Final

Feasibility Study

Frontier Fertilizer Superfund Site

Prepared for:

EPA
U.S. Environmental Protection Agency
Region IX
75 Hawthorne Street
San Francisco, CA 94105

Submitted by:

CH2MHILL
2485 Natomas Park Drive, Suite 600
Sacramento, CA 95833

Contract No. 68-W-98- 225/WA No. 220-RICO-094R

June 2006

ES062006004SAC

Contents

Section Page

Appendixes

Tables

Figures

Acronyms and Abbreviations

µg/kg	micrograms per kilogram
µg/L	micrograms per liter
AFCEE	Air Force Center for Environmental Excellence
ARAR	applicable or relevant and appropriate requirements
BACT	best available control technology
bgs	below ground surface
Cal/EPA	California Environmental Protection Agency
CCl_4	carbon tetrachloride
CCR	California Code of Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COC	chemical of concern
CPT	cone penetrometer
CVRWQCB	Central Valley Regional Water Quality Control Board
DBCP	1,2-dibromo-3-chloropropane
DCP	1,2-dichloropropane
DNAPL	dense nonaqueous phase liquid
DTSC	Department of Toxic Substances Control
DUS	dynamic underground stripping
EDB	1,2-dibromoethane
EPA	U.S. Environmental Protection Agency
FFSOG	Frontier Fertilizer Superfund Oversight Group
FS	feasibility study
ft/d	foot per day
GAC	granular activated carbon
gpm	gallon(s) per minute
GRA	general response action

GTI	Groundwater Technology, Inc.
HAP	hazardous air pollutant
HPO	hydrous pyrolysis oxidation
lb	pound
LNAPL	light nonaqueous phase liquids
M&E	Metcalf and Eddy
MCL	maximum contaminant limit
MCLG	maximum contaminant level goal
mg/L	milligrams per liter
NAPL	non-aqueous phase liquid
NCCCOB	Northern California Central Cleanup Operations Branch
NCP	National Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
PCBs	polychlorinated biphenyls
ppb	parts per billion
ppm	parts per million
PRG	preliminary remediation goal
RAO	remedial action objective
RD	remedial design
RCRA	Resource Conservation and Recovery Act of 1976
RFH	radio frequency heating
RI/FS	remedial investigation / feasibility study
ROD	record of decision
RWQCB	Regional Water Quality Control Board
SDWA	Safe Drinking Water Act
STLC	Soluble Threshold Limit Concentration
SVE	soil vapor extraction
SWRCB	State Water Resources Control Board
TBC	to be considered

TCLP	toxicity characteristic leaching procedure
TCP	1,2,3-trichloropropane
TDS	total dissolved solid
TTLC	Total Threshold Limit Concentration
VC	vinyl chloride
WDR	Waste Discharge Requirement
WQO	water quality objective
ZVI	zero valent iron

Executive Summary

This feasibility study evaluates potential remedial alternatives for soil and groundwater at the Frontier Fertilizer National Priorities List Site (Site) in Davis, California.

The specific remedial action objectives for soil and groundwater include the following:

- Reduce levels of chemicals in onsite soils to prevent future exposures (workers and/or residents) to chemicals in soils above health-protective levels (e.g., U.S. Environmental Protection Agency [EPA] Region 9 Soil preliminary remediation goals [PRGs]).
- Reduce levels of chemicals in groundwater (and chemical sources to groundwater) so that the groundwater could ultimately be used for domestic purposes.
- Prevent future onsite exposures (workers and/or residents) to chemical vapors in indoor air above health-protective levels (e.g., EPA Region 9 Air PRGs).
- Reduce risks to ecological receptors to a level consistent with habitat quality, and proposed future use of the Site.

Based on the initial screening of six alternatives, two alternatives were eliminated (Alternative 3, surface cap plus groundwater extraction and treatment, and Alternative 4, excavation of the source area plus groundwater extraction and treatment) leaving four remedial alternatives for detailed analysis in the feasibility study. Each of the alternatives, with the exception of Alternative 1, includes the following common components (Common Components):

- **Institutional control (restrictive covenant):** Descriptions of contaminated media and respective restrictions are incorporated into affected property deeds with the intent of minimizing risk by limiting exposure until remedial action objectives are reached. Restrictions may include prohibiting residential use and groundwater extraction. Excavation, grading, and trenching may also be limited in the soil source area. Specific building requirements in the source area, such as ventilation system elements, may also be included in the restrictive covenant.
- **Access restrictions:** Access to Media A is restricted with fencing and signage to prevent access by unauthorized personnel until remedial action objectives are reached.
- **Groundwater monitoring:** Groundwater monitoring continues until remedial action objectives are achieved.
- **Temporary cap:** Wood chips or gravel will cover the Site to prevent ecological receptors from contacting contaminated surface soil until the proposed development takes place.

The results of individual and comparative evaluations conducted to analyze the performance of each alternative are as follows:

- **Alternative 1:** No action, is not protective of human health and the environment and is not expected to comply with state and federal regulations. Alternative 1 is used for comparative purposes only.
- **Alternative 2:** Includes groundwater extraction and treatment with granular activated carbon combined with the Common Components discussed above. Groundwater pump and treat is continued until groundwater monitoring indicates that remedial action objectives are achieved. Monitoring to evaluate progress toward achieving remedial action objectives determines if additional extraction or monitoring wells, or modifications to the treatment system, are necessary.
- **Alternative 5:** Remedial action objectives are met by a combination of in situ anaerobic biological degradation for the soil source area, in addition to Alternative 2 and the Common Components.
- **Alternative 6:** Remedial action objectives are met by a combination of in situ heating or thermal destruction using electrical power to heat the soil source area. Alternative 2, the Common Components, and Alternative 5 are also included.

SECTION 1

Introduction

This report presents results of the Frontier Fertilizer Site Feasibility Study (FS). The FS was conducted in accordance with the methodology defined in the *Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988). The remedial investigation and feasibility study (RI/FS) process defined in the guidance includes methodology for characterizing the nature and extent of risks associated with chemicals released at uncontrolled hazardous waste sites (the RI) and for evaluating potential remedial alternatives (the FS). Potential remedial alternatives typically consist of administrative controls and engineered processes that, when implemented, eliminate or reduce risks associated with Site-related chemicals of concern (COCs).

The Frontier Fertilizer Site FS was completed by the U.S. Environmental Protection Agency (EPA) Superfund Division. Lead stakeholders who participated in FS development include the California Environmental Protection Agency (Cal/EPA), Department of Toxic Substances Control (DTSC) (Northern California Central Cleanup Operations Branch [NCCCOB], Regional Water Quality Control Board [RWQCB], Central Valley Region) and the Frontier Fertilizer Superfund Oversight Group (FFSOG). EPA and lead stakeholders solicit input from community members, government agencies, and other interested and potentially affected parties during the study. CH2M HILL supported the EPA in performing and coordinating study activities under EPA Contract No. 68-W-98-225, Work Assignment No. 120-RICO-094R.

1.1 Purpose and Organization of Report

The purpose of this report is to assess potential remedial actions that are appropriate responses to the contamination in groundwater and soil at the Frontier Fertilizer Site (Site). The draft applicable or relevant and appropriate requirements (ARARs) and media-specific technology type/process option screening results were distributed to lead stakeholders in the early stages of the FS, prior to the alternative development phase. Their feedback has been incorporated in the draft FS.

The alternatives developed ensure protection of human health and the environment and an alternative may have any one or combination of measures: (1) the complete elimination of COCs, (2) the reduction of COC concentrations to acceptable human health or environment levels, or (3) the prevention of exposure to COCs. The COCs are contaminants released to the environment during Site activities that were identified in the Final Baseline Risk Assessment Report (Bechtel, 1999b). Alternatives passing the screening phase are then evaluated against the nine criteria developed by statutory requirements of CERCLA Section 121 and the National Contingency Plan.

Once the FS report is finalized, EPA will issue a Proposed Plan that recommends preferred cleanup alternatives for soil and groundwater. As part of a formal 30-day review of the Proposed Plan, EPA will schedule a public meeting to discuss the proposed cleanup alternatives and receive verbal comments. Community members may also provide formal written comments on the Proposed Plan within the 30-day comment period. After the public comment period, the selection of the preferred alternative is documented in the Record of Decision (ROD) that is published with a Responsiveness Summary answering questions and concerns raised during public comment. As the evaluations performed for an FS are generally at a conceptual level, the ROD is followed by a remedial design (RD) phase to provide the detailed engineering plans required to implement the selected alternative during remedial action.

Cleanup alternative development is based on known Site-specific conditions, established ARARs, and the best available data regarding applicability of technology process options. The potential exists that ARARs may change and new Site or option data may become available during testing, design, or remedy implementation. These changes could result in a reevaluation of the selected alternatives.

The FS report is organized as follows:

- **Section 1—Introduction.** Summarizes the FS process and includes a summary of the Site's operational history, investigation results and removal actions, description of COCs, the nature and extent of contaminated media, fate and transport processes that affect COCs in the media, and risks to human health and the environment.
- **Section 2—Identification and Screening of Technologies.** Presents remedial action objectives, including media affected by COCs, exposure routes, remediation goals based on ARARs, and risks to human health and the environment; general response actions for each medium, including estimates of impacted media; and the results of media-specific technology type and process option screening.
- **Section 3—Development and Screening of Alternatives.** Presents alternatives developed to address all affected media and results of the screening phase.
- **Section 4—Detailed Analysis of Alternatives.** Presents results of the detailed analysis of alternatives passing the screening phase.
- **Section 5—Works Cited.** Lists reference material cited in this document.

1.2 Background Information

1.2.1 Site Description

The Site (CERCLIS US EPA ID# CAD071530380) includes a triangular shaped 8 acre parcel that is recorded as Pine Tree Properties. The parcel contains contaminated soil and a groundwater plume that extends north from the parcel. The plume extends north beneath adjacent property and continues beneath an area of residential housing.

The Pine Tree Properties parcel is located in an area zoned for light industrial/business park at the eastern edge of Davis ("Mace Ranch Plan Development, #4-88"). The geographic coordinates of the Site are 38° 33′ 9.5″ N latitude and 121° 42′ 7.0″ W longitude (Township 8 North, Range 2 East, Section 12, Mt. Diablo Baseline and Meridian, Davis, California, 7.5-minute quadrangle). The 8-acre parcel is located at 4301 Second Street in Davis, Yolo County, California (Figure 1-1).

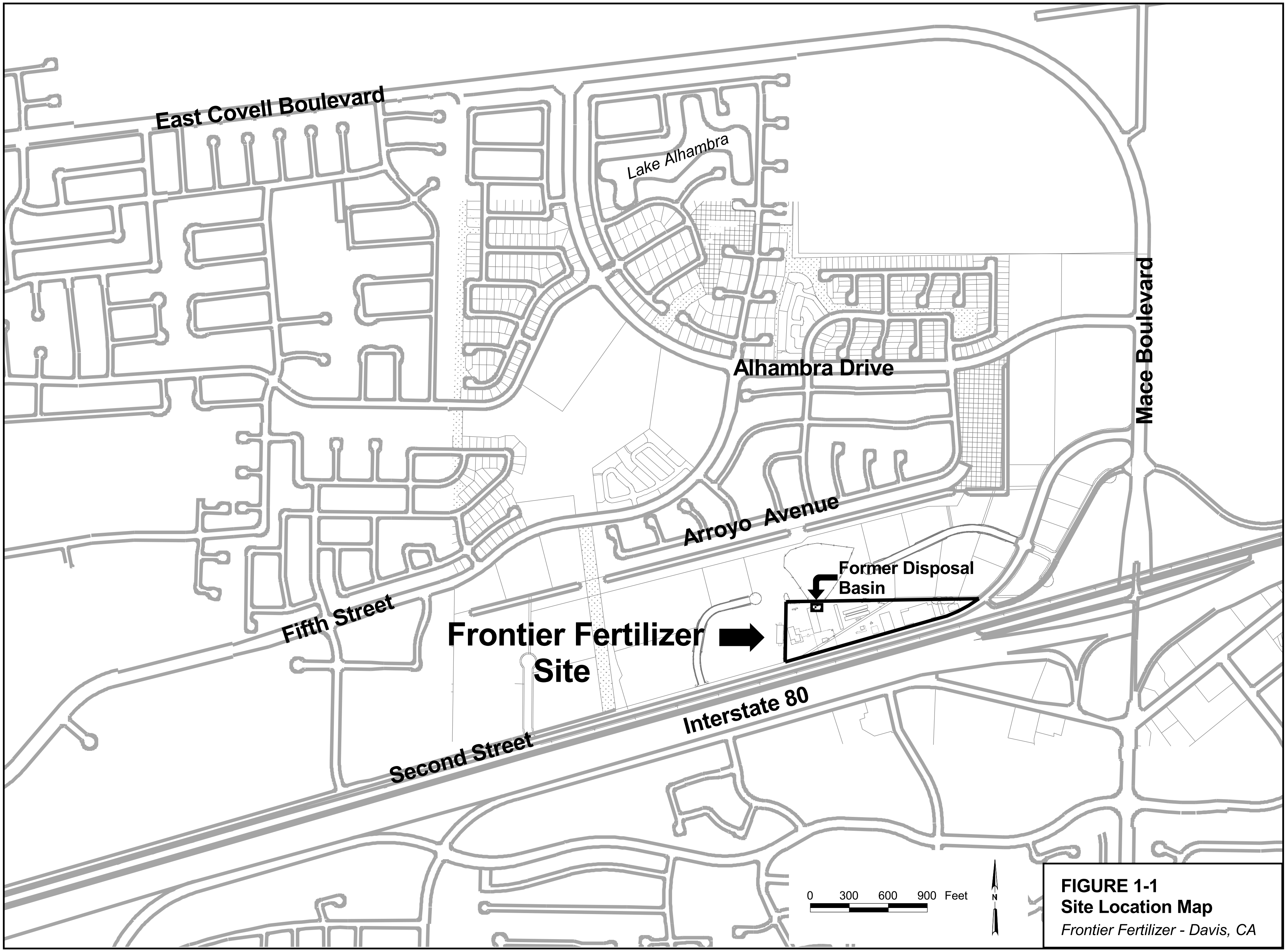


FIGURE 1-1
Site Location Map
Frontier Fertilizer - Davis, CA

CH2M Hill SAC ArcView Project File \\Yosemite\SACGIS\frontier\ArcView\Frontier.apr 11:12 a.m. 01-27-2004

CH2MHILL

The parcel is bounded on the south and east by 2nd Street (formerly County Road 32A), on the north by the new Mace Ranch Light Industrial/Business Park, and on the west by two metal buildings and the new Mace Ranch Light Industrial/Business Park. Construction of the Mace Ranch Light Industrial/Business Park development has begun and will affect the land north, east, and west of the Site. The nearest residence is approximately 600 feet north of the property boundary.

1.2.2 Site History

The Site was first developed in the 1950s as an area to store agricultural equipment. The Barber and Rowland Company operated a pesticide and fertilizer distribution facility on the parcel from 1972 to 1982 and the Frontier Fertilizer Company continued operations from 1982 to 1987. Both companies handled chemicals on the western 4 acres of the parcel. Chemical-related operations consisted of receiving, storing, mixing, and loading pesticides and fertilizers into mobile tanks for farm application. Tanks and containers that previously contained chemicals were rinsed prior to re-use. It appears from the quantity of pesticides found that waste chemicals, mainly pesticides and fertilizer tank or rinsate, were discharged into one or more disposal basins. Other discharges may have occurred near the “pole barn” in the northwest potion of the property boundary. Pesticide handling was discontinued during the 1980s when Yolo County discovered toxic levels of pesticides in the unlined disposal basin. In 1985, Frontier Fertilizer Company excavated approximately 1,100 cubic yards of contaminated soil from below the unlined disposal basin and disposed of the soil on a field east of the Site.

The COCs detected in soil samples consist primarily of pesticides, while the COCs detected in the groundwater are pesticides and carbon tetrachloride (CCl_4). The COCs presenting predominant risks in the groundwater and soil are the fumigants 1,2-dibromoethane (EDB), 1,2-dibromo-3-chloropropane (DBCP), 1,2-dichloropropane (DCP), and 1,2,3-trichloropropane (TCP). CCl_4 also was used as a grain fumigant and the source appears to be separate from the pesticides.

Non-Time-Critical Removal Actions were implemented to mitigate risks and hazards identified during investigation activities. Access to the Site, contaminated media, and associated groundwater extraction and monitoring system components is restricted by fencing and signs. The contaminated groundwater is not currently used as a drinking water source. The drinking water supply for the City of Davis comes from a deeper aquifer.

The first groundwater extraction and treatment system was installed in 1993 by DTSC. In 1995 EPA significantly upgraded the system as a Non-Time-Critical Removal Action. In 2000, the warehouses, shops, “pole barn,” a labor camp complex, a tomato grading station, above-ground storage tanks, and underground storage tanks were removed from the Site leaving only the warehouse that contains the groundwater treatment system. At- or below-grade components of the removed facilities remain in place.

1.2.3 Site Physical Characteristics

Topography and Surface Water

The Site is situated in the Central Valley, which has minor topographic relief. Surface elevations vary on the order of 5 feet over a distance of several thousand feet. The general surface grade across the Site declines in the east-southeast direction until 2nd Street, which acts as a surface flow barrier. The Mace Ranch Park unlined drainage channel is approximately 500 feet north of the parcel and serves as the primary stormwater conveyance and containment for the predominantly developed areas north and west of the parcel. The field north of the parcel and south of the ditch apparently absorbs most rainwater but the balance flows onto the parcel during heavy rain events. Due to general parcel topography and available surface soil permeability, stormwater tends to stay onsite and infiltrate into the soil. Ponded stormwater typically disperses in a day or two after heavy rain events. The average annual rainfall in the Site area is 17 inches, and 17 percent is assumed to recharge the aquifer (CH2M HILL, 2003). Some rainfall evaporates and some is utilized by Site biota.

The Mace Ranch Park drainage channel presents one of the lowest open surface elevations with potential to intercept the shallow water table. The measured elevation is between 2 to 6 feet above the highest recorded water table elevations, measured in the wells in the first quarter 2004, groundwater sampling. Samples of water were collected from the channel north of the extraction well field in March 2004 to evaluate whether flow between contaminated groundwater and the channel resulted in detectable concentrations of COCs. This sampling effort detected no COCs. These data indicated that remediation of surface water and sediments is not an issue at the Site, and therefore is not evaluated further.

Geology

The Site is underlain by Quaternary alluvium to depths exceeding 300 feet below ground surface (bgs). Below this depth, semi-consolidated units of clay and occasional sand/gravel extend to below 2,000 feet bgs. The alluvium deposits represent heterogeneous mixtures of gravel, sand, silt, and clay generated by the changing flowpath of Putah Creek over the past geologic epoch. Fine-grained materials from ancient floodplains predominate in the upper 100 feet, interrupted by discontinuous sand stringers that can be up to 10 feet thick. Between 100 and 300 feet bgs, the subsurface is somewhat more stratified, with permeable sand units displaying greater continuity. Municipal and agricultural wells have historically utilized this depth interval, though recently the City has constructed wells in the deeper semi-consolidated units.

Soil samples have been collected from these deposits and analyzed for the presence of COCs and physical properties (Bechtel, 1997a; CH2M HILL, 2003). Well and soil boring logs, electric logs, cone penetration test logs, and recent soil boring core analyses, including bulk density, porosity, and specific gravity, were used to classify the subsurface to 155 feet bgs in the source area. Only the upper Quaternary alluvial deposits from ground surface to approximately 155 feet bgs have been analyzed for COCs because soil and groundwater contamination appears to be contained within these deposits.

Hydrogeology

Four general water-bearing zones have been designated in the monitored area, from shallowest to deepest, as S-1, S-2, A-1, and A-2 zones. Site monitoring wells are screened in the S-1, S-2, and A-1 zones and water level measurements are typically measured on a quarterly basis. Active extraction wells extract groundwater from the S-1 and S-2 zones. Water-bearing zones are loosely defined at the Site, especially for the S-1 and S-2 zones. Data do not indicate that continuous aquifers or aquitards exist in the top 100 feet, only zones in which sandy materials tend to be encountered. Well yield and aquifer pumping tests have been performed to estimate groundwater zone properties. Significant variations in aquifer vertical and horizontal conductivities are typical across the S-1 and S-2 zones.

Typically, groundwater potentiometric head, that is, groundwater levels, in the S-1, S-2, and A-1 zones are at an annual low at approximately 30 feet bgs in late summer, several months after the end of the rainy season and following approximately 3 months of irrigation pumping. Groundwater levels are at an annual high at approximately 10 feet bgs in late winter, toward the end of the rainy season and following recovery from agricultural pumping. Seasonal fluctuations are largest in the A-1 zone (20 to 30 feet) since it is used as a source of irrigation water for nearby agricultural fields. Historical data indicate that S-1 and S-2 zone groundwater levels typically fluctuate 20 feet annually. Operation of the extraction well field north of the former disposal basin location affects the water table elevation. In the area of the extraction well field, groundwater levels vary with extraction rates, available water in the zone, and hydraulic conductivity between extraction wells and monitored wells.

The extraction system influences gradients in the shallow S-1 and S-2 zones that are impacted by COCs. Outside the area influenced by the extraction system groundwater levels fluctuate seasonally with precipitation, recharge, and water supply pumping. Within the area of influence of the extraction well field, upward vertical gradients are measured between the A-1 and S-2 zones. This effect does not happen throughout the entire area. In general, hydraulic gradients are larger in the downward direction than in the horizontal, outside the area influenced by the extraction well field. This is apparently due to A-1/A-2 zone pumping during the irrigation season. All currently operating extraction wells are screened in the S-1 and S-2 zones. Pump and treat system improvements implemented in 2004 have greatly improved the production from the S1 and S2 zones. The following paragraphs describe the potentially affected groundwater zones.

S-1 Zone. The first groundwater encountered is depicted as the S-1 zone, which extends to a depth of 60 feet bgs. The water table fluctuates from approximately 10 to 30 feet bgs. The S-1 zone consists of alluvium stream channel and floodplain sediments deposited to produce interbedded discontinuous clay, silt, and sand lenses.

Hydraulic conductivity was estimated from hydraulic testing in 11 wells screened in the S-1 zone and subsequent numerical model calibration. Hydraulic testing and well log analysis indicate that a higher permeability area of the S-1 zone extends in a northwest-southeast direction across the Site, including well MW-12A and extending to the eastern portion of the parcel. The hydraulic conductivity in this area is 45 feet per day (ft/d) consistent with sand, whereas near the source area, the S-1 zone ranges between 0.8 and 4.8 ft/d consistent with silt and clay. The general horizontal component of the measured hydraulic gradient across the Site indicates a flow direction to the north/northeast. The extraction well field depresses the water table in the shallow zones.

Total dissolved solids (TDS) in the S-1 aquifer, as calculated from the conductivity in various background wells, is approximately 1,000 parts per million (ppm).

Hydraulic Gradients between S1 and S2. In areas beyond the extraction field zone of influence, the annual vertical gradients calculated from S-1 to S-2 zones range from a maximum of 0.018 to -0.0053 to a minimum of -0.04 to -0.17. The S-1/S-2 gradients in the extraction well field area ranged from a maximum of 0.018 to 0.020 to a minimum of -1.1 to -1.2. Positive gradients represent a tendency for upward flow and negative gradients indicate downward flow.

S-2 Zone. The S-2 zone has been designated at a depth of 60 to 90 feet bgs. It is a series of discontinuous sand lenses of variable thickness and permeability. Low yields from most existing extraction wells suggest the S-2 zone permeability is lower than that of the S-1. An exception to the low yield trend exists at wells X-6B, X-9B, and X-10B. Recent and historical aquifer testing indicate an approximate hydraulic conductivity ranging from 0.2 to 3.7 ft/d. The measured horizontal hydraulic gradient across the Site indicates a flow direction to the north/northeast, similar to the S-1. Measured potentiometric head is depressed around the extraction well field.

TDS in the S-2 aquifer, as calculated from the conductivity in various background wells, is approximately 810 ppm.

Hydraulic Gradients between S-2 and A-1. Annually, the vertical gradients calculated from S-2 to A-1 zone range from a maximum of -0.0009 to -0.20 to a minimum of -0.072 to -0.45 in areas beyond the extraction field zone of influence. The S-2/A-1 gradients in the extraction well field area ranged from a maximum of 0.05 to 0.20 to a minimum of -0.16 to -0.75. Positive gradients represent an upward gradient and negative a downward.

A-1 Zone. The A-1 zone occurs at a depth interval of 90 to 140 feet bgs. It appears to be dipping slightly to the south. The A-1 zone appears to be laterally continuous throughout the area and, reportedly, throughout most of the region. Many local agricultural wells reportedly draw from the A-1 and the deeper A-2 zone. This aquifer has a much higher hydraulic conductivity (estimated as high as 100 ft/d) than either of the shallower zones. Of the three monitored zones, the A-1 potentiometric head changes the most throughout the year; it fluctuates by approximately 30 feet between late winter and late summer. This change is attributed to pumping for agricultural irrigation during the growing season. Although the potentiometric head changes significantly between seasons, the gradient measured across the zone is very small compared to the S-1 and S-2 zones.

TDS in the A-1 aquifer, as calculated from the conductivity in various background wells, is approximately 1,200 ppm.

A-1/A-2 Aquitard. A 25- to 30-foot-thick clay layer, designated as the A-1/A-2 aquitard, underlies the A-1 aquifer and appears to separate it from the A-2 aquifer. This aquitard has been explored at the Site by four soil borings and a few deep borings associated with early monitoring well installations. It may be effectively much thicker than 30 feet in some areas, as most A-2 production well screens occur below 200 feet bgs.

A-2 Aquifer. The A-2 aquifer is a sequence of discontinuous gravel layers extending from 180 to 350 feet bgs. The A-2 aquifer is the primary water supply aquifer in the Davis area including agricultural and municipal supply.

Summary of Previous Investigations and Remedial Actions

The first remedial measures began at Frontier Fertilizer in 1983. Until 1994, investigative and remedial activities were performed by property owners, Yolo County Department of Public Health, or under the remedial orders implemented by the State of California. In 1994, Frontier Fertilizer was added to the NPL and EPA took over management of the Frontier Fertilizer investigation. A summary of investigative activities and remedial measures are presented in Table 1-1.

TABLE 1-1
Previous Investigation and Remedial Activities at Frontier Fertilizer
Frontier Fertilizer Feasibility Study, Davis, California

Sponsor, Contractor, Year	Scope of Activity	Key Findings
Yolo County Department of Public Health, 1983 and 1984	Soil samples of disposal basin area were collected after employee's dog died of pesticide poisoning.	Soil was discovered to be contaminated with EDB, DCP, and DBCP.
Frontier Fertilizer Co., Laugenour and Meikle, 1985	Excavation and disposal of 1,100 cubic yards of soil from the disposal basin area.	The excavation did not remove all of the contaminated soil from the disposal basin, but did help to mitigate the immediate threat of exposure to soil contamination.
Frontier Fertilizer Co., Luhdorff and Scalmanini, Consulting Engineers (LSCE), 1987	Completion of soil and groundwater investigation with the installation of 24 monitoring wells. Completion of a preliminary assessment report.	Groundwater samples collected from well MW-7B, to the north of the Site contained up to 24,000 parts per billion (ppb) of EDB. Extent of soil and groundwater contamination (particularly to the north) was investigated but not defined.
RAMCO Enterprises Inc., Groundwater Technology, Inc. (GTI), 1990	Soil sampling and analysis, installation and sampling of 12 additional monitoring wells. Completion of an RI/FS.	Recommended excavation and treatment for soil contamination and pumping wells for control and treatment of groundwater contamination.
Cal/EPA, Metcalf and Eddy (M&E), 1992	Conducted a focused RI in support of an interim remedial measure. Further delineation of groundwater contamination and testing for aquifer hydraulic properties.	CCl_4 detected to the east of the EDB/DBCP/DCP plume.
Cal/EPA DTSC, URS, 1993	Installed initial groundwater pump and treat system.	Extracted about 0.25 gpm from MW-7B and MW-7C.
EPA, Ecology and Environment, 1994	Investigated levels of pesticide contamination remaining in the soil and attempted to locate source of CCl_4 contamination.	Removal actions considered included vapor extraction and soil excavation. EPA determined that soils with concentrations of EDB, DBCP, and DCP above 1,000 ppb would be considered for removal action.
EPA, CET Environmental Services, 1996	Installed groundwater pump and treat system that replaced initial system.	Granular activated carbon treatment capacity of 80 gpm. 17 wells, initially online July 1995, produced approx. 28 gpm; production increased to ~50 gpm in April 1996.
EPA, Bechtel, 1995 and 1996, 1997, 1999	Interim RI documenting the nature and extent of COCs at the Frontier Fertilizer. Soil, soil gas and groundwater samples taken in 1998-99 to support the Supplemental RI conducted.	Interim RI document produced in 1997 and Supplemental RI produced in 1999.

TABLE 1-1
Previous Investigation and Remedial Activities at Frontier Fertilizer
Frontier Fertilizer Feasibility Study, Davis, California

Sponsor, Contractor, Year	Scope of Activity	Key Findings
EPA, URS, 1999 to 2001	Upgraded and repaired groundwater extraction system, added three extraction well clusters, three monitoring wells to the northwest, and conducted extensive CPT investigation. Above ground structures were also removed during the period.	Findings are summarized in the Supplemental RI #2 report.
EPA, CH2M HILL, 2002 to 2005	Frontier Fertilizer Conceptual Model Update and Capture Zone Analysis. Drilled and sampled four deep soil borings around source area, conducted supplemental CPT investigation to help identify CCl_4 source area and Site potential extraction wells, expanded the extraction system, and refined treatment system performance.	Used recent CPT and boring log data to update subsurface profile and updated Site numerical model. Expanded extraction system increased groundwater control and facilitated increased system capacity of 80 gpm. Findings are summarized in the Supplemental RI #2 report.

Remedial Activities

On July 30, 1983, Yolo County Department of Public Health personnel observed liquid waste (that is, “dark oily liquids”) in the former disposal basin. When they returned 2 days later to collect samples of the liquid they discovered that the basin had apparently been pumped out and its disposition is unknown. In April 1985, the Frontier Fertilizer Company removed approximately 1,100 cubic yards of soil from below and adjacent to the former disposal basin and spread it on a field east of the Site for treatment and disposal.

After monitoring wells showed high levels of pesticides in the groundwater, Cal/EPA DTSC installed a system in 1993 to extract groundwater from monitoring wells MW-7B and MW-7C. The extracted groundwater was treated with granular activated carbon (GAC) to remove the organic chemicals. This system was designed to extract groundwater at a flow rate of 0.25 gallons per minute (gpm) from each well. The system operated until May 1995, when it was dismantled to make way for a larger capacity groundwater pump and treat system. In July 1995, the EPA installed the larger system that is still in operation. The system included 17 extraction wells connected to a GAC treatment plant with capacity to process 80 gpm. EPA applied for Industrial Discharge Permit 15-93-A with the City of Davis, which established a 30 gpm discharge capacity. Nine injection wells were installed and used to return about 30 percent of the treated groundwater to the S-1 and S-2 zones. The injection wells were taken out of service in March 1998 and all treated groundwater was then discharged to the City of Davis sanitary sewer. Subsequent activities included expansion of the groundwater extraction system and installation of wells X-5A, X-5B, and X-5C in September and October 2000, and wells X-6A, X-6B, X-7B, and X-7C in November 2001. Wells X-8B, X-9B, X-10B, OW-20B, and OW-20C were installed in August and September 2003 to further enhance the extraction system.

All of the treated groundwater is currently discharged to the City of Davis sanitary sewer (Industrial User Permit 15-04).

1.2.4 Nature and Extent of Contamination

Investigation and monitoring results conclusively identify that soil and groundwater contain COCs. Impacted media are depicted in Figure 1-2. Investigations confirmed that contaminants related to the Site activities fall into two categories: pesticides and fertilizers. The pesticides EDB, DCP, and DBCP were detected at concentrations above EPA Region 9 screening-level preliminary remediation goals (PRGs) in soil and maximum contaminant levels (MCLs) in groundwater. CCl_4 was also detected in groundwater above the MCL during the investigations and may have been used onsite as a grain fumigant or parts cleaner. Other apparent pesticide-related chemicals such as TCP; 1,2-dichloroethane; 1,3-dichloropropene; and benzene were also detected during investigation or monitoring activities. Nitrate, nitrite, and sulfate are included in the fertilizer category. Other pesticides in the carbamate, organophosphate, and organochlorine families were detected during investigations. Diesel, gasoline, and oil range petroleum hydrocarbons were also detected in soil samples collected from below two aboveground storage tanks (CH2M HILL, 2003). Based on the Final Baseline Risk Assessment Report (Bechtel, 1999b), the primary Site COCs, based on human toxicity and frequency of detection, are EDB, DBCP, CCl_4, and TCP.

Nitrate is not considered a primary COC; however, it will be included in the remedial alternatives discussion because it is found in many Site monitoring wells and possible cleanup options are different than for the Site volatile COCs. Monitoring results indicate that the disposal basin is a possible source for nitrates. Nitrates are not treated by the onsite treatment plant; however, they are treated by the City of Davis Wastewater Treatment Plant. Nitrate is found throughout California’s farming communities; however, given the concentrations found in Site monitoring wells, it is suspected that past disposal practices at the Site have contributed to the groundwater nitrate concentrations. Nitrate, in addition to many other analytes, was monitored for during four consecutive quarterly groundwater events ending the second quarter 2005. Nitrate and nitrite were not included in the Final Baseline Risk Assessment Report since data were not available.

Soil sample analytical results indicate that the major source of contamination, defined by elevated COC concentrations in soil, is below and adjacent to the former disposal basin. The highest COC concentrations were detected in soil samples collected between 20 and 30 feet bgs, which is the lower groundwater table (that is, the elevation where saturated soil is encountered in the fall months). Elevated COC concentrations were also detected in soil samples collected below the water table with the highest deep soil detections at a depth of 60 to 80 feet bgs and north of the basin. Elevated fertilizer concentrations in wells closest to the former disposal basin indicate that waste containing fertilizer may have also been discharged to the basin.

Some compounds identified in the surface soil sampling present a potential risk primarily to ecological receptors. Each of the alternatives evaluated later in Sections 3 and 4 of this FS include a temporary cap of wood chips or gravel for the area unaffected by the remedy. The temporary cap will provide a barrier for ecological receptors until the proposed development occurs. The Site is designated as Light Industrial/Business Park in the “Mace Ranch Plan Development, #4-88.”

Given the volatile characteristics and elevated concentration of VOCs at the Site, VOCs are possibly released to the air above the source area located in the northern portion of the 8-acre Site. VOCs could potentially collect indoors if a building were constructed in this

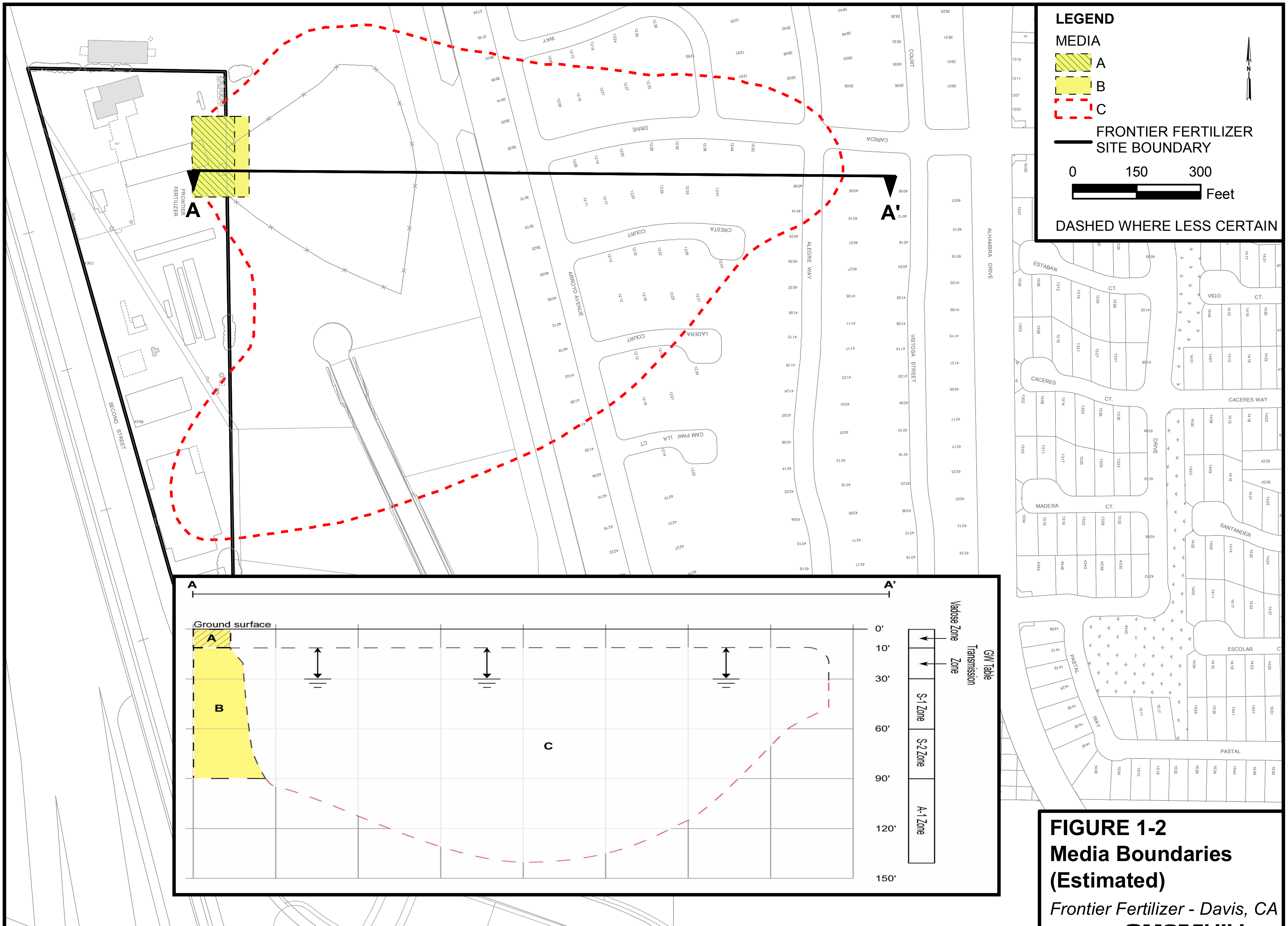


FIGURE 1-2
Media Boundaries (Estimated)
Frontier Fertilizer - Davis, CA

CH2MHILL

SAC \\GLACIER\SACGIS\FRONTIER\MXD\MEDIA.MXD 04/20/2006 12:37:10

location and there were no vapor barriers or other engineering controls in place. Currently there are no occupied buildings present at this location. Monitoring of air at or near the ground surface at the source area and north was performed (Bechtel, 1997) to evaluate VOC concentrations present in air at or near ground surface. The VOC source area appears to be the primary source of VOCs detected near ground surface. These results are summarized in Section 1.2.9.

Investigations have also been completed to determine the presence of non-aqueous phase liquid (NAPL). Although test results did not indicate its presence, it is possible that elevated volatile COC concentrations in the S-2 zone are a result of NAPL that had migrated to the deeper groundwater zone. The presence of ganglia or discontinuous drops of NAPL may be present in part of the source volume soil pore space and is indicated by large variations in soil sample analysis results in samples collected in similar locations. The majority of the soil sample analytical results do not indicate the presence of NAPL, but they do indicate significant variations in COC concentrations across the source volume. These variations contribute to the difficulties of estimating the mass of COCs requiring remediation.

All above-grade structures have been removed from the parcel with the exception of the warehouse previously used to store pesticides. The warehouse is currently housing the groundwater treatment system. Below-grade structures (for example, foundations, pits, etc.) associated with above-grade structures were left in place. No surface water, sediments, or biota have been identified as impacted by COCs. In March 2004, samples from the drainage ditch were analyzed for Site COCs. No COCs were detected.

1.2.5 Estimates of Source Soil Quantity

Soil samples collected during investigation activities (Bechtel, 1997; CH2M HILL, 2003) were used to estimate the source volume and respective mass of volatile COCs. The mass of the COCs and the respective affected soil volume were estimated for the 0-to-30-foot-bgs “shallow” interval and the greater-than-30-foot-bgs “deep” interval separately. All soil samples with detectable concentrations of COCs were collected in the vicinity of the former disposal basin. Estimates of the total mass have been developed for soil contaminated with DBCP, DCP, EDB, and TCP. Rectangular areas were chosen to establish horizontal boundaries of the source volume while the 0-to-30-foot depth interval was dissected into six 5-foot intervals for COC concentration averaging. The east, west, north, and south source area boundaries were established at locations equal distance between sample locations with detected COC and the closest sample away from the basin without detected COCs. Boundaries were established for each 5-foot-thick cell (that is, 0 to 5, 6 to 10, 11 to 15, 16 to 20, 21 to 25, and 26 to 30 feet bgs) and for each of the predominant COCs. After volume boundaries were established, concentrations for all samples within the volume were arithmetically averaged. Since the borings were relatively equally spaced, the detected results were not weighted with respect to their spatial location. The average soil concentration was then multiplied by the soil volume mass to estimate the mass of these four COCs present in the volume.

Results of the COC volume estimates indicate that approximately 30,000 cubic yards of soil contain COCs in the area of the former disposal basin in the depth range of 0 to 30 feet bgs. Estimates of the total COC mass indicate that 80 pounds (lb) of EDB, 127 lb of DCP, 24 lb of TCP, and 604 lb of DBCP are present within this soil volume. COC mass by soil layer is presented in Tables 1-2 to 1-5.

TABLE 1-2
EDB Mass in Soil Borings
Frontier Fertilizer Feasibility Study, Davis, California

Soil Layer (feet bgs)	Soil Volume (cubic yards)	EDB Mass (lb)
0 to 5	3,128	1.17
6 to 10	2,772	4.56
11 to 15	2,114	1.27
16 to 20	3,811	5.03
21 to 25	4,065	38.82
26 to 30	5,290	29.61
Shallow Soil Total	**21,179**	**80.45**
31 to 40	4,333	1.93
41 to 50	4,481	0.70
51 to 60	Not detected	Not detected
61 to 70	4,481	1.51
71 to 80	4,333	9.32
81 to 90	4,815	0.04
91 to 100	4,815	0.05
101 to 110	Not detected	Not detected
111 to 120	4,815	0.02
Deep Soil Total	**32,074**	**13.6**

TABLE 1-3
DCP Mass in Soil Borings
Frontier Fertilizer Feasibility Study, Davis, California

Soil Layer (feet bgs)	Soil Volume (cubic yards)	DCP Mass (lb)
0 to 5	3,868	1.86
6 to 10	3,701	5.52
11 to 15	2,503	13.07
16 to 20	4,177	12.42
21 to 25	5,900	88.55
26 to 30	5,289	5.87
Shallow Soil Total	**22,610**	**127.3**

TABLE 1-3
DCP Mass in Soil Borings
Frontier Fertilizer Feasibility Study, Davis, California

Soil Layer (feet bgs)	Soil Volume (cubic yards)	DCP Mass (lb)
31 to 40	4,519	8.13
41 to 50	4,370	5.89
51 to 60	4,444	1.01
61 to 70	4,778	6.51
71 to 80	4,815	22.85
81 to 90	4,815	0.15
91 to 100	4,185	0.45
101 to 110	Not detected	Not detected
110 to 120	Not detected	Not detected
Deep Soil Total	**31,926**	**44.9**

TABLE 1-4
DBCP Mass in Soil Borings
Frontier Fertilizer Feasibility Study, Davis, California

Soil Layer (feet bgs)	Soil Volume (cubic yards)	DBCP Mass (lb)
0 to 5	2,863	0.90
6 to 10	2,665	2.35
11 to 15	1,774	0.70
16 to 20	3,011	0.17
21 to 25	3,423	588.68
26 to 30	2,606	11.57
Shallow Soil Total	**16,342**	**604.4**
31 to 40	Not detected	Not detected
41 to 50	Not detected	Not detected
51 to 60	Not detected	Not detected
61 to 70	4,704	0.11
71 to 80	4,815	0.08
81 to 90	Not detected	Not detected
91 to 100	4,815	0.02
101 to 110	Not detected	Not detected
111 to 120	Not detected	Not detected
Deep Soil Total	**19,148**	**0.23**

TABLE 1-5
TCP Mass in Soil Borings
Frontier Fertilizer Feasibility Study, Davis, California

Soil Layer (feet bgs)	Soil Volume (cubic yards)	TCP Mass (lb)
0 to 5	1,392	1.48
6 to 10	1,571	1.69
11 to 15	2,485	1.89
16 to 20	3,421	1.26
21 to 25	3,992	15.75
26 to 30	4,005	2.33
Shallow Soil Total	**16,867**	**24.4**

TCP was not analyzed for in deep soil.

A different COC source mass and volume estimation methodology was followed for the deep soil due to the number of deeper borings. A total of four soil borings were advanced down to 155 feet bgs to evaluate vertical extent of COC migration and collect physical property data. COCs were not detected below 115 feet bgs. The deep soil was dissected into 10-foot depths from 30 to 120 feet bgs and into 10-foot-by-10-foot grid spacing. The mass of COC in the deep soil source volume was estimated to extrapolate COC concentrations from each sample location and respective 10-foot depth interval across the respective grid. The mass of COC estimated in each 1,000 cubic foot element within the depth interval was summed to derive the mass within each interval. The mass within each interval was then summed to derive the mass of each of the COCs in the deep soil source volume.

For samples in a depth interval where a COC was detected in at least one sample, locations where the COC were not detected were assigned the value 2 micrograms per kilogram (µg/kg), or half the detection limit. For depth intervals where a COC was not detected in any samples, the mass and volume are reported as not detected. Results of the COC volume estimates indicate that approximately 38,000 cubic yards of soil contain COCs in the area of the former disposal basin in the depth range of 30 to 155 feet bgs. Estimates of COC mass indicate that 13 lb of EDB, 45 lb of DCP, and 0.2 lb of DBCP are present within this soil volume. EDB, DCP, and DBCP mass estimates in deep soil are presented in Tables 1-2 to 1-4. Deep soil TCP mass estimates were not performed because TCP was not included in the analyte suite for soil samples collected below 30 feet bgs.

Variability in the estimated COC mass and source volumes is anticipated due to the number, location, and timing of samples. Most of the soil samples were collected from between 0 to 30 feet bgs. Therefore, the mass estimate for the deeper media has a higher degree of uncertainty. Data indicate that the mass of COCs in the source volume has declined since the samples were collected. Ultimately, soil treatment volumes will be dependent on treatment technology, threshold COC concentrations, and other Site factors.

1.2.6 Nature and Extent of Groundwater Contamination

Since 1993, groundwater samples have been collected and analyzed for COCs during Site investigation and monitoring activities. Site monitoring and extraction wells are identified on Figure 1-3.

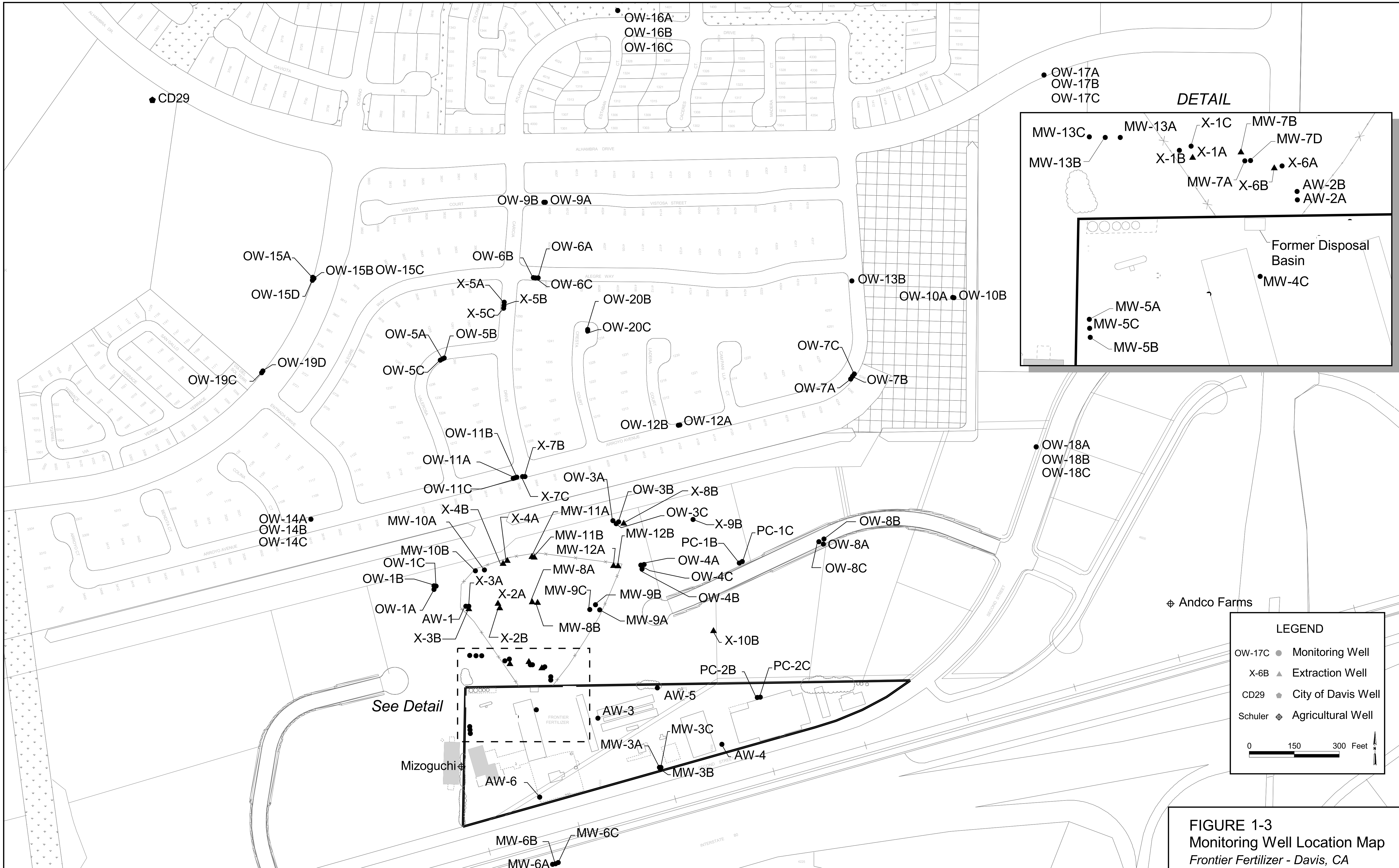


FIGURE 1-3
Monitoring Well Location Map
Frontier Fertilizer - Davis, CA

CH2M Hill SAC ArcView Project File \\Yosemite\SACGIS\frontier\ArcView\Frontier.apr 2:23 P.m. 07-19-2004

CH2MHILL

COCs have been detected in groundwater at concentrations exceeding federal or California primary MCLs in and near the source area and north of the parcel boundary and extraction well field. Generally, the S-1 and S-2 wells with the highest detected pesticide and fertilizer concentrations tend to be located just north and downgradient of the former disposal basin. These wells are included in well clusters X-1, X-6, MW-7, and AW-2. Elevated COC levels have not typically been detected in samples from wells in these clusters that are screened in the A-1 zone. Groundwater monitoring and soil sample analytical results indicate that a significant mass of COCs has not migrated below the S-2 zone. S-2 zone geologic characteristics in the source area and groundwater extraction apparently have impeded vertical migration of COCs. North of the source area, COCs are detected in the A-1 zone at higher concentrations, which indicate a higher conductivity between the S-2 and A-1 zone.

Monitoring results for wells screened in the S-2 and A-1 zones in the X-7 and nearby OW-11 well clusters, which are located about 800 feet north of the former disposal basin, indicate that there is another area, apparently isolated from the source volume, with elevated COC concentrations in groundwater. Possible scenarios that could result in the elevated concentrations in this area near the X-7 and OW-11 well clusters include (1) the groundwater in these wells may have passed through the source area prior to beginning extraction system operation or (2) a preferential flow path exists between the source area and this area that is not intercepted by monitored wells. In general, detected concentrations of COCs have been declining in most wells. The exception to the trend exists in a couple of wells screened in the A-1 zone.

The balance of this section summarizes the wells in which COCs were detected above their MCLs during the *Third Quarter 2005 Groundwater Monitoring Report* (CH2M HILL, 2006). More wells are sampled during third quarter monitoring events than during the other quarterly events.

1.2.7 Groundwater Monitoring Result Summary

The highest concentrations of EDB, DCP, and DBCP are typically detected in S-1 and S-2 zone wells located immediately north of the former disposal basin. Elevated concentrations of these COCs, including the highest concentrations in the A-1 zone, are routinely detected in monitoring wells X-7B and X-7C and the nearby monitoring wells OW-11B and OW-11C. The below sections describe the third quarter 2005 monitoring results of 86 wells.

EDB

EDB was detected at concentrations that exceeded the MCL of 0.05 micrograms per liter (µg/L) in samples collected from 18 wells. The highest EDB concentration of 160 µg/L was detected in a sample collected from monitoring well X-1B.

DCP

DCP was detected at concentrations that exceeded the MCL of 5 µg/L in samples collected from 15 wells. The highest DCP concentration of 2,000 µg/L was detected in a sample collected from well MW-8B.

DBCP

DBCP was detected at concentrations that exceeded the MCL of 0.2 µg/L in samples collected from 11 wells. The highest DBCP concentration of 2.8 µg/L was detected in a sample collected from well MW-7B.

CCl_4

The highest concentrations of CCl_4 continue to be detected in S-1 and S-2 zones in wells located north-northeast of the former disposal basin. CCl_4 was detected at concentrations that exceeded the MCL of 0.5 µg/L in samples collected from 16 wells. The highest CCl_4 concentration of 16 µg/L was detected in a sample collected from monitoring well OW-3B.

TCP

TCP was detected at concentrations that exceeded the California Department of Health Services Action Level of 0.005 µg/L in samples collected from 20 wells (note: the analytical method detection limit was 0.5 µg/L).The highest TCP concentration of 50 µg/L was detected in a sample collected from monitoring well MW-7B.

Nitrate

Nitrate, reported as nitrogen, concentrations exceeded the federal MCL of 10 milligrams per liter in samples collected from 68 out of 86 wells during third quarter 2004. Nitrogen samples were collected during the quarterly events from third quarter 2004 to second quarter 2005, after which they were discontinued.

1.2.8 Nature and Extent of Facility Contamination

Samples of sediment and water were collected from sumps located on the parcel that were apparently used for wastewater management. Total petroleum hydrocarbons were the primary chemicals detected. Additional Site characterization will be appropriate prior to and during demolition activities.

1.2.9 Contaminant Fate and Transport

The two key factors to determine fate and transport are the amount and timing of discharge of COCs released to Site media. Unfortunately, very little is known about the mass of COCs released and the rate at which they were released to Site media, so this is estimated from the soil and groundwater data. Concentration and biogeochemical properties of COCs and Site media determine the persistence of COCs in the environment. The physical and biological factors of the soil and aquifers are also critical in assessing the transport of contamination. Significant remaining concentrations of COCs demonstrate their persistence despite the fact that soils and waters in general are dynamic, open systems where processes such as dilution, volatilization, photolysis, sorption, advection, and microbial biodegradation all contribute toward the reduction of organic compounds (*Report on Bioavailability of Chemical Wastes With Respect to the Potential for Soil Bioremediation,* EPA, R600/R-03/076, October 2003).

Numerical models have been used to predict groundwater and COC transport trends. The MODFLOW program was used to predict general groundwater flow characteristics throughout the Site and the results are included in the technical memorandum entitled *Frontier Fertilizer Groundwater Model Update and Extraction Well Field Plan* (CH2M HILL, 2003).

The Vleach model described in *A One-Dimensional Finite Difference Vadose Zone Leaching Model, Version 2.2* (EPA, 1997) was used to estimate the rate volatile COCs leach from the vadose zone into the groundwater. SourceDK as described in *SourceDK Remediation Timeframe Decision Support System, Version 1.0* (AFCEE, 2004) was used to predict the rate that COCs in the source volume transfer from the soil to the groundwater in the saturated zone. These models are tools that estimate groundwater flow and COC fate and transport characteristics based on general Site conditions. The Site conditions and model parameters are included in Appendix A. Actual characteristics can vary significantly from those predicted due to the heterogeneity of Site hydrogeology and geochemistry. The significant amount of data collected during groundwater monitoring, investigation, and testing activities provide actual characteristics from which trends are derived. Results of treatability studies were also used to evaluate the fate of COCs in native and modified media conditions. Potential exposure points and respective COC concentrations were used to estimate risks to human health and the environment and guide development of remedial alternatives. Fate and transport is described in the following subsections and is broken down into source volume and dissolved phase, that is, groundwater plumes.

Fate and Transport of the Source Volume

After waste mixtures were deposited into the disposal basin in the early 1970s, COCs evaporated and infiltrated vertically downward through the approximately 10-foot-thick vadose zone. The remaining solutions or mixtures infiltrated into the vadose zone through soil. In the course of migrating through the soil, COCs partitioned between soil, soil gas, and groundwater, depending on their physical characteristics. Because nitrate is very soluble in water, it tends to partition into and move with groundwater. DBCP, however, has a low solubility in water and tends to partition into the soil versus moving into the groundwater. Since the volatile COCs have lower solubility in water, they tend to move into soil gas and adsorb to organic material in the soil, and some quantity of the COCs continues to migrate downward to the saturated zone.

As the COC solution or mixture moved closer to the water table, the groundwater in the pore spaces limited the path available for migration and also during part of the year opposed downward movement. Given that the water table elevation annually fluctuates between about 10 and 30 feet bgs, part of the year groundwater rises and opposes the downward migration of COCs. As the groundwater table rises, soil gas is displaced along with COCs that partitioned into the gas phase. In addition to the rising and falling groundwater table, uncontaminated groundwater enters the source area from the south and moves horizontally to the north. Therefore, COCs bound onto soil particles, in pore space, and in remaining soil gas are in contact with uncontaminated groundwater, which results in the COCs partitioning into the aqueous phase and then moving with the groundwater. The balance of the yearly cycle the water table falls, in addition to continuing its northern migration, along with COCs in solution and can migrate downward with the groundwater. As the groundwater table drops, COCs are once again able to partition into the soil gas that replaces the groundwater. As the water table falls, air is drawn into the transition zone becoming oxygen rich and facilitating some aerobic bacteria proliferation. It appears, however, that the Site COCs are not degraded aerobically under Site conditions.

The fate of contaminants in the saturated media depends on the complex physiochemical and biochemical interactions within the saturated zones. The fate of soil COCs is primarily dissolution and diffusion into groundwater or degradation. Once dissolved into groundwater, the contaminants can degrade or volatilize, are potentially degraded biologically, adsorbed onto organic particles in the geologic material (where they may eventually be broken down or desorbed), volatilized into the soil gas (in the vadose and transition zones), diluted, or discharged from the aquifer system at pumping wells. The permeability and continuity of the geologic materials varies significantly and affects the rate that COCs are able to migrate through and away from the source area. Sandy soils have higher flow velocity and volatilization, whereas clays and silts impede COC migration and reduce volatilization rates. The amounts of natural organic material in the soils and aquifer affect the persistence of certain COCs. For example, DBCP's affinity for organic material results in a retardation of transport in groundwater. The fates of the COCs in the saturated media are biodegradation, reductive dehalogenation, and discharge to the surface via pumping wells. Contaminant concentrations are also reduced by dilution with uncontaminated groundwater.

Fate and Transport of Dissolved-phase Contaminants in Groundwater

Investigation and monitoring results identified elevated COC concentrations in groundwater north of the source area. The dissolved COCs, in solution with groundwater, have been detected in the S-1, S-2, and A-1 zones beneath the Site.

COC fate and transport rates were estimated based on the timeframes when fertilizer and pesticide distribution activities occurred and on Site investigation results. Given the heterogeneous characteristics of aquifer media, the rates vary significantly. Sample analytical results indicate that groundwater in the S-1 and S-2 zones containing COCs in the OW-2 wells, migrated more than 600 feet north of the disposal basin in less than 23 years. Aquifer tests indicate that this aquifer is fairly variable. Soil ranges from gravel to clay with variability observed in both the horizontal and vertical direction. The complex nature of the soil and aquifer system at the Site indicates that migration of dissolved phase COCs to the A-1 aquifer occurred along many pathways. For example, elevated COC concentrations above the MCL are detected in well OW-11C. These concentrations may have migrated by either (1) direct downward transport between the S-2 zone and the A-1 aquifer in the disposal basin area followed by lateral migration; or (2) migration directly from the S-2 zone at a location farther downgradient. Downward flow induced by seasonal pumping from the A-1 aquifer probably enhances transport of dissolved pesticides into the A-1 aquifer.

Once the dissolved contaminants have entered the A-1 aquifer, there appears to be significant dilution due to the very high groundwater flux. This results in concentrations that are much lower in the A-1 aquifer than in the S-2 zone.

1.2.10 Baseline Risk Assessment

A baseline human health risk assessment was performed as part of the RI to assess potential human health impacts from contamination at the Site if no remedial actions are taken. Characterization of risk addresses potential cancer and non-cancer risks. Cancer risk is an upper bound estimate of individual excess probability of increased incidence of cancer as a result of exposure to a potential carcinogen. A cancer risk of 1×10^{-6} means that the estimated increase in an individual normal or baseline cancer risk is no greater than 1 in 1,000,000 for a lifetime of exposure. A non-cancer risk is expressed as a hazard index. Hazard indices are the ratio of an exposure level to a nontoxic level. Because a hazard index value of 1 indicates that lifetime exposure has limited potential for causing an adverse effect in sensitive populations, values of 1 or less can generally be considered acceptable. The National Contingency Plan considers an excess lifetime cancer risk of 1×10^{-6} and/or a non-cancer hazard index of greater than 1 as the points of departure for the analysis of remedial alternatives. In the case of contaminated groundwater at the Site where there is a possibility of connection to a drinking water zone, decisions on the type and extent of action to be taken are often made on the basis of EPA's drinking water standards or MCLs. Two risk assessments, the Final Baseline Risk Assessment and the Revised Screening Level Ecological Risk Assessment, were performed to address potential human health and ecological risk, respectively.

Summary of Baseline Risk Assessment

The *Final Baseline Risk Assessment Report for the Frontier Fertilizer Site* (Bechtel, 1999b) evaluated the potential risk to public health from chemicals detected in the soil and groundwater at the Site. The Site is currently vacant and secured and public access is prohibited. Based on the current and potential future land use, and existing Site conditions, the following potential receptors were chosen to assess risk:

- Offsite current residents in the Mace Ranch residential area
- Hypothetical children and adult residents living at the source area, within the 8-acre Site
- Future workers at the 8-acre Site

To evaluate the current risks to people living in the Mace Ranch residential area, EPA assessed the groundwater to indoor air pathway, also known as the "vapor intrusion pathway." The highest concentrations of EDB, DCP, TCP, and CCl_4 in the groundwater (S-1 zone), soil gas, and flux chamber collected in or near the neighborhood were used to estimate the carcinogenic and noncarcinogenic risk associated with the indoor air pathway. As presented in the risk assessment, the risk estimates based on groundwater concentrations present the highest risk of the data sets used in the vapor intrusion pathway assessment. The risk assessment concluded that for current residents in the Mace Ranch subdivision, the current risks (risk of both cancer and non-cancer health effects) are negligible.

For the future risk scenario, EPA evaluated risks based on both residential and industrial land use of the Site. Although residential land use of the Site is considered unlikely, it was evaluated to estimate a reasonable maximum exposure to Site contaminants. Exposure routes examined in the risk assessment included ingestion of soil, dermal contact with soil, inhalation of airborne dust, and inhalation of chemical vapors both indoors and outdoors.

For future residential use, it was assumed that residential development could take place if there were no restrictions placed on the 8-acre Site prior to cleanup. In theory, this hypothetical homeowner could build a house on the most contaminated location of the Site, install a private drinking water well in the most contaminated portion of the groundwater "hot spot," and raise and consume homegrown vegetables. The highest risks in this hypothetical case would result from installing a groundwater well in the "hot spot" and using the water for domestic purposes (drinking, showering, and washing) (8×10^{-1}).

Although the risk assessment evaluated the use of groundwater for domestic purposes, it is considered highly unlikely. Typically, Davis residents use water that is provided by the local water purveyor and that meets safe drinking water standards. EPA would prohibit the installation of groundwater wells for household use (or any other use) within the contaminated zone.

In general, the future residential risks associated with shallow soil are orders of magnitude less than those associated with domestic use of the groundwater. Potential cancer risks for the hypothetical onsite resident were greatest associated with indoor vapor inhalation ($3 x10^{-4}$), followed by soil ingestion and dermal contact (8×10^{-5}), outdoor vapor inhalation (6×10^{-6}), produce consumption (5×10^{-6}), and finally by dust inhalation (1×10^{-10}). Potential residential non-cancer risks for the hypothetical onsite resident were greatest associated with indoor vapor inhalation (24) followed by outdoor vapor inhalation (0.74), soil ingestion and dermal contact (0.26), produce consumption (0.038), and finally by soil inhalation (0.0000088).

Risks also were calculated for a potential worker because a light industrial park is planned for the Site. Potential cancer risks for the industrial worker were greatest associated with indoor vapor inhalation ($< 3 \times 10^{-4}$), followed by soil ingestion and dermal contact (3×10^{-6}), outdoor vapor inhalation (4×10^{-7}), and soil inhalation (2×10^{-11}). Potential non-cancer risks for the onsite industrial worker were greatest associated with indoor vapor inhalation (< 24), followed by outdoor vapor inhalation (0.016), soil ingestion and dermal contact (0.004), and finally by soil inhalation (0.0000022).

Summary of the Screening Level Ecological Risk Assessment

The Screening Level Ecological Risk Assessment (CH2M HILL, 2004) identified EDB and many other non-VOCs as contaminants of potential ecological concern in Site soil. Given the small size of the 8-acre Site, the limited availability and poor quality of onsite habitat, lack of connectivity to offsite habitat, and planned commercial future use of the Site, additional efforts to address the uncertainties in the assessment are not warranted. One of the major uncertainties concerns the analytical data that was collected prior to 1999, which may not adequately characterize the current ecological risk.

Each of the alternatives evaluated later in Sections 3 and 4 of this FS include a temporary cap of wood chips or gravel for the area unaffected by the remedy. The temporary cap will provide a barrier for ecological receptors until the proposed development occurs. If the proposed development does not occur, the surface soils can be resampled to assess the current risk, should an unrestricted use scenario be selected as a potential final outcome for the Site.

SECTION 2

RAOs, ARARs, and Identification and Screening of Technologies

2.1 Introduction

This section develops the remedial action objectives (RAOs) for the groundwater and soil at the Site, and presents a summary of the ARARs and general response actions. This section also presents technologies and process options that EPA is considering as potential remedial alternatives for the Site. Each option is evaluated on the basis of technical implementability.

2.2 Remedial Action Objectives

RAOs define the extent that sites require cleanup to meet the objectives of protecting human health and the environment. RAOs reflect the COCs, exposure routes and receptors, and risk-based acceptable contaminant level for each medium of concern at the Site. RAOs are classified as either general or specific. General RAOs can be applied to all Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites; specific RAOs reflect Site-specific conditions. The general and specific RAOs for the Site are based on the following elements:

- General goals defined by CERCLA and the National Contingency Plan (NCP), 40 Code of Federal Regulations (CFR) Part 300
- Site specific characteristics
- Volume and extent of contamination
- Results of the Baseline Risk Assessment Report
- ARARs from the following State of California agencies: California Integrated Waste Management Board, Department of Health Services, Department of Fish and Game, Department of Toxic Substances Control, Yolo Solano Air Quality Management District, and Regional Water Quality Control Board (a comprehensive list of sources can be found in Appendix B)

Once RAOs have been developed, they can be expressed numerically as target cleanup levels. Target cleanup levels are the chemical concentrations in soil or groundwater that achieve the level of protection specified by the RAOs. These levels provide a basis for delineating the extent and volume of contaminated media in order to evaluate and compare remedial alternatives within the CERCLA FS process. A summary discussion of ARARs is provided in Section 2.2.3. The discussion centers on the chemical-specific ARARs that were considered during development of the target cleanup levels.

2.2.1 General RAOs

The general RAOs for the Frontier Fertilizer Site include the following:

- Protect human health and the environment by reducing the risk of potential exposure to contaminants
- Use permanent solutions to the maximum extent possible
- Consider innovative technologies to reduce the duration and cost of remedial actions
- Restore contaminated areas to the extent necessary to support existing and proposed land uses
- Achieve compliance with ARARs
- Select technologies and process options that are compatible with potential future land use

2.2.2 Specific RAOs

Specific RAOs for the Frontier Fertilizer Site include:

- Reduce levels of chemicals in onsite soils to prevent future exposures (workers and/or residents) to chemicals in soils above health-protective levels (e.g., EPA Region 9 Soil PRGs).
- Reduce levels of chemicals in groundwater (and chemical sources to groundwater) so that the groundwater could ultimately be used for domestic purposes.
- Prevent future onsite exposures (workers and/or residents) to chemical vapors in indoor air above health-protective levels (e.g., EPA Region 9 Air PRGs).
- Reduce risks to ecological receptors to a level consistent with habitat quality, and proposed future use of the Site.

2.2.3 ARARs

Section 121(d) of the CERCLA, 42 U.S.C. § 9621(d), requires that remedial actions at CERCLA sites attain (or justify the waiver of) any federal or state environmental standards, requirements, criteria, or limitations that are determined to be legally applicable or relevant and appropriate. These applicable or relevant and appropriate requirements are referred to as "ARARS." Federal ARARS may include requirements promulgated under any federal environmental laws. State ARARS may only include promulgated, enforceable environmental or facility-siting laws of general application that are more stringent or broader in scope than federal requirements and that are identified by the state in a timely manner.

An ARAR may be either "applicable," or "relevant and appropriate," but not both. If there is no specific federal or state ARAR for a particular chemical or remedial action, or if the existing ARARs are not considered sufficiently protective, then other guidance or criteria to be considered (TBCs) may be identified and used to ensure the protection of public health and the environment. The NCP defines "applicable," "relevant and appropriate," and "to be considered" as follows:

- **Applicable requirements** are those cleanup standards, standards of control, or other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be applicable.

- **Relevant and appropriate requirements** are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified in a timely manner and that are more stringent than federal requirements may be relevant and appropriate.

- **TBCs** consist of advisories, criteria, or guidance that EPA, other federal agencies, or states developed that may be useful in developing CERCLA remedies. The TBC values and guidelines may be used as EPA deems appropriate.

ARARs are identified on a site-specific basis from information about the chemicals at the site, the remedial actions contemplated, the physical characteristics of the site, and other appropriate factors. ARARS include only substantive, not administrative, requirements, and pertain only to onsite activities. Section 121(e) of CERCLA, 42 U.S.C. § 9621(e), states that no federal, state, or local permit is required for remedial actions conducted entirely onsite. Offsite activities, however, must comply with all applicable federal, state, and local laws, including both substantive and administrative requirements that are in effect when the activity takes place. There are three general categories of ARARS:

- **Chemical-specific** ARARs are health- or risk-based concentration limits, numerical values, or methodologies for various environmental media (for example, groundwater, surface water, air, and soil) that are established for a specific chemical that may be present in a specific media at the Site, or that may be discharged to the Site during remedial activities. These ARARs set limits on concentrations of specific hazardous substances, pollutants, and contaminants in the environment. Examples of this type of ARAR include state and federal drinking water standards.

- **Location-specific** ARARs set restrictions on certain types of activities based on Site characteristics. Federal and state location-specific ARARs are placed on the concentration of a contaminant or the activities to be conducted because they are in a specific location. Examples of special locations possibly requiring ARARs may include floodplains, wetlands, historic places, and sensitive ecosystems or habitats.

- **Action Specific** ARARs are technology- or activity-based requirements that are triggered by the specific type of remedial activities selected. Examples of this type of ARAR are Resource Conservation and Recovery Act of 1976 (RCRA) regulations for waste treatment, storage, or disposal.

ARARs Analysis Process

Potential ARARs and TBCs are identified at various points throughout the remedial process. Therefore, as additional information about the Site is developed, including unique features concerning the location, specific chemicals, and proposed remedial actions, additional ARARs may be identified, and the list of potential ARARs refined.

The ARARs analysis process for the Site began with a review of potential federal and state ARARs. EPA solicited state ARARs from the DTSC in 1999. ARARs were considered from the following California agencies: the Integrated Waste Management Board; the Department of Health Services; the Department of Fish and Game; DTSC; the Yolo Solano Air Quality Management District; and the RWQCB. Following the identification of potential ARARs, each requirement was reviewed to determine if it was applicable or relevant and appropriate to the Site-specific COCs identified in the Remedial Investigation (RI), the Site location and features, and the potential remedial alternatives to be investigated in the FS. The following sections contain potential ARARs for the Site.

Potential ARARs and TBCs for the Frontier Fertilizer Site

A discussion of the most significant ARARs relative to the development of remedial alternatives is provided in the following sections. All tables are located in Appendix B. Potential chemical-specific, location-specific, and action-specific ARARs, and brief descriptions of how the ARARs are applied to Site-specific features and remedial alternatives are summarized in Tables B-1, B-2, and B-3.

Potential Chemical-specific ARARs

A complete list of potential chemical-specific ARARs is provided in Table B-1. A description of the most relevant chemical-specific ARARs and their applicability to the COCs and remedial alternatives being evaluated for the Site is provided below.

Safe Drinking Water Act. The Safe Drinking Water Act (SDWA) establishes national primary drinking water standards, Maximum Contaminant Levels (MCLs), to protect the quality of water in public water systems. MCLs are enforceable standards and represent the maximum concentrations of contaminants permissible in water delivered to the public. MCLs are generally relevant and appropriate when determining acceptable exposure limits for waters that are current or potential sources of drinking water. 40 CFR 300.430(e)(2)(i)(B). Additionally, the SDWA sets maximum contaminant level goals (MCLGs), which are non-enforceable health-based goals that are established at levels at which no known or anticipated adverse effects on the health of persons occur. The NCP provides that MCLGs that are set at levels above zero are also generally relevant and appropriate for remedial actions for ground or surface waters that are current or potential sources of drinking water. However, where the MCLG for a contaminant has been set at zero, the MCL is generally the level to be attained by a remedial action addressing ground or surface water that is an actual or potential source of drinking water. The five primary COCs at the Site have MCLGs set at zero, and thus, the MCLs are relevant and appropriate. Table 2-1 presents MCLs for the COCs in groundwater.

TABLE 2-1
MCLs for COCs
Frontier Fertilizer Site Feasibility Study, Davis, California

Contaminant of Concern	Primary MCL (µg/L)	Source
1,2-dibromo-3-chloropropane (DBCP)	0.2	Federal
1,2-dibromoethane (EDB)	0.05	Federal
1,2-dichloropropane (1,2-DCP)	5	CA
Carbon tetrachloride (CCl_4)	0.5	CA
1,2,3-trichloropropane (TCP)	0.005*	CA DHS Action Level

CA = California MCL.

* State Notification Level, not MCL; considered a TBC for purposes of the ARARs discussion. Notification levels are health-based advisory levels for chemicals in drinking water that lack an MCL; the State identifies requirements and recommendations for chemicals detected above this level; a Public Health Goal has been requested which is the first step in the regulatory process.

California drinking water standards, under the SDWA, establish primary MCLs for contaminants that cannot be exceeded in public water systems. The California drinking water MCLs are, in some cases, more stringent than the federal MCLs and, in other cases, less stringent than the federal standards. The more stringent of the state and federal MCLs was chosen as the potential ARAR.

Pursuant to the Water Quality Control Plan for the Sacramento River and San Joaquin River Basins (Basin Plan) discussed below, municipal or domestic drinking water supply is a designated beneficial use of the groundwater subject to remedial action at the Site. Therefore, the state and federal MCLs are relevant and appropriate water quality objectives for groundwater at this Site.

State Water Resources Control Board (SWRCB) Resolution 68-16 (Antidegradation Policy). This resolution requires the continued maintenance of high-quality water of the State. Water quality may not be allowed to be degraded below what is necessary to protect the "beneficial uses" of the water source. Beneficial uses of waters on and in the vicinity of the Site are identified in the Basin Plan.

Resolution 68-16 applies most often to cleanups that involve extracting, treating, and discharging treated groundwater. Activities that discharge to high quality waters (unaffected surface or groundwater) require the use of "best practicable treatment or control" of the discharge to avoid pollution or nuisance and maintain high quality. Best practicable treatment would take into account technical and economic feasibility. Possible remedial options for groundwater involve reinjection of treated groundwater to groundwater, and must take into account the protection of beneficial uses and the maintenance of high-quality waters in the area.

RWQCB's Basin Plan. The State of California established water-quality objectives for the protection of groundwater and surface water under the Porter-Cologne Water Quality Control Act. These water quality objectives are established by the RWQCB for each basin and are based on the beneficial use(s) of the waters. The Basin Plan, dated September 1, 1998, establishes beneficial uses for groundwater and surface water, and water quality objectives designed to protect those beneficial uses. The Basin Plan includes implementation plans and other control measures designed to ensure compliance with regional and statewide plans and policies, and provides comprehensive water-quality planning.

Three elements of the Basin Plan have been identified as potential ARARs by the RWQCB:

- Policy for Investigation and Cleanup of Contaminated Sites
- Policy for Application of Water Quality Objectives
- Wastewater Re-use Policy

The Basin Plan establishes narrative and numeric minimum standards for chemical constituents in groundwater in Chapter III-3.00. The Basin Plan states in part:

> "At a minimum, groundwaters designated for use as domestic or municipal supply (MUN) shall not contain concentrations of chemical constituents in excess of the MCLs."

The narrative standards of the Basin Plan most applicable to Site COCs in groundwater include the following:

> "Groundwaters shall not contain chemical constituents in concentrations that adversely affect beneficial uses." [Chapter III-10.00]
>
> "Groundwaters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in human, plant, animal, or aquatic life associated with designated beneficial use(s). This objective applies regardless of whether the toxicity is caused by a single substance or the interactive effect of multiple substances." [Chapter III-10.00]

SWRCB Resolution 92-49. SWRCB Resolution 92-49, "Policies and Procedures for Investigation and Cleanup and Abatement of Discharges Under Water Code Section 13304," Section III.G addresses the establishment of groundwater cleanup levels and states, in part, that dischargers are required to clean up and abate the effects of discharges in a manner that promotes attainment of backgroundwater quality or the best water quality that is reasonable if background levels cannot be restored. In approving any alternative cleanup level less stringent than background, Resolution 92-49 requires the Regional Board to apply Title 27 CCR Section 20400, and the cleanup level shall:

- Be consistent with maximum benefit to the people of the State
- Not unreasonably affect present and anticipated beneficial use of such water
- Not result in water quality less than that prescribed in the Water Quality Control Plans and Policies adopted by the SWRCB and RWQCBs

Section 2.2.4 discusses the technical and economic infeasibility of remediating the COCs to background levels at the Site.

Title 23 California Code of Regulations Section 2907. This Water Board provision is the regulatory restatement of Resolution 92-49. It was promulgated in accordance with a State law requirement that any quasi-legislative pronouncement such as a Water Board Resolution be reduced to a "clear and concise summary of any regulatory provisions." This regulation represents the Water Board's own interpretation of Resolution 92-49, and as such, it is a valuable tool for understanding the Resolution. Pursuant to this regulation, the RWQCB must require the lowest achievable clean-up levels if restoration of background is not feasible. Moreover, the Regional Board must ensure that dischargers have the opportunity to select cost-effective methods for cleaning up contamination.

RCRA Hazardous Waste Determinations. The RCRA requirements for identification and listing of hazardous waste can be found in CCR Title 22, Division 4.5, Chapter 11. A waste is a RCRA hazardous waste if it is determined to be so under 22 CCR 66262.11, if it exhibits any of the characteristics of ignitability, corrosivity, reactivity, or toxicity identified in Title 22 66261.21, 66261.22(a)(1), 66261.22(a)(2), 66261.23, and 66261.24(a)(1), or if it is listed as a hazardous waste in Article 4 of Chapter 11.

Under the California RCRA program, that is, Chapter 6.5 of the California Health and Safety Code and CCR Title 22, wastes can be classified as non-RCRA, State-only, hazardous wastes if they do not meet RCRA waste criteria, but exceed the Soluble Threshold Limit Concentration (STLC) or the Total Threshold Limit Concentration (TTLC) values listed in 22 CCR 66261.24(a)(2). Additionally, wastes may be considered a State-only hazardous waste if they meet the criteria contained in 22 CCR 66261.101. The toxicity characteristic leaching procedure (TCLP), STLC, and TTLC limits are used to characterize waste during remediation activities and do not represent cleanup levels for soil or groundwater.

For remedial activities that may occur at the Site, any wastes that are generated during construction activities, groundwater and soil monitoring, or through operation of a treatment device, will require waste characterization to determine the appropriate classification of the waste. Some wastes generated at the Site (for example, extracted groundwater, soil cuttings) may be classified as toxicity characteristic waste as defined by contaminant concentrations that exceed the TCLP limits. If these wastes are characterized as hazardous, the management, treatment, and storage of these wastes must comply with RCRA hazardous waste regulations. Following characterization, federal or state hazardous wastes will be disposed of in accordance with California hazardous waste management requirements in 22 CCR 66262.10 through 66262.43.

2.2.4 Compliance with Chemical-specific ARARs

In order to comply with the chemical-specific ARARs described above, the remedial alternatives that are designed to be protective of beneficial uses are evaluated for cleanup to MCLs and background. The purpose of evaluating multiple cleanup levels is to determine the lowest concentration that is technologically and economically achievable pursuant to Resolution 92-49. Where background or non-zero MCLGs are not achievable, EPA has selected the more stringent of the state and federal MCLs as the potential ARAR. MCLs are relevant and appropriate to groundwater cleanups because the groundwater at the Site is a potential source of drinking water, and CERCLA expects to return usable waters to their beneficial uses whenever practicable, 40 CFR §§ 300.430(a)(i1)(iii)(F) and 300.430(e)(2)(i). At a minimum, water dedicated for use as domestic or municipal supply shall not contain concentrations of chemical constituents in excess of MCLs. Fourth Edition of the Water Quality Control Plan (Basin Plan) for the San Joaquin River and Sacramento River Basins, September 15, 1998. The primary COCs detected at the Site do not occur naturally and are not ubiquitous. Therefore, to achieve background levels, the concentrations of these chemicals would have to be not detected.

As discussed in Section 2.2.3, the RCRA groundwater protection standards are identified as relevant and appropriate standards. Section 66264.94 (c) of Title 22 of these requirements specifies that, for corrective actions, concentrations limits greater than background levels can be established only by demonstrating the following conditions:

- It is technologically or economically infeasible to achieve the background value for that constituent
- The constituent will not pose a substantial present or potential hazard to human health or the environment as long as the concentration limit greater than background level is not exceeded

Critical issues for evaluating the technological feasibility of attaining background levels in groundwater in the aquifer are:

- The background level or chemical concentration that must be achieved
- The area that must be restored, by medium (for example, soil or groundwater)
- The volume of material that must be treated or removed
- The availability of demonstrated technologies that can actually achieve background levels

Estimated timeframes for cleanup to MCLs are presented in Table 1 of Appendix A. Based on these estimates, the timeframes for cleanup to background would be significant and technologically infeasible at this time given Site conditions and COCs.

Cleanup levels for contaminated soil at the Site were established based on vadose zone modeling completed as part of the remedial investigation. These cleanup levels will result in maintenance of MCL or lower concentrations in groundwater.

Potential chemical-specific ARAR and TBC criteria for the Site are provided in Appendix B, Table B-1.

2.2.5 Potential Location-specific ARARs

Potential location-specific ARARs and TBC criteria for the Site are provided in Appendix B, Table B-2. Location-specific ARARs are concerned with the area in which the Site is located. To the extent that the remedial action will affect historical resources, streams, floodplains, or wetlands, EPA requires that the potential remedial alternatives comply with the location-specific requirements.

There are no location-specific ARARs that are anticipated to have a significant impact on the selection or analysis of remedial alternatives at the Site. This assumption is based on previous surveys, ecological risk assessments, and water resource assessments that did not reveal any historical, cultural, archaeological resources, wetlands that could be impacted by the remedial alternatives evaluated for the Site. Wildlife habitat will be affected by the proposed alternatives as is expected by the proposed future development of the Site. The Site is designated as Light Industrial/Business Park in the “Mace Ranch Plan Development, #4-88.”

In the event that any significant cultural, historical, archaeological, or ecological resources are anticipated to be impacted by Site remedial activities, or if new information regarding these resources should arise, the ARARs provided in Table B-2 will govern the appropriate communications and actions.

2.2.6 Potential Action-specific ARARs

The federal and state potential action-specific ARARs for the remedial alternatives evaluated for the Site are summarized in Appendix B, Table B-3. These ARARs generally set performance, design, or other similar action-specific controls or restrictions on certain activities related to the management of hazardous substances or the discharge of water and airborne pollutants. Action-specific ARARs of particular significance to remedial action alternatives at the Site are discussed in more detail below.

National Pollution Discharge Elimination System Permit Program

Many of the considered groundwater cleanup alternatives include continued discharge of treated groundwater to the City of Davis Wastewater Treatment Plant. The City of Davis has a NPDES permit to cover the discharges of the plant, and EPA is required to obtain a permit from the City to manage the Site's plant discharge to the City's Wastewater Treatment Plant.

Hazardous Waste Management ARARs under RCRA

EPA has authorized California to implement its own hazardous waste and corrective action programs in lieu of implementing RCRA; therefore, the relevant provisions of the state statutes and regulations (California Hazardous Waste Control Act and Title 22, CCR, Sections 66264 et seq. and 66265 et seq.) are treated as the federal requirements in lieu of the federal statutes and regulations (RCRA, Subtitle C, and 40 CFR 264 and 265). California requirements that exceed the scope of federal requirements for these programs are treated as state requirements.

RCRA requirements are generally applicable under two scenarios: (1) sites where hazardous wastes were treated, stored, or disposed of after the effective date of RCRA; and (2) a CERCLA activity involving treatment, storage, or disposal of hazardous waste. These two scenarios are contingent upon the determination that a RCRA hazardous waste is present and on the identification of the period of waste management (EPA, 1988). For the purposes of this ARARs analysis, only the RCRA requirements that apply to wastes generated, stored, or disposed of during the CERCLA activity are considered applicable. Other RCRA requirements will be considered relevant and appropriate.

The substantive storage requirements of California regulations found in 22 CCR 66262.30 through 66262.34 are applicable to the storage of hazardous wastes generated and stored onsite, such as contaminated groundwater, soil cuttings, and treatment plant residuals. This includes requirements for waste accumulation, container storage, and secondary containment. Any offsite storage of hazardous wastes would be subject to administrative requirements as well.

Air ARARs

Electrical resistance heating is one of the treatment technologies under consideration for COC removal through vapor or steam from the aquifer; therefore, there is the potential for VOCs to be released into the air. Off-gas from steam stripping operation will need to comply with the substantive air emissions requirements of the Yolo County Air Quality Management District. Requirements that are considered to be potential federal ARARs include Rules 2.5, 2.11, 2.19, and 3.13.

2.2.7 Preliminary Cleanup Goals for Soil and Groundwater

The Site preliminary groundwater and soil cleanup goals are based on potential chemical-specific ARARs and TBC criteria. The potential ARARs considered are federal and state MCLs. The TBC criteria considered are EPA Region IX Preliminary Remediation Goals (PRGs), Designated Levels for Constituents in Soil provided by the Central Valley Regional Water Quality Control Board (CVRWQCB) (Table provided in Appendix C), and background concentrations. The CVRWQCB Designated Level Methodology is a calculation yielding chemical concentrations in soil which are not expected to pose a threat to water quality. The water quality goal in the designated level is taken from CVRWQCB's "A Compilation of Water Quality Goals," and may range from a Cal/EPA Cancer Potency Factor to a MCL standard.

Based on the ARARs evaluation, the preliminary cleanup goals for groundwater are MCLs. The soil cleanup values are based on the results of vadose zone modeling documented in the "Supplemental Remedial Investigation Report, 1999." Table 2-2 presents the preliminary cleanup levels for the primary soil and groundwater COCs at the Site.

TABLE 2-2
Preliminary Cleanup Levels for Soil and Groundwater
Frontier Fertilizer Feasibility Study, Davis, California

Contaminant of Concern	Groundwater MCL (µg/L)	Soil Cleanup Values (µg/kg)[c]
1,2-dibromo-3-chloropropane (DBCP)	0.2	1.20
1,2-dibromoethane (EDB)	0.05	0.18
1,2-dichloropropane (1,2-DCP)	5	20
Carbon tetrachloride (CCl_4)	0.5[a]	90
1,2,3-trichloropropane (TCP)	0.5[b]	2.5[b]

[a] California MCL, which is more stringent than the Federal MCL
[b] Detection limit for TCP; there is no MCL for TCP
[c] Soil depth to 10 feet bgs

2.3 General Response Actions

RAOs were presented in Section 2.2 for the Site. Environmental medium-specific general response actions (GRAs) were developed to satisfy the RAOs and include: No Action, Institutional Controls, Monitoring, Containment, In situ Treatment, Collection, Ex situ Treatment, Disposition and Secondary Emission Treatment. Process options refer to the specific processes within each technology type (EPA, 1988).

The GRAs, respective technology types, and process options EPA selected are developed from:

- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988).
- *Rules of Thumb for Superfund Remedy Selection* (EPA, 1997).
- Engineering experience and judgment.

Except for the No Action alternative, each GRA can be achieved by several remedial technologies. Environmental medium-specific GRAs, RAOs, and remediation technologies are presented in Table 2-3. In this context, the following definitions apply:

- Remedial technologies are defined as the general categories of remedies under a GRA. For example, thermal treatment is one of the remedial technologies under the GRA of in situ treatment.
- Process options are specific categories of remedies within each remedial technology. The process options are used to implement each remedial technology. For example, the remedial technology of thermal treatment could be implemented using one of several types of treatment options (for example, in situ media heating).

For the purpose of evaluating different technologies' applicability to Site media, the Site was divided into two categories consisting of:

- Unsaturated media—Unsaturated Source Soils
- Saturated media—Saturated Source Soil and Groundwater Dissolved Plume

Screening-level analyses were conducted maintaining these media as functional and distinct. Variations in the saturated soil conditions required further delineation of Site media for the detailed analysis (Section 4). Technology alternatives selected address each of these Site media and will collectively comprise the overall Site remedial system.

The GRAs identified for the two media categories are:

- **No Action.** No remedial measures are implemented. A No Action alternative is required for consideration by the NCP.
- **Institutional Controls.** GRA includes non-engineered instruments such as administrative and/or legal controls that minimize the potential for human exposure to contamination by restricting land or resource use.
- **Monitoring.** GRA taken to monitor COCs and evaluate affects of native Site biological, chemical, and physical processes.
- **Surface Controls.** GRA that affects COC exposure at ground surface on unsaturated media and mitigates COC migration due to stormwater infiltration.
- **Containment.** GRA that results in contaminated soil being contained or controlled, thereby minimizing or eliminating the migration of contaminants and preventing direct exposure to contamination.
- **In situ Treatment.** GRA taken to treat contaminated media in place to reduce the toxicity, mobility, and/or volume of contaminants.
- **Collection.** GRA taken to physically remove contaminated media from its existing location.
- **Ex situ Treatment.** GRA taken to treat collected contaminated media to reduce the toxicity, mobility, and/or the volume of contaminants.
- **Disposition.** GRA taken to manage collected media.
- **Secondary Emission Treatment.** GRA taken to address COCs in media resulting from other GRAs.

2.4 Identification and Screening of Remedial Technologies and Process Options

Following the development of GRAs, potential remedial technologies and process options for implementing the GRAs were identified (Table 2-3). Alternatives are developed by assembling combinations of technologies appropriate for mediums requiring remediation. Technologies are chosen for consideration based on their established record of successful implementation to (1) remove contaminated media, (2) destroy COCs in contaminated media, (3) remove COCs from contaminated media, or (4) isolate the COC in the contaminated media to prevent exposure. RAOs are established for each media to delineate parameters within which technologies are evaluated. If a technology or combination of technologies cannot meet established objectives, they are removed from further consideration.

A universe of technology types and process options is available to implement the GRAs. Potentially applicable technology types and process options were identified from references developed specifically for CERCLA sites, Internet searches, vendor-supplied information, standard engineering texts, and others. The purpose of drawing on these sources is to ensure that applicable technologies and process options are not overlooked early in the FS process.

Following the identification process, three steps are performed:

- Technical implementability screening
- Evaluation of process options
- Selection of representative process options

These steps are described in the following sections.

2.4.1 Technical Implementability Pre-screening

The evaluation of technical implementability includes a comprehensive list of technology types and process options. The number of technologies is reduced by evaluating the technical implementability of the options. Technical implementability refers to the ability of the remedial technology to achieve RAOs. This initial screening eliminates those technologies and process options that are clearly not applicable or not workable for the contaminants (COCs) and/or characteristics found at the Site.

Technical implementability pre-screening results for potential unsaturated and saturated media remediation technologies and process options are presented in Tables 2-4 and 2-5, respectively. Tables 2-4 and 2-5 briefly describe the technologies and process options associated with GRAs and provide screening rationale.

TABLE 2-3
Remedial Action Objectives, General Response Actions, Technology Types, and Process Options for the Development and Screening of Technologies
Frontier Fertilizer Site Feasibility Study, Davis, California

Environmental Media	Remedial Action Objectives (from site characterization)	General Response Actions (for all remedial action objectives)	Remedial Technology Types (for general response actions)	Technology Process Options
Unsaturated media	Reduce levels of chemicals in onsite soils to prevent future exposures (workers and/or residents) to chemicals in soils above health-protective levels (e.g., EPA Region 9 Soil PRGs)	No action.	No action.	No action.
		Institutional controls: Minimize human contact with contaminated soil.	Institutional controls and access restrictions	Deed restrictions, security fence and signage, monitor restriction effectiveness.
		Monitor.	Monitor COCs to evaluate effects of native site biological, chemical, and physical processes.	Monitor soil to assess COCs concentration changes and human and ecological exposure potential.
	For environmental protection: Reduce risk to ecological receptors to a level consistent with habitat quality and proposed future use of the Site.	Containment actions: Minimize human and ecological receptor contact with soil and soil gas and prevent infiltration of rainwater.	Containment technologies: horizontal and vertical barriers, and monitor.	Cap surface with clay/soil, asphalt, concrete, or multimedia/RCRA cap; sheet piling, slurry wall, grout injection; soil gas and pore water monitoring.
		Collection and/or treatment actions: Minimize short-term and/or long-term human and ecological exposure to COCs via treatment in-place, remove and treat or removal and dispose.	In situ technologies: Biological, chemical, and/or physical treatment.	Anaerobic, cometabolized aerobic, or aerobic with native and/or non-native bacteria, nutrients and cometabolites; wash/desorb COCs with water, hot water or water w/surfactant, combined with GW extraction; soil gas extraction with air vacuum alone or thermal enhanced with electrodes, steam, and/or heated air injection; oxidize/reduce COCs using respective chemical additives in solution with water; solidify/stabilize COCs in soil with cementing chemicals; In situ vitrification.
			Collection and ex situ treatment technologies: Excavate and biological, chemical, and/or physical treatment of soils with COCs detected above acceptable risk thresholds.	Remove soil with excavation equipment, minimize vapor emissions with vapor suppression and/or enclosure, and treat removed COCs with ex situ technologies similar to those listed above (in situ) or thermal destruction such as incineration.
			Collection and disposal technologies: Excavate, haul, and dispose of soils with COCs detected above acceptable risk thresholds.	Remove soil with excavation equipment, minimize vapor emissions with vapor suppression and/or enclosure, haul and dispose removed soil with COCs at another location such as landfill.
Saturated media	Reduce levels of chemicals in groundwater (and chemical sources to groundwater) so that the groundwater could ultimately be used for domestic purposes.	No action.	No action.	No action.
		Institutional controls: Minimize human contact with contaminated soil and groundwater.	Institutional controls, access restrictions, alternate water supply, and monitoring.	Deed restrictions, groundwater use restrictions, fencing and signs, connect to municipal water distribution system, replace or retrofit impacted supply wells, and monitor restriction effectiveness and natural processes.
		Monitor.	Monitor COCs to evaluate effects of native site biological, chemical, and physical processes.	Monitor GW to assess COCs concentration changes and human and ecological exposure potential.
	For environmental protection: Reduce risk to ecological receptors to a level consistent with habitat quality. Remediate contaminants that exceed cleanup goals in groundwater to the extent technically and economically feasible.	Containment.	Containment technologies: Horizontal and vertical barriers, hydraulic containment, and monitoring.	Control migration of COCs with horizontal or vertical barriers (for example, clay/soil, asphalt, concrete, or multimedia/RCRA Cap; slurry or membrane wall; sheet piling; grout injection; extraction/injection wells; hydrofracturing; interceptor trenches) and monitor effectiveness.
		In situ treatment.	In situ treatment technologies: Biological, chemical, and/or physical treatment and monitoring.	Anaerobic, cometabolized aerobic, or aerobic with native and/or non-native bacteria, nutrients and cometabolites; wash/desorb COCs with water, hot water or water w/surfactant, combined with extraction; oxidize/reduce COCs using respective chemical additives in solution with water including passive reactive treatment barriers; solidify/stabilize COCs in soil with cementing chemicals; heating with electrodes to increase hydrolysis, vaporization and mobility; fluid/vapor extraction with in-well air stripping and/or resistive heating; vitrification and monitoring effectiveness.
		Collection.	Collection technologies: Extract groundwater containing COCs with pumps, excavate soil containing COCs, and monitor.	Groundwater: Vertical extraction well, horizontal extraction well, interceptor extraction trench and treat or discharge extracted groundwater and monitor effectiveness. Soil: Remove with excavation equipment (requires dewatering and control of vapor emissions with enclosure).
		Ex situ treatment and disposition.	Ex situ treatment and disposition technologies: Following collection; biological, chemical, and/or physical treatment and disposal.	Following collection options, treat removed COCs in GW and soil with ex situ technologies similar to those listed above (in situ) or thermal destruction such as incineration for soil and GAC, UV oxidation and/or discharge to POTW, injection, surface discharge for GW.

TABLE 2-3
Remedial Action Objectives, General Response Actions, Technology Types, and Process Options for the Development and Screening of Technologies
Frontier Fertilizer Site Feasibility Study, Davis, California

Environmental Media	Remedial Action Objectives (from site characterization)	General Response Actions (for all remedial action objectives)	Remedial Technology Types (for general response actions)	Technology Process Options
Air	Prevent future onsite exposures (workers and/or residents) to chemical vapors in indoor air above health-protective levels (e.g., EPA Region 9 Air PRGs).	Included under unsaturated and saturated media.	None	None
Surface water	Environmental medium not present at site. RAOs, GRAs, technology types, and process options not evaluated.	None	None	None
Sediment	Environmental medium not present at site. RAOs, GRAs, technology types, and process options not evaluated.	None	None	None
Structures	Environmental medium not present at site. RAOs, GRAs, technology types, and process options not evaluated.	None	None	None
Solid wastes	Environmental medium not present at site. RAOs, GRAs, technology types, and process options not evaluated.	None	None	None
Liquid wastes	Environmental medium not present at site. RAOs, GRAs, technology types, and process options not evaluated.	None	None	None
Sludges	Environmental medium not present at site. RAOs, GRAs, technology types, and process options not evaluated.	None	None	None

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
No action	No action	No action	No action is taken.	Required for consideration by NCP.	Yes
Institutional controls	Land use restrictions	Deed restrictions	Establish property use restrictions with a deed to restrict use that would result in exposure to COCs.	Potentially applicable if used in conjunction with other technologies to satisfy RAOs. Dependent on agreement with current and or future land owner.	Yes
Access restrictions	Access restrictions	Restrict access	Control access to areas with COCs with security measures such as fencing and signage.	Potentially applicable if used in conjunction with other technologies to satisfy RAOs. Dependent on agreement with current and or future land owner.	Yes
Monitoring	Monitor COCs and GW head	Monitor COC fate and transport	Natural biological, chemical, and physical processes (such as dilution, dispersion, volatilization, biodegradation, adsorption, and chemical reactions) are allowed to reduce contaminant concentrations to acceptable levels. Short- and/or long-term monitoring including sampling and analysis of soil, soil gas, or GW and analysis of results is performed to evaluate changes in COC concentrations, track progress of attenuation processes, and evaluate effectiveness relative to remedial action objectives.	Does not modify or augment native COC assimilation process(es). Volatile COCs remain available to vapor transport and leaching by rainwater and GW. Monitoring is necessary to demonstrate that contaminant concentrations continue to decrease, to verify that potentially toxic transformation products are not created at levels that are a threat to human health; that the impacted area is not expanding; and, that there are no changes in hydrogeological, geochemical, or microbiological parameters that might reduce the effectiveness of natural attenuation.	Yes
Surface controls	Surface water (rain) control	Grading	Reshaping of topography to prevent run on from adjacent area and resulting ponding that results in infiltration.	Runoff control to minimize erosion would be required.	Yes
		Revegetatation	A systematic revegetation plan includes selection of a suitable plant species, seedbed preparation, seeding/planting, mulching and/or chemical stabilization, fertilization, and maintenance.	Would require irrigation during dry period to maintain vegetative cover. Nutrients are present from past facility activities.	Yes
	Dust and vapor suppression	Water	Water sprayed over area of concern to prevent dust generation.	Typical irrigation system can be used and water from treatment system may be used.	Yes
		Wood chips/rock	Placement of layer of material over media impedes erosion and animal access.	After placement, minimal maintenance required and rainwater can infiltrate reducing quantity of stormwater runoff.	Yes
		Organic agents/polymers/ foams	Organic agents/polymers/foams sprayed over area of concern to prevent dust/vapor generation.	Need to monitor and maintain coverage.	Yes
		Membranes/tarps	Membranes or tarps are spread over area of concern to prevent dust/vapor generation.	Need to monitor and maintain coverage.	Yes
		Hygroscopic agents	Hygroscopic salts absorb moisture into the soil in which they are mixed.	Need to monitor and maintain coverage.	Yes
Containment	Surface vertical barriers	Native soil cap	COCs are covered by a cap constructed from uncontaminated native soil.	Caps do not lessen toxicity or mass of COCs. COC mobility due to advective rainwater infiltration and vapor transport is reduced. Prevents direct contact and erosion while allowing infiltration. Rainwater infiltration may be desirable to provide moisture necessary to support natural biodegradation of the unsat zone contaminants. Does not reduce availability of COCs to GW via water table fluctuations or prevent the horizontal flow of groundwater through contaminated soil. Caps are most effective where most of the underlying waste is above the water table. May not satisfy RCRA technical requirements for cap construction. Cap integrity must not be compromised by present and future land use activities. Caps can be used in conjunction with vertical barriers to further minimize migration.	Yes
		Clay soil cap	COCs are covered by a cap constructed from compacted clay soil.	Similar to “Native Soil Cap Screening Comments” except it further reduces COC mobility due to advective rainwater infiltration and vapor transport due to lower permeability and therefore reduces moisture available for natural biodegradation.	Yes
		Chemical sealant/ stabilizer cap	COCs are covered by a cap constructed from water-dispersible emulsions and/or resins placed over contaminated soil to form a crust that reduces water and wind erosion. Most are nontoxic to plants and animals. Temporary cover only.	Same as “Clay Cap Screening Comments.”	Yes

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
		Synthetic membrane cap	A synthetic membrane placed over prepared soil or geotextile surface that covers impacted area. The membrane is seamed by a variety of methods. The membrane must be compatible with the wastes present and needs to be covered with soil to protect it from ultraviolet light and retard oxidation.	Same as "Clay Cap Screening Comments."	Yes
		Concrete or asphalt cap	COCs are covered by a cap constructed from asphalt or concrete. Paving grade asphalt or concrete placed over the prepared impacted area. Fill settlement must be evaluated in considering a concrete cap design. Sprayed asphalt needs to be covered with soil or opaque reflective paint to protect the asphalt from ultraviolet light and retard oxidation.	Same as "Clay Cap Screening Comments."	Yes
		Multimedia/RCRA cap	COCs are covered by a cap constructed from natural soils, soil admixtures, clay, synthetic membranes, spray-on asphalt, asphalt concrete, or Portland cement concrete and placed over the impacted areas. If properly designed, can meet RCRA requirements.	Same as "Clay Cap Screening Comments," however, can meet RCRA requirements.	Yes
		Cap enhancements	Two ways for cap enhancements are: water harvesting, which uses runoff enhancement to manage water balance and vegetative cover, which reduces soil moisture via plant uptake and evapotranspiration.	Vegetative coverage is designed and maintained to function over and adjacent to the cap. surface grading and drainage is designed and maintained to convey rainwater from the contaminated soil. It may prove to be less costly than a conventional barrier because it uses simple structure or local resources. It is simple in design, easy to install over an existing cap, and easy to remove if other uses for the land emerge in the future.	Yes
	Subsurface vertical barriers	Block displacement	Controlled injection of slurry in notched injection holes produces a horizontal barrier beneath contamination.	Requires injection of slurry or permeability reducing material below contaminants. Would reduce rate of COC migration due to advective GW movement.	Unlikely
		Grout injection	Grout pressure injected at depth through closely spaced drilled holes produces a horizontal barrier beneath contamination.	Requires injection of grout or permeability reducing material below contaminants. Would reduce rate of COC migration due to advective GW movement.	Unlikely
		Ground freezing (cryocell process)	Ground freezing produces a horizontal barrier beneath contamination.	Requires installation of evaporation tubing or cryogenic liquid injection to freeze GW below contaminants. Would reduce rate of COC migration due to advective GW movement.	Unlikely
		Liners	Liners placed to restrict vertical flow can be constructed of the same materials considered for cap construction.	Requires excavation of contaminated soil, installation of liner, and replacement of contaminated soil. Would require management of contaminated soils, including vapor control during excavation.	Unlikely
	Horizontal barriers	Slurry walls (hanging or keyed-in)	Excavated trench around contaminated soil is filled with a slurry of low permeability material, typically soil, bentonite, and water mixture, to provide a barrier to horizontal flow.	Migration of COCs vertically to the GW would not be inhibited. Horizontal and vertical migration could be impeded if the barrier (e.g., slurry wall) were terminated in impermeable material, but a continuous bedrock or clay layer doesn't exist at the base of the contaminated saturated zone to terminate a barrier. If an effective barrier were feasible, it could be combined with in situ treatment technologies or groundwater pumping and/or soil vapor extraction to focus the effect of respective treatment and extraction options on the target volume.	Unlikely
		Vibrating beam	Vibratory force used to advance steel beam into the ground. A relatively thin wall of cement or bentonite is injected as the beam is withdrawn.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
		Permeability-inhibiting curtains	Grout or organic polymer pressure-injected along contamination boundaries in a regular overlapping pattern of drilled holes.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
		Sheet piling	Interlocking steel piles are driven into subsurface along the boundaries of the impacted area.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
		Ground freezing (cryocell process)	Ground freezing technology is used to form a flow-impervious, removable, and fully monitored ice barrier that circumscribes the contaminant source in situ.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
In situ treatment	Permeability enhancement	Pneumatic fracturing	High-pressure injection of air to create self-propped subsurface fracture patterns in the impacted vadose zone that minimize travel time via diffusion. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction.	While it can be used in the saturated subsurface, it is primarily used to fracture soil and rock, including bedrock. The potential exists to open new pathways for the unwanted spread of contaminants. The final location of new fractures is not controllable. Pockets of low permeability may still remain after using this technology. Fracturing is widely used in the petroleum and water-well construction industries. While commercially available, it is an innovative method for use in hazardous waste remediation. Fracturing is an enhancement technology designed to increase the efficiency of other in situ technologies (i.e., vapor or fluid extraction) in difficult soil conditions.	Yes
		Hydraulic fracturing (hydrofracturing)	Hydrofracturing injects pressurized water to increase the permeability of the soil matrix. The process creates fissures that expand away from the well. The fissures are filled with a porous slurry composed of sand and guar gum gel. The sand grains hold the fracture open while an enzyme additive breaks the guar gum down into a thinned fluid. The fluid is pumped from the fracture, leaving permeable subsurface channels. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction.	Same as “Pneumatic Fracturing Screening Comments.”	Yes
		Blast-enhanced fracturing	Blast-enhanced fracturing is used at sites with fractured bedrock formations. Boreholes are drilled, filled with explosives, and detonated to create new highly fractured areas which increase well yields, hydraulic conductivity values, and capture zones.	Same as “Pneumatic Fracturing Screening Comments.”	Yes
		In situ soil mixing (ISSM)	Use of large-diameter augers to physically mix the subsurface soil. Normally done in conjunction with introduction of a fluid or reagent (such as hot air, steam, oxidant, cement, etc.) to promote contaminant treatment or removal. Soil mixing can be combined with vapor extraction, chemical oxidation or reduction, or solidification/stabilization.	ISSM require surface access at all locations where soils are impacted. The technology is particularly suited to shallow applications (i.e., up to about 45 feet below the surface) above the water table. In situ soil mixing for stabilization is commonly used at sites with soil impacted with organics and metals. ISSM with injection of hot air, ambient air, oxidizer, or reducing agents has been demonstrated to remediate clay-rich soils impacted with VOCs in the unsaturated zone.	Yes
	Biological treatment	Anaerobic	An electron donor reagent (substrate) is injected to promote anaerobic conditions, deplete competing electron acceptors, and enhance biodegradation of halogenated organics, principally via biological reductive dehalogenation. Commonly-used substrates include lactate, acetate, alcohols, HRC, molasses, and emulsified vegetable oil.	Existing conditions appear to be more anoxic than oxic; therefore, less effort would be required to support anaerobic bioremediation. Available information indicates that COCs are amenable to anaerobic biodegradation. Existing infrastructure (pump-and-treat system) could be used to facilitate substrate addition and active distribution and mixing.	Yes
		Aerobic	Aerobic biodegradation is enhanced by increasing the concentration of dissolved oxygen in groundwater. Oxygen can be introduced via sparging (air or oxygen), injecting oxygen-enriched water, or by injecting reagents such as hydrogen peroxide or ORC.	Existing conditions tend to be anoxic; therefore, more effort would be required to create and maintain aerobic conditions in the source area target volume. Water from pump-and-treat system could be used to supply oxygen. Some COCs are amenable to aerobic biodegradation whereas available information indicates that others are not.	Unlikely
		Cometabolic aerobic	Oxygen and a primary substrate/inducer are injected to enhance cometabolism of target contaminants. Oxygen creates aerobic conditions. The primary substrate provides carbon and energy for microbial growth and induces microbial production of enzymes that fortuitously initiate transformation of contaminants, such as chlorinated VOCs. Examples of primary substrates include methane, propane, butane, toluene, phenol, and ammonia.	Most experience with this technology is for treatment of chlorinated VOCs. Available information is limited for COCs at this site, so effectiveness is uncertain. The addition of methane or methanol has been demonstrated to degrade chlorinated solvents, such as vinyl chloride (VC) and TCE. Toluene, propane and butane have been used to support the cometabolism of TCE.	Yes
		Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize and/or destroy organic and inorganic contaminants in groundwater and surface water. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phyto-degradation, phyto-volatilization, and phyto-uptake.	Phytoremediation may be applicable for the remediation of COCs. It is not effective for strongly sorbed contaminants (e.g., polychlorinated biphenyls [PCBs]). Poplar trees have been used for TCE, some herbicides, pesticides, and fertilizers. Phytoremediation for extraction or degradation is generally limited to relatively shallow depths of root penetration.	Unlikely

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
	Physical/chemical treatment	Soil vapor extraction (SVE)	Vacuum is applied through wells screened in vadose zone to create a pressure/concentration gradient that induces soil gas including gas-phase COCs to diffuse through soil pore space to the wells. Vacuum emission control system for handling extracted soil gas is typically required. For the soil surface, geomembrane covers are often placed over soil surface to prevent short circuiting and to increase the radius of influence of the wells.	Some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds. Because the process involves the continuous flow of air through the soil, however, it often promotes the in situ biodegradation of low-volatility organic compounds that are aerobically biodegradable. Soils with high organic content or soils that are extremely dry have a high sorption capacity of VOCs. These conditions limit the effectiveness of SVE. Because SVE applies vacuum pressure to subsurface soils, it can raise groundwater levels. As soil becomes saturated, some compounds may dissolve into the water. As a result, groundwater could show increases in contamination levels, especially when this process begins. A potential explosion hazard exists from concentrated fumes released from the vacuum unit.	Unlikely
		Steam or hot air thermally enhanced SVE	Steam or heated air is forced through contaminated volume via injection wells. Soil gas in target volume is collected with SVE and treated ex situ.	Difficult to uniformly distribute steam or hot air in subsurface due to heterogeneous soil permeability, i.e., silts and clays. Difficult to uniformly distribute steam or hot air in subsurface due to the rate heat is lost to the soil versus the rate that steam or hot air can be applied. A potential explosion hazard exists from concentrated fumes released from the vacuum unit.	Unlikely
		Radio frequency heating (RFH) enhanced SVE	The RFH technique heats a discrete volume up to 200ºC to over 300°C using an array of vertical electrodes installed in the soil. RFH enhances SVE in four ways: (1) contaminant vapor pressure and diffusivity are increased by heating; (2) the soil permeability is increased by drying; (3) an increase in the volatility of the contaminant from in situ steam stripping by the water vapor; and (4) a decrease in the viscosity, which improves mobility.	Enhances the recovery of soils impacted with VOCs and SVOCs. Thermally enhanced SVE technologies also are effective in treating some pesticides and fuels, depending on the temperatures achieved by the system. After application of this process, subsurface conditions are excellent for biodegradation of residual contaminants. Removal of aliphatics is limited to about 90 percent effectiveness. A potential explosion hazard exists from concentrated fumes released from the vacuum unit.	Unlikely
		Media heating w/ electrical energy enhanced SVE	Electrical resistance heating or conduction heating increases media temperature using electric energy delivered through electrodes placed in media. Elevated temperature promotes in situ chemical reactions such as hydrolysis and volatizing of target contaminants.	Heating enhances treatment of media impacted with VOCs and SVOCs. Bench-scale tests demonstrated that heating is effective on lower volatility compounds. The presence of buried metal objects presents a safety hazard. The subsurface should be mapped before the heating system is installed. Optimum implementation temperature is determined by balancing cost and risks, although typically not much higher than boiling point of water. Water may need to be added to media to maintain conduction since dry soil is more resistive to electricity.	Yes
		Dynamic underground stripping (DUS) enhanced SVE	A combination of in situ steam injection, direct electrical resistance heating, and fluid extraction to enhance COC removal from the subsurface. It is very similar to enhanced SVE, except that it also treats impacted groundwater. Steam is injected at the periphery of a impacted area to heat permeable subsurface areas, vaporize volatile compounds bound to the soil, and drive contaminants to centrally located vacuum extraction wells.	Demonstrated full scale on fuel hydrocarbons bound in the saturated and unsaturated soil matrix. Laboratory tests indicate effectiveness for a variety of volatile and semi-volatile compounds including diesel fuel and both light nonaqueous phase liquids (LNAPLs) and dense nonaqueous phase liquids (DNAPLs). A demonstration in California found DUS/hydrous pyrolysis oxidation (HPO) to degrade wood preservatives and PCBs. The process uses a large amount of energy. Steam adds significant amounts of water to the subsurface. Precautions must be taken so as not to mobilize contaminants past the capture zones.	Unlikely
		Electrokinetic separation	Electrokinetic remediation is a process in which a low-voltage direct-current electric field is applied across a section of impacted soil. The principle of electrokinetics remediation is similar to a battery. After electrodes (a cathode and anode) are introduced and charged, particles (e.g., ions) are mobilized by the electric current. Ions and water move toward the electrodes.	The effectiveness is sharply reduced for wastes with a moisture content of less than 10 percent. Maximum effectiveness occurs if the moisture content is between 14 and 18 percent. In unsaturated soils, the addition of water could potentially wash contaminants out of the area of influence. The presence of buried metallic or insulating material can induce variability in the electrical conductivity of the soil. Metallic electrodes may dissolve as a result of electrolysis and introduce corrosive products into the soil. In development/demonstration phase and not widely available commercially.	Unlikely
		Soil flushing (washing)	Water is applied to soil to raise the water table into the contaminated soil zone to desorb and mobilize COCs. Contaminants are transferred into groundwater, which is extracted from wells or infiltration trenches for treatment and/or discharge.	Requires saturating target volume via ponding water on surface or shallow infiltration trenches to facilitate advective movement of water through entire target volume. The rate that the water can move through soil pore space controls duration of process. Pressurizing water in shallow injection wells can increase flow rate. Does not degrade COCs; therefore, requires extraction of groundwater containing COCs and surfactant. Could be combined with biological and/or chemical treatment to reduce treatment duration.	Yes

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
		Hot water soil flushing	Hot water is applied to the soil via soil flushing application techniques to enhance the rate of COC desorption. Contaminants are transferred into groundwater, which is extracted from wells or infiltration trenches for treatment and/or discharge. Increased COC volatilization would occur, which may require vapor extraction and treatment.	Same as “Soil Flushing Screening Comments.” Also, it’s difficult to uniformly distribute hot water in subsurface due to the rate heat is lost to the soil versus the rate that hot water can be applied.	Unlikely
		Surfactant enhanced recovery	Wash/flush soil with solution of water and surfactant, e.g., emulsifiers such as detergents, that enhances the physical displacement, solubilization, or desorption of COCs. The solution is thoroughly swept through target volume and is then extracted from wells or infiltration trenches for ex situ treatment and/or discharge.	Same as “Soil Flushing Screening Comments.” Effect of surfactant on the soil permeability and groundwater must be considered. Potential exists for washing the COCs beyond the capture zone. Surfactant may reduce ex situ GAC treatment effectiveness, and an additional treatment process may be required for the surfactant. May be permitting issues associated with surfactant injection.	Unlikely
		Solvent/cosolvent enhanced recovery	Washing/flushing using water plus a miscible organic solvent such as alcohol applied to the vadose zone and thoroughly swept thru target volume to promote contaminant recovery, then extracted from wells or infiltration trenches for ex situ treatment and/or discharge. Benzene, toluene, xylene, CCl_4, etc., are identified solvents for COCs although they may not be appropriate for application.	Same as “Soil Flushing Screening Comments.” Effect of solvent on the soil permeability and groundwater must be considered. Potential exists for washing the COCs beyond the capture zone. Solvent may reduce GAC effectiveness. Significant DNAL has not been detected.	Unlikely
		Reduction	Reducing agents are applied to the contaminated zone as an aqueous solution or slurry to reduce target contaminants to non-hazardous, less toxic, or less mobile chemicals. Commonly-used reducing agents include sodium dithionite, ferrous sulfate, and zero valiant iron (ZVI).	Chemical reduction (dehalogenation) has been shown to be effective for chlorinated solvents such as TCE and PCE and some metals. Requires evaluation of reducing agent effectiveness for decomposing COCs under Site-specific conditions.	Yes
		Oxidation	One or more oxidizing agent is injected into the contaminated zone to oxidize target contaminants to non-hazardous, less toxic, or less mobile chemicals. Commonly used reagents include hydrogen peroxide, potassium permanganate, sodium persulfate, and Fenton’s reagent (hydrogen peroxide and ferrous sulfate). Less common oxidants include ozone and chlorine compounds.	Chemical oxidation of single bonded halogens (alkanes) is generally more difficult than oxidation of alkenes, and may require a more aggressive oxidant or combination of oxidants. Technology normally requires testing to evaluate effectiveness and appropriate dose. Often requires more than one application for thorough treatment. Limited experience with COCs such as EDB, DBCP, DCP, TCP, and CCl_4.	Unlikely
	Immobilization	Solidification/stabilization	Contaminants are physically bound or enclosed within a stabilized mass or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility.	Requires special equipment to apply and mix solidification chemicals into soil and control volatile emissions generated during the process. May not prevent migration of volatile COCs; therefore, long-term emission control would be required.	Yes
		In situ vitrification	Heat is applied to contaminated soils until a solid inert substance is produced. Basically the soil is melted to form a glass-like, monolithic block. Vapor extraction and treatment is required.	High cost with potential toxic off-gases. This technology experienced some disasters in the past, but the problems may have been corrected. Soil subsidence may require backfilling to maintain grade.	Unlikely
Collection	Removal	Excavate hot spots	Remove soil with excavation equipment; minimize vapor emissions with vapor suppression and/or enclosure. The excavated void is backfilled with imported clean soil or treated soil.	Emission of volatile COCs would occur. Excavated soil would require treatment and/or disposal. Water table ranges from ~10 to 30 feet bgs. The highest COC concentrations have been detected in the water table transition zone. Would have to remove uncontaminated and less contaminated soil before excavating subject soil. Resulting wastes must be managed, possibly as hazardous.	Yes
Ex situ treatment	Biological	Biopile/aerobic	Excavated soils are mixed with soil amendments and placed on a treatment area that includes an irrigation system, a leachate collection system, and some form of aeration. The treatment area will generally be covered or contained with an impermeable liner to minimize the risk of COCs leaching out of impacted soil. Soil piles and cells commonly have an air distribution system buried under the soil to pass air through the soil either by vacuum or by positive pressure.	Requires large land area. Biopile treatment has been applied to treatment of non-chlorinated VOCs and fuel impacted soil. Chlorinated VOCs, SVOCs, and pesticides can also be treated, but process effectiveness varies and is only applicable to compounds amenable to aerobic biodegradation. Duration of O&M may last a few weeks to several months. Resulting wastes must be managed, possibly as hazardous. Off-gas may require treatment.	Unlikely
		Biopiles/anaerobic	Same as aerobic process except material is maintained in anoxic state (no aeration).	Requires large land area. Anaerobic biopile process is similar to anaerobic in situ treatment process. Resulting wastes must be managed, possibly as hazardous waste.	Yes

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
		Composting/aerobic	Impacted soil is excavated and mixed with bulking agents and proper organic amendments such as wood chips, hay, manure, and vegetative (e.g., potato) wastes to ensure adequate porosity and provide a balance of carbon and nitrogen to promote thermophilic, microbial activity. There are three process designs used in composting: aerated static pile composting (compost is formed into piles and aerated with blowers or vacuum pumps), mechanically agitated in-vessel composting (compost is placed in a reactor vessel where it is mixed and aerated), and windrow composting (compost is placed in long piles known as windrows and periodically mixed with mobile equipment).	Requires large land area. Not proven for all COCs. Preprocessing of soils typically required to facilitate treatment. Excavation of impacted soils is required and may cause the uncontrolled release of COCs and dust. Windrow composting has the highest fugitive dust emissions (i.e., windblown dust and particulate). Depending on soil type, these emissions may have to be controlled. Composting results in an increase in material because of the addition of amendment material. Resulting solids must be managed, possibly as hazardous waste.	Unlikely
		Landfarming/aerobic and volatilization	Contaminated soil is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.	Requires large land area, VOC emissions must be considered. Preprocessing of soils typically required to facilitate treatment. Resulting wastes must be managed, possibly as hazardous.	Unlikely
	Chemical/physical treatment	Reduction	Same chemical process as in situ reduction process only soil is processed ex situ. Soil excavation, reducing agent distribution and soil mixing equipment required. Dehalogenation is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.	Same as "In situ Reduction Screening Comments" only soil is processed ex situ. Specialized equipment required for reducing agent application and soil mixing. VOC emissions must be controlled. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Oxidation	Same chemical process as in situ oxidation process only soil is processed ex situ. Soil excavation, oxidizer distribution, and soil mixing equipment required.	Same as "In situ Reduction Screening Comments" comments only soil is processed ex situ. Specialized equipment required for oxidizer application and soil mixing. VOC emissions must be controlled. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Soil washing	COCs sorbed onto fine particles are separated from the bulk soil in an aqueous-based system on the basis of particle size. Addition of heat, a leaching agent, surfactant, or chelating agent may be added to increase performance.	Specialized equipment required for handling soil and washing agent. Used wash water and soil vapor typically require treatment. May not be applicable to soils predominated by silts and clays. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Solidification/stabilization	COCs sorbed onto fine particles are physically bound or enclosed within a stabilized mass or chemical reactions are induced between the stabilizing agent and contaminates to reduce their mobility.	Specialized equipment required to apply and mix solidification chemicals into soil and control volatile emissions and dust generated during the process. May not prevent migration of volatile COCs. Resulting solids must be managed, possibly as hazardous waste.	Unlikely
		Solar detoxification	A vacuum is applied to contaminated soil. Extracted contaminants are condensed, mixed with a catalyst, and fed through an illuminated reactor. Contaminants are destroyed by ultraviolet energy from the sun.	Unless using UV lamps, process can only be used during the day. Can produce volatile emissions. Difficult to determine if sunlight or volatilization is responsible for reducing contaminant concentrations. Resulting solids must be managed, possibly as hazardous waste.	Unlikely
		Incineration	High temperatures are used to combust organic contaminants in the presence of oxygen.	Off-gas may require treatment. Limited public acceptance. Typically costly as compared to other potentially feasible technologies. Resulting solids must be managed, possibly as hazardous waste.	Unlikely
		Pyrolysis	Thermal decomposition of contaminants in the absence of sufficient oxygen for complete oxidation. Contaminants are transformed into gaseous components, liquid, and solid (coke).	Gases produced may require further treatment. Potential to produce toxic off-gases. Limited public acceptance. Preprocessing of soils typically required to facilitate treatment. Typically more costly then other potentially feasible technologies. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Hot gas decontamination/ thermal desorption	Contaminants are thermally desorbed from excavated soil at increased temperatures. The off-gas is conveyed to a treatment system.	Requires specialized equipment to handle soil and control vapor emissions and exhaust. Typically combined with gas incinerator and particulate filter to treat exhaust. Typically more costly then other potentially feasible technologies. Resulting wastes must be managed, possibly as hazardous waste.	Yes

TABLE 2-4
Unsaturated Media (Soil Above the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Implementability Screening Comments	Technical Implementability
Re-use	Re-use	Re-use	Contaminated soils and debris are treated to acceptable levels and replaced in original excavation or alternate location.	Requires the excavation remain open until soil is treated or that soil be spread in thin lift over larger area or mounded, if remaining onsite. Site re-use may be impacted. Offsite re-use options depend on soil characteristics, regulatory listing, and finding interested party.	Yes
Disposition	Offsite disposition	Offsite disposal	Contaminated soil and debris are treated and/or disposed of at an offsite RCRA treatment storage and disposal facility.	Requires characterization to confirm shipping, and treatment and/or disposal requirements. Generator remains liable for the waste, including recipient TSDF cleanup.	Yes
Secondary emission treatment	Air emissions/off-gas treatment	Vapor-phase carbon adsorption	Off-gases are pumped through columns containing activated carbon to which dissolved organic contaminants adsorb.	Proven effective for organic contaminants. Can treat down to very low levels.	Yes
		Thermal/catalytic/ oxidation	Organic contaminants are destroyed in a high temperature combustor.	Effective at treating organic chemicals. Limited public acceptance.	Unlikely
		Bio-filtration	Vapor-phase organic contaminants are pumped through a soil bed and sorbed to the solid surface where they are degraded by microorganisms in the soil.	Aerobic process has not been proven effective at degrading the COCs.	Unlikely
		High energy destruction	The high energy destruction process uses high-voltage electricity to destroy VOCs at room temperature.	Not feasible, unproven for COCs. Questionable reliability.	Unlikely
		Membrane separation	This organic vapor/air separation technology involves the preferential transport of organic vapors through a nonporous gas separation membrane.	Not feasible, unproven for COCs.	Unlikely

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
No action	No action	No action	No action is taken.	Required for consideration by NCP.	Yes
Institutional controls	Land use restrictions	Deed restrictions	Establish property use restrictions with a deed for properties over area covering contaminated groundwater that would restrict access to groundwater.	Potentially applicable if used in conjunction with other technologies to satisfy RAOs.	Yes
		Groundwater use restrictions	Same as deed restrictions.	Potentially applicable if used in conjunction with other technologies to satisfy RAOs.	Yes
	Alternate water supply	City water supply	Modification of municipal well system to serve potentially affected residents.	Prevents human exposure to contaminated GW if municipal wells become affected.	Yes
		New community wells	Install new wells if existing wells become affected.	Prevents human exposure to contaminated GW if wells become affected.	Yes
Monitoring	Monitor COCs and GW head	Monitored COC fate and transport	Natural biological, chemical, and physical processes (such as dilution, dispersion, volatilization, biodegradation, adsorption, and chemical reactions) are allowed to reduce contaminant concentrations to acceptable levels. Short- and/or long-term monitoring including sampling and analysis of GW and analysis of results is performed to evaluate changes in COC concentrations, track progress of attentuation processes, and evaluate effectiveness relative to RAOs.	Does not modify native COC degradation process(es). Monitoring is necessary to demonstrate that contaminant concentrations continue to decrease; to verify that potentially toxic transformation products are not created at levels that are a threat to human health; that the impacted area is not expanding; and, that there are no changes in hydrogeological, geochemical, or microbiological parameters that might reduce the effectiveness of natural attenuation.	Yes
Containment	Horizontal barriers	Slurry walls (hanging or keyed-in)	Construction of a grout/slurry wall to contain contaminants from horizontal migration. Excavated trench around contaminated soil is filled with a slurry of low permeability material, typically soil, bentonite, and water mixture, to provide a barrier to horizontal flow. Requires bedrock or clay to key into, to prevent horizontal and vertical migration.	Horizontal and vertical migration could be impeded if the barrier (e.g., slurry wall) were terminated in impermeable material, but a continuous bedrock or clay layer doesn't exist at the base of the contaminated saturated zone to terminate a barrier. If an effective barrier were feasible, it could be combined with in situ treatment technologies or groundwater pumping and/or soil vapor extraction to focus the effect of respective treatment and extraction options on the target volume.	Unlikely
		Vibrating beam	Vibratory force used to advance steel beam into the ground. A relatively thin wall of cement or bentonite is injected as the beam is withdrawn.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
		Permeability-inhibiting curtains	Grout or organic polymer pressure-injected along contamination boundaries in a regular overlapping pattern of drilled holes.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
		Sheet piling	Interlocking steel piles are driven into subsurface along the boundaries of the impacted area.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
		Ground freezing (cryocell process)	Ground freezing technology is used to form a flow-impervious, removable, and fully monitored ice barrier that circumscribes the contaminant source in situ.	Same as "Slurry Wall Screening Comments." Continuity of wall is difficult to achieve and leakage may occur.	Unlikely
	Hydraulic containment	Extraction well	Wells pumped to create gradients that result in contaminated GW migration in the desired direction. Extracted GW could be treated ex situ and/or applied to the soil to enhance in situ treatment.	Extraction system and ex situ treatment system exist at the site and appear to control horizontal migration of most, if not all, contaminated GW. Evaluation of fate of COCs outside horizontal control zone and migrating vertically from the control zone required to determine if modifications are necessary.	Yes
		Interceptor trenches	Excavate trenches and install collection system in porous media backfill to maximize hydraulic control of contaminated water in the target volume.	Specialized trenching equipment has been used to installed trenches to total depths of 100 feet bgs in unconsolidated formations. Trenches provide most comprehensive collection of target GW. May not prevent all vertical migration of target GW.	Yes

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
In situ treatment	Permeability enhancement	Pneumatic fracturing	High-pressure injection of air to create self-propped subsurface fracture patterns in the target zone that minimize travel time via diffusion. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction.	While it can be used in the saturated subsurface, it is primarily used to fracture soil and rock, including bedrock. The potential exists to open new pathways for the unwanted spread of contaminants (e.g., dense nonaqueous phase liquids). The final location of new fractures is not controllable. Pockets of low permeability may still remain after using this technology. Fracturing is widely used in the petroleum and water-well construction industries. While commercially available, it is an innovative method for use in hazardous waste remediation. Fracturing is an enhancement technology designed to increase the efficiency of other in situ technologies (i.e., vapor or fluid extraction) in difficult soil conditions.	Yes
		Hydraulic fracturing (hydrofracturing)	Hydrofracturing injects pressurized water to increase the permeability the soil matrix. The process creates fissures that expand away from the well. The fissures are filled with a porous slurry composed of sand and guar gum gel. The sand grains hold the fracture open while an enzyme additive breaks the guar gum down into a thinned fluid. The fluid is pumped from the fracture, leaving permeable subsurface channels. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction.	Same as “Pneumatic fracturing Screening Comments.”	Yes
		Blast-enhanced Fracturing	Blast-enhanced fracturing is used at sites with fractured bedrock formations. Boreholes are drilled, filled with explosives, and detonated to create new highly fractured areas which increase well yields, hydraulic conductivity values, and capture zones.	Same as “Pneumatic fracturing Screening Comments.” Unlikely that process could be permitted and would receive community acceptance. Would likely disrupt other site activities.	Unlikely
		In situ soil mixing (ISSM)	Use of large-diameter augers to physically mix the subsurface soil. Normally done in conjunction with introduction of a fluid or reagent (such as hot air, steam, oxidant, cement, etc.) to promote contaminant treatment or removal. Soil mixing can be combined with vapor extraction, chemical oxidation or reduction, or solidification/stabilization.	ISSM requires surface access at all locations where soils are impacted. The technology is particularly suited to shallow applications (i.e., up to about 45 feet below the surface) above the water table. In situ soil mixing for stabilization is commonly used at sites with soil impacted with organics and metals. ISSM with injection of hot air, ambient air, oxidizer or reducing agents has been demonstrated to remediate clay-rich soils impacted with VOCs in the unsaturated zone.	Yes
	Biological treatment	Anaerobic	An electron donor reagent (substrate) is injected to promote anaerobic conditions, deplete competing electron acceptors, and enhance biodegradation of halogenated organics, principally via biological reductive dehalogenation. Commonly used substrates include lactate, acetate, alcohols, HRC, molasses, and emulsified vegetable oil.	Existing conditions appear to be more anoxic than oxic; therefore, less effort would be required to support anaerobic bioremediation. Available information indicates that COCs are amenable to anaerobic biodegradation. Existing infrastruction (pump-and-treat system) could be used to facilitate substrate addition and active distribution and mixing.	Yes
		Aerobic	Aerobic biodegradation is enhanced by increasing the concentration of dissolved oxygen in groundwater. Oxygen can be introduced via sparging (air or oxygen), injecting oxygen-enriched water, or by injecting reagents such as hydrogen peroxide or ORC.	Existing conditions tend to be in anoxic; therefore, more effort would be required to create and maintain aerobic conditions in the source area target volume. Water from pump-and-treat system could be used supply oxygen. Some COCs are amenable to aerobic biodegradation whereas available information indicates that others are not.	Unlikely
		Cometabolic aerobic	Oxygen and a primary substrate/inducer are injected to enhance cometabolism of target contaminants. Oxygen creates aerobic conditions. The primary substrate provides carbon and energy for microbial growth and induces microbial production of enzymes that fortuitously initiate transformation of contaminants, such as chlorinated VOCs. Examples of primary substrates include methane, propane, butane, toluene, phenol, and ammonia.	Most experience with this technology is for treatment of chlorinated VOCs. Available information is limited for COCs at this site, so effectiveness is uncertain. The addition of methane or methanol has been demonstrated to degrade chlorinated solvents, such as VC and TCE. Toluene, propane, and butane have been used to support the cometabolism of TCE.	Yes
		Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize and/or destroy organic and inorganic contaminants in groundwater and surface water. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phyto-degradation, phyto-volatilization, and phyto-uptake.	Phytoremediation may be applicable for the remediation of COCs. It is not effective for strongly sorbed contaminants (e.g., PCBs). Poplar trees have been used for TCE, some herbicides, pesticides, and fertilizers. Phytoremediation for extraction or degradation is generally limited to relatively shallow depths of root penetration, which does not extend into the sites target area.	Unlikely

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
	Physical/chemical treatment	Chemical reduction	Reducing agents are applied to the contaminated zone as an aqueous solution or slurry to reduce target contaminants to non-hazardous, less toxic, or less mobile chemicals. Commonly used reducing agents include sodium dithionite, ferrous sulfate, and ZVI.	Chemical reduction (dehalogenation) has been shown to be effective for chlorinated solvents such as TCE and PCE and some metals. Requires evaluation of reducing agent effectiveness for decomposing COCs under Site-specific conditions.	Yes
		Chemical oxidation	One or more oxidizing agent is injected into the contaminated zone to oxidize target contaminants to non-hazardous, less toxic, or less mobile chemicals. Commonly-used reagents include hydrogen peroxide, potassium permanganate, sodium persulfate, and Fenton's reagent (hydrogen peroxide and ferrous sulfate). Less common oxidants include ozone and chlorine compounds.	Chemical oxidation of single bonded halogens (alkanes) is generally more difficult than oxidation of alkenes, and may require a more aggressive oxidant or combination of oxidants. Technology normally requires testing to evaluate effectiveness and appropriate dose. Often requires more than one application for thorough treatment. Limited experience with COCs such as EDB, DBCP, DCP, TCP and CCl_4.	Unlikely
		HPO	Thermal oxidation that uses steam and oxygen to oxidize contaminants.	Limited experience, none with pesticides. Oxidizes other organic carbon materials that are present.	Unlikely
		Air sparging	Air is injected into saturated matrices to remove contaminants through volatilization and increased biological activity.	Some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds. Feasible for some COCs (CCl_4) if aquifer characteristics are suitable for air sparging. Requires control of soil gas, e.g., SVE, to prevent volatile COC emissions.	Unlikely
		Bioslurping	Combines soil venting and vacuum-enhanced free-product recovery, to achieve vapor extraction, aerobic biodegradation, and LNAPL recovery. Treatment is focused at water table interface and capillary fringe.	Generally most applicable when LNAPL and aerobically biodegradable contaminants are present (e.g., fuel hydrocarbons). LNAPL is not present at the site. Some of the COCs are resistant to aerobic biodegradation. Some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds.	Unlikely
		Dual phase extraction	A vacuum system is applied to simultaneously remove various contaminated groundwater and vapors from the subsurface.	Some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds and halogenated COC not amenable to aerobic degradation.	Unlikely
		Passive reactive treatment barriers	ZVI or media with reactive components are placed in the path of contaminated groundwater via a trench, closely placed borings or cone penetration injection that allow water flow through the barrier, which reduces the contaminants.	ZVI has been proven to be effective at degrading chlorinated solvents, e.g., TCE, but not effective at degrading COCs. ZVI is oxidized as target chemicals are reduced. Biological stimulating medium appears to be effective at reducing COCs. Evaluation of effectiveness barrier media at reducing COCs is necessary.	Yes
		In-well air stripping	Uses a double screened well, air injection, and pumping water in the well to act as an in situ air stripper. The vapor stream is then treated ex situ by other technologies.	Some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds.	Unlikely
		DUS, SVE	A combination of in situ steam injection, direct electrical resistance heating, and fluid extraction to enhance COC removal from the subsurface. It is very similar to enhanced SVE, except that it also treats impacted groundwater. Steam is injected at the periphery of an impacted area to heat permeable subsurface areas, vaporize volatile compounds bound to the soil, and drive contaminants to centrally located vacuum extraction wells. Dewatering the saturated zone by pumping prior to steam injection may be required.	Demonstrated full scale on fuel hydrocarbons bound in the saturated and unsaturated soil matrix. Laboratory tests indicate effectiveness for a variety of volatile and semi-volatile compounds including diesel fuel and both LNAPLs and DNAPLs. A demonstration in California found DUS/HPO to degrade wood preservatives and PCBs. The process uses a large amount of energy. Steam adds significant amounts of water to the subsurface. Precautions must be taken so as not to mobilize contaminants past the capture zones.	Unlikely
		Media heating w/ electrical energy, enhanced SVE	Electrical resistance heating or conduction heating increases media temperature using electric energy delivered through electrodes placed in media. Elevated temperature promotes in situ chemical reactions such as hydrolysis and volatization of target contaminants.	Heating enhances treatment of media impacted with VOCs and SVOCs. Bench-scale tests demonstrated that heating is effective on lower volatility compounds. The presence of buried metal objects presents a safety hazard. The subsurface should be mapped before the heating system is installed. Optimum implementation temperature is determined by balancing cost and risks, although typically not much higher than boiling point of water. Water may need to be added to media to maintain conduction since dry soil is more resistive to electricity.	Yes

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
		Surfactant enhanced recovery	Wash/flush target volume with solution of water and surfactant, e.g., emulsifiers such as detergents, that enhances the physical displacement, solubilization, or desorption of COCs. The solution is thoroughly swept through target volume and is then extracted from wells or infiltration trenches for ex situ treatment and/or discharge.	Does not degrade COCs; therefore, requires extraction of groundwater containing COCs and surfactant. Effect of surfactant on the soil permeability and groundwater must be considered. Potential exists for mobilizing the COCs beyond the capture zone. Surfactant may reduce ex situ GAC treatment effectiveness, and an additional treatment process may be required for the surfactant. May be permitting issues associated with surfactant injection.	Unlikely
		Solvent/cosolvent enhanced recovery	Washing/flushing target volume using water plus a miscible organic solvent such as alcohol applied to the vadose zone and thoroughly swept through target volume to promote contaminant recovery, then extracted from wells or infiltration trenches for ex situ treatment and/or discharge. Benzene, toluene, xylene, CCl_4, etc., are identified solvents for COCs although they may not be appropriate for application.	Does not degrade COCs; therefore, requires extraction of groundwater containing COCs and surfactant. Effect of solvent on the soil permeability and groundwater must be considered. Potential exists for mobilizing the COCs beyond the capture zone. Solvent may reduce ex situ GAC treatment effectiveness, and an additional treatment process may be required for the solvent. Significant DNAPL has not been detected. Permitting issues associated with solvent injection are likely.	Unlikely
	Immobilization	Solidification/stabilization	Contaminants are physically bound or enclosed within a stabilized mass or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility.	Requires special equipment to apply and mix solidification chemicals into soil and control volatile emissions generated during the process. May not prevent migration of volatile COCs; therefore, long-term emission control would be required.	Yes
		In situ vitrification	Heat is applied to contaminated soils until a solid inert substance is produced. Basically the soil is melted to form a glass-like, monolithic block. Vapor extraction and treatment is required.	High cost with potential toxic off-gases. This technology experienced some disasters in the past, but the problems may have been corrected. Soil subsidence may require backfilling to maintain grade.	Unlikely
Collection	Removal (soil)	Excavate hot spots	Remove contaminated soil with excavation equipment, minimize vapor emissions with vapor suppression and/or enclosure. The excavated void is backfilled with imported clean soil or treated soil.	Excavation below water table requires dewatering and vapor emission control of volatile COCs. Removed water and excavated soil would require treatment and/or disposal. Water table ranges from ~10 feet to 30 feet bgs. The highest COC concentrations have been detected in the water table transition zone. Would have to remove uncontaminated and less contaminated soil before excavating subject soil. Resulting wastes must be managed, possibly as hazardous.	Yes
	Removal (GW)	Extract GW	Remove contaminated GW with pumping from wells or trench. Extracted water is treated and/or discharged.	Removed water would require treatment and/or disposal depending on COC concentrations and usage or disposal options. Highest COC concentrations have been detected in the S-1 and S-2 zones, although COC concentrations above MCLs have also been detected in the A-1 zone. Water table ranges from ~10 to 30 feet bgs and potentiometric surfaces vary depending on the zone and seasonal variations. Resulting wastes must be managed, possibly as hazardous. P&T systems often require long-term operation to meet RAOs for hydrophobic contaminants because of soil sorption and dissolution of NAPL, the typical "plateauing" of extracted concentrations/mass.	Yes
Ex situ treatment	Biological treatment	Biopile/aerobic	Excavated soils are mixed with soil amendments and placed on a treatment area that includes an irrigation system, a leachate collection system, and some form of aeration. The treatment area will generally be covered or contained with an impermeable liner to minimize the risk of COCs leaching out of impacted soil. Soil piles and cells commonly have an air distribution system buried under the soil to pass air through the soil either by vacuum or by positive pressure.	Requires large land area. Biopile treatment has been applied to treatment of non-chlorinated VOCs and fuel impacted soil. Chlorinated VOCs, SVOCs, and pesticides can also be treated, but process effectiveness varies and is only applicable to compounds amenable to aerobic biodegradation. Duration of operation and maintenance may last a few weeks to several months. Resulting wastes must be managed, possibly as hazardous. Off-gas may require treatment.	Unlikely
		Biopiles/anaerobic	Same as aerobic process except material is maintained in anoxic state (no aeration).	Requires large land area. Anaerobic biopile process is similar to anaerobic in situ treatment process. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Composting/aerobic	Impacted soil is excavated and mixed with bulking agents and proper organic amendments such as wood chips, hay, manure, and vegetative (e.g., potato) wastes to ensure adequate porosity and provide a balance of carbon and nitrogen to promote microbial activity. There are three process designs used in composting: aerated static pile composting (compost is formed into piles and aerated with blowers or vacuum pumps—this is the same as the Biopile/Aerobic process described above), mechanically agitated in-vessel composting (compost is placed in a reactor vessel where it is mixed and aerated), and windrow composting (compost is placed in long piles known as windrows and periodically mixed with mobile equipment).	Requires large land area. Not proven for all COCs. Preprocessing of soils typically required to facilitate treatment. Excavation of impacted soils is required and may cause the uncontrolled release of COCs and dust. Windrow composting has the highest fugitive dust emissions (i.e., windblown dust and particulate). Depending on soil type, these emissions may have to be controlled. Composting results in an increase in material because of the addition of amendment material. Resulting solids must be managed, possibly as hazardous waste.	Unlikely

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
		Landfarming/aerobic and volatilization	Contaminated soil is excavated, applied into lined beds, and periodically turned over or tilled to aerate the waste.	Requires large land area. Not proven for all COCs. VOC emissions must be considered. Preprocessing of soils typically required to facilitate treatment. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Phytoremediation	Uses plants to treat extracted soil and/or groundwater in vessels or ponds.	Requires large area for soil and GW treatment and less area for GW only. Weather affects plant growth, which affects the rate of assimilation. Volatilization and solar radiation also affect COCs.	Unlikely
	Physical/chemical treatment	Granular activated carbon (liquid phase)	Groundwater is pumped through columns containing activated carbon to which dissolved organic contaminants adsorb.	GAC is currently used to remove COCs to below detectable levels. Best available technology for removing low COC concentrations from water.	Yes
		Air stripping (liquid phase)	Groundwater and air are pumped through a vessel (usually in a countercurrent arrangement) to promote partitioning of volatile contaminants into a gas phase. Air stripping is usually done in a packed tower or tray stripper. Off-gas treatment is normally required.	Some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds. Heating the water may increase COC vaporization.	Unlikely
		Ion exchange (liquid phase)	Removes ions from the aqueous phase by exchange with counter ions on the exchange medium.	Not feasible, not amenable to physical properties of COCs. (Used for metals.)	No
		Precipitation coagulation/ flocculation (liquid phase)	Transforms contaminants into an insoluble solid facilitating sedimentation or filtration.	Not feasible, not amenable to physical properties of COCs. (Used for metals.)	No
		Phase separation (liquid phase)	Used to separate nonaqueous-phase liquids from water. Oil-water separators are an example of this technology.	Applicable for removable NAPL mixture.	No
		Sprinkler irrigation (liquid phase)	Involves the pressurized distribution of VOC-laden water through a standard sprinkler irrigation system.	Form of air stripping and since some of the COCs, e.g., DBCP, EDB and TCP, have relatively low Henry's constants, indicating that air stripping would not be an effective means of treatment for these compounds. Heating the water may increase COC vaporization and may result in uncontrolled release of COC vapors. Could have permitting issues associated with air emissions.	Unlikely
		Adsorption/absorption (liquid phase)	In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase.	Adsorption material is often not re-usable, and can get costly if contaminant is at high concentrations.	No; LGAC is best available process
		Reduction (liquid phase)	Same chemical process as in situ reduction process only GW is processed ex situ. GW is extracted, reducing agent is added and mixed with liquid processing equipment for required contact time.	Same as "In situ Reduction Screening Comments" only GW is processed ex situ. Liquid processing equipment is required for reducing agent application and mixing with GW. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Oxidation (liquid phase)	Same chemical process as in situ oxidation process only GW is processed ex situ. GW is extracted, oxidizing agent is added and mixed with liquid processing equipment for required contact time. Often uses a combination of oxidants, such as UV light, hydrogen peroxide, and ozone.	Same as "In situ Oxidation Screening Comments" only GW is processed ex situ. Liquid processing equipment is required for oxidizing agent application and mixing with GW. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Reduction	Same chemical process as in situ reduction process only soil is processed ex situ. Soil excavation, reducing agent distribution and soil mixing equipment required. Dehalogenation is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants.	Same as "In situ Reduction Screening Comments" only soil is processed ex situ. Specialized equipment required for reducing agent application and soil mixing. VOC emissions must be controlled. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Oxidation	Same chemical process as in situ oxidation process only soil is processed ex situ. Soil excavation, oxidizer distribution and soil mixing equipment required.	Same as "In situ Oxidation Screening Comments" only soil is processed ex situ. Specialized equipment required for oxidizer application and soil mixing. VOC emissions must be controlled. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Solar/ultraviolet light detoxification	A vacuum is applied to excavated soil. Extracted contaminants are condensed, mixed with a catalyst, and fed through an illuminated reactor. Contaminants are destroyed by ultraviolet energy from the sun.	Unless using UV lamps, process can only be used during the day. Can produce volatile emissions. Difficult to determine if sunlight or volatilization is responsible for reducing contaminant concentrations. Resulting solids may require disposal as hazardous waste.	Unlikely

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
		Soil washing	COCs sorbed onto fine particles are separated from the bulk soil in an aqueous-based system on the basis of particle size. Addition of heat, a leaching agent, surfactant, or chelating agent may be added to increase performance.	Specialized equipment required for handling soil and washing agent. Used wash water and soil vapor typically require treatment. May not be applicable to soils predominated by silts and clays. Resulting wastes must be managed, possibly as hazardous waste.	Unlikely
		Solidification/stabilization	COCs sorbed onto fine particles are physically bound or enclosed within a stabilized mass or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility.	Specialized equipment required to apply and mix solidification chemicals into soil and control volatile emissions and dust generated during the process. May not prevent migration of volatile COCs. Resulting wastes must be managed, possibly as hazardous waste.	Ulikely
		Incineration	High temperatures are used to combust organic contaminants in the presence of oxygen.	Off-gas may require treatment. Limited public acceptance. Typically costly as compared to other potentially feasible technologies. Resulting solids must be managed, possibly as hazardous waste.	Yes
		Pyrolysis	Thermal decomposition of contaminants in the absence of sufficient oxygen for complete oxidation. Contaminants are transformed into gaseous components, liquid, and solid (coke).	Gases produced may require further treatment. Potential to produce toxic off-gases. Limited public acceptance. Preprocessing of soils typically required to facilitate treatment. Typically more costly then other potentially feasible technologies. Resulting wastes must be managed, possibly as hazardous waste.	Unlikey
		Hot gas decontamination/ thermal desorption	Contaminants are thermally desorbed from excavated soil at increased temperatures. The off-gas is conveyed to a treatment system.	Requires specialized equipment to handle soil and control vapor emissions and exhaust. Typically combined with gas incinerator and particulate filter to treat exhaust. Typically more costly than other potentially feasible technologies. Resulting wastes must be managed, possibly as hazardous waste.	Yes
Re-use	Re-use	Re-use	Contaminated soils and debris are treated to acceptable levels and replaced in original excavation or alternate location.	Requires the excavation remain open until soil is treated or that soil be spread in thin lift over larger area or mounded, if remaining onsite. Site re-use may be impacted. Offsite re-use options depend on soil characteristics, regulatory listing, and finding interested party.	Yes
		Re-use (liquid phase)	Effluent from treatment process are used for irrigation, or placed in evaporation and/or infiltration pond(s), infiltration trench(es) or well(s) to supplement groundwater supply.	Minimizes cost of offsite disposition. Reduces demand on City of Davis collection and treatment system. Collection system design does not include subject discharge, so adjacent development occupation will limit discharge to existing collection system. Offsite re-use options depend on soil characteristics, regulatory listing, and finding an interested party.	Yes
Disposition	Offsite disposition	Offsite disposal	Contaminated soil and debris are treated and/or disposed of at an offsite RCRA Treatment Storage and Disposal Facility.	Requires characterization to confirm shipping, and treatment and/or disposal requirements. Generator remains liable for the waste, including recipient TSDF clean-up.	Yes
		Discharge to surface water (liquid phase)	Discharge extracted GW, either effluent from treatment process or with acceptable quality, to surface water conveyance.	Typically requires NPDES or WDR permit and associated monitoring. COCs may not be only GW components that limit the applicability.	Unlikely
		Discharge to sanitary sewer/POTW (liquid phase)	Discharge extracted GW, either effluent from treatment process or with acceptable quality, to sanitary sewer conveyance.	Existing permit conditions require treatment of COCs to very low levels prior to discharge. Collection system design does not include subject discharge, so adjacent development occupation will limit discharge to existing collection system.	Yes
		Offsite disposal (liquid phase)	Contaminated GW is treated and/or disposed of at an offsite RCRA Treatment Storage and Disposal Facility.	Requires characterization to confirm shipping, and treatment and/or disposal requirements. Liquids are prohibited from disposal in landfills so treatment is required. Generator remains liable for the waste, including the recipient TSDF cleanup.	Unlikely
	Onsite disposition	Deep well injection (liquid phase)	This alternative uses injection wells to place treated or untreated liquid waste into geological formations that have no potential to allow migration of contaminants into potential potable water aquifers.	Option may not be available, and if it is, a permit would be required. Public acceptance and high permitting costs may also preclude this option.	Unlikely

TABLE 2-5
Saturated Media (Soil Below the Water Table, Initial Screening of Technologies and Process Options)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Technical Implementability
Secondary emission treatment	Air emissions/off-gas treatment	Vapor-phase carbon adsorption	Off-gases are pumped through columns containing activated carbon to which dissolved organic contaminants adsorb.	Proven effective for organic contaminants. Can treat down to very low levels.	Yes
		Thermal/catalytic/ oxidation	Organic contaminants are destroyed in a high temperature combustor.	Effective at treating organic chemicals. Limited public acceptance.	Unlikely
		Bio-filtration	Vapor-phase organic contaminants are pumped through a soil bed and sorbed to the solid surface where they are degraded by microorganisms in the soil.	Aerobic process has not been proven effective at degrading the COCs.	Unlikely
		High energy destruction	The high energy destruction process uses high-voltage electricity to destroy VOCs at room temperature.	Not feasible, unproven for COCs. Questionable reliability.	Unlikely
		Membrane separation	This organic vapor/air separation technology involves the preferential transport of organic vapors through a nonporous gas separation membrane.	Not feasible, unproven for COCs.	Unlikely

Unsaturated Media Remedial Technology Pre-screening

The technical implementability pre-screening was completed to filter out remedial technologies and respective process options that were not feasible in unsaturated media at the Site. Pre-screening also eliminates process options that are most likely inappropriate for the Site COCs. The pre-screening results for respective remedial technologies and process options are summarized in Table 2-4. GRAs included in preliminary screening include No Action, Institutional Controls, Monitoring, Surface controls, Containment, In situ treatment, Collection, Ex situ treatment, Re-use, Disposition, and Secondary Emission Treatment.

Remedial technologies evaluated for implementability include no action, land use and access restrictions, monitored natural attenuation, surface water, dust and vapor suppression, surface vertical barriers, subsurface vertical barriers, horizontal barriers, permeability enhancement, biological treatment, physical/chemical treatment, immobilization, removal, re-use, offsite disposition, and air emissions/off-gas treatment. Remedial technology pre-screening is based on implementability of respective process options.

In situ remedial technology process options appear to provide the best opportunity to reduce risks and hazards while minimizing exposure due to excavation and transportation of contaminated media. Those options retained are carried through the technology screening process where they are screened using effectiveness, implementability, and cost.

Saturated Media Remedial Technology Pre-screening

The technical implementability pre-screening was completed to filter out remedial technologies and respective process options that were not feasible in saturated media at the Site. Pre-screening also eliminates process options that are most likely inappropriate for the Site COCs. The pre-screening results for respective remedial technologies and process options are summarized in Table 2-5. GRAs included in preliminary screening are: No Action, Institutional Controls, Monitoring, Containment, In situ Treatment, Collection, Ex situ Treatment, Re-use, Disposition, and Secondary Emission Treatment.

Remedial technologies evaluated for implementability include No Action, Land use restrictions, alternate water supply, monitored, horizontal barriers, hydraulic containment, permeability enhancement, biological treatment, physical/chemical treatment, immobilization, removal, re-use, offsite disposition, and air emissions/off-gas treatment. Remedial technology evaluation is based on implementability of respective process options.

In situ remedial technology options appear to provide the best opportunity to reduce risks and hazards while minimizing exposure due to excavation and transportation of contaminated media. Containment, collection, and ex situ treatment of groundwater appears to provide the best option to control COC migration with groundwater. Those options retained are carried through the technology screening process where they are screened using effectiveness, implementability, and cost.

2.4.2 Remedial Technology Screening

Following the technical implementability pre-screening, the remaining technologies and process options were evaluated in greater detail using the criteria of effectiveness, implementability, and relative cost, which are described below. Following evaluations under these criteria, processes are chosen from a range of process options for a remedial technology. Process options are selected by considering those process options that are the most well-established, proven, and reliable, and that satisfy the Site specific RAOs. One or more representative process options are selected for each technology type to simplify the subsequent development and evaluation of alternatives. More than one process option may be selected for a technology type if the processes are sufficiently different in their performance that one would not adequately represent the other. The selection of representative process options provides more flexibility in the future when the selected remedial action is designed. The specific process option to be used at a particular location at the Site may not be selected until the remedial design phase.

Site- and technology-specific information was used to identify and distinguish differences between the various process options. This information was also used to evaluate each process option with respect to its effectiveness, implementability, and cost. In this section, the assembled remedial alternatives are screened against these criteria, as described below.

Effectiveness

Specific process options are evaluated by considering the following factors:

- The potential effectiveness of a process option to address the estimated areas or volume of contaminated media and meet the goals identified in the RAOs
- The potential impacts to human health and the environment during the construction and implementation phase
- How reliable and proven the process is with respect to the types of contamination and Site-specific conditions

A key aspect of the process options and alternative screening evaluation is the effectiveness of each alternative in protecting human health and the environment. Each process option and alternative is evaluated in terms of its effectiveness in providing protection and the predicted reductions in toxicity, mobility, or volume. Short-term and long-term effectiveness is also evaluated. In this context, “short-term” refers to the construction and implementation period for the alternative. “Long-term” refers to the period after remedial action is completed.

Implementability

Implementability refers to the administrative or institutional aspects of using a technology process. Considered under this criterion are factors such as the ability to obtain necessary permits, the availability and capacity of treatment, storage, and disposal services.

Implementability is evaluated in terms of both the technical and administrative feasibility of constructing, operating, and maintaining a remedial action alternative. Technical feasibility refers to the ability to construct, reliably operate, and comply with regulatory requirements during implementation of an alternative. Technical feasibility also refers to the future operation, maintenance, and monitoring of an alternative after the remedial action has been completed. Administrative feasibility refers to the ability to obtain approvals and permits from regulatory agencies, the availability and capacity of treatment, storage, and disposal services, and the requirements for and availability of specialized equipment and technicians.

Relative Cost

Cost plays a limited role in the screening of process options. Relative capital plus operations and maintenance costs were used rather than detailed estimates. The costs for each process option were evaluated on the basis of engineering judgment relative to the other process options in the same technology type. The primary purpose of the cost-screening criterion is to permit comparative estimates among alternatives. Although these estimates are only order of magnitude, the costs were acceptable for use in the screening as a relative measure of costs to compare the different process options and alternatives.

The technology screening is presented in the following sections for soil and groundwater.

2.4.3 Evaluation of Technologies and Process Options for Unsaturated Media

Results from the screening of remedial technologies and respective process options for unsaturated media at the Site are presented in the following sections and in Table 2-6.

No Action

The no action GRA serves as a baseline against which other options are compared. It is evaluated to determine the risks to public health and the environment if no other GRAs are taken to achieve RAOs. In accordance with the NCP, the no action GRA is retained.

Institutional Controls

Institutional controls are non-engineering methods by which exposure to contaminated media is limited through administrative and/or legal controls. The institutional controls are often implemented in conjunction with other response actions. This may involve the recording of a restrictive covenant on the real property that comprises the former Frontier Fertilizer facility to limit its future use and development, especially the land in and around the former pesticide disposal area. Additional institutional controls may include zoning (as non-residential), deed notices, easements, and other relevant controls. The intention of these restrictions is to limit human exposure. All institutional control technology process options are retained.

Monitoring

Monitoring of chlorinated pesticides and related compounds in soil and groundwater is used to evaluate potential exposure routes and the affects of native physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. Management of organic or inorganic pollutants requires a fundamental understanding of those processes that ultimately affect their fate in surface and subsurface environments. Once released to the environment, these chemicals are affected by a number of processes including:

- Dilution
- Adsorption
- Advection and dispersion
- Volatilization
- Geochemical dynamics
- Chemical or biological transformation (microbial attenuation)

EPA Office of Solid Waste and Emergency Response Directive 9200.4-17 (1997) identifies three lines of evidence that can be used to demonstrate the occurrence of the natural attenuation of chlorinated aliphatic hydrocarbons, including:

- Documented loss of contaminants at the field scale
- Documented presence and distribution of geochemical and biochemical indicators of natural attenuation
- Direct microbiological evidence

All processes noted above will have some role in affecting the fate and transport of the COCs in the subsurface environment. The magnitude of each process will be governed by the prevailing Site conditions and the nature of the chemical under study. Periodic routine monitoring of groundwater is required to confirm the extent of the natural attenuation processes.

Short- and/or long-term monitoring; including sampling and analysis of soil, soil gas, and groundwater, and analysis of results are performed to evaluate changes in COC concentrations, track progress of attenuation processes, and evaluate effectiveness relative to RAOs. Monitoring is retained.

Surface Controls

Reshaping of topography is necessary to prevent run on from the adjacent area and resulting ponding causing infiltration. The resulting ground surface can be coated or covered to minimize exposure to COCs via wind blown dust or vapor emissions. Both surface water control process options and the wood chip or rock option for dust and vapor suppression technology are retained. A temporary cap of wood chip or rock also is added to all alternatives in Section 3 and 4 to prevent ecological receptors from contacting contaminated surface soil.

Containment

Containment is a technology that isolates, minimizes, reduces, or eliminates bulk migration of contaminants in the surface soil and/or subsurface environments. Containment systems (for example, barriers to vertical or horizontal groundwater movement) are used to isolate high concentration areas or source areas to impede migration of dissolved phase or even potentially as free-phase COCs. Contaminated soil and debris can be covered with a cap to limit exposure pathways to human and ecological receptors, reduce infiltration of precipitation, and control leaching of contaminants to groundwater. Caps and subsurface barriers can be constructed from a variety of components, including clay, metal, asphalt, concrete, and synthetic materials. Optimally, horizontal barrier systems are keyed into a confining layer or less permeable material (for example, low permeability clay or bedrock).

Barriers can be less costly than excavation, protective of human health and the environment, and reduce contaminant mobility. However, containment does not reduce the volume or toxicity of contaminants. Barriers may also restrict future land use and may require monitoring and maintenance to ensure performance. The concrete or asphalt cap process option is retained for the ground surface vertical barrier technology. No subsurface vertical or horizontal barriers are retained.

TABLE 2-6
Unsaturated Media (Soil Above Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recommendation
No Action	No action	No action	General Response Action (GRA) wouldn't prevent migration of Chemicals of Concern (COCs). COCs are primarily desorbed into GW as levels rise and fall, and consequently the option would not be effective at achieving Remedial Action Objectives (RAOs).	Not acceptable because RAOs would not be achieved.	No initial cost, no O&M.	**Retain as required by NCP**
Institutional Controls	Land use restrictions	Deed restriction	Would not prevent further migration of COCs. Could prevent exposure to COCs if combined with rigorous monitoring and continued adjustments to restrictions as COCs migrate.	Requires title modifications.	Low initial cost, low O&M.	**Retain, if combined w/ other GRAs.**
	Access restrictions	Restrict Access	Similar to "Deed restriction".	May preclude beneficial uses of the land under restriction.	Low initial cost, low O&M.	**Retain, if combined w/ other GRA.**
Monitoring	Monitor COCs and GW head	Monitor COC Fate & Transport	Similar to "No action". Only effective for soil containing low COC concentrations.	Would require monitoring and a long time period to achieve RAOs without implementation of other options to remediate high concentrations.	Low initial cost, moderate O&M.	**Retain, if combined w/ other GRA.**
Temporary Cap	Surface Barrier to Exposure	Wood chip/rock layer over ground surface	Provides barrier to prevent wind and rain water erosion, reduce stormwater run off and GW evaporation and impedes animal exposure to media.	Would require even layer application and minimal maintenance to maintain year around effectiveness. In combination with other remedial process, it may contribute to acheivement of RAOs.	Low initial cost, low O&M.	**Retain, if combined w/ other GRA.**
Surface Controls	Surface water (rain) control	Grading	Similar to "No action". Would reduce rain water moving vertically through COC contaminated soil. Therefore, effective if combined with other GRAs.	Requires modification of surface to convey rainwater from above COC contaminated soil. In combination with other remedial process, it may contribute to achievement of RAOs.	Low initial cost, low O&M.	**Retain, if combined w/ other GRA.**
		Revegetatation	Similar to "Grading". Would also reduce wind erosion and soil gas emission.	Would require balanced irrigation and other maintenance to maintain year around effectiveness. In combination with other remedial process, it may contribute to achievement of RAOs.	Low initial cost, low O&M.	**Retain, if combined w/ other GRA.**
	Dust and vapor suppression	Water	Similar to "No action". Would also reduce wind erosion and soil gas emission.	Would require balanced distribution and other maintenance to maintain year around effectiveness. In combination with other remedial process, it may contribute to achievement of RAOs.	Low initial cost, low O&M.	**Don't retain, Revegetation is the optimum Process Option.**
		Wood Chips/Rock	Provides barrier to prevent wind and rain water erosion, reduce stormwater run off and GW evaporation and impedes animal exposure to media.	Would require even layer application and minimal maintenance to maintain year around effectiveness. In combination with other remedial process, it may contribute to achievement of RAOs.	Low initial cost, low O&M.	**Retain, option to Revegetation.**
		Organic agents/ polymers/foams	Similar to "Grading". Would also reduce wind erosion and soil gas emission.	Would require initial application and maintenance to maintain year around effectiveness. In combination with other remedial process, it may contribute to achievement of RAOs.	Low initial cost, low O&M.	**Don't retain, Revegetation is the optimum Process Option.**
		Membranes/tarps	Similar to "Organic agents/polymers/foams".	Similar to "Organic agents/polymers/foams".	Moderate initial cost, low O&M.	**Don't retain, Revegetation is the optimum Process Option.**
		Hygroscopic agents	Similar to "Organic agents/polymers/foams".	Similar to "Organic agents/polymers/foams".	Moderate initial cost, low O&M.	**Don't retain, Revegetation is the optimum Process Option.**

TABLE 2-6
Unsaturated Media (Soil Above Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recommendation
Containment	Surface vertical barriers	Native soil cap	Similar to "No action" and "Grading". Would reduce rain water moving vertically through COC contaminated soil. Therefore, effective if combined with other technology options.	Requires excavation of site soil and placement over volume containing COC. Excavation would create area that would collect rain water adjacent to the cap that would drive GW below the cap, consequently reducing the cap effectiveness.	Moderate initial cost, low O&M.	**Don't retain, provides minimal impediment to COC migration to Air and GW.**
		Clay/soil cap	Similar to "No action" and "Grading". Would minimize rain water moving vertically through COC contaminated soil and COC vapors emissions. Therefore, effective if combined with other technology options.	Would require restrictions on land use and maintenance.	Moderate initial cost, low O&M.	**Don't retain, provides minimal impediment to COC migration to Air and GW.**
		Chemical sealant/stabilizer cap	Similar to "Clay/soil cap". Minimal disturbance to surface and facilities during installation. Prevents wind erosion in addition to infiltration and air emissions.	Would require restrictions on land use and maintenance.	Moderate initial cost, low O&M.	**Not Retained, asphalt cap retained as representative cap.**
		Synthetic membrane cap	Similar to "Clay/soil cap". Requires more surface preparation than Chemical sealant/stabilizer cap. Most substantial barrier to infiltration and air emissions.	Would require restrictions on land use and maintenance.	Moderate initial cost, low O&M.	**Not Retained, asphalt cap retained as representative cap.**
		Concrete or asphalt cap	Similar to "Synthetic membrane cap". Prevents wind erosion in addition to infiltration and air emissions.	Would require restrictions on land use and maintenance.	Moderate initial cost, low O&M.	**Retain, as an alternative to primary GRA.**
		Multimedia cap/RCRA cap	Similar to "Synthetic membrane cap".	Would require restrictions on land use and maintenance.	High initial cost, low O&M.	**Don't retain, do to cost and maintenance.**
		Cap enhancements	Enhances cap ability to allow more land use options and reduce cap maintenance.	Would require restrictions on land use and maintenance.	Moderate initial cost, low O&M.	**Don't retain, provides minimal impediment to COC migration to Air and GW.**
	Subsurface vertical barriers	Block Displacement	Similar to "No action". Would impede vertical movement of GW through the barrier, but not horizontal GW movement.	May not create uniform barrier, consequently may not prevent vertical GW migration through the contaminated soil. Would require restrictions on land use.	High initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Grout injection	Similar to "Block Displacement".	May not create uniform barrier, consequently may not prevent vertical GW migration through the contaminated soil. Would require restrictions on land use.	High initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Ground freezing (cryocell process)	Similar to "Block Displacement".	May not create uniform barrier, consequently may not prevent vertical GW migration through the contaminated soil. Would require restrictions on land use.	High initial cost, Moderate O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Liners	Similar to "Block Displacement".	Would require excavation of contaminated soil and restrictions on land use.	High initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
	Horizontal barriers	Slurry walls (hanging or keyed-in)	Similar to "No action". Would impede horizontal movement of GW, depending on water level, but not vertical GW movement. Effective if used as a wall keyed into a vertical barrier to create a containment basin. Water table varies from ~10 to 25' bgs.	Underlying boundary layer doesn't appear to exist, so vertical migration of GW through the contaminated soil would not be impeded. May not create uniform barrier, consequently may not prevent horizontal GW migration through the contaminated soil. Would require restrictions on land use.	Moderate initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Vibrating beam	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Permeability inhibiting curtains	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Sheet piling	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, low O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**
		Ground freezing (cryocell process)	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, high O&M.	**Don't retain, barrier provides minimal impediment to COC migration to GW.**

TABLE 2-6
Unsaturated Media (Soil Above Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recommendation
In-situ Treatment	Permeability enhancement	Pneumatic fracturing	Prominent method to inject treatment media into the soil. Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Would cause movement of COC vapors.	May require permits and easements to access property. Fracturing may be nuisance to neighbors during implementation.	Moderate initial cost, no O&M.	**Retain, if combined w/ other In-Situ Remedial Technology(ies).**
		Hydraulic fracturing (hydrofracturing)	Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Can also inject treatment media into the soil. Would cause movement of COC vapors.	May require permits and easements to access property. Fracturing may be nuisance to neighbors during implementation.	Moderate initial cost, no O&M.	**Don't retain, Pneumatic fracturing is optimal Process Option.**
		Blast-enhanced fracturing	Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Would cause movement of COC vapors.	May not be implementable due to safety concerns.	Moderate initial cost, no O&M.	**Don't retain, Pneumatic fracturing is optimal Process Option.**
		In-situ soil mixing (ISSM)	Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Can also be used to incorporate treatment media into the soil. Would cause movement of COC vapors.	May not be implementable due to safety concerns.	High initial cost, no O&M.	**Don't retain, Pneumatic fracturing is optimal Process Option.**
	Biological Treatment	Anaerobic	The most likely biological process for degradation of COCs. Requires testing to evaluate site-specific effectiveness. May be combined with other processes to increase effectiveness.	Implementable given existing infrastructure available to provide water to create anoxic state and deliver amendments, monitor the effectiveness and, if necessary, contain by-products.	Moderate initial cost, low O&M.	**Retain, if combined w/ other In-Situ Process Options.**
		Aerobic	Unlikely to achieve RAOs via aerobic biological process for COCs.	Similar to "Anaerobic" except volume would not be saturated.	Moderate initial cost, low O&M.	**Don't retain, Anaerobic is optimal Process Option.**
		Cometabolic aerobic	Little data available regarding the efficacy of the cometabolic process for degradation of COCs.	Similar to "Anaerobic" except volume would not be saturated.	Moderate initial cost, low O&M.	**Don't retain, Anaerobic is optimal Process Option.**
		Phytoremediation	Little data available regarding the efficacy of the phytoremediation process for degradation of COCs and may be beyond effective depth.	May require consultation with City of Davis regarding plant type.	Moderate initial cost, low O&M.	**Don't retain, Anaerobic is optimal Process Option.**
	Physical/Chemical Treatment	Soil Vapor Extraction (SVE)	Effective for most COCs. Extracted vapors would require treatment. May be combined with other process, e.g., pneumatic fracturing, to increase permeability and heating to increase removal rate.	May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Steam or hot air thermally enhanced soil vapor extraction (SVE)	Similar to "SVE". Adding heat to soil may volatize COCs with lower vapor pressures and Henry's Law constants, e.g., DBCP, and facilitate removal in gas phase. Requires gas phase emission treatment.	May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Radio frequency heating (RFH) enhanced soil vapor extraction (SVE)	Similar to "SVE". Adding heat to soil may volatize COCs with lower vapor pressures and Henry's Law constants, e.g., DBCP, and facilitate removal in gas phase. May require gas phase emission treatment.	May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Media heating w/ electrical energy / enhanced soil vapor extraction (SVE)	Adding heat to media increases chemical reaction rates and may volatize COCs with lower vapor pressures and Henry's Law constants, e.g., DBCP, and facilitate removal in gas phase. May require gas phase emission treatment.	May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Retain.**
		Dynamic underground stripping (DUS) enhanced soil vapor extraction (SVE)	Similar to "SVE". Adding heat to soil may volatize COCs with lower vapor pressures and Henry's Law constants, e.g., DBCP, and facilitate removal in gas phase. Requires gas phase emission treatment.	May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Electrokinetic separation	Process not demonstrated on COCs and COCs are not ions.	Not implementable	Moderate initial cost, moderate O&M.	**Don't retain, not an effective process.**
		Soil flushing (washing)	Increase the rate of COC desorption and degradation by creating anoxic state. May be combined with other processes to increase effectiveness.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, low O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Hot water soil flushing	Similar to "Soil flushing". Heat delivered by water enhances the COC desorption rate.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Surfactant enhanced recovery	Similar to "Soil flushing". Surfactant delivered by water enhances the COC desorption rate.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Solvent/cosolvent enhanced recovery	Similar to "Soil flushing". Solvent/cosolvent delivered by water enhances the COC desorption rate.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Chemical reduction	Similar to "Soil flushing". Reducing agent delivered by water appears to be effective at dehalogenating COCs. Requires testing to evaluate site-specific effectiveness. Would be combined with other processes to increase effectiveness.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
		Chemical oxidation	Similar to "Soil flushing". Oxidizer delivered by water or gas appears to be less effective than reducing agent at dehalogenating COCs.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, Media heating with SVE is optimal Process Option.**
	Immobilization	Soldification/ stabilization	Requires mixing amendments into soil. May release volatile COCs in process that would require additional gas emission controls.	May require cordination with Air Pollution Control District and land use restrictions.	High initial cost, low O&M.	**Don't retain, other GRA is optimum.**
		In-situ vitrification	Requires high energy to melt soil. May release volatile COCs in process that would require additional controls.	May require cordination with Air Pollution Control District and land use restrictions.	High initial cost, low O&M.	**Don't retain, excessive cost and long term maintenance.**

TABLE 2-6
Unsaturated Media (Soil Above Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recommendation
Collection	Removal	Excavation hot spots	Requires soil excavation and subsequent management. Would release volatile COCs in process that would require emission controls. Volume would vary depending on water table, i.e. between 10' and 25' bgs. Would achieve RAOs.	Air emissions would require monitoring and control. Must be combined with other Technology Process options.	High initial cost, no O&M	**Retain, as an alternative to primary GRA.**
Ex-situ Treatment	Biological	Biopile/Aerobic	Requires soil excavation and subsequent management. Unlikely to achieve RAOs via aerobic biological process for COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Biopiles/anaerobic	Requires soil excavation and subsequent management .Anaerobic mechanism appears to be most likely biological process to achieve RAOs for COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Composting/aerobic	Requires soil excavation and subsequent management. Unlikely to achieve RAOs via aerobic biological process for COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Landfarming/aerobic and volatilization	Requires soil excavation, large area to spread soil and subsequent management. May achieve RAOs via volatization and ultraviolet light oxidation for COCs. Unlikely that air emissions would be acceptable.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, air emissions.**
	Chemical/physical Treatment	Reduction	Requires soil excavation and subsequent management of treated soil and process media. Reductive dehalogenation mechanism appears to be most likely chemical process to achieve RAOs for COCs.	Air and water emissions would require monitoring and control. May require consultation with Air Pollution Control District and the Regional Water Quality Control Board.	High initial cost, moderate O&M.	**Don't retain, In-Situ chemical reduction is optimal GRA.**
		Oxidation	Requires soil excavation and subsequent management of treated soil and process media. Oxidizer delivered by water or gas appears to be less effective than reducing agent at dehalogenating COCs.	Air and water emissions would require monitoring and control. May require consultation with Air Pollution Control District and the Regional Water Quality Control Board.	High initial cost, moderate O&M.	**Don't retain, In-Situ chemical reduction is optimal GRA.**
		Soil washing	Requires soil excavation and subsequent management of treated soil and process media. Desorb COCs from soil with water based solution and treat water with other process. Must be combined with other processes to achieve RAOs.	Air and water emissions would require monitoring and control. May require consultation with Air Pollution Control District and the Regional Water Quality Control Board.	High initial cost, moderate O&M.	**Don't retain, In-Situ soil washing is optimal GRA.**
		Solidification/ stabilization	Requires soil excavation, mixing amendments into soil and subsequent management of treated soil. Would release volatile COCs in process that would require additional controls.	Air and water emissions would require monitoring and control. May require consultation with Air Pollution Control District and the Regional Water Quality Control Board.	High initial cost, low O&M.	**Don't retain, In-Situ GRA is optimal option.**
		Solar detoxification	Requires soil excavation, land farming process and subsequent management of treated soil. Would release volatile COCs in process that would require additional controls.	Air and water emissions would require monitoring and control. May require consultation with Air Pollution Control District and the Regional Water Quality Control Board.	High initial cost, low O&M.	**Don't retain, In-Situ GRA is optimal option.**
		Incineration	Requires soil excavation, incineration process equipment and subsequent management of treated soil. Would release volatile COCs in process that would require additional controls.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	High initial cost, low O&M.	**Don't retain, In-Situ GRA is optimal option.**
		Pyrolysis	Similar to "Incineration".	Similar to "Incineration".	High initial cost, low O&M.	**Don't retain, In-Situ GRA is optimal option.**
		Hot gas Decontamination/ Thermal desorption	Similar to "Incineration".	Similar to "Incineration".	High initial cost, low O&M.	**Retain, as component of excavation Process Option.**
Resue	Reuse	Reuse on-site	Use treated soil on-site to support future site uses. Reuse options depend on GRA implemented, e.g. COCs removed versus bound or contained.	Land use options are affected by GRA implemented to achieve RAOs.	Low initial cost, low O&M.	**Retain, if combined w/ other In-Situ GRA.**
Disposition	Off-site disposition	Off-site disposal	Requires soil excavation, pretreatment and subsequent management of treated soil. Would transfer soil and COCs to Treatment,Storage and Disposal Facility. Require import of soil to replace removed soil.	In addition to collection requirements, transportation, pretreatment and disposal assumed to occur under existing permits.	High initial cost, low O&M.	**Retain, as an alternative to primary GRA.**
Secondary Emission Treatment	Air Emissions/off-gas treatment	Vapor-phase carbon adsorption	Proven effective for COCs. Requires process equipment O&M and GAC disposition.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Retain, if GRA emits gas phase COCs.**
		Thermal/catalytic/ oxidation	May be effective for COCs. Requires evaluation before implementation.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, Vapor-phase carbon adsorption is optimal Process Option.**
		Bio-filtration	Aerobic process does not appear effective for treating COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, Vapor-phase carbon adsorption is optimal Process Option.**
		High energy destruction	May be effective for COCs. Requires evaluation before implementation.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, Vapor-phase carbon adsorption is optimal Process Option.**
		Membrane separation	May be effective for COCs. Requires evaluation before implementation.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, Vapor-phase carbon adsorption is optimal Process Option.**

In situ Treatment

In situ treatment involves modifying media to reduce COC mass or mobility without collecting and removing the media. Biological, chemical, or physical characteristics of the media are modified to obtain desired fate and transport mechanisms. Desired mechanisms enhance native mechanisms to facilitate achievement of RAOs.

In situ technologies and respective process options that were retained include: permeability enhancement by pneumatic fracturing, anaerobic biological treatment, and physical/chemical treatment by heating. No immobilization process options are retained.

Bench-scale testing was performed to evaluate zero valent iron (ZVI), anaerobic biological, and heating process options. Test results indicated that chemical reduction of COCs using ZVI was not effective, although it appeared to reduce nitrate. Test results indicated that enhanced anaerobic conditions created by adding soluble organic carbon substrates stimulated native anaerobic microorganisms to produce an anaerobic-reducing environment. Nitrate was quickly denitrified, but the variability in VOC concentrations in the soil used in the test microcosms resulted in inconclusive results. Groundwater monitoring results from wells close to the source area also show elevated bromide concentrations that may indicate that native conditions, possibly via bacteria or hydrolysis, appear to be degrading VOCs. A treatability study to test in situ thermal destruction showed that heating resulted in a reduction in VOC concentrations with similar variability in soil VOC concentrations.

Collection

Excavation is a removal approach with treatment onsite or offsite, or with disposal at an offsite facility. Soil excavation is normally conducted with the use of a backhoe, power shovel, or in some cases large rotary augers. The machinery used will be dependent on Site conditions and the depth of excavation required. Limited access (for example, buildings or other Site features) may limit the accessibility of excavation machinery. Following excavation, soil can be treated or managed at the Site or treated and/or disposed of offsite. The excavation of hot spots removal technology process option is retained.

Ex situ Treatment

Collected unsaturated media will likely require treatment prior to disposal or re-use. Treatment technologies are similar to those screened under the in situ GRA with the objective of reducing COC mass or mobility. Biological, chemical or physical characteristics of the removed media are modified to obtain desired fate and transport mechanisms. The hot gas decontamination/thermal desorption physical/chemical treatment technology process option is retained for treatment of removed soil.

Re-use

If soil were treated in situ, it will not be excavated and will remain at the Site and if it were treated ex situ at the Site, it may be returned to its original location to fill the excavation pit. Re-use is retained.

Disposition

The representative process option for disposal is the offsite disposal of contaminated soils. In this process option, excavated soil is designated for transport to an approved offsite landfill where appropriate measures will be taken to protect human health and the environment in the vicinity of the facility, either by treatment before disposal or, if treatment is not necessary, by disposing of the soil within an engineered containment system to prevent offsite contaminant migration. The offsite disposal option is retained.

Secondary Emission Treatment

Many of the GRAs have potential to emit COCs during construction and implementation phases; therefore, secondary emission treatment is included. Technology screening includes evaluation of the potential for generating emissions of COCs and potential associated risks. Vapor phase carbon adsorption is retained as the air emission/off-gas treatment technology process option based on retained GRA technologies.

2.4.4 Evaluation of Technologies and Process Options for Saturated Media

Results from the screening of remedial technology and respective process options for saturated media at the Site are presented in the following sections and in Table 2-7.

No Action

The no action GRA serves as a baseline against which other options are compared. It is evaluated to determine the risks to public health and the environment if no other GRAs are taken to achieve RAOs. In accordance with the NCP, the no action GRA is retained.

Institutional Controls

Institutional controls are non-engineering methods by which exposure to contaminated media is limited through administrative and/or legal controls. The institutional controls are often implemented in conjunction with other response actions. This may involve the recording of a restrictive covenant on the real property that comprises the former Frontier Fertilizer facility to limit its future use and development, especially the land in and around the former pesticide disposal area Additional institutional controls may include, but are not limited to, zoning (as non-residential), deed notices, and easements. The intention of these restrictions is to limit human exposure. Land use and access restriction institution control technology process options are retained.

Monitoring

Natural biological, chemical and physical processes, as described in Section 2.4.3.3, are allowed to reduce contaminant concentrations to acceptable levels. Short- and/or long-term monitoring including, sampling and analysis of groundwater and analysis of results, are performed to evaluate changes in COC concentrations, track progress of attenuation processes, and evaluate effectiveness relative to RAOs. Monitored natural attenuation is retained.

TABLE 2-7
Saturated Media (Soil Below the Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recmmendations
No Action	No action	No action	General Response Action (GRA) wouldn't prevent migration of Chemicals of Concern (COCs). Subject COCs are primarily desorbed into groundwater (GW) as it flows through contaminated soil, and consquently the option would not be effective at achieving Remedial Action Objectives (RAOs).	Not acceptable because RAOs would not be achieved.	No initial cost, no O&M.	**Retained as required by NCP**
Institutional Controls	Land use restrictions	Deed restriction	Would not prevent further migration of COCs. Could prevent exposure to COCs if combined with rigorous monitoring and continued adjustments to restrictions as COCs migrate.	Requires title modifications.	Low initial cost, low O&M.	**Retain, if combined w/ other GRAs.**
	Access restrictions	Groundwater use restrictions	Similar to "Deed restriction".	May preclude beneficial uses of the groundwater under restriction.	Low initial cost, low O&M.	**Retain, if combined w/ other GRA.**
	Alternate water supply	City water supply	Would prevent exposure via contaminated GW and would be combined with access restrictions, if City or agricultural wells become affected. Municipal potable water system currently serves residents.	May require modification to municipal system.	High initial cost, moderate O&M.	**Don't retain, unless well(s) are found to contain COCs.**
		New community wells	Would prevent exposure via contaminated GW and would be combined with access restrictions, if City or agricultural wells become affected. Municipal potable water system currently serves residents.	May require modification to municipal system.	High initial cost, moderate O&M.	**Don't retain, unless well(s) are found to contain COCs.**
Monitoring	Monitor COCs and GW head	Monitor COC Fate & Transport	Similar to "No action". Only effective for soil and GW containing low COC concentrations.	Would require monitoring and a long time period to achieve RAOs without implementation of other options to remediate high concentrations.	Low initial cost, moderate O&M.	**Retain, if combined w/ other GRAs.**
Containment	Horizontal barriers	Slurry walls (hanging or keyed-in)	Would impede horizontal movement of GW, depending on water level, but not vertical GW movement. Water table varies from ~10 to 25' bgs and COCs were detected in soil at ~ 85' bgs. Effective if used as a wall keyed into a vertical barrier to create a containment basin, but no continuous vertical barrier has been identified.	Depth of COCs requires specialized excavation and emission control equipment to install wall. Would require restrictions on land use. Installation noise may be nuisance.	High initial cost, low O&M.	**Don't retain, No impermeable boundary layer to key into.**
		Vibrating beam	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, low O&M.	**Don't retain, No impermeable boundary layer to key into.**
		Permeability inhibiting curtains	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, low O&M.	**Don't retain, No impermeable boundary layer to key into.**
		Sheet piling	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, low O&M.	**Don't retain, No impermeable boundary layer to key into.**
		Ground freezing (cryocell process)	Similar to "Slurry walls (hanging or keyed-in)".	Similar to "Slurry walls (hanging or keyed-in)".	High initial cost, High O&M.	**Don't retain, No impermeable boundary layer to key into.**
	Hydraulic containment	Extraction well	Existing extraction wells appear effective at capturing GW with COCs in S-1 & S-2 zones. Aquifer heterogeneity limits effectiveness of extraction wells. A-1 zone appears more homogenous than S-1 & S-2 zone.	Wells may require permits and easements to access property. Infrastructure for trenches requires access to property and restricts respective land use.	High initial cost, moderate O&M.	**Retain.**
		Interceptor trenches	Can be effective in heterogeneous aquifers such as those in S-1 & S-2 zones. Depth of A-1 zone may preclude installation.	Trenches may require permits and easements to access property. Infrastructure for trenches requires access to property and restricts respective land use.	High initial cost, moderate O&M.	**Don't retain, extraction well is optimal Process Option.**

TABLE 2-7
Saturated Media (Soil Below the Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recmmendations
In-Situ Treatment	Permeability Enhancement	Pneumatic fracturing	Proven method to inject treatment media into the soil. Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Would cause movement of COC vapors.	May require coordination to access property. Fracturing may be nuisance to neighbors during implementation.	Moderate initial cost, no O&M.	**Retain, if combined w/ other In-Situ Treatment Remedial Technology(ies).**
		Hydraulic fracturing (hydrofracturing)	Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Can also inject treatment media into the soil. Would cause movement of COC vapors.	May require coordination to access property. Fracturing may be nuisance to neighbors during implementation.	Moderate initial cost, no O&M.	**Don't retain, Pneumatic fracturing is optimal Process Option.**
		Blast-enhanced fracturing	Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Would cause movement of COC vapors.	May require coordination to access property. Fracturing may be nuisance to neighbors during implementation.	Moderate initial cost, no O&M.	**Don't retain, Pneumatic fracturing is optimal Process Option.**
		In-situ soil mixing (ISSM)	Increases permeability and continuity to facilitate an increased rate that gases or liquids can move through soil. Can also be used to incorporate treatment media into the soil. Would cause movement of COC vapors.	May not be implimentable due to nuisance concerns.	High initial cost, no O&M.	**Don't retain, Pneumatic fracturing is optimal Process Option.**
	Biological Treatment	Anaerobic	Proven biological process for degradation of COCs. Requires testing to evaluate site-specific effectiveness. May be combined with other processes to increase effectiveness.	Implementable given existing infrastructure available to monitor the effectivnes and, if necessary, contain by-products with P&T system.	Moderate initial cost, low O&M.	**Retain, if combined w/ other In-Situ Remedial Technology(ies).**
		Aerobic	Unlikely to achieve RAOs via aerobic biological process for COCs.	Similar to "Anaerobic".	Moderate initial cost, low O&M.	**Don't retain, Anaerobic is optimal Process Option.**
		Cometabolic Aerobic	Little data available regarding the efficacy of this cometabolic process for degradation of COCs.	Similar to "Anaerobic".	Moderate initial cost, low O&M.	**Don't retain, Anaerobic is optimal Process Option.**
		Phytoremediation	Little data available regarding the efficacy of this process for degradation of COCs. Water depth may limit the effectiveness.	Requires coordination with City of Davis regarding plant type.	Moderate initial cost, low O&M.	**Don't retain, Anaerobic is optimal Process Option.**
	Physical/Chemical Treatment	Chemical reduction	Proven effective at dehalogenating some COCs. Requires testing to evaluate site-specific effectiveness. Could be combined with other processes to increase effectiveness.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Chemical oxidation	Oxidizer delivered by water solution or gas appears to be less effective than reducing agent at dehalogenating COCs.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Hydrous/pyrolysis/ oxidation	Steam injected into source area may cause hydolysis. Requires testing to evaluate site-specific effectiveness.	Air and water emissions would require monitoring and control. May require consultation with Air Pollution Control District and the Regional Water Quality Control Board.	HIgh initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Air sparging	Extracted vapors would require treatment. Would create oxic state which wouldn't faciliate reductive dehalogenation. Effective for volatizing most COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Bioslurping	Would create oxic state which wouldn't faciliate reductive dehalogenation. Effective for removing NAPL and stimulating aerobic degradation.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, NAPL phase not detected.**
		Dual phase extraction	Would create oxic state which wouldn't faciliate reductive dehalogenation. Effective for removing NAPL and stimulating aerobic degradation.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, NAPL phase not detected.**
		Passive reactive treatment barriers	Reactive agent, such as ZVI for reducing affect, placed in aquifer material through which GW with COCs flow. Placement accomplished via trenching or wells. Requires testing to evaluate site-specific effectiveness. Could be combined with other processes to increase effectiveness.	May require coordination to access property.	High initial cost, low O&M.	**Don't retain, bench scale test indicated ZVI is not an effective process.**
		Surfactant enhanced recovery	Requires mixing of surfactant with GW passing through soil containing COCs to desorb the COCs. Requires combination with other technology to recover and/or treat COCs & surfactants.	May require consultation with the Regional Water Quality Control Board.	Moderate initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Solvent/cosolvent enhanced recovery	Similar to "Surfactant enhanced recovery".	Similar to "Surfactant enhanced recovery".	Moderate initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		In-well air stripping	Extracted vapors would require treatment. Would create oxic state which wouldn't faciliate reductive dehalogenation. Effective for volatizing most COCs.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Dynamic underground stripping (DUS) enhanced soil vapor extraction (SVE)	Similar to "In-well air stripping". Adding heat to aquifer may volatize COCs with lower vapor pressures and Henry's Law constants, e.g., DBCP and facilitate removal in gas phase.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, heating is optimal physical/chemical Process Option.**
		Media heating w/ electrical energy / enhanced soil vapor extraction (SVE)	Adding heat to aquifer increases chemical reaction rates e.g. hydrolysis and may volatize COCs with lower vapor pressures and Henry's Law constants, e.g., DBCP and facilitate removal in gas phase.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Retain, bench scale results indicate effective treatment process.**
	Immobilization	Solidification/stabilization	Requires mixing amendments into soil which may not be practicable. May release volatile COCs in process that would require additional controls.	May require coordination with Air Pollution Control District and land use restrictions.	High initial cost, low O&M.	**Don't retain, In-Situ Physical/Chemical/Biological Treatment is optimal GRA.**
		In-situ vitrification	Requires high energy to melt soil. May release volatile COCs in process that would require additional controls.	May require coordination with Air Pollution Control District and land use restrictions.	High initial cost, low O&M.	**Don't retain, Excessive cost and long term maintenance.**

TABLE 2-7
Saturated Media (Soil Below the Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recmmendations
Collection	Removal (soil)	Excavate hot spots	Requires soil excavation, including dewatering, and subsequent management. Would release volatile COCs and would require emission controls. Specialized equipment required for deep excavation. Would achieve RAOs.	Air emissions would require monitoring and control. Must be combined with other Technology Process options.	High initial cost, no O&M	**Retain, as an alternative to primary GRA.**
	Removal (GW)	Extract GW	Existing extraction wells appear effective at capturing GW with COCs in S-1 & S-2 zones. Aquifer heterogeneity limits effectiveness of extraction wells. A-1 zone appears more homogeneous than S-1 & S-2 zone.	May require City of Davis discharge permit.	Low capital cost, Moderate O&M	**Retain.**
Ex-Situ Treatment	Biological Treatment	Biopile/aerobic	Requires soil excavation and subsequent management. Unlikely to achieve RAOs via aerobic biological process for COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Biopiles/anaerobic	Requires soil excavation and subsequent management. Anaerobic mechanisim appears to be most likely biological process to achieve RAOs for COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Composting/aerobic	Requires soil excavation and subsequent management. Unlikely to achieve RAOs via aerobic biological process for COCs.	Air emissions would require monitoring and control. May require consultation with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Landfarming/aerobic and volatilization	Requires soil excavation, large area to spread soil and subsequent management. May achieve RAOs via volatization and ultraviolet light oxidation for COCs. Unlikely that air emissions would be acceptable.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
		Phytoremediation	Little data available regarding the efficacy of the phytoremediation process for degradation of COCs.	May require consultation with City of Davis regarding plant type.	Moderate initial cost, low O&M.	**Don't retain, In-Situ Anaerobic is optimal GRA.**
	Physical/Chemical Treatment (liquid phase)	Liquid Phase Granular Activated Carbon (LGAC)	Effective for treating all COCs. Process currently in-use at the site to remove COCs from GW. Requires GW collection and management of treated GW.	Limited resources available for treated GW discharge. Discharge requires monitoring and control.	Moderate initial cost, moderate O&M	**Retain.**
		Air stripping	Extracted vapors would require treatment. Effective for desorbing most COCs.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, LGAC is optimal Process Option.**
		Sprinkler irrigation	Unlikely that air emissions would be acceptable. May achieve RAOs via volatization and ultraviolet light oxidation for COCs.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain, air emissions.**
		Reduction	Requires GW collection and testing to confirm effectiveness. Same process as "In-situ chemical reduction".	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M	**Don't retain, LGAC is optimal Process Option.**
		Oxidation	Requires GW collection and testing to confirm effectiveness. Same process as "In-situ chemical oxidation".	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M	**Don't retain, LGAC is optimal Process Option.**
	Physical/Chemical Treatment (soil)	Reduction	Requires soil collection, soil processing equipment and testing to confirm effectiveness. Same process as "In-situ chemical reduction".	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M	**Don't retain, In-situ treatmen is the optimal GRA.**
		Oxidation	Requires soil collection, soil processing equipment and testing to confirm effectiveness. Same process as "In-situ chemical oxidation".	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M	**Don't retain, In-situ treatmen is the optimal GRA.**
		Solar/ultraviolet light detoxification	Requires soil excavation, land farming process and subsequent management of treated soil. Would release volatile COCs in process that would require additional controls.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, low O&M.	**Don't retain, In-situ treatmen is the optimal GRA.**
		Soil washing	Requires soil excavation and subsequent management of treated soil and process media. Desorb COCs from soil with water based solution and treat water with other process. Must be combined with other processes to achieve RAOs.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain, In-situ treatmen is the optimal GRA.**
		Solidification/stabilization	Requires soil excavation, mixing amendments into soil and subsequent management of treated soil. Would release volatile COCs in process that would require additional controls.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, low O&M.	**Don't retain, In-situ treatmen is the optimal GRA.**
		Incineration	Requires soil excavation, incineration process equipment and subsequent management of treated soil. Would release volatile COCs in process that would require additional controls.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, low O&M.	**Don't retain, In-situ treatmen is the optimal GRA.**
		Pyrolysis	Similar to "Incineration".	Similar to "Incineration".	High initial cost, low O&M.	**Don't retain, In-situ treatmen is the optimal GRA.**
		Hot gas decontamination/thermal desorption	Similar to "Incineration".	Similar to "Incineration".	High initial cost, No O&M.	**Retain, as component of excavation Process Option.**

TABLE 2-7
Saturated Media (Soil Below the Water Table, Technology Process Option Screening)
Frontier Fertilizer Feasibility Study, Davis, California

General Response Action (GRA)	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Recmmendations
Reuse	Reuse	Reuse	Use treated soil on-site to support future site uses. Reuse options depend on remedial technology implemented, e.g. COCs removed versus bound or contained.	Land use options are affected by the technology option implemented to achieve RAOs.	Low initial cost, low O&M.	**Retain, as an alternative to primary GRA.**
		Reuse (liquid phase)	Use treated GW on-site for treatment process and/or for irrigation during dry periods. Reuse options depend on remedial technology implemented.	Use as media to limit air and vapor transfer in the vadose zone and as carrier for treatment chemicals. Use as reclaimed water for irrigation may require permitting.	Low initial cost, low O&M.	**Retain, as an alternative to primary GRA.**
Disposition	Off-site disposition	Off-site disposal (soil)	Requires soil excavation, pretreatment and subsequent management of treated soil. Would transfer soil and COCs to Treatment,Storage and Disposal Facility. Require import of soil to replace removed soil.	In addition to collection requirements, transportation, pretreatment and disposal assumed to occur under existing permits.	High initial cost, low O&M.	**Retain, as component of excavation Process Option.**
		Discharge to surface water (liquid phase)	COCs and non-COCs prevent discharge to surface water, without pretreatment. Discharge of treated GW would be limited by conveyance system and receiving body of water.	May require coordination with the Regional Water Quality Control Board for discharge.	Low initial cost, low O&M.	**Retain, as an alternative to primary GRA.**
		Discharge to sanitary sewer/POTW (liquid phase)	COCs prevent discharge to sewer, without pretreatment. Discharge of treated GW would be limited by sewerage system capacity to convey and process the water.	Discharge would require Industrial User Pretreatment permitting. Existing P&T system has permit for discharge.	Low initial cost, low O&M.	**Retain, as an alternative to primary GRA.**
		Off-site disposal (liquid phase)	Off-site treatment of GW would not be effective given the volume requiring transportation. Requires GW collection and transportation to a Treatment,Storage and Disposal Facility.	In addition to collection requirements, transportation, pretreatment and disposal assumed to occur under existing permits.	Moderate initial cost, Moderate O&M.	**Don't retain**
	On-site disposition	Deep well injection (liquid phase	On-site disposal via injection my be an effective process for disposal of GW w/ COCs. Requires GW collection and possibly pretreatment.	Long term consequences of transferring COCs to other formation is unknown.	Moderate initial cost, low O&M.	**Don't Retain, Unlikely to receive permit.**
Secondary Emission Treatment	Air Emissions/offgas treatment	Vapor-phase carbon adsorption	Requires process equipment O&M and GAC disposition. Proven effective for COCs.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Retain, if RA Option emits gas phase COCs.**
		Thermal/catalytic/ oxidation	May be effective for COCs. Requires evaluation before implementation.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Retain, as component of excavation Process Option.**
		Bio-filtration	Aerobic process does not appear effective for treating COCs.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	Moderate initial cost, moderate O&M.	**Don't retain.**
		High energy destruction	May be effective for COCs. Requires evaluation before implementation.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain.**
		Membrane separation	May be effective for COCs. Requires evaluation before implementation.	Air emissions would require monitoring and control. May require coordination with Air Pollution Control District.	High initial cost, moderate O&M.	**Don't retain.**

A groundwater monitoring program is currently in place at the Site and is required to monitor performance of the pump and treat system, effectiveness of containment, and to document cleanup. Monitoring wells are located throughout the plume and at the outer edges of the plume to confirm plume location and evaluate migration. The frequency of well sampling varies depending on the specific data quality objectives for each well; some are sampled quarterly, others semi annual or annually.

Containment

Containment is a technology that isolates, minimizes, reduces, or eliminates bulk migration of contaminants in saturated subsurface environments. Containment systems (for example, barriers to vertical or horizontal groundwater movement) are used to isolate high concentration areas or source areas to impede migration of dissolved phase, or even potentially as free-phase, COCs. Barriers can be constructed from a variety of components, including clay, metal, asphalt, concrete, and synthetic materials. Optimally, horizontal barrier systems are keyed into a confining layer or less permeable material (for example, low permeability clay or bedrock). Barriers can be less costly than soil excavation, protective of human health and the environment, and reduce contaminant mobility. However, containment does not reduce the volume or toxicity of contaminants. Barriers may also restrict future land use and may require monitoring and maintenance to ensure performance.

Groundwater containment can be accomplished by modifying hydraulic gradients to change flow direction. Water pumped from wells with contaminated groundwater requires disposition and may require treatment. The extraction well hydraulic containment technology process option is retained. Horizontal barriers were not retained due to the absence of an impermeable boundary layer.

In situ Treatment

In situ treatment involves modifying media to reduce COC mass or mobility without collecting and removing the media. Biological, chemical or physical characteristics of the media are modified to obtain desired fate and transport mechanisms. Desired mechanisms enhance native mechanisms to facilitate achievement of RAOs.

In situ technologies and respective process options that were retained include: permeability enhancement by pneumatic fracturing, anaerobic biological treatment, and physical/chemical treatment by heating. No immobilization process options are retained. See Section 2.4.3.6 for a summary of process option bench-scale test results.

Collection

Excavation is a removal approach with treatment onsite or offsite, or with disposal at an offsite facility. Soil excavation is normally conducted with the use of a backhoe, power shovel, or in some cases, large rotary augers. The machinery used will be dependent on Site conditions and the depth of excavation required. Limited access (for example, buildings or other Site features) may limit the accessibility of excavation machinery. Following excavation, soil can be treated or managed at the Site or treated and/or disposed of offsite. The excavation of hot spots removal technology process option is retained.

Removal of contaminated groundwater is accomplished by pumping from wells or trenches. Extracted water requires disposition and treatment. The groundwater removal technology process option is retained.

Ex situ Treatment

Collected saturated media will likely require treatment prior to disposal or re-use. Saturated media treatment technologies are similar to those screened under the in situ GRA with the objective of reducing COC mass or mobility. Biological, chemical or physical characteristics of the removed media are modified to obtain desired fate and transport mechanisms. The liquid phase granular activated carbon physical/chemical treatment technology process option is retained for treatment of removed groundwater. The hot gas decontamination/thermal desorption physical/chemical treatment technology process option is retained for treatment of removed soil.

Re-use

As with unsaturated media, soil treated in situ will not be removed and will remain to support future Site activities and, if it were treated ex situ at the Site, it may be returned to its original location to fill the excavation pit. Soil re-use is retained.

Extracted and treated groundwater re-use options depend on water quality, quantity, season, and public acceptability. Reinjection of treated groundwater will be the only onsite re-use option that will accommodate the anticipated flow generated by control or collection technologies. Offsite re-use options could accommodate anticipated flows. Further evaluation of beneficial re-use options for treated water (for example, irrigation and constructed wetlands) can be evaluated to determine feasibility. However, no local area is available for wetlands and an agreement with a local farm operation will be needed to make irrigation viable. Groundwater re-use is retained.

Disposition

As with unsaturated media, the representative process option for disposal is the offsite disposal of contaminated soils. In this process option, excavated soil is designated for transport to an approved offsite landfill where appropriate measures will be taken to protect human health and the environment in the vicinity of the facility, either by treatment before disposal or, if treatment is not necessary, by disposing of the soil within an engineered containment system to prevent offsite contaminant migration. The offsite disposal option is retained.

Treated groundwater has been disposed by discharge into the City of Davis sanitary sewerage system. Offsite disposal of untreated groundwater is an unlikely scenario. Discharge of treated groundwater to surface water may be acceptable and even considered beneficial. The discharge to surface water or the sanitary sewer offsite disposition technology process options are retained.

Secondary Emission Treatment

As with unsaturated media, many GRAs have the potential to emit COCs during construction and implementation phases; therefore, secondary emission treatment is included. Secondary treatment refers to treatment of residuals from a primary treatment process. Technology screening includes evaluation of the potential for generating emissions of COCs and potential associated risks. Ex situ treatment with granular activated carbon (GAC) is currently being used to treat aqueous phase COCs. This process involves some volatilization of groundwater COCs which may require capture and treatment. The preferred secondary treatment process for COCs at the Site is vapor-phase GAC. Vapor-phase carbon adsorption is retained as the air emission/off-gas treatment technology process option based on retained GRA technologies.

SECTION 3

Development and Screening of Alternatives

This section presents results of the remedial alternative development and screening phase of the FS. In accordance with EPA Guidance (EPA, 1988), remedial alternatives are developed by assembling remedial technologies and representative process options, retained during the technology screening phase, to achieve CERCLA § 121 Cleanup Standards at the Frontier Fertilizer NPL Site.

Remedial alternatives were developed based on Site-specific considerations primarily related to the nature of the COCs, that is, their concentration and state (for example, NAPL versus dissolved-phase concentrations), geology and hydrogeologic conditions, and interaction between media. The resulting RAs were then evaluated based on three screening criteria: effectiveness, implementability, and cost. The RAs with the most favorable screening results are retained for further consideration and reviewed through the detailed analysis in Section 4.

3.1 Development of Alternatives

Remedial alternatives were developed by grouping prescreened technology process options into alternatives that meet Site-specific RAOs for the three volumes that comprise the media impacted by chemicals released during Site activities:

- **Media A—Unsaturated source volume.** Soil from the surface to the water table where COCs have been detected, and is at or immediately adjacent to the former disposal basin location. The water table elevation fluctuates between 10 and 30 feet bgs on an annual cycle and a portion of this area was removed during an interim measure as described in the RI report (Bechtel, 1997).
- **Media B—Saturated source volume.** Saturated soil where COCs were detected in soil samples, which is below and extends slightly north of the unsaturated source soil.
- **Media C—Dissolved plume volume.** Includes the volume where COCs are detected in groundwater above RAOs, excluding Media B. The dimension of the dissolved plume is based on monitoring data that are relatively current as compared to investigation data most recently collected in 2001. COCs have been detected in all of the three shallowest monitored zones.

Media A, B, and C are shown on Figure 1-2. Alternatives have been developed for remediation of all three media based on concurrent construction and implementation. The major components of each alternative are presented in Table 3-1. The description of potential remedial alternatives includes the conceptual design basis for each component, if applicable. Specific conceptual design or component details were developed for the FS evaluation of the alternatives selected for comparative analysis only.

3.2 Screening of Alternatives

This section presents results of the screening-level evaluation of developed alternatives. Screening evaluates the developed alternatives against three criteria: effectiveness, implementability, and cost. Alternatives that pass the screening are retained for detailed analysis. Both the short- and long-term effects of an alternative's ability to protect human health and the environment by reducing toxicity, mobility, or volume are evaluated. Short-term timeframe includes both the construction and implementation periods, and long-term is post short-term. The implementation period concludes once RAOs are achieved. Implementability, as a measure of both the technical and administrative feasibility of constructing, operating, and maintaining a remedial alternative, is used to evaluate the combinations of process options with respect to Site-specific conditions. Technical feasibility refers to the ability to construct, reliably operate, and comply with technology-specific regulations during and potentially after remedial alternative implementation. Comparative estimates of relative alternative costs are used during the screening step. A summary of this section is contained in Table 3-2.

3.2.1 Alternative 1—No Action

Description

NCP (40 CFR 300.430[e][6]) requires that a no action alternative (Alternative 1) is evaluated to provide a baseline condition if no remedial action is taken. Because no remedial activities are implemented with the no-action alternative, long-term human health and environmental risks for the Site essentially will be the same as those identified in the baseline risk assessment. Alternative 1 assumes that no actions are taken to remediate COCs in Site media and that current activities (pump and treat, groundwater monitoring, and access restrictions) are not continued.

Criteria Assessment

Alternative 1 does not include any administrative or engineered process options that protect human health or the environment from COCs. In the short term, this alternative is ineffective in achieving RAOs due to the resulting increase in COC mobility and volume of contaminated media. During the construction period—which may include decommissioning of the existing groundwater pump and treat system, monitoring, and access restrictions—little change to the toxicity, mobility, and volume is anticipated. Discontinuance of the existing groundwater pump and treat system operation and groundwater monitoring in addition to unlimited Site access will result in increased exposure to COCs. Termination of hydraulic containment activities (pump and treat system) will allow contaminants to migrate and probably increase the COC concentrations and volume of Media C. Termination of the groundwater monitoring prevents monitoring of COC migration. Elimination of fencing and posting will likely result in worst-case exposure to contaminated soil and groundwater as defined in the risk assessment.

The capital and operational costs of Alternative 1 are assumed to be $0 for the purposes of achieving RAOs.

Alternative 1 is retained to serve as a baseline against which other options are compared.

TABLE 3-1
Remedial Alternative Components
Frontier Fertilizer Feasibility Study, Davis, California

Media	General Response Action (GRA)	Remedial Technology	Process Options	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 3 Surface Cap plus Alternative 2	Alternative 4 Excavation plus Alternative 2	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
Common to all Media	Institutional controls	Land use restrictions	Deed restriction		●	●	●	●	●
	Access restrictions	Access restrictions	Restrict access		●	●	●	●	●
	GW monitoring	Monitor COCs and GW head	Monitor COC fate & transport		●	●	●	●	●
	Temporary cap	Surface barrier to exposure	Wood chip or rock layer over ground surface		●	●	●	●	●
A—Unsaturated Source Zone	Surface controls	Surface water rain controls	Grading			●	●	●	●
			Revegetatation				●	●	●
	Containment	Surface vertical barriers	Concrete or asphalt cap			●			
	In situ treatment	Biological treatment	Anaerobic					●	●
		Physical/chemical Treatment	Media heating						●
	Collection	Removal	Excavate hot spots (soil)				●		
			Soil vapor extraction (SVE)						●
	Re-use	Re-use	Re-use onsite	●	●	●		●	●
	Disposal	Offsite disposition	Offsite treatment & disposal				●		
	Secondary treatment processes	Air emissions/off-gas treatment	Vapor-phase carbon					●	●
B—Saturated Source Zone	Containment/collection	Hydraulic containment	Extraction wells (X-1A, X-6B, MW-7B)		●	●	●	●	●
	In situ treatment	Biological treatment	Anaerobic					●	●
		Physical/chemical treatment	Media heating						●
	Collection	Removal (soil)	Excavate hot spots				●		
		Removal (groundwater)	Extract groundwater		●	●	●	●	●
	Ex situ treatment	Physical/chemical treatment (liquid phase)	Liquid phase GAC		●	●	●	●	●
	Re-use	Re-use	Re-use (soil)					●	●
			Re-use (liquid phase)					●	●
	Disposition	Offsite disposition	Offsite treatment & disposal (soil)				●		
			Discharge to surface (liquid)					●	●
			Discharge to sanitary sewer (liquid)		●	●	●	●	●
	Secondary treatment processes	Air emissions/off gas treatment	Vapor-phase GAC		●	●	●	●	●

TABLE 3-1
Remedial Alternative Components
Frontier Fertilizer Feasibility Study, Davis, California

Media	General Response Action (GRA)	Remedial Technology	Process Options	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 3 Surface Cap plus Alternative 2	Alternative 4 Excavation plus Alternative 2	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
C—Saturated Dissolved Zone	Containment	Hydraulic containment	Extraction wells (S-1 & S-2 zones)		●	●	●	●	●
			Extraction wells (A-1 zone)						
	In situ treatment	Permeability enhancement	Pneumatic fracturing						
		Biological treatment	Anaerobic					●	●
	Collection	Removal (groundwater)	Extract groundwater (S-1 & S-2 zones)		●	●	●	●	●
			Extract groundwater (A-1 zone)						
	Ex situ treatment	Physical/chemical treatment (liquid phase)	Liquid phase GAC		●	●	●	●	●
	Re-use	Re-use	Re-use (liquid phase)					●	●
	Disposition	Offsite disposition	Discharge to sanitary sewer		●	●	●	●	●
	Secondary treatment processes	Air emissions/off-gas treatment	Vapor-phase GAC		●	●	●	●	●

● = Process option is included in alternative(s)

TABLE 3-2
Summary of Remedial Alternative Screening
Frontier Fertilizer Feasibility Study, Davis, California

Remedial Alternative	Remedial Alternative Name	Description	Effectiveness	Implementability	Cost (Capital/Operation and Maintenance)	Retained for Detailed Analysis
1	**No Action**	No actions are taken to remediate COCs. Existing pump and treat, groundwater monitoring, and access restrictions are discontinued.	Increases potential for exposure to COCs in soil, GW and vapor, therefore increases risks to human and environmental health.	Technically feasible, but unlikely to receive administrative acceptance due to the reduced level of protection of human health and environment.	No capital cost, no O&M cost.	Yes
2	**Groundwater P&T**	Existing process options (pump and treat, GW monitoring) and "Common Components" are implemented until RAOs are achieved.	No construction required in the short-term; however, later additional extraction wells may be necessary. Effective at protecting human health and the environment against COC exposure. A long implementation period is predicted due to COC physiochemical characteristics. Once implementation is completed, it is likely that RAOs will be maintained.	Technically feasible. May not be administratively feasible due to the predicted long implementation period to achieve RAOs.	Low capital cost, high O&M cost.	Yes
3	**Surface Cap plus Alternative 2**	Construction of a cap over Media A in addition to implementation of Alternative 2 and "Common Components."	Cap construction presents minor threat and risk to human health. Implementation provides increased protection for human health against COC exposure. The implementation period likely to increase due to slower release of COCs to GW.	Technically feasible. May not be administratively feasible due to the predicted long implementation period to achieve RAOs.	Low capital cost, high O&M cost.	No
4	**Excavation plus Alternative 2**	Excavation of all Media A and Media B to 30 feet bgs in addition to implementation of Alternative 2 and "Common Components."	Excavation presents significant threat and risk to human health and generates a large volume of hazardous waste requiring shipping, treatment, and disposal. Implementation provides increased protection for human health and the environment by removing COC mass with the media.	Technical feasibility depends on offsite hazardous waste treatment availability. May not be administratively feasible due to the exposure potential during excavation and waste management, and the predicted long implementation period to achieve RAOs.	High capital cost, medium O&M cost.	No
5	**Biological Treatment plus Alternative 2**	Construction of an infiltration system in Media A and B to facilitate application of an electron donor solution in addition to implementation of Alternative 2 and "Common Components."	Infiltration system construction presents minor threat and risk to human health. Implementation provides increased protection for human health and the environment against COC exposure. It is likely that the implementation period is further reduced by in situ biological treatment.	May be technically feasible. May not be administratively feasible due to the predicted long implementation period to achieve RAOs.	Medium capital cost, medium O&M cost.	Yes
6	**Thermal Destruction (TD) plus Alternative 2**	Electrodes in the source area will be used to increase subsurface temperature to either below or above 100°C to hydrolyze COCs or to hydrolyze and volatilize COCs, respectively. Alternative 2 and "Common Components" implementation will continue until RAOs are achieved.	In situ TD process construction presents minor threat and risk to human health. Implementation provides increased protection for human health and the environment against COC exposure. It is likely that the implementation period is further reduced by in situ TD.	Alternative is implementable. Complexity is increased due to installation of electrodes and SVE is required if heat media above 100°C to control and treat emissions.	Medium capital cost below 100°C and higher above 100°C, medium O&M cost.	Yes

3.2.2 Alternatives 2 through 6—Common Components

All of the remaining alternatives have four components in common (institutional controls, access restrictions, groundwater monitoring, and a temporary cap). Although the description of these components is not repeated in the discussions for each alternative, differences in their planned implementation are identified where appropriate.

- **Institutional control (restrictive covenant):** Descriptions of contaminated media and respective restrictions are incorporated into affected property deeds with the intent of minimizing risk by limiting exposure until RAOs are reached. Restrictions may include prohibiting residential use and groundwater extraction. Excavation, grading, and trenching will also be limited in the source area. Specific building requirements in the source area, such as ventilation system elements, will also be included in the restrictive covenant.
- **Access restrictions:** Access to Media A is restricted with fencing and signage to prevent access by unauthorized personnel until RAOs are reached.
- **Groundwater monitoring:** Groundwater monitoring continues until RAOs are achieved.
- **Temporary cap:** Wood chips or gravel will cover the Site to prevent ecological receptors from contacting contaminated surface soil.

3.2.3 Alternative 2—Groundwater Pump and Treat

Description

Alternative 2 assumes that existing process options continue to be implemented, but no new actions are performed in the short-term. Monitoring to evaluate progress toward achieving RAOs determines if additional extraction or monitoring wells, or modifications to the treatment system are necessary. Alternative 2 is implemented until groundwater monitoring indicates that RAOs are achieved. Alternative 2 processes include groundwater extraction to collect COCs migrating with groundwater from the source area. Natural processes such as rainwater infiltration through Media A, groundwater migration through Media B, and biological and geochemical interactions with COCs determine the rate COCs can be extracted and treated. Treated groundwater continues to be discharged to the City of Davis sanitary sewer.

A summary of Alternative 2 is presented in Table 3-1.

Criteria Assessment

Alternative 2 process options are the same as those that currently exist at the Site, that is, pump and treat system and groundwater monitoring. Therefore, no construction period occurs. The short-term effectiveness related to implementation depends on the rate that the source of COCs is reduced to levels that result in achievement of RAOs. The current groundwater extraction from S-1 and S-2 zones appears to contain most groundwater that has picked up COCs while passing through the source volume. Reduction of COC mass in the source volume would occur slowly as contaminants travel from Media A and B to downgradient extraction wells. Therefore, the remedial alternative implementation period (the implementation period necessary to achieve RAOs) is long. Also, groundwater monitoring results indicate that COCs have entered the A-1 zone and are detected in the

S-1 zone near the horizontal boundary of the pump and treat system's zone of influence. Some COCs were detected at concentrations above RAOs in groundwater samples collected from these locations.

Alternative 2 appears technically and administratively feasible, even with the predicted long implementation period to achieve RAOs. The pump and treat system infrastructure is currently operating, but most system components will require replacement, some multiple times, during the anticipated long implementation period to maintain performance. Also, the capacity to discharge treated groundwater to the City of Davis sewer may be reduced as planned land developments occur and limit sewer capacity.

The capital costs of Alternative 2 are low since the pump and treat system, monitoring wells, and access controls exist; however, the total operation and maintenance costs will be high due to the 57 years used as the timeframe to achieve RAOs. Fifty-seven years is the average timeframe for the most recalcitrant COC (DBCP) to reach RAOs. This is discussed in more detail in Appendix A.

Alternative 2 is retained for detailed analysis.

3.2.4 Alternative 3—Surface Cap plus Alternative 2

Description

Alternative 3 consists of the installation and maintenance of a concrete or asphalt cap to minimize infiltration of precipitation through the unsaturated source area, Media A, in addition to Alternative 2. The cap is graded to cause rainwater to flow away from Media A, which minimizes leaching of contaminants into Media B. Caps at many sites can reduce infiltration and the associated leaching of COCs into the groundwater. The cap would also impede the migration of vapors from Media A and B upward. For this alternative to remain effective over the long-term, the cap integrity and Alternative 2 process options should be maintained through the implementation period. Capping the unsaturated source soil area may limit COCs in Media A, that is, the rate COCs move from Media A into groundwater but does not reduce the total mass. Reduced mobility can result in lower COC concentrations in groundwater. It also extends the period that the COCs are available to cross the boundaries; that is, it could increase the implementation period. Subsequently, COCs continue to migrate between Media B and C. Alternative 2, described above, continues to control and monitor COC migration in groundwater.

The process options that comprise Alternative 3 can be found in Table 3-1.

Criteria Assessment

During cap construction, potential threats and risks to workers and the community are present due to ingestion of soil particles containing COCs or VOC vapors emitted from soil during grading activities. This could be mitigated through dust control measures. No media are removed from the Site during construction to prevent transfer of volume. Native animal and plant species habitat over Media A are destroyed by the cap as is expected by planned commercial development. Immediately after construction, the cap prevents wind erosion of soils, vapor migration through the surface, and reduces infiltration and respective leaching, but will not significantly reduce contaminant concentrations in the saturated and dissolved volumes.

Concentrations of COCs in groundwater will remain above RAOs after cap construction and during a predicted very long implementation period. The implementation period will depend on the rate that COC concentrations are reduced by native processes and by the groundwater pump and treat system. Long-term effectiveness will depend on the magnitude of groundwater recharge events during the implementation period.

Although technically feasible, the implementation period for Alternative 3 will be longer than the 57 years estimated for Alternative 2. No special tools, techniques, or material will be needed to construct Alternative 3. The cap requires long-term monitoring and restrictions on land use to prevent uncontrolled excavation or other activities that could damage the cap and create exposure pathways to human and ecological receptors.

The direct and indirect capital costs for Alternative 3 are low; however, total O&M costs are high due to long-term pump and treat system O&M and groundwater monitoring.

Alternative 3 is not retained for detailed analysis and will probably not receive regulatory agency approval.

3.2.5 Alternative 4—Excavation plus Alternative 2

Description

The main component of Alternative 4 is the excavation of the unsaturated source zone and the saturated source zone to a depth of approximately 30 feet bgs in addition to Alternative 2 process options. Investigation results indicate that about 90 percent of the VOC mass is included in the excavated soil although soil collected in 2004 for treatability testing indicated that high concentrations of VOCs are present deeper. Excavation to 30 feet bgs is conducted using conventional earthmoving equipment although air emissions from excavation activities is likely to require equipment operators and support personnel to use restrictive personnel protective equipment, including self-contained breathing apparatus. The type and quantity of equipment used will depend on the work area and ambient air VOC concentrations measured during excavation. Due to current work safety VOC ambient air limits (for example, DBCP, and the distance between the excavation and human receptors), it is assumed that emissions to ambient air during excavation will need to be controlled with a tent and air handling and treatment equipment. Since excavation to a depth of 30 feet bgs is planned, it is anticipated that excavation will be carried out in early fall when the water table is low. It is anticipated that additional groundwater extraction and treatment capacity is required to dewater the excavation zone. The existing pump and treat system continues to operate and partially dewater the excavation, although plumbing, and power and control conductors will likely require rerouting to accommodate the excavation. Soil samples will be collected and analyzed during excavation to characterize the waste and the boundary of the excavation. The excavated soil will be transported to minimize air emissions and will be treated and disposed of offsite. The excavation area will be backfilled with clean soil. Even after excavation is completed, it is anticipated that the remaining COCs in Media B will result in RAO exceedances for decades. This is due to the low MCLs for Site-specific VOCs.

Excavation of the volume of Media B deeper than 30 feet bgs will require more extensive dewatering, use of specialized equipment, and more transportation, treatment, and disposal capacity. Even if 99 percent of the VOC mass is removed, fate and transport modeling predict that if only 1 percent of the estimated mass of DBCP remains in the media, it will take decades to achieve RAOs. Deeper excavation was not investigated further due to probable technical and administrative impracticability and higher cost.

The process options that comprise Alternative 4 can be found in Table 3-1.

Criteria Assessment

Excavation and offsite treatment and disposal of shallow source soil will reduce the volume of contaminated media. Excavation of contaminated media and subsequent transportation and treatment will result in VOC emissions into the air, increasing possible risks to the community and construction personnel. After excavation is complete, the duration of the implementation period is reduced because the removed VOC mass will not be available for transfer into the groundwater or vapor phase. Remaining COCs will exist below the low water table level and will continue to migrate between Media B and C due to advection, although a significant reduction in concentrations is predicted. Although excavation to 30 feet bgs will reduce time to meet RAOs, fate and transport modeling predicts that the remaining VOCs will continue to impact groundwater for a long time even with Alternative 2 process options. Native animal and plant species habitat will be destroyed by the excavation as is expected by planned commercial development. Once RAOs are achieved, Alternative 4 should provide long-term effectiveness.

Most elements of Alternative 4 appear to be technically feasible, although the soil excavation, and treatment and disposal of both groundwater and soil removed during excavation will be technically challenging. Alternative 4 may not be administratively feasible based on risks presented during excavation, the availability of offsite treatment, and the long implementation period.

The direct capital costs related to excavation and waste management for Alternative 4 are high and are estimated to be two-fold higher than the thermal destruction (TD) alternative. The total operation and maintenance costs will be medium due to long-term operation of the pump and treat system and groundwater monitoring.

Alternative 4 is not retained for detailed analysis. Excavation of Media A and B to 30 feet bgs will reduce approximately 80 percent of the mass of COCs and reduce the timeframe to reach RAOs in groundwater as compared to Alternative 2, which leaves source mass in place. The risk and costs associated with excavation will be very high; therefore, it is unlikely that Alternative 4 will receive community and regulatory agency approval.

3.2.6 Alternative 5—Biological Treatment plus Alternative 2

Description

The main component of Alternative 5 is in situ biological degradation of COCs in addition to Alternative 2 process options. Results of bench-scale treatability testing described in Section 2 indicate that anaerobic conditions quickly degraded nitrate, nitrite, and sulfate and may degrade Site COCs over a longer timeframe. The degree of success with biological treatment is uncertain; however, there has been some success at other sites with similar COCs.

Electron donors evaluated in the bench-scale test, in order of decreasing cost, are: Hydrogen Release Compound™, Edible Oil Substrate™, methanol ethanol acetate lactate, and beer fermentation process waste. No significant difference in treatment effectiveness between the substrates was observed.

The process will include the design and construction of a system to facilitate continuous application of a dilute solution of substrate in a treated groundwater stream evenly throughout Media A and B. For Media A, application will be accomplished with an infiltration system of perforated pipes installed in a permeable material placed across the ground surface. Continuously applied substrate solution will percolate down through the unsaturated zone and into the saturated zone. For Media B, application could be accomplished with an injection system utilizing existing injection wells (IW-1 thru 6) located upgradient of and screened across the depth of Media B to distribute the solution across the depth of the contaminated media. Process equipment will be installed to create and distribute the solution. A portion of the existing treatment system discharge is used to create the substrate solution for the infiltration/injection system. Substrate would be stored and mixed with the groundwater treatment system effluent within the building housing the existing treatment system, and the substrate solution would be pumped to the infiltration and injection systems. The balance of the treatment system effluent would continue to be discharged to the sanitary sewer. The groundwater extraction system included in Alternative 2 would maintain a gradient across the contaminated zone to help distribute substrate solution and provide collection and treatment of groundwater exiting Media A and B.

Field testing using beer fermentation process waste is planned to further evaluate the application methods. The groundwater extraction system included in Alternative 2 will maintain a gradient so that groundwater exiting Media A and B is collected and processed through the treatment system.

The process options that comprise Alternative 5 can be found in Table 3-1.

Criteria Assessment

Data from other sites and preliminary bench scale test results indicate that anaerobic degradation may reduce the toxicity and mass of COCs. Construction of the process will present minimal threats and risks to the community and construction personnel by treating contaminated media in situ and using existing injection wells. The duration of the implementation period will be determined by the rate that the mass and mobility of COCs in Media A and B are reduced. Based on treatability testing, nitrate, nitrite, and sulfate mass in more permeable soil is expected to rapidly decline. The rate of VOC biodegradation is limited by the availability of oxygen, nitrate, sulfate and possibly other energy sources due to the fact that they are typically more easily utilized by microorganisms. Therefore, the availability of these energy sources in Media A and B must be reduced in order to create conditions favorable to VOC-reducing microorganisms. The COC mass present in the more permeable media soil will be reduced first followed by the mass in the less permeable media soil. This is due to the fact that the substrate will be readily available to microorganisms in the more permeable media soil and take longer to reach microorganisms in contact with COCs in the less permeable media soil. COC concentrations also affect the rate that microorganisms can utilize COCs, that is, high concentrations may be toxic to microorganisms, and therefore they will utilize COCs as they desorb from points with higher concentrations.

For the purpose of evaluating Alternative 5, an implementation period for the anaerobic process of 10 years is used based on data from other sites. After the 10-year implementation of the anaerobic process, it is predicted that it will take 42 additional years to reach RAOs in groundwater (total of 52 years). Groundwater monitoring will be used to evaluate progress during the period. The evaluation will include discontinuing application of solution to the infiltration system when monitoring indicates RAOs are achieved in order to evaluate long-term effectiveness of Alternative 5. The 52-year duration is based on the average timeframe to achieve RAOs for the most recalcitrant COC (DBCP). This is discussed in more detail in Appendix A. The timeframe for cleanup will be updated after source cleanup is accomplished.

Native animal and plant species habitat will be destroyed by the construction of the Media A infiltration system as is expected by planned commercial development. Since implementation includes continuous infiltration of water to all of Media A and B until RAOs are achieved, it is anticipated that any remaining COCs will not be available to desorb into groundwater or soil gas at concentrations that exceed RAOs.

Alternative 5 appears to be technically feasible, although the efficacy will be determined by groundwater monitoring during the implementation and post-implementation period. Alternative 5 appears to administratively feasible based on minimal risks present during construction and implementation.

The direct capital costs related to Alternative 5 are low and total operation and maintenance costs are medium and primarily related to the pump-and-treat system operation and maintenance and groundwater monitoring.

Alternative 5 is retained for detailed analysis. Establishing and maintaining anaerobic and the associated chemical reducing condition in Media A and B will reduce the mass of COCs although the timeframe is uncertain. The minimal risks and costs associated with construction and the estimated implementation period present a desirable RA.

3.2.7 Alternative 6—Thermal Destruction plus Alternative 5

Description

The main component of Alternative 6 is in situ heating, hereafter referred to as TD, of Media A and B in addition to Alternative 5 process options. Technical literature indicates that VOCs undergo hydrolysis rapidly at elevated temperatures. Hydrolysis is the process where halogenated atoms on a molecule are replaced with hydrogen atoms, resulting in a less toxic chemical. Preliminary sample analytical results from bench-scale treatability testing indicate that heating reduced VOC concentrations even with variability in soil concentrations. Groundwater monitoring results also indicate that native conditions, possibly via hydrolysis or microorganisms, appear to be degrading VOCs based on elevated bromide concentrations found in samples from wells near the source area. Heating is not expected to treat nitrate; therefore, the anaerobic degradation process is included (Alternative 5) as a secondary process.

The treatability testing included heating and maintaining test vessels at temperatures below and above the boiling point of water. The higher temperatures appeared to increase the hydrolysis rate for the VOCs. Implementation of an in situ TD process will require that heat energy be applied to Media A and B in order to heat and maintain the desired elevated temperature. The two common methods of media heating are electrical resistive heating and conduction heating. Both methods use electrical power to heat the media. Electrical resistive heating passes electrical current through the soil while the resistance presented by the soil raises the temperature and conductive heating uses heated well casings to conduct heat through the subsurface. To implement either technology, electrodes are installed into the ground so that the target region is heated. Electrodes will be installed, in a honeycomb pattern, through the unsaturated and saturated source area. The vertical limits are set by the depth to which boreholes for electrode construction can be drilled and by the size of the power control unit. For the Site, it is estimated that 60 feet bgs is the deepest possible treatment depth based on discussions with vendors. The rate of hydrolysis, based on the Arrhenius equation, is proportional to the temperature, that is, higher hydrolysis rates occur at higher temperatures. Achieving and maintaining higher temperatures in the media requires higher energy input. Energy demand is primarily based on the volume of groundwater in the media; the higher the volume of groundwater passing through the media the higher the energy demand to maintain the elevated temperature. Given that cooler groundwater is continuously moving through Media B, significant energy input will be required to maintain the elevated temperatures.

Since preliminary test results indicate that TD appears to degrade VOCs both below and above the boiling temperature of water, the two temperatures are evaluated. Construction and implementation of the TD process to facilitate treatment at temperatures less than the boiling point of water and above the boiling point are assumed to be the only differences, that is, no effect on long-term effectiveness. Heating media to temperatures above 100 degrees Celsius (°C) will require higher rates of energy input and will result in higher rates of vapor emissions. Therefore, higher capacity power supply equipment and vapor emission control and treatment equipment will be required to accommodate TD at higher temperatures. Soil vapor extraction wells will be installed to accommodate the higher temperature condition along with vapor conveyance piping and controls. A soil vapor collection system will generate condensate and vapor, which will require treatment with liquid and gas phase activated carbon, respectively. Ultimately, a balance between the duration of the implementation period and the additional risks and cost associated with higher temperatures will be necessary.

The process options that comprise Alternative 6 can be found in Table 3-1.

Criteria Assessment

Preliminary test results indicate that TD will reduce the toxicity and mass of VOCs. Construction will present minimal threats and risks to the community and construction personnel by treating contaminated media in situ. Boring into Media A and B to install electrodes to a depth of 60 feet bgs will present potential for exposure to VOCs because contaminated soil will be brought to the surface and require management using health and safety and waste management procedures. The duration of the implementation period will be determined by the rate that the mass and mobility of VOCs in Media A and B are reduced. For the purpose of evaluating Alternative 6, it is assumed that the implementation period of TD to degrade VOCs will be approximately 1 year and the secondary process of anaerobic degradation to degrade nitrates will be approximately 5 years. The 1-year implementation duration is based on discussions with vendors. Nitrate and nitrite also are treated as part of this alternative, due to the low cost and ease of implementation. Groundwater monitoring will be used to evaluate remedial alternative progress during the period. Application of energy will be discontinued when groundwater monitoring indicates that RAOs are achieved in order to evaluate long-term effectiveness of TD. Native animal and plant species habitat will be destroyed by the construction of the Media A infiltration system and installation of TD components as expected by planned commercial development. The noise related to TD process equipment necessary to power the system and control and treat VOC emissions is expected to be minimal. It is assumed that sufficient electrical power infrastructure is available at the property line. Since implementation includes continuous infiltration of water to all of Media A and B until nitrates are reduced and monitoring after RAOs are achieved, it is anticipated that any remaining COCs will not be available to desorb into groundwater or soil gas at concentrations that exceed RAOs.

Alternative 6 appears to be technically feasible, although the efficacy will be determined by groundwater monitoring during the implementation and post-implementation period. Alternative 6 appears to be administratively feasible based on minimal risks presented during construction and implementation.

The direct capital costs related to Alternative 6 will be medium primarily related to TD, and total operation and maintenance costs are medium primarily related to the timeframes for the pump and treat and groundwater monitoring.

Alternative 6 is retained for detailed analysis. Construction of the TD process presents VOC exposure risks and waste management challenges that could be mitigated to acceptable levels. Implementation of the TD process will result in high electrical energy demand and potential exposure of VOCs due to air emissions both of which could be managed. Establishing and maintaining anaerobic and the associated chemical reducing condition in Media A and B will reduce the nitrate concentrations in groundwater. Moderate risk and costs associated with construction and the estimated 1 year to meet soil RAOs, an additional 5 years to reduce the remaining pesticide and nitrate and nitrite levels in groundwater using biological degradation, and a 44-year implementation period for cleanup of groundwater to MCLs present a desirable RA. The implementation period of anaerobic degradation process for nitrate would be approximately 5 years. After the VOC RAOs are achieved, it is assumed that it will take approximately 38 years for RAOs to be achieved in Media C. The 38-year duration is based on the average timeframe to achieve RAOs for the most recalcitrant COC (DBCP). This is discussed in more detail in Appendix A. The timeframe for cleanup will be updated after source cleanup is accomplished.

SECTION 4

Detailed Analysis of Alternatives

In this section, detailed analysis is completed for the remedial alternatives that passed the screening analysis for application to Site-specific media. The remedial alternatives are evaluated in detail using the standard criteria specified in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988). The remedial alternatives are evaluated individually against each criterion, and then the remedial alternatives are compared to determine specific strengths and weaknesses that must be balanced. The results of the detailed analysis support the selection of a remedial alternative and become the foundation for the ROD.

The nine CERCLA evaluation criteria are as follows:

1. Overall protection of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume through treatment
5. Short-term effectiveness
6. Implementability
7. Cost
8. State acceptance
9. Community acceptance

The NCP (40 CFR Section 300.430[e][9][iii]) categorizes these nine criteria into the following three groups: (1) threshold criteria, (2) primary balancing criteria, and (3) modifying criteria. Each type of criteria has its own weight when it is evaluated. Threshold criteria are requirements that each alternative must meet to be eligible for selection as the Preferred Alternative, and include overall protection of human health and the environment and compliance with ARARs.

Primary balancing criteria are used to weigh effectiveness and cost tradeoffs among alternatives. The primary balancing criteria include long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. The primary balancing criteria represent the main technical criteria upon which the remedial alternative's evaluation is based.

Modifying criteria include state acceptance and community acceptance, and may be used to modify aspects of the Preferred Alternative when preparing the ROD. Modifying criteria are generally evaluated after public comment on the Proposed Plan. Accordingly, only the seven thresholds and primary balancing criteria are part of the detailed analysis phase.

The following subsections contain descriptions of the evaluation criteria, individual evaluations of the remedial alternatives, and a comparative evaluation of remedial alternatives for each affected medium.

4.1 Description of Evaluation Criteria

A description of the nine CERCLA evaluation criteria is provided in this subsection along with the methods and considerations used to evaluate the effectiveness of remedial alternatives in meeting each of the criteria.

4.1.1 Threshold Criteria

Overall Protection of Human Health and the Environment

This evaluation criterion assesses how each remedial alternative provides and maintains adequate protection of human health and the environment. remedial alternatives are assessed to determine whether they can adequately protect human health and the environment from unacceptable risks posed by the Site COCs, in both the short and long term. This criterion is also used to evaluate how risks would be eliminated, reduced, or controlled through treatment, engineering, or institutional controls. The considerations evaluated during the analysis of each remedial alternative for overall protection of human health and the environment are presented in Table 4-1.

TABLE 4-1
Criterion 1—Overall Protection of Human Health and the Environment
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factor	Considerations
Human health protection	Likelihood that the remedial alternative reduces risk to human health resulting from exposure to contaminants in soil and GW via direct contact (dermal and ingestion) or indirect contact (vapor intrusion).
Environmental protection	Likelihood that the remedial alternative reduces the threat to unaffected groundwater/soil by minimizing migration of contaminants. Likelihood that the remedial alternative reduces risk to ecological receptors.

Compliance with Regulatory Requirements

This evaluation criterion is used to determine if each technology would attain federal and state regulatory requirements. Other information, such as advisories, criteria, or guidance, is considered where appropriate during the regulatory requirements analysis. The considerations evaluated during the analysis of the regulatory requirements applicable to each remedial alternative are presented in Table 4-2. Potential action-, location-, and chemical-specific regulatory requirements for the technologies presented in this FS are summarized in Section 2.

TABLE 4-2
Criterion 2—Compliance with Regulatory Requirements
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factor	Considerations
Chemical-specific regulatory requirements	Likelihood that the remedial alternative will achieve compliance with chemical-specific regulatory requirements.
Location-specific regulatory requirements	Determination of whether any location-specific regulatory requirements apply to the remedial alternative. Likelihood that the remedial alternative will achieve compliance with the location-specific regulatory considerations.
Action-specific regulatory requirements	Likelihood that the remedial alternative will achieve compliance with action-specific regulatory requirements (e.g., hazardous waste treatment regulations).

4.1.2 Method Criteria

Long-term Effectiveness and Permanence

This evaluation criterion addresses the long-term effectiveness and permanence of maintaining the protection of human health and the environment after implementing the remedial alternative. The primary components of this criterion are the magnitude of residual risk remaining at the Site after RAOs have been met and the extent and effectiveness of controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes. The considerations evaluated during the analysis of each remedial alternative for long-term effectiveness and permanence are presented in Table 4-3.

TABLE 4-3
Criterion 3—Long-term Effectiveness and Permanence
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factor	Considerations
Magnitude of residual risks	Identity of residual risks (risks from treatment residuals) as well as risks from untreated residual contamination. Magnitude of the remaining risks considering their volume, toxicity, mobility, and propensity to bioaccumulate.
Adequacy and reliability of controls	Likelihood that the remedial alternative will meet required process efficiencies or performance specifications. Type and degree of long-term management required. Long-term monitoring requirements. Operations and maintenance (O&M) functions that must be performed. Difficulties and uncertainties associated with long-term O&M. Potential need for technical components replacement. Magnitude of threats or risks should the remedial action need replacement. Degree of confidence that controls can adequately handle potential problems.

Reduction of Toxicity, Mobility, or Volume through Treatment

This evaluation criterion addresses the anticipated performance of the remedial alternative's treatment technologies in permanently and significantly reducing toxicity, mobility, and/or volume of hazardous materials at the Site. A preference is given to remedial alternatives where treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated media. The considerations evaluated during the analysis of each remedial alternative for reduction of toxicity, mobility, or volume through treatment are presented in Table 4-4.

TABLE 4-4
Criterion 4—Reduction of Toxicity, Mobility, or Volume through Treatment
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factor	Considerations
Treatment process used and material treated	Likelihood that the treatment process addresses the principal threat. Special requirements for the treatment process.
Amount of hazardous material destroyed or treated	Portion (mass) of contaminant that is destroyed. Portion (mass) of contaminant that is treated.
Reduction in toxicity, mobility, or volume	Extent that the total mass of contaminants is reduced. Extent that the mobility of contaminants is reduced. Extent that the volume of contaminants is reduced.
Irreversibility of treatment	Extent that the effects of the treatment are irreversible.
Type and quantity of treatment residual	Residuals that will remain. Quantities and characteristics of the residuals. Risk posed by the treatment residuals.
Statutory preference for treatment as a principal element	Extent to which the scope of the action covers the principal threats. Extent to which the scope of the action reduces the inherent hazards posed by the principal threats at the Site.

Short-term Effectiveness

This evaluation criterion considers the effect of each remedial alternative on the protection of human health and the environment during the construction and implementation process. The short-term effectiveness evaluation only addresses protection prior to meeting the RAO. The considerations evaluated during the analysis of each remedial alternative for short-term effectiveness are presented in Table 4-5.

TABLE 4-5
Criterion 5—Short-term Effectiveness
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factors	Considerations
Protection of the community during the remedial alternative	Risks to the community that must be addressed. How the risks will be addressed and mitigated. Remaining risks that cannot be readily controlled.
Protection of workers during the remedial alternative	Risks to the workers that must be addressed. How the risks will be addressed and mitigated. Remaining risks that cannot be readily controlled.
Environmental impacts	Environmental impacts that are expected. Mitigation measures that are available and their reliability to minimize potential impacts. Impacts that cannot be avoided, should the remedial alternative be implemented.
Time until RAOs are achieved	Time until threats related to construction or implementation are mitigated. Time until any remaining threats are addressed. Time to achieve RAOs.

Implementability

This criterion evaluates the technical feasibility and administrative feasibility of implementing each remedial alternative and the availability of required services and materials. The considerations evaluated during the analysis of each remedial alternative for implementability are presented in Table 4-6.

TABLE 4-6
Criterion 6—Implementability
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factors	Considerations
Technical Feasibility	
Ability to construct and operate the remedial alternative process(es)	Difficulties associated with the construction. Uncertainties associated with the construction.
Reliability of the remedial alternative process(es)	Likelihood that technical problems will lead to schedule delays.
Ease of undertaking additional remedial alternative, if necessary	Likely future remedial alternatives that may be anticipated. Difficulty implementing additional remedial actions, if required.
Monitoring considerations	Migration or exposure pathways that cannot be monitored adequately. Risks of exposure, should the monitoring be insufficient to detect failure.

TABLE 4-6
Criterion 6—Implementability
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factors	Considerations
Administrative Feasibility	
Coordination with other agencies	Steps require coordinating with regulatory agencies. Steps require establishing long-term or future coordination among agencies. Ease of obtaining permits for offsite activities, if required.
Availability of Services and Materials	
Availability of treatment, storage capacity, and disposal services	Availability of adequate treatment, storage capacity, and disposal services. Additional capacity that is necessary. Whether lack of capacity prevents implementation. Additional provisions required to ensure that additional capacity is available.
Availability of necessary equipment and specialists	Availability of adequate equipment and specialists. Additional equipment or specialists that are required. Whether there is a lack of equipment or specialists. Additional provisions required to ensure that equipment and specialists are available.
Availability of prospective remedial alternative process	Whether remedial alternative process under consideration is generally available and sufficiently demonstrated. Further field applications needed to demonstrate that the remedial alternative process may be used full-scale to treat the waste at the Site. When remedial alternative process should be available for full-scale use. Whether more than one vendor will be available to provide a competitive bid.

Cost

This criterion evaluates the cost of implementing each remedial alternative. The cost of a remedial alternative encompasses all engineering; construction; and O&M and monitoring costs incurred over the life of the project. The assessment against this criterion is based on the estimated present worth of these costs for each remedial alternative. Present worth using a 7 percent discount rate is used to estimate expenditures such as construction and O&M that occur over different lengths of time. This allows costs for remedial technologies to be compared by discounting all costs to the year that the remedial alternative is implemented. Table 4-7 presents the cost analysis for the Site.

TABLE 4-7
Criterion 7—Cost
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factors	Considerations
CAPITAL COST ELEMENTS	
Construction Activities	
Mobilization/demobilization	Bringing equipment and personnel to the Site (mobilization) or removing equipment and personnel (demobilization) for purposes of constructing or installing the remedial action. Includes setup/construction and/or removal of temporary facilities and utilities. Does not include mobilization or demobilization specific to constructing or installing an onsite treatment facility.
Monitoring, sampling, testing, and analysis	Sampling, testing, on-or offsite analysis, data management, and quality assurance/ quality control. Includes monitoring to evaluate remedy performance and/or compliance with regulations.
Site work	Activities to establish the infrastructure necessary for the project (i.e., Site preparation). Also includes permanent Site improvements and restoration of areas or Site features disturbed during Site remediation. Site work is generally assumed to be “clean work,” meaning that there is no contact with contaminated media or materials. Excludes all Site work specific to constructing or installing an onsite treatment facility.
Demolition and removal	Demolition/removal of contaminated or hazardous materials or structures. Excludes treatment, offsite transportation, or offsite disposal of contaminated or hazardous materials or structures.
Onsite treatment	Construction or installation of a complete and usable onsite facility for treatment of contaminated media (e.g., soil, solids, and groundwater), including in situ and ex situ techniques. Includes all mobilization and Site work required for the treatment facility.
Offsite treatment/disposal	Final placement of contaminated media, material, or treatment residuals at offsite commercial facilities, such as solid or hazardous waste landfills and incinerators, that charge fees to accept waste based on certain criteria
Contingency	Costs added to cover unknowns, unforeseen circumstances, or unanticipated conditions related to construction or installation of the remedial action.
Professional/Technical Services	
Project management	Services to support construction or installation of remedial action not specific to remedial design or construction management.
Remedial design	Services to design the remedial action, including pre-design activities to collect the necessary data.
Construction management	Services to manage construction or installation of remedial action, excluding any similar services provided as part of construction activities.
Institutional controls	Non-engineering (i.e., administrative or legal) measures to reduce or minimize potential for exposure to Site contamination or hazards (i.e., limit Site access or restrict Site access). California performs IC element, so only boundary survey included.
ANNUAL O&M COST ELEMENTS	
O&M Activities	
Monitoring, sampling, testing, and analysis	Sampling, testing, on-or offsite analysis, data management, and quality assurance/ quality control during the O&M period. Can include monitoring to evaluate remedy performance, compliance with regulations, or monitoring to track migration of contaminant plume.

TABLE 4-7
Criterion 7—Cost
Frontier Fertilizer Feasibility Study, Davis, California

Analysis Factors	Considerations
Extraction, containment, or treatment systems	Operation and maintenance of onsite systems to extract, contain, or treat contaminated media (e.g., soil, groundwater).
Offsite treatment/disposal	Treatment and/or disposal of wastes generated during operation and maintenance (e.g., onsite treatment residuals, monitoring wastes) at offsite commercial facilities, such as solid or hazardous waste landfills and incinerators.
Contingency	Costs to cover unknowns, unforeseen circumstances, or unanticipated conditions associated with annual O&M of the remedial action.
Professional/Technical Services	
Project management	Services to manage O&M activities not specific to technical support.
Technical support	Services to monitor, evaluate, and report progress of remedial action.
PERIODIC COST ELEMENTS	
Construction/O&M Activities	
Remedy failure or replacement	Construction activity to replace an installed remedy or key components of the remedy.
Demobilization of onsite extraction, containment, or treatment systems	Construction activity to dismantle or take down extraction, containment, or treatment facilities or equipment upon completion of remedial action.
Contingency	Costs to cover unknowns, unforeseen circumstances, or unanticipated conditions associated with construction/O&M activities.
Professional/Technical Services	
Five-year reviews	Services to prepare 5-year review reports (if hazardous substances, pollutants, or contaminants remain onsite above levels that allow for unrestricted use and unlimited exposure).
Groundwater performance and optimization study	Groundwater performance and optimization study will be included as part of the 5-year review.
Remedial action report	Services to prepare remedial action report upon completion of remedial action.

Modifying Criteria 8 and 9—Regulatory and Community Acceptance

Regulatory acceptance (or support agency) assessment reflects regulatory preferences and concerns about the preferred remedial alternative based on comments on the FS and Proposed Plan. Community acceptance assessment evaluates the issues and concerns that the public may have regarding the preferred remedial alternative. The community has the opportunity to comment on the preferred remedy during the Proposed Plan 30-day public comment period.

4.2 Individual Analysis of Alternatives

A summary of the detailed analysis for alternatives that passed screening-level analysis is presented in Table 4-8.

TABLE 4-8
Summary of Individual Detailed Analysis of Alternatives
Frontier Fertilizer Feasibility Study, Davis, California

Criteria	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
OVERALL PROTECTIVENESS				
Human Health Protection				
Direct contact (dermal)	Removal of existing Site fencing/signage will increase potential for exposure.	Reduces potential for direct contact in short and long term using controls and ex situ treatment.	Reduces potential for direct contact in short and long term using controls and in situ treatment.	Reduces potential for direct contact in short and long term using controls and in situ treatment.
Soil Ingestion	Removal of existing Site fencing/signage will increase potential for exposure.	Reduces potential for COC ingestion in short and long term using controls and ex situ treatment.	Reduces potential for COC ingestion in short and long term using controls and in situ treatment.	Reduces potential for COC ingestion in short and long term using controls and in situ treatment.
Vapor intrusion	Removal of existing Site fencing/signage will increase potential for exposure.	Reduces potential for vapor intrusion in short and long term using controls and existing ex situ treatment.	Reduces potential for vapor intrusion in short and long-term using controls, in situ source treatment and GW P&T.	Reduces potential for vapor intrusion in short and long-term using controls, in situ source treatment, and GW P&T.
Groundwater ingestion for future users	Removal of existing Site fencing/signage and P&T system will increase potential for exposure.	Reduces potential for COCs to enter GW in the future using controls, ex situ treatment, and natural processes.	Reduces potential for COCs to enter GW in the future using in situ source treatment and ex situ GW P&T.	Reduces potential for COCs to enter GW in the future using in situ source treatment and ex situ GW P&T.
Environmental Protection				
Affect GW/soil	Removal of existing P&T system will increase potential for COC migration to unaffected GW/soil.	Reduces potential for COCs to enter GW and soil using controls, ex situ GW P&T, and natural processes.	Reduces potential for COCs to enter GW and soil using controls, in situ source treatment, and GW P&T.	Reduces potential for COCs to enter GW and soil using controls, in situ source treatment and, GW P&T.
Ecological receptors	No change to exposure to COC in surface soil.	Reduces potential for exposure to COCs in surface soil via a temporary cap until proposed development takes place.	Reduces potential for exposure to COCs in surface soil via a temporary cap until proposed development takes place.	Reduces potential for exposure to COCs in surface soil via a temporary cap until proposed development takes place.
COMPLIANCE WITH ARARs				
Chemical-specific ARARs	Does not meet state and federal MCLs for groundwater.	Likely to achieve state and federal MCLs for GW.	Likely to achieve state and federal MCLs for GW.	Likely to achieve state and federal MCLs for GW.
Location-specific ARARs	No protection for endangered or threatened species, or species of concern.	Temporary cap is used to protect endangered or threatened species, or species of concern from exposure to COCs in surface soil.	Temporary cap is used to protect endangered or threatened species, or species of concern from exposure to COCs. No impact anticipated to resources (wetlands, historical, natural, etc.)	Temporary cap protects endangered or threatened species, or species of concern from exposure to COCs. No impact anticipated to resources (wetlands, historical, natural, etc.)
Action-specific ARARs	Unlikely to meet all ARARs since there will be no action taken.	Likely to meet ARARs since remedy accomplished with minimal potential exposure to COCs.	Likely to meet ARARs since remedy accomplished with minimal potential exposure to COCs.	Likely to meet ARARs since remedy accomplished with minimal potential exposure to COCs.
LONG-TERM EFFECTIVENESS AND PERMANENCE				
Magnitude of Residual Risk				
Magnitude of remaining risk	Discontinue existing P&T and fencing/signage. Increase in potential for exposure to COCs.	Risk eliminated through GW P&T, natural processes, and controls.	Risk eliminated through in situ biological treatment, GW P&T, and controls.	Risk eliminated through in situ biological treatment, TD, GW P&T, and controls.
Source of remaining risk	Source is not treated or removed and additional risk likely due to migration of COCs with GW. Eventually natural processes and dilution may decrease risk. Significant risk likely for about 200 years.	COCs in Media A and B transferred to and transported with GW and treated ex situ, and Media C GW is treated ex situ and by natural processes to achieve RAOs, which include reducing remaining risk. Source of CCl_4 is unknown.	Media A and B are treated in situ, and Media C GW is treated ex situ and by natural processes to achieve RAOs, which include reducing remaining risk. Source of CCl_4 is unknown.	Media A and B are treated in situ, and Media C GW is treated ex situ and by natural processes to achieve RAOs, which include reducing remaining risk. Source of CCl_4 is unknown.
Need for 5-year review	Likely to require frequent and extensive reviews for up to 200 years to monitor exposure routes.	Likely to require many years to achieve RAOs primarily due to COCs in Media A and B.	Likely to require many years to monitor long-term effectiveness, primarily due to COCs in Media C.	Likely to require many years to monitor long-term effectiveness, primarily due to COCs in Media C.

TABLE 4-8
Summary of Individual Detailed Analysis of Alternatives
Frontier Fertilizer Feasibility Study, Davis, California

Criteria	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
Adequacy and Reliability of Controls				
Likelihood to meet RAOs	Unlikely.	Likely.	Likely.	Likely.
Required long-term management/monitoring	Likely to require long-term monitoring.	Likely to require long-term monitoring.	Likely to require long-term monitoring.	Likely to require long-term monitoring.
Required O&M and related issues	No components to require O&M.	Many years of P&T operation requires routine and some non-routine maintenance.	In situ bio process requires minimal O&M in addition to P&T and Site controls. Potential issues include reduced media permeability due to bio growth and increased fouling of P&T system components due to dissolved media.	TD process requires increased O&M respective to Alternative 5, but only for about a year.
Potential need for remedial alternative component replacement	No components to require replacement.	P&T system components require replacement due to Site conditions and usage.	Unlikely to need replacement of in situ bio process components. P&T system and Site control components require replacement due to Site conditions and usage. Slow biological degradation rate of VOCs may require the addition of another technology, e.g., TD.	TD process components may require replacement during implementation in addition to Alternative 5 components. Low temperature heating presents less demand on components than high temperature.
Adequate controls available	No remedial action implemented or controls established.	P&T and controls are available to address potential exposure.	P&T and controls are available to address potential exposure.	P&T and controls are available to address potential exposure.
Land disposal and untreated waste uncertainties	Impact of COCs uncertain but likely to present unacceptable risks.	Ex situ treatment of GW with GAC requires offsite disposition.	Ex situ treatment of GW with GAC requires offsite disposition. In situ treatment does not require offsite disposal and related risks.	Ex situ treatment of GW with GAC requires offsite disposition. In situ treatment does not require offsite disposal and related risks.
<u>REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT</u>				
Treatment process used and material treated	None.	GW P&T, natural processes, and controls address threats.	Anaerobic biological treatment along with GW P&T address principle threats.	In situ TD, possibly SVE and treatment, and Alternative 5 processes address principle threats. TD at higher temperatures may require SVE to control VOC emissions.
Amount of COCs destroyed or treated	None.	GW P&T to treat contaminated media over long time period.	Fifty percent of source area soils are treated in situ with P&T treating remaining contaminated GW.	Eighty percent of source area soils are treated in situ with P&T treating remaining contaminated GW.
Reduction of toxicity, mobility, or volume	No treatment other than natural processes.	Media A and B COCs migrate to GW, which is extracted and treated ex situ. Media C COCs are also extracted and treated ex situ.	Media A and B COCs are changed at the molecular level to reduce toxicity. Media C COCs are extracted and treated ex situ.	Media A and B COCs are changed at the molecular level to reduce toxicity. Media C COCs are extracted and treated ex situ.
Type and quantity of residuals remaining after treatment	No treatment other than natural processes.	Media remains in place during and after implementation, with the exception of extracted GW. GAC from GW treatment is thermally regenerated. In situ process by-products are less toxic chemicals.	Media remains in place during and after implementation, with the exception of extracted GW. GAC from GW treatment is thermally regenerated. In situ process by-products are less toxic chemicals.	Media remains in place during and after implementation, with the exception of extracted GW. GAC from GW treatment is thermally regenerated. In situ process by-products are less toxic chemicals.
Statutory preference for treatment	No treatment other than natural processes.	Satisfies.	Satisfies.	Satisfies.
<u>SHORT-TERM EFFECTIVENESS</u>				
Community protection	Risk to community increased due to elimination of existing fencing/signage.	Construction and plant expansion require health and safety plans and waste management plans to reduce potential for exposure to COCs.	Exposure during construction is controlled with engineering controls. In situ processes minimize potential for exposure to COCs.	Exposure during construction is controlled with engineering controls. In situ processes minimize potential for exposure to COCs. Higher temperature TD will require SVE to control VOCs exposure.
Worker protection	No risk to remedial action workers.	Construction and plant expansion present health and safety plans to reduce exposure to COCs.	Health and safety protection required during excavation.	Health and safety protection required during excavation, drilling, and TD implementation.

TABLE 4-8
Summary of Individual Detailed Analysis of Alternatives
Frontier Fertilizer Feasibility Study, Davis, California

Criteria	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
Environmental impacts	Continued impact from existing conditions.	Construction and plant expansion present health and safety and waste management plans to reduce exposure to COCs.	Bio process infiltration system requires minor construction in Media A.	TD requires boring into Media A and B to install electrodes and pads for equipment. Establishing working hours will minimize potential nuisance due to noise; power consumption is high.
Time unit until RAO is achieved	Long time frame estimated until natural processes achieve RAOs.	Controls and GW P&T system mitigate threats during construction and implementation periods, assumed to be 57 years. Monitoring dictates whether RAOs are achieved.	GW P&T system mitigates threats during construction and implementation of in situ biological treatment process, assumed to be 52 years. Monitoring dictates whether RAOs are achieved.	Controls and GW P&T system mitigate threats during construction and implementation of in situ treatment processes, assumed to be 44 years. Monitoring dictates whether RAOs are achieved.
<u>IMPLEMENTABILITY</u>				
Technical Feasibility				
Ability to construct and operate	No construction or operation.	Existing process components are functioning onsite, and those needed for any modifications are available and easy to install and operate.	Simple to construct and operate infiltration system. Assumes existing injection wells function. Must work around existing GW P&T system.	Installation of electrodes co-located with Alternative 5 components is possible but requires careful planning. Must work around existing GW P&T system.
Reliability of processes	Unknown.	Existing process components have functioned onsite for 10 years, and those needed for any modifications are likely to be reliable.	In situ bio process treatment rate depends on variable media conductivity. Prelim lab test results in mixed conditions indicate nitrate is rapidly treated while VOCs take longer.	Prelim lab test results indicate VOCs are rapidly treated by heating. Alternative 5 conditions affect nitrate treatment effectiveness.
Ease of undertaking additional actions if needed	Depends on changes that occur at Site.	Alternative process implementation will not significantly impede undertaking additional actions, if needed.	Process implementation will not significantly impede undertaking additional actions, if needed.	Process implementation will not significantly impede undertaking additional actions, if needed.
Ability to monitor effectiveness	No monitoring included.	Media A and B is heterogeneous; approximately 10 additional wells are proposed for GW monitoring network to meet monitoring needs.	Media A and B is heterogeneous; approximately 10 additional wells are proposed for GW monitoring network to meet monitoring needs.	Media A and B is heterogeneous; approximately 10 additional wells are proposed for GW monitoring network to meet monitoring needs.
Administrative Feasibility				
Coordination with agencies	Coordination with agencies is part of FS, Proposed Plan, and ROD.	Coordination with agencies is part of FS, Proposed Plan, and ROD.	Coordination with agencies is part of FS, Proposed Plan, and ROD.	Coordination with agencies is part of FS, Proposed Plan, and ROD.
Availability of Services and Materials				
Availability of treatment, storage, and disposal capacity.	None required.	Site data indicate that existing process components may be effective at controlling and monitoring COC migration and minimizing human receptor exposure. If additional expansion is required, components to replace or expand existing processes are readily available.	Spent GAC generated by GW P&T system continues to require regeneration.	TD at high temperature may require collection and treatment of VOCs, in addition to Alternative 5 requirements. Boring cuttings may require offsite management. Capacity for both should be available.
Availability of equipment and specialists	None required.	Equipment and specialists available.	Equipment and specialists available.	Equipment and specialists available.
Availability of processes	None required.	Site data indicate that existing process components are effective at controlling and monitoring COC migration and minimizing human receptor exposure. Components to replace or expand existing processes are readily available.	Site-specific application of biological process requires further development during onsite testing. Not proprietary process and anticipated to be implementable at full scale.	TD process requires further development to establish parameters. Vendors are available to supply proprietary process.

TABLE 4-8
Summary of Individual Detailed Analysis of Alternatives
Frontier Fertilizer Feasibility Study, Davis, California

Criteria	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
CAPITOL COST ELEMENTS				
Construction Activities				
Mobilization/demobilization	$0	$111,000	$143,000	$196,000
Monitoring, sampling, testing, and analysis	$0	$286,324	$314,324	$373,324
Site work	$0	$77,000	$78,000	$88,000
Demolition and removal	$0	$18,000	$18,000	$18,000
Onsite treatment	$0	$410,000	$565,000	$4,565,000
Offsite treatment/disposal	$0	$22,000	$22,000	$65,000
Contingency	$0	$311,150	$399,350	$1,856,750
Total Construction Activity	$0	$1,235,474	$1,539,674	$7,162,074
Professional/Technical Services				
Project management	$0	$66,000	$75,000	$106,000
Remedial design	$0	$75,000	$111,000	$155,000
Construction management	$0	$44,000	$62,000	$87,000
Total Professional/Technical Service	$0	$185,000	$248,000	$348,000
Total Institutional Controls (Survey, other by CA)	$0	$10,000	$10,000	$10,000
TOTAL CAPITAL COST	$0	$1,430,474	$1,797,674	$7,520,074
ANNUAL O&M COST ELEMENTS				
O&M Activities				
Monitoring, sampling, testing, and analysis	$0	$262,000	$278,000	$298,000
Extraction, containment, or treatment systems	$0	$204,000	$230,600	$230,700
Offsite treatment/disposal	$0	$50,000	$50,000	$55,000
Contingency	$0	$77,400	$83,850	$87,600
Total O&M Activity	$0	$593,400	$642,450	$671,300
Professional/Technical Services				
Project management	$0	$82,000	$82,000	$89,000
Technical support	$0	$15,000	$18,000	$18,000
Total Professional/Technical Service	$0	$97,000	$100,000	$107,000
Institutional Controls (By CA)	$0	$0	$0	$0
TOTAL ANNUAL O&M ELEMENTS	$0	$690,400	$742,450	$778,300
TOTAL O&M ELEMENTS	$0	$39,352,800	$38,607,400	$34,245,200
TOTAL O&M ELEMENTS PW w/ 7% DF	$0	$9,654,554	$10,291,842	$10,552,191

TABLE 4-8
Summary of Individual Detailed Analysis of Alternatives
Frontier Fertilizer Feasibility Study, Davis, California

Criteria	Alternative 1 No Action	Alternative 2 Groundwater P&T	Alternative 5 Biological Treatment plus Alternative 2	Alternative 6 Thermal Destruction plus Alternative 5
PERIODIC COST ELEMENTS				
Construction/O&M Activities				
Remedy failure or replacement	$0	$420,000	$420,000	$420,000
Demobilization of onsite extraction, containment, or treatment systems	$0	$1,200,000	$1,250,000	$1,250,000
Contingency	$0	$493,500	$511,000	$511,000
Total Construction/O&M Activity	$0	$2,113,500	$2,181,000	$2,181,000
Professional/Technical Services				
Five-year reviews	$0	$385,000	$350,000	$245,000
Groundwater performance and optimization study	$0	$0	$0	$0
Remedial action report	$0	$185,000	$185,000	$210,000
Total Professional/Technical Service	$0	$570,000	$535,000	$455,000
Institutional Controls (By CA)	$0	$0	$0	$0
TOTAL PERIODIC ELEMENTS	$0	$2,683,500	$2,716,000	$2,636,000
TOTAL PERIODIC ELNTS PW w/ 7% DF	$0	$256,839	$283,497	$340,898
REMEDIAL ALTERNATIVE NON-DISCOUNTED COST	$0	$43,466,774	$43,121,074	$44,401,274
REMEDIAL ALTERNATIVE PRESENT VALUE w/ 7% DF	$0	$11,341,867	$12,373,012	$18,413,163

4.2.1 Alternative 1—No Action

The no-action alternative provides a baseline for comparing other alternatives. Because no remedial process options would be implemented with the no-action alternative, long-term human health and environmental risks for the Site essentially would be the same as those identified in the baseline risk assessment. Alternative 1 assumes that no actions are taken to remediate COCs in Site media and that the current Site activities (pump and treat, groundwater monitoring, and fencing/posting) would not be continued.

Threshold Criteria

Overall Protection of Human Health and the Environment. Alternative 1 provides no control of exposure to the contaminated soil and the groundwater. It also allows for the possible continued migration of the contaminant plume and further degradation of groundwater. Removal of existing fencing/posting could increase the risk of exposure to contaminated soil and groundwater. Ecological receptors could be exposed to contaminants in the surface soil.

Compliance with ARARs. Because no action is being taken, it would not meet any ARARs, such as groundwater MCLs for COCs.

Method Criteria

Long-term Effectiveness and Permanence. This alternative includes no controls for exposure and no long-term management measures. All current and potential future risks would remain under this alternative.

Reduction of Toxicity, Mobility, or Volume through Treatment. This alternative provides no reduction in toxicity, mobility, or volume of the contaminated soil or groundwater through treatment.

Short-term Effectiveness. There would be no additional risks posed to the community, the workers, or the environment as a result of this alternative being implemented.

Implementability. There are no implementability concerns posed by this remedy since no action would be taken.

Cost. The present worth cost and capital cost of Alternative 1 are estimated to be $0 since there would be no action. There will be cost for well abandonment and treatment plant dismantling.

4.2.2 Alternative Common Components

All of the remaining alternatives have four components in common (institutional controls, land use and access restrictions, groundwater monitoring, and a temporary cap). Although the description of these components is not repeated in the discussions for each alternative, differences in their planned implementation are identified where appropriate.

- **Land use restrictions:** Descriptions of contaminated media and respective restrictions would be incorporated into affected property deeds with the intent of minimizing risk by limiting exposure until RAOs are reached. Restrictions may include prohibiting residential use, groundwater extraction, excavation, grading and trenching. Also, for example, if prior to cleanup to RAOs a commercial building is built on or near contaminated soils in the source area, a sub-slab system should be constructed in conjunction with testing to confirm the mitigation system's effectiveness.

- **Access restrictions:** Access to Media A would be restricted with fencing and signage to prevent access by unauthorized personnel until RAOs are reached.
- **Groundwater monitoring:** Assume that groundwater monitoring would continue until RAOs are achieved.
- **Temporary cap:** Wood chips or gravel will cover the Site to prevent ecological receptors from contacting contaminated surface soil.

4.2.3 Alternative 2—Groundwater Pump and Treat

Alternative 2 includes groundwater extraction and treatment with GAC combined with the "Common Components" discussed above. Alternative 2 is implemented until groundwater monitoring indicates that RAOs are achieved. Alternative 2 processes include groundwater extraction to collect COCs migrating with groundwater from the source. Natural processes such as rainwater infiltration through Media A (unsaturated source volume), groundwater migration through Media B (saturated source volume), and biological and geochemical interactions with COCs determine the rate COCs are made available to the groundwater extraction system. Monitoring to evaluate progress toward achieving RAOs determines if additional extraction or monitoring wells, or modifications to the treatment system are necessary. Treated groundwater would continue to be discharged to the City of Davis sanitary sewer.

Threshold Criteria

Overall Protection of Human Health and the Environment. This remedial alternative is protective of human health by minimizing the potential for direct and indirect (vapor intrusion) contact to COCs in soil and groundwater. Public access to Media A and B soil and Media B and C (dissolved plume volume) groundwater continues to be restricted. Implementation of the ex situ processes presents minimal risks to human health since exposure to COCs is minimized through administrative and engineered controls. The temporary cap mitigates exposure of ecological receptors to COCs in soil until the planned development occurs.

Compliance with ARARs. Implementation of this remedial alternative is likely to achieve compliance with chemical-specific regulatory requirements after a long period of implementation. In the near term, it reduces COCs available to migrate from Media A and B into Media C groundwater to below MCLs.

Implementation of this remedial alternative is likely to achieve compliance with potential location-specific regulatory requirements.

No waste material is generated in addition to that currently generated by the ex situ groundwater treatment system, so it is likely that the remedial alternative will achieve compliance with action-specific regulatory requirements.

Method Criteria

Long-term Effectiveness and Permanence. The remedy is expected to achieve RAOs; however, because of slow release mechanisms from soil to dissolved groundwater, achievement of RAOs would take a long time. Results of groundwater monitoring would be used to determine implementation effectiveness and whether continued monitoring would be necessary. Groundwater monitoring would be continued after groundwater extraction is discontinued to evaluate long-term effectiveness. Institutional controls would continue until monitoring confirms treatment processes successfully achieved RAOs.

Reduction of Toxicity, Mobility, or Volume through Treatment. The COCs dissolved in the extracted groundwater will be treated with ex situ carbon absorption process. Natural processes would reduce the concentration of COCs existing outside the zone of influence of the ex situ process extraction system. This remedial alternative meets the statutory preference for using treatment as a principle element to address primary threats posed by the Site through treatment.

Short-term Effectiveness. No major construction would be required in the short-term in order to implement the process; therefore, there would be no threat and risks to the community and construction personnel. If monitoring results indicate groundwater extraction, monitoring or treatment modifications are necessary, associated risks would be mitigated with administrative and engineering controls. Native animal and plant species habitat would be impacted by the temporary cap as by the proposed development.

No additional threat to human health is anticipated during the implementation of this remedial alternative. Access to Media A and adjacent area is restricted during implementation, which reduces potential exposure to emissions of VOCs, and groundwater leaving Media A and B is collected by the groundwater extraction system. Implementation effectiveness depends on the rate that the mass of COCs in the source volume are reduced and RAOs are achieved. Extraction from S-1 and S-2 zones appears capable of containing most of the groundwater that has picked up COCs while passing through the source volume. If time and continued extraction are not effective at removing COCs, additional extraction wells would be installed. Reduction of COC mass in the source volume would occur slowly as contaminants travel from Media A and B to downgradient extraction wells. Therefore, the remedial alternative implementation period, that is, the implementation period necessary to achieve RAOs, would be very long.

The duration of the implementation period will be determined by the rate that the mass and mobility of most COCs in Media A and B are reduced. Groundwater monitoring results indicate that COCs have entered the A-1 zone and are detected in the S-1 zone near the horizontal boundary of the pump and treat system's zone of influence. Some COCs are detected at concentrations above RAOs in groundwater samples collected from these locations. The rate of transfer of COC mass in low permeable media soil, such as silt and clay, will be slower and possibly limited by the rate of diffusion.

For the purpose of evaluating Alternative 2, an implementation period of 57 years is used. 57 years is the average timeframe for the most recalcitrant COC (DBCP) to reach RAOs. The timeframe for cleanup is presented in Appendix A. Groundwater monitoring will be used to evaluate progress during the implementation period. The evaluation will include discontinuing groundwater extraction when monitoring indicates RAOs are achieved in order to evaluate long-term effectiveness of Alternative 2.

Implementability. Alternative 2 is technically feasible given that process components are available and relatively easy to install and operate. Preliminary assessment of Site data indicates that existing process components are effective at controlling COC migration now in some areas and with time and possible future modifications can become effective in other areas to minimize human receptor exposure. Most system components would require replacement, some multiple times, during the anticipated long implementation period to maintain performance. If monitoring indicates that modifications (for example, additional extraction, monitoring, or treatment) are necessary, respective components are available. Improved technologies are also likely to be available in the future.

A significant limitation to this alternative is the capacity to manage treated groundwater. Currently, treated groundwater is discharged to the City of Davis sewer, and as planned land development progresses, sewer capacity may be limited. Other treated water disposition options will be necessary to accommodate an increased groundwater extraction and treatment rate.

It is not anticipated that implementation of this process will have a significant negative impact on existing processes or potential future process option effectiveness. Modifications to existing processes may impact performance of extraction and monitoring wells and result in the need for additional groundwater treatment and disposal capacity.

Remedial action activities will be coordinated with potentially affected public agencies and private parties in accordance with CERCLA.

Alternative 2 does not require excavation unless monitoring during implementation indicates that process modifications are necessary. Therefore, availability of hazardous waste treatment and disposal capacity is not a limiting factor. The largest waste stream generated by this remedial alternative is spent GAC, which is currently transported offsite for regeneration. EPA will continue to evaluate other technologies for groundwater treatment.

It is anticipated that equipment and personnel are available to construct and implement the process. Availability of vendors should not limit implementation of this remedial alternative, although experience levels of operation and maintenance personnel will affect implementation effectiveness.

Cost Estimate. Table 4-9 presents the cost estimate for Alternative 2.

TABLE 4-9
Cost Estimate for Alternative 2
Frontier Fertilizer Feasibility Study, Davis, California

Cost Elements	Non-Discounted Cost ($)	Present Value Cost ($)
Capital cost elements	1,430,000	1,430,000
Total annual O&M*	39,353,000	9,655,000
Total periodic cost	2,684,000	257,000
Total	**43,467,000**	**11,342,000**

* Estimated average annual O&M is $690,400.

4.2.4 Alternative 5—Biological Treatment plus Alternative 2

The primary technology process option of Alternative 5 is in situ biological degradation of COCs in addition to Alternative 2 process options. Alternative 2 process options consist of groundwater control by extraction and ex situ treatment and the "Common Components" of groundwater monitoring, signage/fencing, institutional controls, and a temporary cap. As described in Section 2, preliminary results of bench-scale treatability testing indicate that anaerobic conditions quickly degraded nitrate. Groundwater monitoring results from wells close to the source area also show elevated bromide concentrations that may indicate that native conditions, possibly via bacteria or hydrolysis, appear to be degrading VOCs. The degree of success with biological treatment is uncertain; however, there has been some success at other sites with similar COCs.

Implementation of an in situ enhanced anaerobic bioremediation system consists of applying a substrate in solution with treated groundwater to Media A and B. The substrate is applied to Media A and B in order to initiate and maintain anaerobic and reducing conditions. The substrate, such as beer fermentation process waste, will serve as an electron donor or carbon source to support growth and metabolism of indigenous microorganisms. The substrate supplements nutrients available in Media A and B that are necessary for native microorganism proliferation. Microbial metabolism of the substrate will create and maintain anaerobic conditions, reduce nitrates, deplete competing electron acceptors, and enhance biological reductive dehalogenation of VOCs.

The process will include the design and construction of a system to facilitate continuous application of a dilute aqueous solution of substrate in a treated groundwater stream evenly throughout Media A and B. For Media A, application will be accomplished with an infiltration system of perforated pipes installed in a permeable material placed across the ground surface. Applied substrate solution percolates down through the unsaturated zone and into the saturated zone. For Media B, application could be accomplished with an injection system utilizing existing injection wells (IW-1 thru 6) located upgradient of and screened across the depth of Media B to distribute the solution across the depth of the contaminated media. Process equipment will be installed to create and distribute the solution. A portion of the existing treatment system discharge will be used to create the substrate solution for the infiltration/injection system. Substrate will be stored and mixed with the groundwater treatment system effluent within the building housing the existing treatment system, and the substrate solution would be pumped to the infiltration and injection systems. The balance of the treatment system effluent will continue to be discharged to the sanitary sewer. The groundwater extraction system included in Alternative 2 will maintain a gradient across the contaminated zone to help distribute substrate solution and provide collection and treatment of water exiting Media A and B.

Threshold Criteria

Overall Protection of Human Health and the Environment. This remedial alternative will be protective of human health by reducing potential for direct and indirect (vapor intrusion) contact to COCs in soil and groundwater. Public access to Media A and B soil and Media B and C groundwater will continue to be restricted. Construction and implementation of the in situ process presents minimal additional risks to human health. The existing extraction system will continue to be monitored to ensure that migration of contaminated groundwater is controlled so that the threat to unaffected groundwater is reduced. The temporary cap mitigates exposure of ecological receptors to COCs in soil until the planned development occurs.

Compliance with ARARs. Implementation of this remedial alternative will likely achieve compliance with chemical-specific regulatory requirements, specifically, reduce and maintain COC concentrations in Media B and C groundwater below MCLs. Implementation of this remedial alternative will likely achieve compliance with potential location-specific regulatory requirements. No waste material will be generated in addition to that currently generated by the groundwater treatment system, so it is likely that the remedial alternative will achieve compliance with action-specific regulatory requirements.

Method Criteria

Long-term Effectiveness and Permanence. Results of groundwater monitoring will be used to determine implementation effectiveness and whether continued monitoring would be necessary. Groundwater monitoring will continue after substrate solution infiltration is discontinued to evaluate long-term effectiveness. Groundwater extraction and institutional controls will continue until monitoring confirms treatment processes successfully achieved RAOs.

Reduction of Toxicity, Mobility, or Volume through Treatment. The bulk of COCs in Media A and B will be treated with the in situ anaerobic biological process. Most remaining COCs in Media C groundwater will be treated by the current pump and treat system using GAC. Natural processes will reduce the concentration of COCs detected outside the zone of influence of the in situ treatment process and ex situ process extraction system. This remedial alternative meets the statutory preference for using treatment as a principle element to address primary threats posed by the Site.

Short-term Effectiveness. Construction of the process will present minimal threats and risks to the community and construction personnel by treating contaminated media in situ and using existing injection wells. Local native animal and plant species habitat will be destroyed by the construction of the Media A infiltration system and the temporary cap, as is expected by the proposed development.

No additional threats to human health or the environment are anticipated during the implementation of this remedial alternative. The duration of the implementation period will be determined by the rate that the mass and mobility of COCs in Media A and B are reduced. The COC mass present in the more permeable media soil will be reduced first followed by the mass in the less permeable media soil. This is because the substrate solution will preferentially flow through and therefore be available to microorganisms in the more permeable soil. The rate of reduction of COC mass in low permeable media soil, such as silt and clay, will be slower and possibly limited by the rate of diffusion.

Treatability test results indicate that nitrate was reduced rapidly, apparently by denitrification. VOCs may degrade biologically; however, the lab test did not run long enough to determine definitively that VOC degradation will occur. The rate of VOC degradation using microorganism metabolism is limited by the availability of competing electron acceptors such as dissolved oxygen and nitrate, nitrite and sulfate; electron donors and/or energy sources; and VOC concentrations. Application of sufficient substrate solution facilitates metabolism of competing electron acceptors and VOCs. The microorganism's ability to metabolize COCs is also affected by concentrations of COCs in aqueous and non-aqueous phase.

For the purpose of evaluating Alternative 5, an implementation period of 10 years is used to estimate the treatment period for Media A and B. This timeframe is based on history at other sites with similar COCs. After the bioremediation implementation period is complete, it is estimated that pump and treat will need to be continued for approximately 42 years for RAOs to be achieved in Media C (see Appendix A for modeling results and assumptions used in estimating time to achieve cleanup levels in Media C). Groundwater monitoring will be used to evaluate progress during the implementation period. The timeframe estimate for cleanup will be updated after source cleanup takes place.

Implementability. Anaerobic biological process components are available and relatively easy to install and operate. Preliminary assessment of Site data indicates that an engineered leaching field combined with existing injection wells could apply substrate solution in order to maintain anaerobic conditions. Beer fermentation process waste (that is, substrate) is available from local breweries and effluent from the existing treatment system makes up the balance of the solution. Storage, distribution, and control components are commonly available and easy to assemble, operate, and maintain. Bench-scale testing indicates that the anaerobic process effectively reduces nitrate concentrations and has the potential to reduce VOC concentrations. Further information regarding methods for application will be collected during field testing.

It is not anticipated that implementation of this process will have a significant negative impact on existing processes or potential future process option effectiveness. A potential effect of the anaerobic process is that metals such as manganese become more soluble in reducing conditions and therefore mobilized in groundwater. Since metals currently accumulate in the pump and treat system components, an increased rate of accumulation and resulting maintenance is anticipated.

Alternative 5 appears to be administratively feasible. Remedial alternatives activities are coordinated with potentially affected public agencies and private parties in accordance with CERCLA processes. Remedial alternative construction may impact the ground surface slightly north of the Pine Tree Properties parcel boundary and will be coordinated with the respective property owner.

A benefit of the in situ anaerobic process is that it does not require excavation and ex situ treatment or disposal. Therefore, availability of hazardous waste treatment and disposal capacity is not a limiting factor. The largest waste stream generated by this remedial alternative is spent GAC. The spent GAC is currently transported to an offsite treatment facility for regeneration and reuse. EPA will continue to evaluate alternatives to GAC treatment.

It is anticipated that specialized equipment and personnel are available to construct and implement the process. The anaerobic process and necessary components are not proprietary. Anaerobic degradation of COCs is theoretically practical and bench-scale testing supports the theory. Availability of vendors should not limit implementation of this remedial alternative, although the experience levels of the O&M personnel could impact implementation effectiveness.

Cost Estimate. Table 4-10 presents the cost estimate for Alternative 5.

TABLE 4-10
Cost Estimate for Alternative 5
Frontier Fertilizer Feasibility Study, Davis, California

Cost Elements	Non-Discounted Cost ($)	Present Value Cost ($)
Capital cost elements	1,798,000	1,798,000
Total annual O&M*	38,607,000	10,292,000
Total periodic cost	2,716,000	284,000
Total	**43,121,000**	**12,374,000**

* Estimated average annual O&M is $742,450.

Whether Alternative 5 will receive community and regulatory agency approval will be determined after comments are received on the Proposed Plan.

4.2.5 Alternative 6—Thermal Destruction plus Alternative 5

The main component of Alternative 6 is in situ heating, hereafter referred to as TD, of Media A and B, in addition to Alternative 5 process options. Technical literature indicates that VOCs undergo rapid hydrolysis at elevated temperatures. Hydrolysis is the process of breaking a chemical bond with the addition of water; for halogenated compounds, this usually involves removal of a halogen from the parent compound, resulting in a less toxic chemical. Preliminary results from bench-scale treatability testing indicate that heating effectively reduced VOC concentrations. Heating is not expected to treat nitrate; therefore, the in situ enhanced anaerobic biodegradation process (Alternative 5) is also included as part of Alternative 6. Nitrate and nitrite are treated as part of this alternative, due to the low cost and ease of implementation.

Implementation of an in situ TD process would require that heat energy be applied to Media A and B in order to heat and maintain the desired elevated temperature. The two similar methods considered are electrical resistive heating and conduction heating. Both methods use electrical power to heat the media. Electrical resistive heating passes electrical current through the soil while the resistance presented by the soil raises the temperature; conduction heating uses heated well casings to conduct heat through the subsurface. To implement either technology, electrodes are installed into the ground. Electrodes will be installed, in a honeycomb pattern, through the unsaturated and saturated source area. The vertical limits are set by the depth to which borehole electrode construction can be drilled and by the size of the power control unit. Based on discussions with vendors, a depth of 60 feet bgs is estimated for the Site. The rate of hydrolysis is directly related to temperature; that is, higher hydrolysis rates occur at higher temperatures. Achieving and maintaining higher temperatures in the media requires higher energy input. Energy demand is primarily based on the volume of groundwater in the media. Given that cooler groundwater is continuously moving through Media B, additional energy input will be required to maintain elevated temperature.

Since treatability testing results indicate that TD degrades VOCs at temperatures both below (90°C) and above (110°C) the boiling point of water, two TD conditions are considered in the analysis. Construction and implementation of TD processes to facilitate treatment at temperatures less than the boiling point of water and above the boiling point are assumed to be the only differences, that is, no effect on long-term effectiveness. Heating media to temperatures above 100°C will require higher rates of energy input and result in higher vapor emissions. Therefore, higher capacity power supply equipment and vapor emission control and treatment equipment will be required to accommodate TD at a higher temperature. For the higher temperature condition, soil vapor extraction wells will be installed along with vapor conveyance piping and controls. The soil vapor collection system will generate condensate and vapor, which will require treatment with liquid and gas phase activated carbon, respectively. A balance between the duration of the implementation period and the additional risks and cost associated with higher temperatures will be necessary to determine the preferred condition.

Threshold Criteria

Overall Protection of Human Health and the Environment. This remedial alternative will be protective of human health by reducing potential for direct and indirect (vapor intrusion) contact to COCs in soil and groundwater. Public access to Media A and B soil and Media B and C groundwater continues to be restricted. Construction and implementation of the in situ process presents minimal additional risks to human health and the environment. Installation of TD electrodes will generate contaminated soil cuttings requiring health and safety and waste management procedures to prevent exposure to VOCs. Implementation of the biological and low temperature TD processes could be accomplished simultaneously. Emissions of VOCs to the atmosphere during high temperature TD will be controlled using vacuum extraction and treatment processes. The existing extraction system will continue to be monitored to ensure that migration of contaminated groundwater is controlled so that the threat to unaffected groundwater is reduced. The temporary cap mitigates exposure to ecological receptors to COCs in soil until the planned development occurs.

Compliance with ARARs. Implementation of this remedial alternative will likely achieve compliance with chemical-specific regulatory requirements, specifically, reduce and maintain COC concentrations in Media B and C groundwater below MCLs. Implementation of this remedial alternative will likely achieve compliance with potential location-specific regulatory requirements. Soil cuttings will be generated during construction of both low and high temperature condition TD processes and will require treatment and disposal. The soil vapor extraction component of the high temperature TD process will generate waste streams that will be treated onsite. Carbon waste will continue to be generated by the ex situ groundwater treatment system. It is likely that the remedial alternative will achieve compliance with action-specific regulatory requirements.

Method Criteria

Long-term Effectiveness and Permanence. Since implementation reduces the mass of COCs in Media A and B, it is anticipated that any remaining COCs will not be available to desorb into groundwater or soil gas at concentrations exceeding RAOs. Implementation of either low or high temperature conditions, in addition to anaerobic process, degrades VOCs available to desorb into both groundwater or soil gas. Results of groundwater monitoring will be used to determine implementation effectiveness and whether continued monitoring will be necessary. Monitoring will be performed after biological and TD process implementation is discontinued to evaluate long-term effectiveness. Groundwater extraction and institutional controls will continue until monitoring confirms in situ treatment processes successfully achieved RAOs.

Reduction of Toxicity, Mobility, or Volume through Treatment. Preliminary test results indicate that heating Site media can reduce the toxicity and mass of VOCs available to enter human receptor exposure pathways. Test results also indicate that nitrate mass declines rapidly once anaerobic conditions are established in Site media. Testing indicates that the rate of reduction in VOC mass increases with temperature. TD at temperatures above the boiling point of water will probably eliminate biological process effectiveness and generate VOC emissions that will require collection and treatment. TD at temperatures below the boiling point of water could occur simultaneously with biological treatment and may not generate emissions requiring collection and treatment. Ambient air monitoring will be completed to ensure VOC emissions never exceed unsafe levels.

Short-term Effectiveness. Construction of the process will present minimal threats and risks to the community and construction personnel by treating contaminated media in situ. Boring into Media A and B to install electrodes will present potential for exposure to VOCs because contaminated soil will be brought to the surface and require management. Risk of potential exposure will be managed in accordance with the Site-specific Health and Safety Plan. Native animal and plant species habitat will be destroyed by the construction of the Media A infiltration system and installation of TD components as is expected by the proposed development.

TD at temperatures above the boiling point of water will probably generate VOC emissions that will require collection and treatment. Ambient air monitoring and effective soil vapor collection and treatment system operation and maintenance will mitigate VOC emission hazards. No additional threats to human health or the environment are anticipated during the implementation of this remedial alternative. During implementation of this remedial alternative, groundwater leaving Media A and B is collected and treated by the groundwater pump and treat system.

The duration of the implementation period will be determined by the rate that the mass and mobility of COCs in Media A and B are reduced. For the purpose of evaluating Alternative 6, it is assumed that implementation of TD to degrade VOCs will be approximately 1 year to achieve treatment objectives based on discussions with vendors. The implementation period of anaerobic degradation process will be approximately 5 years. After the TD and bioremediation implementation period is complete, it is estimated that pump and treat will need to be continued for approximately 39 years for RAOs to be achieved in Media C (see Appendix A for modeling results and assumptions used in estimating time to achieve cleanup levels in Media C). A better estimate of cleanup timeframe will be developed after source cleanup takes place. Groundwater monitoring as part of the “Common Components” will be used to evaluate remedial alternative progress during the period. It is assumed that sufficient electrical power infrastructure is available at the property line.

Implementability. Alternative 6 appears to be technically feasible, although its efficacy will be determined by groundwater monitoring during the implementation and post-implementation periods. Only implementability of the TD process is evaluated here since Alternative 5 implementability criteria evaluation results are presented above.

The primary challenges presented by construction of the TD process are the installation of borings to accommodate electrodes and possibly soil vapor extraction wells, power supply equipment and possibly soil vapor treatment equipment. Since the biological treatment infiltration system and TD electrode network are collocated, they will be designed and constructed accordingly. Contaminated soil generated by boring requires management, and power supply equipment capacity depends on the implementation soil temperature and heating method. It is assumed that existing utility lines and transformers that service the Site are capable of supplying electrical energy required for either conduction heating or resistance heating process equipment, in addition to other remedial alternative process equipment. An engineering analysis is performed to assess electrical service capacity and possible effects of TD process construction and implementation on other process performance. The method of heating and the temperature of the TD process will also be evaluated.

Bench-scale testing indicates that the TD process effectively reduces VOC concentrations both above and below the boiling point of water. Although biological bench-scale testing was not performed at elevated temperatures, TD treatment at temperatures lower than boiling point may likely be accomplished concurrently with biological treatment. Process effectiveness is determined with groundwater monitoring during full-scale implementation and the post-implementation period. Exposure and performance monitoring are performed to evaluate compliance with RAOs.

Remedial action activities will be coordinated with potentially affected public agencies and private parties in accordance with established CERCLA processes. It is possible that Alternative 6 at a temperature above the boiling point of water will generate emissions that will require controls. Remedial alternative construction may impact the ground surface slightly north of the Pine Tree Properties parcel boundary and therefore the activity will be coordinated with the respective property owner.

An added benefit of the in situ process is that it does not require excavation and ex situ treatment or disposal. Therefore, availability of hazardous waste treatment and disposal capacity will not limit implementation. The largest waste streams generated by this remedial alternative are soil cuttings from borings, spent GAC, and possibly air emissions from higher temperature treatment. The spent GAC is currently transported to an offsite treatment facility for regeneration and reuse. EPA will continue to evaluate alternatives to GAC treatment.

Anaerobic and TD degradation of COCs is theoretically practical; and bench-scale testing supports the theory. It is anticipated that specialized equipment and personnel are available to construct and implement the process. Operation of TD processes is offered by at least three vendors. Engineering analysis and onsite in situ field testing is used to refine the understanding of physical and chemical characteristics that affect implementation. Availability of vendors does not limit implementation of this remedial alternative, although the experience levels of the O&M personnel will impact implementation effectiveness.

Cost Estimate. Table 4-11 presents the cost estimate for Alternative 6.

TABLE 4-11
Cost Estimate for Alternative 6
Frontier Fertilizer Feasibility Study, Davis, California

Cost Elements	Non-Discounted Cost ($)	Present Value Cost ($)
Capital cost elements	7,520,000	7,520,000
Total annual O&M*	34,245,000	10,552,000
Total periodic cost	2,636,000	341,000
Total	**44,401,000**	**18,413,000**

* Estimated average annual O&M is $778,300.

Whether Alternative 6 will receive community and regulatory agency approval will be determined after comments are received on the Proposed Plan.

4.3 Comparative Analysis of Alternatives

In the following analysis, the alternatives are evaluated in relation to one another for each of the evaluation criteria. The purpose of this analysis is to identify the relative advantages and disadvantages of each alternative. Alternatives 2, 5, and 6 are included in the comparative analysis since all others failed the screening analysis. Alternative 1, the no-action alternative, is required to be included in the analysis.

4.3.1 Threshold Criteria

Overall Protection of Human Health and the Environment

Alternative 1 is not evaluated further because it does not provide adequate protection of human health and the environment. Alternative 2 includes groundwater extraction and treatment with GAC. Both Alternatives 5 and 6 include Alternative 2 processes along with additional in situ processes to treat source volume COCs and therefore, reduce the implementation period duration. The primary difference between Alternatives 5 and 6 is that Alternative 6 includes media heating. All three alternatives will be protective of human health by reducing potential for direct (dermal or ingestion) or indirect (vapor intrusion) contact to COCs in soil and groundwater. All three alternatives include groundwater extraction to control migration of contaminated groundwater and groundwater monitoring to evaluate process effectiveness. A temporary cap of either gravel or wood chips is included as a “Common Component” of Alternatives 2, 5, and 6 to prevent ecological receptors from contacting contaminated surface soil until the proposed development occurs.

Construction and implementation of the in situ source treatment processes presents minimal additional risks to human health and the environment. Alternatives 5 and 6 include in situ stimulation of anaerobic biological conditions in Media A and B, which requires minimal disturbance of contaminated media. The in situ TD process option included in Alternative 6 requires boring into the source volume to install electrodes. The electrode installation generates contaminated soil cuttings which must be managed in accordance with health and safety and waste management procedures to prevent exposure to VOCs. Emissions of VOCs to the atmosphere during implementation of high temperature TD will likely require soil vapor extraction and treatment processes.

Compliance with ARARs

Only Alternative 1 appears to be incapable of achieving compliance with potential chemical-specific, action-specific, and location-specific ARARs. Alternatives 2, 5, or 6 will achieve compliance with ARARs.

4.3.2 Method Criteria

Long-term Effectiveness and Permanence

Implementation of Alternatives 2, 5, or 6 will reduce the mass of COCs in Media A and B, and ultimately Media C. Therefore, it is anticipated that any remaining COCs will not be available to desorb into groundwater or soil gas at concentrations that will exceed RAOs. Implementation of either Alternatives 5 or 6, including either low or high temperature TD, appears to degrade VOCs available to desorb or diffuse into groundwater or soil gas. Alternative 2 processes rely on water moving through the source volume to transport COCs to the extraction system, therefore reducing the mass of COCs. All alternatives rely on groundwater monitoring to determine implementation effectiveness and whether continued monitoring will be necessary after RAOs are achieved.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternatives 2, 5, and 6 treat COCs to protect human health. Alternative 2 uses active groundwater extraction and ex situ treatment to reduce toxicity, mobility, and volume. In addition to Alternative 2 processes, Alternative 5 uses an in situ anaerobic biological process to treat the bulk of COCs in Media A and B, while Alternative 6 uses a combination of in situ heating and biological processes. Remaining COCs in Media C groundwater will be treated with ex situ GAC. Natural processes also will reduce the concentration of COCs existing outside the zone of influence of the in situ treatment process and ex situ process extraction system. All three remedial alternatives meet the statutory preference for using treatment as a principle element to address primary threats posed by the Site.

Short-term Effectiveness

Minimal construction is required to implement Alternative 2. Construction of either Alternative 5 or 6 presents minimal threat and risks to the community and construction personnel because contaminated media is treated in situ. Grading of the ground surface required for installation of the biological treatment process infiltration system will present potential for VOC exposure, which can be mitigated by health and safety and waste management measures. Any construction on the undeveloped property negatively impacts native animal and plant species habitat as is expected by the proposed development.

Alternative 2 processes present minimal threat and risks to the community and O&M personnel, although the potential for exposure is increased due to the anticipated long implementation duration. Implementation of either Alternative 5 or 6 presents minimal threat and risks to the community and operation and maintenance personnel by treating contaminated media in situ. Implementation of the Alternative 6 process at temperatures below the boiling point of water would not require the use of the soil vapor extraction system required by the Alternative 6 process at temperatures above the boiling point of water. Ambient air monitoring, and if appropriate, a soil vapor collection and treatment system will be used to mitigate VOC emission hazards. During implementation of any of the three remedial alternatives, groundwater leaving Media A and B is monitored and collected and treated by the groundwater pump and treat system.

The implementation period duration of any of the remedial alternatives will be determined by the rate that the mass and mobility of COCs in Media A and B are reduced. For the purpose of evaluating Remedial Alternative 2, an implementation period of 57 years is assumed for the purpose of estimating costs in the FS (see Appendix A for modeling results and assumptions used in predicting cleanup timeframes). For Alternative 5, approximately 52 years is used to estimate the treatment period. This timeframe includes 10 years of active bioremediation and an additional 42 years of groundwater pump and treat. It is assumed that bioremediation will remove approximately 50 percent of the COC mass in Media A and B. Since site geology is heterogeneous, it was assumed that half of the COCs would be available for biodegradation. The remaining mass will need to diffuse into the groundwater and be captured by the extraction wells prior to treatment.

For the purpose of evaluating Alternative 6, it is assumed that the implementation period of the anaerobic degradation process to degrade nitrates will be approximately 5 years, and implementation of TD to degrade VOCs will be approximately 1 year. This treatment is estimated to remove 80 percent of the COC mass in Media A and B. Groundwater pump and treat will need to be continued for an additional 38 years, for a total timeframe of 44 years.

For any of the three remedial alternatives, groundwater monitoring will be used to evaluate remedial alternative progress. The evaluation will include discontinuing active treatment, such as pump and treat, application of the aqueous solution, and for Alternative 6, discontinuing application of energy to the electrodes when monitoring indicates RAOs are achieved in order to evaluate long-term effectiveness of the processes. Noise related to TD process equipment necessary to power the system and control and treat VOC emission may present a minor nuisance during implementation. Working hours can be modified to mitigate this nuisance. Alternative 6 energy consumption will be significantly higher than Alternative 5 with higher temperature treatment presenting the highest energy demand. Energy consumption required by the pump and treat system included in Alternatives 2, 5, and 6 will be high due to the long implementation period.

Implementability

Alternatives 2, 5, and 6 appear to be technically feasible, although ultimately their efficacy will be determined by groundwater monitoring during the implementation and post-implementation periods. It is expected that groundwater concentrations will reflect the decreased source area concentrations within a few years for both Alternatives 5 and 6. Alternative 2 processes that are currently operating onsite appear to be effective in some areas, and, if needed, additional extraction wells could be added to remove and treat groundwater containing COCs. Alternative 6 is more challenging to construct than Alternative 5 since it includes TD, in addition to all processes included in Alternative 5. Construction of the biological treatment process, which is included in both alternatives, is relatively easy; however, the effectiveness is less assured. Construction of the Alternative 6 process includes installation of borings to 60 feet bgs to accommodate electrodes, power supply equipment, and possibly soil vapor treatment equipment and soil vapor extraction wells. Since the biological treatment infiltration system and TD electrode network will be collocated in Alternative 6, additional effort is required to design and construct these components. The lower temperature TD option requires less energy than the higher temperature option and therefore generates less contaminated soil and requires lower capacity power supply equipment. It is also assumed that existing utility lines and transformers that service the Site will be capable of supplying power for either alternative, including the higher temperature option. An engineering analysis will be performed to assess the validity of assumptions and possible effects of biological and TD process construction on other remedial alternative process performance.

Anaerobic biological process components included in both alternatives are available and relatively easy to operate. Bench-scale testing indicates that the biological process effectively reduces nitrate concentrations. Data from other sites with similar COCs indicate that anaerobic biological conditions have the potential to reduce VOC concentrations. Process implementability will be determined with groundwater monitoring during field testing, and during full-scale implementation and post implementation periods. TD of VOCs is theoretically practical and supported by the bench-scale testing. Based on preliminary bench-scale test results, TD degrades VOCs quicker than biological means. Bench-scale testing indicates that the TD process effectively reduces VOC concentrations both above and below the boiling point of water. Although biological bench-scale testing was not performed at elevated temperatures, TD treatment at temperatures lower than boiling point probably could be accomplished concurrently with biological treatment. The potential symbiotic relation between heat and biological treatment process is commonly understood and has been investigated (see *The Potential for Reductive Dechlorination after Thermal Treatment of TCE-Contaminated Aquifers* [Friis, 2006]). Heating media above the boiling point will likely halt biological treatment, so in this case, the biological treatment will be implemented first. TD process effectiveness will be evaluated with groundwater monitoring during the full-scale implementation and post-implementation periods. Exposure and performance monitoring will be performed to evaluate compliance with RAOs.

Availability of vendors should not limit implementation of any of the remedial alternatives, although experience levels of the O&M personnel will impact implementation effectiveness. The anaerobic process and necessary components are not proprietary. Resources required to implement Alternative 6 are more limited than those required to implement Alternative 5. At least three vendors have been identified that provide TD services.

It is not anticipated that implementation of Alternatives 2, 5, or 6 will have a significant negative impact on existing processes or other potential process option effectiveness. A potential effect of implementation of the anaerobic process is that metals such as manganese become more soluble in reducing conditions. Since metals currently accumulate in groundwater pump and treat system components, an increased rate of accumulation and resulting maintenance is anticipated. Heating media may increase the rate of biological reactions, up to a point, and increased mobility of VOCs, which will affect the ex situ groundwater treatment system. An engineering analysis will be performed to assess possible effects of implementation of biological and TD processes on other process performance and mitigation plans.

It is possible that Alternative 6 at a temperature above the boiling point of water will generate air emissions that will require a soil vapor extraction system. Construction of either remedial alternative may impact the ground surface slightly north of the Pine Tree Properties parcel northwestern boundary; therefore, the activity will be coordinated with the respective property owner.

A benefit of the in situ process is that it does not require excavation and ex situ treatment or disposal. Therefore, availability of hazardous waste treatment and disposal capacity will not limit implementation of either Alternatives 5 or 6. Given the long implementation duration, Alternatives 2, 5, and 6 will generate a large quantity of spent GAC and used plant and well components. The spent GAC is currently transported to an offsite treatment facility for regeneration and reuse. EPA will continue to evaluate alternatives to GAC treatment.

Cost Estimates

Cost estimates are provided in both non-discounted and present value format (Table 4-12). A 7 percent discount rate was used to calculate present value cost estimates. A 57-year analysis period was used for Alternative 2, a 52-year period was used for Alternative 5, and a 44-year period was used for Alternative 6. The analysis periods are based are predicted implementation periods for respective remedial alternative.

TABLE 4-12
Cost Estimates in Non-discounted and Present Value Format
Frontier Fertilizer Feasibility Study, Davis, California

Remedial Alternative	Non-Discounted Cost ($)	Present Value Cost ($)
Alternative 1 Totals	0	0
Alternative 2 Totals	43,467,000	11,342,000
Alternative 5 Totals	43,121,000	12,374,000
Alternative 6 Totals	44,401,000	18,413,000

Based on cost estimates using both present worth and non-discounted costs, Alternative 1 is the least expensive remedial alternative, followed by Alternatives 2, 5, and 6.

SECTION 5

Works Cited

Air Force Center for Environmental Excellence (AFCEE). 2004. *SourceDK Remediation Timeframe Decision Support System, Version 1.0*.

Bechtel Environmental, Inc. (Bechtel). 1997. *Final Interim Remedial Investigation Report, Frontier Fertilizer*. Prepared for the U.S. Environmental Protection Agency, Region IX. April 28.

_____. 1999. *Final Baseline Risk Assessment Report for the Frontier Fertilizer Site.* Prepared for the U.S. Environmental Protection Agency, Region IX.

CH2M HILL. 2003. *Frontier Fertilizer Groundwater Model Update and Extraction Well Field Plan* Technical Memorandum. July.

_____. 2004. *Screening Level Ecological Risk Assessment.* Prepared for the U.S. Environmental Protection Agency, Region IX.

_____. 2006. *Groundwater Monitoring Report for Frontier Fertilizer Superfund Site, Third Quarter 2005.* Prepared for the U.S. Environmental Protection Agency, Region IX. January.

Friis, Anne Kirketerp. 2006. *The Potential for Reductive Dechlorination After Thermal Treatment of TCE-Contaminated Aquifers.* Institute of Environmental Resources, Technical University of Denmark, January.

U.S. Environmental Protection Agency (EPA). 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.*

_____. 1997. *A One-Dimensional Finite Difference Vadose Zone Leaching Model, Version 2.2*.

_____. 2003. *Report on Bioavailability of Chemical Wastes With Respect to the Potential for Soil Bioremediation.* USEPA, R600/R-03/076. October.

APPENDIX A

Remedial Timeframe Modeling

APPENDIX A

Remedial Timeframe Modeling

Estimating Benefits of COC Mass Reduction on Remedial Timeframes

In order to completely compare the alternatives, an estimate of the duration or timeframe of the remedy was projected. Since predictive modeling has many variable and uncertainties, the important component of the modeling exercise is that the assumptions used in the assessments of the different remedial actions are consistent. The approach at the Frontier Fertilizer site was to first estimate the mass of chemicals of concern and the volume of subsurface media impacted. (These estimates are presented in this FS report.) The mass and distribution of the chemicals were made using soil sample data from the borings in former disposal area collected prior to 2002. Most of the samples were collected in the 0-to-30-foot depth zone. Fewer samples were collected deeper than 30 feet below grade. This area has the greatest uncertainty as to the actual mass of chemicals. However, the same estimate was used for all the alternatives.

Once the mass and distribution of the chemicals were approximated, estimates for fate and transport rates were made using two computer models, SourceDK and VLEACH with MIXCELL. The SourceDK was used to predict the timeframe of reaching the cleanup levels based on the estimated mass in the saturated zone. VLEACH and MIXCELL were used to calculate approximately the timeframe to reach cleanup levels from the mass in the unsaturated zone. The VLEACH estimated the chemical mass flux from the unsaturated zone to the saturated zone and MIXCELL used this information to estimate time to cleanup levels in the groundwater at the boundary of the former waste area. The bulk of the mass remaining is in the saturated zone.

The SourceDK computer model was developed by the Air Force Center of Environmental Excellence to estimate remediation timeframes when comparing different remedial actions. It is a basic screening-level model that produces order-of-magnitude results. Therefore, estimates produced by this model should be used in comparison and not as absolute results. The assumptions and modeling input for VLEACH/MIXCELL and SourceDK are included in this appendix.

The models were run for four different scenarios with each scenario run for the three primary chemicals: DBCP, EDB and DCP. The scenarios are as follows:

- **Scenario 1—No Mass Reduction with Pumping:** No removal or treatment of COCs in the vadose and saturated zones, and continued groundwater extraction. This scenario matches the assumptions in Alternative 2.
- **Scenario 2—Fifty Percent Mass Reduction with Pumping:** Fifty percent removal or treatment of COCs, and continued groundwater extraction. This scenario was used to estimate Alternative 5, bioremediation. Bioremediation is only as effective as the ability for the biomatter and nutrients to distribute throughout the subsurface. Since the site

geology is heterogeneous, it was assumed that only half of the chemicals of concern would be available for biological degradation.

- **Scenario 3—Eighty Percent Mass Reduction with Pumping:** Eighty percent removal or treatment of COCs in the vadose and saturated zones, and continued groundwater extraction. This scenario was developed to approximate Alternative 6. Although in situ thermal treatment has successfully treated 99 percent of the chemical of concern, it is infeasible to treat the entire saturated zone. The bulk of the mass (80 percent) is in the area where the in situ thermal treatment will be applied.
- **Scenario 4—No Mass Reduction without Pumping:** No removal or treatment of COCs in the vadose and saturated zone, and discontinue groundwater extraction. Alternative 1 implementation timeframe is based on this scenario.

In addition to the four scenarios, the model input parameters were varied to estimate low, average, and high timeframes for each scenario.

Results

The models described earlier were used to estimate how long it would take for concentrations of the three primary chemicals of concern to reach cleanup levels at the boundary of the former waste pit area. The results of the modeling are included in Table A-1.

TABLE A-1
Estimate of Remedial Timeframes
Frontier Fertilizer, Davis, California

COC	Scenario 1—No Removal w/ Pumping Time (years) Low/Average*/High	Scenario 2—50% Removal w/Pumping Time (years) Low/Average*/High	Scenario 3—80% Removal w/Pumping Time (years) Low/Average*/High	Scenario 4—No Removal w/o Pumping Time (years) Low/Average*/High
Unsaturated Zone (VLEACH & MIXCELL)				
EDB	29 to 64	26 to 59	16 to 39	52 to 85
DBCP	55 to 97	46 to 81	34 to 53	84 to > 100
DCP	4 to 14	0 to 4	0 to 0	16 to 57
Saturated Zone (SourceDK)				
EDB (+/- 2)	9/18/**37**	8/17/34	7/15/30	259/ > 500/ > 500
DBCP (+/- 20)	**5**/109/ > 500	5/98/ > 500	4/83/500	153/ > 500/ > 500
DCP (+/- 10)	0/1/**11**	0/1/10	0/1/8	3/31/312
Site Remedial Timeframe	**57**	**52**	**44**	**> 500**

* Average only included for Saturated Soil cleanup timeframes calculated with SourceDK.

The results of the SourceDK model for Scenario 1 were compared to actual groundwater data collected since 2002. (The initial mass of contaminants used was derived from samples collected prior to 2002.) This data showed that the model runs that best fit the actual data for the past 4 years were the high estimate for EDB, the low estimate for DBCP, and the high estimate for DCP. These values are bolded in the table. This may indicate that more EDB and DCP mass are present than the sample results indicate, or that there may actually be less DBCP than calculated. Since the groundwater measurement point is about 50 feet downgradient from the source, it could bias the results, making them appear lower. Scenario 1 reflects existing site conditions in which the comparison of the model output and measured concentrations is appropriate.

In estimating the site remedial timeframe, the average of the low and average timeframes for DBCP was used (that is, 5 and 107 divided by 2 equals 57 years). Although the model indicated that DBCP was cleaning up more in-line with the low estimate; to be conservative, the average of the low and average values was used. This value was compared to the high-end of DCP and EDB, and the highest from among the three was used. Finally, the timeframe was compared to the values produced by the VLEACH and MIXCELL models and if it fell into those ranges, it was listed as the estimated timeframe. This approach was applied to the other scenarios.

As stated earlier, the purpose of this exercise is to compare the alternatives. Clearly, the range of timeframe under each scenario is large, so an accurate prediction of timeframes is infeasible. The number of variables and the assumptions that must be made make any modeling exercise a tool, not a predictor. Based on this exercise, there are a few conclusions that can be made. First, all the remedies will require pump and treat for an extended period of time. Removing mass in the beginning may not significantly shorten the duration of pump and treat due to low RAOs.

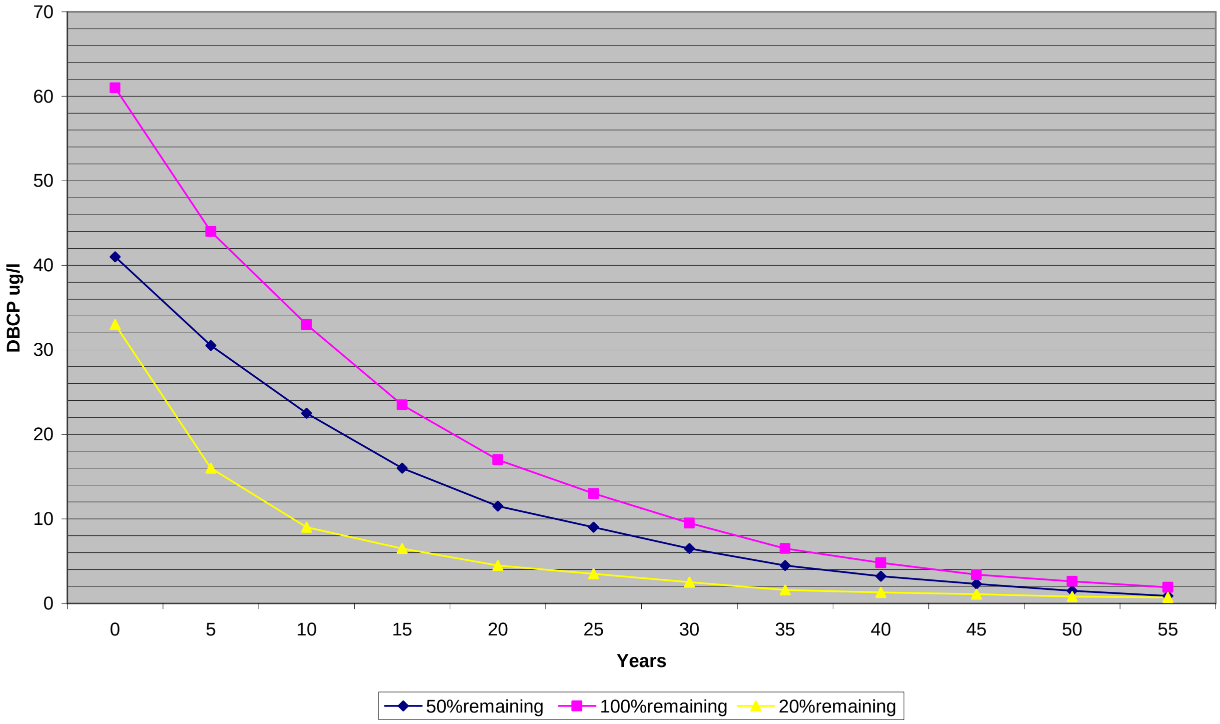
What Table A-1 does not show is what the pump-and-treat system may look like if partial source removal is completed initially. The concentration vs. time of all the remedial alternatives is an exponential decay curve. Therefore, initially large amounts of mass are removed but, over time, the amount of mass removed each year gets less and less. Therefore, it takes significant time to achieve the cleanup levels for EDB and DBCP whose drinking water standards are extremely low. However, removing mass in the beginning of the treatment will result in EDB and DBCP levels dropping much faster than if left untreated (see Figure A-1). This will result in a smaller plume remaining to treat in a faster time than if the source area is not reduced initially.

References

Farhat, S.K., P.C. de Blanc, C.J. Newell, J.R. Gonzales, and J. Perez. 2004. *SourceDK User's Manual*. Groundwater Services, Inc. April.

Dynamac Corporation. 1997. *VLEACH A One-Dimensional Finite Difference Vadose Zone Leaching Model*. Developed for EPA.

Figure A-1
DBCP over time starting at different % remaining



Vadose Zone Model Input Parameters

VLEACH Methodology

During this effort, VLEACH model methodology was used to estimate the groundwater mass loading rate, and the subject mass loading rate was input to MIXCELL in order to derive contaminant concentrations in groundwater. This section summarizes the various parameters used by the models during the analysis.

VLEACH describes the movement of an organic contaminant within and between three different phases: (1) as a solute dissolved in water, (2) as a gas in the vapor phase, and (3) as an adsorbed compound in the solid phase. Equilibration between the phases occurs according to distribution coefficients defined by the user. In particular, VLEACH simulates vertical transport by advection in the liquid phase and by gaseous diffusion in the vapor phase.

These processes are conceptualized as occurring in a number of distinct, user-defined polygons that are vertically divided into a series of user-defined cells. The polygons may differ in soil properties, recharge rate, and depth to water. However, within each polygon, homogeneous conditions are assumed except for contaminant concentration, which can vary between layered cells. During each time step the migration of the contaminant within and between cells is calculated. Hence, VLEACH can account for heterogeneities laterally but is limited when simulating vertical heterogeneity.

Initially, VLEACH calculates the equilibrium distribution of contaminant mass between the liquid, gas, and sorbed phases. Transport processes are then simulated. Liquid advective transport is calculated based on values defined by the user for infiltration and soil water content. The contaminant in the vapor phase migrates into or out of adjacent cells based on the calculated concentration gradients that exist between adjacent cells. After the mass is exchanged between the cells, the total mass in each cell is recalculated and re-equilibrated between the different phases. These processes are conducted for each time step, and each polygon is simulated independently. At the end of the model simulation, the results from each polygon are compiled to determine an overall area-weighted groundwater impact for the entire modeled area.

For computational purposes each polygon is divided vertically into a series of cells. When developing a model simulation, it is important to fully understand the implications of the VLEACH conceptualization. The following assumptions are made in the development of VLEACH:

1. Linear isotherms describe the partitioning of the pollutant between the liquid, vapor, and soil phases. Local or instantaneous equilibrium between these phases is assumed within each cell.

2. The vadose zone is in a steady state condition with respect to water movement. More specifically, the moisture content profile within the vadose zone is constant. This assumption will rarely occur in the field. Although moisture gradients cannot be simulated, the user can estimate the impact of various moisture contents by comparing results from several simulations that cover the common or possible ranges in soil moisture conditions.

3. Liquid phase dispersion is neglected. Hence, the migration of the contaminant will be simulated as a plug. This assumption causes higher dissolved concentrations and lower travel time predictions than would occur in reality.

4. The contaminant is not subjected to in situ production or degradation. Since organic contaminants, especially hydrocarbons, generally undergo some degree of degradation in the vadose zone, this assumption results in conservative concentration values.

5. Homogeneous soil conditions are assumed to occur within a particular polygon. This assumption will rarely occur in the field. Although spatial gradients cannot be simulated, the user can estimate the impact of non-uniform soils by comparing results from several simulations covering the range of soil properties present at the site. However, initial contaminant concentrations in the soil phase can vary between cells.

6. Volatilization from the soil boundaries is either completely unimpeded or completely restricted. This assumption may be significant depending upon the depth of investigation and the soil type. In particular, after a depth of 1 meter, volatilization to the atmosphere will decrease significantly.

7. The model does not account for non-aqueous phase liquids or any flow conditions derived from variable density.

VLEACH Parameter Considerations

The VLEACH user's manual provides a detailed sensitivity analysis of all model input parameters. The results of the sensitivity analysis indicate that the organic carbon coefficient, infiltration velocity, and fraction organic carbon have the greatest impact on both soil contamination and groundwater loading (Dynamac Corporation, 1997). Since the organic carbon coefficient is well defined for the analyzed compounds, only the volumetric water content and organic carbon content were varied to change model outputs. The volumetric water content was varied instead of the infiltration rate because the two parameters are indirectly proportional.

The two model parameters, volumetric water content and organic carbon coefficient were varied to determine the sensitivity of the model to the various parameters and to provide a range of calculated mass loading rates.

To create the highest mass loading rate over the shortest period of time, the volumetric water content was set to 0.16 and the organic carbon content was set to 0.004 g/g. To create a lower mass loading rate over a longer period of time the volumetric water content was set to 0.35 and the organic carbon content was set to 0.0078 g/g. The volumetric water content and organic carbon content values were selected to represent the range of values observed from site data. These inputs created two mass loading rate output files, a high and low loading, that became the input to the MIXCELL model.

Frontier Fertilizer Source Area Simulation VLEACH Input Parameters

a. **Title**. A title of up to 80 characters can be defined that describes the simulation. The title will be printed with each output file.
[Card 1: TITLE (A80) **<Frontier Fertilizer Source Area Simulation>**]

b. **Number of Polygons**. The number of polygons conceptualized for the site. Each polygon will have a unique set of parameter data.
[Card 2: NPOLY (I3) **<1 polygon>**]

c. **Timestep**. The model timestep given in years.
[Card 3: DELT (G10.0) **<0.01 year>**]

d. **Simulation Time**. The total time length of the simulation given in years.
[Card 3: STIME (G10.0) **<100 years>**]

e. **Output Time Interval**. The time interval at which the groundwater impact and mass balance results are printed to the .OUT file. The output time interval is in years.
[Card 3: PTIME (G10.0) **<1 year>**]

f. **Profile Time Interval**. The time interval at which the vertical concentration profile results are printed to the .PRF file. The profile time interval is in years.
[Card 3: PRTIME (G10.0) <1 **year**>]

g. **Organic Carbon Distribution Coefficient (K_{oc})**. The organic carbon distribution coefficient describes the partitioning of the contaminant with organic carbon. The coefficient is in units of ml/g. Values from *Risk Assessment Information System (RAIS), Oak Ridge National Laboratory*.
[Card 4: KOC (G10.0) **<EDB = 43.8, DBCP = 130.8, DCP =67.7, & TCP = 130.8>**]

h. **Henry's Constant (K_H)**. Henry's constant is an empirical constant that describes the liquid-gas partitioning of the contaminant. Henry's constant is a function of the solubility and partial vapor pressure of the contaminant at a given temperature. VLEACH utilizes the dimensionless form of Henry's constant given as $M/L3_{AIR}$ and $M/L3_{WATER}$. The dimensionless form of K_H can be determined from the more common form having the units of atmospheres-cubic meters per mole (atm-m^3/mol) using the following equation $K_H = K_{H'}/0.0246$ at 27°C where K_H is dimensionless and $K_{H'}$ is in units of atm-m^3/mol. Values from RAIS.
[Card 4: KH (G10.0) **<EDB = 0.027, DBCP = 0.006, DCP = 0.115, & TCP = 0.014>**]

i. **Water Solubility (S)**. Values defining the water solubility of the contaminant must have units of milligrams per liter (mg/L). Values from RAIS.
[Card 4: CMAX (G10.0) **<EDB = 3,910, DBCP = 1,230, DCP = 2,800, & TCP = 1,750>**]

j. **Free Air Diffusion Coefficient (Di)**. The free air diffusion coefficient describes transfer of the contaminant due to Brownian motion in the air phase. The coefficient is in square meters per day (m^2/day). Values from RAIS.
[Card 4: DAIR (G10.0) **<EDB = 0.188 , DBCP = 0.183 , DCP = 0.676 , & TCP = 0.613>**]

Polygon Data (COC source area)

Polygon input values for the following parameters.

k. **Title.** A title of up to 80 characters can be defined that describes the simulation. The title will be printed with each output file.
[Card 1: TITLE (A80) **<Pesticide Source Area>**]

l. **Area.** This parameter defines the area of the polygon in square feet.
[Card 2: AREA (G10.0) **<**Use largest area of S1 & S2 for all COCs due to relative similarity of estimated boundaries; Lx=246′ and Ly=108′ so **Area = 26,568 ft^2>**]

m. **Vertical Cell Dimension.** This parameter defines the vertical height of each cell within the polygon. The cell dimension is in feet.
[Card 2: DELZ (G10.0) **<1 foot>**]

n. **Recharge Rate.** The groundwater recharge rate describes the velocity of water movement through the vadose zone. The rate is given in feet per year. In the vadose zone, the hydraulic conductivity of the soil is an increasing function of the water content of the soil. Hence, the groundwater recharge rate should be equal to or lower than the hydraulic conductivity of the soil at the modeled water content. It should be noted that this parameter is extremely difficult to estimate as in reality it will vary with respect to time. It is strongly suggested that a range of possible recharge values be utilized to evaluate the potential variability of the results due to uncertainty associated with this parameter.
[Card 2: Q (G10.0) **<0.241 ft/yr**, from Frontier Fertilizer Groundwater Model Update and Extraction Wellfield Plan,(CH2M HILL July, 2003) "Average annual rainfall in the Davis area is 17 inches (DWR, 1994), with the majority occurring between November and April. It is assumed that approximately 15-20% of rainfall recharges groundwater."**>**]

o. **Dry Bulk Density.** This parameter describes the mass of dry soil relative to the bulk volume of soil. It is described in units of grams per cubic centimeters (g/cm^3).
[Card 2: RHOB (G10.0) **<1.55 g/cm^3>**]

p. **Effective Porosity.** The effective porosity describes the volume of void space within the soil that is potentially fillable with water. The effective porosity equals total porosity minus irreducible water content, that percentage of total volume that water is retained due to capillary forces. Effective porosity is a dimensionless parameter. Porosities reported in the Supplemental RI ranged from 48 to 44 percent between 4 and 9 feet bgs (Bechtel, 1999). Using the same Bechtel calculations, the average effective porosity between 0 and 10 feet bgs would equal 39.1 percent.
[Card 2: POR (G10.0) **<0.39>**]

q. **Volumetric Water Content.** The water content of the soil in percent total volume. This parameter is assumed constant in time and space; however, this rarely occurs in nature. The volumetric water content can neither exceed the porosity of the soil nor be lower than the irreducible soil water content.
[Card 2: THETA (G10.0) **<0.16 summer to 0.35 winter>**]

r. **Soil Organic Carbon Content.** The fraction organic content of the soil is the relative amount of organic carbon present in the soil. This parameter defines the amount of potential adsorptive sites for the contaminant in the solid phase. The fraction organic content can be determined from laboratory analyses or is documented in some soil descriptions of the Soil Conservation Service.
[Card 2: FOC (G10.0) **<0.004 to 0.0078 g/g>**]

s. **Concentration of Recharge Water.** This parameter defines the contaminant concentration in milligrams per liter (mg/L). If the recharge water is derived from precipitation, the contaminant concentration will typically be set at zero.
[Card 3:CINF (G10.0) **<0 mg/L>**]

t. **Upper Boundary Condition for Vapor.** This parameter defines the contaminant concentration in mg/L in the atmosphere above the soil surface. If the upper boundary of the polygon is considered impermeable to gas diffusion, enter a negative value.
[Card 3: CATM (G10.0) **<0 mg/L>**]

u. **Lower Boundary Vapor Condition for Vapor.** This parameter defines the contaminant concentration in mg/L in the groundwater at the base of the vadose zone. If the lower boundary of the polygon is considered impermeable to gas diffusion enter a negative value.
[Card 3: CGW (G10.0) **<EDB=0 μg/L, DBCP= 0 μg/L ,DCP= 0 μg/L, TCP= 0 μg/L>**]

v. **Cell Number.** The cell number defines the number of cells within the polygon. The number of cells is equal to the polygon height divided by the Cell Vertical Dimension.
[Card 4: NCELL (I5) **<10>**]

w. **Plot Variable.** Variable to denote the plotting option. "Y" or "y" indicates that a plot file containing the soil contaminant profile will be created.
[Card 4: PLT (A1) **<y>**]

x. **Plot Time.** Plot time defines the time in years for which the soil contaminant profile data will be created for the plot file.
[Card 4: PLTIME (G10.0) **<100>**]

y. **Initial Contaminant Concentration.** This value defines the initial contaminant concentration in the soil within a single or set of cells. The concentration is given in units of micrograms per kilogram (µg/kg). The input is given by recording the number of the upper and the lower cells (J1 and J2, respectively) and the defined concentration (XCON) in those cells. The initial contaminant concentration must be defined for all cells within the polygon.
[Card 5: J1,J2, XCON (2I5,G10.0) Card 5 is repeated as necessary until each cell has been described and the bottom cell (J2) equals the Cell Number (NCELL) **<EDB-1,5,143 & 6,10,629; DBCP-1,5,120 & 6,10,338; DCP-1,5,184 & 6,10,571; TCP-1,5,406 & 6,10,412>**]

MIXCELL Methodology

MIXCELL, programmed in Microsoft Excel, uses a macro in conjunction with mass-loading results computed by VLEACH to derive contaminant concentration. This macro computes transient concentrations in a mixing cell, based on the contaminant mass loading from the vadose zone, as computed by VLEACH. The mixing cell simulates a representative volume of a given aquifer. Note: Careful consideration of the cell dimensions must be made because they imply a contaminant dispersion length. This program only accounts for the liquid portion of the saturated zone (sorbed contaminant mass is not accounted for).

MIXCELL Parameter Considerations

The MIXCELL model input was changed to model two different scenarios: a pumping and non-pumping scenario for each high and low mass estimate from the VLEACH model. The pumping and non-pumping model inputs represent average measured gradients taken December 2003 to September 2004.

MIXCELL Parameter Inputs

Input File. The input file is a comma separated value (cvs) file that contains the time, concentration, and mass data for the modeled contaminant. For each year, there is a corresponding mass entering the groundwater, which is obtained from the output of VLEACH. The concentration is assumed zero for all model runs.

Note: The VLEACH model performs calculations for every 0.01 year (see **timestep**), but only displays the calculated rate of mass transfer to groundwater for every year. When the rate of mass transfer changes dramatically during the course of a year, the displayed rate of mass transfer at integer numbered years (that is, 1.00, 2.00 …) does not accurately reflect the average mass transfer for the period. To correct for this, the cumulative mass is used to determine an average mass transfer rate. The difference between cumulative mass for the year and previous year is divided by the time period (always 1 year) to give the average mass transfer rate.

Top and Bottom Cell Width. The width of the groundwater cell being evaluated. The cell width was defined in the VLEACH area data. **<Width = 246 ft>**

Top and Bottom Cell Length. The length of the groundwater cell being evaluated. The cell length was defined in the VLEACH area data. **<Length = 108 ft>**

Top Cell Thickness (ft). This is the thickness of the S-1 zone. The MIXCELL model assumes the S-1 and S-2 are broken into two cells to account for heterogeneity within the zone that might cause incomplete mixing. **<The top cell thickness = 50 ft>**

Bottom Cell Thickness (ft). This is the thickness of the S-2 zone. The MIXCELL model assumes the S-1 and S-2 are broken into two cells to account for heterogeneity within the zone that might cause incomplete mixing. Combined with the top cell, the depth of the S-1 zone is assumed 60 feet bgs, with the top 10 feet bgs composing the vadose zone. **<The bottom cell thickness = 30 ft>**

Top Cell Porosity. The porosity of the soil in the S-1 zone. See VLEACH effective porosity for source. <**Porosity = 46%>**

Bottom Cell Porosity. The porosity of the soil in the S-1 zone. See VLEACH effective porosity for source. **<Porosity = 46%>**

Retardation Factor. This value is the ratio of the water velocity to contaminant velocity. The larger the retardation factor, the slower the contaminant is transported through the groundwater, causing the groundwater contamination to peak at a lower concentration, but to last for a longer duration. The factor is without units. **<EDB = 1.5, DBCP = 2.4, DCP = 1.7, & TCP = 2.4>**

Vertical Darcy Flux into Top Cell (ft/day). This is the recharge rate used in VLEACH. The vertical darcy flux is the rate at which recharge water enters the top cell. Upward groundwater flux is positive.
[<**0.241 ft/yr (or 0.000660 ft/day),** from *Frontier Fertilizer Groundwater Model Update and Extraction Wellfield Plan,(*CH2M HILL, July, 2003) "Average annual rainfall in the Davis area is 17 inches (DWR, 1994), with the majority occurring between November and April. It is assumed that approximately 15-20% of rainfall recharges groundwater.">]

Horizontal Darcy Flux Into Cells (ft/day): The flux of groundwater into the cells in the horizontal direction. The flux is calculated from the product of the horizontal conductivity and the site gradient. Two gradients are used for modeling: the gradient with extraction wells operating and the gradient without extraction wells operating. **<With pumping = 0.056 ft/day, without pumping = 0.002 ft/day>**

Vertical Darcy Flux Between Top and Bottom Cell Interface (ft/day): The vertical darcy flux is the rate at which water travels vertically through the S-1 zone toward the S-2 zone. Upward Groundwater Flux is Positive. **<With pumping = -0.304 ft/day, without pumping = -0.0504 ft/day>**

Vertical Darcy Flux Across Bottom Boundary (ft/day). The vertical darcy flux is the rate at which water travels vertically through the S-2 zone toward the A-1 zone. Upward Groundwater Flux is Positive. **<With pumping =0.00124 ft/day, without pumping = -0.00846 ft/day>**

Initial Contaminant Concentration in Groundwater_TopCell (µg/L). The concentration of contaminant in the groundwater in the top cell at time 0 years. **<Initial Top Concentration = 0.0>**

Initial Contaminant Concentration in Groundwater_BottomCell (µg/L). The concentration of contaminant in the groundwater in the bottom cell at time 0 years. **<Initial Bottom Concentration = 0.0>**

SourceDK Tier 2 Model Input Parameters

SourceDK Methodology

The SourceDK model is used to estimate remediation timeframes. The model has three tiers that can be used to predict remediation timeframes given known site conditions and variables. The methods used by the tiers are data trending, concentration versus time using a box model, and process analysis using a simple flushing model. For the purpose of analyzing the Frontier Fertilizer source area, the tier 2 box model was used. The tier 2 model can also take into account biological degradation, but biological degradation was assumed to not be occurring.

The tier 2 box model is represented as a box with a steady flow of groundwater flowing through the cell. Within the cell is a mass of contaminants partitioned to the soil and a concentration of contaminants that partition to the groundwater. The contaminants in the groundwater are then carried out of the box by the inward flow of groundwater. The concentration in the groundwater is continually decreasing, because as more water flows through the cell, mass is removed from the cell. There is a direct relationship between the mass in soil and concentration in groundwater (that is, within the box, a 10 percent reduction in soil mass results in a 10 percent reduction in groundwater concentrations).

The tier 2 model predicts concentration vs. time trends assuming the source is a simple box containing COC mass, there is a certain mass discharge out of the box, and the source concentration vs. time trend will follow a first-order decay pattern. The source decay is a function of the groundwater concentration in the source area and the amount of available mass in the source area at time equal to zero. The relationship between the mass is used to estimate the source decay rate constant in the box, which is then used to predict groundwater concentration vs. time values.

SourceDK Input Parameters

Darcy Velocity (ft/yr). The velocity, or flux, of groundwater through the source volume. The velocity is the average of the horizontal and vertical components of the velocity for the S-1 and S-2. The horizontal and vertical components are the same as those used for the MIXCELL model. **<Pumping = 184, No Pumping = 7.0>**

Average Source Groundwater Concentration at time = 0, assumed 2001 (µg/L). The average concentrations detected in groundwater samples collected from CPT-11 hydropunch and wells X-6A & B during 2001 are used. The hydropunch sample from CPT-11 was collected from source media, and wells X-6A and B are directly down gradient of the source area. **<EDB = 172 , DBCP = 164, DCP = 4,468>**

Source Length (ft). The length of the groundwater cell being evaluated. The cell length was defined in the VLEACH area data. **<Length = 108 ft>**

Source Width (ft). The width of the groundwater cell being evaluated. The cell width was defined in the VLEACH area data. **<Width = 246 ft>**

Source Thickness (ft). The thickness of the source volume. The cell width was defined in the MIXCELL data. **<Thickness = 80 ft>**

Source Mass (kg). The amount of mass in the source volume. Computed from 1995 soil sample results from borings in the former disposal basin. **<EDB = 40, DBCP = 273, DCP = 75>**

Uncertainty Range (+/-). The uncertainty associated with source mass estimations.
<Range EDB = +/-2, DBCP = +/- 20, & DCP = +/-10>

APPENDIX B

ARARs Analysis

TABLE B-1
Potential Chemical-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Standard, Requirement, Criterion, or Limitation	ARAR Status	Description	Comment
1	Resource Conservation and Recovery Act (RCRA) Hazardous Waste Determination Title 22 CCR, Division 4.5, Chapter 11, 66261.21, 66261.22(a)(1), 66261.22(a)(2), 66261.23, and 66261.24(a)(1) or Article 4, Chapter 11, 22 CCR 66260.200	Potentially Applicable	A hazardous waste is considered a RCRA hazardous waste if it exhibits any of the characteristics of ignitability, corrosivity, reactivity, or toxicity, or if it is listed as a hazardous waste.	Wastes generated during construction, monitoring, or remediation at Frontier Fertilizer must be characterized and managed in accordance with RCRA requirements.
2	California Hazardous Waste Determination 22CCR 66261.24(a)(2), 22CCR66262.11	Potentially Applicable	Wastes can be classified as non-RCRA, state-only hazardous wastes if they exceed the Soluble Threshold Limit Concentration (STLC) or Total Threshold Limit Concentration (TTLC) values, but do not exceed the federal standards.	Wastes generated during construction, monitoring, or remediation at Frontier Fertilizer must be characterized and managed appropriately.
3	National Drinking Water Standards (MCLs) Federal Safe Drinking Water Act 42 U.S.C. 300g-1 40 CFR 141.61	Relevant and Appropriate	Establishes national primary drinking water standards and Maximum Contaminant Levels (MCL) to protect the quality of water in public water systems. MCLs represent the maximum concentrations of contaminants permissible in a water system delivered to the public. MCLs are generally relevant and appropriate when determining acceptable exposure limits for groundwater that is a current or potential source of drinking water.	National primary drinking water standards are health-based standards for public water systems (MCLs). The National Contingency Plan (NCP) defines MCLs as relevant and appropriate for groundwater determined to be a current or a potential source of drinking water in cases where MCL goals are not ARARs. Groundwater in the vicinity of Frontier Fertilizer has been designated for drinking water use.
4	California Safe Drinking Water Standards (MCLs) State MCLs found in 22 CCR §64435 and §64444.5	Relevant and Appropriate	Establishes primary MCLs for contaminants that cannot be exceeded in public water systems. In some cases, the California drinking water standards are more stringent than the federal MCLs.	Like federal MCLs, state MCLs are relevant and appropriate as cleanup goals for groundwater determined to be a current or a potential source of drinking water. Groundwater in the vicinity of Frontier Fertilizer has been designated for drinking water use.

TABLE B-1
Potential Chemical-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Standard, Requirement, Criterion, or Limitation	ARAR Status	Description	Comment
5	Regional Water Quality Control Board's Water Quality Control Plan (Basin Plan) Chapters 2 and 3	Potentially Applicable	The Water Quality Control Plan (also known as the Basin Plan) for the Sacramento and San Joaquin river basins, dated September 1, 1998, establishes beneficial uses for groundwater and surface water, water quality objectives designed to protect those beneficial uses, and implementation plans to achieve water quality objectives.	The narrative water quality objectives (WQOs) described in the Basin Plan may be considered for groundwater discharges. The substantive provisions of Chapters 2 and 3, narrative standards for groundwater and surface water standards, are potentially applicable.
7	Waste Discharge Requirements (WDRs), 23 CCR 2591 (a)	Potentially Applicable	A WDR establishes narrative and chemical-specific requirements for the discharge of treated wastewater to land (including an evaporation/percolation pond and irrigation fields) in the vicinity of Frontier Fertilizer.	Potentially applies to any remedial activity at Frontier Fertilizer that will potentially impact the nature or volume of wastewater discharged to land.
8	Concentration Limits, 22 CCR 66264.94 (b),(c)	Potentially Relevant and Appropriate	Provides basis for decisionmaking on alternate concentration limits for hazardous constituents.	Potentially applicable to the technical infeasibility of remediating to background levels.

TABLE B-2
Potential Location-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
1	Critical habitat such as nesting habitat upon which endangered species or threatened species depend.	Substantive portions of the Endangered Species Act of 1973 (16 USC 1531-1538, 1539); 50 CFR Part 200, 50 CFR Part 402 Substantive portions of the California Endangered Species Act (CA Fish and Game Code, Division 3, Chapter 1.5) Substantive portions of the Native Plant Protection Act (CA Fish and Game Code, Division 2, Chapter 10)	Potentially Applicable	Requires action to conserve endangered species or threatened species, including consultation with the United States Department of the Interior, Fish and Wildlife Service.	No endangered or threatened species have been identified at Frontier Fertilizer. The Frontier Fertilizer Site may be a habitat for the burrowing owl, a species of concern in California. Remedial actions at Frontier Fertilizer must be sensitive to the regulations that protect wildlife and plant species of special status.
2	Within area where action may cause harm to migratory birds (that is, nesting habitats, foraging areas, etc.).	Migratory Bird Treaty Act (16 USC 703), 50 CFR 10.13	Potentially Applicable	Establishment of a federal prohibition, unless permitted by regulations, to "pursue, hunt, take, capture, kill…" any migratory bird or any part, nest, or egg of any such bird.	Many common migratory species have been identified at Frontier Fertilizer. Remedial actions at Frontier Fertilizer must be sensitive to the regulations that protect migratory birds.
3	Within area where action may cause harm to birds (that is, nesting habitats, foraging areas, etc.).	California Fish and Game Code, Div. 4, Part 2, Chapter 1, 3503.	Potentially Applicable	It is unlawful to take, possess, or needlessly destroy the nest or eggs of any bird, except as otherwise provided by this code or any regulation made pursuant thereto.	Many common avian species have been identified at Frontier Fertilizer. Remedial actions at Frontier Fertilizer must be sensitive to the regulations that protect birds, including the burrowing owl.
4	Within area where action may cause irreparable harm, loss, or destruction of significant artifacts	National Archaeological and Historical Preservation Act (16 USC Section 469); 36 CFR Part 65	Potentially Applicable	Alteration of terrain that threatens significant scientific, prehistoric, historic, or archaeological data may require actions to recover and preserve artifacts.	The proposed remedial alternatives will not alter or destroy any known prehistoric or historic archaeological features at Frontier Fertilizer. Although Frontier Fertilizer is completely developed, it remains unpaved in many areas. However, because there is a possibility that buried historic or prehistoric remains could be discovered during construction, mitigation measures to protect the area would be required if such a discovery were uncovered.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
2	RCRA hazardous waste treatment	22 CCR 66265.370 and 66265.377	Potentially Relevant and Appropriate	Establishes requirements for owners and operators of interim status facilities that thermally treat hazardous waste in devices other than those that use flame combustion.	Substantive provisions are relevant and appropriate for treatment by in situ electrical resistance heating.
3	Cleanup of releases to the environment*	27 CCR Section 20400 and 23 CCR 2550.4	Potentially Applicable	Concentration lists must be established for groundwater, surface water, and the unsaturated zone. Must be based on background, equal to background, or for corrective actions, may be greater than background, not to exceed the lower of the applicable WQO or the concentration technologically or economically achievable. Specific factors must be considered in setting cleanup standards above background levels.	Applies in setting groundwater cleanup levels for all discharges of waste to land.
6	Land use covenants	22 CCR 67391.1(a)(b)(c)(d)	Relevant and Appropriate	LUC Agreements are proprietary controls, agreed to by property owners, to implement Institutional Controls at sites where there has been a release of hazardous substances, and where some wastes will remain in place. The LUC Agreements allow ongoing use of property as long as the cleanup remedy is not compromised by current or future development.	Applies if contamination will remain onsite above levels suitable for unrestricted use.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
16	Groundwater monitoring	22 CCR 66264.97(b)(1)(a)(b)(c)(d), (2), (4), (5), (6), (7) and (e)(1), (2), (3), (4), (5)	Relevant and Appropriate	Establishes general requirements for groundwater monitoring systems for hazardous waste facilities.	These regulations require general water quality monitoring of groundwater at Frontier Fertilizer. The intent of these requirements is currently being met under the existing groundwater monitoring program. Additional monitoring wells may be required during remedy implementation.
18	Control of air emissions	Yolo-Solano AQMD—Rule 2.5, Nuisance	Potentially Relevant and Appropriate	No discharge from any source, contaminants which cause injury, detriment, nuisance or annoyance.	Applicable to remedial actions that may result in air emissions.
19	Control of air emissions	Yolo-Solano AQMD—Rule 2.11, Particulate Matter	Potentially Applicable	Limits visible particulate emissions to the property line.	Applicable to remedial actions that may result in the production of particulate matter.
20	Control of air emissions	Yolo-Solano AQMD—Rule 2.19 (a) Particulate Matter Process Emission Rate	Potentially Applicable	Provides PM_{10} emission rates (lbs/hr) based on process material weights.	Applicable to remedial actions that may result in air emissions.
22	Control of air emissions	Yolo-Solano AQMD—Rule 3.4 New Source Review	Potentially Relevant and Appropriate	Establishes performance and monitoring standards for new air emission sources. New sources exceeding the primary pollutant thresholds are required to apply the best available control technology (BACT).	This requirement is applicable to treatment technologies with potential to emit primary pollutants to the atmosphere.
23	Control of air emissions	Yolo-Solano AQMD—Rule 3.13, Toxics New Source Review (T-BACT for HAPs)	Potentially Applicable	Requires the best available control technology for toxics (T-BACT) at any constructed or reconstructed major source of hazardous air pollutants (HAPs).	Applicable to remedial actions that may result in emissions of HAPs (currently CCl_4 and 1,2 DBCP are listed as HAPs) in quantities greater than 10 tons per year of 1 HAP, or a combined total of 25 tons for multiple HAPs). Rule 3.13.110 contains criteria for exemptions from this process.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
24	Hazardous waste treatment facility	22 CCR 66264.14	Relevant and Appropriate	Any proposed treatment facility is anticipated to maintain a fence in good repair that completely surrounds the active portion of the facility. A locked gate at the facility should restrict unauthorized personnel entrance.	Security prevents entry from unauthorized personnel.
25	Hazardous waste treatment facility	22 CCR 66264.15-16	Relevant and Appropriate	The hazardous waste facility standards require routine facility inspections conducted by trained hazardous waste facility personnel. Inspections are to be conducted at a frequency to detect malfunctions and deterioration, operator errors, and discharges that may be causing or leading to a hazardous waste release and a threat to human health or the environment.	Applicable to any proposed groundwater treatment facilities for this site.
26	Hazardous waste treatment facility	22 CCR Div 4.5, Chap. 14, Art. 3	Potentially Relevant and Appropriate	Facility design and operation to minimize potential fire, explosion, or unauthorized release of hazardous waste.	Applicable to any proposed groundwater treatment facilities for this site.
27	Hazardous waste treatment facility	22 CCR Div. 4.5, Chap. 14, Art. 6	Potentially Applicable	The requirements present the groundwater monitoring system objectives and standards to evaluate the effectiveness of the corrective action program (remedial activities). After completion of the remedial activities and closure of the facility, groundwater monitoring will continue for an additional 3 years to ensure attainment of the remedial action objectives.	Applicable to any proposed groundwater treatment facilities for this site.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
28	Hazardous waste treatment facility	22 CCR Div. 4.5, Chap. 14, Art. 7	Potentially Applicable	The closure and post-closure requirements establish standards to minimize maintenance after facility closure to protect human health and the environment.	The closure and post-closure requirements may be applied to the treatment alternatives. Clean closure of the treatment facility through equipment decontamination and removal of any hazardous waste is anticipated.
29	Hazardous waste container storage	22 CCR 66264.171, 172, 173, 174	Potentially Applicable	Containers of RCRA hazardous waste must: 1. Be maintained in good condition. 2. Be compatible with hazardous waste to be stored. 3. Be closed during storage except to add or remove waste. 4. Have adequate secondary containment when stored onsite.	These requirements are applicable to any hazardous wastes that are generated and stored temporarily in containers at Frontier Fertilizer prior to offsite disposal and may include wastes such as soil, debris, or treatment residuals (water, sludge, filters).
30	Hazardous waste container storage	22 CCR 66264.175 (a) and (b)	Potentially Applicable	Place containers on a sloped, crack-free base, and protect from contact with accumulated liquid. Provide a containment system with a capacity of 10 percent of the volume of containers with liquids. Remove spilled or leaked waste in a timely manner to prevent overflow of containment system.	These requirements are applicable to hazardous wastes that are generated and stored temporarily in containers at Frontier Fertilizer prior to offsite disposal.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
31	Hazardous waste container storage	22 CCR 66262.30 through 66262.33	Potentially Applicable	Prior to transportation, containers would be packaged, labeled, marked, and placarded in accordance with RCRA and Department of Transportation requirements.	These requirements are applicable to containers that are used to contain hazardous wastes that are sent offsite for disposal.
32	Shipping hazardous waste offsite	22 CCR 66262.11- 66262.23	Potentially Applicable	Prior to transportation, generator must determine whether waste is hazardous prior to shipping waste offsite. Once determination has been made, generator must obtain and use a manifest.	Applicable to actions that send hazardous waste (including treatment byproducts) offsite for treatment, storage, or disposal.
33	Hazardous waste accumulation	22 CCR 66262.34	Potentially Relevant and Appropriate	Accumulation of hazardous wastes onsite for longer than 90 days would be subject to the substantive RCRA requirements for storage facilities.	These requirements are applicable to hazardous waste that is stored temporarily onsite prior to offsite disposal.
39	Treatment	22 CCR 66264.601-603 and 22 CCR 66265.401	Relevant and Appropriate	These regulations include design, operation, maintenance, and closure requirements for miscellaneous treatment units and units that use chemical, physical, or biological treatment methods to treat hazardous waste.	These requirements are relevant and appropriate
40	Treatment	22 CCR 66264.192, 193, 194, and 196	Relevant and Appropriate	These regulations include requirements to ensure that tanks and ancillary equipment are adequately designed, operated, and maintained to ensure that the tank system will not fail.	Substantive portions of these requirements may be relevant and appropriate to tanks that are used during hazardous waste treatment.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
42	Disposal	42 U.S.C. 6939 b (b)	Potentially Applicable	This policy established by EPA exempts water from LDRs, if two conditions are met: • Groundwater has been treated to reduce hazardous constituents prior to reinjection. • The CERCLA response action must be sufficient to protect human health and the environment.	These requirements are relevant and appropriate to treated reinjected groundwater.
43	Discharge of waste to water including discharge to soil	State Water Resources Control Board Resolution 68-16 ("Antidegradation Policy")	Potentially Applicable	Requires that high-quality surface- and groundwaters be maintained to the maximum extent possible to protect all beneficial uses unless certain findings are made. Discharges to high quality waters must be treated using best practicable treatment or control, necessary to prevent pollution or nuisance and to maintain the highest water quality consistent with maximum benefit to the people of the state. Requires cleanup to background water quality or to lowest concentrations technically and economically feasible to achieve.	Remedial actions at Frontier Fertilizer that involve reinjection of treated groundwater must comply with substantive provisions to protect beneficial uses and the maintenance of high-quality waters in the area. If degradation is allowed, the discharge must meet best practical treatment or control, and result in the highest water quality possible consistent with the maximum benefit to the people of the state.
44	Surface and groundwater cleanup	State Water Resources Control Board Resolution 92-49, IIIg	Relevant and Appropriate	Requires that RWQCBs ensure that dischargers clean up and abate the effects of discharges in a manner that promotes the attainment of either background quality or water quality that is reasonable if background water quality cannot be restored.	Remedial alternatives that include discharges to groundwater must consider attainment of the highest water quality that is economically and technically achievable. Potentially relevant to cleanup of discharges that affect or may affect the waters of the state.

TABLE B-3
Potential Action-specific ARARs
Frontier Fertilizer Remedial Alternatives and ARARs, Davis, CA

	Location	Requirement	ARAR Determination	Description	Comments
48	Underground Injection of treated groundwater	40 CFR 144.12, excluding the reporting requirements in 144.12 (b), 144.12 (c)(1), 146.12 (d) and 146.13 (a), (b), (d)	Relevant and Appropriate	An approved UIC program is required in states listed under SDWA Section 1422. Class I wells and Class IV wells are the relevant classifications for CERCLA sites. Class I wells are used to inject hazardous waste beneath the lowermost formation that contains a USDW within 0.25 mile of the well.	Injection wells for Alternative 2 will be Class V wells under the UIC program. There are currently no specific technical requirements for injection into Class V wells. Substantive provisions of the UIC rules are relevant and appropriate only to the extent necessary to ensure that reinjection of treated groundwater will not cause the aquifer underlying the Frontier Fertilizer Site to violate primary drinking water regulations.
50	Water discharges	SWRCB Resolution 88-63	Potentially Relevant and Appropriate	Specifies that with certain exceptions all ground and surface waters have the beneficial use of municipal or domestic water supply. SWRCB Resolution 88-63 applies to all sites that may be affected by discharges of waste to groundwater or surface water. The resolution specifies that with certain exceptions all groundwater and surface waters have beneficial use of municipal or domestic water supply. Exceptions include: • TDS exceeds 3,000 mg/L or • Water source does not provide sufficient water to supply a single well capable of producing an average sustained yield of 200 gallons per day.	Applies in determining beneficial uses for waters that may be affected by discharges of waste.

APPENDIX C

Designated Levels for Soil

Department of Toxic Substances Control

Alan C. Lloyd, Ph.D.
Agency Secretary
Cal/EPA

8800 Cal Center Drive
Sacramento, California 95826-3200

Arnold Schwarzenegger
Governor

January 20, 2006

Ms. Bonnie Arthur
U. S. Environmental Protection Agency, Region IX
75 Hawthorne Street
San Francisco, California 94105-3941

DESIGNATED LEVELS FOR SOIL, FRONTIER FERTILIZER, DAVIS, CALIFORNIA

Dear Ms. Arthur:

The Department of Toxic Substances Control (DTSC) received the December 22, 2005 letter transmitted to you by the Central Valley Regional Water Quality Control Board (CVRWQCB) regarding calculated designated levels for the Frontier Fertilizer Site. This letter included a spreadsheet identifying the highest concentrations of compounds in soil which will not be expected to pose a threat to water quality. In many instances, the water quality goal is identified as the California Public Health Goal for drinking water or other standard not promulgated in California. Upon our review, DTSC believes a clarifying response to this letter is warranted.

As you know, the Frontier Fertilizer site is subject to Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) for remedial actions conducted under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Compliance with a State ARAR requires that the standard be promulgated, more stringent than the Federal requirement, and identified in a timely manner. As identified in a June 14, 1992 Memorandum posted at: http://www.waterboards.ca.gov/centralvalley/available_documents/site_cleanup/arars.pdf web site, "In addition to ARARs, EPA evaluates to-be-considered requirements (TBCs), which are nonpromulgated criteria, advisories, guidance, or proposed regulations issued by the federal or state government that are not legally binding and do not have the status of potential ARARs." The CVRWQCB's Designated Level Methodology is identified as a TBC performance standard for cleanup level determination. It presents a method for determining whether a waste or a contaminated site poses a threat to water quality.

U. S. Environmental Protection Agency (U.S. EPA) is preparing a feasibility study for the site which will define the remedial action objectives to be achieved and possibly provide preliminary cleanup goals. As the State lead on the project, DTSC requests U. S. EPA view results of a Designated Level Methodology identified in the letter no more than a TBC standard recognizing that other methodologies, ARARs or actual data results may be more appropriate in meeting remedial action objectives.

If you have any questions, please contact Mr. Steven Ross at (916) 255-3694.

Sincerely,

Richard Hume, Chief
National Priority List Unit

cc: Ms. Amy Terrell
Private Sites Cleanup Unit
Central Valley Regional Water Quality Control Board
11020 Sun Center Drive, #200
Rancho Cordova, California 95670-6114

Mr. Duncan Austin
Central Valley Regional Water Quality Control Board
11020 Sun Center Drive, #200
Rancho Cordova, California 95670-6114

Mr. Steve Deveral
Hydrofocus
P.O. Box 2401
Davis, California 95617

Mr. Jeff Pinnow
County of Yolo Health Department
20 Cottonwood Street
Woodland, California 95695

Mr. Steve Ross
Hazardous Substances Engineer
National Priority List Unit
Department of Toxic Substances Control
8800 Cal Center Drive
Sacramento, California 95826-3200

California Regional Water Quality Control Board

Central Valley Region

Robert Schneider, Chair

Alan C. Lloyd, Ph.D.
Secretary for Environmental Protection

Sacramento Main Office
11020 Sun Center Drive #200, Rancho Cordova, California 95670-6114
Phone (916) 464-3291 • FAX (916) 464-4645
http://www.waterboards.ca.gov/centralvalley

Arnold Schwarzenegger
Governor

7 February 2006

Ms. Bonnie Arthur
USEPA Region IX
75 Hawthorne Street
San Francisco, CA 94105-3941

CORRECTION TO DESIGNATED LEVELS TRANSMITTAL, FRONTIER FERTILIZER, COUNTY ROAD 32A, DAVIS, YOLO COUNTY

In our 22 December 2005 letter, we transmitted designated cleanup levels for soil that we believe will be protective of groundwater given the data obtained from soil samples obtained near the groundwater surface elevation. In our transmittal letter, we erroneously stated that "It was clear that cleanup goals had not been prepared for soil that would be protective of groundwater." Our statement should have stated that *Designated Levels* had not been prepared for soil that would be protective of groundwater.

We apologize for the error, and recognize that several different cleanup goals for soil and groundwater will be evaluated and identified for this site. I hope that this clarifies our intent.

If you have any questions, you may contact me at (916) 464-4680.

AMY TERRELL
Private Sites Cleanup Unit

cc: Mr. Jeff Pinnow, Yolo County Dept of Env. Health, Woodland
Mr. Steve Ross, DTSC, Sacramento
Mr. Paul Seday, CH2M Hill, Sacramento
Mr. Steven Deverel, HydroFocus, Inc., Davis

Rcv'd 12/27/05

California Regional Water Quality Control Board

Central Valley Region

Robert Schneider, Chair

Alan C. Lloyd, Ph.D.
Secretary for Environmental Protection

Sacramento Main Office
11020 Sun Center Drive #200, Rancho Cordova, California 95670-6114
Phone (916) 464-3291 • FAX (916) 464-4645
http://www.waterboards.ca.gov/centralvalley

Arnold Schwarzenegger
Governor

22 December 2005

Ms. Bonnie Arthur
USEPA Region IX
75 Hawthorne Street
San Francisco, CA 94105-3941

DESIGNATED LEVELS FOR SOIL, FRONTIER FERTILIZER, COUNTY ROAD 32A, DAVIS

In our 2 December 2005 telephone conversation regarding the progress at the Frontier Fertilizer site in Davis, it was clear that cleanup goals had not been prepared for soil that would be protective of groundwater. Central Valley Regional Water Quality Control Board (Regional Water Board) staff have prepared designated levels for soil, which are attached.

These designated levels were developed based on soil borings obtained from near the water table, 25 feet below ground surface, which contained constituents of concern. Since contaminants were detected at the water table, Regional Water Board staff assumed that the entire soil column is saturated with contaminants, thereby removing the potential for attenuation of these constituents within the soil profile.

These designated levels represent the worst case conditions at this site. If there are areas of the site in which soil contaminants are not present throughout the soil profile, but only reside in the upper two to three feet, the designated levels could be more lenient by a factor of 10, since additional attenuative capacity could be assumed in the soil profile.

Please be aware that these designated levels primarily take groundwater protection into account, and to a lesser extent, human health. There are also other site-specific means to obtain cleanup values for soil that are protective of groundwater, such as some vadose zone transport models.

If you have any questions, you may contact me at (916) 464-4680.

Amy Terrell

AMY TERRELL
Private Sites Cleanup Unit

Enclosure

cc: Mr. Paul Seday, CH2M Hill, Sacramento
Mr. Steve Ross, DTSC, Sacramento
Mr. Steven Deverel, HydroFocus, Inc., Davis
Mr. Jeff Pinnow, Yolo County Dept of Env. Health, Woodland

Designated Levels for Constituents in Soils, Frontier Fertilizer, Davis

Regional Water Quality Control Board, Central Valley Region

Chemical	Concentrations Detected in Soil[1]	Highest Concentrations in Groundwater[2]	Water Quality Goal[3,4]	Method Detection Limits	Basis for Goal	Attenuation Factor	Leachability Factor	Total Designated Level[4]
Inorganic Compounds								
Ammonia plus Ammonium			1.5 mg/l	0.1 mg/l	Taste and Odor Threshold			
Nitrate (as nitrogen)		170 mg/l	10 mg/l	2 mg/l	California Primary MCL for Drinking Water			100 mg/kg (sum of Nitrate-N, Nitrite-N and Ammonia+Ammonium)
Sulfate			250 mg/l	10 mg/l	California Secondary MCL (recommended level)	1	1	250 mg/kg
Fumigants								
1,2-dibromo-3-chloropropane (DBCP)	2600 ug/kg	5.2 ug/l	0.0017 ug/l	0.02 ug/l	California PHG for Drinking Water	1	1	0.0017 ug/kg
1,2,3-trichloropropane (TCP)	1,100 ug/kg	110 ug/l	0.005 ug/l	0.005 ug/l	California DHS Notification Level for Toxicity	1	1	0.005 ug/kg
Volatile Organic Compounds								
benzene		1 ug/l	0.15 ug/l	0.5 ug/l	California PHG for Drinking Water	1	1	0.15 ug/kg
bromodichloromethane			0.27 ug/l	0.5 ug/l	Cal/EPA Cancer Potency Factor as a Drinking Water Level	1	1	0.27 ug/kg
carbon tetrachloride		25 ug/l	0.1 ug/l	0.5 ug/l	California PHG for Drinking Water	1	1	0.1 ug/kg
chloroform			1.1 ug/l	0.5 ug/l	Cal/EPA Cancer Potency Factor as a Drinking Water Level	1	1	1.1 ug/kg
1,2-dibromoethane (EDB)	6800 ug/kg	210 ug/l	0.01 ug/l	0.5 ug/l	California PHG for Drinking Water	1	1	0.01 ug/kg
1,2-dichloropropane (DCP)	9,700 ug/kg	1,600 ug/l	0.5 ug/l	0.5 ug/l	California PHG for Drinking Water	1	1	0.5 ug/kg
trichloroethene (TCE)			0.8 ug/l	0.5 ug/l	California PHG for Drinking Water	1	1	0.8 ug/kg
tetrachloroethene (PCE)			0.06 ug/l	0.5 ug/l	California PHG for Drinking Water	1	1	0.06 ug/kg

Footnotes

[1] Concentrations detected at 25 feet below ground surface on 12/3/04

[2] Highest concentrations in groundwater obtained June 2005

[3] Reference: *A Compilation of Water Quality Goals* , Regional Water Quality Control Board, Central Valley Region, August 2003, updated May 2005

[4] Designated Level is the concentration that may remain in soil and is not expected to pose a threat to water quality.
When Water Quality Goals or Designated Levels are lower than the method detection limit for the constituent, the method detection limit becomes the cleanup goal.

Abbreviations

- Cal/EPA California Environmental Protection Agency
- DHS Department of Health Services
- MCL Maximum Contaminant Level
- PHG Public Health Goal

7 December 2005