definitive estimate. Reasonable parameters have been relied upon in the derivation of this critical source term, but there is currently no known information regarding typical volumes of CT used of or disposed of at the source area.

- Location of vertical conduits to the Lower 180-Foot Aquifer – numerical simulations suggest that MCWD Well No. 8 was probably the vertical conduit that hydraulically linked the A-Aquifer to the Lower 180-Foot Aquifer; however, downward migration of CT to the Upper 180-Foot and Lower 180-Foot Aquifers would have ceased when this well was destroyed in 1996. This may explain the lower CT concentrations in the western Upper 180-Foot Aquifer CT plume relative to those in the eastern plume.

- Source of VC observed with Westbay monitoring wells – sequential sample collection during extended purging of select Westbay monitoring well ports should determine whether VC is off-gassing from well components (e.g., PVC) or if it is actually present within the formation. Recommendation: select a monitoring zone and collect a sample from the sample port; bail the inner casing as much as possible and open the associated Westbay purge port; collect a sample from within the inner casing via bailer or pump as the inner casing is progressively purged; the initial detection of VC followed by detections at lower concentrations or non-detection would indicate that VC is off-gassing from monitoring well components and is not present within the formation.

10.8 Conclusions

The following conclusions are made based upon data collected as part of the OUCTP field program presented above:

- Contribution to the CT plume in the A-Aquifer as mass leaching from the overlying vadose zone had ceased or become insignificant prior to SVE activities, as indicated by low CT concentrations beneath the source area. The SVE pilot study has effectively removed all CT mass from within the vadose zone and future contribution to the A-Aquifer is not likely or anticipated.

- Continued migration of CT in the A-Aquifer has resulted in a two-mile long plume at low concentrations. However, this plume represents a ‘slug’ effect that would eventually dissipate given sufficient time; however, at an unacceptably slow rate that would, in the meantime, result in continued migration westward beneath the City of Marina.

- Temporary operation of an infiltration gallery associated with the OU2 GWTS resulted in a transient displacement of CT east of the current groundwater divide. Further migration in this area/direction is not likely given that infiltration activities have ceased and a westward groundwater flow direction predominates.

- The injection of lactate downgradient of the source area resulted in the immediate removal of dissolved oxygen near the recirculation well and the associated decrease of CT concentrations in groundwater. An anaerobic environment has persisted for at least eight months following the injection of lactate as indicated by low DO concentrations near the recirculation well.

- Gravel material west of a wave-cut terrace in the underlying FO-SVA clay significantly increases the rate of CT migration in this area, relative to migration east of this feature within finer-grained dune sand. The presence and continued migration of CT in this area will require specific attention with respect to remediation.

- Interception of the A-Aquifer by at least two active vertical conduits, surrounding one existing monitoring well and one private irrigation well, have resulted in the downward migration of CT into the underlying Upper 180-Foot Aquifer and, in the case of the latter conduit, both the Upper and Lower 180-Foot Aquifers. The monitoring well, MW-B-13-180, is recommended for destruction. Further evaluation of a possible vertical conduit at or near the Mini-Storage well should be conducted, including: additional analysis of groundwater samples for tracer compounds (i.e., THMs) in surrounding monitoring wells; retrofitting the Mini-Storage well for groundwater elevation measurements, and an evaluation of maintenance procedures at this irrigation well. Should a vertical conduit be shown to co-exist with this well, it could either be destroyed, converted into a treatment extraction well, or monitored while A-Aquifer remedial activities proceed. These alternatives are further considered in Volume III.

- A reversal in groundwater flow directions results in CT migration to the southeast in the Upper 180-Foot Aquifer and to the east in the Lower 180-Foot Aquifer. Migration of CT in the Upper 180-Foot Aquifer will likely be limited by planned extraction related to the OU2 GWTS. Subsequent migration of CT in the Lower 180-Foot Aquifer should be limited upon removal of the CT sources to this aquifer.

- Aquifer tests indicate hydraulic parameters typical of clean, well-sorted dune sand in the A-Aquifer and coarse gravel material in the Lower 180-Foot Aquifer. Storage values are consistent with unconfined and confined conditions, respectively.

- Simulation of transient groundwater flow and mass transport within the OUCTP aquifers has provided useful insight into transient mechanisms controlling groundwater conditions within the study area. In particular, the 1997/98 El Niño event resulted in a significant increase in storage within the A-Aquifer and that recovery is only now occurring in many areas within the study area.

- Predictive analysis of groundwater flow and mass transport simulations are further discussed in Volume III regarding potential remedial alternatives.

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Copies 11 - 13:	MACTEC

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